EXPERIMENTAL EVALUATION OF SIZE EFFECT ON DEFORMATION CRACKING AND STRENGTH IN FIBEROUS CONCRETE MODERATE DEEP BEAM

Synopsis of the

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A horizontal structural member capable of bearing the load, resist bending, is called Beam. Bending occurs due to external load, self-weight and due to span. Generally, beam can be classified according to their span to depth ratio (L/D) and shear span to depth ratio (a/D) .American Concrete Institute (ACI) 318-1995 gives special provisions for deep flexural members

1. Shallow beam : $L/D \geq 6.0$ or $a/D > 2.5$
2. Moderate Deep beam: $2.0 < L/D < 6.0$ or $1.0 < a/D < 2.5$
3. Deep beam : $0.5 < L/D \leq 2.0$ or $a/D < 1$

Shallow beams are characterized by linear strain distribution, The analysis of shallow beams is based on simple bending theory with the assumption that plane sections normal to the axis remain plane after bending.

Moderate deep beams fail under flexure-shear failure. These types of beams are transition between shallow and deep beams concerning all its properties related to its structural behavior under applied loading. As the beam become shorter or deeper the stress distribution becomes non-linear with the tensile stresses concentrating towards the bottom of the beam. The stress at mid span deviate more and more from those predicted by the simple bending theory.

Deep beams are structural elements loaded as simple beams in which a significant amount of the load is carried to the supports by a compression force combining the load and the reaction. As a result, the strain distribution is no longer considered linear, and the shear deformations become significant when compared to flexure.

As per Indian code IS: 456-2000[1] (page no.51, clause no. 29.1) has specify a beam shall be classified as a Deep beam when the ratio of effective span to overall depth, l/D is less than 2.0 for a simply supported beam and 2.5 for a continuous beam.

FIBER REINFORCED CONCRETE

Fibrous concrete can be defined as a composite material consists of mixture of ordinary concrete and discontinuous, discrete, uniformly dispersed suitable fibers which increases its structural integrity. Fiber stands as an alternative to increase the load carrying capacity of concrete in tension. Fibers added to concrete to increase the toughness and tensile strength. Fibers improves in the resistance of cracking and deformation in concrete. Different types and properties of fiber are added to concrete. Fiber is a small piece of reinforcing material possessing aspect ratio properties. There are different types of fiber can be used in the concrete such as steel fibers, glass fibers, synthetic fibers and natural fibers.

NECESSITY OF FIBER REINFORCED CONCRETE

The use of concrete as a structural material is limited to certain extent due to deficiencies like brittleness, poor tensile strength, poor resistance to impact strength, fatigue and low ductility.

The role of fibers are essentially to arrest any advancing cracks by developing the forces at the crack tip, thus delaying their propagation across the concrete matrix. The ultimate cracking strain of the composite is thus increased to many times greater than that of unreinforced matrix.

Admixtures like fly ash, silica fume, granulated blast furnace slag and metakaolin can be used to produce higher grade of concrete. Reinforcing capacity of fiber is based on length of fiber, diameter of fiber, the percentage of fiber ,orientation of fibers and aspect ratio of fiber. Aspect ratio is ratio of length of fiber to its diameter which plays an important role in fiber reinforced concrete.

POLYPROPYLENE FIBROUS CONCRETE (PFRC)

Polypropylene is 100 % synthetic fiber which is derived from 85 % propylene. The monomer of polypropylene is propylene which is by product of petroleum. Polypropylene fibers are hydrophobic, they do not absorb water. Therefore, when placed in a concrete matrix they need only to be mixed long enough to insure dispersion in the concrete mixture. The mixing time of fibrillated fibers should be kept to a minimum to avoid possible shredding of the fibers. There are different forms of polypropylene fibers available in the market like mesh form, bunchy form, and monofilament non fibrillated form. Generally, fiber content may vary with 0.1% to 0.7 % of volume of concrete. As per literature optimum dosage is 0.5 to 1.5 %. Addition of fibers results in increase in tensile strength and flexural strength. It controls formation of micro cracks. Hence it is ideal for seismic designs and high strength concrete.

