A COMPARATIVE STUDY ON THE STRESS-STRAIN BEHAVIOUR OF STANDARD GRADE HFRSCC UNDER CONFINED AND UNCONFINED STATES

M Chandrasekhar[1], M V Seshagiri Rao[2], Maganti Janardhana[3]

[1]Research Scholar, Department of Civil Engineering, JNTUH, Hyderabad, India.
[2]Professor, Department of Civil Engineering, JNTUH, Hyderabad, India.
[3]Associate Professor, Department of Civil Engineering, JNTUH, Hyderabad, India.

ABSTRACT

Self compacting concrete (SCC), developed by Hajime Okamura, has proved to be an excellent concrete in terms of its compactability, flowability and durability apart from strength studies have proved that the effiencency of the SCC can be further increased by introduction of fibres like steel fibres, glass fibres etc. further enhances their toughness, tensile strength, resistance to crack propagation there by further enhancing the durability properties. The present paper deals with the behaviour of standard grade hybrid fibre reinforced self compacting concrete which is made with a combination of steel and glass fibres in suitable proportion. .It is observed that the confinement of the concrete has increased the 28 days strength from 12.39% to 28.2% for different percentages of confinements and It peak stress and corresponding strain at peak stress increases with increase in percentage confinements. An empirical equation is proposed between E and $f_{ck,}$ in the form of $E= 5700\sqrt{f_{ck.}}$ Out of the two analytical models were proposed for the stress-strain behaviour of HFRSCC under different confinements it is observed that the model based on Seanz equation is closely agreeing with experimental results.

KEYWORDS

Hybrid Fibre Reinforced Self Compacting Concrete (HFRSCC), Confinement, Fibre Index, Toughness, Ductility Factor (DF).

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 behaviour of Hybrid Fibre Reinforced Self Compacting Concrete (HFRSCC) of standard grade i.e., M30. The properties of strength, stress-strain behaviour, toughness index, energy absorption were studied and analytical models were developed for the stress-strain behaviour of plain SCC and HFRSCC of M30 grade based on the experimental investigation.

II. EXPERIMENTAL PROGRAMME

The first phase of experimental programme M30 grade SCC and HFRSCC were developed to satisfy EFNARC guidelines. The specimens were cast with and without confinements in the form of hoops 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 confirming to IS: 12269 was used in the investigations. River sand confirming to Zone-II and coarse aggregate 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 and viscosity modifying agents with poly carboxylic ether base were used in developing the SCC. Anti-crack high dispersion glass fibres with aspect ratio of 857 with a filament length of 12mm and steel fibres of 12mm length and with a aspect ratio of 30 were used in developing HFRSCC. 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.

Table 1: Details of M30 grade concrete mix

Grade of concrete	Cement kg/m^3	Fine Aggregate kg/m^3	Coarse Aggregate kg/m^3	Fly Ash kg/m^3	Glass Fibre kg/m^3	Water kg/m^3	SP lt/m^3	VMA lt/m^3
M30	330	860.6	794.4	150	0.63	186	6.75	0.33

Table 2: Fresh properties of HFRSCC

Designation	Slump Flow (mm)	T_{50} Slump Flow (s)	V Funnel (s)	V Funnel at 5 Min. (s)	L Box H_2/H_1
SCC	665	2.68	3.93	8.31	0.947
HFRSCC	655	4.69	6.85	10.68	0.89

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 behaviour 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 M30 grade concrete without fibres and with hybrid fibres under different confinements. HFRSCC was made with a fibre dosage of 0.63 kg/m^3 glass fibres and 31.42 kg/m^3 steel fibres. The fibre index obtained for HFRSCC 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)	Cylinder compressive strength (MPa)
1	$HFRSCC_p$	-	-	37.51	31.68
2	$HFRSCC_{3R}$	0.798	3 hoops	-	36.16
3	$HFRSCC_{4R}$	1.062	4 hoops	-	38.48
4	$HFRSCC_{5R}$	1.327	5 hoops	-	39.62
5	$HFRSCC_{6R}$	1.591	6 hoops	-	44.12

