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HAWASSA UNIVERSITY INSTITUTE OF TECHNOLOGY

DEPARTMENT OF CIVIL ENGINEERING

COMPARISON OF TIES CONFIGURATION FOR COLUMN UNDER COMPRESSIVE LOAD

MSc in Structural Engineering

By Henok Shiferaw

A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science

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ABBREVIATIONS

ABS	Acrylonitrile butadiene styrene
ACI	American concrete institute
ASTM	American standard testing of materials
CDPM	Concrete damage plasticity model
EBCS	Ethiopian building code of standard
EC	Euro code
ECC	Egyptian code for the design and Constriction of Reinforced concrete structures
ES EN	Ethiopian code as European norm
FE	Finite element
GL	Gauge length
IC3	Introduced category 3
IC4	Introduced category 4
IS	Indian standard
LVDT	Linear voltage displacement transducer
PC	Plain concrete
UTM	Universal testing machine

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ABSTRACT

A tied column in the reinforced concrete structure is the one in which longitudinal bars are tied together with smaller diameter bars at intervals up the column. In Ethiopia most building in the seismic area have tied column. Ties should confine core concrete properly. One way to enhance confinement is using proper detailing, seismic hook. However, installation (bending) of confining reinforcement with a 135-degree hook (seismic hook) is not easy. Therefore, in practice, many construction workers in most part of our country with high seismic zones: Zone 3 and Zone 4 apply a confining reinforcement with a 90-degree hook (fixed by wire mesh) .But most of the building codes recommend using a 135-degree hook, especially in this seismic zones.

In the present study, a comparison of two type of ties configuration by taking 150x150x465(mm) reinforced concrete specimens made. This study proposed two different type of ties configuration Introduced category 3 (IC3) and Introduced category 4 (IC4) and compared with 90^0 ties configuration under peak load and load-deformation behaviors. Three samples cast for each ties configurations having 8mm ties and three plain concrete with the same size. Additionally, two samples with similar geometry for 90^0 and 135^0 compared having 6mm ties.

Concentric axial compression load applied with the universal testing machine and average axial deformation were measured using linear voltage displacement transducer. The strain gauge was placed in ties at mid-height of the column.

From observed experimental program ties with 90^0 configurations got the least performance for both diameter ties, its peak axial strength was 23.24% lower than seismic hook configuration for 8 mm ties. Introduced configuration 3 (IC3) was in good proximity with standard 135^0 hook; axial peak load reduction of IC3 was 8.33% from 135^0 hook. But IC4 result was similar to 90^0 ties configuration. In addition to experimental study analytical and nonlinear finite element model for 8mm formulated and the result was in good agreement with a standard hook.

1 INTRODUCTION

1.1 Background

We have many structures that can be classified depending on the type of primary stresses that may develop in their members under major design loads. Compression members develop mainly compressive stresses under the action of external loads, the column is a special case of a compression member that is vertical. Generally, the column can experience an axial load with or without moment.

A tied column in the reinforced concrete structure is the one longitudinal bars are tied together with smaller bars at intervals up the column. Most buildings in the non-seismic region are with tied column. Ties are small reinforcement bars usually from 6 to 10 mm in diameter. Ties keep longitudinal bars in place and confines core concrete.

In a tied column in a non-seismic region, the ties are spaced roughly, the width of the column apart, as a result, provide relatively little lateral restraint to the core. Outward pressure on the sides of the ties due to lateral expansion of the core merely bends them outward, developing an insignificant hoop-stress effect. Hence, normal ties have little effect on the strength of the core in a tied column. They do, however, act to reduce the unsupported length of the longitudinal bars, thus reducing the danger of buckling of those bars as the bar stress approaches yield.

When high strength and/or high ductility are required, the bars are placed in a circle, and the ties are replaced by a bar bent into a helix or spiral, such a ties called a spiral ties. The spiral acts to restrain the lateral expansion of the column core under high axial loads and, in doing so, delays the failure of the core, making the column more ductile. Spiral columns are used more extensively in seismic regions.

In our country most building in seismic area tied column. And the detailing of the most building is not according to specific codes. Most building codes require the ties of column anchored properly. With end hook bend angle of 135^0. [1, 2, 3, 4]

This improper hooking of column ties especially in seismic area reduce confinement of core concrete and also reduce axial load carrying capacity of the column and makes the column less ductile.

In this study, confinement of tied column specimens with proper 135^0 end hook (seismic hook) and 90^0 end hook (fixing by wire mesh) under compression load were compared. Results were discussed from the load-deflection curve. Finite element simulation was also compared with test result and analytical models.

1.2 Statement of the problem

In practice in our country most building constructed in high seismic zones; zone 3 and zone 4 used improper tie configuration (90^0 end hook fixing by wire mesh).In small scale collected data ,in some town of our country; Addis Ababa, Hawassa, Dilla and Adama this construction practice observed. Bending of the bar to form proper end hook (135^0) is not easy therefore workers in construction site apply improper end hook of transverse reinforcement. In addition lack of continuous supervision of this detailing was observed from real-world practice. Proper detailing of reinforced concrete increase confinement of core concrete under axial compression. Building codes and researchers state to use proper end hook arrangement in seismic areas. Therefore it is important to study the confinement behavior of both detailing configurations for columns located in seismic areas.

1.3 Objectives of the study

General objective

- The main objective of this research is to investigate confinement effect on axial load carrying capacity of reinforced concrete column due to detailing

Specific objectives

- to compare the influence of shear reinforcement (ties) with proper end hook and improper end hook under compressive load

  I. on percentage increase of axial load capacity
  II. on axial load vs. average axial deformation behavior
  III. transverse reinforcement (ties) axial strain comparison

- to check introduced ties configuration in the enhancement of axial load capacity of 90-degree hook

1.4 Scope of the study

By applying different load type one can understand many structural properties of the column. This study mainly focuses on short square tied column under concentric compression. The comparison was made only by changing end hook configuration; keeping other parameter's constant like the effect of concrete grade, reinforcement grade etc.

1.5 Methodology

To asses, comparative effect first literature was revised close to the study area. Then the experimental program set up using a literature review. Column samples cast for an axial concentric compression test. Finally, simulation of the column was performed using finite element software.

1.6 Organization of the study

From out of six chapters; chapter two address rough review of code recommendation and researchers result regarding detailing. Chapter three explains material and method which is used in the experimental program. Chapter four discuss the result of experiment and comparison with an analytical model made. In chapter five Finite element modeling performed using non-linear software ABAQUS 6.14. Finally in the last chapter conclusion and recommendation drew from the above discussions.

2 LITERATURE REVIEW

2.1 Different code review

2.1.1 ACI CODE

ACI 318-05 code [3] section 7 generally describes standard hook for stirrups and ties bend depending on bar size and seismic hook configuration. Specifically, section 7.10.4 explains the requirement of lateral reinforcement for compression members. All in prestressed bars or vertical bars in tied column shall be enclosed by lateral ties; the Vertical spacing of ties shall not exceed 16 longitudinal bar diameters or 48 ties bar etc. Generally, column specially constructed in seismic hazard zones; the code recommend following transverse reinforcement detail shown in figure 2.1 below as an example

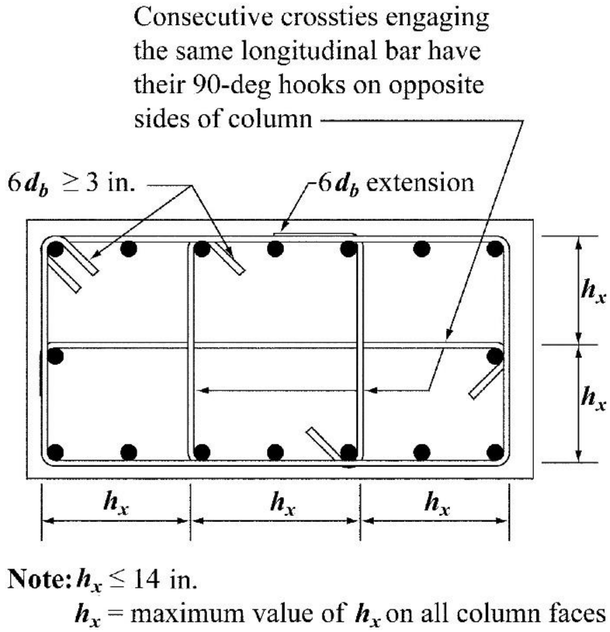


Figure 2. 1Example of transverse reinforcement in columns (ACI 318-05)

Figure 2.1 shows transverse reinforcement by one hoop and three cross ties. The hoop is transverse reinforcement having bend not less than 135 degrees and 6-times diameter of the bar into the interior of the stirrup and greater than 3in. While cross ties indicate transverse reinforcement having bend not less than 90 degrees in one end and 135-degree bend in opposite end with the same extension to core concrete as a hoop.

ACI 318 [3] section 10.3.6.2 gives maximum design axial strength of compression member shall not be greater than $\emptyset P_{n,\,max}$. Which defined as the sum of the forces carried by the concrete and the longitudinal reinforcement. For non pre-stressed members with tie reinforcement conforming to properties arrangements given by

$\emptyset P_{n,max} = 0.8\emptyset[0.85 f_c' \left(A_g - A_{st}\right) + f_y A_{st}]$... (2.1)

Where

$\emptyset P_{n,max}$ = maximum design axial strength, f_c' = specified compressive strength, A_g=Gross area of concrete section, f_y= specified yield strength of reinforcement,A_{st}= total area of non-pre-stressed longitudinal reinforcement

2.1.2 EBCS 1995 OLD CODE

In EBCS 2 1995[1] provision of structural concrete describes detailing is one major criterion to achieve design consideration. It gives minimum bending diameter in accordance with size and type of bars. For stirrup and ties for bar≤16Ø bend shall be not less than 4Ø. Ties and stirrups recommended anchorage is a hook (135^0 to 180^0) for plain bars; anchorage by bends (90^0 to 135^0) for deformed bars without specifying detail structural member type. seismic provision of old code EBCS 8 1995 [4] states for hoop requirement in beams, columns or wall closed stirrups with 135^0 bent-in bent end recommended.

2.1.3 EC 2004 and or ES EN 2015

EC 1992 2004 , EC 1998 2004 , ES EN 1992-1-1:2015 and ES EN 1998-1-1:2015 [2,5,6,7,]both codes states that the diameter of the transverse reinforcement (links, loops or helical spiral reinforcement) should not be less than 6 mm or one quarter of the maximum diameter of the longitudinal bars, whichever is the greater. The transverse reinforcement should be anchored adequately. Also in the design of the structure for earthquake part, both codes recommend using of hoops to confine core concrete by ties.

Similar to ACI code stated above Euro code 1992-1-1-2004 [2] and ES EN 1992-1-1-2015 [6] ,total load carrying capacity is summation of concrete and steel contribution by assuming there is perfect bond between concrete and steel which gives equal strain in both materials. At failure all steel reinforcement assumed has yielded therefore using equilibrium, design carrying capacity of concentric reinforce concrete compression member given by Eq 2.2.

$N_{rd} = f_{cd} * A_c + A_{st} f_{yd}$ .... (2.2)

Where

N_{rd}= design value of the applied axial force, f_{cd}=design value of concrete compressive strength, f_{yd}=design yield strength of reinforcement.

2.1.4 Egyptian code/ECC203-201 [8]

This code also recommend to confine core concrete properly. Axial load capacity can be obtained by similar concept form those above codes for a perfectly straight column without eccentricity and moment ultimate design strength given by P_u

$$P_u = \frac{0.67 f_{cu} * A_c}{\gamma_c} + \frac{A_{st} * f_y}{\gamma_s} \quad \text{...(2.3)}$$

Where

f_{cu} = cube strength of concrete , γ_c= safety factor for concrete=1.75 , γ_s= safety factor for reinforcement=1.34

2.1.4 IS (Indian standard)

IS 456:2000 [9] plain and concrete code of practice describes a reinforced concrete compression member shall have transverse or helical reinforcement so disposed that every longitudinal bar nearest to the compression face has effective lateral support against buckling. The effective lateral support is given by transverse reinforcement either in the form of circular rings capable of taking up circumferential tension or by polygonal links (lateral ties) with internal angles not exceeding 135^0.

Secondary reinforcement, such as stirrups and transverse ties, complete development lengths and anchorage shall be deemed to have been provided when the bar is bent through an angle of at least 90^0 round a bar of at least its own diameter and is continued beyond the end of the curve for a length of at least eight diameters, or when the bar is bent through an angle of 135^0 and is continued beyond the end of the curve for a length of at least six bar diameters or when the bar is bent through an angle of 180° and is continued beyond the end of the curve for a length of at least four-bar diameters. It allows different hook angle for different cases.

IS 13920:1993 [10] recommend transverse reinforcement for the rectangular column, rectangular hoops. A rectangular hoop is a closed stirrup, having a 135^0 hook with 10 diameter extension (but not <75mm) at each end, that is embedded in the confined core as shown in figure 2.2 below

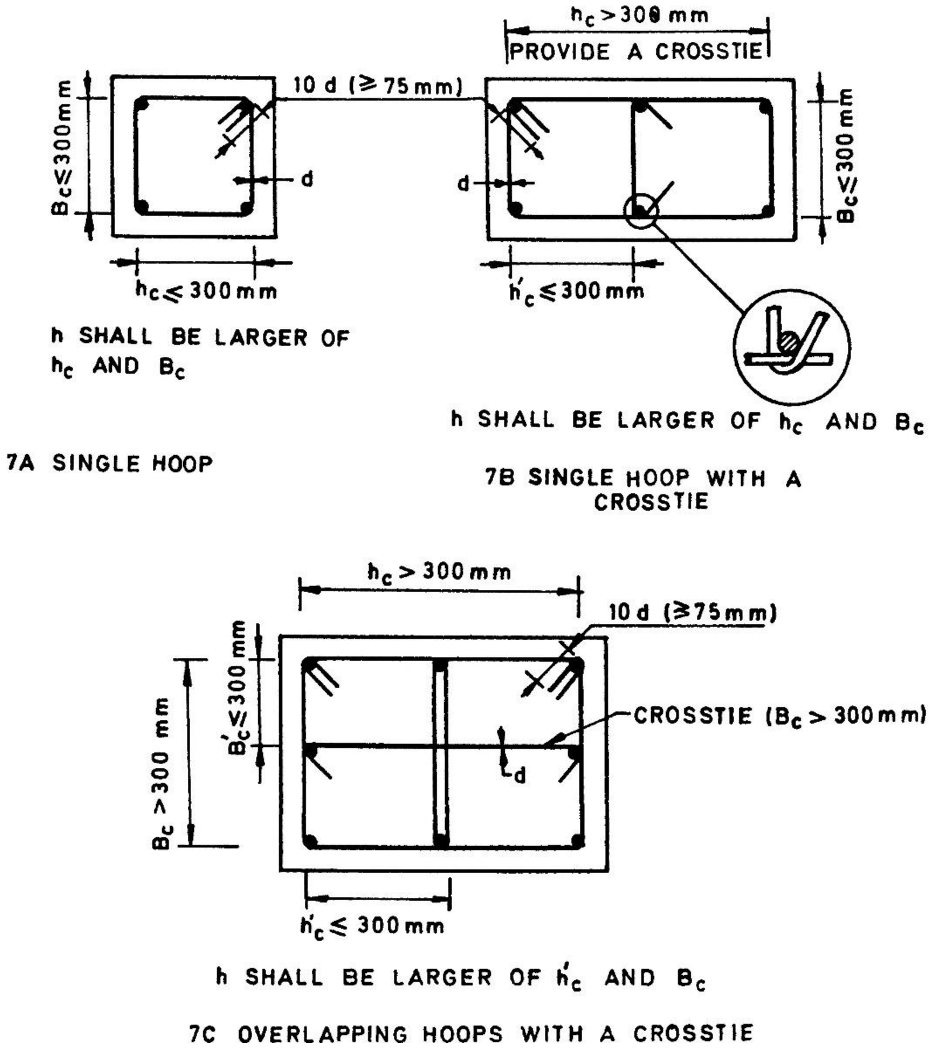


Figure 2. 2 Transverse reinforcement in column (IS 13920:1993)

This code also recommends to use a hoop (135^0 hook) and cross ties with 135^0 at both ends.

2.1.5 Code of practice for structural use of concert 2013

This manual prepared by the building a department of the government of the Hong Kong administrative region (China).

All corner bars and alternate bars (or bundle) in an outer layer of reinforcement should be supported by links, with or without crossties, passing around the bars and having an included angle of not more than 135^0 (see figure 2.3a). No bar within a compression zone should be further than 150 mm from a restrained bar. Links should be adequately anchored by means of hooks bent through an angle of not less than 135^0 (see figure 2.3b). Crossties should be adequately anchored by means of hooks bent through an angle of not less than 135^0 at one end and 90^0 at the other end and should be alternated end for end along the longitudinal bars (see figure 2.3c). Where there is adequate confinement to prevent the end anchorage of the link from "kick off" (see figure 2.3d),

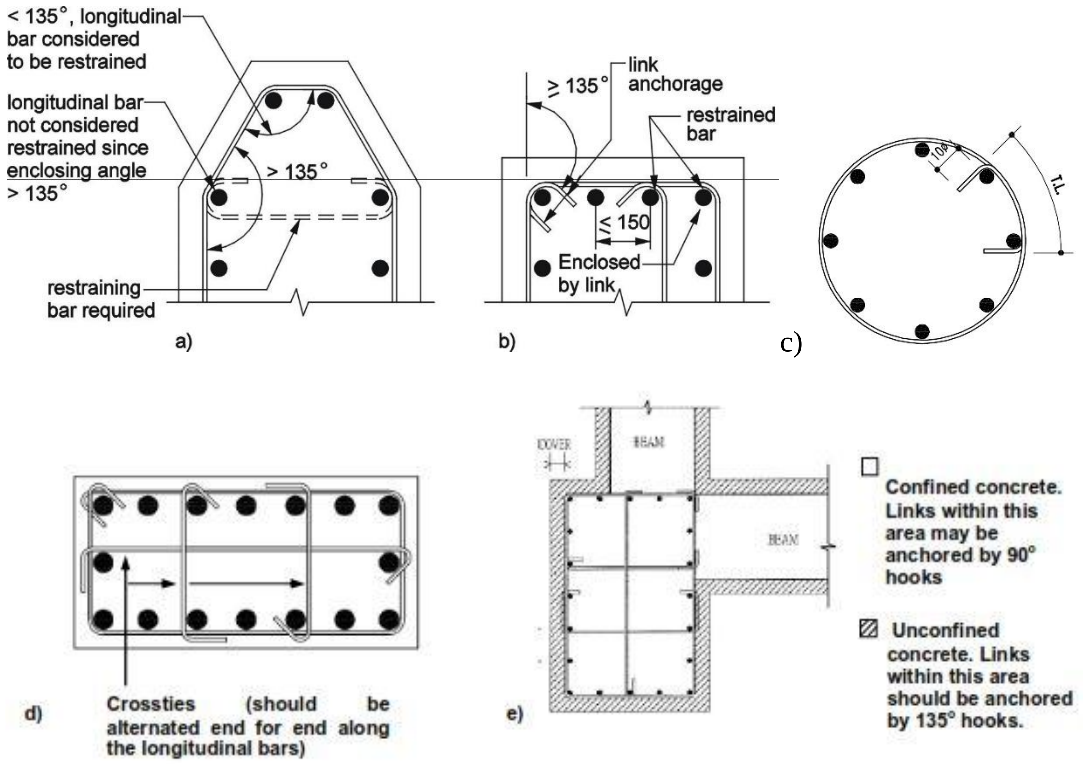


Figure 2. 3 Column transverse reinforcement (code of practice for structural use of concrete 2013) [11]

2.2 Previous work review

2.2.1 Ahmad K et al (2012)

In their paper, they deal with studies on the compressive strength of reinforced concrete specimens having confinement in various quantities. Studies on reinforced cement concrete specimens were used to understand the influence of the lateral confinement on the compressive strength of concrete samples. Cylindrical and square reinforced concrete test specimens having the height to diameter (or width) ratio as 2 were used for their study. The specimen was prepared with different spacing of hoops and having seismic and non-seismic hooks. Their paper deals with the variation of peak strength with a volumetric ratio of transverse steel to the confined concrete core.

