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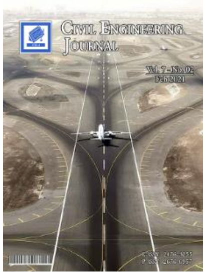

Review Article

Shear Strength Models for Steel Fibre Reinforced Concrete Beams: Current Scenario

Ranjodh Singh [1*], Harvinder Singh [2]

[1] *Research Scholar, IKG Punjab Technical University, Jalandhar, India.*

[2] *Professor, GNDEC, Ludhiana, India.*

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Abstract

This review paper presents a comprehensive comparative analysis of various studies conducted on the shear strength of Self-compacting Concrete (SCC) and Normally Vibrated Concrete (NVC) in order to determine the sustainability and affordability of SCC as a construction material. Compaction is the main factor in concrete production. NVC needs compaction and vibration to remove the entrapped air which is both expensive and time-consuming. But SCC has flow ability and passing ability. Although SCC takes a greater amount of paste content, thereby raising the cost of building material, yet the use of such waste material as fly ash, silica, etc. comes in handy as paste content. Thus, the advantages offered by SCC in terms of increased strength as well as cost reduction makes it a highly desirable construction material. The review has selected the works of some eminent scholars on concrete and has analyzed them through individual as well as comparative perspective. A close analysis has helped filter out relevant works for the current study. This process of selection has proved helpful to include most standard works available in the review. Major findings have been enlisted at the end and ways to improve concrete behaviour have been suggested.

Keywords: Self-Compacting Concrete; Shear Models; Shear Strength; Steel Fibers; Workability; Beams.

1. Introduction

It is a well-known fact that shear capacity is one of determining factors in robust building construction. This capacity is generated by beams having longitudinal structure aided by stirrups which produces a high compression force and tension reinforcement [1-3]. However, the structure alone cannot protect beams from cracks; it requires the right kind of concrete. With the advancement in civil engineering technology, extensive research has been carried out on shear capacity of concrete structures, proposing various models/designs [4-5]. Of these, Self-Compacting Concrete (SCC) has emerged as a promising building material considering its low cost and high performance. It is the latest generation concrete having both low and high grades. It has high deformability and resistance against segregation and bleeding. However, the lack of knowledge and practice of casting SCC and its structural maintenance services pose a serious challenge in its practical utilization in construction concrete industry. Secondly, some experts and designers have a concern that SCC is probably not strong enough in shear and torsional strengths because of some hesitation in mechanisms resisting shear, notably the interlocking mechanism of aggregates [6-8].

* Corresponding author: ranjodh6051@gmail.com

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Further, most of the research till date has shown that shear strength is obtained by the contributions of the un-cracked conventionally vibrated concrete (CVC) in the compression zone which ranges from 20 to 40%, interlocking of aggregate ranges from 35% to 50%, and dowel action of the longitudinal steel ranges from 15 to 25% [9-10]. Needless to say, SCC has become a potential area of research globally, producing a substantial body of models and designs vis-à-vis concrete preparation. The present paper attempts to document some of the prominent models and designs in order to select the best out of them.

2. Shear Strength of SCC: History

Over the last three decades a large scale work has been done on the shear strength of concrete with different fibre ratio. Binary and ternary blends of SCC have been reported to have the standard ratio, chiefly due to their environmental impact assessment and cost deduction. Somehow ternary and quaternary blends are not found sufficiently useful. Various experiments have been performed to find out fresh and hard properties of different SCC with mineral admixtures. These primarily include samples having a constant water/binder ratio varying from 0.44 to 0.58 and a total binder/cement content of 450 kg/m^3 [11]. It is observed that the ternary use of cement when added with silica fumes provides the best result.

Similarly an experimental study was conducted to evaluate the suitability and ease of various workability test methods of SCC by Soo-Duck et al. (2006) [12]. The findings suggested that SCC is workable when its water binder ratio varies between 0.35 to 0.42. It was clear that SCC used in structural concrete industry should have slump flow values between 620 to 720 mm and L-box test ratio (h2/ h1) ≥ 0.7, J-Ring flow from 600 to 700 mm, slump minus J-Ring flow dia. ≤ 50 mm, or V-funnel test time ≤ 8 sec.

