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Behavior of self compacting concrete under axial compression with and without confinement

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***Abstract*—Self compacting concrete recently developed concept in which the ingredients of the concrete mix are proportioned in such a way that it can flow under its own weight to completely fill the form work and passes through congested reinforcement without segregation and self consolidate without any mechanical vibration. In the present investigation M45 grade of SCC were developed using BIS method of mix design. To justify the fresh properties of the thus developed concrete slump flow test,T_{50} cm test, J ring test, V funnel test, L box test and fill box test were conducted and fresh properties are checked as per EFNARC specifications. The standard sizes of 24 numbers of cubes,24 numbers of cylinders, and 24 numbers of beams were cast with and without confinement to determine the mechanical properties viz. compressive strength, split tensile strength, flexural strength and Modulus of Elasticity respectively. It is observed that the confinement of the concrete has increased the 28 days strength from 20 percent to 41.1 percent for different percentages of confinements and It peak stress and corresponding strain at peak stress increases with increase in percentage of confinements. Two analytical models were proposed to study the stress strain behavior of SCC under different confinements, It is observed that model based on L.S.Hsu and C.T.T.Hsu equation is closely agreeing with experimental results.**

***Key words:* Self compacting concrete, Admixture, Confinement, Mix design, stress strain behavior**

I. INTRODUCTION

Self compacting concrete (SCC) is a very special concrete by its inherent characteristics like self compactability, segregation resistance, flowability and improved performance. However the basic property of weakness in tension remains. The concept of fibre reinforcement in SCC was introduced to improve its strength, toughness,

resistance to cracking there by further improving its durability and enhancement of energy. Various fibres were like steel, glass, polypropylene etc were tried by many researchers and results have been reported indicating enhancement in the performance characteristics of the SCC. The present studies are aimed to study the mechanical behavior of Self Compacting Concrete (SCC) under axial compression with and without confinement of standard grade i.e., M45. The properties of strength, stress-strain behavior, toughness index, energy absorption were studied and analytical models were developed for the stress-strain behavior of confined SCC and unconfined SCC of M45 grade based on the experimental investigation.

II. EXPERIMENTAL PROGRAMME

The first phase of experimental programme M45 grade SCC and FRSCC were developed to satisfy EFNARC guidelines. The specimens were cast with and without confinements in the form of standard sizes of cubes, cylinders and beams under different percentages of confinements. In the second phase tests were conducted for the mechanical properties.

Analytical Programme: Using the stress-strain results under axial compression for different levels of confinement, mathematical models are developed and compared.

Materials Used: Ordinary Portland cement of 53 grade (ultratech) confirming to IS: 4031 was used in the investigations. Fine aggregate is natural and obtained from local market confirming to Zone-III and coarse aggregate is obtained from local crushing plant, Robo silicon Keesaragutta, Hyderabad confirming to gradations given by IS: 2386 was used. Fly ash of Type-II from Vijayawada Thermal Power Station, Andhra Pradesh confirming to IS: 3812 was used. Super plasticizer is used as Gillenium B233 and viscosity modifying agent used as Sika stabilizer in developing the SCC. Steel fibres of 6mm diameter and with a aspect ratio of 50 were used in developing FRSCC. Different trial mixes were investigated in the laboratory and the mix with following constituents, as shown in Table 1 and 2, was arrived at and used in the further investigation.

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Table 1: Details of M45 grade concrete mix

Grade of concrete	Cement kg/m^3	F.A kg/m^3	C.A kg/m^3	Fly Ash kg/m^3	Water kg/m^3	SP lt/m^3	VMA lt/m^3
53	415	858	761	138	190	5.08	0.17

Table 2: Fresh properties of SCC

Designation	Slump Flow (mm)	T50 Slump Flow (s)	V Funnel (s)	V Funnel at 5 Min. (s)	L Box H2/H1	U Box (H2-H1)
SCC	730	3	7.54	12.2	0.97	1.5

Specimen Preparation and Testing: Standard cubes of 100mm size and cylinders of 150mm diameter and 300mm length were cast for studying the compressive strength and stress-strain behavior of concrete. The cylinder specimens were cast without any confinement and with different percentages of confinement in the form of hoops as shown in Table 3. The specimens cast were cured for 28 days and tested as per BIS specifications. The cylinder specimens were tested in 1000kN strain control Universal Testing Machine under 0.02mm/s strain rate.

III. DISCUSSION AND TEST RESULTS

Table 3 shows the cube and cylinder compressive strength of M45 grade concrete without fibres and with fibres under different confinements. FRSCC was made with a fibre dosage of 31.42 kg/m3 as steel fibres. The fibre index obtained for FRSCC is 0.124.

Table 3: SCC with different Steel confinement and mechanical properties

S.No	Designation	Volume of Confinement (%)	Type of confinement	Cube compressive strength (MPa) At 28 days	Cylinder Compressive Strength (MPa) At 28 days
1	FRSCC	0	6 Hoops	63.22	61.68
2	FRSCC	0.562	6 Hoops	-	66.16
3	FRSCC	0.827	6 Hoops	-	68.48
4	FRSCC	1.091	6 Hoops	-	69.68

IV. STRESS-STRAIN BEHAVIOUR OF SELF COMPACTING CONCRETE

Based on the experimental data and Fig, the relationship obtained between percentage confinement versus stress ratio and percentage of confinement(c) versus strain ratio for SCC are

as follows:

A stress strain curve is a graph derived from measuring load stress versus strain for a sample of materials. In concrete the rate of increase of stress is less than that of increase in strain because of formation of micro cracks between the interfaces of aggregate and cement paste. The stress strain behavior of concrete is prime parameter as it is a very much important aspect in designing, predicting the flexural behavior and estimating toughness of concrete.

