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Prediction Of Shear Strength For Moderate Deep Beam

Correlation Of Size effect Parameter With Shear Strength In Reinforced Concrete Moderate Deep Beam

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Abstract — *A modified formula of Canadian standards association (CSA-A23.3-04) proposed for prediction of shear strength in reinforced concrete moderate deep beams. The proposed equation for predicting the shear strength of moderate deep beams incorporates shear span to depth ratio, ratio of longitudinal steel reinforcement, ratio of effective length to overall depth as a size effect parameter. The validation of proposed formula done with author's experimental test result which include ultimate load of beam, ductility of beam, reserved strength of beam, load deflection characteristic of total 15 beams of different concrete series.*

Keywords- Size effect, moderate deep beam, Ultimate load, Fibrous Concrete, Shear span to depth ratio, load deflection behavior

I. INTRODUCTION

The shear behavior of reinforced concrete deep beam has been a subject of investigation since 1955. A warehouse roof collapse took place at Robins Air Force Base near Shelby, Ohio, early on the morning of August 17, 1955 due to failure of deep beam. This accident ignites the research work in shear behavior of concrete deep beams. Moderate deep beam is a part of deep beam having a/d ratio from 1 to 2.5. It has long been recognized that, due to their small shear-span to depth ratios ($a/d \leq 2.5$), moderate deep beams can carry significantly larger shear forces than slender beams. From among the application of such beams, we can refer to moderate deep beam utilized in tall building construction, offshore structures, complex foundation systems, nuclear structures, and water tank structure. From a modelling point of view, moderate deep beams do not obey the classical plane-sections-remain-plane hypothesis, and therefore require different models than slender beams. The strength of moderate deep beams is usually controlled by shear rather than flexure, provided a normal amount of longitudinal reinforcement is used. An understanding of the shear strength behavior of moderate deep beams is an essential prerequisite for achieving optimum design and proportioning of such members.

There are plenty of researchers who have studied various subjects related to moderate deep beams. Some predictive equations have been proposed for evaluating the size-dependent shear strength of such beams. Kani (1966 and 1967)[1] was amongst the first to investigate the effect of absolute member size on concrete shear strength after the dramatic warehouse shear failures. Walsh (1972)[2] confirmed that the critical strength of the concrete beams decreases with increase in the beam depth, where a characteristic depth of 225 mm has been identified to observe the size effect on concrete beams. Bazant (1980, 1983)[3] was responsible for developing size effect law based on infinite series and limiting its applicability to the size range of 1:32. Haung and Lee (2000)[4] proposed model which was originates from the strut-and-tie model. In last decade Arslan (2014, 2017)[5][6] proposed shear strength prediction equation for steel fiber reinforced concrete and poly propylene fiber reinforced concrete deep beams.

The important factors that affected the shear capacity of the deep beams were shear span to depth ratio (a/d), compressive strength of concrete, longitudinal reinforcement, horizontal shear reinforcement and vertical shear reinforcement. Several researchers discovered that failure mode is dependent on (a/d) substantially. Berg (1962)[7] found increase in shear capacity with decreasing of (a/d) ratio. Nevertheless, Ferguson[8] explained what Berg shown, increased resistance to diagonal tension in case of small (a/d), Rao (2012)[9] carried out experiment on deep beams with varying depth. Various researcher carried out experimental work with varying above parameter to generate the best model for prediction of shear strength of deep beam. On the other way F. Minelli (2013)[10] worked on mitigate the size effect of deep beam with including optimum amount of steel fibers in concrete. Ramadan (2018)[11] compare different model of analysis of deep beam and proposed new empirical formula.

Based on the literature survey as shown above, it can be concluded that the shear strength prediction of moderate deep beams is not accurate with existing formulas of different codes. This paper tries to explore area of size effect factor influencing the shear strength parameter of moderate deep beams. The objectives of this research study is find out the effects of longitudinal steel ratio, length to depth ratio (Le/D) ratio and shear span depth ratio(a/d) on moderate deep beam. The research also includes the ultimate load and load deflection characteristics comparison between reinforced concrete series, steel fiber reinforced concrete series and polypropylene fiber reinforced concrete sires of moderate deep beams. The experimental sequence carried out on 3 series (RCC, PFRC, and SFRC) of beams each series include 5 Nos. of beams. In the experiment ultimate load, first crack load and load deflection characteristic observed. A new formula proposed considering size effect parameter using statistical analysis in SPSS software provides satisfactory results when compared with experimental values. Effect of fibers on ultimate load shows better results as it is intended to be used.

