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BEHAVIOUR OF RCC COLUMNS CONFINED BY DIFFERENT TYPES OF HOOKS

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ABSTRACT

Twenty-seven short concrete columns reinforced with longitudinal steel and circular spirals or hoops were tested to failure under monotonic axial compression. Effects of different variables, such as amount and type of lateral steel, lateral steel spacing, and specimen size, on the behavior of columns were investigated. The relation between lateral pressure on concrete and concrete strength enhancement, and the variation of spiral steel stress and confinement effectiveness coefficient k with respect to the amount of spiral steel were also investigated. Requirements of the ACI 318-89 Building Code related to the minimum volumetric ratio of spiral reinforcement and the maximum spiral pitch of 80 mm (3 in.) were critically examined. An increase in the volumetric ratio of spiral steel was found to significantly improve strength and ductility of confined concrete, the effect on ductility being more pronounced. The maximum effect of spiral steel spacing was observed for the amount of spiral steel, which was approximately equal to that required by the ACI code. The specimen size appeared to have no significant effect on the behavior of similarly confined columns of different sizes.

1. INTRODUCTION

1.1 General

A column is generally a compression member supporting beams and slabs in a structural system and having an effective length exceeding three times the least lateral dimension. A column may be considered to be short when its effective length does not exceed 12 times the least lateral dimension. If the ratio of effective length to least lateral dimension exceeds 12, the column is considered as long or slender for design purposes.A column may be defined as an element used primarily to support axial compressive load and with a height of at least three times its least lateral dimension. A compression member subjected to pure axial load rarely occurs in practice. All columns are subjected to some moment which may be due to accidental eccentricity or due to end restraint imposed by monolithically placed beams or slabs. The strength of column depends on the strength of a materials, shape and size of the cross section, length and the degree of positional and directional restraints at its ends. A column may be classified based on different criteria such as:

1. Shape of cross-section
2. Slenderness ratio

3. Type of loading, and
4. Pattern of lateral reinforcement.

A column may be rectangular, square, circular, or polygon in cross-section. The code specifies certain minimum reinforcement bars depending on its shape as will be discussed later.A column may be classified as short or long column depending on its effective slenderness ratio. A long column is designed to resist the applied loads plus additional bending moments induced due to its tendency to buckle.

A column may be classified as follows based on type of loading;

1. Axially loaded columns.
2. A column subjected to axial load and uni-axial bending.
3. A column subjected to axial load and bi-axial bending.

A reinforced concrete column can also be classified according to the manner, in which the longitudinal bars are laterally supported, that is,

1. Tied column.

2. Spiral column.

Concrete structures are commonly used for various types of structures all over the world, including a wide range of buildings, bridges, dams, etc. Moreover, they are designed and constructed in different climates and seismic zones. In general, overall performance and behavior of concrete structures under applied loads depends on the response of their force resisting systems. Behavior of the force resisting systems, in turn, depends on the response of the individual structural elements, such as reinforced concrete columns. Specifically, deformation capacity or the so-called “ductility” of these force resisting systems is an important parameter that influences the performance of structures under various loading conditions.

In particular, RC columns are important structural elements, and play a significant role in overall ductility and capacity of the reinforced concrete structures. Not surprisingly, accurate performance assessment of a reinforced concrete structure is closely tied to realistic assessment of the strength and performance of its columns. The most important design consideration for ductility in plastic hinge region of reinforced concrete columns is the provision of transverse reinforcement that confines the core of the compressed concrete. Though it is commonly recommended in various codes that columns subjected to lateral forces such as seismic loads must be designed according to the displacement or recently performance based approach; it appears that the newly edition of the RPA on the subject is still not suitable to provide the necessary lateral steel content required for a given ductility demand.The examination of its content shows that the aspect of confinement and its positive influence towards the enhancement of the section moment capacity is still not considered in the design of reinforced concrete columns. In fact rectilinear ties in reinforced concrete columns play an important role in enhancing the strength and ductility. Under axial loads, concrete pressure in the lateral direction of the column section acts on the lateral ties and the resistance of the ties may restrain the core concrete to a degree. With the increase of axial loads, initial cracks are propagated in the parallel direction with longitudinal bars at the corners of the column section. Around the yielding of longitudinal bars, the concrete cover spalls off and begins to unload. The confined columns exhibit a more load carrying capacity after the spalling. When the maximum axial load is exceeded, the longitudinal bars buckle and the hook of ties is open. The prediction of the ultimate behavior of reinforced concrete columns subjected to large seismic lateral forces relies mainly on the relationships of the constituent materials. This study involves an introduction of a new model for concrete confinement considered as a crucial element in seismic design. Several important factors are taken into account such as: concrete strength, amount and strength of transverse reinforcement and the distribution of longitudinal bars. Using available test results reported in the past years, a regression analysis was carried out.