They stated during earthquakes the failure in columns may occur due to poor or improper confinements. In India and some other countries, it is a practice to tie the compression members with hoops having 90^0 hooks but it has been recommended by seismic codes to provide 135^0 hooks for proper confinement.

Two different geometry were used 150x150mm and length of 300mm square cross-section and 300mm height diameter of 150mm circular cross-section. Longitudinal reinforcement of 8mm and 6mm bar for rectangular and circular cross section used respectively.5mm closed stirrups with 25, 50, 75,100,125, and 150 mm spacing applied for booth configurations.

Ahmad K et al [12] showed that increasing ratio of transverse reinforcement (ratio of the volume of the hoop to the volume of the core) increase peak strength of column for both stirrup configurations.AS other factors kept constant seismic hook has higher compressive capacity than a non-seismic hook.

2.2.2 Iswandi I et al (2012)

After observation of installation of a confining reinforcement with a 135-degree hook is not easy and poor performance in a recent earthquake at Indonesia; Iswandi I et al [13] presents a study that introduces an additional element that is expected to improve the effectiveness of concrete columns confined with a non-code compliant confining reinforcement. The additional element, named a pen-binder, is used to keep the non-code compliant confining reinforcement in place. The effectiveness of this element under pure axial concentric loading was investigated comprehensively

The specimens tested in this study were 18 concrete columns, with height to with ratio of 2.8 applied. The main test variables were the material type of the pen-binder, the angle of the hook, and the confining reinforcement configuration. The test results indicate that adding pen-binders can effectively improve the strength and ductility of the column specimens confined with a non-code compliant confining reinforcement.

Types of materials were used in this case, i.e.: steel and ABS (acrylonitrile butadiene styrene) plastic. The use of a plastic material for the pen-binder is to avoid corrosion of the material due to the inadequacy of the concrete to cover the pen-binder. Steel Pen-binder has a greater effect than plastic Pen binder. Pen-binder and application was shown in figure 2.4 below

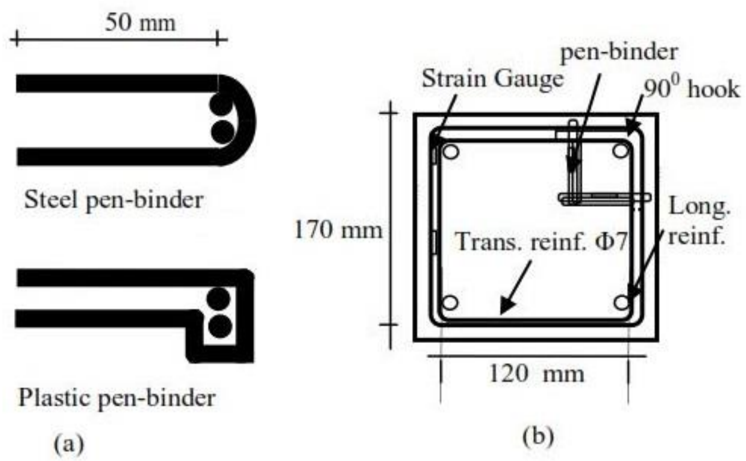


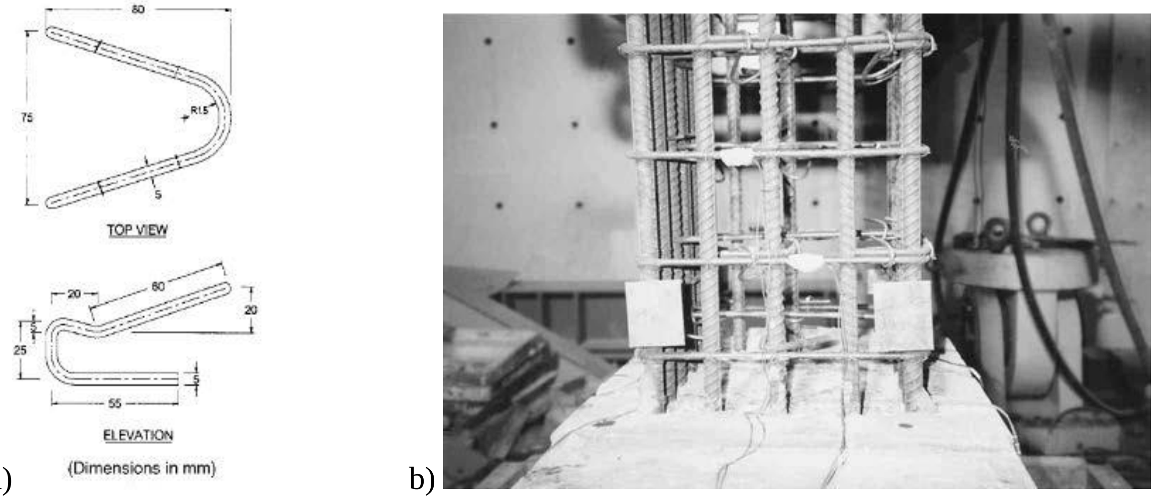
Figure 2. 4 a) pen-binder geometry b) strain gauge placement, Iswandi I et al (2012)

2.2.3 Panitan L et al (2003)

Panitan L et al [14] in their technical paper published in ACI structural journal did an experimental investigation of the effectiveness of hook-clips in improving the performance of conventional 90-degree hook-ties and crossties in moderately confined reinforced concrete (RC) tied columns. The tie configurations provided in the five large-scale specimens tested included 90-degree hook-ties and crossties, with and without hook-clips, and 135-degree hook-ties.

To prevent premature opening 90-degree hook, supplementary ties or hook clips has been embedded in the concrete core with its holding the legs of ties. Five 400 x 400 mm in cross-section and 1500 mm height column used. The columns were subjected to moderate levels of compression and cyclic lateral loads.

The hook clip fabricated from 5 mm diameter mild steel bar whose yield strength and modulus of elasticity were 450 Mpa and 204 Gpa. Detail hook clip and installation are shown in figure 2.5 below



a) b)

Figure 2. 5 (a) Details of hook-clip; and (b) hook-clips engaging 90-degree peripheral ties and crossties. Panitan L et al (2003)

They observe hook-clips were found to be effective in preventing opening of 90-degree hooks in tied columns under moderate ductility demand, resulting in significant enhancement of the ductility and energy dissipation capacity of columns confined with 90-degree hook peripheral ties and crossties. The hook-clips were resulting in the displacement ductility factor and energy dissipation capacity to be increased by approximately 85 and 400%, respectively.

2.2.4 Guney Ozcebe and Murat Saatcioglu (1987)

This is also ACI technical paper Guney O et al [15]. An experimental investigation was conducted to examine the effect of confinement in concrete columns subjected to simulated seismic forces. Mainly behavior of column under seismic effect with cross tie having both ends with 135^0 hook and cross ties having 135^0 at one end and 90^0 in opposite end.

The experimental program included full-scale tests of reinforced concrete columns with different arrangements of confinement steel. The columns were subjected to constant axial compression and incrementally increasing lateral load reversals.

Test results indicate that the inelastic response of concrete columns improves very significantly with proper confinement of core concrete. Crossties supporting the longitudinal reinforcement between the corner bars are highly effective in confining the core concrete.

A total of four full-size column specimens were tested under simulated seismic loading. The specimens represented a portion of a first-story column between the foundation and the inflection point.

Three configurations were used for transverse reinforcement. The first configuration labeled Type A, consisted of closed perimeter hoops with 135-degree end hooks, extending at least 10 tie diameters into the confined core. The other two configurations included crossties in addition to the perimeter hoops. Type B included crossties with 135-deg hooks extending at least 10 bar diameters into the confined core, engaging two opposite longitudinal bars between the corner bars. Type C was identical to Type B except that one end of the crossties had a 90-deg hook with an extension not less than 8 bar diameters.

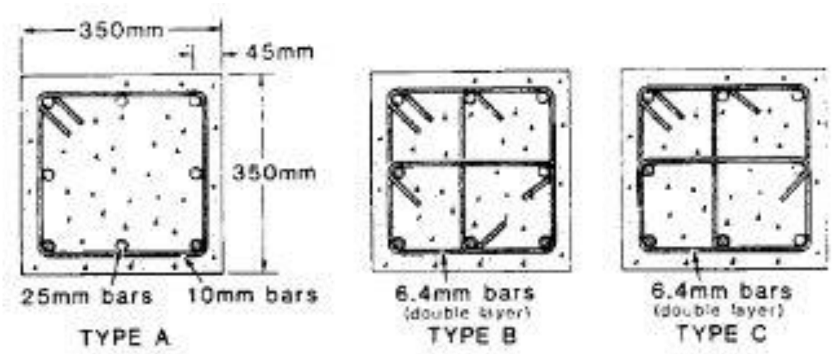


Figure 2. 6 Geometric details of test specimens Guney O (1987)

One of the conclusions after conducting experiment the researches come were: Nonlinear response of concrete columns to cyclic loading improves very significantly with the use of a proper confinement configuration and also Crossties with a 135-deg hook at one end and a 90-degree hook at the other end perform as satisfactorily as those with 135-deg hooks at both ends.

2.3 Analytical Stress – strain curve

2.3.1 Saatcioglu and Razvi

Saatcioglu and Razvi [16] from a large volume of test data, including poorly confined and well-confined concrete they establish the parameters of the analytical model. Confinement by a combination of different types of lateral reinforcement is evaluated through superposition of individual confinement effects. There model was simple to use, and sown to produce good predictions of experimental data for circular, square, and rectangular sections confined with spirals, rectilinear hoops, cross ties, welded wire fabric, and combinations of different types of lateral reinforcement.

The form of Eq. (2.3) originated by Richart et al. [17] has been widely used to calculate the strength of confined concrete. Test results show that the coefficient k_1 decreases with the increase of confinement pressure [16, 17]

$$\frac{f'_{cc}}{f'_{co}} = 1 + k_1 \frac{f_l}{f_{co}} \quad \text{..........} (2.3)$$

Test results show that the coefficient k_1 decreases with the increase of confinement pressure [17,18] and from the regression analysis of test data, reflects the variation of coefficient k_1 with lateral pressure.

$$k_1 = 6.7(f_{le})^{-0.17} \quad \text{..........} (2.4)$$

Where, f_l = uniform confining pressure, f'_{cc}=confined strengths of concrete in a member, f'_{co}= unconfined strengths of concrete in member and f_l = uniform confining pressure.

For rectangular section, saatcioglu and razvi [16] proposed Eq 2.6 for confined strengths of concrete f'_{cc} calculation by considering coefficient k_2 to reduce uniform lateral pressure to equivalent uniform pressure f_{le} and eq4.4 becomes

$$\frac{f'_{cc}}{f'_{co}} = 1 + k_1 \frac{f_{le}}{f_{co}} \quad \text{..........} (2.5)$$

$$f_{le} = k_2 f_l \quad \text{..........} (2.6)$$

$$f_l = \frac{\sum A_s f_{yt} sin\alpha}{s b_c} \quad \text{..........} (2.7)$$

α = the angle between the transverse reinforcement and b_c and is equal to 90° if the transverse reinforcement is perpendicular to b_c. b_c is the dimension of core concrete measured from the centerline of ties, A_s transverse reinforcement area and f_{yt} tensile yield strength of transverse reinforcement.

$$k_2 = 0.26\sqrt{\left(\frac{b_c}{s}\right)\left(\frac{b_c}{s_l}\right)\left(\frac{1}{f_l}\right)} \leq 1.0 \quad \text{..........} (2.8)$$

Where; s= transverse reinforcement spacing, s_l = longitudinal reinforcement spacing

Next stress-strain relationship proposed by above researchers for confined concrete presented. The relationship consists of a parabola for the ascending branch, and a linear portion for the descending branch and constant residual strength is assumed at 20% strength level. The following expression is suggested for the parabolic ascending portion.

$$f_c = f'_{cc}\left[2\left(\frac{\varepsilon_c}{\varepsilon_1}\right) - \left(\frac{\varepsilon_c}{\varepsilon_1}\right)^2\right]^{\frac{1}{(1+2K)}} \leq f'_{cc} \quad \text{..........} (2.9)$$

Where; ε_c= concrete strain, ε_1 = strain corresponding to peak stress of confined concrete and K coefficient defined as

$K = \frac{k_1 f_{le}}{f'_{co}}$ …………………………………………..………………………………. (2.10)

$\varepsilon_1 = \varepsilon_{01}(1 + 5K)$ ……………………………………………..……...……………...…. (2.11)

Where; ε_{01} = the strain corresponding to peak stress of unconfined concrete and can be taken as 0.002.

Descending branch of stress-strain curve proposed by staacioglu and razvi[16] have straight portion until the strain of ε_{20} which corresponding to 20% of peak confined strength .To get the slope of descending part strain at 85% strength level beyond the peak ε_{85} and peak stress and strain will be used.

$\varepsilon_{85} = 260\rho\varepsilon_1 + \varepsilon_{085}$ ………………………………..…………………...…..………. (2.12)

$\rho = \frac{\sum A_s}{s(b_{cx}+b_{cy})}$ ………………………………..…………………………….…………. (2.13)

Where; ε_{085} = the strain at 85% strength level beyond the peak stress of unconfined concrete, and value of 0.0038 can be taken. The summation sign in eq2.13 indicates the total area of transverse reinforcement in two directions, crossing b_{cx} and b_{cy}.

2.3.2 Karim M. El-Dash 1 And Osama O. El-Mahdy Model [18]

The model of the above researchers demonstrates the good predictive capability for concrete columns of normal strength to high strength concrete. In addition, the model is shown to be applicable for a wide range of quantity and configuration of lateral reinforcement with the volumetric ratio to concrete from 0.2% to 4%.

The following relationship is utilized by researchers to predict the compressive strength of confined concrete columns;

$f_{cc} = f_{co} + 1.8\, f_l$ …………………………………………………………..……………… (2.14)

Where: f_l is lateral confining pressure and given by

$f_l = k_s\, k_f\, \rho_{st}\, f_{yt}$ ………………………………………………………..…………………. (2.15)

Where; ρ_{st} , is the volumetric ratio of the transverse reinforcement to the confined concrete core and f_{yt} is the yield strength of the transverse reinforcement.

The coefficient, k_s, is induced to consider the effect of lateral pressure variability in the vertical direction and coefficient, k_f accounts for the change in confining pressure with the change in the ratio of unconfined concrete strength to yield strength of the lateral reinforcement and given by:

$K_s = \left(1 - \frac{s}{b}\right)^2$ ………………………………………………..……………. (2.16)

$$K_f = 1 - \left(\frac{f_{co}}{f_{yt}}\right)^2 \quad \text{……………………………………………..………………} \quad (2.17)$$

And *s/b re*present*s* the relationship between the spacing between transverse reinforcement to column breadth,

2.4 Conclusion from literature

All the above researchers aimed in one way or another to enhance strength and ductility of the concrete column. We can observe that 90-degree hook showing lower capacity than a standard seismic hook. The researcher's tried to enhance 90-degree hook capacity by different methods as described above. First of all, application of researchers method was to reduce ease of construction and workload but on the contrary preferred method by researchers were also requires additional work and material. Iswandi I et al [13] suggest applying additional element, steel and plastic pen binder also Panitan L et al [14] applied hook – clips to increase 90-degree hook capacity. Prefabrication of pen binders and hook clips will be time-consuming and have an additional cost to the project.

Therefore this study compared the capacity difference of 90-degrees and 135-degree ties arrangement with column samples that full fill Euro code minimum column confinement requirement, ACI and IS minimum column size/height definition.

As described by Guney O et al [15] Crossties with a 135-deg hook at one end and a 90-degree hook at the other end perform as satisfactorily as those with 135-deg hooks at both ends. Inspired by this; the present research study the effectiveness of perimeter ties with a 135-degree hook at one end and a 90-degree hook at the other end (IC3). And as we know the main use of 1.5mm fixing wire used in reinforced concrete were to place transverse reinforcement (stirrups) in required place along longitudinal reinforcement. Additionally by considering this using of wire to prevent opening of 90-degree hook (IC4) were checked for axil load capacity.

3 MATERIALS AND METHODS (EXPERIMENTAL SETUP)

3.1 General

This part describes the properties of the materials used for the experimental program, mix design for target concrete strength, test units size criteria, the construction method employed and test setup and procedure that followed.

3.2 Materials

3.2.1 Cement

Cement used for the specimen was Portland Pozzolana Cement. The cement used was delivered in standard gunny bags and latter it placed until use in dry place to avoid the deterioration of the cement. The specific gravity of the cement was 3.15.

3.2.2 Water

Water fit for drinking is generally suitable for making concrete. The potable water available in the compound is used for mixing of concrete and also for curing of test units. It was checked by the sense of smell, sight, and taste for purities.

3.2.3 Fine Aggregate

The fine aggregates used for casting of all the specimens is river sand. The fine aggregates were sieved through 4.75 mm sieve. Fineness modulus, silt content and gradation curve given below.

Table 3. 1 Sieve analysis result of fine aggregate

Sieve Size [mm]	Weight Retained [gm]	% Retained	Cumulative Courser [%]	Cumulative Passing [%]
12.5	0	0.00	0.00	100.00
9.5	10	2.00	2.00	98.00
4.75	20	4.00	6.00	94.00
2.36	35	7.00	13.00	87.00
1.18	135	27.00	40.00	60.00
0.6	190	38.00	78.00	22.00
0.3	75	15.00	93.00	7.00
0.15	15	3.00	96.00	4.00
Pan	20	4.00	100.00	0.00
Sum=	500			

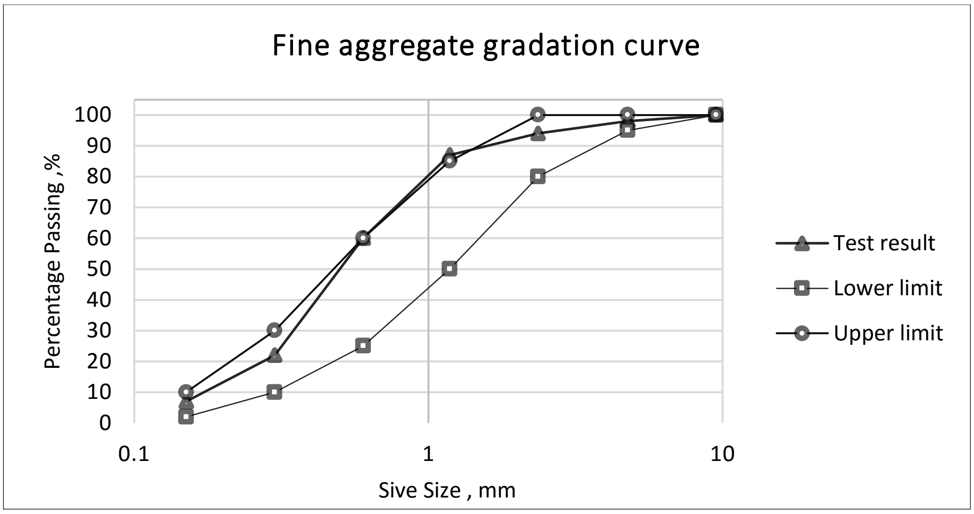


Figure 3. 1 gradation curve of fine aggregate

Table 3. 2 summarized properties of fine aggregate

Silt Content (%)	**3.44**
Fineness Modulus	**3.28**

3.2.4 Course Aggregate

The coarse aggregates used in the mixes are Granite Stones from the quarries. The gradation curve is given below.