Further, The Taguchi method is applied to determine the outcome of an analytical approach consisting of variable factors. It can predict the combination of standard factors for optimal factor level by measuring the significant variance in factor level. Taguchi's experiment design theory for optimum design was used by Gesoğlu et al. (2009) [13] to study mix proportions of high strength self-compacting concrete (HSSCC). Best mix proportions were obtained by conducting ultra-Sonic Pulse Velocity Test, Compressive strength and Tensile strength and minimization of Air, Water and permeability.

El-Sayed et al. (2010) [14] derived the equation for designing the shear capacity of the concrete beams reinforced with FRP. Equation 1 was derived from a model and was simplified to provide the design formulae. The designing equation for it is as shown below:

$$V_{c,f} = \left(\frac{\rho_f E_f}{90\beta_1 f_c'}\right)^{\frac{1}{3}} \left(\frac{\sqrt{f_c'}}{6} b_w d\right) \leq \frac{\sqrt{f_c'}}{6} b_w d \tag{1}$$

Fibre, as pointed out above, has a great impact on the shear strength of SCC. Fibre enhances the strength and workability properties of concrete. Fibres used in mix are available in different size distribution of skeletal structure and they are defined on the basis of specific surface area. Iqbal et al. (2016) [15] studied the strength properties of SCC beams using steel fibre. They concluded that steel fibre concrete improved the strength of existing structure. There was about 14 to 58% improvement in cracking load when reinforced with 40mm, 50mm, 60mm diameter bars reinforced in tension side. Voo et al. (2010) [16] calculated the shear value characteristics of beams with fibre-reinforced high performance concrete having no stirrups. They reported that the HPSCRC beams with different testing variables like l/d ratio, i. e. shear span and effective depth value, the type and the volumes of the fibres, etc. It was noted that there was a significant and specific distribution in cracking produced through the web. This cracking was prior to the direction and formation of crack failure. Gao et al. (2020) [17] proposed a shear strength calculation model of polymer fibre reinforced beams without stirrups. He presented a linear Equation 2 to determine shear strength:

$$\frac{\mathrm{V_c^{exp}}}{\sqrt{\mathrm{f_c'}}\mathrm{bd}} = 0.4(\mathrm{k} + 0.1) \tag{2}$$

The previous models of shear, i. e. ISIS M03-07, ACI 440.1R-15, CSA S806-12, CSA S6-14, JSCE-97, AASHTO LRFD-17, BISE-99, and CNR DT203-06 were unable to reflect the reinforcement ratio properly.

López et al. (2020) [18] calculated the shear strength of continuous and cantilever beams with shear reinforcement ratios varying from 0 to 20%. The results so obtained were checked and validated against Eurocode 2, ACI 318-19 [4], and Model Code 2010. Some other scholars put forward equations to calculate shear strength of concrete beams depending on various parameters. Ruiz et al. (2015) [19] gave his review on shear transfer action in RC beams with rectangular cross section. The governing parameters were also discussed which were a) Shear transfer across reinforced concrete b) Contribution of shear transfer action in slender beams c) Contribution of top part on shear transfer d) Contribution of bottom part on shear transfer. Singh (2017) [20] predicted the ultimate shear strength capacity of SCC flexural beam members. For it a design model showing the influence of shear strength capacity of SCC beams was presented. Also Singh (2017) proposed a closed forum solution to calculate shear strength capacity of Steel Fibre Reinforced Concrete (SFRC) rectangular beams having no web reinforcement. A theoretical formulation was presented herein for this purpose. Its efficacy was checked with available design guidelines, empirical relations, and experimental test data.

Moving on, some other notable works on shear strength maximization are credited to Yacob et al. (2019) and Mohammed et al. (2019) [21, 22]. Yacob et al. (2019) evaluated the shear strength of geopolymer concrete beams. The test variables were shear span to effective depth ratio with different transverse ratios. All of the beams failed in shear aside from two beams; one had higher α/d proportion and one had small size. These beams failed in flexural-shear mode. All the GC beams showed their high shear strength. Mohammed et al. (2019) evaluated the shear strength of RCC beams prepared with recycled brick aggregates. The main parameters were steel ratio variation (0.82 to 1.23%) and shear span to effective depth ratio.

