2. LITERATURE REVIEW

2.1. GENERAL

Few investigations were carried out to investigate the size effect in RCC and fibrous concrete beams having different types of Loading condition, Geometry, Concrete material, various fibres, and span to depth ratio. Few Researcher work on moderate deep beam to investigate size effect and its failure characteristic. Some Researcher tried to explore size effect solution with using different Model of Analysis.

A general view of published literature of some of the investigators on size effects is briefly described.

2.2. LITERATURE SURVEY

2.2.1. Size Effect on Diagonal Shear Failure of Beams Without Stirrups

Zdenek P. Bazant and Mohammad T. Kazemi(25)

Authors have presented the results of test on Diagonal shear failure of Reinforced concrete beams without stirrups. The beams were geometrically similar, and the size range was 1:16. The diagonal shear failure of reinforced concrete beams has long been known to be a brittle type of failure. Brittleness implies the existence of size effect on the failure load, which is due to the release of stored elastic energy and the progressive nature of failure. This aspect of brittleness has so far been neglected by design codes.

For propagating failures in which the fracture process is not concentrated at a point but takes place within a finite zone ahead of the fracture front, the size effect is transitional between plasticity and linear elastic fracture mechanics. A transitional size effect may be simply described by the law proposed by Bazant.

$\sigma_N = B\, ft\, (1 + \beta)^{(-0.5)} \quad \beta = (d/do)$

In which do and B are empirical constants and ratio β is called the brittleness number, σ_N is nominal stress at failure, d is a characteristic dimension (Depth) of the structure and ft is tensile strength.

Two different test series, with effective beam depths d have been carried out. In the first series, with sizes in the ratio 1:2:4:8, the longitudinal reinforcing bars were straight, while in the second series, with sizes in the ratio 1:2:4:8:16, the reinforcing bars were provided with right-angled hooks at the beam ends to prevent bond slip and bar pullout at failure. The length-to-height ratio of all the beams was L/d = 6, and the span-to-depth ratio was L/d = 7. The loads were positioned so that the shear span was always equal to 3d and the total height equal to 5d/4 and 16d/13 for the first and second series, respectively. The thickness of all the specimens was equal to 38.1 mm.

From the test results authors had concluded that the diagonal shear failure exhibits a strong size effect of fracture mechanic type, due to difference in the stored energy that can be released to derive the failure propagation. For the Ultimate load there is a strong size effect, while for the first diagonal crack-initiation load the size effect is small or negligible, imposition of a certain margin of safety against the crack-initiation load does not insure a uniform margin of safety against the ultimate load. Consequently, a requirement based on the ultimate load must be introduced into design codes, which means the size effect has to be considered.

2.2.2. FIBER CONCRETE DEEP BEAM IN SHEAR

R. Narayanan And I. Y. S. Darwish Test-1988[58]

A rapid method of computing the Ultimate shear strength of a steel fiber concrete deep beam has been presented in this paper for design purpose by the authors. Three parameters were taken in the experiment such as the volume fraction of fibers, shear span-to-depth ratio, and the concrete compressive strength. The effects of fiber incorporation on Deflection, Strain, Crack width, Crack patterns, Failure modes, Cracking shear load, and Ultimate shear load have been examined. The principal design equation from Kong, Robins, and Sharp has been modified to account for the steel-fiber content. This new equation was validated with test observations.

Investigations reported shows that the inclusion of steel fibers in reinforced concrete deep beams resulted in enhancing their deformation characteristics at all stages of loading up to failure, as well as improving their shear resistance. Fiber concrete Deep beams exhibit substantial increases in their Ultimate load as well as in the first crack load. By incorporating steel fibers in Deep Beams are potentially important and Practical construction method.

Twelve reinforced concrete deep beams were tested under two symmetrically placed concentrated loads. Each simply supported beam cross section 100 x 400 mm and span 1000 mm. Four deformed steel bars with 20 mm diameters were used in two layers. The amount of tension reinforcement in each beam corresponded to a value of 3.55%. Three cubes, 100 mm side, were prepared from each batch and used for determining the compressive strength of the fiber concrete, in conjunction with the casting of the beam test specimens.

Demountable gauge measurements (using Whittemore Gauges) were taken at eight levels along the depth at mid-span of each beam to obtain longitudinal surface strains during the test. The central deflection was measured using a transducer gauge connected to a calibrated digital voltmeter.

During the progress of the test the following observations were recorded. the development of crack, Propagation of crack, Width of crack and Deflections at mid-span longitudinal surface strains at different levels of loading along the depth at mid-span. General behavior of the beam under load and its mode of failure was observed. First Shear crack observed at Ultimate load. The cube tests were carried out to obtain the compressive strength of concrete.

Authors observed that at the early stages of loading, the beam behave in an elastic manner up to about 75% of the Ultimate load. An in-elastic stage then followed with increasing deformations until the Ultimate load was reached. In all specimen diagonal shear cracks were observed first at location of about

0.4D from the bottom and at loads ranging from 23 to 40% of the Ultimate loads. They were initiated along a line joining the loading point and reaction points. In all the beams develop such cracks and behave like as tied arches until collapse. From the initial loading the strain distribution across the depth of the beam was nonlinear. The location of the neutral axis at midspan changed during testing in some cases. The shear failure generally occurred due to the propagation of closely spaced diagonal shear cracks that eventually lead to the splitting of the beam from top to bottom.

An Analytical Model has been proposed by Kong, Robins and Sharp to predict the Ultimate shear strength of Deep beams made of conventionally reinforced concrete. As the behavior of the Fibrous concrete beams can be broadly treated in a similar way, this equation can be extended to Fiber concrete Deep Beams by substituting f_{spf} for f_{sp} as follows

$$\mathbf{V\,ult = c1\left(1 - 0.35\frac{\mathit{Xe}}{\mathit{ha}}\right) fspf.\,b.\,ha + c2\sum_{i=0}^{n} Ast.\frac{y}{ha}\,.\sin^2\alpha}$$

Where,

C1 = An empirical coefficient equal to 1.05 for Normal weight concrete and 0.75 for light weight concrete

C2 = An empirical coefficient equal to 100 N/mm² for plain round bars and 225 N/mm² for deformed bars

X_e = The effective clear shear span, mm

h_a = The effective height h or l, whichever is smaller, mm

f_{spf} = The split cylinder strength, N/mm²

b = The breadth of the beam, mm

A_{st} = The area of the individual web bar (for the purpose of this equation, the main longitudinal bars are considered as web bars), mm²

y=The depth of the bar measured from the top of the beam, mm

$$\mathbf{fspf} = \frac{\mathbf{fcuf}}{\boldsymbol{A}} + \mathbf{B} + \mathbf{C}\sqrt{\mathbf{F}}$$

Where,

f_{cuf} = The cube strength of fiber reinforced concrete, N/mm^2

A = Non-dimensional constant having a value of $(\mathbf{20} - \sqrt{\mathbf{F}})$

B = Dimensional constant having a value of 0.7 N/mm^2

C = Dimensional constant having a value of 1 N/mm^2

$$\boldsymbol{F} = \frac{\boldsymbol{lf}}{\boldsymbol{df}} . \boldsymbol{\rho}\mathbf{f}. \boldsymbol{\beta}$$

Where, $\frac{lf}{df}$ =fiber aspect ratio

ρf = Fiber volume fraction in the mix

β =Bond factor (based on large series of pullout test β has been assigned a relative value of 0.5 for fiber having circular cross section, 0.75 for crimped or hookedfibers,1.0 for indented fibers).

Comparison of Experimental and Theoretically results shows a very good correlation has been obtained. The mean value for the ratio of observed strength to the predicted strength for the 13 test is 0.298 with standard deviation of 0.063.

They concluded that the inclusion of steel fibers to concrete deep beams resulted in enhanced stiffness and reduced crack widths. The primary cause of failure was diagonal cracking, which led to the splitting of the beam along the diagonal cracks. Ultimate shear load could be estimated by equation presented in this paper.

2.2.3. BEHAVIOUR OF REINFORCED CONCRETE DEEP BEAMS IN FLEXURE AND SHEAR

S. N. Patel And S. K. Damle test [12]

In this thesis authors have studied the behavior of Reinforced Concrete Deep Beam in flexure and shear and expression for Ultimate shear strength of Reinforced Concrete Deep Beam without web reinforcement was developed considering splitting of an elliptical section whose major axis lies on a line joining the load and support points.

A static test on Deep Beam was performed. Ten beams under single point load and ten beams under two-point loads were tested in simply supported condition. Beams have span-to-depth ratios ranging from 1.0 to 2.5 and shear span-to-depth ratios ranging from 0.33 to 1.25. Plain round mild steel bars were provided as main tension reinforcement. Two types of web reinforcement, horizontal and inclined bars were provided. Electrical resistance strain gauges were applied on web reinforcement to study the strain variation on same.