Table 3. 3 Sieve analysis result of course aggregate

Sieve Size [mm]	Weight Retained [gm]	% Retained	Cumulative Courser [%]	Cumulative Passing [%]
37.5	0	0.00	0.00	100.00
25	800	8.00	8.00	92.00
19	2600	26.00	34.00	66.00
12.5	4100	41.00	75.00	25.00
9.5	1600	16.00	91.00	9.00
4.75	800	8.00	99.00	1.00
Pan	100	1.00	100.00	0.00
Sum=	10000			

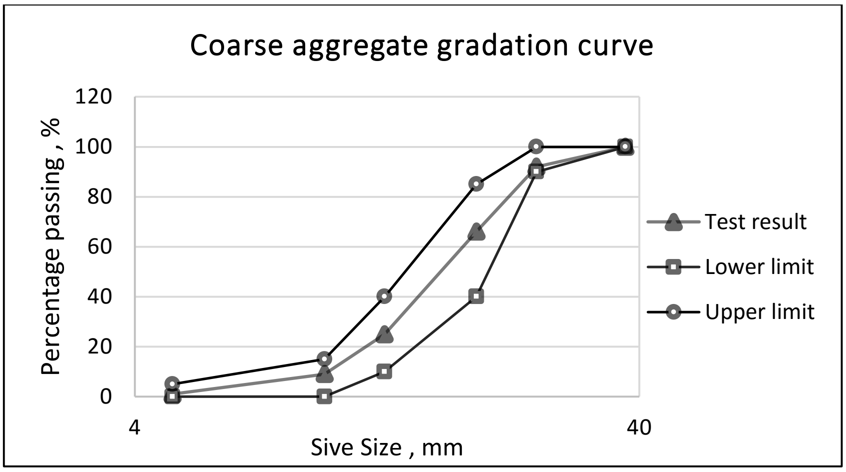


Figure 3. 2 gradation curve of coarse aggregate

Figure 3. 3 Fineness Modulus of coarse aggregate

Fineness Modulus	3.1

3.2.5 Reinforcement Bars

There are several types of reinforcing bars, designated by the ASTM. These steels are available in different grades as Grade 40, Grade 50, and Grade 60 etc. For this thesis three different sized bars used. Diameter 6mm and diameter 8mm reinforcement bars were used as transverse reinforcement and diameter 12mm reinforcement bar as longitudinal bar. Here reinforcements Grade, diameter and some mechanical properties obtained from laboratory test are shown in Table 3.4

Table 3. 4 Material properties of reinforcing bar

Designation	Area (mm2)	Yield load [KN]	Yield stress[Mpa]	Failure load [KN]	Failure Stress [Mpa]	Mass/ Length Kg/m	Elongation (%)	Average Tensile Failure	Average Tensile Yield Stress[Mpa]
Ø6,1	28.274	16.330	577.556	20.100	710.892	0.183	18.644	726.336	588.284
Ø6,2	28.274	16.860	596.301	20.850	737.418	0.184	20.588		
Ø6,3	28.274	16.710	590.995	20.660	730.698	0.188	19.429		
Ø8,1	50.265	38.500	765.933	44.370	882.713	0.383	11.034	839.277	744.248
Ø8,2	50.265	36.510	726.343	41.310	821.836	0.388	8.844		
Ø8,3	50.265	37.220	740.468	40.880	813.282	0.381	10.345		
Ø12,1	113.097	75.500	667.567	85.730	758.02	0.868	12.821	754.807	665.002
Ø12,2	113.097	75.020	663.322	85.570	756.605	0.879	12.739		
Ø12,3	113.097	75.110	664.118	84.800	749.797	0.874	12.903		

3.2.6 Strain Gauge

A strain gauge is a sensor whose resistance varies with applied force: it converts force, pressure, tension, weight etc… into a change in electrical resistance which can be measured. When an external force is applied to stationary object stress and strain are the results.

The strain gauge is one of the most important sensors of the electrical measurement technique applied to the measurement of mechanical quantities. As their name indicates they are used to measure strain.

To measure and study strain in ties of selected sample test units. For this thesis, BF350-3AA strain gauge is used. Detailed specification is shown in table

Table 3. 5 Specification of BF350-3AA strain gauge

Specification	BF350-3AA
Nominal resistance Ω	350
Tolerance resistance	<±0.1%
Gauge factor	2-2.2
Gauge factor resistance	<±1%
Strain limit	2.00%
Fatigue life	>10^7
Working temperature range	-30^{0}C - +80^{0}C

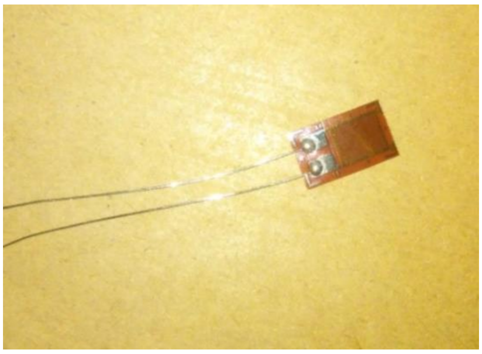


Figure 3. 4 BF350-3AA strain gauge

3.2.7 Mix Design

Concrete proportions must be selected to provide necessary place ability, density, strength, and durability for its application.

Design mix of target C25 grade concrete and above according to ACI (Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete (ACI 211.1-91)) [19] was used for casting of the column specimen. But target strength were not achieved during testing of cubes; but for research purpose C20 concrete can be acceptable. Table 3.6 below shows detail mix design.

Table 3. 6 Concrete mix design for C25 (Target)

No	Description	Amount	Unit	Reference ACI 211 1-91 [14]	Remark
1	Slump	25-50	mm	Table A1.5.3.1	
2	Maximum Aggregate size	25	mm		
3	Mixing water for above slump and aggregate size for non-air entrained concrete	179	Kg/m^3	Table A1.5.3.3	
4	W/C ratio	0.69		Table A1.5.3.4(a)	
5	Cement content	259.4	Kg/m^3		
6	Coarse aggregate			Table A 1.5.3.6	
	dry-roded volume	0.65			FM=3.1
	Unit weight	1588	Kg/m^3		
	Dry mass	1032.2	Kg/m^3		
7	Mass of fresh concrete	2380	Kg/m^3	Table A1.5.3.7.1	
8	Fine aggregate	909.4	Kg/m^3		Mass Basis

From ACI mix design for building column minimum and maximum slump is 25mm and 100mm.For the tested maximum aggregate size and slump range of 25mm – 100mm mixing water were selected 179Kg/m^3.Water to cement ratio selected for corresponding cylindrical strength of 20Mpa.Samples tested after 90 days of their cast. Which is acceptable for comparative study.

Table 3. 7 Achieved Compressive strength of cubes at test day

Sample	1	2	3	4	5	6	Average
Compressive strength at test day (Mpa)	21.77	20.44	18.99	19.11	20.01	23.11	20.57

- **Statistical Variations in Concrete Strength**

Variations in the properties or proportions of constituents, as well as variations in the transporting, placing etc. lead to variations in the strength of the finished concrete. Therefore we need to express the degree of dispersion on the basis of percentage. And check the quality of concrete according to specified ACI 214. [20]. Calculated coefficient of variation was 7.79% and very good concrete control for general construction testing

3.3 Methods (Experimental Setup)

3.3.1 General

3.3.2 Test unit geometrical and material criteria

All test units dimensioned, the area of longitudinal bars used and spacing lateral ties are according to ES EN 1992-1-1:2013 [6]and ES EN 1998-1-1:2013 [7]. To investigate the post-peak behavior of sample, taken cross-sectional dimension, height and other parameters are set to full fill DC-M.

Table 3. 8 ES EN 1998-1-1 requirement of the column with DC-M

Section	Code recommendation		Provided	Status	Remark
5.4.1.1(1)	**Material**				
	concrete grade	≥C16/20	C20	ok	
	Steel grade	Class B or C			
5.4.1.2	**Geometry**				
	Cross-sectional dimension			ok	
	greater than Le*(1/10)		150mm>465/10=46.5		
5.4.3.2.1(3)	**Resistance**			ok	
	vd<0.65		1	for testing	to crash specimen
5.4.3.2.2(1)	**Longtiudral reinforcement ratio**				
	rmin=	0.01	0.02	ok	
	rmax=	0.04		ok	
5.4.3.2.2(5)	**Crtical length**				
	Lo/hc<3			ok	
	then whole sectin be lcr		lcr=465 whole lenght		
5.4.3.2.2(8)	**Core concrete confinement**				see next section
	αωwd≥30μφ*vd*εsyd*bc/bo-0.03				
5.4.3.2.2(11	**Spacing for min ductility**				
	S=min{bo/2:175:8dbl}..........(a)		s=46mm for Diam 8	45mm for	
			S=47mm for Diam 6	both	
	max distance b/n cosiquative			ok	
	logtiudnal bars is 200mm				

From ES EN 1998-1-1:2013[7] section 5.4.3.2.2(6) adequate confinement of the concrete core achieved by fulfilling

$\alpha\omega_{wd} \geq 30\mu_{\varphi} * \nu_{d} * \varepsilon s_{yd} * b_{c}/b_{o} - 0.035$ ....………………….. (3.1)

Where

μ_{ϕ} is the required value of the curvature ductility factor

ν_{d} is the normalized design axial force ($\nu_{d} = N_{Ed}/A_{c} \cdot f_{cd}$);

$\varepsilon_{sy,d}$ is the design value of tension steel strain at yield;

h_{c} is the gross cross-sectional depth (parallel to the horizontal direction in which the value of μ_{ϕ} as used;

h_{o} is the depth of confined core (to the centerline of the hoops);

b_{c} is the gross cross-sectional width;

b_{o} is the width of the confined core (to the centerline of the hoops);

α is the confinement effectiveness factor, equal to $\alpha = \alpha_{n} \cdot \alpha_{s}$, with

ω_{wd} is the mechanical volumetric ratio of confining hoops within the critical regions.

For Ductility class medium (DC-M) ω_{wd} can be taken as $\omega_{wd} \geq 0.08$ and for this thesis by considering $\omega_{wd}=0.08$.

$$\omega wd = \frac{volume\ of\ confining\ hoop}{volume\ of\ concrete\ core} * \frac{\mathrm{fyd}}{fcd} \quad (3.2)$$

$$\omega wd = \frac{\mathrm{Ash}}{bo*s} * \frac{\mathrm{fyd}}{fcd} \quad (3.3)$$

$$Ash = \frac{\omega wd*bo*s*fcd}{fyd} \quad (3.4)$$

A_{sh} is total area of horizontal hoops.

Detailed calculation of the area of horizontal hoops given in the table below for both ties diameter. f_{yd} = design yield strength reinforcement, f_{cd}= design value of concrete compresive strenght.

Table 3. 9 provided area of horizontal hoops

	Ties bars diameter (mm)		Remark
	Ø6	Ø8	
Min ω_{wd}	0.08	0.08	For DCM
f_{yd} (Mpa)	511.55	647.17	
f_{cd} (Mpa)	9.06	9.06	
b_o	94	92	Cover=25mm
Spacing(s) for minimum ductility	46	47	section 5.4.3.2.2(11)
Ash_{min} (mm2)	6.125	4.84	
$A_{sh\ provided}$ (mm2)	28.26	50.24	

Different building codes give different amount of embedment length of bent bars. EBCS 2 1995(7.1.2) [1] states to use ≥4Ø for ties and stirrups, ES EN 1992 (8.5) [6] also states for anchorage of links and shear reinforcements to use ≥5Ø but >50mm recommends and ACI 315-99 [20] recommends to extend ties 6db but not less than 75mm. For this comparative study extension of 75mm used for perimeter ties to observe difference clearly.

Figure 3.5 below, shows specimen geometry, category (IC3 and IC4) describes introduced ties configuration. Introduced category 3 (IC3) shows when bending of one leg of ties 135^0 and other 90^0 also Introduced category 4 (IC4) shows 90^0 ties configuration additionally wired by 1.5mm fixing steel wire at location half of extended dimension. PC is plain concrete with the same dimension as reinforced concrete column.

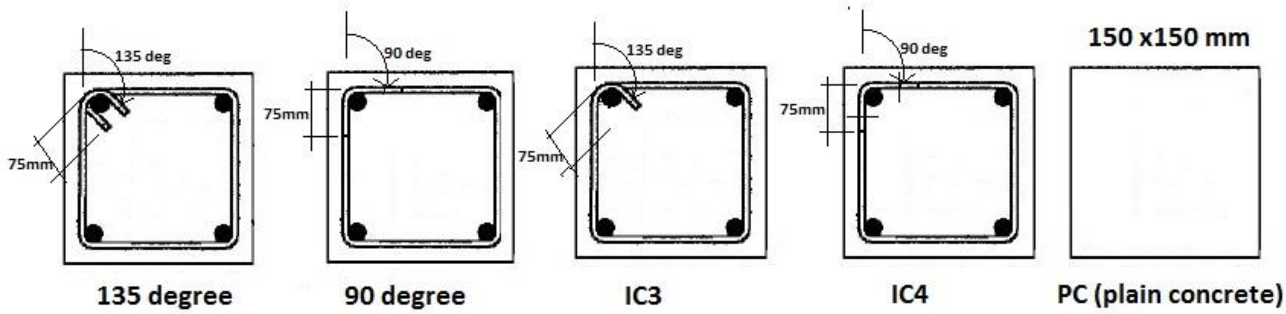


Figure 3. 5 Illustration of the specimen geometry

Table 3. 10 Detail test specimen summary

Specimens			Longitudinal Reinforcement		Transverse Reinforcement		Hook Configuration
Category		Designation	ρ_l	f_y (Mpa)	S,mm	f_{yh} (Mpa)	
Ø6	**1**	CC(135)	0.0201	665	45	588	135-degree hook
		NC(90)	0.0201	665	45	588	90-degree hook
Ø8	**2**	CC(135)	0.0201	665	45	744	135-degree hook
		NC(90)	0.0201	665	45	744	90-degree hook
	3	IC3	0.0201	665	45	744	One leg 90 and one leg 135-degree hook of perimeter ties
	4	IC4	0.0201	665	45	744	90-degree hook and additionally wire by 1.5mm wire

ρ_l= ratio of longitudinal reinforcement to concrete area s= spacing of ties

3.3.2 Manufacturing of specimens

The height of the test units was chosen to be 465 mm for aspect ratio criteria. Both EBCS 2 1995 [1] and EC 1992 1-1 2004 [2] does not give clear value for the minimum length of the column. EBCS 2 1995 section 7.2.4.1 [1] states the minimum lateral dimension of a column shall be at least 150mm.

Indian Standard IS 456:2000 [9] section 25.1.1 describes Column or strut is a compression member, the effective length of which exceeds three times the least lateral dimension. So, by considering 465mm as effective length (lo=l section 5.8.3.2 2(a) [2] specimen fulfills both width and length requirement of those codes.

In addition, ACI318-05 [3] code in section 2.2 defines a column as a member with a ratio of height-to-least lateral dimension exceeding 3 used primarily to support the axial compressive load. Proposed column ratio is =465/150=3.1 which satisfies ACI column definition. This study focuses on confinement of core concrete by a different configuration of ties. Different codes show that confinement of core does not have relation with the size (length) of the specimen. [1, 2, 3]

The construction sequence consisted of tying the cages, fixing the strain gauges to the transverse reinforcement at mid-height and placing the cages in the painted and oiled molds. The cages were fixed in position to provide required cover by spacers.

- **Formwork and Reinforcement cages**

For each test units, 20 mm construction plywood was used to produce 465mm by 150mm mold. Before casting of column samples formwork was painted and oiled.

Figure 3. 6 Formwork and Reinforcement cages

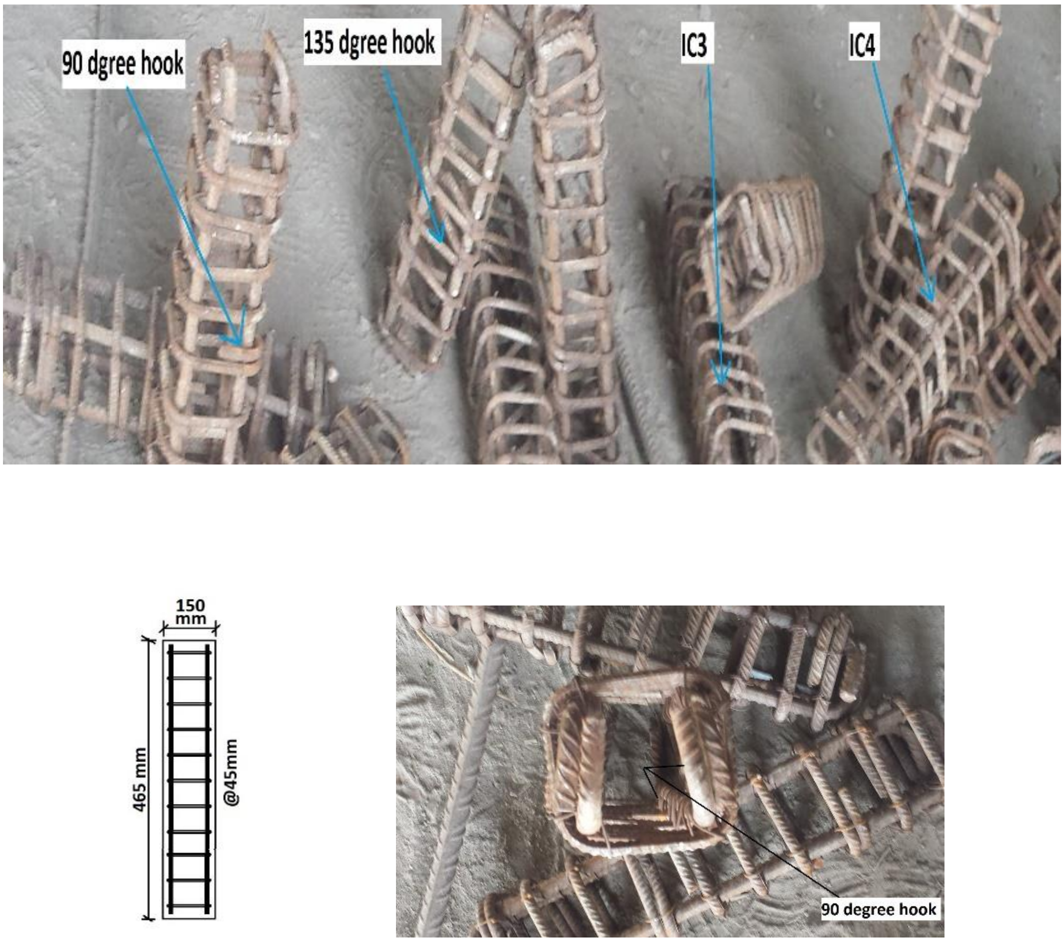


Figure 3. 7 Reinforcement cages and Schematic drawing of reinforcement

- **Strain gauge fixing**

Two strain gauges were used to study the behavior of the column. Two of them was placed in the transverse steel at mid height to measure the strain. Before fixing the strain gauges, the surface of steel was lightly ground smoothly to ensure a straight surface when applying the sheet.