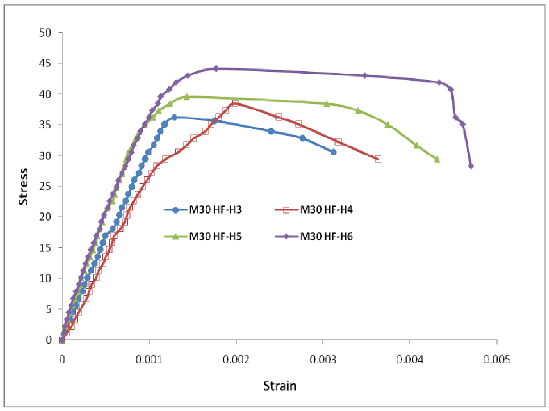

Fig 1: Stress-strain behavior of HFRSCC with and without confinement

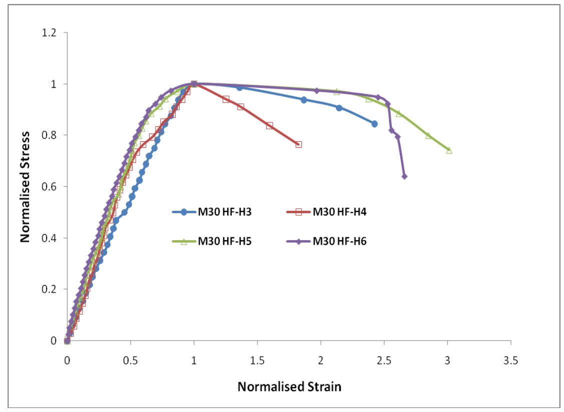

Fig 2: Normalized Stress-strain behavior of HFRSCC with and without confinement

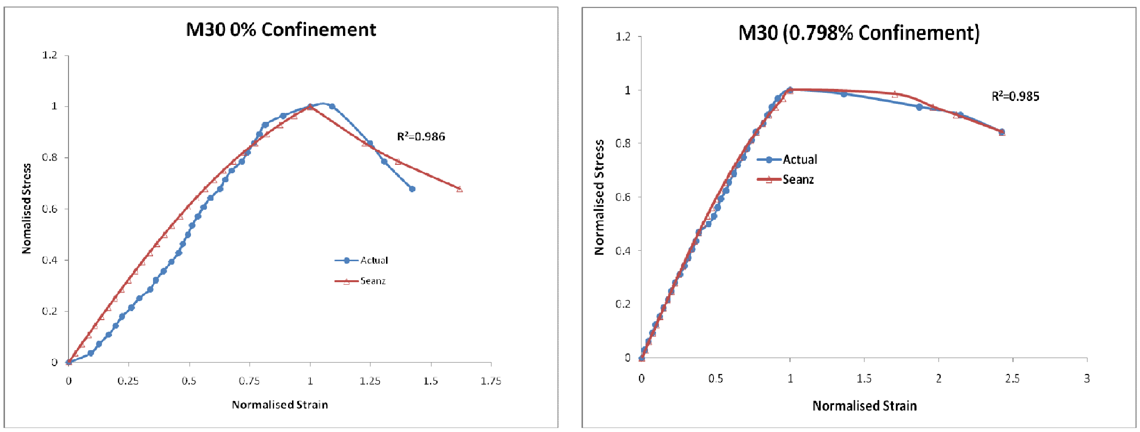

Fig 4(a). Comparisson of actual stress-strain curves and Seanz model stress-strain curves

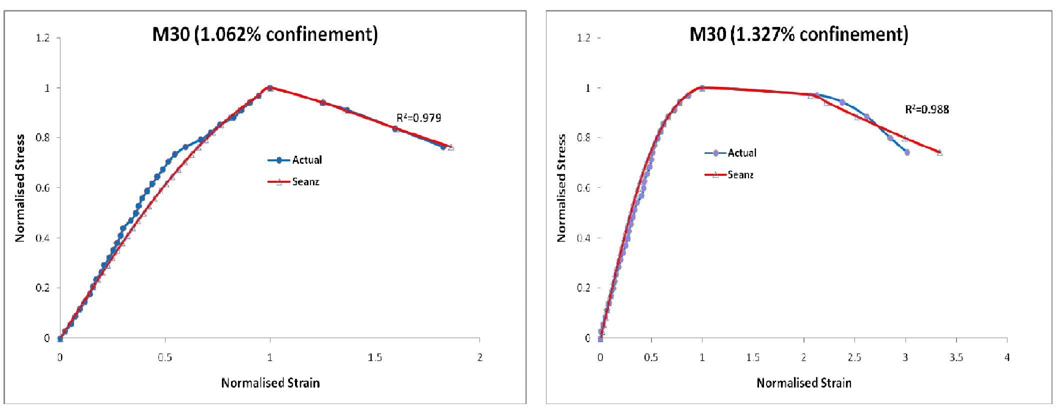

Fig 4(b). Comparisson of actual stress-strain curves and model Seanz stress-strain curves