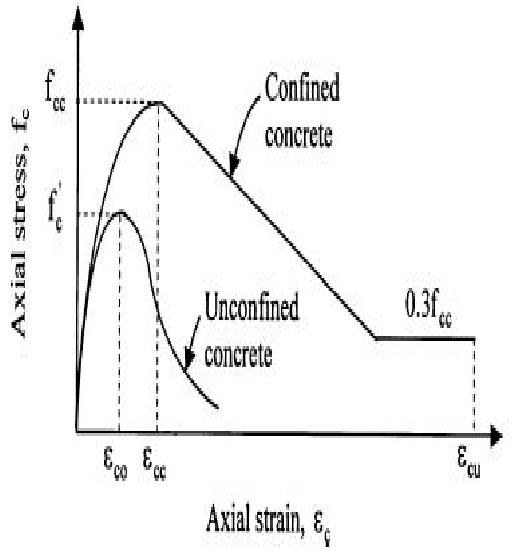


Fig 1.1 Proposed stress–strain curve for confined normal strength concrete

1.2 Concrete columns and their behavior

Columns are structural members that support axial load with or without bending moments; however, if the member supports axial load and moment, it is called a beam-column. These structural members can be horizontal, vertical or inclined. In this text, by columns we mean vertical structural members that support axial load with or without moments. In a structure, these vertical members support the loads of floors and roof and eventually transmit these forces to the structure's foundation. Although concrete columns can have several types of cross sections, such as rectangular, circular, T-shape, L-shape, this study considers only the RC columns with circular and square cross sections. Also, based on the type of the lateral reinforcement used in these RC columns, they are divided into two main categories of tied columns and spiral columns.

Tied columns have individual hoops (stirrups), spiral columns are those that their hoops have the form of a spiral. Figure 1.2 shows tied and spiral column.

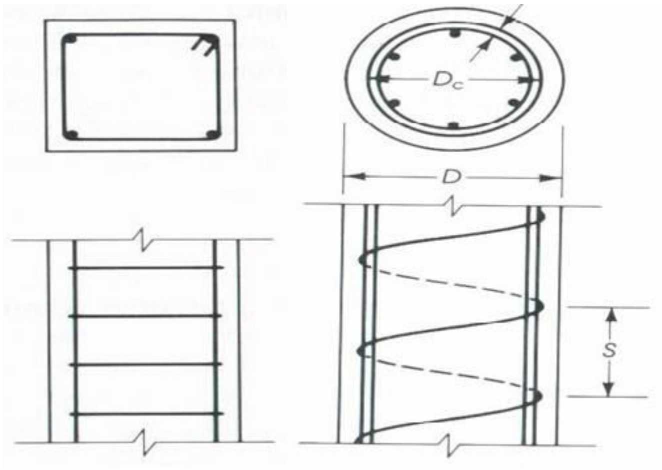


Fig 1.2 Tied and spiral column

2. LITERATURE REVIEW

3.1 Size effect on compressive strength of plain and spirally reinforced concrete cylinders

by Jin-Keun Kim, Seong-Tae Yi, Chan-Kyu Park, and Seok-Hong Eo Many experimental and theoretical investigations have been carried out to examine the reduction phenomenon of compressive strength of cylindrical concrete specimens with size, but up until now, an adequate analysis technique has not been developed. In this paper the fracture mechanics type size effect on the compressive strength of cylindrical concrete specimens was studied, with the diameter, the height/diameter ratio, and the volumetric spiral ratio of cylinder considered as the main parameters. For this purpose, theoretical and statistical analyses were conducted. First, a size effect equation was proposed to predict the compressive strength of cylindrical concrete specimens with various diameters and height/diameter ratios. Second, the model equation derived from the plain concrete was extended for predicting the compressive strength of spirally reinforced concrete cylinders. The proposed equation showed good agreement with the existing test results for concrete cylinders with and without spiral reinforcement An adequate analysis technique for reduction trend of compressive strength of cylindrical concrete specimens with size has not yet been presented. The research described is intended to propose model equations that predict the compressive strength of cylindrical specimens with and without spiral reinforcement in case of various height/diameter ratios based on nonlinear fracture mechanics. The proposed equations could be applicable to the strength correction of core samples from concrete structures and the prediction of compressive strength of circular columns.