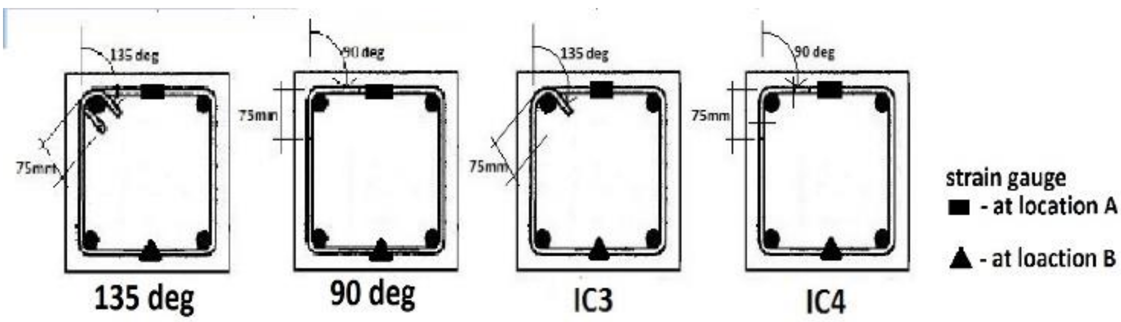
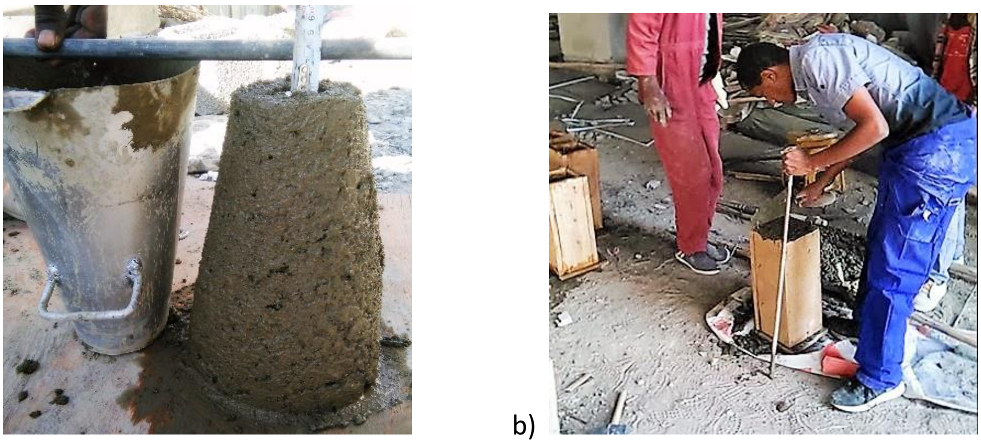


Figure 3. 8 Strain gauge fixing position

Figure 3. 9 Strain gauges fixed in reinforcement (middle ties)

- **slump check and casting**

The mixed concrete was placed and well vibrated. For each batch of mix required mix design slump were checked. 6 150 x 150 mm test cubes were cast and vibrated.



a) b)

Figure 3. 10 a) slump check b) casting

- **curing and ready specimens for test**

a) 

b)

c) 

Figure 3. 11 a) Before formwork removal b) curing c) ready specimens for test

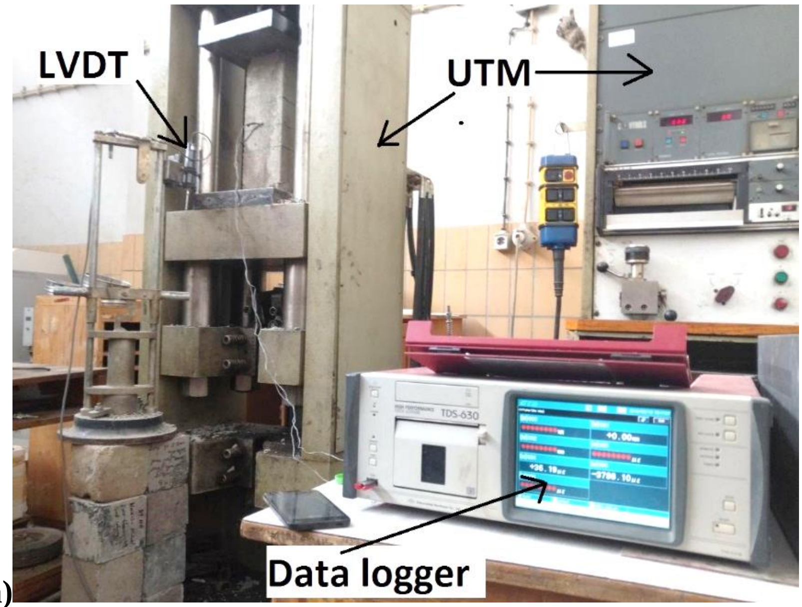
3.3.3 Test setup and Instrumentation

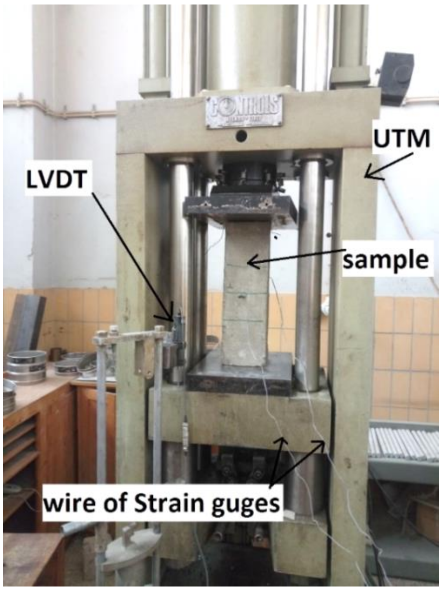
All column was fully instrumented to measure the applied vertical load and vertical average axial deflections and also the axial strain on the stirrups. In order to measure the axial deflection of the specimen linear voltage displacement transducers (LVDT) attached to rigid steel and placed at near each test specimen and pointed to the top of the bottom steel collars (machine moveable part) to provide continuous data recording even after the spalling of concrete cover. The continuous average axial strain of the test specimen can be obtained from the average axial shortening readings from LVDT divided by the original vertical length of the test region.

Axial strain in transverse reinforcement recorded from attached strain gauges to the data logger machine. LVDT were connected to a data logger which can give continuous average axial deformation.

3.3.4 Test procedure

Universal Testing Machine controls solution with maximum axial compression capacity of 2000KN used. After correctly positioning the specimen and the transducer, the test started on the universal testing machine (UTM), data logger and LVDT channel. The axial deflection data from the LVDTs channel to the data logger, the corresponding applied compression load and strain reading of strain gauges continuously captured by video camera. Using recorded video load-deflection curve and stirrups strain history were plotted. In order to see the post-peak behavior of testing specimen peak sensitivity of the machine is converted to 600KN. But Firstly used digital UTM (load rate was automatically set and sensitivity easily adjusted) failed after testing column samples with diameter 6mm ties and plain concrete. Then the rest samples were tested on other manually load and sensitivity controlled UTM. The test setup is shown in Fig. 3.12

a) 

b) 

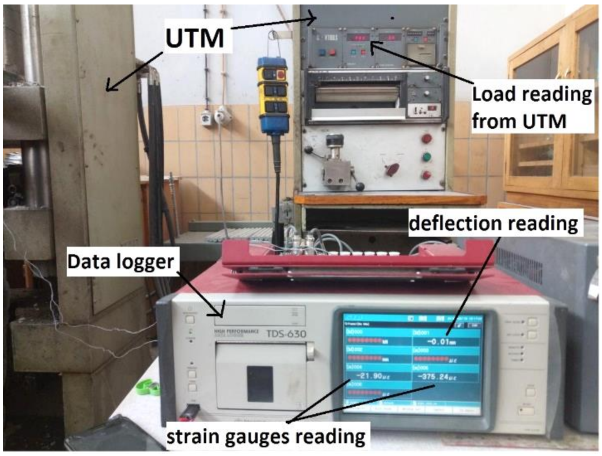
c) 

Figure 3. 12 a) UTM ,Data logger b) UTM and sample c)Reading from UTM and Datalogger

4 RESULT AND DISCUSSION

4.1 Introduction

For all column result presented and discussed in the following sections. Results from experimental investigation of the column with both diameter 6 and 8 mm ties configuration described. Discussion points were peak strength, failure mode, hoop strain, and comparison. Following that experimental results are compared with the different theoretical model.

4.2 Diameter 6mm ties specimens

4.2.1 Peak load

From observed test results the 135^0 hook configuration showed greater peak load than 90^0 hook ties configuration. As shown below 135^0 hook configuration showed enhancement of 90^0 hook peak load by 11.17%.

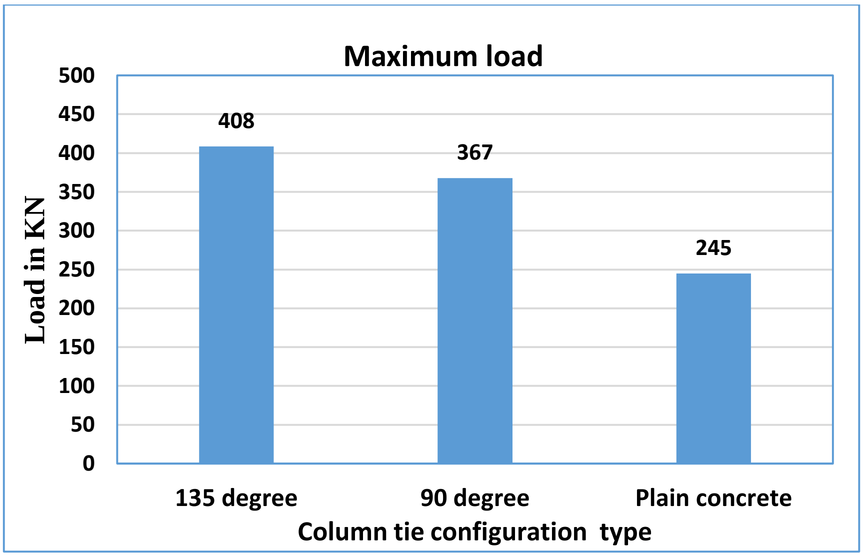


Figure 4. 1 maximum failure load of diameter 6mm ties column

4.2.2 Load vs. average axial deformation

To determine the actual distribution of stresses within a member, it is necessary to analyze the deformations which take place in that member. An important aspect of the analysis and design of structures relates to the deformations caused by the loads applied to a structure. It is important to avoid deformations so large that they may prevent the structure from fulfilling the purpose for which it is intended.

The graph between axial load and axial deformation to understand the load-deformation behavior is necessary, with varying transverse reinforcement configuration. The graphical representation of load-deformation behavior is shown in Fig 4.2

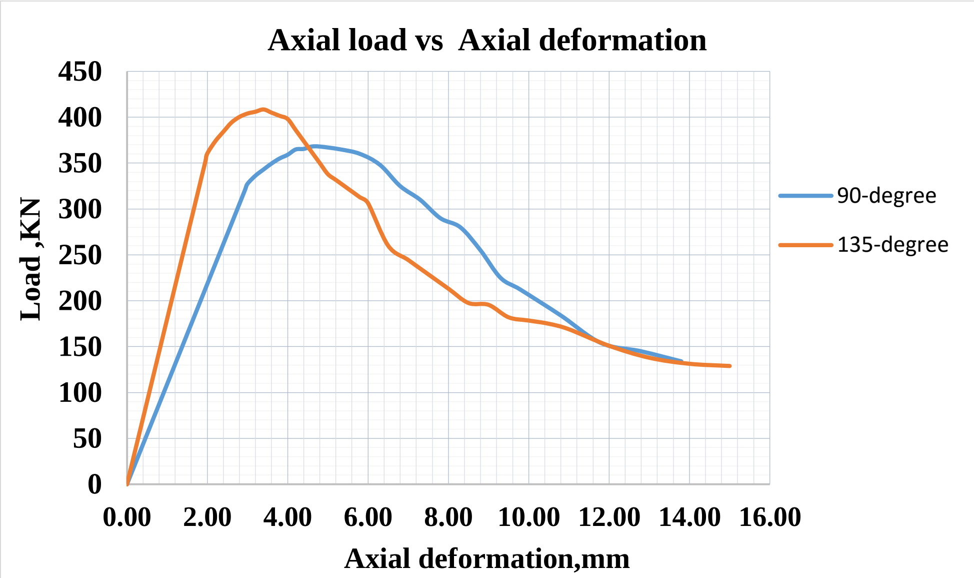


Figure 4. 2 Average axial loads vs. average axial deformation of diameter 6mm ties column

The average axial deformation obtained from the LVDTs that measure the relative movement between the top and bottom platens. The observed deformation was relatively large which is caused by the relatively higher deformability of the topping in the ends of a specimen consequently, the average axial deformation obtained is acceptable for comparison purpose. Load-deformation curve of both configurations showed similarity in ascending and descending part.

Here discussing the axial stiffness of column with different ties configuration presented. Mathematically it can be expressed as the slope of the load-deformation curve in the elastic region. Clearly, we can see that yield points from the above figure 4.2 both sample by having linear relation up to yield points.

Column with 135^0 ties configuration yield load is around 360.4KN with deformation of 2mm and column with 90^0 tie configuration has yield load of 327.3KN with deformation of 3mm. The slope which is stiffness became 180.2KN/mm and 109.1KN/mm for 135^0 and 90^0 ties configuration respectively. This implies that the code recommended tie configuration has high deformation resistance than non-code compliance ties configuration.

Also, 135^0 ties configuration reaches its peak load 408KN at small deformation 3.4mm, but tie configuration with 90^0 reaches its peak load 367KN at 4.6mm. After peak load stiffness decreased suddenly up to a deformation value of 11.5mm and the decrement became marginally slow after this for both configurations but 135^0 configuration is the one with high stiffness reduction as shown in fig 4.2.

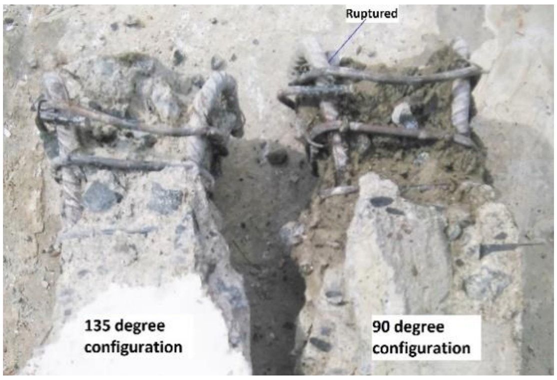
4.2.3 Failure mode / observed behavior

At the early stage of loading, both columns were showing very similar behavior. And still for increased load both ties configuration was showed similar failure mode to end but the formation of surface cracks and spalling of cover concrete comparatively delayed for 135^0 ties configuration.

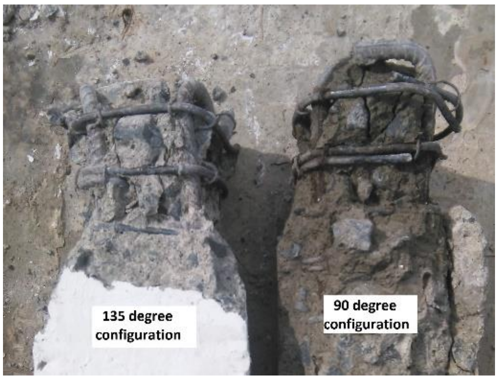
Just before cover spalling approximately at 85% of peak load vertical longitudinal surface cracks were first observed. Formation of crack gives intermittent cracking sounds when concrete cover release energy as a tensile force. Then falling of cover concrete due to the widening of vertical crack occurred. Finally, the inclined crack started near the edge and extended little downward after little while there was first hook fracture lead failure of the column. Also at the end of testing buckled shape of longitudinal bar observed for both tie configurations. Fig 4.3 below illustrates the appearance of typical specimens at various loading stage.

a) Before test b) surface, inclined crack and cover spalling c) at test end

Figure 4. 3 test observation at different stages of loading



a) Column after testing side view



b) column after testing front view

Figure 4. 4 90^0 and 135^0 ties configuration at the end of testing

Figure 4.4 a and b show response of different ties configuration at the end of testing. For all pictures, we can observe that three raw of ties from top to bottom along samples height. In fig 4.4a of 90^0 tie configuration first top raw tie was completely ruptured the same raw of 135^0 tie configuration just opened up but relatively still in a good position to confine core concrete than 90^0 tie configuration. In fig 4.4b front view of the same column as in fig4.4a for both configuration second and third raw ties were as the position at the start of the test. Core concrete of 135^0 tie configuration undisturbed up to the top edge as compared to 90^0 ties configuration. This implies that tie configuration with 135^0 confined core concrete properly.

As shown in fig 4.4 longitudinal bar of 90^0 ties configuration was highly buckled than 135^0 ties configuration. Especially ties in the first raw can't handle buckling of longitudinal bar. For both cases inward buckling of the longitudinal bar to core concrete was observed. This was due to the crashing of core concrete lead to bars to buckling into the core concrete.

4.3 Diameter 8mm ties specimens

4.3.1 Peak load

Here for 8mm transverse reinforcement columns, there was four different type of ties configuration 90^0, 135^0, introduced category 3 and introduced category 4.Average of 3 samples from each configuration were shown in fig4.5.

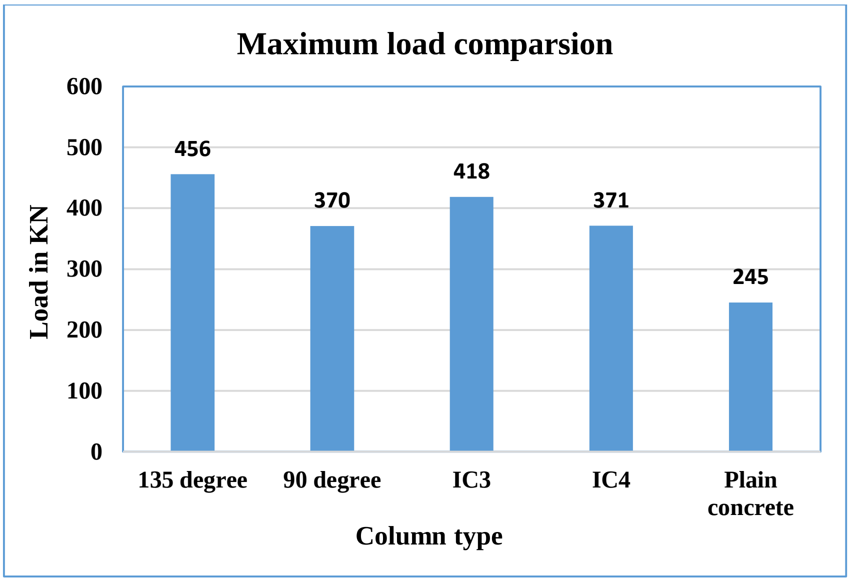


Figure 4. 5 maximum failure load of diameter 8mm ties column

Fig 4.5 shows various column type peak load comparison. The uncertainty related to the predicted peak strength was found to be relatively low for all column types, the coefficient of variation ranging from 2.84 to 9.51 percent. 135^0 configuration has 23.24% and IC3 configuration has 12.97% higher load carrying capacity than 90^0 configurations. But IC4 gives almost similar value as 90^0 ties configuration that means using additional 1.5mm fixing steel wire to ties does not give a different result from the non-code compliant configuration. Proposed IC3 showed 8.33% peak load reduction from standard 135^0 configuration. But 18.85% reduction for 90^0.