A complete stress strain curve is needed for rational design and analysis of concrete structure especially for design of concrete stress that build in severe environment need durable concrete because of huge amount of construction expenses and difficulty in concrete repairs.

Stress-Strain calculations for 0% steel at 28 days

Table 3. gives the cube and cylinder compressive strength of the design mix at different ages. The final mix cast cylinder specimens are tested at 28 days under strain control. The rate of strain is 0.02mm per second the deformation was measured at every 20KN intervals. The model readings along with stress-strain calculations for zero percentage steel at 28 days were given in Table 4. The stress-strain curve and normalized stress-strain curve for zero percentage confinement was shown in fig 2 and 3 respectively. The peak stress is 35.0848 N/mm2 and the strain at peak stress is 0.002.The maximum strain 0.0023 is noted at 0.5 times of the peak stress. The curve of the figure is smooth and uniform in the ascending part but it has a sharp fall in descending portion.

Table 4: Stress-Strain calculations for 0% steel at 28 days

SL.NO.	STRAIN	STRESS	NORMALIZED SRAIN	NORMALIZED SRESS
1	0.000006	1.137	0.003	0.0322
2	0.000029	2.2636	0.0145	0.064
3	0.000044	3.395	0.022	0.096
4	0.000059	4.527	0.029	0.129
5	0.000075	5.658	0.037	0.161
6	0.000102	6.790	0.051	0.193
7	0.000123	7.922	0.061	0.225
8	0.000142	9.054	0.071	0.258
9	0.000164	10.18	0.082	0.290
10	0.000193	11.31	0.096	0.322
11	0.000205	12.44	0.102	0.354
12	0.000225	13.58	0.112	0.387
13	0.000278	14.71	0.139	0.419
14	0.000312	15.84	0.156	0.451
15	0.000338	16.97	0.169	0.483
16	0.000377	18.10	0.188	0.516
17	0.000392	19.24	0.196	0.548
18	0.000420	20.37	0.210	0.580

19	0.000445	21.50	0.222	0.612
20	0.000475	22.63	0.237	0.645
21	0.00048	23.76	0.24	0.677
22	0.000505	24.89	0.253	0.709
23	0.000555	26.03	0.277	0.742
24	0.000605	27.16	0.302	0.774
25	0.000699	28.29	0.349	0.806
26	0.000795	29.425	0.397	0.838
27	0.0009	30.557	0.45	0.870
28	0.0010078	31.689	0.503	0.903
29	0.0011145	32.821	0.557	0.935
30	0.00134	33.953	0.67	0.967
31	0.002	35.084	1	1
32	0.0021	28.294	1.05	0.806
33	0.0023	20.371	1.15	0.580

Stress-Strain calculations for 0.562% steel at 28 days:

The stress-strain curve and normalized stress-strain curve for 0.562% confinement was shown in figure 4&5 respectively. The peak stress is 44.98 N/mm2 and the strain at peak stress is 0.0027.The maximum strain is 0.0042 is noted at 0.5 times of the peak stress. The comparison of analytical method and experimental results of normalized stress-strain curve for the cylinders with 0.562% steel at 28 days are shown in figure 6.

Stress-Strain calculations for 0.827% steel at 28 days

The stress-strain curves and normalized stress-strain curves for 0.827 % confinement was shown in figure 8&9 respectively. The peak stress is 49.425 N/mm2 and the strain at peak stress is 0.003795.The maximum strain is 0.0053 is noted at 0.5 times of the peak stress. The comparison of analytical method and experimental results of normalized stress-strain curve for the cylinders with 0.827% steel at 28 days are shown in figure 10

Stress-Strain calculations 1.091% steel at 28 days

The stress-strain curves and normalized stress-strain curves for 1.091 % confinement was shown in figure 13&14 respectively. The peak stress is 53.294 N/mm2 and the strain at peak stress is 0.00315.The maximum strain is 0.00519 is noted at 0.5 times of the peak stress. The comparison of analytical method and experimental results of normalized stress-strain curve for the cylinders with 1.091% steel at 28 days are shown in figure 15

The figure 16 shows the comparison of experimental results for the cylinders with different percentages of confinement steel at 28 days. The figure shows the compressive strength and strain at peak stress increases with increase in percentage of confinement steel. The percentage in strength is increased 29.04, 32.26, and 35.5 respectively for 0.562, 0.827, and 1.091 percentage of confinement steel. The percentage in strain is increased at peak stress is 22.3, 23.3, 25.6 respectively for 0.562, 0.827, 1.091, percentage of confinement steel compare with 0% confinement steel