On the basis of the theoretical and statistical analyses for the size effect of compressive strength of plain and spirally reinforced concrete cylinders, the following conclusions are drawn.

1. Model equations for predicting the compressive strength of concrete cylinders with and without spiral reinforcement are suggested based on nonlinear fracture mechanics.
2. The effect of maximum aggregate size on the size effect of the compressive strength is negligible within the practical size range. This means that the effect of maximum aggregate size on the width of the microcrack zone can be ignored compared with the effect of the characteristic dimension defined as *hi* - b*di*.
3. The size effect is mitigated with increasing volumetric spiral ratio, and the minimum volumetric spiral ratio needed to eliminate the size effect is increased with increasing compressive strength of concrete.

2.2 Stress-strain behavior of square confined concrete column

Hisataka SATO1 And Katsuhiko YAMAGUCHI2

It is generally accepted that the strength and ductility of reinforced concrete column can be improved through confinement of the plastic hinge regions. This improvement ensures seismic stability of the structure during a strong earthquake.

Therefore, column confinement is an important component of earthquake resistant reinforced concrete buildings. The characteristics of confined concrete have been researched extensively, and the primary parameters of confinement have been identified both experimentally and analytically. Analytical models have been developed, usually on the basics of a specific set of test data. These models, although producing good predictions in many applications, have limitations in terms of cross-sectional shape and reinforcement arrangement. Therefore the confinement effect of lateral reinforcement, perimeter hoops and intermediate tie bars, is not obvious. The research described in this paper was an experimental investigation of the confinement effect of intermediate tie bars.Four reinforced concrete columns and one plain concrete column with a square cross section shown in Fig.1 were cast vertically. Normal strength concrete with specified compressive strength of 35 N/mm2 was used. The specifications of the test units are summarized in Table 1 The height was 966 mm including the bearing steel on top and bottom of the test units. Two different configurations were used for the lateral reinforcement with yield strength of 1430 N/mm2. The diameter and cross sectional area of each longitudinal bars were 6.2 mm and 30 mm2, respectively. Sixteen longitudinal bars with yield strength of 404 N/mm2. The diameter and cross sectional area of each longitudinal bars were 13 mm and 127 mm2, respectively.An experimental program involving short concrete column with complex tie configurations was performed.

The following conclusions can be drawn from the results of these tests:

1. Buckling of longitudinal reinforcement was a cause of the reduction in stiffness and strength of confined column.
2. Stiffness and ductility of confined column are effectively improved by increasing the number of inner tie bars.

2.3 Confinement reinforcement design for reinforced concrete columns

P. Paultre, M.ASCE1; and F. Légeron, M.ASCE2

This paper presents new equations for the design of confinement reinforcement for ductile earthquake-resistant rectangular and circular columns based on performance measured in terms of curvature demand. These equations are developed from a parametric study of a large number of columns to reach a certain level of sectional ductility and account for the influence of concrete strength, transverse reinforcement yield strength, axial load level, and transverse confinement reinforcement spatial distribution. Simplification of these equations, while retaining the main controlling parameters, leads to design equations appropriate for design codes. These equations are then validated against a large set of experimental results. Their implementation in the Canadian Standard for *Design of Concrete Structures* is explained.The objective of this article is to develop new equations for the determination of confinement reinforcement for rectangular and circular concrete columns applicable to concrete strength up to 120 MPa and confinement steel strength up to 1,400 MPa.

These equations are developed from a comprehensive study considering the effects of parameters playing an important role in column ductility. Based on this approach, simplified equations for the design of confinement reinforcement are proposed that are suitable for code use and indeed form the basis for the new confinement requirements of the new CSA A23.3 Standard _CSA 2004_. The proposed equations are compared with experimental results of 93 square and circular columns made with normal- and high strength material that have been tested by different researchers.The methodology for the derivation of new equations to calculate confinement reinforcement for ductile earthquake-resistant rectangular and circular columns based on performance measured interms of curvature demand is presented. These new equations account for the influence of concrete strength, transverse reinforcement yield strength, axial load level, and transverse confinement reinforcement spatial distribution. Simplification of the geometric coefficient of confinement effectiveness and conservative expression for the effective transverse reinforcement stress allowed simplification of the equations giving the required amount of confinement reinforcement while retaining the main controlling parameters. These equations were then validated against a large set of experimental results. Their implementation in the Canadian Standard for Design of Concrete Structures is explained. The new confinement requirements are superior to those in the current ACI Code or CSA-94 Standard, which are not based on performance levels and do not account for levels of axial loads, high-strength concrete, and high-yield strength of transverse reinforcement steel. The methodology presented here can easily be applied to a displacement-based design of confinement reinforcement. The application of the design equation to determine confinement for shear walls and hollow-core sections needs to be investigated.