STEEL FIBORUS REINFORCED CONCRETE (SFRC):

Steel fibers are used to prevent plastic and drying shrinkage in concrete. Further research and development revealed that addition of steel fibers in concrete significantly increases its flexural toughness. The energy absorption capacity, ductile behavior prior to the ultimate failure reduced cracking, and improve durability. Steel fiber content used between 0.3% to 2.5% by volume in plain concrete. Classification of steel fibers done according to cross sectional shape and geometrical shape of fiber i.e. hook end type, crimped type, arch with band ends. Addition of Steel fibers increases impact resistance, control crack growth and crack widening, increases the ductility, increases the shear strength and tensile strength of concrete.

AIMS AND SCOPE

Moderate Deep beams and Deep beams have a wide application in structural engineering field. Numerous investigations have been carried out and reports were published regarding the shear strength and the load-deformation behavior of Moderate Deep beams and Deep beams, but very few works have been reported on the study of evaluation of size effect on deformation, crack pattern and shear strength in Moderate Deep beam.

As moderate deep beams fail in flexure shear mode. Different researchers they have not considered the size effect parameter in Shear strength formula. The formula related to crack width of RCC, PFRC and SFRC is revised by using the size effect parameter. In the present investigation in crack analysis the types of crack pattern, number of cracks position and propagation of cracks observed related to size effect in case of Moderate Deep beam .

LITERATURE REVIEW: -

A transitional size effect may be simply described by the law proposed by Bazant $\sigma N = \beta\ ft\ (1 + \beta)(-0.5)$ $\beta = (d/da)$ In which da and β are empirical constants and ratio β is called the brittleness number, σN is nominal stress at failure, d is a characteristic depth of the specimen and ft is tensile strength. G. Appa Rao And R. Sundaresan refined strut-and-tie model. The generic form of the size effect law has been retained considering the merits of Siao's model and modified Bazant's size effect law which was modified by Kim and park. Using the large experimental data base reported in the literature. The proposed equation for predicting the shear strength of deep beams incorporates the compressive strength of concrete, ratios of the longitudinal to web reinforcement, shear span-to-depth ratio and the effective depth. Ahmed I. Ramadan and Aly G. Aly Abd-Elshafy takes formulas from Egyptian Code- ECP203-10, ACI Building Code 318-14, Canadian code CSA A-23.3-94 , European Code EC2 (2011), BS 8110 (1985) British code and Zsutty's (1968) formula for prediction of shear strength of Deep Beams and compare results with proposed equations. Jin- Keun Kim and Yon-Dong Park takes the rational and mechanics based equation is proposed for the prediction of shear strength of reinforced concrete beams without web reinforcement. This prediction is based on basic shear transfer mechanisms, a modified Bazant's size effect law, and numerous published experimental data, including high-strength concrete beams with compressive strengths of concrete up to 100 MPa. Comparisons with experimental data indicate that the proposed equation estimates properly the effects of primary factors, such as concrete strength, longitudinal steel ratio, shear span-to-depth ratio, and effective depth.

EXPERIMENTAL SET UP:-

Total 75 beams had been casted and tested under central point load and two point load to find the shear strength of the Moderate Deep beam. The test specimen consist 21 nos. of Moderate Deep beam having effective span to overall depth ratio 2 (i.e. L/d =2). All these 21 numbers of beams having three series of beams. Each series consist of 7 beam having depth ranging from 150 mm to 600 mm and span 300 mm to 1200 mm. Plain concrete (R), Reinforced concrete (RL) and Fibrous concrete (RLF).Each beam having reinforcement ratio 0.3 % and anchored at end with the length of 0.8 Ld Beam sizes are selected as per BAZANT'S size effect laws, which are given as,

Minimum Width(b) and depth (d) > 3 x da.(da = size of aggregate)

Provided Width(b) = 75 mm >(3 x da = 3 x 20 = 60mm),

Provided Depth(D) = 150 mm >(3 x da = 3 x 20 = 60mm)

Largest Depth(D) $\nless$ 10 x da,

Provided Largest Depth (D) = 600 mm> (10xda= 10 x 20 = 200mm)

The ratio $\frac{\text{Largest Depth}}{\text{Smallest Depth}} = 4$ Provided Ratio = $\frac{600}{150} = 4$

d/da = 4,8,16 acceptable and d/da = 3,6,12,24 preferable. All specimen should be geometrical similar in two direction with third dimension kept constant . Span = Varying, Depth = Varying and Width = Constant. Width of all the beams (b) were kept constant as 75mm. That means L/d and a/d ratio remain same for all specimens.