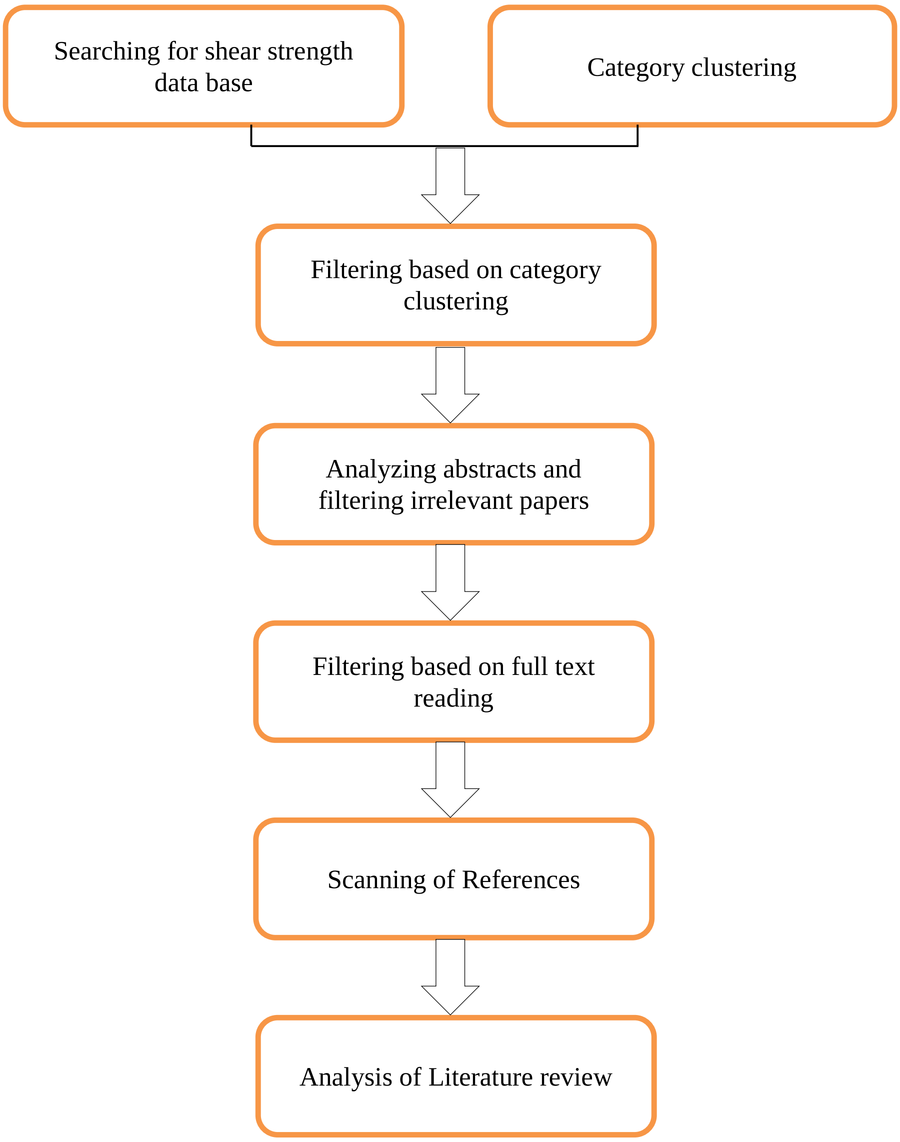

Figure 1. Flow Chart Showing the Research Methodology

The authors of this review paper used following five methods of shear design and reviewed them.

i. Compression Field Theory

ii. Truss Approaches with Concrete Contributions

iii. Shear Friction Theory

iv. Strut and Tie Model.

v. Some latest research work on the shear design of reinforced concrete beams.

These theories have included the American Concrete design guidelines ACI 440,1R-06 [23], the Canada Standard Association, CAN/CSAS806-02, ISIS Canada manual, ISIS-M03-07, the British Institution of Structure Engineer's guidelines, and the design recommendations provided in the society of the Japan's Civil Engineers. In addition to this, Modified Compression Field Theory (MCFT) was reviewed and compared with the results obtained experimentally (see Table 1). Moreover Asteris et al. (2017) [24] derived the comparison of the results with the experimental findings demonstrates the ability of artificial neural networks to approximate the compressive strength of self-compacting concrete in a reliable and robust manner. The table given below records some of the universally-acknowledged shear equations. The purpose of presenting them together is to understand their individual as well as relative value.