2.4 Reinforced concrete columns confined by circular spirals and hoops

By Shamim A. Sheikh & Murat T. Tokucu

The relation between lateral pressure on concrete and concrete strength enhancement,and the variation of spiral steel stress and confinement effectiveness coefficient k with respect to the amount of spiral steel were also inestigated.Requirement of the ACI 318-89 building code related to the minimum volumetric ratio of spiral reinforcement and the maximum spiral pitch of 80mm were critically examined.An increase in the volumetric ratio of spiral steel was found to significantly improve strength and ductility of confined concrete,the effect on ductility being more pronounced. In well confined specimens, the confinement effectiveness coefficient k corresponding to the maximum concrete force was between 2.1 and 4.0.Use of spiral steel in a column results in enhancement of strength and ductility of concrete. Whereas the replacement of cover concrete contribution toward the load carring capacity of a column by the enhanced strength of confined concrete is a convenient and plausible criterion for the design of spiral reinforcement, the enhancement in ductility is a more important outcome of confinement, considering extensive redistribution of forces at large deformations.Effect of different variables on confined concrete behavior- based on the analysis procedure described previously, the final stress-strain curves of confined concrete were established for all the specimens and used to evaluate effects of different variables on confined concrete behavior.

3. MATERIALS AND METHODOLOGY

3.1 Materials used

3.1.1 Cement

In this experiment 43 grade ordinary Portland cement (OPC) with brand name Vasavadatta was used for all concrete mixes. The cement used was fresh and without any lumps. The testing of cement was done as per IS: 8112-1989. The specific gravity of cement was found to be 3.15. The physical properties of cement used are as given in table 3.1.

Table 3.1 Physical properties of cement

Particulars	**Experimental result**	**As per standard**
1.Fineness	268 m^2/kg	225 m^2/kg
2.Soundness		
a) By Le Chatelier mould	1.00 mm	10 mm
b) By Autoclave	0.16	0.8 maximum
3.Setting time (minutes)		
a) Initial set	200 minutes	30 minutes minimum
b) Final set	270 minutes	600 minutes maximum
4.Comp strength (M Pa)		
a) 3 days	34	23 MPa
b) 7 days	44	33 MPa
c) 28 days	58	43 MPa
Temperature during testing	27.81^{0} C	27° C ± 2%

3.1.2 Fine aggregate

The sand used for the experimental program was locally procured and was confirming to zone-II. The specific gravity of fine aggregate was found to be 2.62.

3.1.3 Coarse aggregate

Locally available coarse aggregate having the maximum size of 10 mm were used in the present work. The specific gravity of coarse aggregate was found to be 2.81.

3.1.4 Silica fume, Fly ash, & Metakaolin

The silica fume used in the experimentation was obtained from Elkem laboratory, Navi Mumbai. 15% of cement by its weight is replaced by silica fume in all the mixes. The chemical composition of silica fume is shown in table 3.3.

Table 3.3 Chemical composition of silica fume

Chemical composition	Percentages
Silica (SiO_2)	89
Alumina (Al_2O_3)	0.50
Iron oxide (Fe_2O_3)	2.50

Alkalies (Na_2o+K_2O)	1.20
Calcium oxide (CaO)	0.50
Magnesium oxide	0.60

3.1.5 Water

Portable tap water was used for the preparation of specimens and for the curing of specimens.

3.1.6 Superplastisizer

conplast-430 superplastisizer manufacture by Fosroc Chemicals, Belgaum was used in this experimentation. Its use enhances the workability of the mix, helps in providing a better compaction and finishing. It also permits a reduction in water content upto 25%. A dosage of 1% by weight of cement was used.

3.2 Mix Design

The mix design procedure adopted to obtain a M25 grade concrete is in accordance with IS 10262- 2009. The specific gravities of the materials used are as tabulated in the table 3.4.

Table 3.4 Specific gravities of materials used.

Material	**Specific gravity**
Cement	3.15
Fine aggregate	2.62
Coarse aggregate	2.81

The design steps are as follows

Step 1: Determination of the target strength for mix proportioning

$$f_{ck}^{'} = f_{ck} + 1.65s$$

Where, $f_{ck}^{'}$ = target mean compressive strength at 28 days

f_{ck} = characteristics compressive strength at 28 days

s = standard deviation.

