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A REVIEW OF BEHAVIOR OF REINFORCED CONCRETE DEEP BEAMS

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Abstract: Reinforced concrete deep beams are structural members having depth much greater than normal in relation to their span, while the thickness in the perpendicular direction is much smaller than either span or depth. The strength of deep beams is usually controlled by shear, rather than flexure. In this study, the previous researches related to reinforced concrete deep beams will be reviewed. These researches approximately started in the second half of the past century. Large numbers of researchers studied the behavior of concrete deep beams and the determination of their capacity. Some of these researches are experimental investigations carried out by testing a number of deep beams with variation in some parameters, while the others are theoretical to estimate deep beam capacity by developing some theories and suggestion of equations for calculating its capacity and comparisons were made with those adopted by some codes. Because of the large number of these researches, their review requires large part of this study, and because the prior studies elaborately reviewed the pioneer researches, only the researches made since year 2000 will be reviewed in this study.

Keywords: *Deep beams, shear strength, Normal strength, High Strength, Self-Compact Concrete, Fibers Concrete.*

1. Introduction

Because of deep beam proportions, its strength is usually controlled by shear rather than flexural. On the other hand, its shear strength is significantly greater than that predicted using expressions developed for slender beams [1]. Therefore, special design methods to account for these differences are required. Stresses in deep beams before cracking can be studied using the methods of two dimensional elasticity. Such studies show that the plane sections before bending do not necessarily remain plane after bending where significant warping of cross sections occurs because of high shear stresses. Consequently, flexural stresses are not linearly distributed even in the elastic range and the usual methods for calculating section properties and stresses cannot be applied [2].

Tests indicated that because of biaxiality of compressive stress in the concrete compression zone, ultimate strain much larger than usual value (ε_{cu} = 0.003) may occur [2]. In deep beams subjected to concentrated loads, the distribution of principal tension and compression stresses is as shown in Figure 1 [3], where the compression stresses at the center of line joining load with support are approximately in the same direction of this line while the tension stresses are perpendicular to this line.

In the middle of beam span, the bottom face is subjected to pure tension stresses while the top face is subjected to pure compression stresses. The cracks appear in direction normal to the tensile stress trajectories. As the load increases, the cracks widen and propagate and more cracks open. Because the shear span is small, the compressive stresses at the support region affect

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__Corresponding author:__ hassanfala@gmail.com the magnitude and direction of the principal tensile stresses.

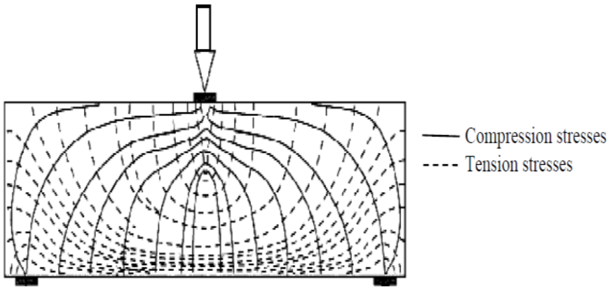

Figure 1. Principal stress trajectories in deep beams [3]

Because of the special behavior of deep beams, some codes such as the ACI Code [4] and Canadian Code (CSA) [5] provide guidance for their design while other codes or standards such as the British standards (BS8110)[6] do not include their design8,9. BS8110 explicitly states that "for the design of deep beams, references should be made to specialist literature".

2. Modes of Failure of Deep Beams

Failure of reinforced concrete deep beams may be in one of the following modes that are summarized in many references [7, 8, 9 and 10]:

1- **Flexural failure:** This type of failure occurs when the (a/d) ratio is relatively large and the beam has low percentage of tension steel, therefore it fails by yielding of tension reinforcement at the section of maximum moment as shown in Figure 2. Such type of failure rarely occurs in practice [7].