Based on test results of 20 beams expression to find the stress variation in web reinforcement at different level was established. The proposed formula for the shear capacity of deep beam was given as

$$W = 2V_u = \left[\frac{3\, f_t\, b\, d}{\left\{1 + 0.75\left(\frac{a}{d}\right)^2\right\}^{\frac{1}{2}}}\right] + \left[\frac{f_y}{\{1 + \left(\frac{a}{d}\right)^2\}^{\frac{1}{2}}}\right]\sum^{n}\left[\frac{y_i}{d} + 0.4\right] A_{si}\sin\left(\alpha_1 + \theta\right)$$

Finally, the Ultimate shear loads have been calculated for Deep Beam data available in literature by several existing formula and by developing the formula in this research work and compared with the actual test results. The Ultimate loads given by the proposed formula shows good agreement with the test results of the beam.

2.2.4. RC DEEP STUDIED EXPERIMENTALLY AND BY THE FINITE ELEMENT METHOD

P. J. Robins Test [11]

Fifty Tests on normal weight and thirty-eight light weight reinforced concrete Deep beams with span-to-depth ratio ranging from 1.0 to 3.0 and with shear span-to-depth ratio ranging from 0.35 to 1.18 were carried out. The main purpose was to understand the effect of web reinforcement in simply supported deep beams.

The effective span of specimen was 762 mm and total length was 915 mm. Normal weight concrete beams were reinforced with single 20 mm diameter plain round bar and light weight concrete beams were reinforced with single 16 mm diameter deformed bar. Depending on type and amount of web reinforcement each group subdivided into eight series consisting of five beams of varying depth from 254 mm to 762 mm.

The failures of the beams were usually observed in one of the following ways:

- Deep penetration of one or more of the existing diagonal cracks into compressive zone at the loading point or at the support causing immediate failure by crushing of concrete.
- The propagation of diagonal cracks splitting the beams approximately along the line joining the loading point and support point.
- Crushing of strut like portion of concrete between two diagonal cracks.
- Crushing of concrete at load bearing blocks.
- Vertical splitting above a support, followed by crushing of concrete near the bearing block.

In this test, P. J Robins recognized the diagonal cracks as the widest and the most dangerous ones, while flexural cracks remain small and quite harmless. He concluded that initial cracking load is insignificantly affected by web reinforcement but not with Ultimate load.

Robins proposed the following shear strength formula:

$$V = C_1\left(1 - 0.35\,\frac{x}{D}\right) f_t\, b\, D + C_2 \sum^{n} \left\{A\left(\frac{y_i}{D}\right) sin^2\alpha_i\right\}$$

Where,

V = Ultimate shear strength of the beam (N)

C1 = Empirical coefficient equal to 1.4 and 1.0 for normal weight and light weight concrete respectively

C2 = Empirical coefficient equal to 130 N/mm^2 for plain round bars and 300 N/mm^2 for deformed bars

ft = Split cylinder tensile strength (N/mm^2)

b = Width of the beam (mm)

D = Overall depth the beam (mm)

A = Area of individual web reinforcement bar

yi = the depth at which an individual web bar intersects the potential diagonal crack

Potential diagonal crack assumed to be inclined at an angle of tan^{-1} (D/x) to the horizontal for uniformly distributed top loading. Robins suggested this inclination to be tan^{-1} (4D/L) to the horizontal.

Robins also concluded that the proposed formula can be used for the effects of different geometry of web reinforcement, and It can be applicable for light weight concrete deep beams.

2.2.5. Effect of Steel Fiber Content on Behaviour of Concrete Beams With And Without Stirrups

Dipti Ranjan Sahoo And Abhimanyu Sharma [48]

In this paper an experimental study on a series of 12 Reinforced Concrete and steel fiber reinforced concrete (SFRC) beam specimen to study their shear flexure strengths, Failure mechanism, and Ductility response under monotonic loading. The main parameters varied in this study were the concrete compressive strength, Percentage of longitudinal reinforcement, Shear span to depth ratio, and Amount of transverse reinforcement. End hooked steel fiber of volume fraction ranging from 0.75% to 1.5% are used in the specimen. The test result shows that addition of steel fiber enhanced shear and flexure strength. The addition of 0.5% fiber content in the beam with shear stirrup changed the mode of failure brittle to ductile. Whereas minimum fiber content of 1.0% was required to achieve the ductile response of the beams without stirrups. Using curve fitting method on the available test data, simple expression was also derived to predict the shear strength of medium to large scale flexure members with varying fiber contents.

Following equation are derived by curve fitting method

$V_u = (0.251 + 0.173\ V_u + 0.069 v_f^{2}) \sqrt{f'c}\ b\ d$ (for d<300)

$V_u = (0.202 + 0.377\ V_u - 0.113 v_f^{2}) \sqrt{f'c}\ b\ d$ (for d>=300)

Above equations use only a single variable that is fiber fraction $v_f$to compute the shear strength of SFRC beams. Due to limited test data available for SFRC beams with 2% fiber content, the correlation is established only up to a fiber content of 1.5% a value regarded as upper limit in the practice.

Based on this study following conclusion carried out.

- The addition of steel fibers enhances the flexure strength and ductility of the SFRC members with sufficient shear stirrups. The addition of higher dose of fiber greater than 0.5% does not significantly improve the flexure strength. A minimum fiber content of 0.5% is required to change the failure mode of flexural members from shear to flexure.
- The addition of 0.75% fiber content in the flexural members without shear stirrups found sufficient to achieve the Ultimate resistance which is same as the conventional RCC member with shear stirrups.
- Two simple expressions relating the fiber content to the shear of SFRC members are derived using a large set of test results for both medium scale and large-scale beams.

2.2.6. Evaluation of Size Effect on Shear Strength of Reinforced Concrete Deep Beams Using Refined Strut-And-Tie Model

G Appa Rao And R Sundaresan [41]

This paper reports on development of size-dependent shear strength expression for Reinforced Concrete Deep Beams using 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 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 and the web reinforcement, shear span-to-depth ratio and the effective depth.

The total nominal shear strength, $v_n$offered by the concrete and the web reinforcement shall be calculated by Eqs,

$$v_n = \frac{11.40\rho^{0.35}\sqrt{f'_c}}{1+2\left(\frac{a}{d}\right)}\left(0.38+\frac{1}{\sqrt{1+\left(\frac{d}{25d_a}\right)}}\right)+0.02\rho^{-0.08}\rho_{\mathrm{h}}f_y\left(\frac{d}{a}\right)+0.31\rho_v f_y\left(\frac{a}{d}\right)$$

Where,

V_n= Nominal shear strength of the beam

ρ = *Ast/(bd)* Main tensile reinforcement ratio

f'_c=Characteristic cylindrical strength of concrete in MPa

a = Shear span i.e. distance from the load and nearby reaction

d = Effective depth of beam in mm

da = Maximum size of coarse aggregate in mm

ρ_h = Ash/(bsh) Ratios of horizontal web reinforcement

ρ_v= Asv/(bsv) Ratios of vertical web reinforcement

The following conclusions can be drawn from the studies on RC deep beams with the analysis of the data base.

- It is appropriate to incorporate the size effect in the design of RCC deep beams with shear Reinforcement for predicting the uniform strength irrespective of the beam size.

- The proposed expression is simple to use as compared to the other existing size effect models, which require laborious iterative procedure.
- The decrease in nominal stress at failure with the increase in size has been accounted for in the size effect law or in other words, making the stress at failure to depend on size for uniform strength for different range of depths in practice.
- Since the behavior of short beams ($1 < a/d \leq 2.5$) and slender beams are different from that of deep beams, different equations for these specific cases are required.

2.2.7. Size Effect on The Shear Strength Of RCC Deep Beams

Kenji Kosa, Satoshi Uchida, Tsutomu Nishioka, And Horoshi Kobayashi [53]

To grasp the size effect in reinforced concrete (RC) deep beams with a shear span ratio (a/d) of 1.5, an experiment was conducted using various effective depths (300～1400 mm) as the parameters. Strains within the specimens were measured utilizing dummy reinforcements and acrylic bars.

In this experiment, a total of 25 specimens with various parameters, such as a/d (0.5, 1.0, 1.5), shear reinforcement ratio Pw (0.0, 0.4, 0.8%), effective depth d (300-1400 mm) was tested.

The following conclusions were drawn from the study on the size effect of deep beams with a/d=1.5 (shear span ratio).

- When failure behavior of large and small specimens was compared under the same average shear stress, the crack length /d became 12.17 in a large specimen (d=1400mm) and 5.90 in a small specimen (d=400mm). It means that crack propagation is quicker in a large specimen than in a small specimen.
- From the investigation of the size effect, two types of failure patterns were found. The size effect which decreases the shear stress by $d^{-1/3}$ was found to exist as a whole.

- From the investigation of the strut width of specimens with d=300～1400mm, it was found that the apparent strut width decreased by $d^{-\frac{1}{3}}$ as the member size increased, Then, a localized failure occurred and the relative shear strength decreased.