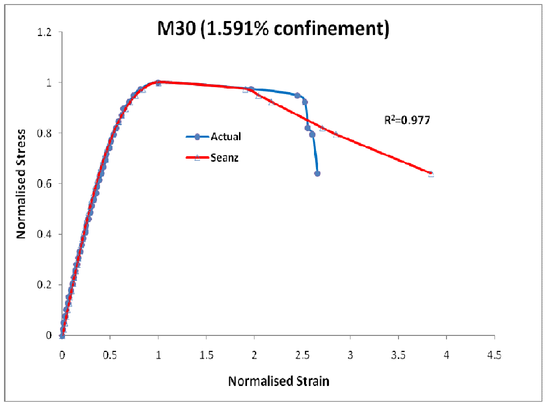

Fig 4(c). Comparisson of actual stress-strain curves and Seanz model stress-strain curves

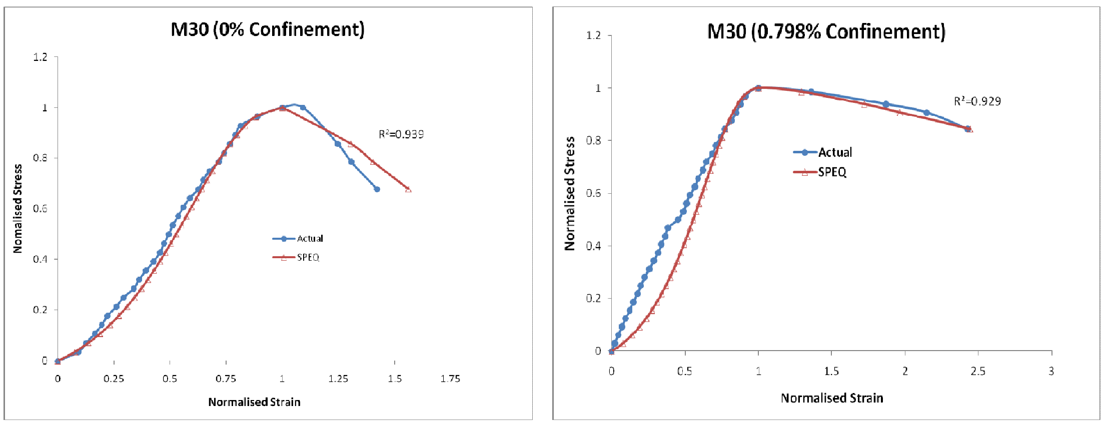

Fig 5(a). Comparisson of actual stress-strain curves and SPEQ model stress-strain curves

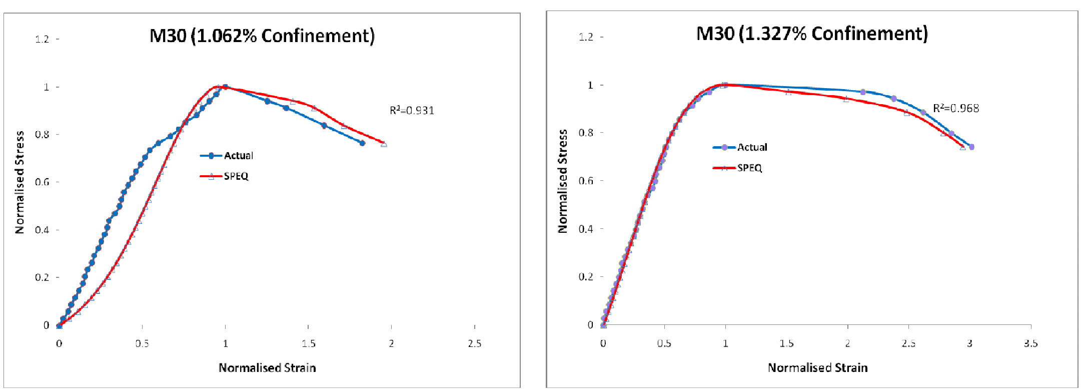

Fig 5(b). Comparisson of actual stress-strain curves and SPEQ model stress-strain curves