The only varying parameter for this study was tied hook detailing. Knowing that confinement different observed in different ties arrangement relative to unconfined concrete. Confinement increase of 51%, 71%, and 86% gain in 90^0, 135^0 and IC3 column respectively. Proposed IC3 have only 15% difference in confinement increase of standard 135^0 hook

4.3.2 Load vs. average axial deformation

The graphical representation of load-deformation behavior is as shown in Fig 4.6. For diameter 8mm transverse reinforcement.

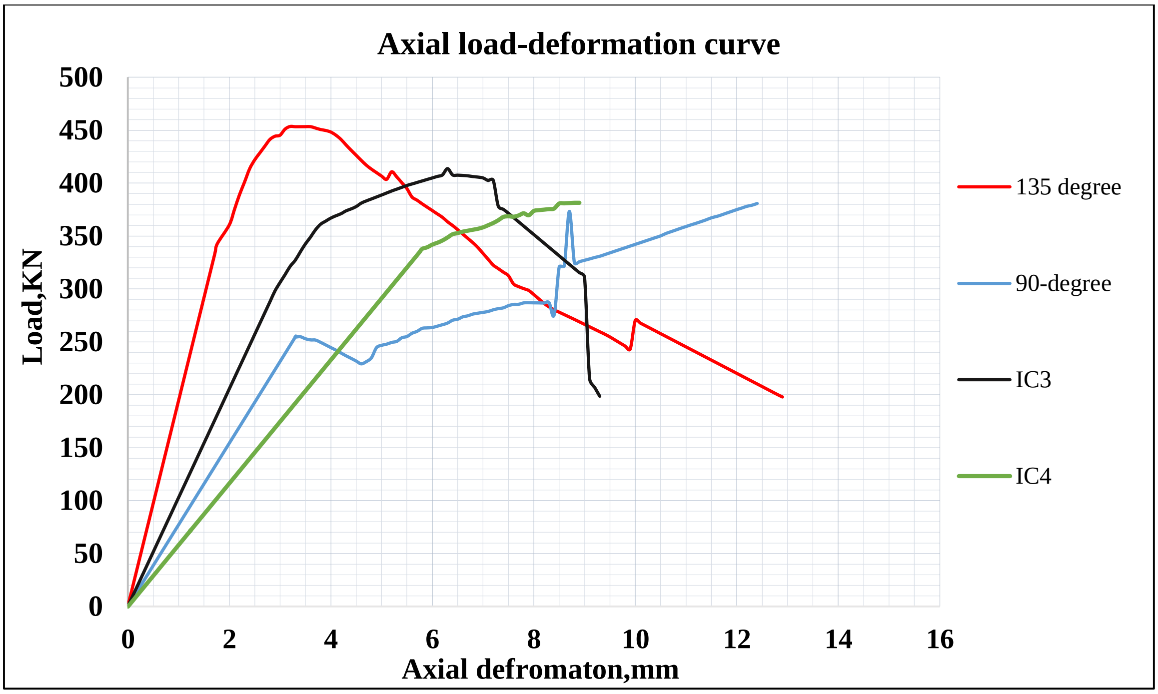


Figure 4. 6 Axial load-deformation curve diameter 8 mm stirrup

Due to testing was made using force based UTM with manually operated load rate; post peak behaviors for all samples with diameter 8mm ties configuration were not obtained in this test. The previous curve for diameter 6mm test captured post-peak behavior by using large peak load sensitivity of test machine unlike test machine used for 8mm ties. But due to better confinement of 135^0 and IC3 columns showed post peak deformation.

The general behavior of axial load – axial deformation curve were showed similarity in the initial portion of the graph. Axial deformation was calculated by taking over all sample length. The presence of concrete pastes to get smooth surface at top and bottom of samples and end to end measurement of deformation lead curve for all samples to have different axial stiffness in ascending branch.

Column with 135^0 ties configuration was the one having a high resistance of deformation from the applied axial load. Peak capacity gained in smaller deformation than others.IC4 and 90^0 Tie configuration were gained there peak value at larger deformation comparatively from both 135^0 and IC3 ties configuration.

Also, ductility is the ability of a material to deform beyond elastic limit without high degradation of strength fig 4.6 column with 135^0 and IC3 configuration have deformation beyond peak load. Qualitatively we can tell that they give relative good ductility. While column 90^0 and IC4 have no post-peak behavior in this similar test case.

As we know limiting of axial shortening will be necessary for reinforced concrete column especially in tall buildings. Column shortening induces additional stress in beams, nearby attached elements and fails for its intended purpose if worsts to failure.

4.3.3 Hoop strain of transverse reinforcement

The axial strain of transverse reinforcement was recorded using strain gauge placed in transverse reinforcement located nearly at the center of column length. Unfortunately, most of the strain gauges were not able to function properly they were damaged possibly while casting of the concert. The result of functioned strain gages was plotted in fig.4.7.

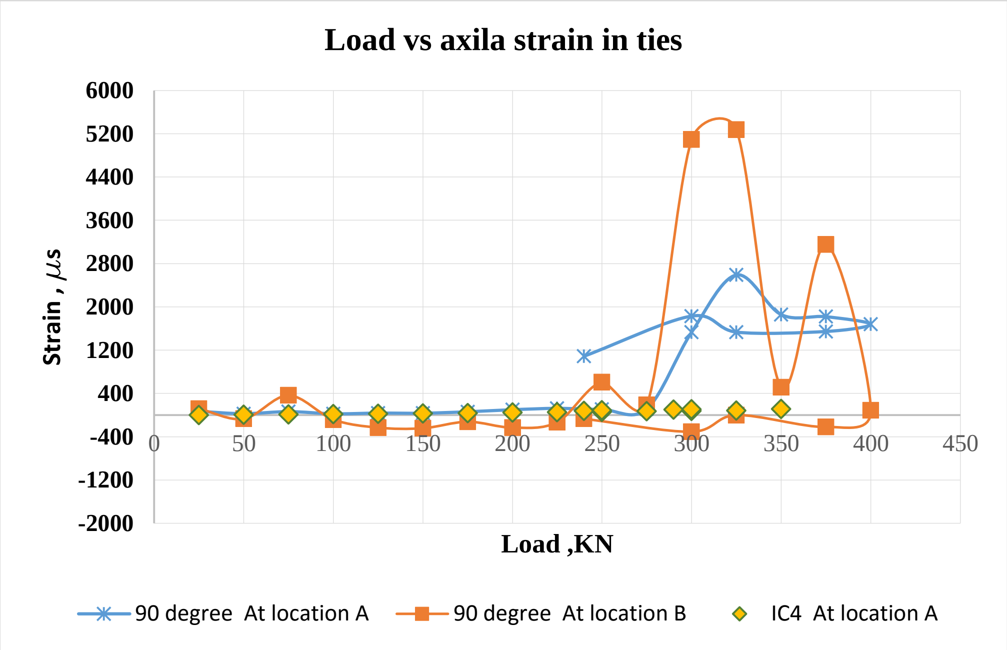


Figure 4. 7) Strain vs. load curve for a 90-degree hook and IC4

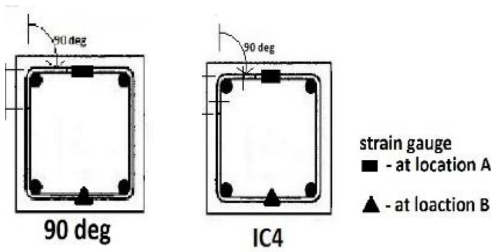


Figure 4. 8 Strain gauge location for 90^0 and IC4

Due to a shortage of available strain gauge small number was used and from that only four of them functioned properly. It would be hard to reach in full conclusion with this limited data and erratic reading with increased load. From observation of Fig4.7 maximum axial strain reading in transverse reinforcement for IC4 were near zero. Peak strain reading at location B was around 5.2‰ greater than yield strain of transverse reinforcement which is 3.72‰ for 90 degrees. In addition in location, A of 90-degree hook sample peak strain was 2.6‰.

Using strain gauge in this study was to compare the strain of 135^0; 90^0; IC3 and IC4 ties configuration at the middle height of the column. Due to improper functioning of strain gauges in $135^0$and IC3 configuration, I cannot capture that. But from the above figures, we can say that not all transverse reinforcement located at the middle of the column would not yield before crushing of column.

4.3.4 Failure mode / observed behavior

The failure mode of 8 mm ties configuration was similar to diameter 6mm ties but with more undisturbed core concrete. Tested column failure by crushing as expected major failure mode in short column. Generally, the overall crushing failure of column specimen behavior can be categorized into two forms.

a) Vertical longitudinal small cracks started around mid-section of the column. Slowly with the increased load, this cracks extended to both top and bottom edge. Then edges at end of column start falling leading to wider crack width in the middle section. Finally spalling of cover and concrete hoop fracture sound causes with a reduction in load carrying capacity was the end of the test. For most tested concrete core concrete was in a similar manner as for cast in the central region.

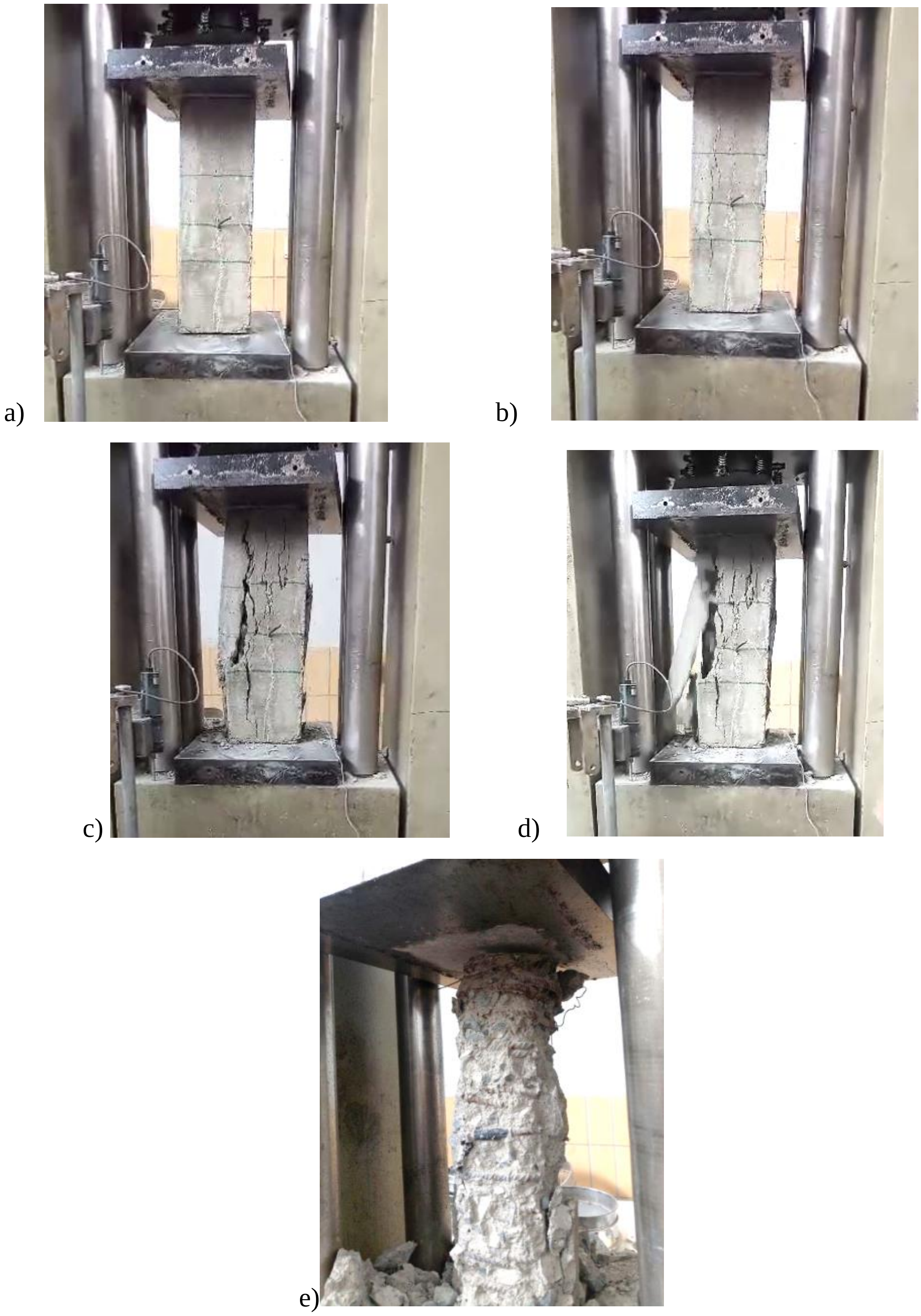


Figure 4. 9 Figure of Failure form a: before the start of test b) Initiation of vertical crack near center c) Crack widening and extending to ends d) Falling of cover e) after cover removal by hand and end of test

b) Other columns with small no failure mode were starting longitudinal crack near the edge and sudden crushing of top or bottom edge of the column, in addition, one column exhibited inclined shear failure. Column failed in this form were having an intact column surface at the end of the test.

Figure 4. 10 Failure form of b; crushing failure near at the end

Failure form A shows complete longitudinal columnar failure and form B exhibited failure around the end of the column. But usually, most failure mode in a standard cube and the cylindrical test will be central region swelling with confined end zone. This is due to end region restraining effect (confinement of top and bottom) by friction between concrete and steel plate. M.D.Kotsovos et al [22] described standard cube height to width ratio 1:1 their strength and failure mode influenced by end conditions. They stated the effect of end friction is important for a short column, but practically disappears when the height-to-width ratio exceeds 2.

Height – to-width ratio of column employed in this study was 3.1:1 this leads to negligible end effect according to M.D.Kostsovos et at[22]. Therefor Failure form, A one can observe overall columnar failure. Also in failure form B due to stress concentration around end zones local failure of concrete observed. Later failure form was also similar to the failure of the column with diameter 6mm transverse reinforcement in section 4.2.3.

In order to see detail behavior of core concrete and embedded reinforcement; complete easily removal of cover concrete made.

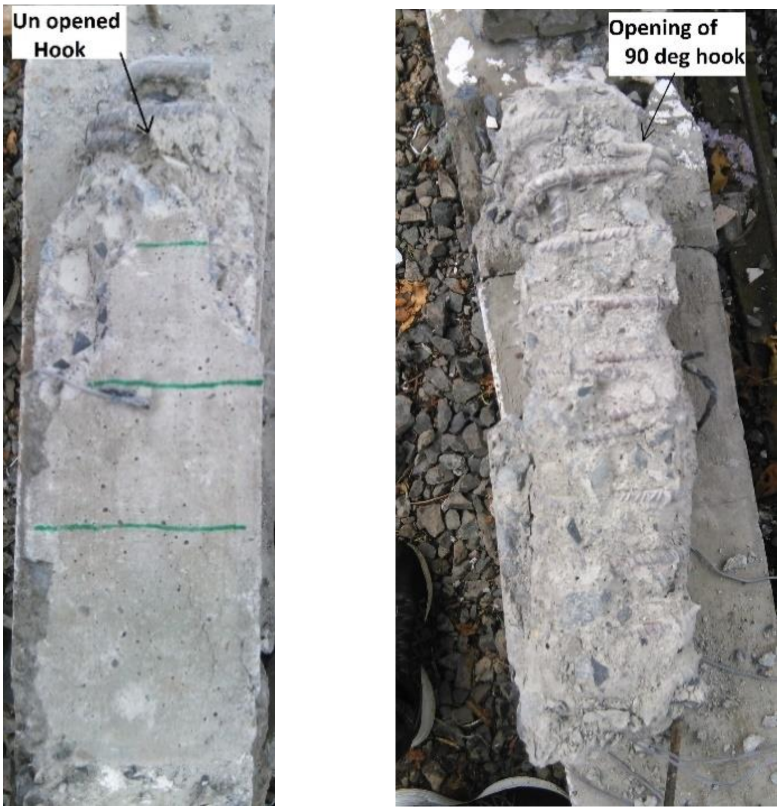


Figure 4. 11 Failure of 135^0 ties (left) and 90^0 ties (right) configuration

From the above picture, we can easily observe that unpenning of 135^0 ties configuration. Core concrete and surface got a little damage; on the contrary picture in right shows opening of 90^0 hooks. With the increase of axial load opening of 90^0 hooks lead to a lateral expansion of core concrete and axial deformation. In addition poisons effect of the concert; axial deformation and lateral expansion of core concrete make cover spalling. This damage of concrete observed in more pronounced for 90^0 ties configuration and IC4 configuration.

Figure 4. 12 Failure of IC3 (left) and IC4 (right) configuration

Above figure, Fig4.12 illustrate reinforcement and overall introduced column behavior after the test. Introduced ties configuration (IC3) surface and core get small damage as 135^0 ties configuration. End hook condition for one leg bend as 135^0 was unopened; while one leg which bends as 90^0 was not completely opened like 90^0 tie configuration. This can tell us this configuration was preferable than 90^0 configuration. And the use of additional wire doesn't give negligible enhancement in peak strength or ductility of column (picture in right). Rupture of additional wire with hook opening observed. Provided wire can't reduce 90^0 hook opening.

4.3.5 Experimental and Analytical Peak load comparison

The analytical computation was made from both different code recommendation and the researcher's developed confinement formula. Table 4.3 below shows the analytical and experimental comparison for each four type of transverse reinforcement configuration which is 135^0 ,90^0 , IC3 and IC4. Analytical formulation have similar value for similar test category but test results shows different peak load capacity for each test category; therefore values in table under codes and researchers with different category will have different experimental /analytical result.

Table 4. 1 experimental peak load comparison with analytical model

	Normalized peak load in KN (Pexperimentalt/$P_{analytical}$)				
Ties configuration	ACI-318	Eurocede-2	Egyptian code ECCS-203	Saatcioglu and razvi	Karim el-dash
90 degree	0.770	0.800	0.941	0.788	0.896
135 degree	0.949	0.988	1.160	0.971	1.104
IC3	0.870	0.906	1.063	0.890	1.012
IC4	0.770	0.804	0.944	0.790	0.898

The axial load capacity of the columns made using 135^0 ties configuration was in a good agreement with all analytical models. IC3 (Introduced category three) configuration was also in close agreement with both code recommendations and analytical models but IC3 test results show slightly lower value for ACI.90^0 configuration and IC4 were not much close to analytical models except Egyptian code and Karim el-dash model.

4.3.6 Analytical and Experimental Load-deformation curve

The load-deformation curve below shown additionally incorporating staacioglu and razvi analytical model. The analytical model given by saatcioglu and razvi was in good proximity to experimental result especially with code recommended tie configuration (GL=165mm).

Difference raised between saatcioglu and razvi analytical model with others experimental results due to different gauge length. Large deformation was observed in the experiment from the start of the test. possible cause of this would be as described earlier sections smashing of end concrete easily. When you see the test result with a gauge length of 165mm, curve best fit to analytical model up to around 200KN this implies gauge length effect in ascending branch of the curve. The gauge length used for strain measurement significantly also affects the slope of the falling branch of stress-strain curves of confined concrete [23]. The smaller gauge length to core concrete gives gentler slope for falling branch region.