2.2.8. Can Stirrups Suppress Size Effect on Shear Strength of RC Beams?

Qiang Yu and Zdeněk P. Bažant [40]

This paper demonstrates the size effect on the shear strength of Reinforced concrete (RC) beams with stirrups. There are two separate and independent ways: (1) Fracture mechanics, based on finite-element analysis calibrated by a large beam test; and (2) Purely statistical analysis in which a newly assembled database of 234 tests is filtered to eliminate spurious size effects caused by no uniformity of secondary influencing parameters. Conclusions were as follow:

- Although stirrups mitigate the size effect on the shear strength of RC beams, they cannot suppress it completely, regardless of the stirrup ratio.
- The stirrups, whether minimum or heavier, do not change the shape of the size effect curve but push it, in the logarithmic scale, into larger sizes, increasing the transitional size by almost one order of magnitude. Thus the size effect of shear strength is mitigated in the small-size range (up to about 1 m or 39.4 in. beam depth), but remains the same in the large size range.
- Although the spacing of stirrups significantly affects the inclination of the diagonal shear crack, it has a negligible effect on the shear strength of beam.
- The probability distribution of beam strength identified from the database shows that about 3.5% of beams of depth d<0.5 mhave a strength lower than required by the code. For d<1, 2, 6 m, this percentages rises to 6.5, 15.7, and 55.1%, respectively, if the size effect is

ignored. The corresponding failure probabilities for d< 0.5, 1, 2, and 6 m are 10^{-6}, 10^{-5}, 10^{-4}, and 10^{-3}, respectively, if the size effect is ignored. The first probability is acceptable, but the others are not.

2.2.9. Role of Diagonal Tension Crack in Size Effect of Shear Strength of Deep Beams

Y. Tanaka & T. Shimomura & M. Watanabe (39)

This paper clarifies the effect of cracking propagation behavior especially on the size effect of deep reinforced concrete beams. Total 17 deep beams were tested in this study. Experimental factors are Specimen size, Depth, Shear span to Effective depth ratio (a/d) and Bonding of longitudinal bars. 6 beams were un-bonded not to induce diagonal tension crack. As a result, these un-bonded beams had small size effect regardless of a/d. while bonded beams showed relatively strong size effect in case of 1.5 of a/d. Because the cracking pattern of diagonal crack influences on the strength of compressive concrete strut. They developed simplified truss model which can deal with the effect of diagonal cracking path on the strength of deep beams and short beams. Proposed model was verified with past researches. As a result, it was clarified that proposed model tends to overestimate the shear strength when bearing failure occurs.

In this study, loading test of RCC deep beams was conducted. The effect of a/d, effective depth and bond of rebar were examined in the test. Based on the test results, estimation method of shear strength is proposed and verified. As a result, following conclusions are made.

- Size effect of shear strength is not significant when a/d is less than 1.0 or when rebar is unbounded on the condition that bearing failure is avoided.
- There is possibility that size effect is reduced when bearing stress is less than compressive strength. This is because the propagation of diagonal crack is prevented in such a case.

- The location of diagonal crack occurs at 25 mm of variation. The value corresponds to maximum size of aggregate.
- Proposed model is verified fora/d ranges 1 to 2. However, proposed model tends to overestimate the strength of deep beams.

2.2.10. Parametric Study of Shear Strength of Concrete Beams Reinforced With FRP Bars

Job Thomas, S. Ramadas [64]

This paper describes the model originally proposed by IS:456 for the prediction of shear strength of concrete beams reinforced with steel bars is Modified to incorporate the influence of FRP bars as longitudinal reinforcement. The size effect of the beam based on Regression Analysis. Total eight concrete beams longitudinally reinforced with FRP bars were cast and tested over shear span to depth ratio of 0.5 and 1.75.(Deep beam and Moderate deep beams) The shear strength test data of 188 beams published in various literatures were also used. The proposed model accounts for Compressive strength of concrete (fck), Modulus of Elasticity of FRP rebar (Ef), Longitudinal Reinforcement ratio, shear span to depth ratio (a/d) and size effect of beams

The existing various codes of practices JSCE, BISE, CNR-DT 203 NRC-06 ,ACI 440.1R-06 , ISIS-M03-07 and CAN/CSA S806-11 for the design of FRP reinforced concrete structures were developed by modifying the models originally proposed for steel Reinforced concrete beams. This can be attributed to the fact that the mechanism of load transfer in steel reinforced beams and FRP reinforced beam are similar

Modified IS model given by Researcher is

$$V_c = k_1\, k_2\, \tau_c bd$$

$$\tau_c = \frac{0.85\sqrt{0.8 f_c k}\left(\sqrt{1+5\beta}-1\right)}{6\beta}$$

$$\beta = \frac{0.8\, f_{ck}}{45.55\, p_t} > 1.0$$

$$k_1 = \begin{cases} 2.2\, d/a + 0.12; & \text{when } a/d \le 2.5 \\ 1.0 & \text{when } a/d \ge 2.5 \end{cases}$$

$$k_2 = \begin{cases} 1.0 & \text{when } d \le 300 \text{ mm} \\ \dfrac{750}{450+d} & \text{when } d > 300 \text{ mm} \end{cases}$$

Where,

k1 is a function of shear span to depth (a/d) ratio

factor k2 accounts for the size effect of beams. The following points to be concluded.

The predicted shear strength of beams using the proposed model and 11 models proposed by other researchers was compared with the corresponding experimental results. The mean of predicted shear strength to the experimental shear strength for the 86 beams accounted for the validation of the proposed model is found to be 0.93. The result of the statistical analysis indicates that the prediction based on the proposed model corroborates with the corresponding experimental data

- When the shear span to depth ratio decreases, the shear strength increases which may be due to the arch action. It was found to be significant when the shear span to depth ratio is < 2.5 in FRP reinforced concrete beams
- When the grade of concrete increases, the shear strength of concrete beam increases which may be due to the increased shear stresses offered by uncracked depth of concrete in beam in addition to the interlocking action of aggregates.
- When the FRP longitudinal reinforcement ratio increases, the shear

strength of concrete beam increases due to the dowel action of FRP longitudinal bar.

- The model originally proposed by IS:456 for the prediction of shear strength of steel reinforced concrete beams has been modified to predict the shear strength of concrete beams reinforced with FRP bars using Regression Analysis.
- The proposed model derived based on the statistical Regression Analysis is non-iterative and simple.

2.2.11. A Comparative Analysis of Codes Prediction of Shear Resistance in Beams Without Shear Reinforcement

Ofonime A. Harry, Ifiok E. Ekop (51)

Shear provisions in codes are based on empirical equations derived from experimental test results without any rational theory to explain its behavior. Some of these expressions, for example BS 8110, ACI 318 and Eurocode 2 takes into account the effect of Reinforcement Ratio, Effective depth and Concrete compressive strength while Canadian code considers the shear strength to be a function of concrete compressive strength only. The new Model code 2010 considers the shear strength of beams as a function of longitudinal strain in the web. This brings about disparity in shear strength prediction from different codes. This paper examines the accuracy of shear strength predictions in beams without shear reinforcement. The study involves analysis of comparative shear strength prediction from five different codes: BS 8110, Eurocode 2, Canadian code, ACI code 318 and Model code 2010. A total of 435 experimental test results from database of shear critical beams in literature were used for the study. Conclusions are as follows:

- Model code 2010 under estimate the shear strength of beams when compared to predictions from BS 8110, Euro code 2, ACI code 318 and Canadian code.
- BS 8110, Eurocode 2 and ACI 318 code can fairly predict shear strength of beams without web reinforcement better than Model code 2010 and Canadian code.

- Canadian code shear prediction had the highest percentage of unsafe design which is about 27.8% followed by prediction from ACI 318 code with 12.2%.

2.2.12. Shear Characteristics of High-Strength Concrete Deep Beams Without Shear Reinforcements.

Keun-Hyeok Yang, Heon-Soo Chung, Eun-Taik Lee, Hee-Chang Eun(31)

Based on the strength at the first diagonal crack of Normal-strength concrete and normal beams without consideration of size effects, the ACI code specifies the shear strength of deep beams. It is necessary to evaluate whether the ACI equation for deep beams is applicable to high-strength concrete deep beams with reinforcement ratio less than 1% and to consider size effects. Twenty one beam specimens were tested to investigate their shear characteristics with the variables of concrete strength, shear span/depth ratio, and overall depth. The decrease in shear span/depth ratio and the increase in overall depth under the same shear span/depth ratio lead to more brittle failure, with wide diagonal cracks and high energy release rate related to size effects. The high-strength concrete deep beams exhibited more remarkable size effects with regard to brittle behavior.

This experimental study interpreted the shear characteristic of high-strength concrete deep beams including size effects of beam section and evaluate the validity of the ACI code. From this experimental study, it was observed that the specimens of a/d = 0.5 show less sensitive size effects than a/d = 1.0, and more brittle failure of concrete strut and higher energy release rate as the results of size effects with the decrease in a/d. The concrete strength was rarely related to the strength increase of deep beams due to the size effects at a/d = 0.5 but the deep beams at a/d = 1.0 showed sensitive size effects. As a result of size effects, the Ultimate shear stresses corresponding to a/d of 0.5 and 1.0 were proportional to $d^{0.57}$ and $d^{0.33}$respectively. It can be concluded that the ACI code prediction to give the diagonal crack load and the

Ultimate strength of normal-strength and high-strength concrete deep beams of overall depth greater than 1000 mm should include the size effects.