The test specimen consists 24 nos. of Moderate Deep beam having effective span to overall depth ratio 3 (i.e. L/D =3). The test specimen consists of two types, first types having 5 beams and second types having 7 beams. Beams have depth ranging from 100 mm to 400 mm and effective span ranging from 300 mm to 1200 mm. The depth is varying from 100 to 400 mm. The span is varying from 300 to 1200 mm. Each series having different types of concrete Moderate Deep beam, fibrous RCC and fibrous layered RCC Beam.

An experimental work was conducted on 30 nos. of Moderate Deep beams which were divided in 3 series i.e. RCC Moderate deep beams (10 Number), PFRC Moderate deep beams (10 Numbers) SFRC Moderate deep beams (10 Numbers). Amongst all 10 beams of a particular group, size differs from 700mm to 1500mm in span and 150mm to 400mm in depth. Bearing plates having size 75 mm length x 75 mm width x 6 mm thickness for a/d ratio 1 placed at the loading points and at the supports. For the a/d ratio of 2, 100 mm length x 75 mm width x 6 mm thickness plates were used as loading plate and at supports. Concrete cover provided to the stirrups was 25 mm. Side cover is taken as 15 mm from face of the beam.

TEST MATERIALS

In Experiments the Portland pozzalona cement of grade 53, ordinaly river sand having fineness modules of 2.8 and maximum size of sand is 4.75 mm, and crushed basalt gravels having a maximum size of 20 mm and 10 mm were used as a coarse and fine aggregate respectively. The concrete mix of M 25 grade of concrete with water cement ratio of 0.45 was used for all beams. Steel fiber and Polypropylene fibers are used in preparing fiber reinforced concrete. The qty of fibers taken as 0.7% by volume. Longitudinal tension reinforcement consists of High yield strength deformed bars (415 N/mm^2) used, Vertical Shear Reinforcement (stirrups) are not provided in fibrous concrete Moderate Beam. Cubes (150mm) and cylinders (150mm diameter and 300mm height) cast to check the compressive strength and for splitting tensile strength of concrete.. All specimens were curing at least for 28 days in curing water tank.

SIZE EFFECT PARAMETERS CONSIDERED FOR MODIFICATION OF SHEAR STRENGTH AND CRACK WIDTH EQUATION.

Lots of work had been carried out for maximum crack width equation and many researchers have considered various size effect parameters only for flexure crack in a RCC and Pre-stressed members. While a very little work had been done for maximum shear crack width in Moderate Deep beam especially considering a size effect parameter and incorporating fibers in it. List of parameters are given as : Longitudinal reinforcement ratio ,Shear reinforcement ratio (ρw) ,Steel rebar arrangement ,Grade of steel (fy), Grade of concrete (fck), Steel stress (fs), Strain in steel (εs),Strain in concrete at level of reinforcement (εc),Concrete cover (Cc),Bond factor (bond between reinforcement and concrete), load application duration, modular ratio (m), Diameter of bar (Φ), Strain distribution factor, Shear span to depth ratio (a/d), Effective length to overall depth ratio (L_{eff}/D), Modulus of Elasticity of steel (Es), Fiber aspect ratio (diameter/length), % of fiber reinforcement, Depth of neutral axis (x_u), and Maximum bar spacing (s).

From the above list of parameters, Le/D (effective length to depth ratio) and Φ/ρ (ratio of diameter of bar to percentage reinforcement) are taken into consideration to evaluate the maximum crack width and crack behavior. Aspect ratio of fiber (Φ/l) and % of fibers are also correlated with the equation obtained for controlled specimen of RCC. Wide range of variations was observed in crack width for various L/d ratio and effect of fibers are affirmative for reducing crack widths. A factor which compares the width of crack of FRC beams with simple RCC beams at the Ultimate load.

CRACK PATTERNS

In Moderate Deep beam crack pattern is important to understand the shear deformational behavior of beams which predominantly fails in flexture shear. In RCC members mainly three types of cracks are observed: flexure cracks, flexure-shear cracks and shear cracks. In shallow beams, the predominant crack is flexure crack. In Moderate Deep Beams, the predominant crack is flexure-shear crack. In Deep beams, the predominant crack is shear crack.