From IS 456-2000, Table 8, s = 4MPa

Therefore target strength = 25 + (1.65×4)

= 31.6 MPa.

Step 2: Selection of water /cement ratio

Referring IS 456-2000, Table 5, W/C ratio = 0.40

Step 3: Selection of water content

Referring IS 10262- 2009, Table 2, Maximum water content for coarse aggregate with maximum 10mm maximum size = 208 kg/m^3.

Use of superplasticizers permits the reduction in water content up to 30%.

Applying a water reduction of 25%

Quantity of water = 208 – [208 × (25/100)]

= 208 – 52

= 156 Kg/m^3.

Step 4: Calculation of cement content

W/C ratio = 0.40

Therefore, cement content = 156 / 0.40

= 390 Kg/m^3.

Referring to IS 456- 2000, Table 5, Minimum cement required = 250 Kg/m^3 < 325 Kg/m^3

Hence the cement content is adequate.

Step 5: Determination of the volume of coarse aggregates

Referring IS 10262- 2009, Table 3, volume of coarse aggregate per unit volume of concrete corresponding to a maximum size of coarse of 10mm and fine aggregate corresponding to grading zone II,

Volume of coarse aggregate = 0.46 m^3

Step 6: Mix Calculations

- Volume of concrete = 1 m^3
- Volume of cement = Weight of cement / Specific gravity of cement= (390 / 3.15) × (1 / 10^3)= 0.123 m^3

- Volume of Water = Weight of water / Specific gravity of water

= 156 / 1000= 0.156 m^3

- Volume of Coarse aggregate = 0.46 m^3
- Volume of Fine Aggregate = 1 – 0.123 – 0.156 – 0.46 = 0.281 m^3
- Total quantity of aggregates = 1 – 0.123 – 0.156 = 0.721 m^3

- Mass of coarse aggregate= 0.721 × 0.46 × 2.81 × 10^3= 931.96Kg/m^3
- Mass of fine aggregate = 0.721 × 0.281×2.62 x 10^3

= 530.81Kg/m

Step 7: The mix proportion obtained are as shown in the table 4.5

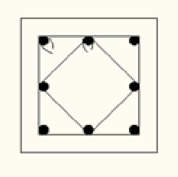
Table 3.5 Mix proportion

W/C ratio	Cement	Fine aggregate	Coarse aggregate
0.40	390 kg/m^3	530.81 kg/m^3	931.96 kg/m^3
0.40	1	1.361	2.39

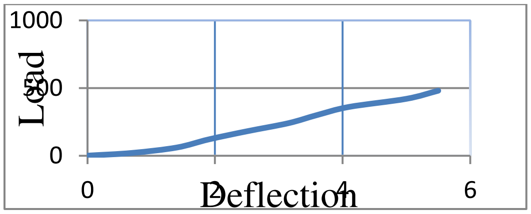
4. EXPERIMENTAL RESULTS

This chapter deals with the test results of behavior of RCC columns confined by different types of hoops, the compression test for 32 columns are done and the load vs deformation graphs are taken for ultimate load. The having 4 configuration of steel confinement and 3 admixtures(Fly ash, silica fume, metakoline) of about 15% are added and these are compared with the results of reference concrete.

DIAGONAL HOOK- METAKOLINE



Input Parameters		Results	
Serial no	.1	Ultimate load(kn)	519.5
Specimen width(mm)	150	Disp. At ulti. Load(mm)	6.2
Cube Age(days)	28	Compressive strength(N/mm2)	23.089
		Breaking load(kn)	70.1
		Yield load(kn)	188.7



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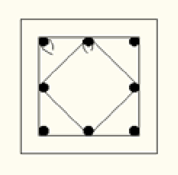
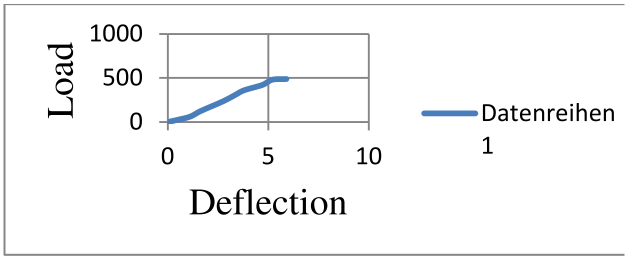
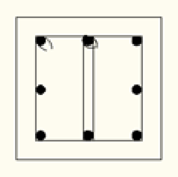