2.2.13. Shear Strength Of Normal And High-Strength Fibre Reinforced Concrete Beams Without Stirrups

Madhusudan Khuntia, Bozidar Stojadinovic, and Subhash C. Goel [28]

This paper presents a rational and uniform procedure for predicting the shear strength of normal and high-strength Fiber reinforced concrete (FRC) beams. A design equation is suggested for evaluating the Ultimate shear strength of FRC beams based on the basic shear transfer mechanisms and numerous published experimental data on concrete strength up to 100 MPa (14,500 psi). In addition to concrete strength, the influence of other variables such as Fiber factor, Shear span-to-depth ratio, Longitudinal steel ratio were considered as size effect parameter. The modeling approach is similar to that applied for conventional Reinforced concrete beams, except for some modifications suggested in this paper, to account for the effect of the fibers. The comparison between computed values and experimental observed values were shown to validate the proposed Analytical Equation.

The final equation for Fiber factor is as given below,

$F = \beta vf \left(\frac{lf}{df}\right)$is imperial equation. Where, F = Fiber factor

β= factor for fiber shape and concrete type, taken as1 for hooked or crimped steel fiber, 2/3 for plain or round steel fiber with normal concrete, 3/4 for hooked or crimped steel fiber with lightweight concrete. Factor β has a similar influence as the bond factor suggested by Narayanan and Darwish. Though the above expression has been derived for steel fiber, similar equations can be contemplated for other types of fiber with modifications in β and τ.

V_f= Fiber contentby percentage volume of beam in %,$\frac{lf}{df}$ = Aspect ratio of fiber,

l_f = Length of fiber in mm ,d_f = Diameter of fiber in mm

From an extensive literature review and an analytical study presented in this paper, the following conclusions can be drawn.

- Inclusion of steel fibers in the concrete mix improves the shear strength of RCC beams and tends to change the mode of failure from Brittle shear to Ductile flexure.
- The Ultimate shear strength of FRC beams increases with an increase in fiber factor and concrete strength. For short beams (a/d< 2.5), it increases with a decrease in a/d ratio due to the presence of arch action.
- Addition of fibers is more beneficial for High-strength concrete in comparison with Normal strength concrete.
- The Ultimate shear strength of FRC beams without stirrups can be conservatively computed by using the following simplified equation.

2.2.14. Prediction of Shear Strength of Reinforced Concrete Beams Without Web Reinforcement.

Jin-Keun Kim and Yon-Dong Park [27]

A 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 mechanism, 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 (14,500 psi). 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. It is shown that the proposed equation is considered to be better than the other equations compared in this study with respect to accuracy and estimation of primary factors. A simplified design equation is also derived within the limited range of effective depth for practical purposes.

Many equations have already been proposed to estimate the shear strength of reinforced concrete beams. To evaluate the proposed model, three well-known equations are selected for comparison: 1) Zsutty's equation deduced by Multiple Regression Analysis 2) Bazant's equation derived based on Bazant's size effect law and 3) the ACI Code equation. On the basis of the results obtained in this study, for practical design, a simple and accurate equation deduced from the simplification of all proposed equation is derived as:

$$W = 2V_u = 15.5 f'^{\alpha/3}_c \rho^{3/8} (0.4 + d/a) \left(\frac{1}{\sqrt{d}} + 0.07 \right) \; for \; d \geq 250mm$$

The accuracy of the simplified equation is nearly identical compared with the original equation and considered to be better than those of the other equations compared in this study. The effect of concrete strength on the shear strength of beams with a/d< 3.0 is estimated well by introducing failure mode index.

2.2.15. Shear Strength Prediction for Deep Beams

Shyh-Jiann Hwang, Wen-Yao Lu, and Hung-Jen Lee[30]

Authors have presented a softened strut-and-tie model for determining the shear strengths of Deep Beams. The proposed model originates from the strut-and-tie concept and satisfies equilibrium, compatibility, and constitutive laws of cracked reinforced concrete. The shear strength predictions of the proposed model and the empirical formulas of the ACI 318-95 Code are compared with the collect experimental data of 123 deep beams.

The major discrepancy between the prediction of the proposed model and the ACI 318-95 Code comes from the different hypothesis of shear strength for deep beams. Based on the observation of concrete crushing in the diagonal direction, the softened strut-and-tie model assumes that the shear strength of deep beams depends on the softened compressive behaviour of concrete within the diagonal strut. At the same time web reinforcement plays important role. One is to form tension ties and transfer shear force in diagonal path. The other is to control the crack widths and retard the softening process of the cracked concrete. The ACI Code method assumes that the shear strength of deep beams is derived from the combination of the tensile strength of the concrete and the yielding strength of the web reinforcement, but this does not correlate well with the observed failure phenomenon of concrete crushing in the web.

Based on test results in the literature and comparison of these results with the proposed model and the ACI Code formulas, the following conclusions can be made:

- The softened strut-and-tie model consistently reproduced 123 deep beam measured shear strengths with reasonable accuracy for a wide range of horizontal and vertical web reinforcement ratios, concrete strengths, and shear span depth ratio.
- In general, the ACI Code's predictions are conservative for the selected test results in this paper and more pronounced conservation can be found for deep beams without web reinforcement and with high-strength concrete and a low a/dratio.

2.2.16. Statistical Prediction Equations for RC Deep Beam without Stirrups

Ahmed I. Ramadan(&) and Aly G. Aly Abd-Elshafy [62]

This paper presents a semi-empirical approach adopted in which a data base of existing experimental and literature results of deep beams, d > 300 mm & d < 300 mm, failing in shear under two-point loads statically at mid-span was constructed. The database, 725 deep beams, was used to propose two simplified shear equations using Multiple Regression Analysis, IBM-SPSS-Statistics used to find out and evaluate the most important factors affecting the Ultimate shear strength formulating them in a suitable predictive equation for the Ultimate shear strength of deep beams without web reinforcement (stirrups). The test database covers a wide range of individual parameters as cylindrical concrete compressive strength (20≤f'c≤104 MPa), longitudinal main steel reinforcement ratio (0.17% to 6.64%), effective depth of deep beams d varying from 127–1000 mm, shear span to effective depth ratio varying from 1 to 2.5, Beam width “b”, b/d < 1, where all database from literature were based on two point loading.

Researchers take formulas from Egyptian Code- ECP203-10, The 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 as per below.

$$v_u = \left(\frac{d}{a}\right)^{2.35} * \rho^{0.85} * f'^{0.177}_c * \left[0.7 + \left(\frac{a}{d}\right)^{1.55}\right]\left[\frac{0.3*\rho}{\rho+(d)^{\left(\frac{d/a}{b}\right)}}\right]^{0.05} \text{(in MPa)}$$

Authors used SPSS –IBM software for non-liner Regression Analysis of data and proposed above equation. Conclusion from the research work is as below:

- The failure mode was significantly altered by changing the beam depth, where sufficient ductility was achieved in small size beams, and relatively very high brittleness was observed in large size beams.
- The Ultimate loads increase as shear span to depth ratio (a/d) decreases, this is because cracks form in the shear regions at places of high moments which are towards the applied concentrated loads, as shear span to depth ratio (a/d) decreases this distance also decreases, and the slope of the cracks become steeper.
- The different design equations considered in this study do not accurately reflect the increase in shear capacity of beams with shorter shear spans (a/d = 1.5). Most of the design models are excessively conservative, and the code predictions only seem to be more accurate as a/d increases beyond a value of 2.0.

2.2.17. Shear Size Effect in Simply Supported RC Deep Beams

Hui Chena, Wei-Jian Yia, Zhongguo John Mac[55]

In this study, researcher try to separate and identify the influences of the bearing plate size on the shear size effect, existing deep beam tests on shear size effect are classified. It is verified that the shear size effect of deep beams with a fixed bearing plate size is stronger compared to deep beams with proportionally varied plate sizes. By using a non-linear analysis software ATENA based on concrete fracture and plasticity theory and a mechanical model called cracking strut-and-tie model (CSTM), the shear size effects of the classified test groups are accurately predicted.

The shear strength of deep beams is related to bearing plate(or column) size according to principles of the STM, so the shear size effect of deep beams is also affected by the bearing plate size and differs from that of slender beams. Considering that the shear strength of deep beams is sensitive to the boundary conditions, the existing experimental tests on the shear size effect are classified into two series: tests with constant bearing plate size and tests with proportionally varied bearing plate sizes.