Table 1. Different Available Shear Strength Models

Design code	Shear strength	Nomenclature
Eurocode 2 (2004) [25]	$V_{max} = 0.5bdf_c'v$ $v = 0.6\left(1 - \frac{f_c'}{250}\right), \quad f_c' \ in\ MPa$	b=Beam width, d=Effective depth, f_c' =Compressive strength of concrete
Eurocode 2 (2004) [25]	$V_u = \min\{(0.9\,.\,[0.6(1-\frac{f'_c}{250})]\,\frac{f'_c}{\gamma_c}\,\frac{1}{\cot\emptyset + ten\emptyset}) : 0.90\,p_{sw}\frac{f'_{yw}}{\gamma_s}\cot g\emptyset\}$ $p_{sw} = \frac{f'_{yw}}{\gamma_s}\,. \leq 0.5\,.\left[0.6\,.\left(1-\frac{f'_c}{250}\right)\right].\ \frac{f'_c}{\gamma_c} \qquad 0.4 \leq \cot g\emptyset \leq 2.5$	p_{sw} = area of steel reinforcement $\cot g\emptyset \leq 2.5$
ACI Committee 318-95 (1996) [26]	$V_{max} = {}^5/_6\sqrt{f_c'bd}, \quad f_c' \leq 70$ MPs	b= Beam width, d= Effective depth, f_c' =Compressive strength of concrete
CSA A23.3-M04 Committee. [27]	$V_{max} = 0.25f_c'bd$	b= Beam width, d= Effective depth, f_c' =Compressive strength of concrete
ACI Committee 318 (2014) [28]	$V_{max} = 0.2f_c'bd$	b= Beam width, d= Effective depth, f_c' =Compressive strength of concrete
ACI 440.1R-06 [28]	$V_c = \frac{2}{5}\sqrt{f'_c}\,b_w\,C \qquad C = kd \qquad K = \sqrt{2p_fn_f} + (p_fn_f)^2 - p_fn_f$	p_f = reinforcement ratio in flexure
CAN/CSA-S806 [29]	$V_c = 0.035\lambda_d\theta_c\,(f'_cp_fE_f\frac{V_f}{M_f}d)^{1/3}\,b_wd$	θ_c =Inclination of Concrete; λ_d =Factor to account for Light weight concrete; E, V and M Fibre factors, i.e. elasticity, volume
JSCE [30]	$V_c = \beta_d\beta_{dp}\beta_{dn}f_{vcd}b_wd/\gamma_b$	β_d- Strength reducing factor of concrete.
ACI Building Code (1999) [31]	$(V_n)_{rc} = V_r + V_c$ $V_r = \frac{A_VF_{yh}d}{S} \leq 0.67\sqrt{f_c'}bd$ $V_c = 0.17\sqrt{f_c'}bd$ (Member sub to Shear & bending) $V_c = 0.17\left(1 + 0.073\frac{N_u}{A_g}\right)\sqrt{f_c'}bd$ (Shear, Bending & axial compression) $V_c = 0.17\left(1 + 0.29\frac{N_u}{A_g}\right)\sqrt{f_c'}bd$ (Shear, Bending & axial tension)	v_n = nominal shear stress v_r = permissible horizontal shear stress
ACI Building Code (1962) [32]	$V_{uc} = \left(0.157.\sqrt{f'_c} + 17.2\,.\,p\,.\frac{d}{b}\right) < 0.30\,.\sqrt{f'_c}$ $V_{uc} = \frac{A_{sw}}{b.S}\,.f_{yw} = p_{sw}\,.f_{yw} \quad V_u = V_{uc} + V_{us}$	$\sqrt{f'_c}$= a measure of concrete tensile strength
CAN3 (2004) [33]	$V_u = \emptyset_c.\beta\,.\sqrt{f'_c} + \emptyset_s\,.p_{sw}\,.f_{yw}.cot0 \leq 0.25\,.\emptyset_c.f'_c$ $\beta = \frac{0.4}{b.S1 + 1500\frac{f_y}{2\,.E_s}} \qquad \emptyset = 29° + 700\,.\frac{f'_c}{2.E_s}$	$\emptyset_c = 45$
Authors	**Design Expressions**	
Zararis (2003) [34]	$V_u = \xi.(f'_c)^{0.66}\,.\frac{x_c}{d} + \left(0.5 + 0.25\,.\frac{a}{d}\right).p_{sw}\,.f_{yw}$ $\xi = 0.3\,.(1.2 - 0.2\,.\frac{a}{d}\,.d)$	
Arslan (2007) [35]	$V_u = 0.12\,.\sqrt{f'_c} + 0.02\,.\ \emptyset_s\,.(f'_c)^{0.65} + p_{sw}\,.f_{yw}$	