Input Parameters		Results	
Serial no	1.1	Ultimate load(kn)	487.45

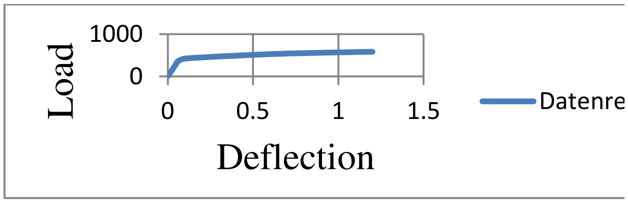
Specimen width(mm)	150	Disp. At ulti. Load(mm)	5.9
Cube Age(days)	28	Compressive strength(N/mm2)	21.664
		Breaking load(kn)	65.87
		Yield load(kn)	163.45



DOUBLE HOOK – SILICA FUME



Input Parameters		Results	
Serial no	2	Ultimate load(kn)	582.60
Specimen width(mm)	150	Disp. At ulti. Load(mm)	1.2
Cube Age(days)	28	Compressive strength(N/mm2)	25.893
		Breaking load(kn)	509.60
		Yield load(kn)	541.60



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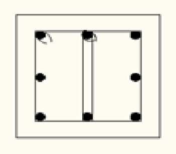
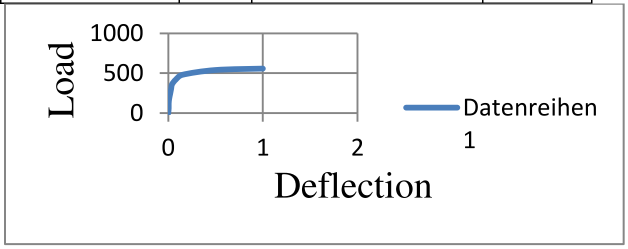
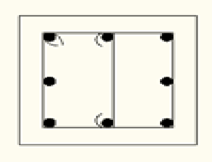


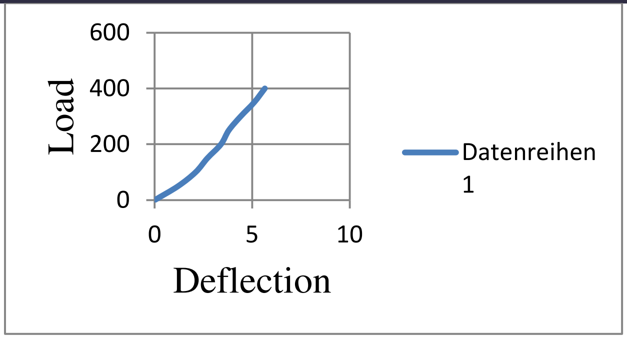
Input Parameters		Results	
Serial no	2.1	Ultimate load(kn)	557.45
Specimen width(mm)	150	Disp. At ulti. Load(mm)	1
Cube Age(days)	28	Compressive strength(N/mm 2)	24.775
		Breaking load(kn)	506.3
		Yield load(kn)	528.5



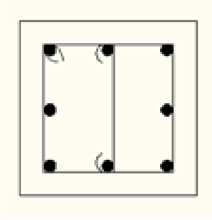
SINGLE HOOK – SILICA FUME



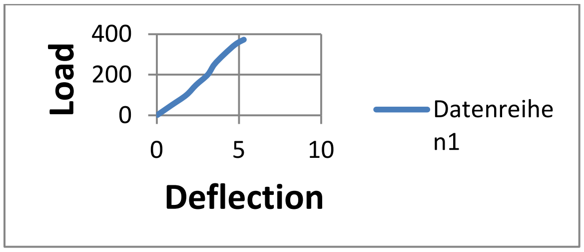
Input Parameters		Results	
Serial no	3	Ultimate load(kn)	400
Specimen width(mm)	150	Disp. At ulti. Load(mm)	5.7
Cube Age(days)	28	Compressive strength(N/mm 2)	17.777
		Breaking load(kn)	254.40
		Yield load(kn)	281.30