MODES OF FAILURE

The modes of failure in Moderate Deep beam containing fibers can be of different types such as flexure failure, flexure shear failure, diagonal compression failure, and local compression failure, anchorage failure at support and split& diagonal tension failure.

1) Flexure Failure :-It is due to the yielding of longitudinal main steel bars. Flexure cracks appeared first in the region of maximum bending moment and initiated from the soffit of the beam. Flexural crack(s) will propagate upwards quickly.

2) Flexure-Shear Failure :- As the loading reaches 40-50%, the flexure cracks in shear span extend quickly towards the loading point with width wider in bottom and narrow upwards.

3) Shear Failure :-Shear failure is generally classified as diagonal tension failure and shear compression failure. In shear compression failure parallel inclined cracks occur between the loading point and support point. This beam appears strut between the load point and the support.

4) Local Compression Failure:-At support and point of applied concentrated load, the value of vertical stress is very large. A local compression failure may occur due to local crushing of concrete at the points of supports.

5) Anchorage Failure :-This type of failure occurs at near the support (junction of strut and tie). If there is not properly supported slip takes places and all tensile stresses generate at the junction of support and create the anchorage failure.

MODIFIED EQUATION FOR SHEAR STRENGTH OF THE MODERATE DEEP BEAM

In present experimental work P. J. ROBBINS original formula is modified with incorporating size effect factor given by Z. P. BAZANT and looking to the graph of comparison the calculated nominal shear stress show close agreement with experimental nominal shear stress. Modified P. J. ROBBINS formula as, λ_o = 13.68 incorporated in the Original P.J.Robbins formula.

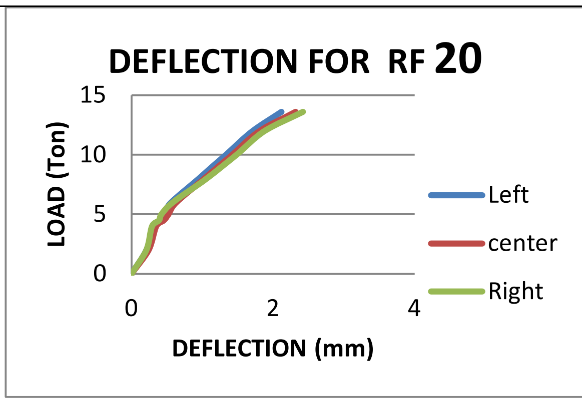
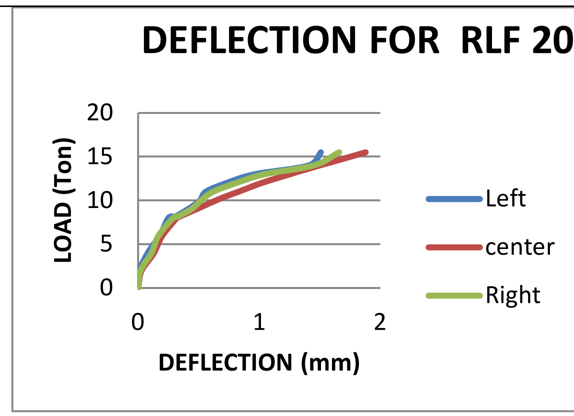
The Experimental Normal shear stress decreases as the member depth increases so the Bazant size effect factor incorporated into original P J ROBBINS formula we get modified P.J.ROBBINS formula. By Using Modified P.J. ROBBINS formula the Nominal Shear stress very close to experimental Nominal shear stress. The calculated nominal shear stress by using P. J. ROBBINS original formula not considered the member depth, while experimental results shows Nominal shear stress decreases as member depth increases. It seems that in Original P. J. ROBBINS formula size effect parameter not considered.

The following assumption are taken in size effect factor incorporated in research work.

1. Size effect factor "S_f" is proportional to "$d^{(-1/3)}$" ($S_f \propto d^{-\frac{1}{3}}$)
2. Size effect factor for normal concrete is not affected by f_{ck} while for high strength concrete size effect factor is more significantly affected by f_{ck}.
3. Effect of fiber considered with Tensile strength of concrete (f_t)
4. In Concrete beam the size effect is considered with respect to geometry of the beam.
5. S_f does not affect longitudinal reinforcement or vertical shear reinforcement.
6. In this equation we are trying to consider size effect factor(S_f) with concrete term (Vc) only.

