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Allowable Span/Depth Ratio of SFRSCC Beams using SVM

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Abstract

Many codes of practices specify basic span to effective depth ratio to control the deflections in case of traditionally vibrated concrete (TVC) beams. These values are modified for tensile steel ratio, compression steel ratio, steel grade and breadth of web of the flange. A similar specification has not been come across for fibre reinforced TVC/SCC beams.A method is proposed in this work for steel fibre reinforced SCC beams using SVM (Support Vector Machine) Technique. The proposed formula includes modular ratio, aspect ratio, tensile steel ratio and volume fraction. The computed deflections were compared with test data. A satisfactory agreement was noted. Further, a simplified effective moment of inertia function is suggested using SVM technique. Design charts were developed for easy application. A comparison has been done between the effective depths obtained from SVM, rupture limit state and serviceability limit state

Keywords: SVM, TVC, Design charts, fibre reinforced

Introduction

The congestion of steel reinforcement in case of heavily reinforced structure is over come by self compacting concrete (SCC) in Japan in 1980's. The adavantages include the elimination of compaction work results in reduction of cost of placement, reduction in construction time and which in turn improves the productivity. Higher toughness bridging ability, long term durability helps in improving the technical benefit of SCC. The flow properties of fresh concrete can be altered by the use of steel and synthetic fibers.

In recent development fibres have been made to include in plain SCC but those studies are limited to small scale specimens such as cubes prisms etc. further the research is going on large scale industries that is if it is applied on large scale structures how it behave. Therefore the idea of utilizing the fiber reinforced cementetious composites in structural elements has been included from past decades.

1.1 Support Vector Machine Technique (SVM)

SVM is one of the machine learning techniques (MLT). It is derived from statistical learning theory in 1964 by Vapnik and Chervonenkis. The foundations of SVM have been developed by Vapnik (1995) at AT&T Bell Laboratories.

Using the SVM technique and the parameters, an equation has been developed for mid-span deflection. The SVM has a good ability to generalize and resolve some practical problems such as small samples, nonlinearity and high-dimensional input space. SVM calculation takes the form of a problem in convex quadratic optimization ensuring that the solution is optimal.

Weka software is based on SVM technique. It processes a collection of machine learning algorithms for data mining and machine learning tasks, feature selection, classification, regression, clustering, association rules and visualization. Using this software an equation for the mid-span deflection of a simply supported singly reinforced concrete beam under two-point loading is developed considering the following parameters of beam: length, breadth, depth, compressive strength of concrete(fck), load(w) , area of steel(Ast), characteristic strength of steel, aspect ratio (α) and steel ratio (ρ).

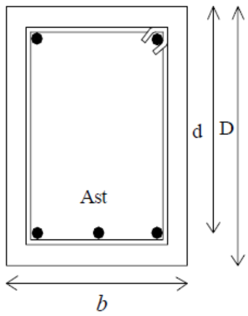
Literature Review

Balaguru et.al [1] designed an experimental program to study the influence of fibre type, volume fraction, and fibre length and matrix composition. Ziad Bayasi and Jack Zeng [2] carried an experimental investigation on fresh and hardened material of fibrillated polypropylene fibre reinforced concrete varying fibre lengths between ½ and ¾ and volume fractions were 0.1, 0.3 and 0.5 percent. Faisal F.Wafa and Samir A.Ashour [3] pointed out that the mechanical properties of high strength concrete with and without fibres are different with respect to normal strength concrete. Hugo S.Armelin and Paulo Helene [4] stated that there is no difference b/w Steel Fibre Reinforced dry mix shotcrete and plain dry mix shotcrete. Barzin Mobasher and Cheng Yu Li [5] stated that toughening and strengthening in FRC composites can be achieved by using of experimental R-curve graph to characterize the fracture process. Victor C.Li et.al [6] demonstrated that by improving the tensile property through fibre reinforcement, shear capacity can be improved and the ultimate shear strength can be improved to 180 percent with a volume fraction of two percent of short fibres.

Method of Analysis using SVM Technique

Deflection can be calculated using elastic deflection formula and the computed deflection at service load can be checked against the permissible deflection. Many code of practice specify the limiting deflection as a fraction of effective span. That is IS456-2000 specify the limiting total deflection of $(\frac{\mathbf{l}}{\mathbf{250}})$th of the span.

In the present work, a limiting span to effective depth ratios expression is derived based on the limiting total deflection criteria Fig.1shows the sectional details of a singly reinforced beam.