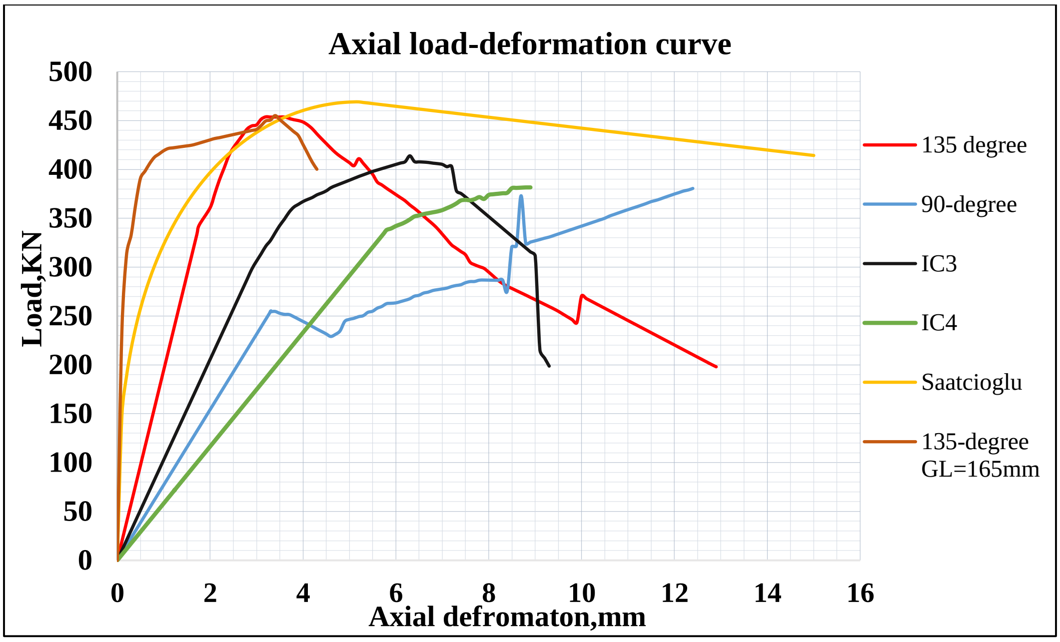


Figure 4. 13 Comparison of analytical and experimental curve

For this study whole column length was taken as gauge length. One reason for this was to get full load deformation relation after complete removal of cover concrete, secondly this study focus on the comparative evaluation of ties configuration with similar gauge length.

Trials and One of presented column sample with135^0 ties configuration; axial deformation measurement taken by using 165mm gauge length. By reducing cross-sectional size from the top and bottom of the column. Load-deformation relation was in good proximity with saatcioglu et al theoretical load-deformation curve. After disintegrating and removal of cover concrete LVDT can't capture whole load deformation results up to end see fig 4.14

Figure 4. 14 LVDT with gauge length 165mm

Generally analytical models of confinement established by testing column samples and by finding correlating equation using different boundary equation, observation, regression analysis etc. Usually, this established analytical model depends on test geometry, material property etc. therefor it is very difficult to find a model that exactly predict each test; so good agreement will be fair.

5 FINITE ELEMENT MODELING

5.1 Introduction

The development of computer technology and finite element theory is helping us by saving time, high accuracy and low-cost analysis of numerical calculation etc. Engineer's use nonlinear software's for analysis and design of structures for the above reasons. For this study, columns were modeled and analyzed in nonlinear finite element software with the same material prosperity as conducted experiment and output compared with experimental results.

5.2 About the software

Simulation of this study was made using Abaqus 6.14 nonlinear finite element software. Abacus is one of the largest universal finite element analysis software and increasingly commonly used in research works and engineering. The program results in a good agreement with experimental outputs in various research.

5.3 Identification of constitutive parameters

5.3.1 Constitutive material parameters

In this paper, the concrete is modeled using the concrete damage plasticity model (CDPM) available in Abacus (2014). It uses the concept of isotropic damage elasticity in combination with isotropic tensile and compressive plasticity to represent the inelastic behavior of concrete. Table 5.1 shows constitutive material parameters and scalar values.

Table 5. 1 constitutive material parameter of concrete

parameters for concrete	values
Cylindrical compressive strength	16Mpa
Initial stiffness (Young's modulus)	29Gpa
Tensile strength	1.9Mpa
Poisons ratio	0.2

Using corresponding compressive strength tensile strength and modulus of elasticity was found from Euro code 2. For concrete poisons ratio of 0.2 was also taken.

The additional material parameter used in CDP was taken from researchers Yenus D et al [24]. ψ = dilation angle of taken 31^0 as and ϵ= eccentricity 0.1, the K=0.666 shape of the longitudinal surface in the deviatoric plane, $\frac{f_{bo}}{f_{co}}$ = 1.16 ratio of biaxial and uniaxial compressive stress at failure and Viscosity parameter =0.001

5.3.2 Concrete constitutive law in compression

There are many analytical constitutive models suggested for concrete material. For this study stress-strain relation for non-linear structural analysis proposed by Euro code 2 [2] used.

$$\frac{\sigma_c}{f_{cm}} = \frac{k\eta - \eta^2}{1+(k-2)\eta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5.1)}$$

Where;

$$\eta = \frac{\varepsilon_c}{\varepsilon_{c1}}$$

ε_{c1} = is the strain peak stress , for C20 concrete = 1.9‰

$K=1.1E_{cm} \text{ X } |\varepsilon_{c1}|/f_{cm}$

And from table 3.1 of [4] E_{cm} = 29 Gpa , f_{cm} = 24 Mpa for corresponding concrete strength. Here inelastic strain can be obtained by subtracting elastic strain which value at 0.4 of peak stress from the total strain.

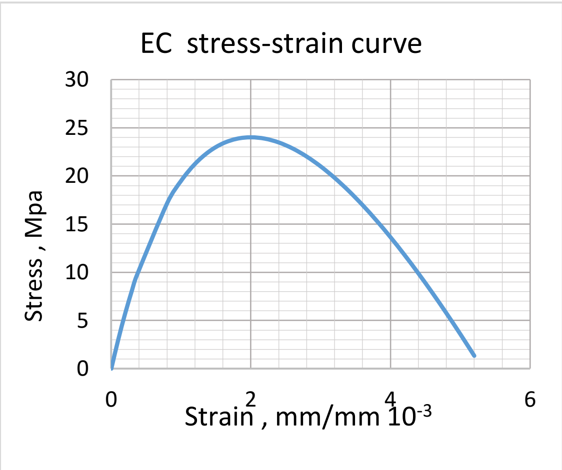
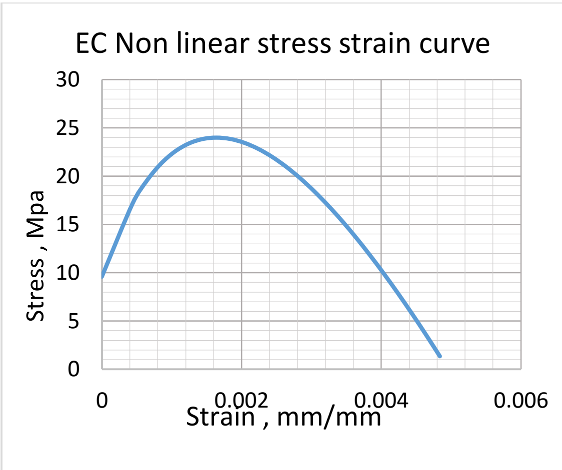


Figure 5. 1 a) EC stress-strain curve



b) Ec non linear stress - strain curve

5.3.3 Concrete constitutive law in Tension

The tensile stress-strain relationship gives in equation 5.4 from Yenus D et al [24]. Tensile stress-strain relation is straight up to peak uniaxial tensile strength and then determined by exponential expression.

$$\sigma = f_t \left(\frac{\varepsilon_t}{\varepsilon}\right)^{(0.7+1000\varepsilon)} \quad , \quad \varepsilon_t = \frac{f_t}{E_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5.2)}$$

Where; f_t , ε_t peak tensile uniaxial stress and cross ponding strain taken from Euro code 2 [2] table 3.1 .

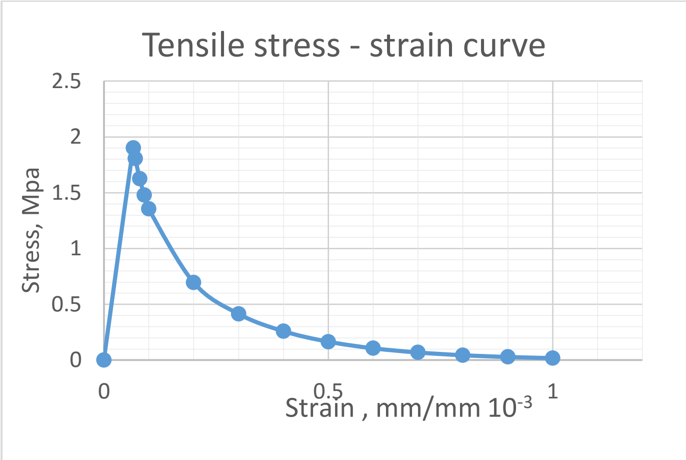


Figure 5. 2 Tensile stress-strain curve for concrete

Reinforcement used in Finite element modeling was had similar material property as described in chapter three with the initial stiffness of 200Gpa.

5.4 Modeling

5.4.1 The model

Simulation of the mechanical response of the specimens has been done by Abaqus 6.14 using concrete damage plasticity constitute model as described earlier. The model has been created into parts to generate the best possible mesh on parts and then assembled as a solid homogenous instance.

Reinforcement bars modeled as embedded inside concrete solid elements which are quite easily through embedding constraint but doesn't consider slip of reinforcement. Embedding constraint is used, the truss elements of reinforcement are joined to concrete solid elements. Transverse reinforcement was modeled as totally closed wire and shown in figure 5.1 below.

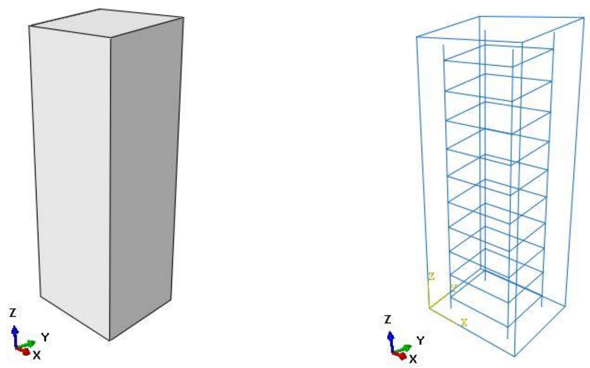


Figure 5. 3 a) concrete specimen instance model (left) b) assembled part-whole model (right)

5.4.2 Boundary condition

An experimental test was conducted using a Universal testing machine (UTM) with steel platen at both top and bottom end. To simulate this end condition behavior, the boundary condition of specimens are specified as U1=U2=U3=0 pin end at bottom and U3=-15mm for the upper end with amplitude shown below. Uniform axial gravity loads have been applied in ramp amplitude.

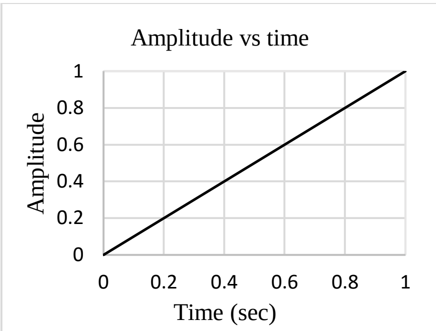


Figure 5. 4 loading system's amplitudes applied on the model

5.4.3 Mesh size

For this model different mesh size were considered. Finite element solution is largely dependent on mesh size. To eliminate this effect coarser mesh size and refined mesh size were used to get converged result to unique solution.C3D8R an 8 node linear brick element mesh with different mesh size were used. By considering initial mesh size 46.5mm which is one-tenth of the height of column with mesh interval of the 1.5mm solution was converged at 24mm element mesh size and in fair agreement with experimental results. Different mesh size and mesh sensitivity check shown below.

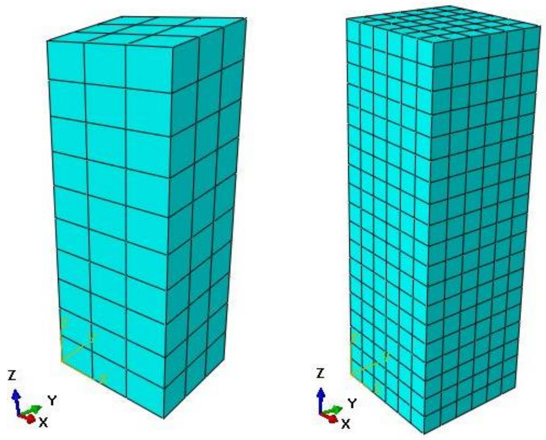


Figure 5. 5 Different mesh generated for Abaqus model a) 46.5mm left C) 24mm right

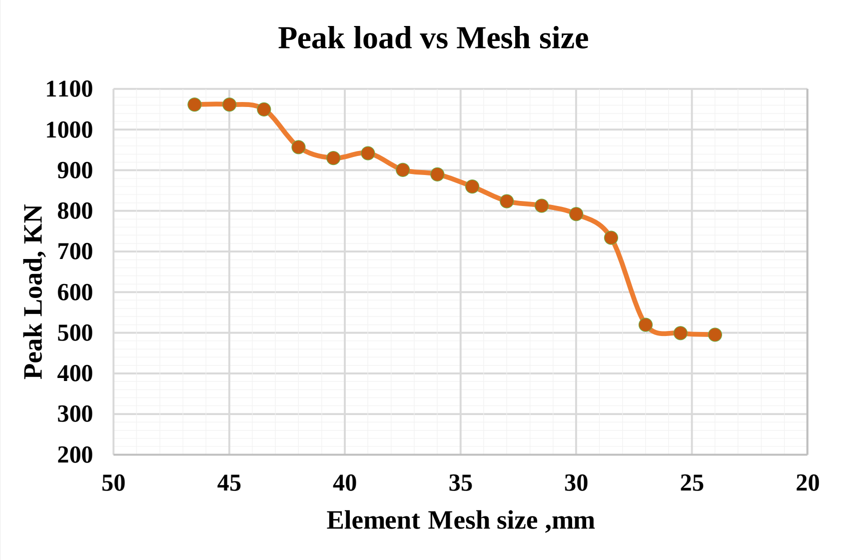


Figure 5. 6 Element mesh refinement

From above figure 4.16 peak load was dropped from 1060KN to 495KN by refining mesh. Initially, for element size around 45mm, peak load were 1060KN but this could not result in because of theoretical section analysis was far from this result. From 43.5 up to 27 mm element size continuous dropping of peak load observed. After that for the next three element size with equal mesh interval peak load were stabilized around 500KN. Therefore we can take Finite element software result will be 495KN.

5.5 Result of FE modeling and Experiment

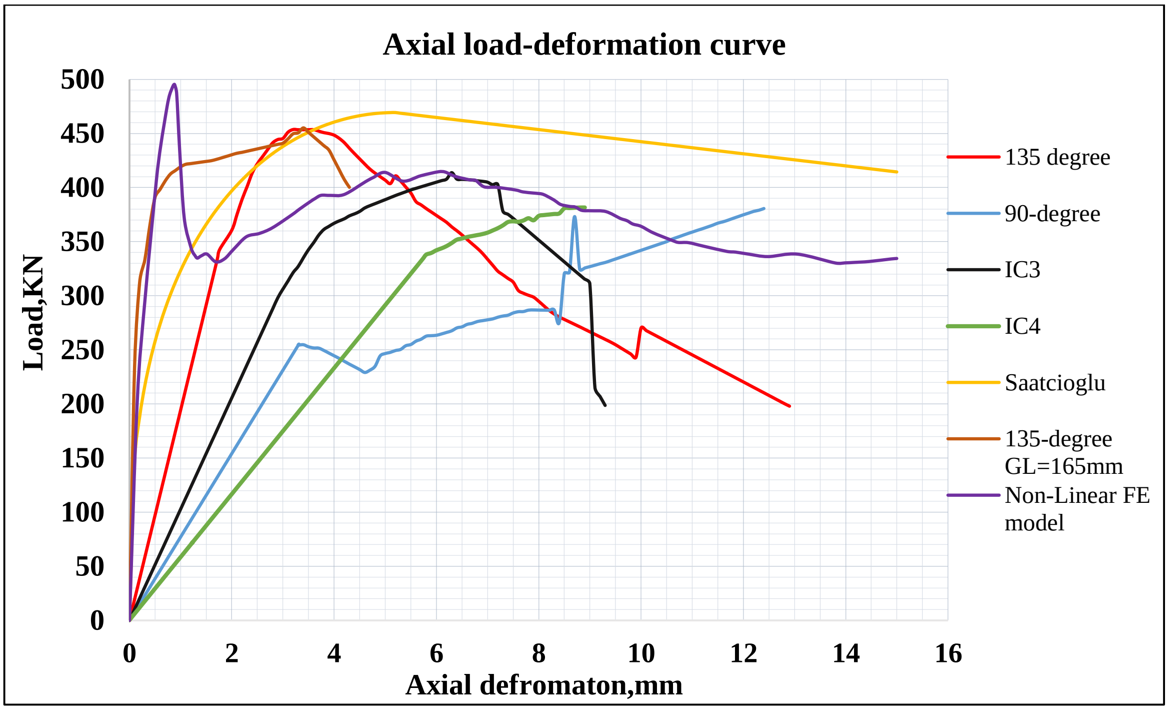


Figure 5. 7 Load-deformation curve including FE modeling for diameter 8 mm ties

Here all experimental, analytical and finite element software simulation shown in above figure 5.5. Peak strength obtained from finite element simulation was 495KN.we can say that it is fairly in near to code recommended ties configuration.

FE ascending branch fairly captured by 135-degree ties configuration with gauge length 165mm. As described in the previous section smashing of ends during the test by stress concentration makes a curve to have larger initial deformation and this cause other test results to have smaller ascending branch slope.

In the descending branch; after reduction of peak load FE model has a second maximum peak load. This is not a confinement case for the tied column. In tied columns after sapling of cover capacity reduced and core, concrete crush lead to buckling of longitudinal bars a, this occurs suddenly . While in spiral columns core enhanced by triaxial stress result from the effect of spiral reinforcement, the column can undergo large deformation with second maximum load. For this study column modeled in FE software as closed stirrups, this possibly lead modeled tied column to attain second peak load with large sustained deformation

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This study mainly focused on the comparative study of 90-degrees and 135-degree ties configuration under peak load capacity and its load-deformation behavior. Additionally to check introduced ties configuration in capacity enhancement.

Some of the conclusions reached from the above experimental and analytical study

- By consideration of minimum required confinement in Euro code and minimum ACI column height definition size, 90-degree ties configuration perform the least strength than standard seismic hook ties configuration. Peak load of 135-degree configuration higher than by 11.17% for diameter 6mm and 23.24% for diameter 8mm bars from 90-degree tie configuration (using fixing wire) for tested column size and reinforcement arrangement.
- IC3 ties configuration axial load capacity larger than 90^0 hooks by 12.97%% and lower than by 8.33% form seismic hook configuration.
- The test result showed using of 1.5mm fixing wire as IC4 will not increase the axial load capacity of 90^0 hook configuration.
- FE peak load result was in fair agreement with the experimental result for 135^0 ties configuration (with 7.87% reduction). Ascending branch in load –deformation also captured in FE model for GL of 165mm test. But Post peak behavior was different, experimental results do not show an increment of load after peak load but software result gave second peak load this possibly implies; effective confinement of closed stirrups after peak load in FE model. Using closed stirrups while modeling increase peak capacity.

