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" A state of the art review of Static Analysis of Multi Layers RC Deep Beams Under Combined Shear and Torsion"

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ABSTRACT

RC deep beams, which serve as transfer girders in bridges and tall buildings, are crucial structural systems that must be safe since they bear heavy loads across small spans. The shear strength and pure torsion together of deep beams is not reliably and properly predicted by recent design standards in practice codes, and in some situations, they are dangerous. To improve current design methodologies and more precisely anticipate the shear and torsion capacity of such members, it is the goal of this effort to understand the behavior of (hybrid) deep beams and their controlling factors. This study examines the impact of vertical and horizontal reinforcement and shear span ratios on failure modes and strengths. This study summarizes earlier research on strengthening Deep (hybrid) beams by the ratio of vertical and horizontal reinforcement resist both shear and torsion and adding SFRC technology. It also illustrates the impact of several strengthening materials of concrete, fiber reinforced concrete and ultra-high strength concrete (UHSC) and their effect on the flexural strength of RC beams

Keywords: Deep Beam, Shear Reinforcement, ABAQUS, Finite element.

1. Introduction

In structural engineering, deep beams are a very interesting member, because deep beams have a depth of at least a quarter of the span approximately [1], deep beams are usually used in marine installations, foundations, and high-rise buildings, Normal Strength Concrete (NSC), the strength of concrete is significantly influenced by the properties of its constituents and the mix design parameters [2], and is used in structural concrete because its cost is suitable and easy to construction, but in special cases and conditions special reinforced concrete layered (hybrid) are used, for example, Normal strength Concrete (NSC) and high strength concrete and ultra-high strength concrete (UHSC) ...etc.

The deep bundle, a structural component, behaves primarily under the influence of shear deformation. A thorough examination is necessary for the deep beam, which is made more challenging by the presence of additives, structural differences, and a change in the quality of the concrete [3]. This article offers numerical calculations made to precisely forecast shear strength, which is important because shear failure can occur abruptly and is disastrous.

Ultra-high strength concrete (UHSC) is a distinct type of concrete with superior mechanical properties and excellent durability. It was first developed in the 1990s by the Bouygues' Laboratory in France for the purpose of obtaining superior properties such as high strength and durability.

(UHSC) can be developed through the technique of enhancing microstructural of the cementitious materials. Both Cheyrezy and Richard referred to a set of key principles for developing RPC (Richard, and Cheyrezy, 1995) [4]:

1- Exclude coarse aggregates to enhance the homogeny.
2- Utilize silica fume as it possesses the pozzolanic characteristics.
3 - Increase the density by improving the granular mix.
4- Utilize super plasticizer to reduce the water-cement ratio to obtain the required workability.
5- Apply pressure during casting.
6- Employ fibers to improve ductility.
7- Post-set heat-treatment to improve the microstructure.

(UHSC) has unique features that make it an interesting subject for researchers. The Sherbrooke pedestrian/bikeway bridge which was created in Canada in July 1997, was the first practical application of (UHSC) technology as shown plate (1).