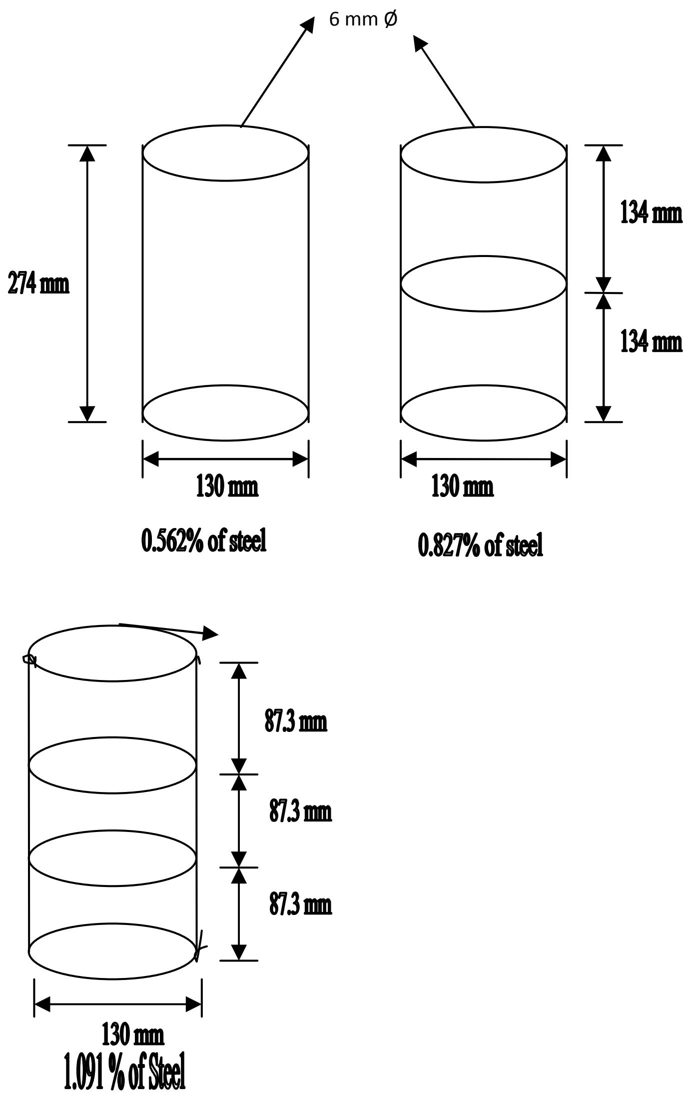

FIG 1: Different arrangements of Lateral Confindment

V. NON DIMENSIONAL STRESS STRAIN CURVES

An examination of the stress strain curve indicates that the behavior is similar for all the specimens. The similarity leads to the conclusion that there is only unique shape of the stress strain diagram, if expressed in a non dimensional form along both the axes. The said form can be obtained by dividing the stress at any level by peak stress and the strain will have the same point at the peak stress. By non-dimensionalising the stress and strain as above the behavior can be represented as a general behavior.

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The stress strain diagrams obtained were normalized for further investigation. The stress- strain curves obtained experimentally for SCC were normalized as specified above and normalized stress-strain values were calculated.

An analytical equation has been fit for the normalized stress strain diagram of fly ash concrete. The developed stress strain curves were fitted with an analytical equation using L.S Hsu and C.T.T Hsu model.

The following conditions should be considered while proposing the equations to represent the stress strain relationship.

1) The equation(s) should compare favorably with all the experimental data

2) The Ascending and Descending branches of the stress-strain curve should be implied, and the equations should represent both the ascending and descending branches of the curve

3) The mathematical form should be simple in form and easily usable in analysis

The developed equation is in the form of:

$\boldsymbol{\eta = n \beta x^a / (n \beta - 1 + x^{n\beta b})}$ $0<x<1$ (Ascending Portion)

$\boldsymbol{\eta = n \beta x^a / (n \beta + x^{n\beta b})}$ $1<x<x_d$

(Descending Portion)

Where η = normalized stress

x= normalized strain

$\eta = f_c / f'_c$

$x = \varepsilon / \varepsilon_0$

The following boundary conditions are used

1) At $(\varepsilon/\varepsilon_0) = 0.0$, $(f/f_0) = 0.0$

2) At origin $(df_c)/(d\varepsilon) = E_i$

Where f_c is concrete stress and E_{it} is Initial Tangent Modulus.

3) At the point of Maximum stress $dY/dX = 0$

$(df_c/df'_c)/(d\varepsilon/d\varepsilon_0) = 0$

Y = Normalized Stress.

x = Normalized Strain.

A, B = Constants in ascending portion.

A', B' = Constants in descending portion.

VI. MATHEMATICAL CALCULATION HSU MODEL

Various empirical stress-strain relationships for concrete have been studied and the empirical equation by L.T Hsu and C.T.T Hsu has been used which is given as

$$\eta = n \beta x / (n \beta - 1 + x^{n\beta}) \quad 0<x<x_d$$

Where η = normalized stress

x= normalized strain

$\eta = f_c / f'_c$

$x = \varepsilon / \varepsilon_0$

n, β are material parameters

Where $\beta = 1/ 1- [f_c / (Eit^*\varepsilon_0)]$

E_{it} = Initial Tangent modulus

ε_0 = Strain corresponding to peak stress.

f_c = stress

f'_c = peak stress of concrete

The value of β depends on the shape of the stress strain curve, n depends on strength of material, x_d is the strain at $0.3f_c$ in the descending portion of the stress-strain curve.

