Effects of Vertical and Slant Shear Reinforcement on the Strength of a Simply Supported Deep Beam

Abstract

This research investigates the shear strength behaviour of deep beams with different angles of inclinations of the transverse reinforcements with thelongitudinal reinforcements. A mix ratio of 1:1½:3 of concrete was used in this investigation with a total number of three (3) deep beam models of 150×300×750 mm and the characteristic compressive strength was determined to be 14.5 N/mm^2. The study concludes that the ultimate resisting load of the beam depends on the angle of inclination of the shear links and maximum with 90^o inclination angle of the shear links which decreases with a decrease in the angle of inclination. Hence, all shear reinforcement must not be inclined at an angle other than 90^o to the longitudinal reinforcement to avoid shear-compression failure along the shear diagonal.

Keywords: Deep beam; shear link; shear reinforcement; longitudinal reinforcement; shear failure.

1.0 INTRODUCTION

1.1 Background to the Research

In a high-rise building, deep beams are usually required at the lower storey to support massive load over long span between column supports. Deep beams are flexural members with larger depth in comparison to their span (Kong and Chemrouk, 2002).

Reinforced-concrete (RC) deep beams are structural elements that are usually used as load carrying structural members [Mohamed, et al., 2017; Cao, et al., 2019]. These beams are tedious in design as a result of the nonlinear effect of different parameters on their properties and shear strength [Shahnewaz, et al., 2020; Demir, et al., 2019]. Shear stress is notably one of the known failure modes of RC deep beams, which generally causes severe failure and loss of life [Zhang *et al.*, 2020].

The bending and shear stresses are the most important design consideration of a simply reinforced concrete deep beam. Over the years, many researchers have carried out research on various design criteria such as size effect (Althin and Lippe, 2018; Chen *et al.*, 2019; Hussein *et al.*, 2018; Kok andYin, 2022; Mulatu, 2019), aggregate size effect (Deng *et al.*, 2017; Lou *et al.*, 2020; Alqarni *et al.*, 2020; Christianto *et al.*, 2022), shear length to depth ratio (Liu and Polak, 2022; Jin *et al.*, 2019), side face reinforcement, percentage of reinforcement, crack width criteria, and shear span deflection were varied to analyze the ultimate shear strength of reinforced concrete deep beams. However, there are scarce reported researches on the effect of vertical and slant orientations of shear reinforcement on the strength of simply supported deep beams. Hence the need for this work.

2.0 LITERATURE REVIEW

2.1 DEEP BEAMS

In their research, Matamoros and Wong (2003), focused on establishing the relationship between the strength of deep beams and the forces in the main strut and ties of the strut-and-tie models. Matamoros and Wong (2003), proposed design equations, based on experimental results from 175 simply supported deep beams from literature, using strut-and-tie model. They found out that the strength reduction coefficient for concrete in the main strut was found to decrease with the inclination angle of the strut, thereby given lower values specified by ACI 318 Standard (2002).

Reinforced concrete structural elements, with depth comparable to span are generally termed as deep beams. In these structural elements, the distribution of strains across depth of the cross section will be nonlinear and most of load is carried to the supports by a compression strut joining the load and the reaction (Praveen and Pillai, 2008). These structural members normally behaves like the D (disturbed) regions, which are normally being designed using empirical formulae or using past experience (Praveen and Pillai, 2008). Praveen and Pillai, (2008) used strut and tie method (STM), to develop equations for finding the area of main steel required to have a balanced type of failure and to find the ultimate capacity of deep beams failing in different failure modes and these equations were compared with experimental results and a good agreement was found.

Research was conducted on deep beams designed by strut –and –tie method, to determine their strengths (Niranjan and Patil, 2012), and their experimental results were compared with the theoretical results obtained by finite strip method. From their results, Niranjan and Patil (2012), noted that the flexural steel required by strut and tie method was 15% to 30% more than determined by finite strip method for shear span 200mm to 230mm, and also the overall average load at first crack was approximately half of the ultimate failure load.