II. EXPERIMENTAL SEQUENCE

The test program was carried out to find shear strength prediction of moderate deep beam. Total 15 Nos. of beams specimens experimentally tested for finding out ultimate shear load.

A. Speciman :

Moderate deep beams of 3 different series were taken to identify the size effect on ultimate shear strength. Each of the series having 5 Nos. of beam. Each of the beam have rectangular cross section and constant breadth (b) of 75mm. Shear span to depth (a/d) ratio was kept 1 for all the specimen. The below table shows the different series and size if beams.

Table 1 Details of Specimens

Beam		Effective length(Le)	Overall depth (D)	Effective depth(d)	Shear span(a)	a/d	Le/D	Longitudinal steel ratio (ρ)	Bars detail	Fiber detail
		mm	mm	mm	mm					
RCC	A2	800	225	200	200	1	3.56	0.0067	2 Nos.-8#	--
	B	900	275	250	250	1	3.27	0.0084	2 Nos.-10#	
	C	1000	325	300	300	1	3.08	0.007	2 Nos.-10#	
	D	1100	375	350	350	1	2.93	0.006	2 Nos.-10#	
	E	1200	425	400	400	1	2.82	0.0075	2 Nos.-12#	
PFRC	A2	800	225	200	200	1	3.56	0.0067	2 Nos.-8#	0.7 % of concrete volume Polypropylene fiber added
	B	900	275	250	250	1	3.27	0.0084	2 Nos.-10#	
	C	1000	325	300	300	1	3.08	0.007	2 Nos.-10#	
	D	1100	375	350	350	1	2.93	0.006	2 Nos.-10#	
	E	1200	425	400	400	1	2.82	0.0075	2 Nos.-12#	
SFRC	A2	800	225	200	200	1	3.56	0.0067	2 Nos.-8#	0.7 % of concrete volume steel fiber added
	B	900	275	250	250	1	3.27	0.0084	2 Nos.-10#	
	C	1000	325	300	300	1	3.08	0.007	2 Nos.-10#	
	D	1100	375	350	350	1	2.93	0.006	2 Nos.-10#	
	E	1200	425	400	400	1	2.82	0.0075	2 Nos.-12#	

B. Material:

All 15 specimens were cast in adjustable steel molds. All the specimens casted with M-25 grade of concrete confirming mix design of IS10262-2009[12]. Fiber used in fibrous concrete was end hooked type steel fibers in SFRC and monofilament type polypropylene fiber in PFRC detail specification shown in *Table 3*. In all test specimens, high yielding strength deformed reinforced bar (HYSD) of grade Fe500 with diameter as shown in Table 1 were used as longitudinal reinforcement. For details mix design refers *Table 2*.

C. Instrumentation and test procedure:

All the beams were tested on universal testing machine in two-point load bending of 200 tones capacity for compression. Deflection gauges used under the beam for find out the deflection of the beam with increasing the load. Three dial gauge is used, one at center and other two dial gauge on left and right side near the support to measure deflection in beam. The central dial gauge has least count of 0.002mm while remaining two dial gauge has least count of 0.01 mm. All the beams were simply supported at two support. Beams placed, aligned in centered and leveled in both the direction with the help of level tube. Deflection gauges reading were taken at proper load interval. First crack load and ultimate load was recorded and crack propagation was traced by the use of pencil.

Table 2 Mix design specification for 1 m^3 of concrete

f_{ck}	25 N/mm^2	
Max. size of aggregate	20 mm	
W/c ratio	0.45	
Mass of cement	337.56 kg (OPC-53)	
Mass of fine aggregate	836.99 kg	
Mass of coarse aggregate	1131.37 kg	
Water	151.81 lit.	
Mass of fibers	Polypropylene fiber - 6.4 kg	
	Steel fibers -55 kg	