6.2 Recommendation

- After observing weakens of 90^0 ties configuration in this experimental study. Authorities, Consulting firms, contractors and related bodies in relation to this firm must apply code recommended detailing for future construction of a reinforced concrete structure in this country.

- For future studies, axial load and ductility enhancement should be studied in a large-scale program, high strength concrete . . . etc.

- Even though finite element program gives a reasonable result, the difference between modeling of rectangular stirrups as closed hoop and actual installation as 135^0 end hook for a reinforced concrete structure using finite element program should be considered in detail for future study.

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APPENDIX

Appendix A: Load Deformation curves

Appendix A, 1 Diameter 6 mm tie deformation vs. load curve

90 degree		135 degree		90 degree		135 degree	
Deformation, mm	Load , KN	Deformation, mm	Load , KN	Deformation, mm	Load , KN	Deformation, mm	Load , KN
0.00	0	0.00	0	4.40	365.4	4.60	362
0.56	60.7	0.42	76.4	4.60	368	4.80	350
0.74	80.3	0.93	168	4.80	368	5.00	338
0.94	102.9	1.31	236	5.30	365	5.20	331.68
1.20	131.2	1.50	270.5	5.80	360	5.40	325.36
1.41	154	1.65	297.1	6.30	348	5.60	319.04
1.62	176.2	1.74	313.8	6.80	325	5.80	312.72
1.81	198	1.86	335.7	7.30	310	6.00	306.4
1.98	215.6	1.95	352.1	7.80	290	6.50	260.1
2.10	229.5	2.00	360.4	8.30	280	7.00	244.48
2.26	247	2.20	373.9	8.80	255	7.50	228.86
2.43	265	2.40	384.2	9.30	225	8.00	213.24
2.60	284	2.60	394.1	9.80	212	8.50	197.62
2.78	303	2.80	400.3	10.80	184	9.00	195.6
2.94	320.5	3.00	404	11.80	154	9.50	182
3.00	327.3	3.20	406	12.80	145	10.00	178.5
3.20	336.3	3.40	408.44	13.80	134	10.50	175
3.40	343	3.60	404.96			11.00	169
3.60	349.5	3.80	401.48			12.00	151
3.80	355	4.00	398			13.00	138
4.00	359	4.20	386			14.00	131.4
4.20	364.8	4.40	374			15.00	129

Appendix A, 2 Diameter 8mm tie Deformation vs. Load Curve

135 Degree Hook						90 Degree Hook				
Deformation	samples		Avg Load, KN	Deformation	135 degree GL=165mm	Deformation	samples			Avg Load, KN
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.38	56.53	91.50	74.02	0.10	234.69	0.10	2.92	16.75	3.33	7.67
0.43	66.02	101.00	83.51	0.20	312.70	0.15	5.83	25.03	4.94	11.93
0.48	71.40	115.30	93.35	0.30	333.02	0.20	9.33	31.20	6.13	15.55
0.53	82.60	124.50	103.55	0.40	365.40	0.25	13.22	37.37	7.31	19.30
0.59	91.00	140.20	115.60	0.50	391.00	0.30	16.46	43.53	8.67	22.89
0.65	96.30	156.00	126.15	0.60	398.35	0.37	19.53	55.13	10.10	28.25
0.72	104.20	175.00	139.60	0.70	406.20	0.42	22.30	63.50	11.54	32.45
0.82	121.50	196.00	158.75	0.80	412.45	0.48	25.16	71.88	12.98	36.67
0.89	135.50	210.00	172.75	0.90	415.80	0.53	27.76	80.83	14.42	41.00
0.97	148.30	228.30	188.30	1.00	419.18	0.59	30.36	89.69	15.86	45.30
1.05	162.40	247.30	204.85	1.10	421.47	0.64	34.20	98.56	16.38	49.71
1.15	177.70	269.00	223.35	1.20	422.13	0.69	36.80	106.50	16.81	53.37
1.24	192.30	288.10	240.20	1.30	422.80	0.76	42.00	117.00	17.24	58.75
1.32	201.60	310.00	255.80	1.40	423.47	0.83	48.00	126.80	17.67	64.16
1.40	226.10	317.00	271.55	1.50	424.13	0.92	54.20	140.00	18.09	70.76
1.51	241.20	345.00	293.10	1.60	424.80	1.00	62.30	151.00	18.52	77.27
1.60	260.40	361.00	310.70	1.70	426.00	1.06	67.30	158.00	18.95	81.42
1.72	280.10	387.00	333.55	1.80	427.42	1.10	73.40	162.30	19.80	85.17
1.76	295.50	390.00	342.75	1.90	428.84	1.18	80.80	172.10	20.00	90.97
2.00	313.10	408.20	360.65	2.00	430.27	1.29	89.70	187.40	20.55	99.22
2.10	329.60	420.23	374.92	2.10	431.69	1.39	95.30	204.00	21.82	107.04
2.20	345.10	433.00	389.05	2.20	432.53	1.45	101.50	210.20	23.15	111.62
2.30	362.10	440.00	401.05	2.30	433.59	1.54	110.10	219.50	26.07	118.56
2.40	379.20	448.00	413.60	2.40	434.64	1.63	118.30	232.10	27.11	125.84

2.50	389.10	455.00	422.05	2.50	435.70	1.69	127.80	234.10	28.31	130.07
2.60	397.10	460.00	428.55	2.60	436.76	1.76	137.40	240.00	30.54	135.98
2.70	409.10	460.97	435.04	2.70	437.80	1.86	150.20	248.30	32.78	143.76
2.80	421.10	461.71	441.41	2.80	438.87	1.94	160.10	255.00	34.65	149.92
2.90	426.30	462.57	444.44	2.90	439.93	2.06	179.80	261.20	36.49	159.16
3.00	426.96	463.91	445.44	3.00	440.99	2.12	180.40	272.10	38.33	163.61
3.10	437.22	465.25	451.24	3.10	444.97	2.27	203.50	280.40	40.16	174.69
3.20	440.75	466.60	453.68	3.20	449.69	2.39	223.50	287.80	42.00	184.43
3.30	438.96	467.94	453.45	3.30	450.57	2.47	232.40	292.30	46.73	190.48
3.40	437.65	469.28	453.47	3.40	455.11	2.57	245.10	298.00	51.45	198.18
3.50	436.35	470.62	453.49	3.50	451.02	2.65	257.10	300.20	56.18	204.49
3.60	435.04	471.97	453.51	3.60	446.92	2.77	272.40	307.40	60.90	213.57
3.70	433.73	470.56	452.15	3.70	442.83	2.93	296.40	312.50	69.60	226.17
3.80	432.42	469.11	450.77	3.80	438.73	3.01	303.70	317.30	75.40	232.13
3.90	431.12	468.68	449.90	3.90	434.64	3.10	318.10	319.60	78.30	238.67
4.00	428.57	468.25	448.41	4.00	425.58	3.17	332.10	320.34	82.00	244.81
4.10	423.14	467.82	445.48	4.10	416.51	3.26	342.10	320.53	91.00	251.21
4.20	417.71	465.25	441.48	4.20	407.45	3.31	350.20	320.73	95.20	255.38
4.30	412.27	460.18	436.23	4.30	400.20	3.31	341.65	320.93	103.50	255.36
4.40	407.30	455.23	431.27			3.30	331.01	321.12	111.30	254.48
4.50	402.63	450.28	426.46			3.40	324.54	321.30	118.50	254.78
4.60	397.97	445.33	421.65			3.50	315.99	321.51	121.20	252.90
4.70	393.78	440.38	417.08			3.60	307.44	321.71	126.30	251.82
4.80	389.91	436.79	413.35			3.70	298.89	321.90	134.10	251.63
4.90	386.04	434.12	410.08			3.80	290.34	322.10	136.00	249.48
5.00	382.17	431.44	406.81			3.90	281.78	322.29	137.00	247.02
5.10	378.30	429.10	403.70			4.00	273.23	322.49	138.00	244.57
5.20	394.57	427.10	410.84			4.10	264.68	323.08	138.60	242.12
5.30	386.93	425.10	406.02			4.20	256.13	323.20	139.00	239.44
5.40	379.29	421.66	400.48			4.30	247.58	323.40	139.40	236.79

5.50	371.65	418.23	394.94			4.40	239.02	323.80	140.20	234.34
5.60	359.23	414.79	387.01			4.50	230.47	324.10	140.90	231.82
5.70	356.36	411.63	384.00			4.60	221.92	324.50	141.10	229.17
5.80	352.63	408.50	380.57			4.70	220.10	325.19	148.60	231.30
5.90	349.33	405.47	377.40			4.80	225.10	325.61	154.00	234.90
6.00	346.03	402.38	374.21			4.90	244.20	326.04	163.20	244.48
6.10	342.73	399.30	371.02			5.00	245.30	326.46	168.20	246.65
6.20	339.43	396.22	367.83			5.10	247.10	326.88	169.30	247.76
6.30	336.13	391.10	363.62			5.20	250.80	327.30	170.20	249.43
6.40	332.50	387.64	360.07			5.30	252.60	327.73	171.00	250.44
6.50	328.54	383.78	356.16			5.40	256.40	328.16	177.00	253.85
6.60	324.14	379.92	352.03			5.50	257.40	328.58	179.00	254.99
6.70	319.74	376.02	347.88			5.60	259.60	329.00	185.60	258.07
6.80	315.34	372.30	343.82			5.70	259.27	329.42	191.00	259.90
6.90	309.72	368.64	339.18			5.80	257.71	329.85	200.60	262.72
7.00	302.28	365.08	333.68			5.90	256.16	330.27	203.00	263.14
7.10	294.84	361.52	328.18			6.00	254.60	330.69	205.30	263.53
7.20	287.40	357.97	322.69			6.10	253.05	331.11	210.20	264.79
7.30	284.25	354.40	319.33			6.20	251.49	331.54	215.50	266.18
7.40	281.10	350.84	315.97			6.30	249.94	331.97	221.20	267.70
7.50	277.95	347.28	312.62			6.40	248.39	332.40	230.30	270.36
7.60	274.80	335.00	304.90			6.50	246.83	332.83	234.30	271.32
7.70	271.65	333.00	302.33			6.60	245.28	333.25	242.20	273.58
7.80	268.49	332.40	300.45			6.70	243.72	333.68	246.30	274.57
7.90	265.34	332.00	298.67			6.80	242.46	334.11	252.10	276.22
8.00	262.19	327.50	294.85			6.90	241.38	334.54	255.20	277.04
8.10	259.04	322.30	290.67			7.00	240.31	334.97	258.20	277.83
8.20	255.89	317.21	286.55			7.10	239.23	335.40	261.30	278.64
8.30	254.13	312.20	283.17			7.20	238.16	335.83	266.70	280.23
8.40	250.97	309.83	280.40			7.30	237.09	336.26	270.60	281.32

8.50	248.80	307.45	278.13			7.40	236.01	336.69	273.60	282.10
8.60	246.63	305.08	275.86			7.50	234.94	337.12	280.40	284.15
8.70	244.47	302.71	273.59			7.60	233.86	337.54	284.50	285.30
8.80	242.30	300.34	271.32			7.70	232.79	337.97	285.60	285.45
8.90	240.13	297.84	268.99			7.80	231.71	338.40	290.20	286.77
9.00	237.97	295.34	266.66			7.90	230.64	338.83	291.30	286.92
9.10	235.80	292.84	264.32			8.00	229.57	339.26	291.60	286.81
9.20	233.63	290.34	261.99			8.10	228.49	339.69	292.10	286.76
9.30	231.47	287.84	259.66			8.20	227.42	340.12	292.40	286.65
9.40	229.30	285.34	257.32			8.30	226.34	340.55	294.10	287.00
9.50	226.69	282.84	254.77			8.40	187.40	342.55	296.20	275.38
9.60	223.43	280.34	251.89			8.50		344.55	296.93	320.74
9.70	220.16	277.84	249.00			8.60		346.55	297.37	321.96
9.80	216.90	275.34	246.12			8.70		348.55	397.90	373.22
9.90	213.63	272.84	243.24			8.80		350.55	298.43	324.49
10.00		270.34	270.34			8.90		352.55	298.97	325.76
10.10		267.84	267.84			9.00		354.55	299.50	327.02
10.20		265.34	265.34			9.10		356.55	300.03	328.29
10.30		262.84	262.84			9.20		358.55	300.80	329.67
10.40		260.34	260.34			9.30		360.55	301.10	330.82
10.50		257.84	257.84			9.40		362.18	302.68	332.43
10.60		255.34	255.34			9.50		363.81	304.26	334.04
10.70		252.84	252.84			9.60		365.44	305.84	335.64
10.80		250.34	250.34			9.70		367.07	307.42	337.25
10.90		247.84	247.84			9.80		368.71	309.00	338.85
11.00		245.34	245.34			9.90		370.34	310.58	340.46
11.10		242.84	242.84			10.00		371.97	312.16	342.07
11.20		240.34	240.34			10.10		373.60	313.73	343.67
11.30		237.84	237.84			10.20		375.23	315.31	345.27
11.40		235.34	235.34			10.30		376.87	316.89	346.88

11.50		232.84	232.84			10.40		378.50	318.47	348.48
11.60		230.34	230.34			10.50		380.13	320.05	350.09
11.70		227.84	227.84			10.60		381.76	322.83	352.30
11.80		225.34	225.34			10.70		383.39	324.55	353.97
11.90		222.84	222.84			10.80		385.03	326.28	355.65
12.00		220.34	220.34			10.90		386.66	328.00	357.33
12.10		217.84	217.84			11.00		388.29	329.55	358.92
12.20		215.34	215.34			11.10		389.92	331.10	360.51
12.30		212.84	212.84			11.20		391.55	332.50	362.03
12.40		210.34	210.34			11.30		393.19	334.10	363.64
12.50		207.84	207.84			11.40		394.82	335.80	365.31
12.60		205.34	205.34			11.50		396.45	337.90	367.18
12.70		202.84	202.84			11.60		398.08	338.70	368.39
12.80		200.34	200.34			11.70		399.72	340.10	369.91
12.90		198.00	198.00			11.80		401.35	341.90	371.62
						11.90		402.98	343.50	373.24
						12.00		404.61	345.20	374.91
						12.10		406.24	346.60	376.42
						12.20		407.88	348.18	378.03
						12.30		409.51	348.61	379.06
						12.40		411.14	350.20	380.67

IC3					IC4				Non Linear FE	
Deformation	Samples			Avg Load, KN	Deformation	Samples		Avg Load, KN	Deformation	Avg Load, KN
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0
0.04	8.07	3.83	1.52	4.47	0.10	1.64	9.91	5.78	0.15	200.75116
0.08	14.47	7.66	3.05	8.39	0.20	3.28	19.82	11.55	0.3	294.51108
0.12	16.24	15.57	4.57	12.13	0.23	4.92	21.90	13.41	0.525	406.16548
0.13	18.00	16.95	6.10	13.68	0.31	6.56	29.20	17.88	0.609375	438.16272
0.16	19.70	21.20	7.62	16.17	0.38	8.20	36.55	22.38	0.735937	474.88704
0.19	22.36	27.40	9.15	19.64	0.45	9.84	42.30	26.07	0.783398	485.33372
0.22	25.30	32.70	10.67	22.89	0.51	11.48	48.30	29.89	0.85459	494.09608
0.26	30.04	38.20	12.20	26.81	0.58	13.12	53.91	33.52	0.881287	495.1442
0.32	34.78	45.60	17.45	32.61	0.64	14.76	59.36	37.06	0.921332	487.44668
0.36	39.53	51.40	20.82	37.25	0.70	16.40	64.80	40.60	0.9814	434.18512
0.42	46.50	60.30	24.19	43.66	0.77	19.20	70.53	44.87	1.0715	371.28
0.46	48.90	66.70	26.96	47.52	0.83	22.30	73.87	48.09	1.20665	343.77976
0.54	62.10	75.10	29.48	55.56	0.86	24.50	75.83	50.17	1.24044	339.89896
0.59	67.70	83.50	32.00	61.07	0.89	25.70	77.64	51.67	1.27423	337.5592
0.66	73.40	91.60	37.63	67.54	0.98	35.20	79.46	57.33	1.32491	334.72528
0.73	80.40	101.10	43.25	74.92	1.04	39.70	80.90	60.30	1.40094	336.73256
0.79	84.40	110.80	48.88	81.36	1.10	45.80	82.19	64.00	1.51497	338.45768
0.87	90.70	119.60	56.70	89.00	1.14	49.80	83.47	66.64	1.68602	331.274
0.97	100.20	135.40	64.90	100.17	1.17	51.80	84.76	68.28	1.85707	334.03368
1.08	109.30	147.90	75.20	110.80	1.24	58.40	86.04	72.22	2.02813	342.51304
1.12	114.40	148.70	82.40	115.17	1.22	54.70	87.53	71.12	2.28471	354.44508
1.23	120.40	165.40	92.40	126.07	1.35	64.30	93.27	78.79	2.54128	357.53892
1.29	130.10	172.50	96.40	133.00	1.46	71.10	98.79	84.95	2.79786	362.82556
1.41	140.70	188.50	104.50	144.57	1.59	79.80	105.60	92.70	3.18273	374.97348
1.52	155.00	201.10	114.10	156.73	1.68	82.01	113.60	97.81	3.32706	380.10396
1.61	168.30	206.50	122.30	165.70	1.79	87.60	120.72	104.16	3.54354	387.218

1.72	170.40	223.10	137.71	177.07	1.89	92.10	127.83	109.97	3.62473	389.66896
1.83	180.20	234.20	150.13	188.18	2.00	97.80	135.40	116.60	3.7465	392.74884
1.91	186.50	241.20	161.88	196.53	2.11	102.70	143.50	123.10	3.92916	392.66092
2.05	207.60	255.20	171.00	211.27	2.20	105.10	151.30	128.20	4.20316	393.61972
2.15	220.30	264.01	179.20	221.17	2.30	106.36	161.50	133.93	4.61414	405.31816
2.24	232.00	273.10	186.33	230.48	2.37	108.13	168.30	138.22	4.76827	409.2676
2.31	240.00	279.30	194.00	237.77	2.43	109.90	173.50	141.70	4.99945	413.9052
2.44	260.00	291.50	201.67	251.06	2.52	111.67	182.20	146.94	5.34622	405.82912
2.53	266.50	303.40	209.33	259.74	2.64	115.90	191.50	153.70	5.69299	410.8042
2.60	272.10	311.40	217.00	266.83	2.72	120.20	196.30	158.25	6.03976	414.48384
2.68	280.10	317.60	229.93	275.88	2.87	129.60	204.60	167.10	6.1698	414.26212
2.81	296.10	326.20	242.86	288.39	3.01	136.80	213.40	175.10	6.36486	410.29064
2.90	308.00	330.70	255.79	298.16	3.10	141.70	219.40	180.55	6.65745	406.9566
3.00	315.40	335.40	267.70	306.17	3.20	148.90	224.00	186.45	6.76717	406.56584
3.10	323.00	340.20	277.80	313.67	3.27	154.10	227.00	190.55	6.93175	400.6096
3.20	336.40	342.30	285.70	321.47	3.32	157.20	229.40	193.30	7.17862	400.095
3.30	344.20	344.20	293.20	327.20	3.41	161.20	236.00	198.60	7.54893	397.66936
3.40	354.20	345.60	305.50	335.10	3.47	164.30	240.00	202.15	7.6878	395.9222
3.50	362.00	347.20	318.70	342.63	3.51	167.40	242.00	204.70	7.8961	394.82992
3.60	371.70	349.60	325.80	349.03	3.60	174.50	245.00	209.75	7.97421	394.51804
3.70	379.50	352.00	336.66	356.05	3.70	181.20	249.30	215.25	8.09138	393.56116
3.80	383.20	357.20	343.32	361.24	3.79	187.60	253.40	220.50	8.26713	389.27668
3.90	385.60	358.90	348.03	364.18	3.84	191.60	256.30	223.95	8.33303	387.29368
4.00	387.90	360.40	352.73	367.01	3.97	201.00	261.20	231.10	8.43189	384.21304
4.10	389.20	361.72	356.66	369.19	4.06	208.00	265.40	236.70	8.58018	382.65752
4.20	390.10	362.80	360.50	371.13	4.15	214.00	269.10	241.55	8.63579	382.31656
4.30	393.40	363.87	364.34	373.87	4.22	222.00	270.00	246.00	8.71921	381.8592
4.40	394.10	364.85	368.18	375.71	4.29	228.00	271.80	249.90	8.84433	378.80936
4.50	396.00	365.76	372.02	377.93	4.37	234.00	275.10	254.55	9.03201	378.46552
4.60	401.00	366.62	375.86	381.16	4.50	241.00	283.50	262.25	9.31353	377.71672