(a) Singly Reinforced Beam

Fig 1: Sectional details of rectangular beams

Modulus of elasticity of concrete is given by

$$E_c = 4733\sqrt{0.8f_{ck}} \quad (1)$$

We have Ieff,

$$I_{eff} = k_1 bd^3 \quad (2)$$

And k1 is calculated using SVM concept as

$$k_1 = 0.11(\frac{E_s}{E_c} v_f \rho^2 (\alpha)^{0.5}) + 0.0797 \quad (3)$$

The central deflection under two point loading is given by

$$\delta = \frac{23wl^3}{648E_cI_e} \quad (4)$$

Where,

E_c = modulus of elasticity of concrete

v_f = fibre volume fraction

E_S = modulus of elasticity of Steel

α = aspect ratio of fibres

F_{ck} = compressive strength of concrete N/mm^2

ρ= Steel Ratio

Serviceability Deflection

Serviceability shall be evaluated for a total number of twenty four beam data where consider for proposing an analytical method for predicting short term deflection of steel fibre reinforced self compacting concrete (SFRSCC) beams.

4.1 Load Deflection Curves

Cracking load 'Pcr ' is given by

$$P_{cr} = f_r \frac{bD^2}{l} \quad (5)$$

Deflection at cracking load given by, 'δcr'

$$\delta_{cr} = \frac{23(P_{cr})l^3}{648E_cI_g} \quad (6)$$

Working load' Pw '

$$P_w = \frac{P_u}{1.5} \quad (7)$$

Deflection at working load given by

$$\delta_w = \frac{23(P_w)l^3}{648E_cI_{effsvm}} \quad (8)$$

Table 1 : Ratio of computed to expérimentale déflections

Investigator	specimen no.	deflection experimental (mm)	Deflection Svm (mm)	Ratio of svm/exp	Calculated svm/0.495 (mm)	Ratio of cal/exp
Vijay Anand	SCC1	5.50	1.48	0.27	2.99	0.54
[7]	SCC2	5.80	2.51	0.43	5.07	0.87
	SCC3	6.70	3.41	0.51	6.87	1.02
	SFRSCC4	5.00	1.66	0.33	3.35	0.67
	SFRSCC5	5.30	2.59	0.49	5.24	0.99
	SFRSCC6	6.30	3.56	0.57	7.20	1.14

	SFRSCC7	4.00	1.54	0.39	3.12	0.78
	SFRSCC8	5.70	2.39	0.42	4.84	0.85
	SFRSCC9	6.20	3.42	0.55	6.90	1.11
Balazs and Kovacs [8]	RC-A6	10.80	5.62	0.52	11.35	1.05
	RC-A7	12.00	6.08	0.51	12.29	1.02
	RC-A8	10.80	5.62	0.52	11.35	1.05
	RC-A9	12.30	5.88	0.48	11.87	0.97
	RC-B6	10.20	7.34	0.72	14.82	1.45
	RC-B9	10.00	7.22	0.72	14.59	1.46
	A1V1	4.00	4.86	1.22	9.82	2.46
	A1V2	3.20	4.92	1.54	9.95	3.11
	A1V3	4.00	4.74	1.19	9.58	2.39
	A2V1	4.30	5.15	1.20	10.40	2.42
	A2V2	4.10	4.86	1.18	9.81	2.39
	A2V3	2.90	5.10	1.76	10.30	3.55
	A3V1	3.70	4.75	1.28	9.60	2.59
	A3V2	4.30	5.31	1.23	10.73	2.49
	A3V3	3.00	4.68	1.56	9.46	3.15
					MEAN	1.65
					CV	0.55

Computation of Effective Depths

5.1 Limiting Effective Depths using Various Criteria

The effective depths of a typical singly reinforced beam have been calculated using (a) limit state of rupture in flexure, (b) limit state deflection, (c) using a proposed method. It is to be mentioned here that both the method that is limit state of rupture and limit state of strength are independent of the ratio of sustained load to the service load. While the proposed method involves the ratio of sustained load to service load.

5.1.1 Limit State of Rupture in Flexure (Strength Criteria)

$$M_u = \left(\sigma_u b(D - k_1 D) + A_s f_y\right)(d - 0.475 k_1 D) \quad (9)$$

Where,

$$M_u = \frac{wl^2}{8} \quad (10)$$

Modulus of rupture of fibre in tension

$$f_r = 0.4(f_{ck})^{2/3} \quad (11)$$

Therefore we have f_t

$$f_t = \frac{f_r}{1.416} \quad (12)$$

- Ultimate fibre concrete strength σ_u

$$\sigma_u = f_{ult} = 1.34f_t + (0.0016 + 0.84\eta v_f)\tau(\alpha) \quad (13)$$

- Modified it as below for calculating k_1

$$k_1 = \frac{1.11\sigma_u bd + A_s f_y}{0.8963 f_c' bd + 1.11\sigma_u bd} \quad (14)$$