<u>Deflection Characteristics</u>

In all beams during testing the deflection measures at right side, central and left side at specified distance along the span under central point and two point load. In all beams RF=Fibrous RCC Beam and RLF= Fibrous layered RCC Beam.

	
Deflection of $(75 \times 200 \times 700)$ Size FIBEROUS RCC (RF) beam	Deflection of $(75 \times 200 \times 700)$ Size FIBEROUS LAYERED RCC (RLF) beam

From the graphs of Load vs Deflection it is observed that, during the first elastic stage the curve is almost linear line. After yielding of beam the curve changed its slope and it became more flat. There was a considerable deviation in load deflection curve after the yielding of beam, which occurs first cracking and yielding of beam which caused a sudden increase in deflection.

Figure shows load deflection curves of various series of beam tested in this investigation are presented. Generally during elastic stage the central deflection was slightly more than the left and right deflections under one point load. In some of the beams in which major cracks appeared in shear zones suddenly, the corresponding side of the deflection increases slightly more than the central deflection.

Sample calculation of Ultimate Shear Strength Using Modified Eurocode-02 Equation for RCC , PFRC and SFRC beam. The size effect factors β = $0.07\sqrt{fck}$, Vf,lf and df incorporated in the Eurocode formula.

In CSA A23.3-04 the shear strength equation is modified with size effect parameter. The modified equation is given below

$$\boldsymbol{W_{mod}} = \mathbf{2\ x}\ \left(\frac{\mathbf{230}}{\mathbf{1000+d}}\right) \mathbf{x} \sqrt{f_c'}\ \mathbf{x}\ \boldsymbol{\lambda}\ \mathbf{x}\ \boldsymbol{\phi_c}\mathbf{x}\ \frac{\boldsymbol{k}\ \mathbf{x}\ \boldsymbol{\rho}^{\mathbf{0.344}}}{\left(\frac{a}{D}\right)^{\mathbf{1.23}}}\ \mathbf{x}\ \boldsymbol{b_w}\ \mathbf{x\ D}$$

in above beam formula the size effect parameter $\boldsymbol{r}\ \mathbf{x}\sqrt{\boldsymbol{\rho}\ \mathbf{x}(\mathbf{1}+\mathbf{4}\boldsymbol{F})\boldsymbol{f_c}}$ added in PFRC beam and SFRC Beam.

Maximum crack width for RCC moderate deep beam

$$W_{max} = \frac{0.03217\beta f_s \sqrt[3]{d_c A_o}\left(\frac{\Phi}{\rho}\right)^{\left(0.052*^{Le}/_{D}\right)}}{1+\left(\frac{L_e}{D}\right)^{-1.245}} \times 10^{-3}$$

L=Effective span, b = Width of beam, D,h=overall depth of beam, d_{eff} =Effective depth of beam, d_c = Concrete clear cover, A=shear span, fck = Characteristics compressive strength, E_s = Modulus of elasticity of steel bars, Φ = Diameter of bars, n =Number of bars, S = Maximum bar spacing, P= Ultimate Load.

Maximum crack width for PFRC moderate deep beam

$$W_{max} = \frac{0.03217\times10^{-3}\beta f_s \sqrt[3]{d_c A_o}\left(\frac{\Phi}{\rho}\right)^{\left(0.052*^{Le}/_{D}\right)}}{1+\left(\frac{L_e}{D}\right)^{-1.245}} - \frac{2}{3}\%V_f \sqrt[2]{^{l_f}/_{d_f}}$$

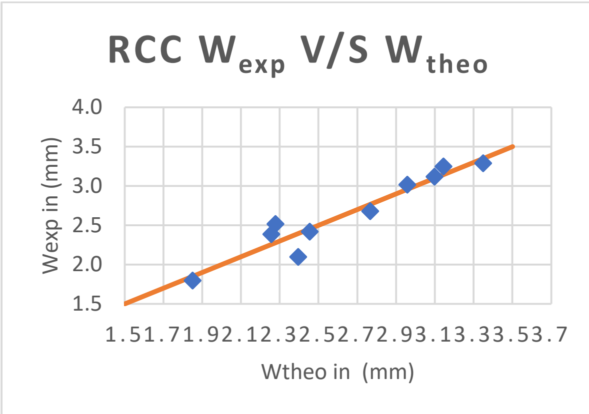
Maximum crack width for SFRC moderate deep beam