Strut-and-Tie Models (STM) are models for the design of concrete beams, which comprises of struts, ties and nodes as the basic tools. (Ahmed, et al, 2013). In their study (Ahmed, et al, 2013), the Strut-and-Tie Modeling was based on Load-Transfer-Mechanisms as a unified method to analyze, design and detailing for deep and slender concrete beams. Examples from literature were re-analysed with refined STM based on load transfer mechanisms and results are compared and from the results of the study,it was concluded that the proposed approach will require true reinforcement demand depending on dominant force transfer action in concrete beam.

In their study, El-Demerdash et al, (2014), usedone group of simple shallow beams and one group of simple deep beams. STM approach was applied to both groups of beam, they were also tested experimentally, andin addition, a three-dimensional nonlinear finite element analysis using ANSYS 12.0 computer program was employed for the analysis using the **STM** method. Comparison of the results the STM, experimental results and that of the of analysis using ANSYS 12.0 computer program were carried out.

Nine high strength reinforced concrete beams that satisfied the minimum shear reinforcement criteria as per ACI code, were tested, by Arun, and Ramakrishnan (2014) and investigated their size effects on shear strength for medium depth beams (d ranges from 305 to 560 mm), ultimate shear capacity and failure modes. The test results were compared with the strengths predicted by ACI code, CEB-FIP Model, Zsutty’s equation, Okumaro’s equation and also with Bazant’s method. From the results Arun, and Ramakrishnan (2014), found out that, the ACI code and Okumaro’s equation can predict the shear strength trend reasonably well for slender beams,the Bazant’s method is underestimating the ultimate strength and thatthe accuracy of the Zsutty’s equation is relatively better than ACI approaches, but it does not take in to account the size effect.

The results of experiments carried out on ordinary/deep beams with openings from literature were compare with that of 3-D nonlinear FEA using ANSYS-12 package. The variables considered are concrete compressive and tensile strength, span-to-depth ratio, shear span-to-depth ratio, physical and mechanical properties of horizontal, vertical web reinforcement and main steel, loading position and opening dimensions. From the research it was found out that the STM method can be used to obtain a reasonable lower bound estimate of the load carrying capacity of RC ordinary/deep beams with openings. Also, the 3-D nonlinear FEA of simple and continuous NSC and HSC ordinary/deep beams with/without openings yields accurate predictions of both the ultimate load and the complete response (El-Demerdash, et al 2015).

Through experimental study, Panjehpour, M., Chai, H. K., and Voo, aimto refine STM through the strut effectiveness factor and increase result accuracy. Six RCdeep beams with different shear span to effective-depth ratios (a/d) of 0.75, 1.00, 1.25,1.50, 1.75, and 2.00 were experimentally tested under a four-point bending set-up. The ultimateshear strength of deep beams obtained from non-linear finite element modeling andSTM recommended by ACI 318-11 as well as AASHTO LRFD (2012) were compared withthe experimental results. An empirical equation was proposed to modify the principal tensilestrain value in the bottle-shaped strut of deep beams. The equation of the strut effectivenessfactor from AASHTTO LRFD was then modified through the aforementioned empiricalequation. An investigation on the failure mode and crack propagation in RC deep beamssubjected to load was also conducted.

Bernoulli’s hypothesis cannot be applied to some beam’s regions, termed as ‘D regions’ or ‘Discontinuity regions’. Deep beams are normally termed as ‘D regions’ or ‘Discontinuity regions’, hence the Brazilian code of practice (Associação Brasileira de Normas Técnicas [ABNT], 2014) approves the design of these elements using Strut-and-Tie Method (STM), which is based on forces acting in hypothetical truss models.Silveira, and Souza (2017), used the Stress Field Method (SFM) to analyse deep beam, which is based on the knowledge of the stresses acting inside of a structure. The purpose of this method is to identify the load carrying mechanisms inside of a complex region. Silveira, and Souza (2017), deployed the Jconcsoftware package, which is based on the Non-Linear Elastic-Plastic Stress Fields (NL-EPSF), for the design and analysis of some deep beams. Based on some validations and comparisons, Silveira, and Souza (2017), propose a solution based on the SFM for the analysis, design, and detailing of deep beams, and the parameters established by the ABNT (2014) for the deep beams were evaluated based on the simulations.