Russo et al. (2013) [36]	$V_u = \frac{1+\sqrt{\frac{5.08}{da}}}{\sqrt{1+\frac{d}{25-da}}} \cdot \left[p^{0.4} \cdot f'^{\,0.39}_{c} + 0.5 \cdot p^{0.83} \cdot fy^{00.89} \cdot \frac{a}{d}^{-1.2-0.45\frac{a}{d}}\right] + 0.36 \cdot p^{0.2} \cdot \sqrt{f'_c} \cdot (p_{sw} \cdot f_{yw})^{0.6}$	
Campione et al. (2014) [37]	$V_c = \left\{0.886 . j_0 . \sqrt{p} . \sqrt{\frac{d}{b}}\right) . \sqrt{p} . + \left(\frac{1.168 * j_0 * s_{rm}}{\sqrt{b} . d . p}\right) . p . \frac{d}{b} . \sqrt{f'_c}$	It was observed that following assumptions were made d=500 mm, a/d= 2, s_{rm}= 50 mm, the second term of Eq. Proves to be 0.09, which was negligible therefore for practical application it can be utilized.
Weng et al. (2001) [38]	$(V_n)_{comp} = (V_n)_s + (V_n)_{rc}$ Shear Capacity of Composite member $(V_n)_s = 0.6F_{ys}\,A_{ws}$ $(V_n)_{rc} = \min[(V_n)_{rc1}\;(V_n)_{rc2}]$ $(V_n)_{rc1} = A_V F_{yh}\left(\frac{d}{s}\right) + 0.17\left(1 + 0.073\,\frac{N_u}{A_g}\right)\sqrt{f'_c}bd$ (Diagonal Shear Capacity)	(Vn)=shear capacity of steel shape in composite member, $(Vn)_{rc}$= shear capacity of the RC portion in composite member, A_{ws} = area of steel web; $(Vn)_{rc1}$ and $(Vn)_{rc2}$ = shear capacities of the RC portion controlled by diagonal shear failure and shear bond failure
Liu et al. (2012) [39]	$V_{MOD} = \frac{2}{5}\gamma_f\sqrt{f'_c}\,b_w\,C$	γ_f = equal to 0.82, f'_c = the specified compressive strength of concrete (MPa),
Choi et al. (2015) [40]	$V_{max} = \frac{1}{3}f'_c c_u b \;\le V_f$ $C_u = \frac{(pf_s - p'\,f_s')d}{0.85\,f_c'\beta_1}$	V_f= shear corresponding to the flexural strength of the Member, c_u= depth of the concrete compression zone determined by using the force-equilibrium and the compressive strain $\alpha\varepsilon_0$=0.003
Singh (2016) [41]	$\tau_c = 0.87(\rho t)0.67\{(fc) - 0.64 + \{\frac{3.2\sqrt{\rho t}}{\left(\frac{a}{d}\right)1.82}\}\alpha$	

From the above table, it can be deduced that the Eurocode 2 model has a remarkable degree of accuracy to calculate shear strength. ACI 318-2005 model predicts the underestimated shear strength capacity. Comparatively, the ACI model is not as precise as the Eurocode 2 model because the former has normal standard deviation value 0.33 for lower grades and 0.44 for higher grades. Similarly, the deviation values in the CSA A23.3M04 model are 0.76 for lower grades and 0.83 for higher grades which are considered overestimated and can lead to unsafe design. It is noted that these models apply the modified compression field theory to calculate shear value still. However, the model proposed by Singh (2015) yields more accurate results [42]. This is because unlike CSA A23.3-14, which is the result of merging the modified compression field theory with a sectional based approach, the proposed model incorporates the modified compression field theory into a strut and tie based approach. Also the results shown in Euro 2 code 2004 [43] are comparable. Results showed that the characteristics of shear strength of RC beams without shear reinforcement compared well to other codal provisions. Comparing the codes, it was realized that the prediction uniformity of the low strength RC beams was significantly enhanced by SFRSCC. In contrast to those without shear reinforcement, more cracks of larger widths were found in the beams with shear reinforcement. In contrast to the corresponding b, beams subject to cyclic loads exhibited wider crack widths. The first diagonal shear crack load of beams without shear reinforcement was between 42-92% of the failure load, while 42-58% of the failure loads ranged from those of beams with shear connections. There was lower post-diagonal shear resistance to the SFRSCC concrete beams without shear connections. It is proposed that the reinforcing bar anchorage in SFRSCC RC beams should be adequately constructed to ensure that no premature failure occurs under cyclic loads.