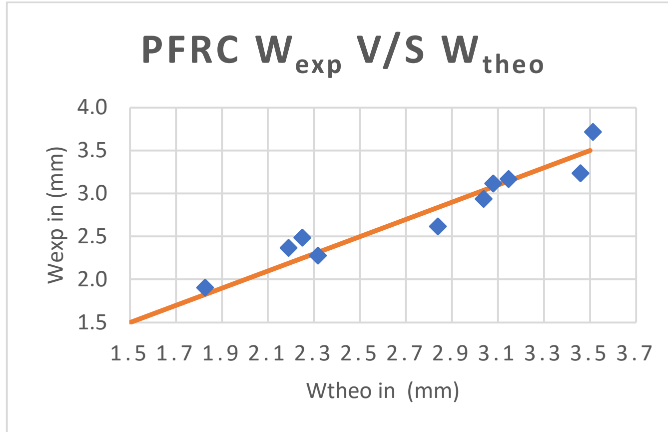
$$W_{max} = \frac{0.03217\times10^{-3}\beta f_s \sqrt[3]{d_c A_o}\left(\frac{\Phi}{\rho}\right)^{\left(0.052*^{Le}/_{D}\right)}}{1+\left(\frac{L_e}{D}\right)^{-1.245}} - 3.616\%V_f \sqrt[2]{^{l_f}/_{d_f}}$$

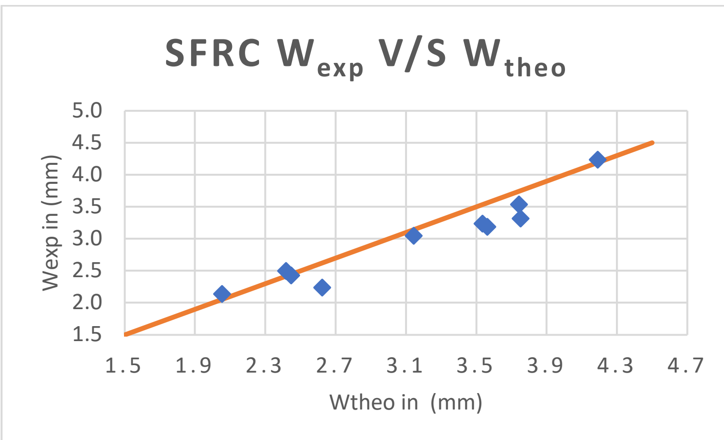
RESULTS AND DICUSSION FOR CRACK WIDTH OBTAINED EXPERIMENTALLY AND THEORETICALLY

Moderate deep beams of various sizes were experimentally investigated for the analysis of maximum crack width and a theoretical expression was derived to predict the crack width. Obtained results shows scattered values with maximum error around ±15%. The values are in a narrow range of unit slop and zero intercept line which expresses that W_{exp} values and W_{theo} values are almost equal. Above obtained formula for RCC specimens best fits with the experimental values.

Comparison of experimental crack width Vs predicted values







PFRC and SFRC specimens also shows same trend as of RCC specimens. Error between experimental and calculated values for PFRC specimens fluctuate around ±10%. As FRC material reduces crack width thus in modified equation of RCC, a fiber factor is deducted to get the crack width for FRC material which offers satisfactory results with minimal errors. In case of SFRC W_{exp} Vs W_{theo} ratio error is around 11%. Crack width decreases in PFRC material compared to RCC. In SFRC lowest crack width was observed with respect to RCC & PFRC.

Conclusions

1. Comparisons of test results and theoretical values for R.C.C. Moderate Deep Beams without horizontal stirrups, ("R" beams series) were tested and its Ultimate load were compared with Original P J Robin, Modified P J Robin, Modified IS, Original Equation and Modified Equation. Average error given by *Modified Equation is 5.20%*,for beams with horizontal stirrups, ("RL" beams series) average error is *20.90%* , for beams with fibers without horizontal

stirrups, ("RF" beams series) average error is -4.02% and for beams with fibers with horizontal stirrups ("RLF" beams series) Average error is 1.494% from the test results.