Calculation of β

For the cylinder with 0.562% of steel

$f'_c = 44.98$ N/mm^2

$E_{it} = 5700\sqrt{44.98} = 38228.26$ MPa

$\varepsilon_0 = 0.0027$

$\beta = 1/ 1- [44.98/ (38228.26*0.0027) = 1.772$

For the cylinder with 0.827% of steel

$f'_c = 49.425$ N/mm^2

$E_{it} = 5700\sqrt{49.425} = 40072.662$ MPa

$\varepsilon_0 = 0.00379$

$\beta = 1/ 1- [49.425/ (40072.662*0.00379) = 1.482$

For the cylinder with 1.091 % of steel

$f'_c = 53.294$ N/mm^2

$E_{it} = 5700\sqrt{53.294} = 41611.56$ MPa

$\varepsilon_0 = 0.00315$

$\beta = 1/ 1- [53.294/ (41611.56*0.00315)] = 1.685$

For plain cylinder i.e. cylinder with 0% of steel

$f'_c = 35.084$ N/mm^2

$E_{it} = 5700\sqrt{35.084} = 33762.096$ MPa

$\varepsilon_0 = 0.0020$

$\beta = 1/ 1- [35.084/(33762.096*0.002) = 2.081$

Table 8: Material Parameter β

% of Steel	Peak Stress (N/mm^2)	β (Material Parameter)
0	35.084	2.081
0.562	44.98	1.685
0.827	49.425	1.482
1.091	53.294	1.772

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Based on the data obtained from the stress-strain curves the following empirical equations for the stress-strain curves has been developed from the empirical equation developed by L.S Hsu and C.T.T Hsu.

For ascending portion of the curve

$\boldsymbol{\eta = n\,\beta\, x^{a} / (n\,\beta - 1 + x^{n\beta b})}$ ------ (1)

Here n =1 for ascending portion.

a, b depend on the confinement. For descending portion of the curve

$\boldsymbol{\eta = n\,\beta\, x / (n\,\beta - 1 + x^{n\beta})}$ -------- (2)

n depends on the stress strain curve.

Based on the stress strain values obtained from the experiments we have arrived at the values for a, b for cylinders with different confinements

Table 9: Values of a, b for different confinements

% of steel (p)	**0**	**0.562**	**0.827**	**1.091**
A	0.5	1.05	0.95	1.2
B	0.1	0.95	1.05	0.83

For the Descending portion the equation has been proposed but value of n depends on confinement whose values are shown in below table below.

Table 10: Values of n for different confinements

% of steel (p)	Value of n
0	3
0.562	5.5
0.827	4.5
1.091	4.7

The equations for the Ascending and Descending portion of the stress-strain curves for different confinements are

Table 11: Stress-Strain Equations

% of steel	Equation (Ascending portion)	Equation (Descending portion)
0	$\eta = 2.081\, x^{0.75} / (1.511 + x^{1.887})$	$\eta = 7.532\, x / (6.532 + x^{7.532})$
0.562	$\eta = 1.685 x^{1.05} / (1.03 + x^{1.928})$	$\eta = 11.165\, x / (10.165 + x^{11.165})$
0.827	$\eta = 1.482\, x^{0.95} / (1.027 + x^{2.128})$	$\eta = 9.121\, x / (8.121 + x^{9.121})$
1.091	$\eta = 1.772\, x^{1.2} / (0.952 + x^{1.62})$	$\eta = 9.174\, x / (8.174 + x^{9.174})$

CARREIRA AND CHU'S MODEL: The model proposed by carriera and chu is a general form of stress-strain curve as represented by the following equation:

For ascending portion of the curve

$$f_c = f'_c \{\beta(\varepsilon/\varepsilon_0)\}/\{\beta - 1 + (\varepsilon/\varepsilon_0)^{\beta}\}]$$

For descending portion of the curve

$$f_c = f'_c \{K_1\beta(\varepsilon/\varepsilon_0)\}/\{K_1\beta - 1 + (\varepsilon/\varepsilon_0)^{k_2\beta}\}]$$

Where K_1 and K_2 are correction factors

$$K_1 = (50/ f'_c)^{a}$$

$$K_2 = (50/ f'_c)^{b}$$

Where a, b are constants

Table 12: Values of a, b for different confinements

% of steel (p)	**0.562**	**0.827**	**1.091**
A	3.5	1.2	9.5
B	8.5	8	2

Table 14: Values of correction factors for different confinements

% of steel (p)	**0.562**	**0.827**	**1.091**
K_1	1.5828	1.0187	0.4327
K_2	3.0503	1.1318	0.8383

Where β is a material parameter that depends on the shape of the stress-strain diagram.
It is given by

$$\beta = 1/[1-\{ f_c' \varepsilon_0 E_{it}\}]$$

Where,

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f'_c = Ultimate compressive strength.
ε_0 = Strain at ultimate.
E_{it} = Initial Tangent Modulus

Calculation of β

For the cylinder with 0.562% of steel

$f'_c = 44.98$ N/mm^2
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$\varepsilon_0 = 0.0027$