In their researchChristianto, et al (2022), the size effect on shear strength of concrete beams without coarse aggregate was studied, by evaluating the ACI 318-14, ACI 318-19, and Eurocode 2 formulas. The beams were tested under two concentrated loads. The beams were designed without any stirrups. Based on the analysis, the ACI 318-19 approach provides the best prediction with the mean strength ratio and coefficient of variation of 1.5086 and 0.26, respectively. The ACI 318-19 also indicates insignificant downward trend on the strength ratio vs. effective depth. The test results show that the size effect is in good agreement with the Bažant's size effect law. In this paper, modifications to the existing formula are given to provide more accurate prediction.

Zhang et al. (2020), investigated the shear strength of deep reinforced concrete beams, with a new intelligent model depending on the hybridization of support vector regression with bio-inspired optimizationapproach called genetic algorithm (SVR-GA).The SVR-GA was used to predict the shear strength of reinforced concrete (RC) deepbeams based on dimensional, mechanical and material parameters properties. The adopted SVR-GA modelling approach isvalidated against three different well established artificial intelligent (AI) models, including classical SVR, artificial neuralnetwork (ANN) and gradient boosted decision trees (GBDTs).

The comparison assessments provide a clear impression ofthe superior capability of the proposed SVR-GA model in the prediction of shear strength capability of simply supporteddeep beams. The simulated results gained by SVR-GA model are very close to the experimental ones.

ACI-318M, (2011) classifies a horizontal structural member as a deep beam when the ratio of its effective length (Le) to the overall depth (h) is less than or equal to 4 (i.e. Le ≤4h). The two common type of cracks observed on deep beams are diagonal and flexural cracks. Slant shear reinforcement refers to the inclined bars that are placed diagonally in the shear span of a deep beam while vertical shear reinforcement refers to the use of stirrups placed vertically along the span of the deep beam(Shyamala, 2022).

Shear failures in beams are classified based on the cracking patterns which can be initiated through flexural cracks or through shear tension particularly in the web (Yang, 2014). Once the concrete is cracked, no tensile forces are transmitted across the cracks of a deep beam. The only force that keeps the two forces from sliding past one another is the interlocking of the concrete aggregate in deep beams. The interlocking force can be very strong and can provide between 33 to 50% of the shear resistance of the beam (Christianto *et al.*, 2022). This is the critical point where the shear and tension reinforcements get activated and prevent full separation and sliding of the concrete.

Mohammed and Ismail (2021) predicted a new computer artificial intelligence model for shear prediction of RC beams on the basis of XGBoost ensemble tree and MARS model as a robust AI methodology for RC beam prediction. However, the compressive strengths of concrete tested were less than 40 MPa and therefore recommended that dataset, parameter and model uncertainties can be explored for better understanding of the underlying complexity.

Deng *et al.* (2017) confirmed the sensitivity of the shear strength to the maximum aggregate size for beams cast without shear reinforcement. Lou *et al.* (2020) explicitly ran a finite element simulation to clarify the significant size effect on the coefficient of variation (COV) to anchor the probability distribution of shear strength by choosing a safety factor.

Alqarni *et al.* (2020) experiments on the effect of coarse aggregate characteristics on the shear behaviour of reinforced concrete slender beams under three-point loading configuration and proposed a shear strength model using the simplified ACI - 318 equation. Christianto *et al.* (2022) evaluates the ACI 318-19 and Eurocode 2 to propose a formula for predicting the size effect on shear strength of concrete beams without coarse aggregate with stirrup and without stirrup.

However, the shear-span ratio has an ignorable influence on the size effect of shear strength since shear-span ratio of 2.0 is nearly 50% lower than that of beams with shear-span ratio of 1.0 (Liu and Polak, 2022).