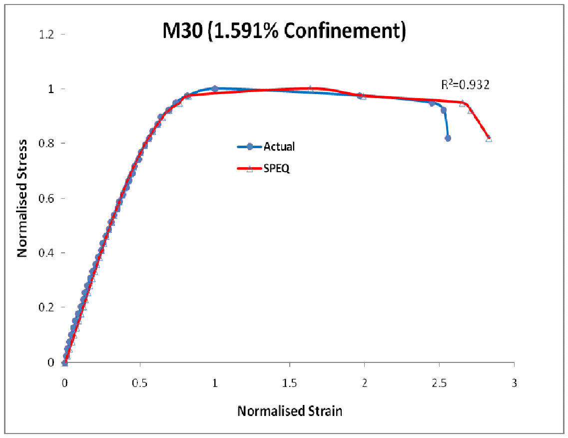

Fig 5(c). Comparisson of actual stress-strain curves and SPEQ model stress-strain curves

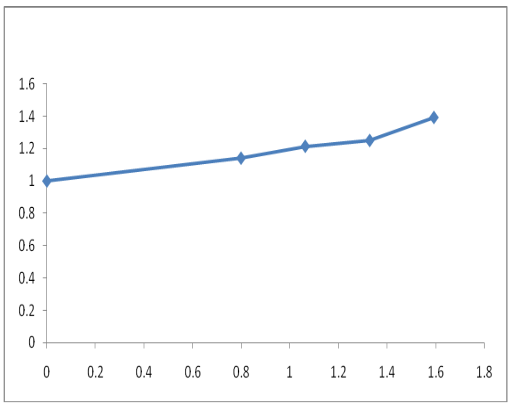

Fig 6: variation of stress ratio with % confinement

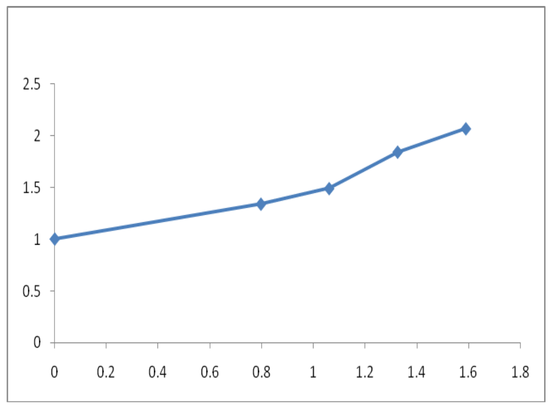

Fig 7: variation of strain ratio with % confinement

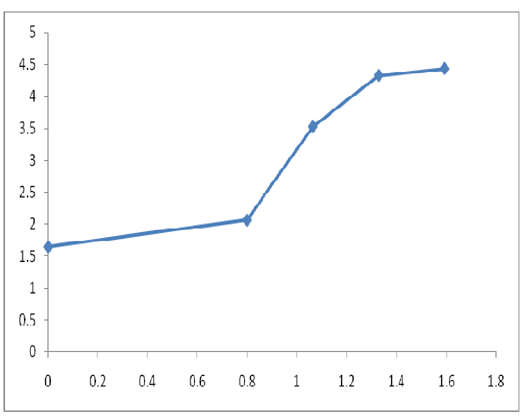

Fig 8 . Relation between %confinement and %increase in ductility

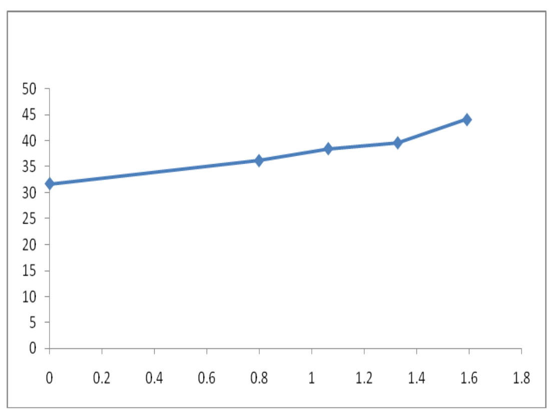

Fig 9.Relation between %confinement and %improvement of compressive strength

From the stress-strain curves shown in Fig 1 - 5, the values of ultimate strength (f_u), strain at ultimate strength (ε_u) ,strain at 85% of ascending ($\varepsilon_{0.85u}$ Asc) and descending portion ($\varepsilon_{0.85u}$ Dsc) were obtained.