2. The comparisons of test results and theoretical values for average of Ultimate Shear Strength ratio (Wu test/ Wu Theo) for "R" beams series, by Modified Equation is 1.03. for "RL" beams series series, by Modified Equation is 1.21, for "R" beams series by Modified Equation is 0.04, for "RL" beams series by Modified Equation is 0.10 and for "RF" beams series, by Modified Equation is 0.87, For "RF" beams series by Modified Equation is 0.12 and for "RLF" beams series, by Modified Equation is 1.01, For "RLF" beams series by Modified Equation is 0.02.
3. The comparisons of test results and theoretical values for overall average of Ultimate Shear Strength ratio (Wu test/ Wu theo) for all beams (For R, RL, RF, and RLF beams series) by Modified Equation is 1.02. Whereas the values obtained from equations of original P J Robin, Modified P J Robin, Modified IS and Original Equation are 0.63, 0.85, 1.96 and 0.74 respectively.
4. The comparisons of test results and theoretical values From nature of graph of "R" beams series Size Effect by Modified Equation are same as test result, Where as in "RL" and "RF" beams series nature is same but values are different and in "RFL" beams series nature and value are almost same.
5. During testing of beams, it is noticed that for a given Moderate Dep beam, as point load increase, flexure cracks are formed at the bottom of the beam. With further increase in the loading, these flexural cracks propagate from bottom to top of the beam in the direction of transferring load from load point to support. These flexure cracks continue up to certain depth from bottom of beam. Further increasing the load the flexure cracks are widen and shear cracks starts in shear zone of the beam and ultimately beam will fail in shear. In shear crack the tensile stresses are perpendicular to direction of loading from point load to support while compressive stress develops from load point to support.
6. Most of Beams were failed in Flexure-Shear mode of failure. Except H/SFRC, I/SFRC and J/SFRC which fails in Flexure, this may be because of the Shear strength of beam enhance due to steel fibers.
7. Looking to the failure pattern of beams, the diagonal shear cracks appeared along the line joining the load and support reveals the elliptical pattern of strain distribution. Except H/SFRC,I/SFRC and J/SFRC which fails in Flexure.
8. comparisons of test results and theoretical value for all beams. The values obtained from original P.J. Robinson equation are incomparable with test results. But values obtained from modified P.J. Robinson equation are nearly

same to the test values. After adding the size effect parameter in the equation test results and experimental results are nearly same.

9. Ultimate load for RCC and PFRC were almost same but in SFRC series ultimate loads increases up to 29 % due to steel fibers.
10. PFRC series ultimate loads were varying from RCC about 2 to 10 %, so it concluded that fiber content 0.7 % were not optimum dosage, fiber content must be increase.
11. First crack load increases from RCC to PFRC and from PFRC to SFRC series, due to addition of fiber.
12. Looking to the values of Ultimate load, Deflection, First Crack load and Crack width at any load stage it can be concluded that in all fibrous beam good control of deflection and crack width compare to RCC series. It is also noticed that in fibrous series deflection and crack width were reduced at any given level compare to RCC series. Less crack width in this case reveals the ability to transmit tensile stresses across diagonal crack was increased in fibrous beams when compare to that of RCC beams.
13. Steel fiber dosage 0.7 % is more effective than the polypropylene fiber 0.7% dosage, which can clearly notice in first crack load and ultimate load results.
14. Experimental results of the present work were compared with theoretical result for RCC and fibrous series. Theoretical results are calculated using Canadian standard formula CSA-A23.3-04, by observing theoretical results all the experimental results were showing 85 to 90 % of variation. This result generates thus needs of modification with respect to size effect in CSA formula.
15. In CSA standard formula, there were missing important parameter like longitudinal steel ratio, shear span to depth ratio which directly related to shear strength of moderate deep beam.
16. Experimental results of the present work were compared with the existing formulas of size effect proposed by various researchers as APPA RAO (2012) and modified IS 456-2000 formula. All the results of RCC series are near about the G. APPA RAO's proposed formula but in the cases of fibrous concrete results are differ by 10 to 12 %. All the beams results predicted by modified IS 456-2000 varying by 55-60 % from experimental results.

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