Jin *et al.* (2019) developed a novel size effect law (SEL) for predicting the influence of stirrup ratio and shear-span on the shear failure and size effect of RC beams of different sizes quantitatively using a three-dimensional meso-scale simulation method.

The vertical shear reinforcement significantly increases the shear strength of deep beams by providing stirrups to effectively restrain the inclined shear cracks. Slant shear reinforcement increases the shear capacity of deep beams by redistributing the shear forces along the inclined bars (Shahnewaz*et al.*, 2020).

3.0 MATERIALS AND METHODS

The materials and methods used for this work are stated below.

3.1 Materials

The materials used for this work are: cement, fine aggregate, coarse aggregate, steel bars and potable water. These materials are fully described in this section.

The cement use was Grade 42.5 Portland Cement, and was purchased at the cement shop opposite FUTA north-gate in Akure metropolis, Ondo state, Nigeria. The fine and coarse aggregates were sourced from Akure South Local Government area of Ondo State. Aso, the reinforcing bars used were the hot-rolled high yield steel of diameters 10 mm and 12 mm respectively.

The grade of concrete used for the work was determined through trial mixes of cement, fine aggregate, coarse aggregate and water.

The equipment used for the compressive test of hardened concrete of this work was the Universal Testing Machine (UTM).

3.2 Methods

3.2.1 Tests on Materials

Various tests were carried out on the materials to ascertain their suitability for use in this study. The tests that were performed on fine aggregate is the particle size distribution test. For coarse aggregate, particle size distribution test, aggregate impact value (AIV), aggregate crushing value (ACV) and specific gravity tests were carried out.

3.2.2 Tests on Concrete

Workability test was carried out on fresh concrete, while compressive test was carried out on the hardened concrete. Forty concrete cubes of size 150 mm x 150 mm x 150 mm were produced from the concrete mix used to cast the pad footings. Ten cubes each were tested at 7th, 14th, 21st and 28th days respectively using universal testing machine (UTM), to determine the characteristics strengths of the concrete.

The characteristic compressive strength of concrete cubes can be determined using Equation (1).

$$f_k = \bar{x} - 1.64\sigma \qquad (1)$$

Where f_k is the characteristic strength and σ is defined by Equation (2)

$$\sigma = \sqrt{\frac{\sum(x-\bar{x})^2}{n}} \qquad (2)$$

Where x – the strength of a sample

$\bar{x}$ – Average Concrete Cube Compressive Strength

n – The number of samples

σ – Standard deviation

3.2.3 Tests on Reinforcement Bars

For the reinforcement used for the work, tensile tests were carried out on steel reinforcing bars, according to BS 4449 (1997), to determine their characteristic strengths.

3.3.3 Experimental Programme

A total number of four (4) beams were prepared and cast with varying angles of inclination of the stirrups as shown in Plate 1. Each beam had a length of 750 mm with rectangular cross section of 300 mm x 150 mm as indicated in Table 1. The flexural reinforcement consisted of

2Y10 mm deformed steel bars which were placed at the bottom of the beam cross section. A 2Y10 mm as compression reinforcement placed at the top of cross section and Y8 mm as shear reinforcement at spacing of 100 mm arranged in varying degrees of inclination. The beams prepared for this work are simply supported deep beams with effective span to effective depth l_e/d ratios of 2.0 and shear span to effective depth (a/d) ratios of 1.0 respectively, which are within the ACI 318 (2002) code provisions. The loading was a point load, applied at the center of the beam with the shear span to depth ratio (a/d) of 1.0 for the beam with effective length of 550 mm. The beams were tested until they failed under a point load set up. This was done using the universal testing machine (UTM) with maximum capacity of 300 kN.