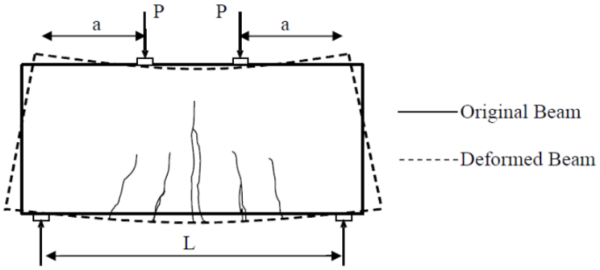

Figure 2. . Flexural failure of deep beams [7]

2- **Flexural-shear failure**: This type of failure occurs when there is a moderate amount of tension steel and the development of the inclined shear cracks is normally preceded by vertical flexural cracks at section of maximum moment. The main cracks causing the final failure are propagating upwards starting from the support towards the load points [7] as shown in Figure 3.

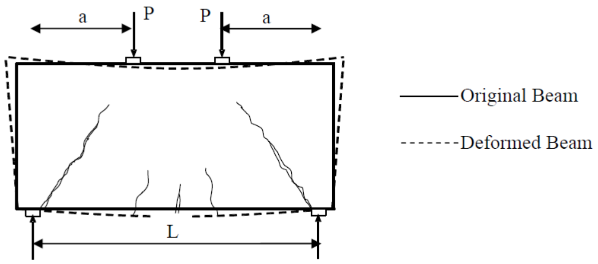

Figure 3. Flexural-shear failure of deep beams [7]

3- **Diagonal splitting failure**: This type of failure occurs when the final shear crack extends between a load and a support and it grows outwards from mid span as shown in Figure 4. This mode of failure occurs by clean and sudden fracture nearly along the line joining support with the load point. Also this mode is akin to the splitting of a cylinder under diametral compression and it is the most common mode in practice [7].

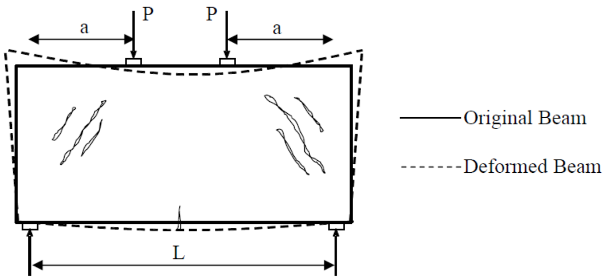

Figure 4. Diagonal splitting failure of deep beams [7]

4- **Diagonal compression failure**: An inclined crack first develops nearly along line joining the load and the support points. After a small further increase in the load, a second parallel inclined crack appears closer to the support than the first one and extends upwards as the load increases. The final failure is due to the destruction of the portion of concrete between these two cracks which acts like a strut between the load and the support positions, where the compression stresses in concrete reach their maximum capacity before the cracks penetrate the compression zone. This mode of failure occurs in low compressive strength concrete deep beams or these have high percentage of shear reinforcement [7].

5- **Bearing failure:** This type of failure occurs either under the load regions or above the supports due to the development of high stresses in these regions. This mode of failure occurs in very deep beams [7].

6- **Anchorage failure**: During the formation of inclined cracks, the strains and stresses in the steel bar near the supports increase rapidly until they are of the same order of magnitude as those occurring at mid span. After inclined cracking, the steel strains and stresses adjacent to the support increase at a slightly greater rate than those at mid span and become approximately constant along the span. Therefore, if the tension steel is not properly anchored near the support, anchorage failure may occur [7].

3. Review of Normal Strength Concrete Deep Beams

In 2002, Aguilar et al [11] tested four simply supported reinforced concrete deep beams under two concentrated loads. Each beam has 305 × 915 × 4470 mm dimensions with 28 MPa concrete compressive strength. The main parameters considered are the horizontal and vertical shear reinforcement ratios. Also they compared main test results with results of the ACI318-99 Code [12] equations and strut and tie model method (STM) adopted by the ACI318-02 Code [13].

They noted that at failure, all specimens exhibited diagonal cracks and some crushing of concrete in the flexural compression zone near loading plate. Two of specimens which have sufficient horizontal shear reinforcement failed by flexure while another two specimens, which were reinforced by little amount of horizontal shear reinforcements, failed by shear compression. The load deflection plots for all specimens are convergent. Also they noted that yielding of both longitudinal bars and transverse bars occurred before or at failure and a large reduction in strains occurred at longitudinal bars within the support plate region. They concluded that the ACI318-99 Code [12] approach and STM methods were conservative in estimating the shear capacity by comparison with test results. Also the provisions for vertical and horizontal reinforcement according the ACI 318-99 Code [12] did not properly reflect the behavior of test specimens. STM model gives better representation and leads to reduction in amount of required shear vertical and horizontal reinforcement.