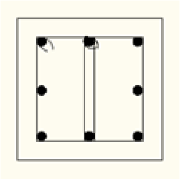
SINGLE HOOK – SILICA FUME



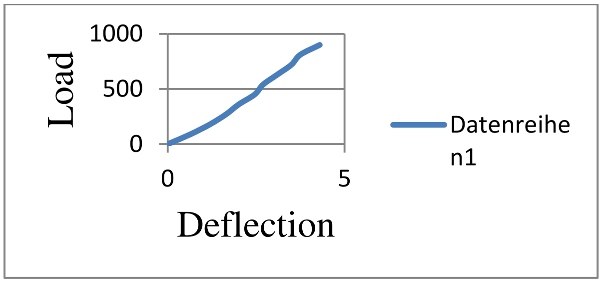
Input Parameters		Results	
Serial no	3.1	Ultimate load(kn)	372.45
Specimen width(mm)	150	Disp. At ulti. Load(mm)	5.3
Cube Age(days)	28	Compressive strength(N/mm2)	16.553
		Breaking load(kn)	254.40
		Yield load(kn)	281.30



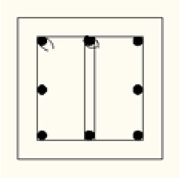
DOUBLE HOOK – METAKOLINE



Input Parameters		Results	
Serial no	4	Ultimate load(kn)	899.15
Specimen width(mm)	150	Disp. At ulti. Load(mm)	4.3
Cube Age(days)	28	Compressive strength(N/mm2)	39.962
		Breaking load(kn)	144
		Yield load(kn)	759.50

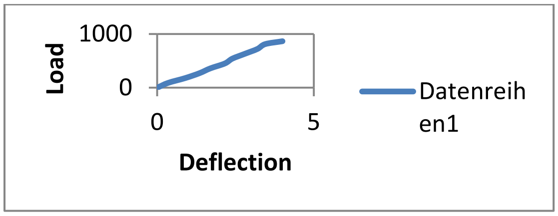


DOUBLE HOOK – METAKOLINE

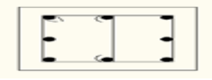


Input Parameters		Results	
Serial no	4.1	Ultimate load(kn)	863.24
Specimen width(mm)	150	Disp. At ulti. Load(mm)	4
Cube Age(days)	28	Compressive strength(N/mm2)	38.366
		Breaking load(kn)	112.3

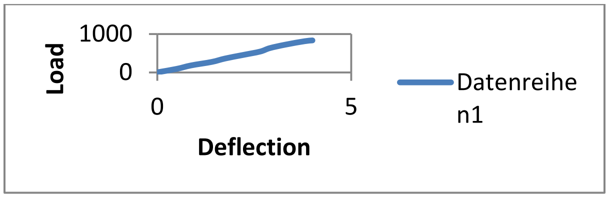
		Yield load(kn)	721.56



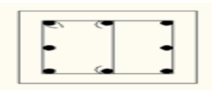
SINGLE HOOK – METAKOLINE



Input Parameters		**Results**	
Serial no	5	Ultimate load(kn)	831.1
Specimen width(mm)	150	Disp. At ulti. Load(mm)	4.0
Cube Age(days)	28	Compressive strength(N/mm2)	36.938
		Breaking load(kn)	139
		Yield load(kn)	720.60

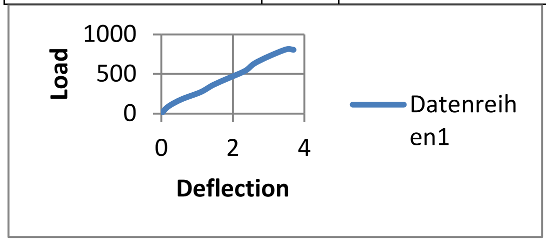


SINGLE HOOK – METAKOLINE

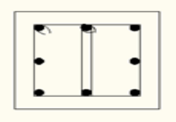


Input Parameters		**Results**	
Serial no	5.1	Ultimate load(kn)	80
Specimen	150	Disp. At ulti.	3.7

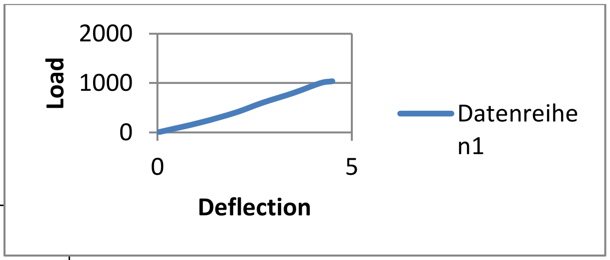
width(mm)		Load(mm)	
Cube Age(days)	28	Compressive strength(N/mm2)	35.737
		Breaking load(kn)	123
		Yield load(kn)	687