4.0 RESULTS AND DISCUSSION

4.1 Preliminary Tests Materials

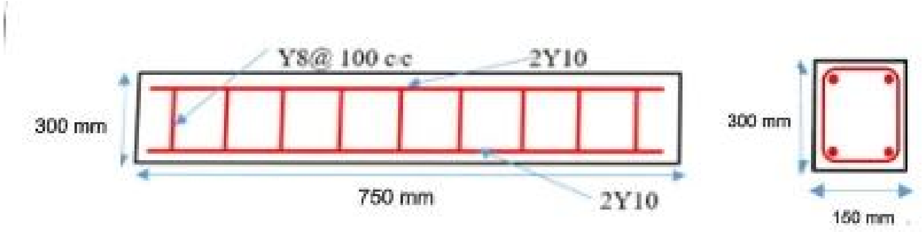
The summary of results of the tests conducted on the materials used in making the concrete are presented in this section. From the tests carried out on the fine aggregate, the uniformity coefficient (C_u) and the coefficient of gradation (C_c) were determined to be 14 and 2.93 respectively. For a well graded soil the value of coefficient of uniformity C_u must be greater than 4 and C_c should be between the ranges of 1 to 3. Therefore, the fine aggregate was well-graded.

The specific gravity of the fine aggregate used for the researchwas determined to be 2.65, while the Bulk Density was 2156.58 kg/m^3.

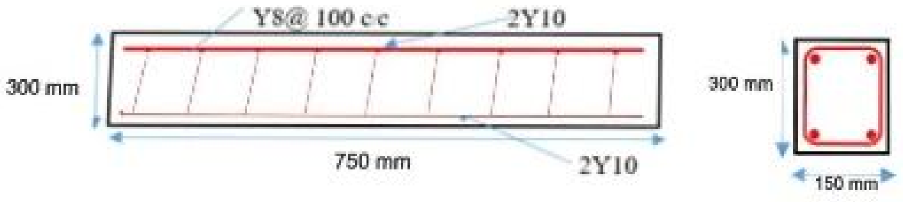
Table 1: Experimental Beams Details

Beam No.	Longitudinal Section	Cross Section

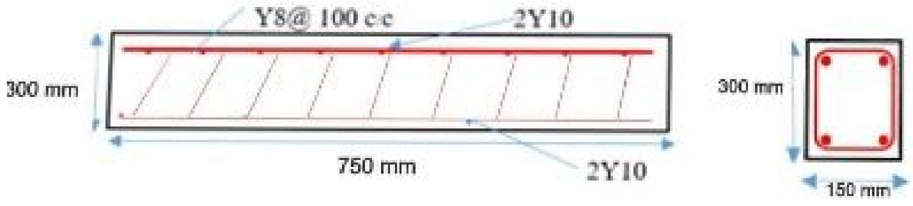
B1 – 90.0^0



B2 – 67.5^0



B3 – 45.0^0



The Aggregate Impact Value (AIV) and Aggregate Crushing Value (ACV), and specific gravity tests were carried out on the coarse aggregate. From the tests, the AIV, ACV and specific gravity were determined to be 20.51 % and 29.21 % respectively. Since these values did not exceed 30%, shows that it conforms to the code.

From the tensile tests carried out on reinforcing bars used for the research, yield strength for the 8mm and 10mm are 727.60MPa and 519.62 MPa respectively.

From the slump test carried out on the fresh concrete, out in accordance with British Standards (BS EN 12350-2:2009), the slump was determined to be 25mm which is adequate, as slump values recommended for mass concrete structures and pavements ranges between 25 to 50 mm.

Compacting Factor test was carried out in accordance to British Standards (BS EN 12350-2:2009). From the test, the compacting factor is 0.90. This value of compacting factor is satisfactorily as it falls within the range of 0.85 – 0.92 which is the recommended value for concreting of lightly reinforced sections without vibrations or heavily reinforced sections with vibrations.

4.2 Tests on Hardened Concrete

In order to determine the characteristic strengths of the concrete used for the work, compressive tests were carried out on concrete cubes.From the test results, the characteristic strength f_k of the concrete sample at the 7th day was 9.06 N/mm^2, while that of 14th, 21st and 28th days were 10.44 N/mm^2, 12.65 N/mm^2 and 14.15N/mm^2 respectively.