The values of stress ratio (f_u / f'), strain ratio (ε_u /ε') and ductility factors were obtained for different confinements which are shown in Table 4.

Table 4: stress ratio (f_u / f'), strain ratio (ε_u /ε') and ductility factors were obtained for different confinements

Sl. No	Designation	Fibre Index	Confinement	Peak stress N/mm^2 fu	f_u/f'	Strain at peak stress	$\varepsilon_u/\varepsilon'$	$\varepsilon_{0.85u}$ Asc x 10^{-6}	$\varepsilon_{0.85u}$ Dsc x 10^{-6}	Ductility Factor
1	$HFRSCC_p$	0.124	0	31.6768	1	0.00096	1	734	1206	1.64305
2	$HFRSCC_{(3R)}$	0.124	0.798	36.16	1.14153	0.001285	1.338542	875	3088	2.06329
3	$HFRSCC_{(4R)}$	0.124	1.062	38.48	1.21477	0.00143	1.489583	1501	3097	3.52914
4	$HFRSCC_{(5R)}$	0.124	1.327	39.62	1.25076	0.00177	1.84375	874	3878	4.33173
5	$HFRSCC_{(6R)}$	0.124	1.591	44.12	1.39282	0.001988	2.070313	1040	4505	4.43707

From Table 4, it can be observed that, for a given fibre index, the ductility factor increases with the increase in the confinement level. However, beyond 1.327 percent of confinement (5 stirrups), the increase in ductility factor is marginal. The percent increase in compressive strength beyond one percent confinement is observed to be more.

Relation betweeen percentage confinement, stress ratio, strain ratio and ductility factor:

Based on the experimental data and Fig 1-5 ,the relationship obtained between percentage confinement versus stress ratio and percentage of confinement(c) versus strain ratio for HFRSCC are as follows:

$$f_u= f'(0.088c^2+0.094c+1.002)$$
$$\varepsilon_u= \varepsilon'(0.343\,c^2+0.139c+0.998)$$

The plots for the above are shown in Fig.6 and Fig.7. From the above data, an empirical equation relating the ductility factor and percentage of confinement (c) is obtained which is as follows.

$$DF= 1.950c+1.336$$

The plot for the improvement in ductility with percentage of confinement is shown in Fig.9

Stress-Strain behaviour: From the Fig.2, it can be observed that the behaviour is almost similar for plain SCC and HFRSCC for the given grade of concrete. However it is observed that stress and corresponding strain increases with the introduction of fibres. Further it is also observed that the increase in stresses and strains are more in HFRSCC. It is observed that the non-dimensional stress-strain behaviour in the post peak region up to 85% of ultimate stress level is almost similar. Fig.2 shows the normalised stress-strain behaviour for different mixes.

Model based on Seanz equation:

A single equation proposed based on Seanz model is proposed to explain the stress-strain behaviour as shown below

$$f/f_u = \frac{A(\varepsilon/\varepsilon_u)}{1+B\,(\varepsilon/\varepsilon_u)^2} \qquad \text{------------------- (1)}$$

The boundary conditions are considered taking into account the ratios of stresses, strains, ultimate stresses and strains at ultimate stresses. The boundry conditions used are as follows.

1) At $\varepsilon/\varepsilon_u$ =1; f / f_u =1 ------------------- (2)
2) At $\varepsilon/\varepsilon_u$ =1; d (f / f_u)/d ($\varepsilon/\varepsilon_u$) =1

By satisfying the boundary conditions, constants for ascending and descending portions are obtained. Based on the above conditions, the constants for ascending and descending portions of the curve are as follows:

For HFRSCCp:

A=1.331 and B=0.331 for ascending portion and A=6.91 and B=5.91 for descending portion.