In 2004, Seo et al [14] investigated whether the standard hook anchorage at ends of the positive moment region can be replaced with mechanical anchorage using steel head and its effect on shear behavior of deep beams were also studied. Eight specimens with headed mechanical anchorage and two specimens with standard hook were tested under two point loads. All specimens were 160 × 600 × 2500 mm in dimensions. The considered parameters were anchorage type, shear span to depth ratio (a/h) and vertical and horizontal shear reinforcement amounts. Experimental results indicate that the specimens with headed reinforcement as a mechanical anchorage showed better resistance by comparing the results with the case of 90-degree hook anchorage. This is because of axial compression forces that result from obstruction of end plates to the axial deformation. The beam with shear reinforcement satisfying the ACI 318-02 [13] Code requirements showed effective behavior for crack control and ductile behavior after yield. For most specimens, the concrete parts in compression strut were destroyed after formation of diagonal cracks showing brittle fracture of specimens.

Also, when a/h =1, the strains of vertical and horizontal shear reinforcement were similar after yielding of longitudinal bars. However, when a/h = 0.5, horizontal reinforcement showed higher strain than vertical reinforcement after formation of diagonal cracks, i.e. the horizontal reinforcement has higher contribution than vertical reinforcement to shear strength when the a/h ratio is low. The study shows that the Strut and Tie modal of the ACI 318-02 Code [13] is conservative in predicting shear strength; therefore it is a desirable method for design of deep beams.

In 2006, Kosa et al [15] studied the shear resistance of deep beams by conducting vertical loading tests on 16 simply supported deep beam specimens. The considered parameters were shear span to effective depth ratio (a/d : 0.5,1,1.5), shear reinforcement ratio (ρw : 0.0, 0.4, 0.8) and effective height (300, 400, 500, 600). They found that specimens with $a/d \le 1$ fractured by shear compression mode, but specimens with a/d = 1.5 fractured by propagated diagonal crack.

When a/d = 1.5, the crack width is controlled by tensile force, therefore, the shear reinforcement can provide shear resistance in combination with the concrete in the compressive range. Also, the comparison between experimental shear strength and theoretical strength calculated using equation proposed by the authors is made. The average of ratio of experimental strength to calculated strength for all specimens was 1.35. This means that the proposed equations underestimate the shear capacity of deep beams.

In 2008, Roy et al [16] performed laboratory tests on 12 deep beams in which the longitudinal reinforcement was anchored into the support using short straight bar anchorages. Specimens were constructed using three different shear span to effective depth ratios (a/d :1 , 1.5 , 2). Failure in all beams, except those with the shortest anchorage length, occurred due to strut crushing. Test results show that shorter anchorage lengths than required by ACI 318-05 Code [17] are effective in developing the yield stress of bars at the end of the extended nodal zone and they are able to transfer shear from the load point into the support.

This result is consistent with shorter anchorage length required by bars embedded in concrete regions subjected to lateral confining pressure. In cases where the reinforcement did not reach yielding, the force transfer mechanism in the deep beams apparently changed from a predominantly tied-arch mode to a truss mode allowing the specimens to achieve approximately the same load during the tests and failing by strut crushing. The study reveals that anchorage length of straight bars over supports of simply supported deep beams could be decreased due to existing lateral confining pressures.

In 2009, Birrcher et al [18] made an experimental study to investigate the effect of member depth on the strength of reinforced concrete deep beams. Tests were conducted at shear span to effective depth ratios (a/d) of 1.2, 1.85, and 2.5 on specimens with a 525 × 575 mm, 525 × 1050 mm, and 525 × 1875 mm cross section. To investigate the depth effect, nine simply-supported specimens with a total span length of 6375 mm were conducted. The longitudinal tension reinforcement ratio was approximately 0.023.

The experimental shear strength results, which are normalized by the factor (f′c bwd) for all of the test specimens, indicate that the normalized shear strength significantly decreases with increasing effective depth. This reduction is small for the specimens loaded with an a/d ratio of 2.5. This indicates that a small size effect exists for slender beams of a/d > 2. Also it can be concluded that the normalized shear strength of deep beams of a/d < 2 decreases significantly with increasing effective depth.