4.3 Test on the Beams

The results of the tests of experimental beams are given in Table 2. From the test results, the load at first crack for B1 – 90.0^0 is 144.5 kN, while that of ultimate load is 190.65 kN. For beam B2 – 67.5^0, the load at first crack is 125.62 kN, while that of ultimate load is 165.45 kN, and for beam B2 – 45.0^0, the load at first crack is 108.92 kN, while that of ultimate load is 146.58 kN.

From these results, reducing the angle of inclination of the stirrups from 90^0, there is corresponding decrease in the first crack and ultimate loads for the beams. For beams B2 – 67.5^0 and B3-45^0 there are corresponding decrease in the first crackby 13.1% and 24.7% respectively when compared with that of B1 – 90.0^0. Also for beams B2 – 67.5^0 and B3-45^0 there are corresponding decrease in the ultimate load by 13.2% and 23.1% respectively when compared with that of B1 – 90.0^0.

Table 2: Experimental Load at first crack and failure loads

Beam Type	Shear spacing angle (degree)	Load at first crack (kN)	Max. force (kN)	L (mm)	B (mm)	D (mm)	Reinforcement
B1 – 90.0^0	90.0^0	144.56	190.65	750	150	300	2Y10 T/B
B2 – 67.5^0	67.5^0	125.62	165.45	750	150	300	2Y10 T/B
B3 – 45.0^0	45.0^0	108.92	146.58	750	150	300	2Y10 T/B

Plate 1: Loading of beams with 90^o and 45.0^0 shear reinforcements

4.4 Estimation of load and shear capacities for the beams

Using equations (3) to (6), the load and shear capacities were determined. The summary of the results of the estimations are presented in Table 3.

$$M_R = 0.156\, f_{cu} b d^2 (3) (Mosley\ and\ Bungey, 1990)$$

For simply supported beam:

$$M_R = \frac{PL}{4} \quad (4)$$

From which:

$$P = \frac{4M_R}{L} \quad (5)$$

Where:

M_R – moment of resistant of the beam

P – applied load

L – effective span of the beam

For the estimation of shear capacities of the beams, equation (6) was used.

$$V = vbd = \left(\frac{A_{sv}}{s_v}\ x\, 0.87\, f_{yv} + bv_c\right) d \qquad (6)\,(Mosley\ and\ Bungey, 1990)$$

Where:

V = Shear resistance

ν = shear stress

A_{sv} = area of shear reinforcement

f_{yv} – strength of shear reinforcement

ν_c = ultimate shear stress determined from Table 3 of BS 8110-1(19977)

Table 3: Summary of actual and estimated ultimate loads

S/No.	Beam type	Actual ultimate load (kN)	Estimated ultimate load (kN)
i.	B1 – 90.0^0	190.65	771.78
ii.	B2 – 67.5^0	165.45	771.78
iii.	B2 – 45.0^0	146.58	771.78

From Table 3, the estimated ultimate load is 771.78 kN, while the actual ultimate loads are 190.65 kN, 165.45kN, and 146.58kN, for beams B1-90.0^0, B2 – 67.5^0 and B3 – 45.0^0 respectively. This shows that the estimated loads overestimated the load capacities of the beams by over 300%.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

In this study, a total of three (3) reinforced concrete deep beam specimens were tested using the shear span – to – depth ratio and effective beam depth of 2.0 and 275 mm respectively. The general behaviors of the test specimens were examined and the effects of the test parameters on the measured shear strengths of the specimens were investigated. The following can be concluded from the study:

a) The characteristic strength of concrete with mix ratio 1:1½:3 was determined to be 14.5 N/mm^2.

b) From the crack behavior and failure pattern, it can concluded that the beams under loading failed by shear – compression failure.

c) The ultimate resisting load of the beam depends on the angle of inclination of the shear links.

d) The ultimate load of the beams is maximum with the angle of inclination of the shear links to be 90^o, and decreases with decrease in the angle of inclination.

e) The estimated ultimate load and shear capacity are greater than the actual ultimate load and shear capacity.

5.2 RECOMMENDATION

Based on the conclusions above,it is recommended that theshear reinforcement must not be inclined at an angle other than 90^o to the longitudinal reinforcement.