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For the cylinder with 0.827% of steel

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$\varepsilon_0 = 0.00379$

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0.562	44.98	1.685
0.827	49.425	1.482
1.091	53.294	1.772

The equations for the Ascending and Descending portion of the stress-strain curves for different confinements are

Table 16: Stress-Strain Equations

% of steel	Equation (Ascending portion)	Equation (Descending portion)
0	$F_c = 90.92X/(1.511+X^{2.511})$	$f_c = 190.54X/(2.814+X^{7.146})$
0.562	$F_c = 89.01X/(1.03+X^{2.03})$	$f_c = 140.89X/(2.213+X^{6.192})$
0.827	$F_c = 99.79X/(1.027+X^{2.027})$	$f_c = 101.65X/(1.065+X^{2.294})$
1.091	$F_c = 106.6X/(0.952+X^{1.952})$	$f_c = 46.12X/(0.1554+X^{1.636})$

VII. COMPARISON GRAPHS OF BOTH THE MODELS

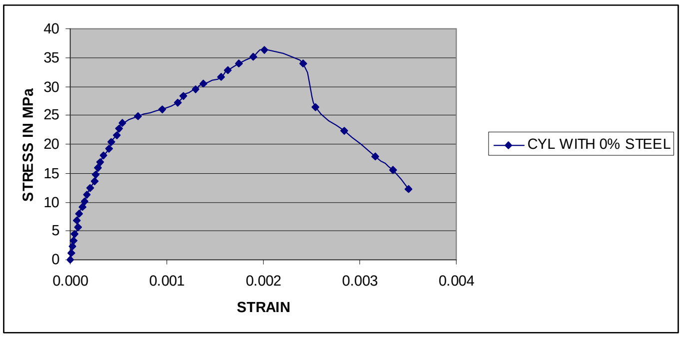

Fig 2: Stress Strain relationship of M_{45} grade concrete

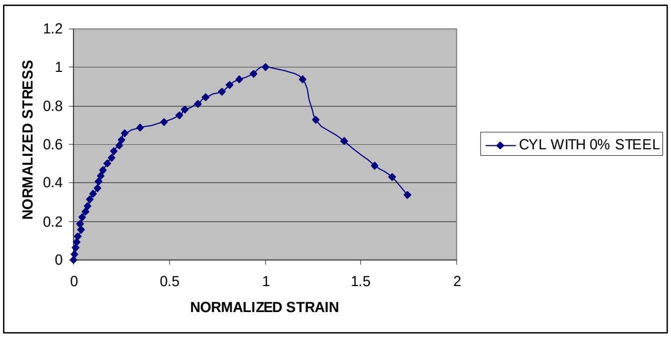

Fig 3: Normalized Stress strain relationship of M_{45} grade concrete

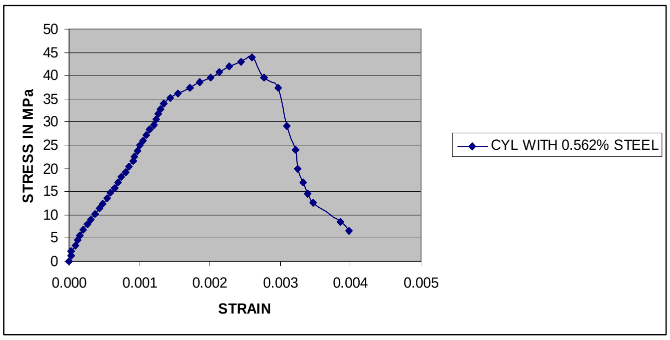

Fig 4: Stress vs. Strain Curve for cylinder with 0.562% steel at 28 days

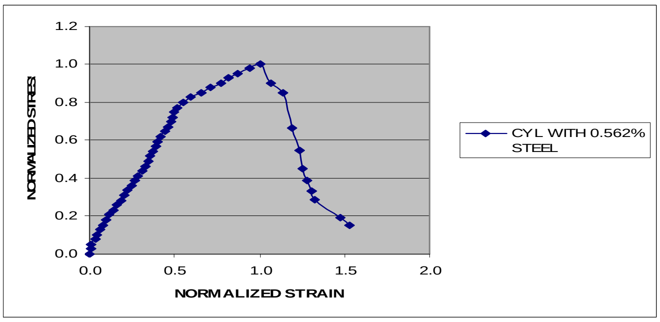

Fig 5: Normalized Stress vs. Strain Curve for cylinder with 0.562% steel at 28 days

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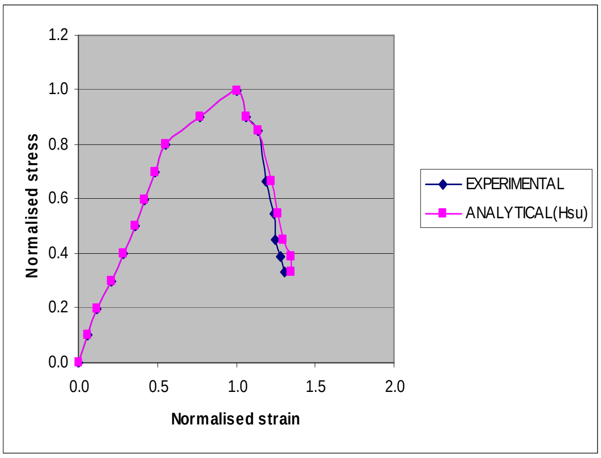