For $HFRSCC_{3R}$:

A=1.2732 and B=0.2732 for ascending portion and A=1.620 and B=0.620 for descending portion.

For $HFRSCC_{4R}$:

A=1.33 and B=0.33 for ascending portion and A=2.39 and B=1.392 for descending portion.
For $HFRSCC_{5R:}$
A=1.8128 and B=0.8128 for ascending portion and A=1.526 and B=0.526 for descending portion.
For $HFRSCC_{6R:}$
A=1.8854 and B=0.8854 for ascending portion and A=1.571 and B=0.571 for descending portion
The stress-strain diagram obtained from the above equation and experimental data is given by Fig 4. The regression coefficients obtained for HFRSCCp, $HFRSCC_{3R}$, $HFRSCC_{4R}$, $HFRSCC_{5R}$, $HFRSCC_{6R}$ are 0.986, 0.985, 0.978, 0.988, and 0.977 respectively.

Model based on single polynomial empirical equation:
The model is taken in the form of

$$f = \frac{(A\varepsilon+D)}{(1+B\varepsilon+C\varepsilon^2)} \qquad \text{----------- (3)}$$

where f is the stress and ε is the strain at different levels. The non dimensional stress strain equation is given in the form

$$f/f_u = \frac{A_1(\varepsilon/\varepsilon_u) + D_1}{1+B_1(\varepsilon/\varepsilon_u) + C_1(\varepsilon/\varepsilon_u)^2} \qquad \text{---------- (4)}$$

The boundary conditions for ascending and descending portion of the stress – strain curve are
At $\varepsilon/\varepsilon_u=0$; $f / f_u=0$; At $\varepsilon/\varepsilon_u=1$; $f / f_u=1$; At $\varepsilon/\varepsilon_u=1$; $d(f / f_u)/d(\varepsilon/\varepsilon_u)=1$
Additional boundary conditions used for ascending portion are as follows:
For HFRSCCp: at $\varepsilon/\varepsilon_u=0.85$; $f / f_u=0.7610$; For $HFRSCC_{3R}$= at $\varepsilon/\varepsilon_u=0.85$; $f / f_u=0.7778$; For $HFRSCC_{4R}$= at $\varepsilon/\varepsilon_u=0.85$; $f / f_u=0.7556$; For $HFRSCC_{5R}$= at $\varepsilon/\varepsilon_u=0.85$; $f / f_u=0.61147$; For $HFRSCC_{6R}$= at $\varepsilon/\varepsilon_u=0.85$; $f / f_u=0.5896$.
Additional boundary conditions used for descending portion of stress-strain curve are
For HFRSCCp: at $\varepsilon/\varepsilon_u=0.85$; $f / f_u=1.239$; For $HFRSCC_{3R}$= at $\varepsilon/\varepsilon_u=0.85$; $f / f_u=2.4023$; For $HFRSCC_{4R}$= at $\varepsilon/\varepsilon_u=0.85$; $f / f_u=1.56$; For $HFRSCC_{5R}$= at $\varepsilon/\varepsilon_u=0.85$; $f / f_u=2.7127$; For $HFRSCC_{6R}$= at $\varepsilon/\varepsilon_u=0.85$; $f / f_u=2.55$.

Based on the above conditions, the constants for ascending and descending portions of the curve are as follows:
For HFRSCCp:
A=0.425; B=-1.5747; C=1; D=0 for ascending portion and A=0.26; B=-1.7418; C=1; D=0 for descending portion.
For $HFRSCC_{3R}$:
A=0.359 and B=-1.641 for ascending portion and A=4.65 and B=2.65 for descending portion.
For $HFRSCC_{4R}$:
A=0.45 and B=-1.552 for ascending portion and A=1.146 and B=-.854 for descending portion.
For $HFRSCC_{5R:}$
A=1.4 and B=-0.6006 for ascending portion and A=6.13 and B=4.13 for descending portion.
For $HFRSCC_{6R:}$
A=1.6189 and B=-0.381 for ascending portion and A=5.346 and B=3.346 for descending portion.
The stress-strain diagram obtained from the above equation and experimental data is given by Fig 6. The regression coefficients obtained for HFRSCCp, $HFRSCC_{3R}$, $HFRSCC_{4R}$, $HFRSCC_{5R}$, $HFRSCC_{6R}$ are 0.939, 0.929, 0.931, 0.968, and 0.932 respectively.