After testing of 2 series of beam, having each series 6 beams and also tested that beam with FEM software – ATENA Researcher concluded that:

- The existing deep beam tests were classified to separate and identify the influences of the bearing plate (or column) size on the shear size effect. It was verified that the shear size effect of deep beams with fixed bearing plate size is stronger compared to deep beams with proportionally varied plate size.
- When the bearing plate size is designed to vary in proportion to the beam height, the bearing plate size effect is eliminated, thus the size effect of deep beams in shear is determined by the beam depth effect, which is caused by the inherent properties of concrete. Through analysing the FEM and CSTM results, it was showed that the concept of interface shear

transfer (by aggregate interlock) can provide a possible explanation for the phenomenon.

2.2.18. Are Steel Fibres Able To Mitigate Or Eliminate Size Effect In Shear??

Fausto Minelli, Antonio Conforti, Estefanı´a Cuenca, Giovanni Plizzari [56]

This paper reports some recent results of an experimental test on Fiber reinforced concrete (FRC) beams under shear loading tested at the University of Brescia: nine full scale beams, having a height varying from 500 to 1500 mm, were tested for investigating the effect of steel fibers on key parameters influencing the shear response of concrete members, with special emphasis on size effect. All tested members contained no conventional shear reinforcement and different amounts of steel fires: 0, 0.64 or 1 % by volume.

Nine full-scale beams were produced and tested under a three point loading system and a shear span-to-depth ratio (a/d) of 3. Longitudinal reinforcement was positioned in two layers and the reinforcement ratio was approximately 1 % for all test specimens. Steel fibers adopted in this research were hooked ends, 50 mm long, with a diameter of 0.8 mm, leading to an aspect ratio of 62.5. The tensile strength of fibers was about 1100 MPa.A normal strength concrete having a target characteristics strength f_{ck} of about 30MPa, provided by a concrete supplier, was utilized. Based on the experimental results the following main conclusion can be drawn:

- Fibers substantially mitigate the size effect in shear: the size effect descending trend becomes less steep with increasing FRC toughness and the shear failure (and then the size effect) appears at higher effective depths of members.
- Fibers, even in relatively low amount, greatly influence the shear behaviour of beams, basically by delaying the occurrence of the shear

failure mechanism and, by altering the collapse from shear to flexure, with enhanced bearing capacity and ductility.

2.2.19. Shear Strength of Steel Fiber Reinforced Concrete (SFRC) Slender Beams

Guray Arslan [46]

In this study, by using the basic principle of mechanics and considering the slenderness effect of SFRC beams without stirrups, a new design expression is proposed for the shear strength of SFRC beams. The proposed equation and researchers' predictions are compared to the test results of 170 SFRC beams without stirrups.

The failure of a shear critical Reinforced Concrete (RC) beam without stirrups occurs usually with the sudden formation of a critical diagonal tension crack. In SFRC beams, control of cracking resulting from normal stress is more effective in comparison with the ones without fibers and the fibers provide increased stiffness after cracking. The steel fibers help to form bridges through developing cracks in the concrete and provide more resistance to the crack growth. This eliminates the possibility of a sudden failure in concrete and allows for a more progressive failure. Researcher studied various model for prediction of shear strength of concrete and considering the influence of the slenderness ratio (a/d), the following equation is derived for the ultimate shear strength of SFRC beams without stirrup:

$$v_u = \left(0.2 f_c^{2/3} \left(\frac{c}{d}\right)\left(1 + 0.032 f_c^{1/6}\right) + \sqrt{\rho(1 + 4F) f_c}\right)\left(\frac{3}{a/d}\right)^{.33}$$

Here, f_c = compressive strength, ρ = longitudinal steel ratio, F = % of fiber, a/d = shear span to depth ratio.

From the research following conclusions are drawn by the researcher:

- When the slenderness ratio is lower than 4.0, large scatter in the ratio of the experimental to the proposed shear strength for existing test data is observed.
- It can also be noted that the proposed shear strength is in good agreement with the test results. Eleven different prediction equation gives better results, when compared with test data for beams without stirrups.

2.2.20. Shear Behaviour of Polypropylene Fiber Reinforced-Concrete Beams Without Stirrups

Guray Arslan, Riza Secer Orkun Keskin,Mehdi Ozturk[57]

In the study reported here, the influence of polypropylene fibers on the shear behaviour of RC beams without stirrups was experimentally investigated. The test specimens comprised two RC beams and nine polypropylene fiber RC beams. The main test variables were the shear span-to-effective depth ratio and the volume fraction of polypropylene fibers. The beams, with shear span-to-effective depth ratios (a/d) of 2·5, 3·5 or 4·5 and fiber contents (V_f) of 0, 1, 2 or 3% by volume, were tested under a concentrated load at mid-span.

Researcher developed formula for prediction of shear strength for polypropylene fiber reinforced concrete. They just modified fiber factor and evaluating polypropylene strength factor known as PSR.

$$F = \boldsymbol{PSR} * \sqrt{\boldsymbol{\rho(1+4F)f_c}}$$

In above equation PSR is calculated as 0.7 from the regression analyses of experimental data. Author concluded following points from the research.The use of polypropylene fibers increased the shear strength and ductility of RC beams failing in shear.

Beams with shear span-to-effective depth ratios (a/d) of 2·5 and 3·5 failed in shear, whereas beams with a/d =4·5 failed in flexure. Even a 3·0%

volume fraction of polypropylene fibers was insufficient to change the failure mode of the beams with a/d =2·5 and 3·5 from shear to flexure.

2.2.21. Shear Behaviour of Reinforced Concrete Deep Beams

Kamaran S. Ismail, Maurizio Guadagnini, and Kypros Pilakoutas(63)

This paper presents an experimental investigation into the structural behaviour of 24 reinforced concrete (RC) deep beams examining parameters affecting shear capacity such as shear span-depth ratio, concrete compressive strength, web reinforcement ratio, and effective beam depth. The beams were 1800 mm long, had a clear span of 1400 mm and a section of 400 mm deep by 100 mm wide. The specimens were flexural reinforced with six 16 mm bars distributed in three layers, with two bars in each layer. At both ends of the beams, the longitudinal reinforcement was extended beyond the supports and terminated with 90-degree hooks to ensure proper anchorage and prevent bond failure.

Author compared experimental results with four modal code (1) ACI-318-14 (2) AASHTO LRFD (3) EC-2 (4) MODEL CODE 2.0. Researcher also derived various parameters influencing the size effect. The various parameters include compressive strength of concrete, vertical and horizontal steel reinforcement, effect of effective depth. On the basis of the experimental results presented in this study and the assessment of different design approaches, the following conclusions can be drawn:

- Shear span-depth ratio is the most important parameter that controls behaviour and shear capacity of RC deep beams.
- Concrete compressive strength has more influence on the shear strength of deep beams than shear reinforcement. However, the presence of shear reinforcement is crucial in controlling crack propagation and providing ductility to deep beams.

- There is a difference of approximately 15% to 20% on the experimental effectiveness factor of deep beams with and without shear reinforcement. Among the models examined in this paper, ACI 318-14 is currently the only code of practice that accounts for the effect of shear reinforcement on the effectiveness factor.

2.2.22. Size Effect in Shear Failure of Longitudinally Reinforced Beams Zdenek P. Bazant and Jin-KeunKim(22)

Consequences of recent fracture mechanics studies of concrete for analysing diagonal shear failure of longitudinally reinforced beams or one-way slabs without shear reinforcement were studied. The cracking produced by shear was assumed to propagate with a dispersed zone of microcracks at the fracture front. Dimensional analysis of the energy release rate then shows that the nominal shear stress at failure should not be a constant but should vary $\left(1+\frac{d}{\lambda_0 * da}\right)^{-0.5}$, in which d = beam depths, d. = maximum aggregate size, and λ_0 = constant. For relatively small beams, representing the great majority of those tested in the laboratories, the nominal stress at failure is nearly constant. however, deeper beams it considerably declines with increasing size. This trend is confirmed by previous experimental results. In addition to the size effect, a rational formula for the effect of steel ratio and shear span is derived.

From the experiment researcher provide a formula for prediction of shear strength and concluded the following points.

- For diagonal shear failure of reinforced beams and one-way slabs without shear reinforcement, it is appropriate to consider the size effect which theoretically results from a dimensional analysis of the energy release rate in the propagation of fractures that have a dispersed cracking zone at their front.
- As a function of the ratio of beam depth *d* to maximum aggregate size *da,* the nominal shear strength exhibits a gradual transition from the

strength criterion (which prevails for $d/d_a < 25$) to an energy criteria for fracture (which prevails for $d/d_a > 25$). For extremely large beam depths, the size effect of linear elastic fracture mechanics is approached asymptotically.

- A rational, mechanics-based formula for the effect of steel ratio and relative shear span can be obtained by superimposing the shear forces transmitted by composite beam action and by arch action.

2.2.23. Another Look At Cracking And Crack Control In Reinforced Concrete.

Robert J Frosch [29]

This study investigates the development of the crack control provisions and the crack width equation considering thick concrete cover. However, currently used crack control methods that are based strictly on statistical reasoning become unworkable with the use of thick covers. Use of new formula is supported by an evaluation of existing test data; based on this equation, a design recommendation is presented for the control of cracking that addresses the use of both coated and uncoated reinforcement.