Fig 6: Comparison of analytical and experimental stress strain curves for the cylinder with 0.562% steel at 28 days

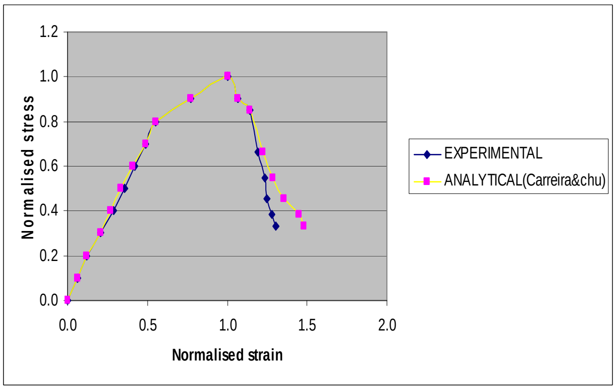

Fig 7: Comparison of analytical and experimental stress strain curves for the cylinder with 0.562% steel at 28 days

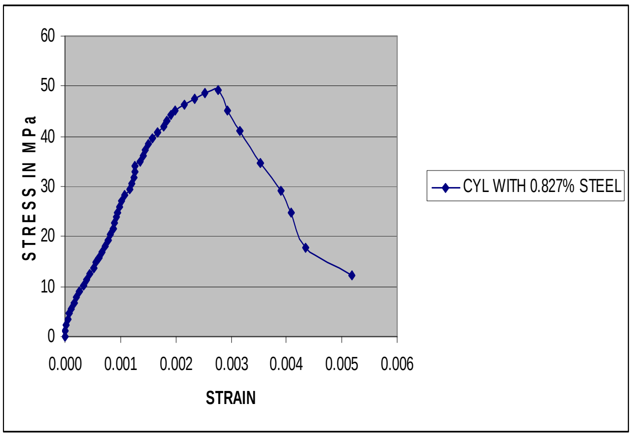

Fig 8: Stress vs. Strain Curve for cylinder with 0.827% steel at 28 days

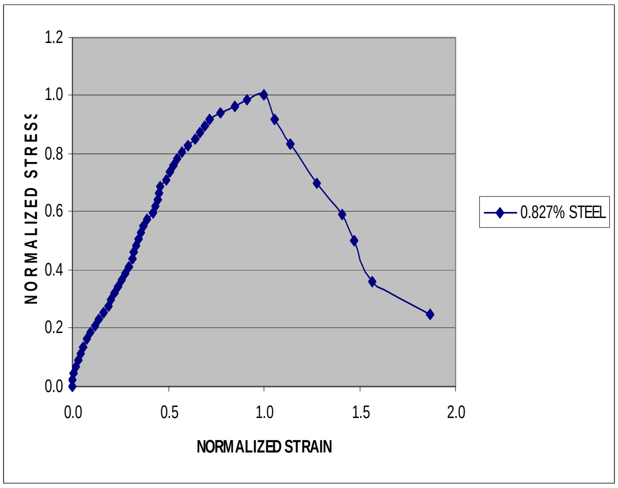

Fig 9: Normalized Stress vs. Strain Curve for cylinder with 0.827% steel at 28 days

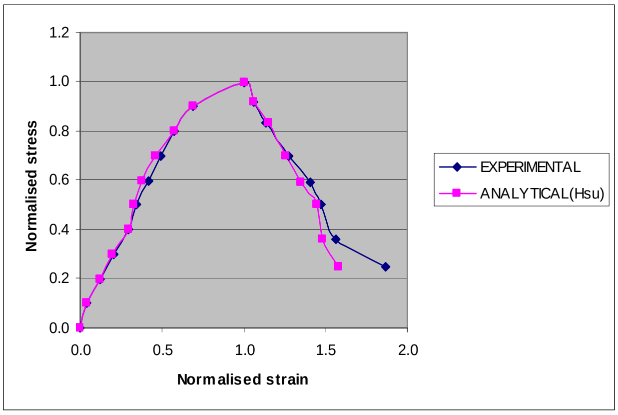

Fig 10: Comparison of analytical and experimental stress strain curves for the cylinder with 0.827% steel at 28 days

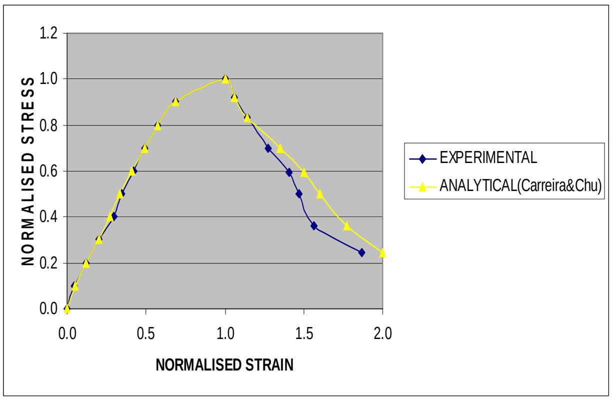

Fig 11: Comparison of analytical and experimental stress strain curves for the cylinder with 0.827% steel at 28 days