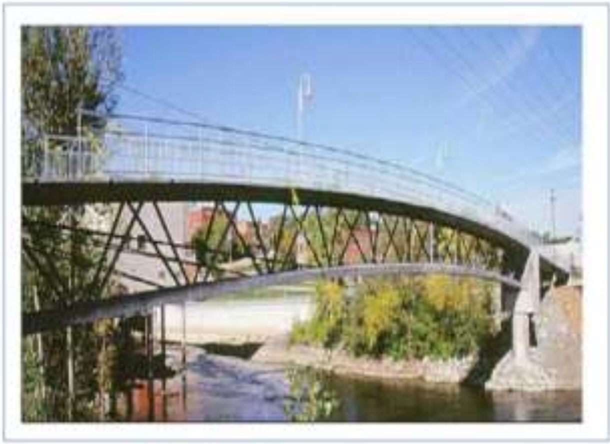


Plate (1) Sherbrooke Bridge, Quebec, Canada

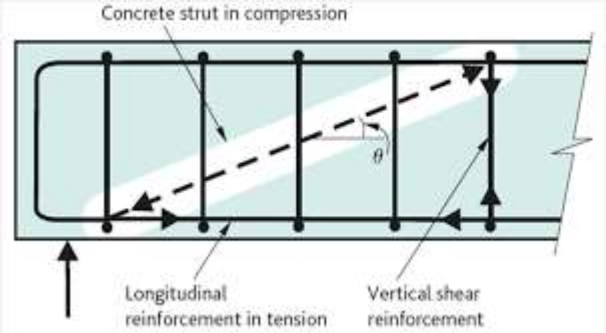
Transfer girders in tall structures, which are characterized as deep beams vulnerable to heavy loads, have a substantial amount of depth in compared to the shear span. Shear span to effective depth ratios of no more than two are required for deep beams.

While those with a ratio larger than two are referred to be narrow beams. Whereas deep beams shear predominantly by compression strut and tension tie, narrow beams shear primarily by beam-action. The inadequate shear strength of the deep reinforced concrete beam can be effectively increased by transverse external post-tension. They found that the failure mechanism changed from enhanced ductility and stiffness to closer to ductile flexural failure, and that all shear strengthened specimens perform significantly better than the reference specimen in terms of ultimate load carrying capacity. Time and money are limited for the experiment, but the numerical model simulates the behavior of deep beams that were assessed using the finite element method (FEM). The efficient and user-friendly computer program ABAQUS analyzes the behavior of concrete structures using the finite element approach. In this study, deep beams strengthened by transverse external post-tension are examined using a finite element model created with ABAQUS.

2. Shear behavior

There is currently no agreement on the function of size influence in the shear illustrated in Fig. due to the complexity of the shear behavior of deep beams and the dearth of fig. (1). because their plane parts do not keep parallel while bending, deep beams are not flexural elements. Determining the strength of deep beams cannot be done using the stress study principles developed for thin beams, as they are neither appropriate nor sufficient.

Figure .1. Shear behavior



3. Torsion

The rotation of the structural part carrying the torque load about its longitudinal axis is referred to as torsion. Another notion involves loading the structural component in a way that causes a few forces to be applied around its longitudinal axis, with the structural member's response being a rotation around its axis. A torsion case can be found on many structural elements, most of which are used in bridges, and a reinforced concrete core can be found around the elevator shaft of a structural member. Torsion in bridges develops because of the horizontal transformational big for dispersed vertical loads. Torsion is integrated with the shear and bending factors from a scientific perspective. Before the first fracture appears, concrete behaves as an isotropic, elastic material, and the reinforcing is disregarded [5]. When the first crack appears, the behavior of reinforced concrete parts differs. Torsional moments affect many structural components, particularly those on bridges, and have a significant impact on structural designs. It is clear that further scientific research is required to address this issue. For regular reinforced concrete beams, all prior torsional strengthening investigations focused on various strip layouts [6 – 7]. As shown in Figure (2), these concrete beams split during pure torsion.

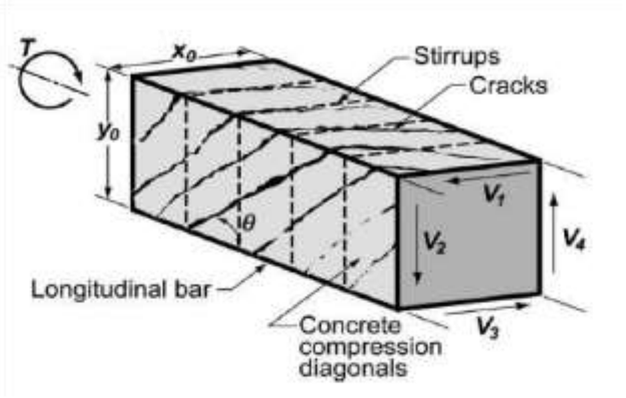


Figure .2. Space Truss Analogy [8]