Table 3 Properties of fibers

Property	Steel Fiber	Polypropylene Fiber
Cross section	Circular	circular
Length	30 mm	6 mm
Equivalent diameter	0.6 mm	3x10^{-3} mm
Aspect ratio	50	2000
form	Hook end type	Monofilament
Volume	0.7 % by volume of concrete	0.7 % by volume of concrete
Density	7850 Kg/m^3	910 Kg/m^3

III. DERIVATION OF SHEAR STRENGTH FORMULA

A. *Foundation formula:*

The foundation formula used of Canadian standard association CSA A23.3-04[13]. As per CSA-A23.3-04 design for shear in beams were given in chapter 11 from clause no 11.3 to 11.7 (page no.57 to 66). Shear resistance for concrete beam can be determined as per cl.11.3.3 as shown in below equation.

$$V_c = \beta \sqrt{f'_c}\lambda\ \phi_c b_w \mathrm{D} \quad (1)$$

Ultimate shear strength can find out by incorporating respective value in above formula, the basic formula can shown,

$$W_u = 2\,V_c = 2\left(\frac{230}{1000+d}\right)\sqrt{f'_c}\lambda\ \phi_c b_w \mathrm{D} \quad (2)$$

Incorporating the size effect parameter in above equation, in above equation β is a function of depth and maximum aggregate size, compressive strength of cylinder included. Based on the research three variable included in size effect parameter.

1. Effective length to depth ratio (Le/D)
2. Shear span to depth ratio (a/d)
3. Longitudinal reinforcement ratio (ρ)

The proposed equation takes the form as shown below:

$$W_{eq} = 2V_c = 2\left(\frac{230}{1000+d}\right)\sqrt{f'_c}\,\lambda\,\phi_c b_w\ \mathrm{D}\left(\frac{a\left(\frac{l_e}{D}\right)\rho^b}{\left(\frac{a}{d}\right)^c}\right) \quad (3)$$

Where a, b and c are regression coefficient to be find out by statistical analysis.

B. *Ultimate shear strength formula*

The relevant data from 15 reinforced concrete beams were used in the proposed regression analysis, the relevant data for which are presented in Table 1. Regression analysis was carried out using IBM -SPSS software with the help of 77 beams relevant data[14][15][16][17][18]. Ratio of Le/D varied from 2 to 6 in beams while a/d ratio varied from 1 to 2.5 for specific moderate deep beam case. Longitudinal steel ratio take from all the beams as mentioned in Table 1.

The solutions for the regression coefficients (after appropriate rounding) led to the following equation for predicting the shear strength of moderate deep beam:

$$W_u = 2\left(\frac{230}{1000+d}\right)\sqrt{f'_c}\ \lambda\ \phi_c\ b_w\ \mathrm{D}\left[\frac{k\ \rho^{0.344}}{\left(\frac{a}{d}\right)^{1.23}}\right] \quad (4)$$

Where,

$k = 11.96 \text{ x} \left(\frac{l_e}{D}\right)$

β = Size effect constant

f'_c = Compressive strength of cylinder in MPa

λ = Factor used for light weight concrete (for normal concrete taken as unity)

ϕ_c = Resistant factor for concrete (taken as 0.65)

b_w = Width of member in mm

D = Overall depth of member in mm

d = effective depth of member in mm

a= shear span of member in mm

ρ = longitudinal steel reinforcement ratio

l_e = effective length of member in mm

IV. COMPARISION OF PROPOSED EQUATION WITH EXPERIMENTAL RESULTS

The ultimate shear strength from predicted by proposed equation and experimental obtain ultimate shear strength were compared for verification of the proposed model. The calculated ultimate load by proposed equation and experimental results graph compered as follows:

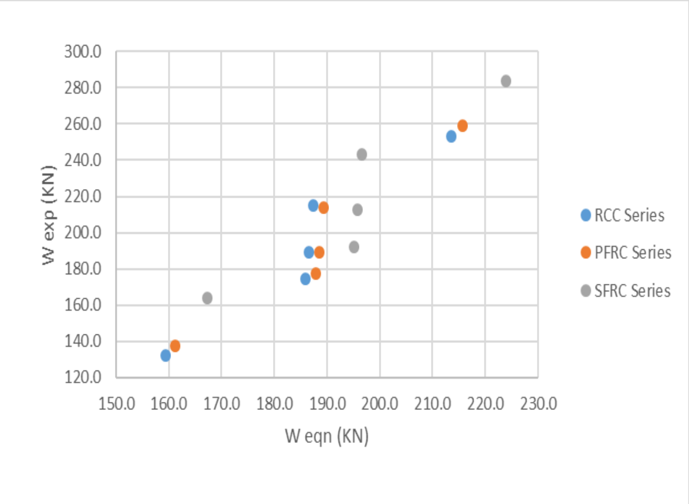

Figure 1 W_{exp} vs. W_{eqn}

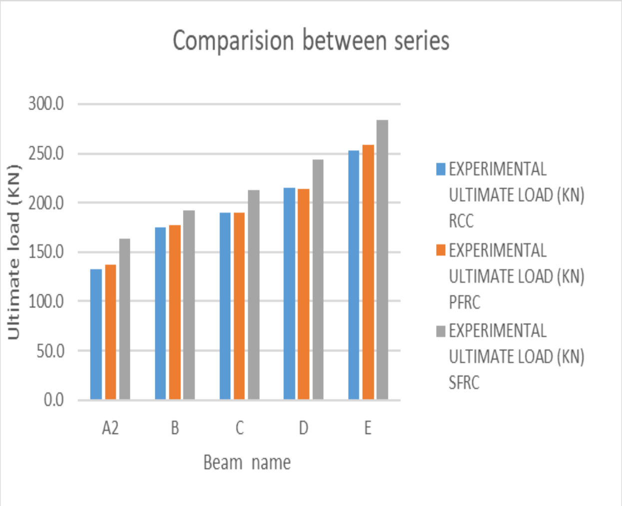

Figure 2 Ultimate load comparison

Table 4 Comparison of ultimate load between different series

Beam name	RCC Series			PFRC Series			SFRC Series		
	W_u Eqn. (KN)	W_u Exp. (KN)	W_u Exp./W_u Eqn.	W_u Eqn. (KN)	W_u Exp. (KN)	W_u Exp./W_u Eqn.	W_u Eqn. (KN)	W_u Exp. (KN)	W_u Exp./W_u Eqn.
A2	159.4	132.4	0.83	161.1	137.3	0.85	167.3	163.8	0.98
B	185.9	174.6	0.94	187.9	177.6	0.94	195.1	192.3	0.99
C	186.6	189.3	1.01	188.6	189.3	1.00	195.8	212.9	1.09
D	187.4	214.8	1.15	189.4	213.9	1.13	196.6	243.3	1.24
E	213.5	253.1	1.19	215.7	259.0	1.20	224.0	283.5	1.27

From the above Figure 1, we can say that proposed equation predict accurate results as compared to experimental values in RCC series. In the case of PFRC and SFRC the variation between W exp. And W eqn. is quite large about ±27 %, while error in RCC series is near about ±15%. Form the Figure 2, ultimate load increases as depth of beam increases. SFRC series have higher ultimate load than PFRC and PFRC have higher ultimate load than RCC series of beam for same size.

V. LOAD DEFELECTION CHARACTRISTICS

Load deflection behavior finds out for the all the series of beams by experimental sequence. Three deflection gage used, one at center and other two at end to find out ductility and reserved strength of the beams. All the specimens tested under two- point loading (pure shear case) in UTM of 200 tonne capacity.