3. Conclusions

The review of the various models to calculate the shear strength of Self-Compacting Concrete (SCC) gives out some significant results. SCC is more cost-effective and environment-friendly as it uses fly ash, silica, etc. as ingredients. It has another peculiar advantage over normal concrete in that it does not need vibrator to settle the paste content, thereby saving time in the preparation of concrete. Some concrete specialists have experimented with the impact of different types of fibre on concrete and have concluded that by and large fibre increases the shear capacity of SCC. Further, binary, ternary and quaternary blends made by mixing concrete with fly ash, limestone powder, granite filler, and micro silica give different results. Of these, the binary has the standard ratio. Further, Contrasting information and different codes and conditions, the conversation might be finished up as follows:

- ACI code thinks little of the shear limit of concrete beams with no shear reinforcement. It gives lower shear estimations of RCC beams as contrasted with the test Specimens. ACI Code emphasizes the importance of boundaries like shear length to profundity proportion, compressive strength of concrete only, without considering the impact of longitudinal steel proportion;

- Canadian code does not consider the impact of shear span to effective depth ratio and longitudinal steel proportion. It chiefly focuses on the compressive strength of concrete;
- The model presented by Singh (2016) [41] is quite conservative in estimating the shear strength of concrete with steel fibers. There is a scope to improve the presented formulae to enhance compressive strength and save shear reinforcement by deriving it for higher grades.

4. Declarations

4.1. Author Contributions

Conceptualization, R.S. and H.S.; investigation, R.S. and H.S.; resources, R.S. and H.S.;; writing—original draft preparation, R.S. and H.S.; writing—review and editing, R.S. and H.S.; visualization, R.S. and H.S. All authors have read and agreed to the published version of the manuscript.

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4.4. Conflicts of Interest

The authors declare no conflict of interest.

5. References

[1] Al-Musawi, Abeer A., Afrah A. H. Alwanas, Sinan Q. Salih, Zainab Hasan Ali, Minh Tung Tran, and Zaher Mundher Yaseen. "Shear Strength of SFRCB without Stirrups Simulation: Implementation of Hybrid Artificial Intelligence Model." Engineering with Computers 36, no. 1 (December 10, 2018): 1–11. doi:10.1007/s00366-018-0681-8.

[2] Bousselham, Abdelhak, and Omar Chaallal. "Mechanisms of Shear Resistance of Concrete Beams Strengthened in Shear with Externally Bonded FRP." Journal of Composites for Construction 12, no. 5 (October 2008): 499–512. doi:10.1061/(asce)1090-0268(2008)12:5(499).

[3] Ashour, Ashraf F., and Ilker Fatih Kara. "Size Effect on Shear Strength of FRP Reinforced Concrete Beams." Composites Part B: Engineering 60 (April 2014): 612–620. doi:10.1016/j.compositesb.2013.12.002.

[4] Singh, Harvinder. "Steel Fibers as the Only Reinforcement in Concrete Slabs: Flexural Response and Design Chart." Structural Engineering International 25, no. 4 (November 1, 2015): 432–441. doi:10.2749/101686615x14355644771090.

[5] Asteris, Panagiotis G., and Konstantinos G. Kolovos. "Self-Compacting Concrete Strength Prediction Using Surrogate Models." Neural Computing and Applications 31, no. S1 (April 28, 2017): 409–424. doi:10.1007/s00521-017-3007-7.

[6] Tang, C. Y., and K. H. Tan. "Interactive Mechanical Model for Shear Strength of Deep Beams." Journal of Structural Engineering 130, no. 10 (October 2004): 1534–1544. doi:10.1061/(asce)0733-9445(2004)130:10(1534).

[7] Lee, Deuck Hang, Sun-Jin Han, Kang Su Kim, and James M. LaFave. "Shear Capacity of Steel Fiber-Reinforced Concrete Beams." Structural Concrete 18, no. 2 (February 26, 2017): 278–291. doi:10.1002/suco.201600104.

[8] Yapa, Hiran D., and Janet M. Lees. "Rectangular Reinforced Concrete Beams Strengthened with CFRP Straps." Journal of Composites for Construction 18, no. 1 (February 2014): 04013032. doi:10.1061/(asce)cc.1943-5614.0000416.

[9] Alam, M. S., and A. Hussein. "Effect of Member Depth on Shear Strength of High-Strength Fiber-Reinforced Polymer–Reinforced Concrete Beams." Journal of Composites for Construction 16, no. 2 (April 2012): 119–126. doi:10.1061/(asce)cc.1943-5614.0000248.