Crack width at level of reinforcement can be considered as follows,

$$Wc = \varepsilon_s Sc$$

Where, Wc = crack widthε_s= reinforcement steel strain = $\frac{fs}{Es}$Sc = crack spacing, fs = reinforcement steel stress, Es = Modulus of elasticity of steel

Crack width is a function of multiplication of strain in steel and spacing of cracks. Frosch gave a formula for spacing of crack as a function of concrete cover in this research. Crack spacing decreases with increasing load and stabilizes after the reinforcement reaches a critical stress. Further stress increases act only to widen the existing cracks.

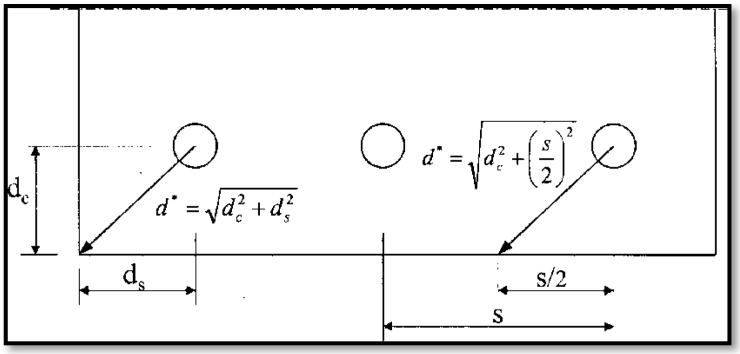

Figure 2-1Controlling Cover Distance

$$S_c = \Psi_s d^*$$

S_c = crack spacing d* = controlling cover distance; andΨ_s= crack spacing factor: 1.0 for minimum crack spacing; 1.5 for average crack spacing; and 2.0 for maximum crack spacing.

Final crack width formula,

$$W_c = 2\beta \frac{f_s}{E_s}{}^2 \sqrt{{d_c}^2 + \left(\frac{s}{2}\right)^2}$$

This equation was coined by R. J. Frosch for concrete cover thicker than 2.5 inch.

2.2.24. New Formula for Maximum Crack Width and Crack Spacing In Reinforced Concrete Flexure Members

Byung Hwan Oh and Young-Jin Kang(24)

Accurate prediction formulas for the maximum crack width and average crack spacing in reinforced concrete flexural members are proposed in this research paper. The purpose of this paper is, therefore, to propose simple, yet accurate, prediction equations for the maximum crack width and crack spacing in reinforced concrete flexural members. To this end, an experimental program was set up and a series of tests on reinforced concrete beams was carried out in the present study. The test results were then compared with the proposed formulas. Five reinforced concrete test beams have been designed to investigate crack width and crack spacing. Influencing design variables that affect greatly crack spacing and width, includes the concrete cover, diameter of steel bars, reinforcement ratios, spacing of steel bars, and steel stress.

The crack spacing and crack width are the major variables that are needed in the nonlinear finite element analysis of cracked reinforced concrete structures. The cracking theory developed was based on the energy criterion of fracture mechanics as well as the strength criterion. The theory indicates that the crack spacing depends mainly on the axial tensile strain of bars ε_s, bar diameter D, bar spacing b_1, fracture energy of concrete G_r, and its elastic modulus E_c.

Variables used for proposing formula were, A_1/A_{s1}, t_b/h_2, $1/\rho_e$, f_t'/E_c, G_f/b_1E_c, D/b_1, and ε_s. Formula proposed by Oh and Kang,

$$\frac{Wmax}{D} = a_0(\varepsilon s - 0.0002)R$$

$$R = \frac{h_2}{h_3}\ ,\ A_1 = \frac{A_e}{m}\ ,\ A_e = \mathrm{b} \times h_1\ ,\ h_1 = \frac{(h-x)^3}{3(d-x)^2}\, a_0 = 159\left(\frac{t_b}{h_2}\right)^{4.5} + 2.83\left(\frac{A_1}{A_{s1}}\right)^{1/3}$$

The value W_{max} represents the maximum crack width at the extreme tension face and R represents the ratio between the distance h_2 and h_3 as shown in Figure

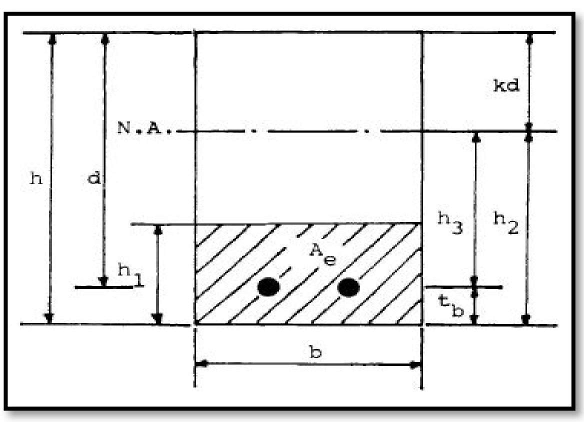

Figure 2-2 Schematic Diagram for Cross Section Properties

- The comprehensive comparisons with 747 data points indicate that the proposed formulas for the maximum crack width show better correlation with various test data than the Gergely and Lutz formula.
- It is also seen that the crack width formula of ACI 318 may be un-conservative in some cases for the design of concrete members.

2.2.25. Crack Width Evaluation for Flexural RC Members

Said M. Allam, Mohie S. Shoukry, Gehad E. Rashad, Amal S. Hassan[43]

In this research work, five reinforced concrete rectangular models were investigated theoretically to investigate codes provisions beside some equations found in the literature concerning the crack width calculation of reinforced concrete members subjected to flexure. The models include different parameters such as reinforcement steel ratio, steel rebar arrangement and reinforcement grade. Also, to verify the accuracy of the building code equations and the equations developed by researchers a comparison against some experimental data available in the literature was carried out.

The crack width of a flexural member is obtained by multiplying the maximum crack spacing by the mean strain of the flexural steel reinforcement. Therefore, the crack width depends on the nature and the arrangement of the reinforcing steel crossing the cracks and the bond between the steel bars found in the tension zone of concrete.

The Following conclusions are taken

- With the increase of reinforcement ratio, the concrete contribution in tension decreases, the mean steel strain increases, consequently the crack width increases. However, for crack control, it is suggested to limit the reinforcement ratio instead of limiting the steel stress.
- The reinforcement detailing (i.e. the bars distribution) is an important factor affecting crack width. With the well choice of bar arrangement

(larger number, smaller diameter) better bond between concrete and steel occurs resulting in a reduction in the crack spacing.

- Most equations proposed by the building codes overestimate the effect of the concrete cover on the calculated values of crack width when compared with the experimental results.
- Comparison of building codes against experimental results revealed that the Egyptian code gives underestimated values of crack width for members reinforced with low reinforcement ratios especially at low level of steel stresses. The Egyptian code equation expresses the tension stiffening as a function of the steel stress. For the calculation of the steel stress just after the first cracking, the Egyptian code assumes that the force resisted by concrete in tension is completely neglected immediately after the occurrence of the first crack.

2.2.26. Experimental Investigation On Shear Cracking Behaviour in Reinforced Concrete Beams With Shear Reinforcement

Mohamed Zakaria, Tamon Ueda, Zhimin Wu and Liang Meng-2009(37)

Study focuses on improving our understanding of shear cracking behaviour of reinforced concrete beams and its influential parameters. 10 simply supported beam specimens were experimentally investigated for the effects of the various influential parameters. All 10 specimens were cast in wooden moulds using ready mix concrete with a characteristic strength of 40 MPa and a maximum size of aggregate of 25 mm. In the mix proportions of concrete, ordinary Portland cement was used and water-cement ratio was kept at 0.50 with the addition of an admixture. 10mm diameter deformed reinforced bars were used for shear reinforcement. For longitudinal reinforcement, varying diameter of bar, yield strength and modulus of elasticity were adopted for finding correlation with it.

To find out shear crack displacement parameters such as shear crack opening ((width) in the direction perpendicular to shear crack) and shear crack sliding (slip that occurs in the direction of shear crack), surface strain and shear crack angle were recorded with the help of demec points.