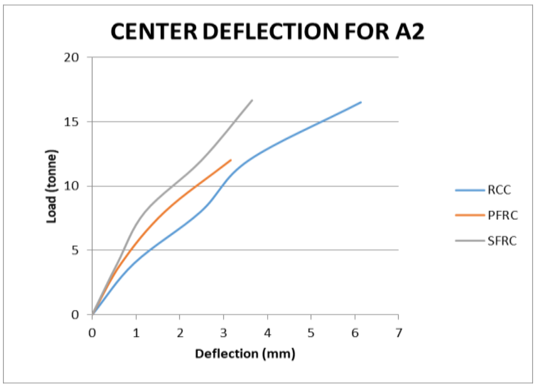

Figure 3 Load vs. deflection for A2

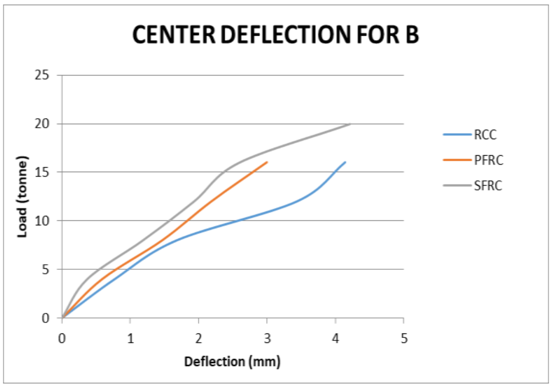

Figure 4 Load vs. deflection for B

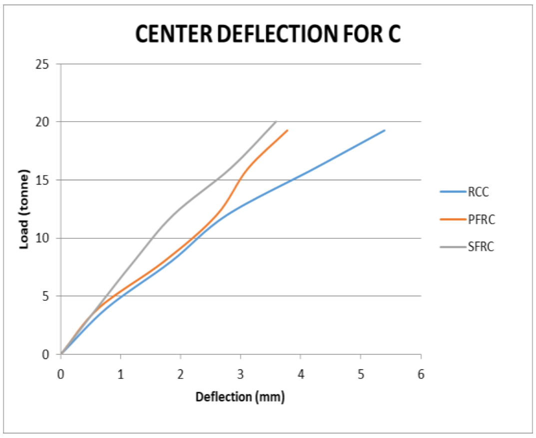

Figure 5 Load vs. deflection for C

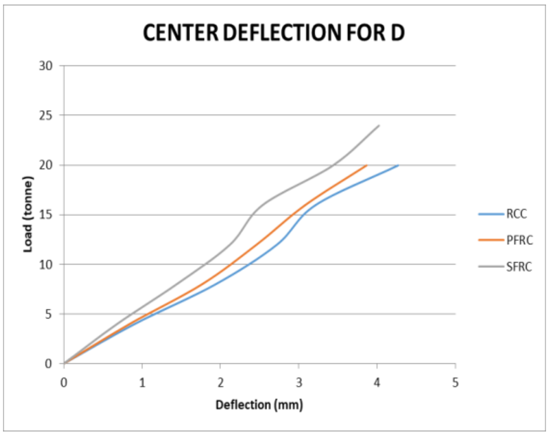

Figure 6 Load vs. deflection for D

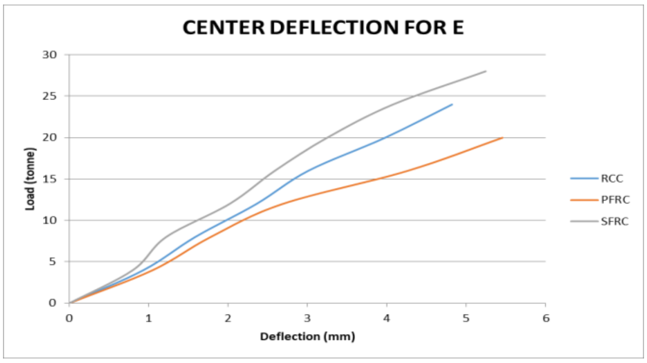

Figure 7 Load vs. deflection for E

From the above figures, load vs. deflection graph are linear up to first crack appeared but after that slope of graph changes drastically. Deflection increases as SFRC to PFRC to RCC at constant load. Ductility increases as RCC to PFRC to SFRC series for same size of beam. Deflection found maximum in RCC series of beam while minimum deflection found in SFRC series of beam. Crack found wider in RCC series of beams due to presence of steel fibers. Generally, all beams found fail in flexural shear or in pure shear case.

VI. CONCLUSION

- From the ultimate load result it clearly seen that as beam depth increases load carrying capacity of moderate deep beams increases. Depth increases from 225 to 425 mm accordingly load carrying capacity increases 190 % for RCC series, 180 % for PFRC and SFRC series.

- From the ultimate load readings, ultimate load for RCC and PFRC were almost same but in SFRC series ultimate loads increase up to 25 % due to steel fibers

- PFRC series ultimate loads were varying from RCC about 2 to 5 %, so it concluded that fiber content 0.7 % were not optimum dosage, fiber content must be increase for increase the shear strength.

- Experimental results of the present research work are compared with modified CSA-A23.3-04 formula and the results shows that ± 20 % variation in RCC series, for PFRC and SFRC Beam series fiber factor may have introduced in proposed equation for getting accurate result.

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