[10] American Concrete Institute (ACI440.1R-06). Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars. Farmington Hills, Michigan, USA: American Concrete Institute; 2006.

[11] Monserrat López, Andrea, Pedro Fco. Miguel Sosa, José Luis Bonet Senach, and Miguel Ángel Fernández Prada. "Experimental Study of Shear Strength in Continuous Reinforced Concrete Beams with and Without Shear Reinforcement." Engineering Structures 220 (October 2020): 110967. doi:10.1016/j.engstruct.2020.110967.

[12] Hwang, Soo-Duck, Kamal H. Khayat, and Olivier Bonneau. "Performance-based specifications of self-consolidating concrete used in structural applications." ACI Materials Journal 103, no. 2 (March 2006): 121.

[13] Gesoğlu, Mehmet, Erhan Güneyisi, and Erdoğan Özbay. “Properties of Self-Compacting Concretes Made with Binary, Ternary, and Quaternary Cementitious Blends of Fly Ash, Blast Furnace Slag, and Silica Fume.” Construction and Building Materials 23, no. 5 (May 2009): 1847–1854. doi:10.1016/j.conbuildmat.2008.09.015.

[14] El-Sayed, Ahmed K., and Khaled Soudki. “Evaluation of Shear Design Equations of Concrete Beams with FRP Reinforcement.” Journal of Composites for Construction 15, no. 1 (February 2011): 9–20. doi:10.1061/(asce)cc.1943-5614.0000158.

[15] Iqbal, Shahid, Ahsan Ali, Klaus Holschemacher, Thomas A. Bier, and Abid A. Shah. “Strengthening of RC Beams Using Steel Fiber Reinforced High Strength Lightweight Self-Compacting Concrete (SHLSCC) and Their Strength Predictions.” Materials & Design 100 (June 2016): 37–46. doi:10.1016/j.matdes.2016.03.015.

[16] Voo, Yen Lei, Wai Keat Poon, and Stephen J. Foster. “Shear Strength of Steel Fiber-Reinforced Ultrahigh- Performance Concrete Beams Without Stirrups.” Journal of Structural Engineering 136, no. 11 (November 2010): 1393–1400. doi:10.1061/(asce)st.1943-541x.0000234.

[17] Gao, Danying, and Changhui Zhang. “Shear Strength Calculating Model of FRP Bar Reinforced Concrete Beams Without Stirrups.” Engineering Structures 221 (October 2020): 111025. doi:10.1016/j.engstruct.2020.111025.

[18] Monserrat López, Andrea, Pedro Fco. Miguel Sosa, José Luis Bonet Senach, and Miguel Ángel Fernández Prada. “Experimental Study of Shear Strength in Continuous Reinforced Concrete Beams with and Without Shear Reinforcement.” Engineering Structures 220 (October 2020): 110967. doi:10.1016/j.engstruct.2020.110967.

[19] Fernández Ruiz, M., A. Muttoni, and J. Sagaseta. “Shear Strength of Concrete Members without Transverse Reinforcement: A Mechanical Approach to Consistently Account for Size and Strain Effects.” Engineering Structures 99 (September 2015): 360–372. doi:10.1016/j.engstruct.2015.05.007.

[20] Singh, Harvinder. “Steel Fiber Reinforced Concrete.” Springer Transactions in Civil and Environmental Engineering (2017): 172. doi:10.1007/978-981-10-2507-5.

[21] Yacob, Noor S., Mohamed A. ElGawady, Lesley H. Sneed, and Aly Said. “Shear Strength of Fly Ash-Based Geopolymer Reinforced Concrete Beams.” Engineering Structures 196 (October 2019): 109298. doi:10.1016/j.engstruct.2019.109298.

[22] Mohammed, Tarek Uddin, Kamal Hossain Shikdar, and M.A. Awal. “Shear Strength of RC Beam Made with Recycled Brick Aggregate.” Engineering Structures 189 (June 2019): 497–508. doi:10.1016/j.engstruct.2019.03.093.

[23] American Concrete Institute (ACI440.1R-06). Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars. Farmington Hills, Michigan, USA: American Concrete Institute, (2006).

[24] Asteris, Panagiotis G., and Konstantinos G. Kolovos. “Self-Compacting Concrete Strength Prediction Using Surrogate Models.” Neural Computing and Applications 31, no. S1 (April 28, 2017): 409–424. doi:10.1007/s00521-017-3007-7.