4. Past Experience

4.1. Single Layer Reinforced Concrete (RC) Deep Beams

De Paiva and Siess (1965) [9] carried out experimental works to test 19 simply supported deep beams of normal concrete under the action of twopoints load. The dimensions of the beams were similar with cross-sectional area of 7 in × 4 in or 9 in × 3 in of a 24 in length. The performance of the beams was tested in terms of ratios of length to depth, web reinforcement, longitudinal steel reinforcement, and the inclined or vertical stirrups mode of the wen reinforcement. The results indicated that the failure mode was changed from flexural to shear and the beams ultimate load was increased with the increase in the amount of longitudinal steel reinforcement. For beams failing in flexural, the ultimate strength was not changed with the increase in the strength of concrete. Meanwhile, web reinforcement had no impact on the production of inclined cracks with minor impact on the concrete ultimate strength. Smith and Vantsiotis (1982) [10] tested 52 deep beams under the impact of two pound loads with the same details of 102 mm × 356 mm crosssectional area, 1.94 % longitudinal steel reinforcement to tensile steel reinforcement, and 0.1 longitudinal steel reinforcement to compression steel reinforcement. The study aimed at investigating the behaviour of deep beams under the impact of the ratios between shear span to effective depth (0.77, 1.01, 1.34, and 2.01), and the amounts vertical web reinforcement (0.18 to 1.25 %) and horizontal web reinforcement (0.23 to 0.91%). The results indicated that the increase in the ratio of shear span to effective depth decreased the ultimate load capacity. Web reinforcement had a moderate impact on the ultimate load capacity with no impact on the production of cracks. Horizontal web reinforcement only slightly impacted the ultimate shear strength, with the impact was more pronounced with the ratio of shear span to effective depth of less than one. The calculated ultimate shear strength value from $1/3\sqrt{f'c}$ bd was the same as the stirrups contribution of the strength.

Oh and Shin (2001) [11] examined the impact of two-point loads on 53 simply supported beams. This was conducted with various parameters including the ratio of shear span to effective depth of 0.5 to 2%, the ratio of effective span to depth of 3 to 5%, concrete compressive strength between 23 and 74 MPa, the amount of horizontal web reinforcement between 0 to 0.94%, and the amount of vertical web reinforcement between 0 and 0.34%. The results showed that the mode of shear failure was controlled by the ratio of shear span to effective depth regardless of the compressive strength. At low shear span to effective depth and high compressive strength, the ultimate load was slightly impacted by horizontal web reinforcement. At this case, the produced failure was sudden without warning. Salamy et al. (2005) [12] aimed at stimulating the performance of deep beams under two-point load with various failure pattern, failure loads, and cracking spreads. The results were compared to experimental work. Several parameters were tested included effective depth of 400, 600, 800,1000, 1200, and 1400 mm, ratio of shear span to effective depth of 0.5, 1, and 1.5, and ratio of horizontal web reinforcement of 0.0%, 0.4% and 0.8% in shear span. The results showed that the results obtained from analytical models were more reliable than the experimental results. The study concluded that the finite element simulation model can be effectively utilised for simulating the behaviour of deep beams with considerable reduction in time and costs in comparison with experimental works.

Khafaga (2012) [13] made a comparison between two groups of reinforced concrete deep beams. The first group included 7 beams with reduced weight concrete of lightweight clay aggregate in a partial replacement of normal aggregates. The second group included 4 beams of normal concrete. Tested parameters included grade and weight of concrete, the ratio of span to depth, and the amount of stirrups. The performance of the beams was studied in regards with the load-deflection response, load-strain response, failure mode, stiffness and ductility, ultimate load capacity, first shear cracking loaf, and the relationship between shear strains and stresses. The results indicated that reduced weight concrete showed a decrease in the ratio tension to compression, modulus of elasticity, and lower decrease in the ultimate capacity in comparison with normal concrete. Also, the loads causing the first shear cracks were greater in reduced concrete beams with the increase in the ratio of shear span to effective depth reducing the ultimate loads and cracks. The shear capacity was improved by the use of shear reinforcement. Due to the concrete grade, the normal weight concrete sections showed greater improvement in the ultimate load capacity than the reduced weight concrete beams.