4.70	402.69	367.37	379.70	383.25	4.64	250.00	290.50	270.25	9.59505	371.39512
4.80	404.62	368.11	382.59	385.11	4.73	257.10	294.30	275.70	9.66543	370.2724
4.90	406.56	368.86	385.48	386.97	4.86	263.10	302.80	282.95	9.73581	369.11044
5.00	408.49	369.60	388.41	388.83	4.96	272.20	305.70	288.95	9.84138	366.1784
5.10	410.43	370.35	391.45	390.74	5.02	277.50	307.40	292.45	9.99973	364.132
5.20	411.74	371.72	394.49	392.65	5.14	288.00	311.00	299.50	10.2373	358.12268
5.30	412.63	372.98	397.53	394.38	5.24	295.00	315.70	305.35	10.5936	351.35692
5.40	413.52	374.25	400.57	396.11	5.33	302.40	319.10	310.75	10.7272	349.22692
5.50	414.41	375.52	403.61	397.85	5.45	311.00	324.10	317.55	10.9276	348.9962
5.60	414.41	376.78	406.62	399.27	5.49	313.00	326.40	319.70	11.2282	345.70452
5.70	414.41	378.05	409.63	400.70	5.59	322.00	329.70	325.85	11.6792	340.91344
5.80	414.41	379.31	412.64	402.12	5.73	334.29	333.80	334.05	11.8483	340.28796
5.90	414.41	380.58	415.66	403.55	5.80	339.00	336.80	337.90	12.1019	338.41984
6.00	414.41	381.85	418.67	404.98	5.90	340.00	339.00	339.50	12.4824	336.13084
6.10	414.41	383.11	421.68	406.40	6.00	343.00	341.00	342.00	13.0531	338.41772
6.20	414.41	384.38	424.70	407.83	6.10	345.40	342.11	343.76	13.8031	330.17404
6.30	429.40	385.64	426.32	413.79	6.20	348.50	343.26	345.88	13.9906	330.33204
6.40	409.26	386.91	427.35	407.84	6.30	353.00	344.40	348.70	14.1781	330.76992
6.50	406.23	388.17	428.37	407.59	6.40	358.00	345.54	351.77	14.4594	331.58232
6.60	403.21	389.44	429.40	407.35	6.50	359.00	346.69	352.85	14.8812	333.906
6.70	400.18	390.28	430.46	406.97	6.60	360.00	348.43	354.22	15	334.382
6.80	397.16	390.20	431.47	406.28	6.70	360.00	350.24	355.12		
6.90	394.13	390.70	432.50	405.78	6.80	360.00	352.06	356.03		
7.00	390.50	390.91	433.54	404.98	6.90	360.00	353.87	356.94		
7.10	382.16	391.12	434.57	402.62	7.00	360.87	355.68	358.28		
7.20	373.82	391.73	443.10	402.88	7.10	361.67	358.90	360.29		
7.30	365.48	391.20		378.34	7.20	362.75	362.00	362.38		
7.40	357.14	393.51		375.33	7.30	364.98	365.00	364.99		
7.50	348.80	394.40		371.60	7.40	367.22	369.00	368.11		
7.60	340.46	394.71		367.59	7.50	369.46	368.00	368.73		

7.70	332.12	395.01		363.57	7.60	372.00	364.70	368.35		
7.80	323.78	395.32		359.55	7.70	373.00	366.01	369.51		
7.90	315.44	395.63		355.54	7.80	376.00	367.15	371.58		
8.00	307.10	395.94		351.52	7.90	371.00	368.40	369.70		
8.10	298.76	396.24		347.50	8.00	378.10	369.40	373.75		
8.20	290.42	396.55		343.49	8.10	378.72	370.28	374.50		
8.30	282.08	396.86		339.47	8.20	379.33	370.67	375.00		
8.40	273.74	397.16		335.45	8.30	379.95	371.06	375.51		
8.50	265.40	397.47		331.44	8.40	380.56	371.46	376.01		
8.60	257.06	397.70		327.38	8.50	380.76		380.76		
8.70	248.72	398.01		323.37	8.60	381.00		381.00		
8.80	240.38	398.39		319.39	8.70	381.24		381.24		
8.90	232.04	398.70		315.37	8.80	381.48		381.48		
9.00	223.70	398.70		311.20	8.90	381.50		381.50		
9.10	215.36			215.36						
9.20	207.02			207.02						
9.30	198.68			198.68						

Appendix B: Theoretical calculations

1-Saatcioglu et al load deformation curve

Peak Load calculation

$$\frac{f'_{cc}}{f'_{co}} = 1 + k_1 \frac{f_{le}}{f_{co}}$$

$$f_{le} = k_2 f_l$$

$$f_l = \frac{\sum A_s f_{yt} sin\alpha}{s b_c}$$

$$k_2 = 0.26\sqrt{\left(\frac{b_c}{s}\right)\left(\frac{b_c}{s_l}\right)\left(\frac{1}{f_l}\right)} \leq 1.0$$

$$k_1 = 6.7(f_{le})^{-0.17}$$

fco=	10.88889	Mpa
As=	50.24	one leg
fyt=	744	Mpa
s=	46	mm
bc=	92	mm
sl=	78	mm
fl=	17.66473	Mpa
bc/s	2	
bc/sl	1.179487	
1/fl	0.05661	
K2=	0.091358	
k1=	6.176457	
fle=	1.61382	
fcc=	20.85658	Mpa
fcc=	**469.273**	**KN**

Ascending Branch of curve

$$f_c = f'_{cc}\left[2\left(\frac{\varepsilon_c}{\varepsilon_1}\right) - \left(\frac{\varepsilon_c}{\varepsilon_1}\right)^2\right]^{\frac{1}{(1+2K)}} \leq f'_{cc}$$

$$K = \frac{k_1 f_{le}}{f'_{co}}$$

$$\varepsilon_1 = \varepsilon_{01}(1 + 5K)$$

$$\rho = \frac{\sum A_s}{s(b_{cx} + b_{cy})}$$

$$\varepsilon_{85} = 260\rho\varepsilon_1 + \varepsilon_{085}$$

K=	0.9154
e01=	0.002
e1=	0.011154
$\rho =$	0.011871
ε085=	0.0038
$\varepsilon 85 =$	0.038228

$$1/(1+2K)$$

0.353257

Dessending branch

Load at 85% of peak		398.8821
Slope b/n peak load & 85% of peak load		-2599.98
having form y= mx +b	b=	498.2731

Appendix B, 1 Theoretical saatcioglu et al load-deformation curve

Deformation mm	ec	ec/e1	(ec/e1)2			fc
0	0	0	0	0	0	0
0.1	0.000215	0.01928	0.000372	0.038189	0.315544	148.0764
0.2	0.00043	0.038561	0.001487	0.075635	0.401699	188.5064
0.3	0.000645	0.057841	0.003346	0.112337	0.461945	216.7784
0.4	0.00086	0.077122	0.005948	0.148296	0.50956	239.1227
0.5	0.001075	0.096402	0.009293	0.183511	0.549393	257.8154
0.6	0.00129	0.115682	0.013382	0.217983	0.583839	273.9797
0.7	0.001505	0.134963	0.018215	0.251711	0.614277	288.2637
0.8	0.00172	0.154243	0.023791	0.284696	0.641588	301.0799
0.9	0.001935	0.173524	0.03011	0.316937	0.66637	312.7093
1	0.002151	0.192804	0.037173	0.348435	0.689051	323.353
1.1	0.002366	0.212085	0.04498	0.379189	0.70995	333.1605
1.2	0.002581	0.231365	0.05353	0.4092	0.729312	342.2466
1.3	0.002796	0.250645	0.062823	0.438468	0.747329	350.7014
1.4	0.003011	0.269926	0.07286	0.466992	0.764154	358.5971
1.5	0.003226	0.289206	0.08364	0.494772	0.779914	365.9924
1.6	0.003441	0.308487	0.095164	0.521809	0.794711	372.9363
1.7	0.003656	0.327767	0.107431	0.548103	0.808633	379.4694
1.8	0.003871	0.347047	0.120442	0.573653	0.821753	385.6264
1.9	0.004086	0.366328	0.134196	0.59846	0.834134	391.4367
2	0.004301	0.385608	0.148694	0.622523	0.845832	396.926
2.1	0.004516	0.404889	0.163935	0.645843	0.856892	402.1161
2.2	0.004731	0.424169	0.179919	0.668419	0.867356	407.0266
2.3	0.004946	0.44345	0.196647	0.690252	0.87726	411.6744
2.4	0.005161	0.46273	0.214119	0.711341	0.886636	416.0744
2.5	0.005376	0.48201	0.232334	0.731687	0.895513	420.2401

2.6	0.005591	0.501291	0.251292	0.751289	0.903916	424.1833
2.7	0.005806	0.520571	0.270994	0.770148	0.911867	427.9146
2.8	0.006022	0.539852	0.29144	0.788263	0.919387	431.4436
2.9	0.006237	0.559132	0.312629	0.805635	0.926494	434.7788
3	0.006452	0.578412	0.334561	0.822264	0.933205	437.928
3.1	0.006667	0.597693	0.357237	0.838149	0.939534	440.8981
3.2	0.006882	0.616973	0.380656	0.853291	0.945496	443.6956
3.3	0.007097	0.636254	0.404819	0.867689	0.951101	446.326
3.4	0.007312	0.655534	0.429725	0.881343	0.956362	448.7947
3.5	0.007527	0.674815	0.455375	0.894254	0.961287	451.1063
3.6	0.007742	0.694095	0.481768	0.906422	0.965888	453.2651
3.7	0.007957	0.713375	0.508904	0.917846	0.970171	455.275
3.8	0.008172	0.732656	0.536784	0.928527	0.974144	457.1395
3.9	0.008387	0.751936	0.565408	0.938464	0.977814	458.8619
4	0.008602	0.771217	0.594775	0.947658	0.981188	460.4449
4.1	0.008817	0.790497	0.624886	0.956108	0.984269	461.8911
4.2	0.009032	0.809777	0.655739	0.963815	0.987065	463.2029
4.3	0.009247	0.829058	0.687337	0.970779	0.989578	464.3824
4.4	0.009462	0.848338	0.719678	0.976999	0.991813	465.4313
4.5	0.009677	0.867619	0.752762	0.982475	0.993774	466.3512
4.6	0.009892	0.886899	0.78659	0.987208	0.995462	467.1436
4.7	0.010108	0.90618	0.821161	0.991198	0.996882	467.8097
4.8	0.010323	0.92546	0.856476	0.994444	0.998034	468.3503
4.9	0.010538	0.94474	0.892534	0.996946	0.99892	468.7663
5	0.010753	0.964021	0.929336	0.998705	0.999543	469.0583
5.1	0.010968	0.983301	0.966881	0.999721	0.999901	469.2268
5.2	0.011183	1.002582	1.00517	0.999993	0.999998	469.2719
5.3	0.011398	1.021862	1.044202	0.999522	0.999831	469.1938

NB: Descending branch From Peak load 459.26KN until load reaches 0.2fcc=91.85KN would be straight line with above slope.

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Peak load

$f_{cc} = f_{co} + 1.8 f_l$

fco	=	10.88889	Mpa
fl	=	Ks*Kf*fyt*ρst	
fyt	=	744.28	Mpa
Ks	=	0.260988	
Kf	=	0.879045	
ρst	=	0.024271	
fl	=	4.144258	Mpa
fcc	=	18.34855	Mpa
fcc	=	**412.8425**	**KN**

Appendix C: Hoop Strain

Appendix C, 1-Hoop strain

	90 degree Hoop strain, $\mu\varepsilon$	IC4-A Hoop strain, $\mu\varepsilon$		90 degree Hoop strain, $\mu\varepsilon$	
				Sample -2	
Load, KN	Sample-1	Sample-1	Load, KN	Location A	Location B
25	0.95	15.24	25	69.52	118.1
50	4.76	11.43	50	26.67	-67.62
75	10.48	10.48	75	64.76	364.76
100	15.24	8.57	100	24.76	-80.95
125	22.86	5.25	125	37.14	-230.48
150	28.57	6.67	150	35.24	-241.9
175	37.14	7.62	175	61.9	-121.9
200	47.62	7.62	200	100	-230.48
225	54.29	11.43	225	124.76	-128.57
250	61.9	11.43	250	104.76	608.57
275	68.57	10.48	275	114.29	188.57
300	77.14	12.38	300	1532	5091.43
325	85.71	5.75	325	2590.48	5276.19
350	111.4	18.1	350	1857.14	517.18
300	105.31	10.48	375	1819.05	3153.33
290	101.31	1.9	400	1679.05	87.62
250	88.57	1.9	375	1545.71	-218.1
240	80.1	-2.86	325	1534.24	0.95
			300	1830.48	-305.71
			240	1089.52	-67.62

Appendix D: Data Collection format

Data Collection Format

1. **Location of the project**

   Country: Ethiopia

   Town : Addis Ababa

   Seismic Zone: Zone 3 ☑

   Zone 4 ▢

   Zone 5 ▢

2. **About the Project**

   Story level : 1B G+9

   Uses: Residence ▢

   Mixed used ☑

   Real estate ▢

   Commercial ▢

   Hotel ▢

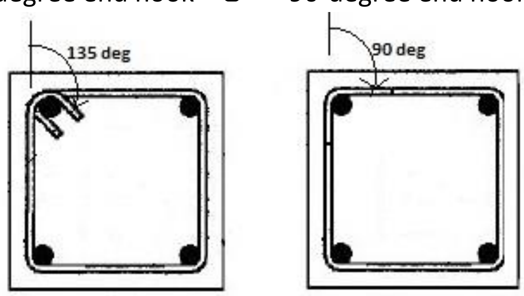
   School ▢

3. **Profession's providing this data**

   Site Engineer ☑ Forman ▢ Supervisor ▢

4. **Type of transverse reinforcement (end anchorage) used in construction site for rectangular columns**

   135-degree end hook ▢ 90-degree end hook ☑



5. **Level of end anchorage used in site that selected in above (4)**

   Always ☑ Sometimes ▢ Rarely ▢ Never ▢

Sample column detail pictures on construction site





Small scale data on detailing of ties end anchorage

No	Location of project		About the project		Data source	End anchorage	Level used
1	Addis Ababa	Zone 3	1B G+9	Mixed use	Site engineer	90^0 hook	Always
2	Adama	Zone 4	2B G+8	Hotel	Site engineer	90^0 hook	Always
3	Addis Ababa	Zone 3	2B G+9	Mixed use	Site engineer	90^0 hook	Always
4	Dilla	Zone 4	G+3	School	Site engineer	90^0 hook	Always
5	Addis Ababa	Zone 3	3B G+9	Mixed use	Site engineer	90^0 hook	Always
6	Addis Ababa	Zone 3	G+12	Mixed use	Site engineer	90^0 hook	Always
7	Hawassa	Zone 4	G+6	Commercial	Site engineer	90^0 hook	Always
8	Adama	Zone 4	G+5	Mall	Site engineer	90^0 hook	Always
9	Addis Ababa	Zone 3	G+6	Hotel	Site engineer	90^0 hook	Always
10	Addis Ababa	Zone 3	3BG+22	Mixed use	Site engineer	135^0 hook	Always
11	Dilla	Zone 4	G+2	Warehouse	Site engineer	90^0 hook	Always
12	Addis Ababa	Zone 3	3BG+12	Mixed use	Site engineer	135^0 hook	Always
13	Addis Ababa	Zone 3	2BG+10	Mixed use	Supervisor	135^0 hook	Always
14	Addis Ababa	Zone 3	G+9	Commercial	Site engineer	90^0 hook	Always
15	Addis Ababa	Zone 3	G+4	Mixed use	Site engineer	90^0 hook	Always
16	Addis Ababa	Zone 3	G+4	Condominium	Supervisor	90^0 hook	Always
17	Addis Ababa	Zone 3	G+4	Condominium	Site engineer	90^0 hook	Always
18	Addis Ababa	Zone 3	G+4	Condominium	Site engineer	90^0 hook	Always
19	Addis Ababa	Zone 3	G+4	Mixed use	Site engineer	90^0 hook	Always

Appendix E: ACI mix design procedure tables

TABLE A1.5.3.1 — RECOMMENDED SLUMPS FOR VARIOUS TYPES OF CONSTRUCTION (SI)

Types of construction	Slump, mm	
	Maximum*	Minimum
Reinforced foundation walls and footings	75	25
Plain footings, caissons, and substructure walls	75	25
Beams and reinforced walls	100	25
Building columns	100	25
Pavements and slabs	75	25
Mass concrete	75	25

*May be increased 25 mm for methods of consolidation other than vibration

TABLE A1.5.3.3 — APPROXIMATE MIXING WATER AND AIR CONTENT REQUIREMENTS FOR DIFFERENT SLUMPS AND NOMINAL MAXIMUM SIZES OF AGGREGATES (SI)

Slump, mm	Water, Kg/m^3 of concrete for indicated nominal maximum sizes of aggregate							
	9.5*	12.5*	19*	25*	37.5*	50†*	75†‡	150†‡
Non-air-entrained concrete								
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
25 to 50	181	175	168	160	150	142	122	107
75 to 100	202	193	184	175	165	157	133	119
150 to 175	216	205	197	184	174	166	154	—
Recommended average§total air content, percent for level of exposure:								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5**††	1.0**††
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5**††	3.0**††
Extreme exposure‡‡	7.5	7.0	6.0	6.0	5.5	5.0	4.5**††	4.0**††

TABLE A1.5.3.4(a) — RELATIONSHIPS BETWEEN WATER-CEMENT RATIO AND COMPRESSIVE STRENGTH OF CONCRETE (SI)

Compressive strength at 28 days, MPa*	Water-cement ratio, by mass	
	Non-air-entrained concrete	Air-entrained concrete
40	0.42	—
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70

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