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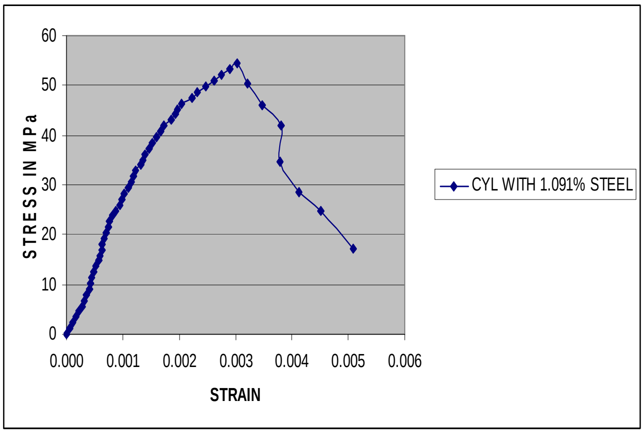

Fig 12: Stress vs. Strain Curve for cylinder with 1.091% steel at 28 days

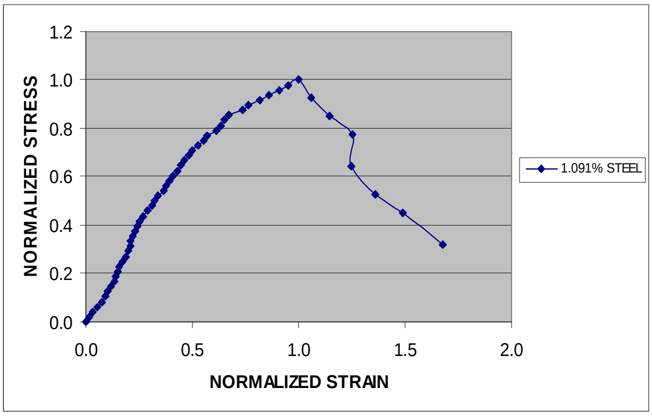

Fig 13: Normalized Stress vs. Strain Curve for cylinder with 1.091% steel at 28 days

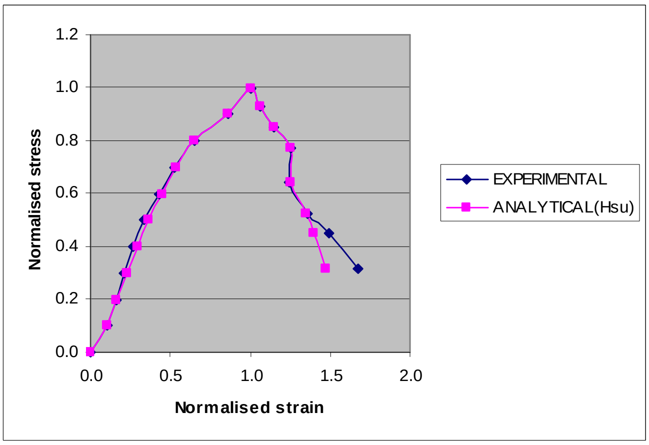

Fig 14: Comparison of analytical and experimental stress strain curves for the cylinder with 1.091% steel at 28 days

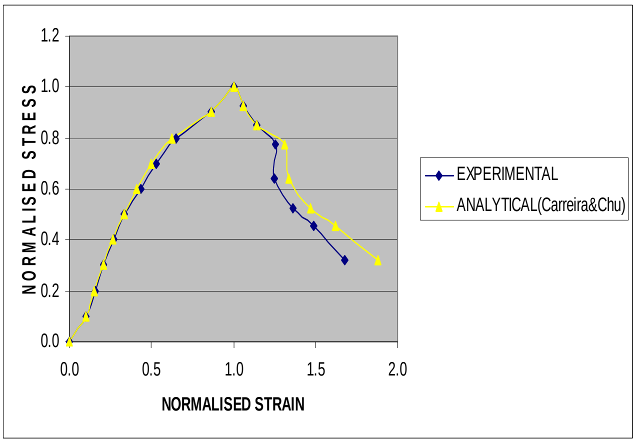

Fig 15: Comparison of analytical and experimental stress strain curves for the cylinder with 1.091% steel at 28 days

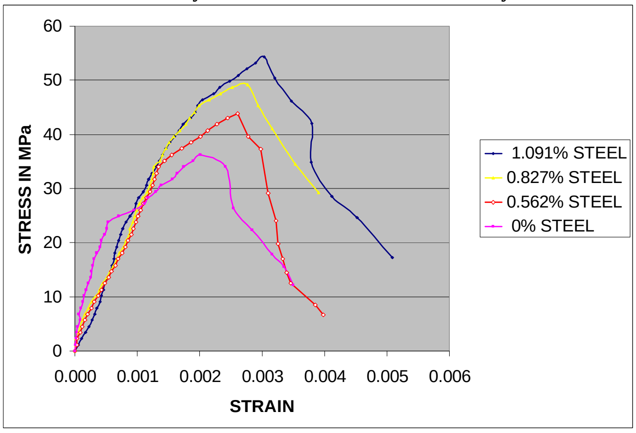

Fig 16: Comparison of Stress vs. Strain graphs of cylinders with different confinements at 28 days

CONCLUSIONS

Studies have been carried out on behavior of SCC with and without confinement under axial compression. The parameters studied include compressive strength, flexural strength test and comparison of stress-strain calculations of SCC with and without confinement. Based on the study conducted the following conclusions are drawn.