Ismail, K.S., Guadagnini, M., and Pilakoutas, K. (2017) [14] developed a non-linear strain compatibility model for studying the performance of RC deep beams by considering the equilibrium of strains and stresses across the cross sectional area of deep beams. The model utilised a developed visual basic code. Literature database was used for obtaining the strain values across the depths of various state of RC deep beams. These values were used in simplified formulas to develop strain profiles for each case of the study developed model. The distribution of strain is different from normal beams in accordance with the ratio of span to depth, loading conditions, and structural system. The developed model was able to demonstrate the impact of shear deformation over the cross-sectional area of the beams which was validated according to the literature.

Hafezolghorani, M., Hejuzi, F., Vaghei, R., Jaafar, M.S.B., and Karimzade, K. (2017) [15] conducted a numerical analysis for investigating the behaviour of RC deep beams with calibration and validation based on experimental literature works. In order to obtain adequate match between experimental and numerical results, a bilinear model was adopted with concrete damage plasticity for concrete and Von Mises failure for steel. Significant database was used for developing empirical models for the use in two formulas 5o estimate the ultimate shear strength of the beams under static loadings. The configuration of samples was shown in Fig. (3) With deformation modulus was 210000 MPa, steel reinforcement yield stress was 376 MPa, and concrete compressive strength was 37.8 MPa. The formulas were able to accurately predict the ultimate shear strength if deep beams in comparison with some approach implemented with the use of European Standard EN 1992-1-1 (2004) and ACI Committee 318 (2011).

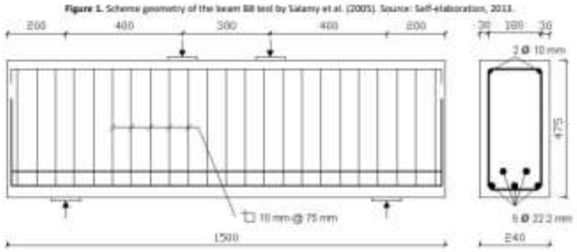


Figure .3. Samples Configuration [15]

Revanna et al. (2020) [16] utilised ABAQUS modelling to validate the commonly used method available in literature for testing the deep beams in flexure. The model was accurately able to indicate the overall performance of the beams and thus can be used for analysing other types of deep beams. The results obtained from modelling were higher than experimental results though the results in terms of the ultimate load and displacement, and the yield load and displacement were very close to experimental results. The tensile and compression failures were perfectly predicted from the models. Sri Harsha et al. (2021) [17] analytically studied the impact of several parameters of 6 RC deep beams and compare the results to experimental works and codes including STM and ACI 318. The parameters included compressive strength, size and geometry, distribution of reinforcement, ratio of span to depth, behaviour of load-deflection, and distribution of strain and damage from tension. The comparison included displacements, ultimate loads and damage from tension. For defining the shear strength of deep beams, a new equation was proposed by the modelling through ABAQUS. Modelling results indicated that the proposed shear formula was able to predict 80% of the experimental data with a range from 66 to 110% of the measured shear strength. The results so indicated that high stresses were available in the cracks paths while low stresses were present in the un-cracked areas. It was also found that there was a difference of 8% between the modelling and experimental results of deflections while 22% difference was indicated for the ultimate loads. It was concluded that the STM code design procedure can provide a conservative result while ACI provided overestimating through a strength reduction factor. Sattaratphaijit et al. (2022) [18] used ABAQUS software to investigate the behaviour of RC Deep Beams consists external transverse post-tension. The model was developed by using a database from literature experimental works for verification. Two groups of deep models were used with two beams for each and a ratio of span to depth equalling 1.5 and 2.0 for the groups respectively. The post tensioning for a beam in each groups was constant of 653 MPa and the others were used as references without post tension. The modelling results were similar to the test results with a difference that dis not exceed 7.8%. It was found that the ratio of span to depth was the control parameter on the performance of the beams. The diagonal cracking of concrete was delayed by the use of post-tension which considerably improved the shear strength of the beams.