[25] Code, Euro. "2, Design of concrete structures-Part 1-1: General rules and rules for buildings, BS EN 1992-1-1: 2004." British Standards (BSi) (2004).

[26] ACI Committee 318-95, “Review of Building Code Requirements for Structural Concrete (ACI 318-95) and Commentary (ACI 318R-95) by ACI Committee 318.” Journal of Architectural Engineering 2, no. 3 (September 1996): 120–120. doi:10.1061/(asce)1076-0431(1996)2:3(120.3).

[27] Canadian Standards Association (CSA). “Design of concrete standards for buildings.” CAN3-A23.3, Rexdale, Ontario, Canada. (2004).

[28] ACI Committee 318, Building Code Requirements for Structural Concrete and Commentary, American Concrete Institute, Farmington Hills, MI, (2014).

[29] Canadian Standards Association (CAN/CSA S806-02). “Design and Construction of Building Components with Fibre Reinforced Polymers.” Rexdale, Ontario, Canada: Canadian Standards Association, (2002).

[30] JSCE 2010 Concrete Committee. "Standard Specifications for Concrete Structures—2007." Japan Society of Civil Engineers: Tokyo, Japan (2010).

[31] ACI Committee 318. “Building Code Requirements for Structural Concrete (ACI 318-05). American Concrete Institute, Farmington Hills, MI, (1999).

[32] ACI Committee 318. “Building Code Requirements for Reinforced Concrete (ACI 318-56).” ACI Journal Proceedings 59, no. 12 (1962). doi:10.14359/7970.

[33] Canadian Standards Association (CAN/CSA S806-02). “Design and Construction of Building Components with Fibrebre Reinforced Polymers.” Rexdale, Ontario, Canada: Canadian Standards Association, 2004.

[34] Zararis, Prodromos D. "Shear strength and minimum shear reinforcement of reinforced concrete slender beams." Structural Journal 100, no. 2 (March 2003): 203-214.

[35] Arslan, Güray. “Shear Strength of Reinforced Concrete Beams with Stirrups.” Materials and Structures 41, no. 1 (February 28, 2007): 113–122. doi:10.1617/s11527-007-9223-3.

[36] Russo, Gaetano, Denis Mitri, and Margherita Pauletta. “Shear Strength Design Formula for RC Beams with Stirrups.” Engineering Structures 51 (June 2013): 226–235. doi:10.1016/j.engstruct.2013.01.024.

[37] Campione, G., A. Monaco, and G. Minafò. “Shear Strength of High-Strength Concrete Beams: Modeling and Design Recommendations.” Engineering Structures 69 (June 2014): 116–122. doi:10.1016/j.engstruct.2014.02.029.

[38] Weng, C. C., S. I. Yen, and C. C. Chen. “Shear Strength of Concrete-Encased Composite Structural Members.” Journal of Structural Engineering 127, no. 10 (October 2001): 1190–1197. doi:10.1061/(asce)0733-9445(2001)127:10(1190).

[39] Liu, Ruifen, and Chris P. Pantelides. “Shear Capacity of Concrete Slabs Reinforced with Glass-Fiber-Reinforced Polymer Bars Using the Modified Compression Field Theory.” PCI Journal 57, no. 3 (June 1, 2012): 83–99. doi:10.15554/pcij.06012012.83.99.

[40] Choi, Kyoung-Kyu, Woo-Chang Sim, Jong-Chan Kim, and Hong-Gun Park. “Maximum Shear Strength of Slender RC Beams with Rectangular Cross Sections.” Journal of Structural Engineering 141, no. 7 (July 2015): 04014184. doi:10.1061/(asce)st.1943-541x.0001156.

[41] Singh, Harvinder. “Flexural Modelling of Steel-Fibre-Reinforced Concrete Member with Conventional Tensile Rebars.” Proceedings of the Institution of Civil Engineers - Structures and Buildings 169, no. 1 (January 2016): 54–66. doi:10.1680/stbu.14.00054.

[42] Singh, Harvinder. “Steel Fibers as the Only Reinforcement in Concrete Slabs: Flexural Response and Design Chart.” Structural Engineering International 25, no. 4 (November 1, 2015): 432–441. doi:10.2749/101686615x14355644771090.

[43] Code, Euro. "2, Design of concrete structures-Part 1-1: General rules and rules for buildings, BS EN 1992-1-1: 2004." British Standards (BSi) (2004).