REFERENCES

ACI Committee 318. (2002). *Building Code Requirements for Structural Concrete. ACI 318-02.* American Concrete Institute, Farmington Hills, Mich., 443 pp.

Ahmed, M., Yasser A., Mahmoud H., Ahmed, A., Abdulla M. S. and Nazar, S. (2013). Load Transfer Mechanism Based Unified Strut-and-Tie Modeling for Design of Concrete Beams. *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*. Vol. 7, No. 3. Pp. 225 – 262.

Alqarni, A. S., Albidah, A. S., Alaskar, A. M., and Abadel, A. A. (2020). The effect of coarse aggregate characteristics on the shear behavior of reinforced concrete slender beams. *Elsevier Journal Construction and Building Materials, 264, 120189 pp 1-21.* doi:10.1016/j.conbuildmat.2020.120189

Althin, A., and Lippe, M. (2018). Size effects in shear force design of concrete beams. *TVBK-5265.*

Arun, M. and Ramakrishnan, S. (2014). Size effect on shear behaviour of high strength RC slender beams. *International Journal of Research in Engineering and Technology.*Vol. 03 Issue: 08. Pp. 113 – 118.

Associação Brasileira de Normas Técnicas. (2014). NBR 6118 – Projeto de estruturas de concreto - Procedimento. Rio de Janeiro, RJ: ABNT.

BS 812 – 2 (1995). *Tests on Aggregates: Part 2. Methods for Determination of Density*. British Standards Institution.

BS 8110 – 1 (1997). *Structural Use of Concrete: Part 1. Code of Practice for Design and Construction*. British Standards Institution.

BS EN 12350 – 2 (2009). *Testing Fresh Concrete. Slump Test*. British Standards Institution.

Cao, J., Bloodworth. A. G., and Xu, M. (2019). Efficient two-way shear grillage model solution for bridge RC four-pile caps under wall loading. *J Bridg Eng.* 24:4019071

Chen, H., Yi, W. J., and Hwang, H. J. (2018). Cracking strut-and-tie model for shear strength evaluation of reinforced concrete deep beams. *Engineering Structures.*

Christianto, D., Makarim C.A., Tavio, and Joseph A. H. (2022). A proposed formula for predicting size effect on shear strength of concrete beams without coarse aggregate. *International Journal on Engineering Applications (IREA), 10(3), pp. 220-226*

Demir, A., Caglar, N., and Ozturk, H. (2019). Parameters affecting diagonal cracking behavior of reinforced concrete deep beams. *Eng Struct.* 184:217–231

Deng Q., Yi W.J., Tang F.J. (2017). Effect of coarse aggregate size on the shear behaviour of beams without shear reinforcement. *ACI Structural Journal 114 (5).*

El-Demerdash, W. E, El-Metwally, S. E., El-Zoughiby, M. E., and Ghaleb, A. A. (2014). Strut-and-Tie Model and 3-D Nonlinear Finite Element Analysis for the Prediction of the Behavior of RC Shallow and Deep Beams with Openings. Salah E. El-Metwally/et al/Engineering Research Journal. Vol. 141. Pp. 50 – 70.

El-Demerdash, W. E., El-Metwally, S. E., El-Zoughiby, M. E., Ahmed A., and Ghaleb, A. A. (2015). Behavior of RC Shallow and Deep Beams with Openings Via the Strut-and-Tie Model Method and Nonlinear Finite Element. *Arabian Journal for Science and Engineering*. DOI 10.1007/s13369-015-1678-x

Hussein, G., Sayed, S. H., Nasr, N. E., and Mostafa, A. M. (2018). Effect of loading and supporting area on shear strength and size effect of concrete deep beams. *Ain Shams Engineering Journal*, *9*(4), 2823-2831. doi:10.1016/j.asej.2017.11.002

Jin, L., Wang, T., Jiang, X., and Du, X. (2019). Size effect in shear failure of RC beams with stirrups: Simulation and formulation. *Engineering Structures, 199, 109573*. pp 1-23, doi:10.1016/j.engstruct.2019.109573

Kok, E., and Yin, Z. (2022). Beam Depth Size Effect in Simply Supported Reinforced Concrete Deep Beam (*Doctoral dissertation, UTAR*).