4.2. Layered (Hybrid) RC Deep Beams

Mahmood et al. (2010) [19] used nonlinear finite element modelling to study the behaviour of hybrid RC rectangular deep beams. The behaviour of the RC concrete beams was not able to be modelled up to failure in the linear finite element analysis. The material and loading tests results showed that the concrete nonlinear behaviour should be considered when evaluating the mode of failure. This study attempt to develop a modelling code by implementing a rate-independent plasticity model describing various concrete types (high and normal concrete). The obtained results were adequately agreed with the experimental results. Muhammed et al. (2012) [20] conducted a finite element modelling by the use of ANSYS (v.9.0) code to analyse the flexural performance of high strength, normal strength, and hybrid reinforced concrete deep beams. The beams were constructed with two reinforcement ratios (3.56% and 1.43%) and subjected to two-point loads. The results indicated a close agreement with the experimental results. The ultimate load decreased by 7.2% with the increase in the layer thickness of normal concrete by 8% in the hybrid beam at 3.56%reinforcement ratio. Meanwhile, the ultimate load decreased by 11.3% due to the increase in the layer thickness of normal concrete by 8% in the hybrid beam though at 1.43% reinforcement ratio. In addition, the ultimate load increased by (3.9%-5.2%) and (1.67% -18.33%) for (ρ=3.56% and 1.43%) for the increase in the strength of normal concrete in the hybrid beams by (34%-79%) respectively. While, the ultimate load increased by (3.9%-5.2%) and (5% -6.67%) for (ρ=3.56% and 1.43%) for the increase in the strength of high strength concrete in the hybrid beams by (29%-63%) respectively.

Sarsam et al. (2017) [21] used finite element modelling (ANSYS) to study the shear performance of deep beams strengthened with a layer of carbon fibre composites materials. Five beams were strengthened in various directions including inclined, horizontal, and vertical orientations of the fibre materials. Two beams were used as references beams without the addition of the fibres. The concrete was a lightweight aggregate concrete and was produced by the use of locally available natural aggregates (porcelanite). Two ratios between the shear span to depth was used. The results showed that the efficiency of the model to simulate the behaviour of the beams by comparison to the available results. The modelling indicated the ultimate load, crack patterns, deflection at mid-span, and first shear crack.

Saad & Rasheed (2018) [22] conducted experiments to cast and test 6 deep beams subjected to two-point loads. Four of the beams were casted by the addition of reactive powder concrete in the tension layer to the normal concrete in the compression layer. Also, two beams were only casted with the use of normal concrete. The results indicated that the use of hybrid section considerably increased the ultimate and first cracking loads. Further increase in the ultimate load was obtained by increasing the thickness of the reactive powder concrete layer. Also, the decrease in the shear span to depth ratio resulted in a stiffer load-deflection response.

Hassan et al. (2020) [23] conducted rhetorical and experimental works to investigate the performance of hybrid deep beams subjected to two point loads. The beams were made with the same dimensions though were casted in a new approach of hybrid beams. These combined the use of fibre concrete in shear span and normal concrete in the middle span. The aim was to increase the strength against cracking from diagonal shear failure .A total of 3 beams were casted and tested under repeated loading at 50%, 70% and 90% of ultimate load and 1 beam was used as a reference and tested under monotonic loading. Thequantity of shear reinforcement, and steel fibres were investigated. The results showed that the theoretical results determined from the ACI 318M-11 Code using the Strut and Tie approach provided a conservative value in comparison with the experimental results. The use of repeated loading decreased the ultimate load at various levels. Zhang et al. (2020) [24] tested 8 deep beams with HTRB600 reinforced high strength concrete subjected to point load with dimensions of 200 mm × 600 mm × 1600 mm and span to depth ratio of 2. The impact of various parameters was studied including the ratio of shear span to depth (0.3, 0.6, and 0.9), the ratio of vertical stirrup (0% to 0.5%), and the ratio of longitudinal reinforcement (0.67%, 1.05%, and 1.27%). The results showed that the beams with small ratio of shear span to depth exhibited diagonal compression failure and impacted by the amount and distribution of web reinforcement. The shear capacity increased with the increase in the longitudinal reinforcement and decrease in the ratio of shear span to depth. Comparing the results with the calculated shear capacity from various code indicated that CSA A23.3-04 and EN 1992-1-1:2004 provided conservative values while GB50010-2010 and ACI 318-14 agreed with the experimental work.