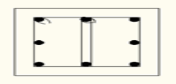
DOUBLE HOOK – FLY ASH



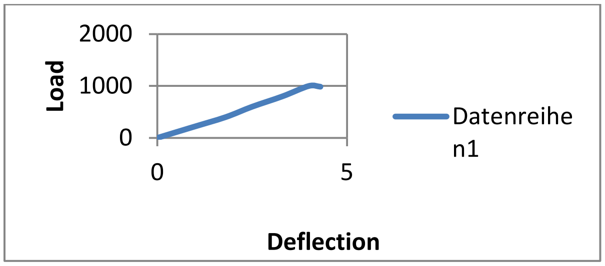
Input Parameters		**Results**	
Serial no	6	Ultimate load(kn)	1035.45
Specimen width(mm)	150	Disp. At ulti. Load(mm)	4.5
Cube Age(days)	28	Compressive strength(N/mm2)	46.020
		Breaking load(kn)	143.8
		Yield load(kn)	816.70



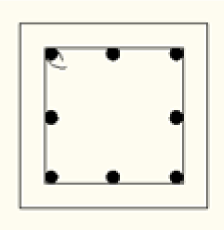
DOUBLE HOOK – FLY ASH



Input Parameters		Results	
Serial no	6.1	Ultimate load(kn)	984.7
Specimen width(mm)	150	Disp. At ulti. Load(mm)	4.3
Cube Age(days)	28	Compressive strength(N/mm2)	43.764
		Breaking load(kn)	112.9
		Yield load(kn)	789.3

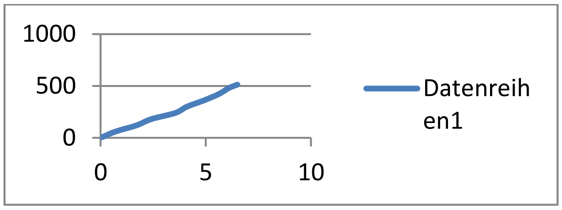


NORMAL HOOK – SILICA FUME

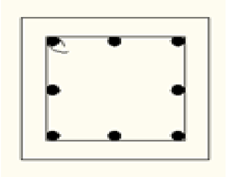


Input Parameters		Results	
Serial no	7	Ultimate load(kn)	512.10
Specimen width(mm)	150	Disp. At ulti. Load(mm)	6.5
Cube Age(days)	28	Compressive strength(N/mm2)	22.760
		Breaking load(kn)	158.20
		Yield load(kn)	384.7

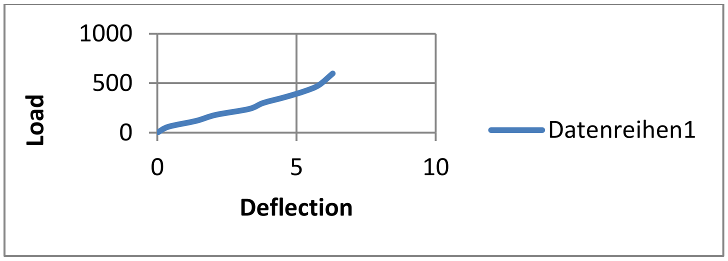
			0



NORMAL HOOK – SILICA FUME



Input Parameters		Results	
Serial no	7.1	Ultimate load(kn)	597.78
Specimen width(mm)	150	Disp. At ulti. Load(mm)	6.3
Cube Age(days)	28	Compressive strength(N/mm2)	26.568
		Breaking load(kn)	156.6
		Yield load(kn)	407.2



CONCLUSIONS

Following conclusions are drawn based on the experimental study performed on RCC columns with different hoop configurations:

As a general, reduction of the buckling length of the hoop by using struts and its fixation in the hoop and longitudinal steel gives increase in the confined compression with consequent increase in the failure load of the column.

- The use of struts in the hoop was recommended because of better economic and technical aspects. This arrangement gives the highest failure load, lowest hoop strain and the lowest in percentage of steel hoop. Also, this arrangement can be increase in the load design by percentage nearly (10%).
- As a general, reduction of the buckling length of the hoop by using struts and its fixation in the hoop and longitudinal steel gives increase in the confined compression with consequent increase in the failure load of the column.
- The increase in concrete strength due to confinement was observed to be between 2.1 and 4.0 times the lateral pressure.
- A larger number of laterally supported longitudinal bars results in higher flexural strength and ductility.
- The use of struts in the hoop was recommended because of better economic and technical aspects.
- Buckling of longitudinal reinforcement was a cause of the reduction in stiffness and strength of confined column.
- Stiffness and ductility of confined column are effectively improved by increasing the number of inner tie bars.

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