- Confinement of concrete has increased the strengths at 28 days from 21.1% to 50.78%.
- The ascending portion of the stress-strain curve is more linear and steeper as the compressive strength increase
- For the descending portion of stress-strain curve, the deviation between the analytical and experimental values become large and large as the concrete strength increases in Carriera and Chu model. So this model does not adequately represent the descending portion of the curve
- An increase in volume of transverse reinforcement directly improves both the strength and ductility of confined SCC. The increase in strength was found to be

24% at 0.827% volume of transverse steel and 42% at 1.091% volume of transverse steel for circular sections

- The ductility i.e. the ratio of the strain at peak stress of confined concrete to the strain at peak stress of corresponding unconfined concrete, varied from 21% to 51% for 0.827% to 1.091% of volumetric ratio for circular specimen.
- Circular sections with circular hoops as confinement are more effective than square sections with rectilinear confinement. The percentage increase in strength was 42% and 30% for circular sections and square sections respectively at 1.091% volume of transverse steel
- The percentage increase in ductility was 51% and 46% for circular sections and square sections respectively at 1.091% volume of transverse steel. So, to have same percentages increase in ductility square sections require more volumetric ratio of transverse steel than circular sections

REFERENCES

[1]. Hajime Okamura and Masahiro Ouchi "Self Compacting Concrete" by; Journal of advanced Concrete Technology, Vol 1, No.1, 5-15, April 2003

[2]. HSU, L.S & H.S.U. C.T.T (1994) "Stress Strain Behavior of steel fibre reinforced concrete under compression" ACI Structural Journal V91, No: 4 July-August pp 448-457

[3]. N. Bouzoubaâ M. Lachemi Self-compacting concrete incorporating high volumes of class F fly ash Cement and Concrete Research Volume 31, Issue 3, March 2001, Pages 413-420

[4]. Mohammed Sonebi Medium strength self-compacting concrete containing fly ash Cement and Concrete Research Volume 34, Issue 7, July 2004, Pages 1199-1208

[5]. Tarun. R.Naik, Rudolf K Kraus, Yoon-moon chun, Fetullah canpolat and Bruce W. Ramme Use of limestone quarry by-products for developing self-compacting concrete Presented and Published at the CANMET/ACI (SDCC-38) Three-Day International Symposium on Sustainable Development of Cement and Concrete, October 5-7, 2005, Toronto, CANADA

[6]. Rowland V Shitindi, Yuji Kato, Stress Strain behavior of concrete confined by Fibre reinforced plastics Material Science research international Vol 4, No3 pg 163-170(1998)

[7]. NRD Murthy, RamaSeshu D, Rao MVS. "Constitutive behavior of Fly ash Concretes with steel fibres in ordinary grade, IE (Institute of Engineers) Journal "–Vol, 88 (2007) 41-46.

[8]. H. Y. Leung and C. J. Burgoyne Compressive Behavior of concrete confined by aramid fibre spirals

[9]. T. Suresh Babu, M.V. Seshagiri Rao and D. Rama Seshu Mechanical properties and stress- strain behavior of Self compacting concrete with and without glass fibres Asian Journal of Civil Engineering VOL. 9, NO. 5 (2008) Pg 457-472

[10]. P J Tikalsky, P M Carrasquillo and R L Carrasquillo. "Strength and Durability Considerations affecting Mix Proportioning of Concrete Containing Fly ash". ACI Materials Journal, vol 85, 1988

[11]. A. Ravichandran, K. Suguna and P.N. Ragunath Strength Modelling of High-Strength Concrete with Hybrid Fibre (combination of steel and polyolefin fibres) Reinforcement. American Journal of Applied Sciences: 219-223, 2009 ISSN 1546-9239.

[12]. N.Ganesan "Strength and Behavior of Steel Fibre reinforced in SCC" by, January 6-8, 2005, SERC, Chennai.

[13]. S.Girish, B.S.Putte Gowda, Jagadish Vengala and R.V. Ranganth. "Influence of different Super Plasticizers on the properties of SCC

[14]. L. Lam and J.G. Teng Stress–strain model for FRP-confined concrete under cyclic axial compression Engineering Structures Volume 31, Issue 2, February 2009, Pages 308-321

[15]. Subramanian.S and Chattopadyay.D 'Experiments for Mix Proportions of Self Compacting Concrete', The Indian Concrete Journal, January 2002, pp.13-20

[16]. IS 12269-1987(Reaffirmed 1999), Specification for 53 Grade Ordinary Portland cement, 1st reprint, September 1993.

[17]. IS 2386-1963, Method of Tests for Aggregates for Cement.

[18]. IS 456-2000, Indian Standard Plain and Reinforced Concrete-Code of Practice, 4th revision, 1st Reprint, September 2000

[19]. "Self Compacting Concrete", the Indian Concrete Journal, Vol.78, No.6 June 2002.