IV. CONCLUSIONS

Based on the experimental studies on the Hybrid Fibre Reinforced Self Compacting Concrete under axial compression under unconfined and confined states in the form of hoops; the following conclusions are arrived.
Hybrid Fibre Reinforced Self Compacting Concrete of M30 grade satisfying EFNARC guidelines can be developed using a select mixture of glass and steel fibres with improved performance. There is an improvement in the peak stress and strain at 85% of ultimate strength in the descending portion for HFRSCC. The confinement of the concrete has increased the 28 days strength from 12.39% to 28.2% for different percentages of confinements. There is an increase in the value of secant modulus (E) for

M30 grade HFRSCC with confinement. An empirical equation is proposed between E and $f_{ck,}$ which is as follows:

$$E = 5700\sqrt{f_{ck}} \text{ (where E and } f_{ck} \text{ are in MPa)}$$

It is observed that peak stress and corresponding strain at peak stress increases with increase in percentage of confinements. Two analytical models were proposed for the stress-strain behaviour of HFRSCC under different confinements. It is observed that in the ascending portion, single equation can be used for different confinements. However, as the variation is considerable for descending portion of the curve, different constants are proposed for different confinements. It is also observed that the model based on Seanz equation is closely agreeing with experimental results.

REFERENCES

[1]. Hemant Sood, Khitoliya. R.K. and Pathak."Incorporating European Standards for testing Self Compacting Concrete in Indian conditions". International Journal of Recent Trends in Engineering, Vol.1, No.6, May 2009.pp:41-45
[2]. Kayat.K.H."Workability, testing and performances of Self-Compacting Concrete". ACI Materials Journal, May-June 1999, pp.346-353.
[3]. Bouzoubaa, N., and Lachemi, M., (2001). "Self-compacting concrete incorporating high volumes of class F fly ash: preliminary results", Cement and Concrete Research, Vol. 31, pp 413-420.
[4]. Corinaldesi, V., and Moriconi, G., (2004). "Durable fiber reinforced self-compacting concrete", Cement and Concrete Research, Vol. 34, pp.249-254.
[5]. EFNARC, "Specifications and Guidelines for Self-Compacting Concrete", EFNARC, UK (www.efnarc.org), February 2002, pp. 1-32.
[6]. Leemann, A., and Hoffmann, C., (2005). "Properties of self compacting and conventional concrete-differences and similarities". Magazine of Concrete Research, Vol. 57, No. 6, August , pp. 315-319.
[7]. Okamura, H. and Ozawa, K., (1995). "Mix design for self-compacting concrete", Concrete Library of JSCE, 25, pp. 107-120.
[8]. Su N., Hsu K C., and Chai H W., (2001). "A simple mix design method for self- compacting concrete", Cement and Concrete Research, Vol. 31, pp. 1799-1807.
[9]. Avram, C., I. Facaoaru, O. Mirsu, I. Filimon, and I. Tertea, "Concrete Strength and Strains", Elsevier Scientific Publishing Company, pp.105-133, 249-251 (1981).
[10]. Dehn, F., K. Holschemacher, and D. Weisse, "Self-Compacting Concrete - Time Development of the Material Properties and the Bond Behavior", LACER No. 5, pp.115-123 (2000).
[11]. Gebler, S.H. and P. Klieger, "Effect of Fly Ash on Some of the Physical Properties of Concrete", Portland Cement Association, R & D Bulletin 089.01T (1986).
[12]. Srinivasa Rao.P, SeshadriSekhar.J."Strength properties of Glass Fiber SCC". Indian Concrete Journal, Vol.88, February 2008 pp: 61-65.
[13]. Suresh Babu.T, Seshagiri Rao.M.V and Rama Seshu.D."Mechanical properties and Stress-Strain Behaviour of Self Compacting Concrete with and without Glass Fibres", Asian Journal of Civil engineering (Building and Housing) Vol.9, No.5 (2008), pp: 457-472
[14]. www.efnarc.org European Specifications and guidelines for Production & Use of SCC, February and May 2005.
[15]. EFNARC guidelines for Viscosity Modifying Agents.
[16]. Hayakawa,.Matsuaka.M.J,and Shindoh,T."Development and application of Super workable concrete". RELIM International workshop on Special Concretes: Workability and mixing, Paisley, 1993.
[17]. Kazim Turk, Sinan Caliskan and Salih Yazicioglu. "Capillary water absorption of Self Compacting Concrete under different Curing conditions" Indian Journal of Engineering & Material Sciences, Vol.14, October 2007.pp: 365-372.
[18]. Brameshuber, W. and Uebachs, S., (2002). "Self-Compacting Concrete – Application in Germany", 6th International Symposium on High Strength/High Performance Concrete, Leipzig, June, pp. 1503-1514.
[19]. Kumar P., Haq M. Ajazul and Kaushik, S.K. (2004). Early age strength of SCC with large volumes of fly ash, Indian Concrete Journal, Vol. 78, No. 6, p 25-29.
[20]. Leemann, A., and Hoffmann, C., (2005). "Properties of self compacting and conventional concrete-differences and similarities". Magazine of Concrete Research, Vol. 57, No. 6, August , pp. 315-319.
[21]. Munn, C., (2003). "Self Compacting Concrete (SCC): Admixtures, Mix Design Consideration and Testing of Concrete" A Technical Paper Presented in the Meeting of the ACI, Saudi Arabia Chapter, Eastern Province, October.
[22]. Nagamoto, N., and Ozawa, K., (1997). "Mixture proportions of self-compacting high performance concrete", ACI International, SP-172, pp. 623-636.