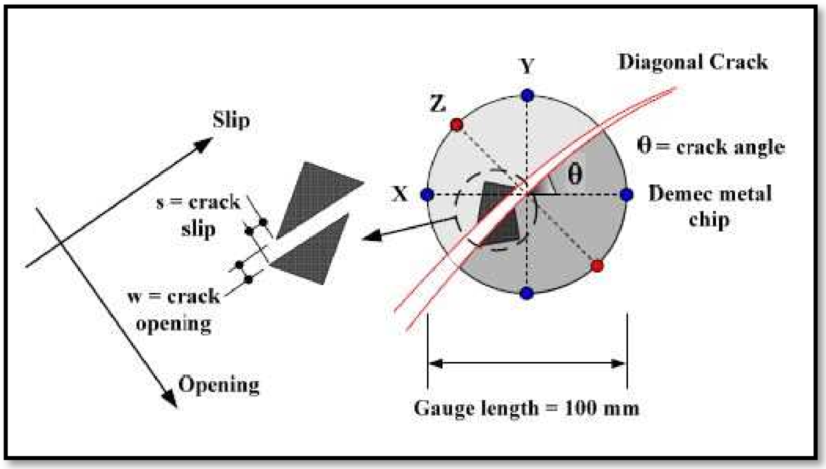

Figure 2-3 shear crack displacements model

Proposed prediction model for crack width is given by,

$$w_{avg} = K(c_s)^a\left(1/\rho_w\right)^b\left(1/\rho_t\right)^c s_{m\theta-avg}\varepsilon_w s_{m\theta} = \frac{1}{\frac{\sin\theta}{s_{mx}}+\frac{\cos\theta}{s_{my}}}$$

$$s_{mx} = 2\left(c_x+\frac{s_x}{10}\right)+k_1k_2\frac{d_{bx}}{\rho_x} s_{my} = 2\left(c_y+\frac{s_y}{10}\right)+k_1k_2\frac{d_{by}}{\rho_y} K = 0.112K_sK_t$$

Where,K= constant for type of r/e.

c_s = side concrete cover to shear reinforcement (mm)

ρ_w = shear reinforcement ratio, $\rho_w = A_w/b_wS_y$

ρ_t = longitudinal reinforcement ratio, $\rho_t = (A_s + A_{ps})/b_w d_e$

$s_{m\theta\text{-}avg}$= shear crack spacing at the crack formation phase and the stabilized cracking phase, and $s_{m\theta\text{-}avg}=1.25s_{m\theta}$

$s_{m\theta}$= shear crack spacing at the stabilized cracking phase

ε_w= shear reinforcement strain

$k_{s=}$ a constant for shear reinforcement hook type, k_s = 1.0 for closed shear reinforcement with ordinary 135° hook, k_s = 1.2 for closed shear reinforcement by lap-splicing two U-shaped shear reinforcement

$k_{t=}$ a constant for shear reinforcing bar type, k_t = 1.0 for deformed bars & 1.2 for plain bars. The following conclusions observed.

- Shear cracks width increases proportionally with both the strain of shear reinforcement and with the spacing between shear cracks.
- Larger beams show greater diagonal crack spacing, and hence result in wider shear crack width in comparison to the smaller beams.
- The experimental results show that increasing the side concrete cover to stirrup leads to wider diagonal crack spacing and partial absence of shear crack opening control at the surface of the elements.
- Increasing the longitudinal reinforcement amount can better control shear crack opening. The larger amounts of longitudinal reinforcement cause smaller spacing between shear cracks, and thus result in smaller shear crack openings.

2.2.27. A New Formula For Prediction Of Crack Widths In Reinforced And Partially Pre-Stressed Concrete Beams

S.H. Chowdhury and Y. C. Loo [61]

This paper presents a simple, yet accurate, formula for predicting the crack widths in both reinforced and partially prestressed concrete flexural members. As part of the research, a series of tests on full-size reinforced and partially prestressed concrete beams was carried out. The proposed average crack width prediction formula is derived statistically incorporating four beam parameters namely, the average crack spacings (l_{cr}), the ratio of the average bar diameter to the reinforcement ratio (Φ/ρ), the concrete cover (c) and the average spacing between reinforcing bars (s).

$$w_{cr} = \frac{f_s}{E_s}\left(0.6(c-s) + 0.1\left(\frac{\Phi}{\rho}\right)\right) Wmax = 1.5 \times Wcr$$

Where, W_{cr}= average crack width (mm), fs/Es = strain in tensile reinforcement

c = clear cover (mm), s = maximum bar spacing (mm), Φ/ρ = ratio of bar diameter to percentage of steel W_{max} = maximum crack width (mm)

Above equation coined by S.H. Chowdhury and Y.C Loo is tested for 106 beams which reveals that accuracy is appreciable. Its performance is as good as those of the ACI and the Eurocode formulas but superior to that of the British Standard recommendation. Compared with all the three code methods, the proposed formula is more versatile as it is applicable to both reinforced and prestressed beams.

2.2.28. Analytical Methods To Estimate The Crack Width In RC Beams

Arvind, Narendra H[50]

In this research work an analytical investigation was carried out to study the cracking behaviour of RC beams in various conditions. A total of 58 beams previously casted by various different researchers were adopted for this study. Effect of concrete cover and grade of steel on crack width is compared for different formulas given by various codes. The crack width estimation was done for this using the expressions given by Indian, American, Egyptian, European and Chinese codes.

As from the above analytical study it was observed that, American expression over estimates the width of the cracks almost in all cases and the other expressions under estimate it. Reason can be the usage of steel stress in direct correlation with the crack while other expressions use the value of the stress in steel only to calculate the strains. When the grade of steel used increases, the resultant increase in crack width is quite high, but such a steep increase is not recorded by any expression other than the ACI 318. This is because for f_y 500 steel, the stress at working load predicted by all the codes lie in the range of 300 N/mm^2 but the American code predicts a stress of 350 N/mm^2. This is mainly due to the high modular ratio, the effect of which is prominent as the grade is increased. This observation again proves that the longitudinal stress in steel reinforcement is the most important parameter.

2.2.29. Prediction Of Crack Width For Fiber-Reinforced Polymer-Reinforced Concrete Beams

Sameh R. Salib and George Abdel-Sayed-2004.[59]

A report published in 1972 (ACI Committee 224) outlined the formulas developed to predict the maximum crack width in steel-reinforced concrete beams. One of these formulas was developed by Gergely and Lutz (1968) as follows,

$W_{max} = 0.076 \times 10^{-3} \times f_x \times \beta \sqrt[3]{d'a}$ (kip-in. units)

Where a = tension area per bar; d_c = concrete cover of outermost bar measured from the center of that bar; f_x = tensile stress in longitudinal bars; W_{max} = maximum crack width measured at the extreme beam bottom level; and β= ratio of distances to the neutral axis from the extreme beam bottom level and from the centroid of longitudinal bars.

Based on the presented study, following conclusions can be observed:

- The original formula, developed by Gergely and Lutz (1968) to predict crack width in concrete beams reinforced with steel bars, has been modified for FRP-reinforced concrete, taking into account the difference between steel and FRP bars regarding the mechanical properties as well as the bond characteristics.
- The proposed modifications for the mathematical form of the original formula can be imposed into other crack width formulas for steel-reinforced concrete beams to be applicable when using FRP bars.
- The results of the proposed formula have been found in better agreement with the corresponding experimental results than those obtained by the current design guidelines for FRP-reinforced concrete beams.

2.2.30. Crack Control In Reinforced Concrete Structures

Edward G. Nawy[21]

The aim of this paper is to expound briefly the present state of knowledge on permissible sizes of cracks, particularly flexural induced cracks under short-term loading.

Some important information on dependency of crack width;

- Crack width is a function of crack spacing up to a certain limit.
- Crack width and spacing follow a normal distribution.
- Crack width is a function of steel strain, hence stress. The relationship, though nonlinear, sometimes conveniently approximated to linear relationship in the case of beams.
- Shrinkage strain and tensile strain in the concrete zone between any two cracks is very small and can be neglected.
- The magnitude of concrete cover has an important effect on crack width.

Crack width equations;

1. Kaar-Mattock equation: $w_s = 0.115\sqrt[4]{A}fs \times 10^{-6}$
2. Gergely-Lutz equation: $w_b = 0.091\sqrt[3]{t_b A}fs \times 10^{-6}$
3. Cement and Concrete Association equation: $w_b = 3.3C\frac{f_s}{E_s}\left(\frac{h-kd}{d-kd}\right)$

Where, A= ratio of effective concrete area in tension to number of bars

f_s= steel stress, t_b= concrete cover, E_s= Modulus of elasticity of steel, h= overall depth of beam, d= effective depth of beam, kd= depth of neutral axis.

2.2.31. Polymer And Steel Fiber-Reinforced Cementitious Composites Under Impact Loading—Part 1: Bond-Slip Response

V. Bindiganavile and N. Banthia[60]

In this two-part paper, the response of polymer and steel fiber reinforced cement-based composites to impact loading is investigated. In Part 1, single-fiber pull out tests were conducted and the fiber-matrix bond-slip responses were obtained. A straight, undeformed polyolefin fiber, two lengths of a sinusoidally deformed polypropylene fiber, and a flat-end steel fiber were investigated. For the impact fiber pull out tests, a newly designed, instrumented impact machine was used. With the load applied in the direction of fiber alignment, two rates of impact pull out and one rate of quasistatic pull out were investigated. It is shown that the viscoelastic nature of polymeric materials may prove to have an added advantage when such composites are subjected to dynamic loads.