- Ultimate moment

$$M_u = \frac{wl^2}{8} \quad (15)$$

- Effective depth 'd'

$$M_u = \left(\sigma_u b(D - k_1 D) + A_s f_y\right)(d - 0.475 k_1 D) \quad (16)$$

Where, M_u = Moment of resistance, A_s= Area of steel, f_y= Yield strength of fibres, f_c'= cylinder compressive strength, b= Beam Width, h= Depth of beam, σ_u= Ultimate strength of fibre reinforced concrete, τ = Bond strength of matrix, V_f= Volume fraction of fibres, α = Aspect ratio of fibres, f_t= Tensile strength of fibres

5.1.2 Limit State Of Deflection (Deflection Criteria)

The effective depth of singly reinforced beam has been calculated using limit state of deflection. ACI318-14 specifies this limiting effective depth as one by sixteenth of the span.

5.1.3 Proposed Method

The effective depths of singly reinforced SFRSCC beam have been calculated using the proposed method on SVM technique. The following data has been assumed l=6000mm, b=230mm, f_y=415N/mm^2, E_s=200 kN/mm^2, α=60, w=30kN/m, v_f =0.005, Though the computation have been done for ρ = 0.25 to 2.0, w_s/w = 0.2 to 1.0.

The total deflection is limited to a value of $\frac{l}{250}$

$$\delta = \frac{\alpha w l^4}{E_c I_e} + \frac{\lambda \alpha w_s l^4}{E_c I_e} \quad (17)$$

By substituting the value of $\alpha = \frac{5}{384}$ and $\lambda = 2$ we have

$$\left(\frac{l}{d}\right)\left(\frac{w}{E_c b}\right)^{0.33} = \left[\left(\frac{384}{5*250}\right)\frac{k_1}{\left(1+2\frac{w_s}{w}\right)}\right]^{0.33} \quad (18)$$

using SVM concept, the formula for k_1 is obtained as

$$k_1 = 0.11\left(\frac{E_s}{E_c} v_f \rho^2 (\alpha)^{0.5}\right) + 0.0797 \quad (19)$$

The value of $\left(\frac{l}{d}\right)$ can be calculated using Eq. (18) and Eq.(19) knowing the value of aspect ratio (α), steel ratio (ρ), volume fraction (v_f), modulus of elasticity of concrete and steel (E_s , E_c), the value of k_1 was calculated. This value of k_1 is substituted in Eq (18) and $\left(\frac{l}{d}\right)$ was calculated. To compute the same, the ratio of sustained load to service load (w_s/w), breadth of beam and the service load are to be substituted in Eq (18).

Table 2: Comparison of effective depths (mm)

ρ %	strength limit state	deflection limit state	proposed method for (w_s/w) 0.2	0.4	0.6	0.8	1
0.25	393.98	375	400.66	435.31	465.11	491.47	515.24
0.50	371.46	375	391.33	425.17	454.27	480.02	503.23
0.75	352.97	375	377.53	410.17	438.25	463.09	485.49
1.00	337.49	375	361.10	392.33	419.19	442.94	464.36
1.25	324.33	375	343.63	373.35	398.91	421.51	441.89
1.50	312.00	375	326.23	354.44	378.71	400.17	419.52
1.75	303.14	375	309.57	336.34	359.37	379.73	398.10
2.00	294.48	375	293.98	319.40	341.27	360.61	378.05

It is noticed that the depths are reduced for low percentage of sustained load to total load on the other hand for high percentage of steel and higher ratio of sustained load to service load the effective depths obtained from the code being less. It is not sufficient to limit the deflection to permissible values. Hence the effective depths would have to be increased to the value calculated by the proposed method.

5.2 Design Charts

Alternatively, the design charts were prepared as follows, The following variables are considered the sustained load to total load (w_s/w) ratio as 0.2 to 0.8, 'α' aspect ratio varied as 15 to 90, v_f volume fraction 0.00 to 0.015. And tensile steel ratio 'ρ' value varied as 0.01 to 0.04.

The above combination result in 480 number of design points. The value of k_1 ranges from 0.07 to 0.14 for design points considered. The design curves have been generated by having the values of (w_s/w) along x axis and $\left(\frac{l}{d}\right)\left(\frac{w}{E_c b}\right)^{0.33}$ along y axis.

Table 3: Value of $\frac{l}{d}\left(\frac{w}{E_c b}\right)$

k1 / (w_s/w)	0.070	0.080	0.090	0.100	0.110	0.120	0.130	0.140
0.00	0.282	0.294	0.306	0.317	0.327	0.336	0.346	0.354
0.20	0.252	0.263	0.274	0.284	0.293	0.301	0.309	0.317
0.40	0.232	0.242	0.252	0.261	0.269	0.277	0.285	0.292

0.60	0.217	0.227	0.236	0.244	0.252	0.259	0.266	0.273
0.80	0.205	0.215	0.223	0.231	0.239	0.245	0.252	0.258
1.00	0.196	0.205	0.213	0.220	0.228	0.234	0.240	0.246

The above variation is shown in the form of design charts.