[23]. Okamura, H. and Ouchi, M., (1999). "Self-compacting concrete-development, present and future", Proceedings of the First International RILEM symposium on Self-Compacting Concrete, pp. 3-14.
[24]. Okamura, H. and Ouchi, M., (2003). "Self-compacting concrete", Journal of Advanced Concrete Technology, Vol. 1, No. 1, April, pp. 5-15.
[25]. Su N., Hsu K C., and Chai H W., (2001). "A simple mix design method for self-compacting concrete", Cement and Concrete Research, Vol. 31, pp. 1799-1807.
[26]. Bartos, J. M., "Measurement of Key Properties of Fresh Self-compacting Concrete", CEN/PNR Workshop, Paris (2000).
[27]. Dehn, F., K. Holschemacher, and D. Weisse, "Self-Compacting Concrete - Time Development of the Material Properties and the Bond Behavior", LACER No. 5, pp.115-123 (2000).
[28]. Dodson, V., "Concrete Admixtures", VNR Structural Engineering Series (1990).
[29]. Duval, R. and E. H. Kadri, "Influence of Silica Fume on the Workability and the Compressive Strength of High-Performance Concretes", Cement and Concrete Research Journal, Vol. 28, Issue 4, pp.533-547 (1998).
[30]. Khayat, K.H. and Z. Guizani, "Use of Viscosity-Modifying Admixture to Enhance Stability of Fluid Concrete", ACI Materials Journal, pp.332-340 (1997).

Authors Biographies

M Chandrasekhar, a Consulting Engineer, is a post graduate is Industrial Structures from NIT Suratkal. He is having 33 years of professional Experience and involved in number of important design and construction works of structures and National Highways. At present he is pursuing Ph.D in JNT University, Hyderabad.

Dr. M. V. Seshagiri Rao, Presently professor of Civil Engineering, JNTUH College of Engineering, Hyderabad having 33 years of Research, Teaching, Construction and consultancy experience. He has guided 15 Ph.D projects, 110 M.Tech projects and published more than 100 research papers, mostly on special concretes. He held various administrative posts in JNTU like Head of civil Engineering department, Vice principal, Director of industrial consultancy services, Chief Engineer etc..He was awarded three best paper awards, one out standing concrete technologist award and one state teacher award. He has published two books. His interests are special concretes, NDT and rehabilitation of structures

Dr. M. Janardhana, Associate Professor in Civil Engineering obtained his Ph.D from IIT Chennai; Madras. He has 15 years of Teaching, Research and Consultancy experience. He has published 15 research papers and 15 M.Tech projects. He has co authored a book on basic structural analysis. At present he is guiding one Ph.D scholar. He was awarded with Brij Mohan Lal Best Paper award for his paper on special concretes. His interests are special concretes, NDT and rehabilitation of structures and Earth quake Engineering.