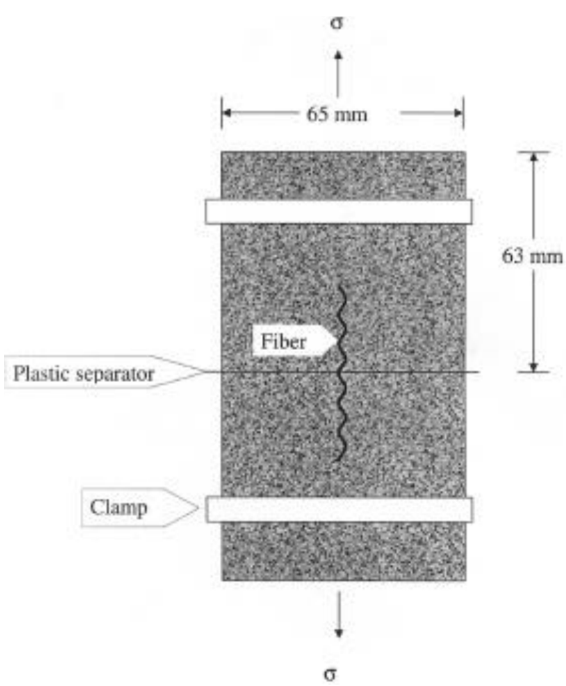

Figure 2-4 schematics of fiber pullout specimen

Here are some concessionary points from the above experiment,

- Static and impact loading may cause similar damage to the fibers tested. While polypropylene fibers showed fibrillation and splitting, steel fibers lost their flat ends during pull out.
- For deformed polymeric fibers, if a pull out mode of failure may be preserved, the performance of deformed polypropylene fibers may

approach that of the steel fibers both on the basis of energy absorbed to the peak load and on the basis of the total pull out energy.

- The energy absorbed to peak pull out load increases with an increase in the loading rate if the mode of fiber failure is preserved. Steel fiber was once again an exception where the energy absorption was seen to decrease at very high rates of pull out, even when the fiber failure mode did not change.

2.2.32. Summary Of Crack Width Formulas

Crack width measurement equations given by different codes and researchers are tabulated below:

NAME OF CODE/RESEARCHER	EQUATION
IS 456-2000 CODE	$W_{cr} = \frac{3a_{cr}\varepsilon_m}{1+\frac{2(a_{cr}-C_{min})}{h-x}}\ (mm)$ $\varepsilon_m = \varepsilon_1 - \frac{b(h-x)(a-x)}{3E_sA_s(d-x)}$
ACI 318-19	$W = 0.076\beta f_s\sqrt[3]{d_cA_0} \times 10^{-3}\ (in)$ $\beta = \frac{h-x}{d-x}$
ECP 203-2007	$W_K = \beta\varepsilon_{sm}S_{rm}$ (mm) $\varepsilon_{sm} = \frac{f_s}{E_s}\left(1-\beta_1\beta_2\left(\frac{f_{scr2}}{f_s}\right)^2\right)$ $S_{rm} = 50 + 0.25k_1k_2\frac{\emptyset}{\rho_{eff}}$
Gergely and Lutz	$W_b = 0.076\sqrt[3]{t_bA}f_s\beta \times 10^{-3}(in)$

Oh and Kang	$\frac{Wmax}{D} = a0(\varepsilon s - 0.0002)R$ $a_0 = 159\left(\frac{t_b}{h_2}\right)^{4.5} + 2.83\left(\frac{A_1}{A_{s1}}\right)^{1/3}$ $R = \frac{h_2}{h_3}$, $A_1 = \frac{A_e}{m}$, $A_e = \mathrm{b} \times h_1$, $h_1 = \frac{(h-x)^3}{3(d-x)^2}$
Mohamed Zakaria	$w_{avg} = K(c_s)^a \left(1/\rho_w\right)^b \left(1/\rho_t\right)^c s_{m\theta-avg}\varepsilon_w$ $s_{m\theta} = \frac{1}{\frac{\sin\theta}{s_{mx}} + \frac{\cos\theta}{s_{my}}}$ $s_{mx} = 2\left(c_x + \frac{s_x}{10}\right) + k_1 k_2 \frac{d_{bx}}{\rho_x}$ $s_{my} = 2\left(c_y + \frac{s_y}{10}\right) + k_1 k_2 \frac{d_{by}}{\rho_y}$ $K = 0.112 K_s K_t$
S.H. Chowdhury and Y.C.Loo	$w_{cr} = \frac{f_s}{E_s}\left(0.6(c-s) + 0.1\left(\frac{\Phi}{\rho}\right)\right)$ (mm) $Wmax = 1.5 \times Wcr$
Lakshmi T N, Jayasre S	$w_{cal} = \frac{f_s}{E_s}\left[0.03\left(\frac{\Phi}{\mu}\right) + 0.021\left(\frac{sf_y}{nf_{ck}}\right) + 1.4c\right]$(mm) $w_{exp} = \left[0.04\left(\frac{f_s}{f_{ck}}\right) + 1\right] w_{cal}$
R.J Frosch	$W_c = 2\beta \frac{f_s}{E_s}^2 \sqrt{d_c^{\,2} + \left(\frac{s}{2}\right)^2}$ (mm)

Findings from Literature Study:

1. The most important parameter influencing the size effects were shortlisted from literature as follows:
    - Effective length to overall depth ratio (Le/D)

- Shear span to depth ratio (a/D)
- Longitudinal steel ratio
- Ratio of depth to maximum aggregate size.
- Effective length to depth ratio.
- Compressive strength of concrete.

2. There were fiber content contribution in the shear strength of beams which were linearly related to percentage of fiber, specification and type of fiber.
3. Characteristics of failure in Moderate Deep Beams were different from ordinary deep beams and shallow beams, different equation required for prediction of shear strength for moderate deep beam.
4. As according to strut and tie method of analysis for deep beam, cross section area of strut influences the size effect. Therefore, dimension of bearing plate directly affects the strut area.
5. Fiber added to concrete at optimum dosage, so size effect can be mitigate.
6. As per classification of beams, a/D<1 termed as deep beam and a/D ≥ 1 termed as moderate deep beam, so a/D = 1 was transition zone.
7. Nonlinear regression analysis used for model generating and data analysis for modification of existing formula
8. Fiber contribution in shear strength of moderate deep beams as follows for steel fiber contribution and polypropylene fiber contribution.

   For FRC: $\boldsymbol{r\sqrt{\rho(1+4F)f_c}}$

   Where $\boldsymbol{r}$ and F varying as per type of fiber.

   $\boldsymbol{r}$ is function of a/D ratio, and $\boldsymbol{F}$ is function of (Aspect ratio, volume of fiber, shape factor)
9. Crack width is an important parameter for serviceability criteria and aesthetics point of view. Also to predict the post cracking behavior of RCC member, a vital importance is given in many research work described above for flexural crack while shear crack is also as much as important in case of moderate deep beams.

10. Crack width is primarily a function of the deformation of reinforcement between the two adjacent cracks.
11. Mainly, crack width depends on lot of parameters but the parameters related to reinforcement is of much concern. Stress, strain, reinforcement ratio, diameter of bars are major influencing factors in the crack initiation and widening. One of the observations from above literature regarding reinforcement stress is to limit the usage of reinforcement steel though it is key player in controlling crack width. Because as reinforcement ratio increases, the concrete contribution in tension decreases, the mean steel strain increases, consequently the crack width increases[4].
12. Concrete cover is also a prime factor that contributes significantly in controlling crack width. Many research works had already been carried out by adopting concrete cover as a parameter of interest. To underline the importance of reinforcement cover, R.J Frosch have given a formula considering thicker concrete cover[2]as the usage of thick cover is surging now a days for protecting bars against harsh environment.
13. Bond between concrete and steel reinforcement takes part in transfer of tensile stress from concrete to rebar that is also a considerable factor for identification of cracking behaviour.
14. As cracking is a random behaviour subject to a large degree of scatter (possible up to 45 percent), statistical study based on accumulation of research data is necessary. Many variables affect the development and characteristics of cracks. The major ones are: percentage of reinforcement, bond characteristics and size of bar, concrete cover and concrete stretched area, distribution of reinforcement, and bond and tensile strength of concrete[11].
15. Use of steel and polypropylene fibers and its capacity to control cracks has raised great hopes for improving deformation characteristics and ductility of members subjected to shear.
16. Contribution of fibers in delaying crack initiation and also improving member’s load carrying capacity is noteworthy.

17. Fiber pull out test reveals more energy requirement compared to normal concrete. As energy absorption increases in fibrous concrete, initial load bearing capacity increases compared to normal concrete.

2.3. OBJECTIVE

1. To evaluate the Size effect parameter in Shear strength Equation of Reinforced Cement Concrete (RCC) Moderate Deep Beam, Fibrous Reinforced Concrete (FRC) Moderate Deep Beam.
2. To incorporate the Size effect parameter in Shear Strength Equation given by Previous Researcher and Compare the Modified Shear strength equation with other Researcher's shear strength equation.
3. To measure the deflection occurs in RCC and FRC Moderate Deep beam.
4. To incorporate the size effect parameter in Compressive Shear strength equation given by various codes.
5. To study the crack pattern in RCC and FRC Moderate Deep Beam.
6. To add the Size effect parameter in Crack width formula given by previous research work.