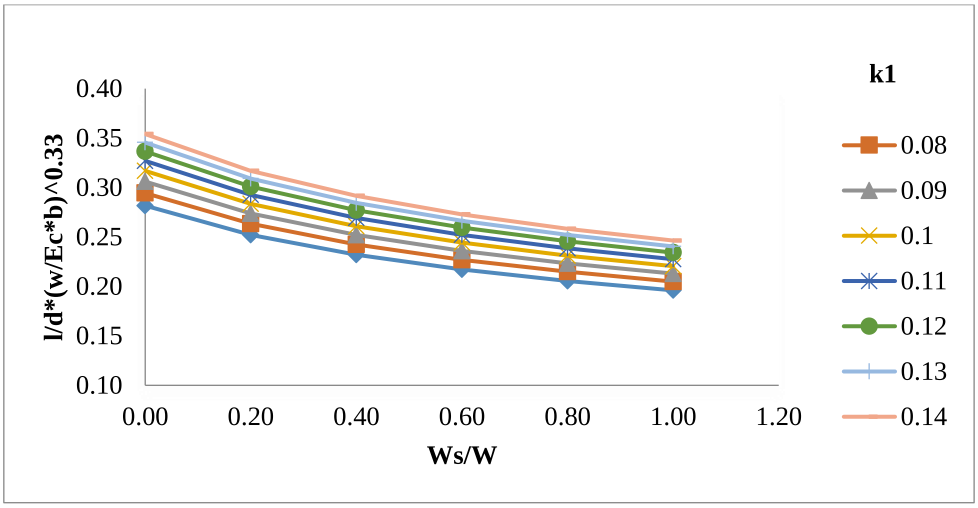


Fig 2 : Design chart for singly reinforced beams.

5.2.1 Illustrative example

Calculate the effective depth of a singly rain force beam for the data

l=6000mm, b=230mm, f_{ck}=50$\mathrm{N/mm^2}$,E_s=200000$\mathrm{N/mm^2}$, w=30kN/m, k_1=0.07 ,$\frac{w_s}{w} = 1$

Modulus of elasticity of concrete

$$E_c = 4733\sqrt{0.8f_c'}$$

$$E_c = 4733\sqrt{0.8 * 50}$$

$$E_c = 29934.12\mathrm{N/mm^2}$$

And we have,

$$\left(\frac{l}{d}\right)\left(\frac{w}{E_c b}\right)^{0.33} = \left[\left(\frac{384}{5 * 250}\right)\frac{k_1}{\left(1 + 2\frac{W_s}{W}\right)}\right]^{0.33}$$

$$\left(\frac{l}{d}\right)\left(\frac{w}{E_c b}\right)^{0.33} = 0.196$$

$$\left(\frac{6000}{d}\right)\left(\frac{30000}{29934.12 * 1000 * 230}\right)^{0.33} = 0.196$$

$$\left(\frac{102.11}{d}\right) = 0.196$$

d = 520.96mm

Summary and Conclusions

A method is proposed to determine the effective depth of singly reinforced steel fibre reinforced SCC beams. The method has been developed using SVM techniques. The input contains the variables of concrete and steel grade, tensile steel ratio modulus of elasticity of steel and concrete, volume fraction, aspect ratio. A large number of design points have been generated by including the above variables.

Using SVM technique, a suitable formula has been arrived at. The suggested effective moment of inertia function is of the form of

$$I_{eff} = k_1 bd^3$$

Where

$$k_1 = 0.11\left(\frac{E_c}{E_s} v_f \rho^2 \alpha^2\right) + 0.0797$$

To validate the above formula, short term deflections have been computed and compared with the test data. The comparison shows that the proposed method is able to predict the short term deflections satisfactorily at working load. Also the theoretical load defection curve shows the actual trend of the experimental load deflection curve.

After validation of the proposed formula, the limiting span to effective depth ratio has been derived. The computed effective depths have been compared with those obtained from limit state of rupture in flexure, limit state of deflection. It is to be noted here that the proposed method considers the ratio of sustained load to service load as an important parameter.

The critical ratio w_s/w=1.0 has been used for comparison with other method. The study points out that for higher ratio of (w_s/w) and for higher tensile ratio (ρ), the effective depths obtained from the rupture limit and deflection limit state is to be increased to satisfy the limiting deflection criteria

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