4.3. Shear Behaviour of RC Deep Beams

Salamy et al. (2007) [25] compared experimental results of shear span to depth ratio and shear strength of deep beams with analytical results. The experimental analysis was conducted by the use of the Strut and Tie approach while the analytical model was carried out by the use of FE code [DIANA 8.1.2]. The modelling results in terms of the maximum carrying load capacity was about 0.8 times the experimental analysis. This provided a satisfactory result. Faroque and Kumar (2015) [26] utilised various codes including Indian Standard (IS), Construction Industry Research and Information Association (CIRIA), and

American Concrete Institution(ACI) to analysis the shear behaviour of deep beams. According to each code, the lengths of the beams were 5.5 m, 5m, and 4.5 m respectively. Graph were drawn for the impact impact shear span to depth ratio (a/d) on shear strength with constant shear and movement (Fig.4). The graph showed that the shear stress decreased with the increase in the ratio of shear span to depth.

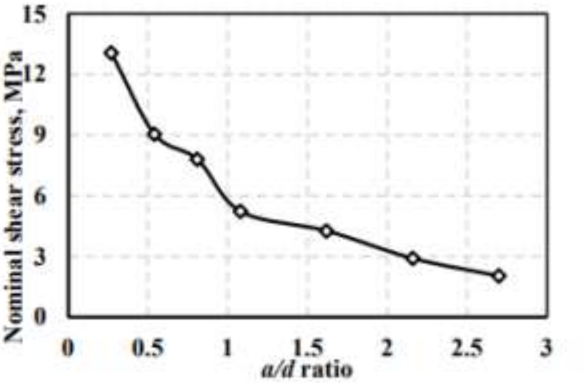


Figure .4. Impact of shear span to depth (a/d) ratio on shear behaviour of deep beams [26].

Ababio et al. (2017) [27] investigated the shear performance of RC deep beams through experimental and analytical studies. 3 deep beams were casted and tested and validated through ANSYS modelling. It was found by experimental results that the failure modes of the beams were diagonal cracking either propagated from existed flexural cracks to point loads or from the area around the support to loading points. The patterns of cracking were indicated through the modelling. Also, the experimental results in terms of loaddeflection responses were correlated with the modelling results which were more than 89% of the former. The experimental results showed a slightly lower stiffness than modelling results which could be attributed to the micro-cracking that was presented in the experimental beams as well as imperfections in materials that could not be modelled.

Hussain et al. (2020) [28] examined the impact of the ratio shear span to effective depth on the mechanical characteristics of medium scale reinforced concrete deep beams. 3 samples were prepared with the same dimensions (150mm × 300 mm × 1250mm), reinforcement details, and concrete grade. The ratios of shear span to effective depths (a/d) were 0.75, 1.25, and 1.75 under the impact of four-points load. The results indicated that the structural response of the beams were significantly impacted by the change in the a/d ratio, which provided two failure modes namely strut compression mode and splitting diagonal mode. The a/d ratio of 1.75 caused higher deflection than the other ratios. Also, the a/d ratio of 1.75 provides ultimate load lower by 20% than the a/d ratio= 0.75. The impact of the ratios on ductility was slight since all the beams were failed in shear. As the ratios reduced from 1.75 to 0.75, the stiffness of the beams increased by about 122%, though the improvement was also indicated in the flexural toughness of about 18.1%. Maa et al. (2022) [29] studied the impact of various variables on the shear performance of deep beams by a database from 833 samples of deep beams. The variables included concrete compressive strength, ratio of shear span to depth, ratio of web (shear) reinforcement, and the ratio of depth to width of the beams.