Kong, F. K., and Chemrouk, M. (2002). Reinforced Concrete Deep Beams. In F. K. Kong (Eds.), *Reinforced Concrete Deep Beams* (Chapter one). Taylor and Francis.

Liu, S., and Polak, M. A. (2022). Estimating shear strengths of GFRP reinforced concrete deep beams with indeterminate strut-and-tie method. In *Current Perspectives and New Directions in Mechanics, Modelling and Design of Structural Systems* (pp. 511-512). CRC Press.

Lou W., Le J., Rasoolinejad M., and Bazant Z.P. (2020). Coefficient of Variation of Shear Strength of RC Beams and Size Effect. *American Society of Civil Engineers*, *147(2)* DOI: 10.1061/(ASCE)EM.1943-7889.0001879.

Matamoros, A. B. and Wong, K. H. (2003). Design of Simply Supported Deep Beams Using Strut-and-Tie Models. *ACI Structural Journal*. Nov./Dec. Pp. 704 – 712.

Mohamed, K., Farghaly, A. S., and Benmokrane, B. (2017.) Effect of vertical and horizontal web reinforcement on the strength and deformation of concrete deep beams reinforced with GFRP bars. *J Struct Eng*. 143:4017079

Mohammed, H. R. M., and Ismail, S. (2021). Proposition of new computer artificial intelligence models for shear strength prediction of reinforced concrete beams. *Engineering with Computers*. doi:10.1007/s00366-021-01400-z

Mosley, W. H., and Bungey, J. H. (1990). *Reinforced Concrete Design, 4th Edition*. Macmillan Education Ltd. London.

Mulatu, B. A. (2019). The Effect of Beam Size on Shear Strength of Reinforced Concrete Deep Beams. *Department of Civil Engineering, Addis Ababa Science and Technology University*, pp. 1-77.

Niranjan B.R, and Patil, S.S. (2012). Analysis and Design of deep beam by using Strut and Tie Method. Journal of Mechanical and Civil Engineering. Volume 3, Issue 4 (Sep-Oct. 2012), PP 14-21.

Panjehpour, M., Chai, H. K., and Voo, Y. L. (2015). Refinement of Strut-and-Tie Model for Reinforced Concrete Deep Beams. *PLOS ONE*. DOI:10.1371/journal.pone.0130734.

Praveen, N. P., and Pillai, T. M. M. (2008). Analysis and Design of Simply Supported Deep Beams Using Strut and Tie Method. *Advances in Structural Engineering*. Vol. 11 No. 5. Pp. 491 – 499.

Shahnewaz, M., Rteil, A., and Alam, M. S. (2020). Shear strength of reinforced concrete deep beams-A review with improved model by genetic algorithm and reliability analysis. *In Structures* (vol. 23, pp. 494-508).

Shyamala, G. (2022). Impact of reinforcement and geometry of deep beam–Research perspective. *Materials Today: Proceedings*, 68(5), pp. 1556-1561. https://doi.org/10.1016/j.matpr.2022.07.189

Silveira, M. V. G., and Souza, R. A. (2017). Analysis and Design of Reinforced Concrete Deep Beams using the Stress Fields Method. *Acta Scientiarum*. Vol. 39. Issue 05. Pp. 587 – 599.

Yang, Y. (2014). Shear behaviour of reinforced concrete members without shear reinforcement.

Zhang, G., Ali, Z. H., Aldlemy, M. S., Mussa, M. H., Salih, S. Q., Hameed, M. M, Al‐Khafaji, Z. S., and Yaseen, Z. M. (2020). Reinforced concrete deep beam shear strength capacity modelling using an integrative bio‐inspired algorithm with an artificial intelligence model. *Engineering with Computers*. https://doi.org/10.1007/s00366-020-01137-1