4.4. Torsional Behaviour of RC Deep Beams

Tamim et al. (1993) [30] studied the torsion behaviour by testing 20 deep beams made with high strength concrete of 51.01, 58.53, 76.60 and 83.66 MPa and various depth to width ratio from 1 to 5. The results indicated that the stiffness of the beams and their torsional capacities increased though the twist angle decreased with the increase in the strength and concrete and the reduction of the depth to width ratio. The beams failed violently and suddenly along a smooth surface. In addition, the concrete strength and the depth to width ratio impacted on the inclinations of cracking on the surfaces of the beams. The study proposed a modification to the torsional strength equation of the ACI 318-8 code for including the impact of high strength concrete for deep beams. The code equation is made for normal concrete shallow beams under torsion. The suggested equation provided an adequate estimation for the testing torsional results. Al-Nuaimi et al. (2013) [31] tested the use externally bonding Carbon Fibre Reinforced Polymer (CFRP) to strengthen reinforced concrete deep beams under the impact of torsion. A total of 8 beams were used: 6 with CFRP at various spacing and number of layers and 2 without CFRP as references samples. For the CFRP beams, box sections and solid sections were used for each two beams. The beams were made between previous conducted experiments on the beams with the modelling results of this study. The results indicated that the use of the CFRP increased the ultimate torque by 9.8%for box sections and by 15.6% for solid sections. The torsional performance of the beams with various CFRP layers and compressive strength of concrete was also investigated in a parametric study.

Wisam et al. (2021) [32] carried out a parametric study with the use of finite element modelling to investigates the strength and performance of ring deep beams with T-sections. The investigated parameters included the compressive strength of concrete, type of loading, and number of supports. The results indicated that the increase in the concrete compressive strength by 45 to 190% increased the positive movements, negative moments, torsional moments, ultimate load by2 0.4-71.3%, 20- 69.7%, 15.6-43.8% and 21-73% respectively, and decreased the deflection by 1.4-11%. In addition, changing the type of loadings from concentred to uniformly distributed loads over 33, 50, 67 and 100% of the span length decreased the positive moments, torsional moments, and deflections by 23-36%, 3-11% and 6-14% respectively. Such change caused an increase on yet negative moment and ultimate load by 2-21% and 6-85% respectively. Meanwhile, the increase in the number of supports by 25 to 100% decreased torsional moments, positive moments, negative moments, and deflections by 11-50%, 38-76.4%, 38.6-76.8% and 14-39% respectively and increased the ultimate load by 82-348%.

4. Conclusions

From the reviewed literature, it was indicated that the mechanical behaviour of deep beams particularly in terms of shear and failure modes depends on various variables. This included the ratios of shear span to effective depth, the ratio of span to depth, the availability and amount of shear (web) reinforcement, and the compressive strength of concrete. In addition, layered beams represent a relatively a new concept of deep beams that requires deep understanding and studies to understand their behaviours and importance. Most of the existed studies dealt with the addition of another material to the concrete and few studies are available regarding the use of different strengths of concrete in several layers. Meanwhile, most of the studies regarding the behaviour of deep beams are concerned about the shear strength with very few studies were conducted on torsional behaviour. No study was found on the behaviour of deep beams under both shear and torsion. Furthermore, although modelling has been evolving vastly, few studies have considered the use of ABAQUS finite element analysis for deep beams. This research aimed at providing an insight into the behaviour of layered deep beams made from several layers of various concrete strength in several cases under the combined shear and torsion. It was believed that such work will fill the knowledge gap on this area toward better utilisation of deep beams.

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Conflict of Interest

The authors reaffirm that there is no conflict of interest with the publishing of this article.

Abbreviations

FEM	Finite element method
SFCR	Steel Fiber reinforced concrete
NSC	Normal Strength concrete
UHSC	ultra-high strength concrete
RC	Reinforced Concrete

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