The normalized shear strength of slender beams (a/d > 2) decreases with increasing depth to a much lesser extent. Shear strength was calculated using strut and tie model of ACI 318-08 Code [19]. The comparison between experimental and analytical results shows conservatism of this method for all specimens and there was very little differences in the ratio of Vtest / Vcalc for the deep beam specimens (a/d < 2) as the effective depth increased.

In 2011, Tuchscherer et al [3] presented an experimental program to evaluate the benefit of distributing stirrups across the web of deep beams subjected to shear forces. Six full-scale beams were tested. All specimens were tested with shear span to effective depth ratio (a/d) of 1.84. Four tests were conducted on specimens with a 530 × 1120 mm cross section and two tests were conducted on beams with 910 × 1220 mm cross section. The primary experimental variables were number of stirrup legs distributed across the web and the amount of web reinforcement. Based on the results of the testing program, it was observed that the addition of closely spaced stirrups does not significantly improve the shear capacity or serviceability performance. Due to the fact that web reinforcement is relatively ineffective in deep beams, a limitation of stirrup spacing across the web may be inefficient or unnecessary. They concluded that stirrups must be provided at spacing no farther than a distance (d) from one another.

Choi, et al. [20] tested four deep beams, two cast with normal concrete (NC) and two with self-compacted concrete (SCC) to study their shear behavior and performance. Both NC and SCC specimens were designed for a high-strength of 50 MPa. The tested beams had 180×360×1700 mm dimensions and a/d=1.43. Two various reinforcement ratios for web, stirrups spaced at 100 mm and 50 mm, were investigated. The results indicated that the SCC deep beams having standard shear reinforcement presented a somewhat higher load carrying capacity than the relating NC deep beams. Whereas the SCC deep beams have jammed shear reinforcement presented a similar load ultimate capacity to the relating NC deep beams. Shear cracks initiated in the range of 33% to 41% of ultimate load at both sides of the parallel layers to the inclined strut and continued instantaneously in the directions of both upward to loading and downward to supporting points. For all beams, at 13% to 17% of the maximum load, the flexural cracks appeared in the middle region and they did not enter into the compression region. Lastly, a sudden shear-compression failure took place in all tested deep beam specimens. It was found that the initial stiffness was similar for all specimens cast with both NC and SCC.

Abdul-Razzaq [21] studied the effect of heating on twenty-four small scale simply supported deep beam specimens cast by normal concrete. Specimens were exposed to 300-700$_o$ for one hour which caused a reduction in ultimate capacity by about 15-41%. The reason for this capacity loss was attributed to the reduction in concrete compressive strength that took place due to high temperature on one hand and to the variation in thermal expansion coefficient between reinforcing steel and concrete on the other hand.

4. Review of High Strength Concrete Deep Beams

In 2001, Oh and Shin [22] tested fifty three symmetrically loaded reinforced concrete deep beams with compressive strengths in the range of 23 MPa to 74MPa to determine their diagonal cracking and ultimate shear capacities. The effective span to effective depth ratio (le/d) was varied from 3.0 to 5.0, and the shear span to effective depth ratio (a/d) varied from 0.5 to 2.0. All the beams were singly reinforced longitudinally with a ratio of 0.0129 and 0.0156. The ratio of vertical shear reinforcement ranged from 0 to 0.0034, and ratio of horizontal shear reinforcement ranged from 0 to 0.0094.

The ultimate shear failure mode of deep beams is governed by (a/d) ratio regardless of concrete strength. At a lower a/d ratio, deep beams with high strength concrete fail abruptly without any warning, which could be seen in deep beams with normal-strength concrete. The concrete strength has a significant effect on the ultimate shear strength. Test results indicate that the ultimate shear strength of deep beams can be predominantly determined by a/d ratio.

In 2003 Yang et al [23] tested twenty one beams to investigate their shear characteristics with values of concrete strength ranging between 31.4 MPa and 78.5 MPa, shear span to depth ratio of (a/h) 0.5 and 1, and overall depth in ange between 400 and 1000 mm. The decrease in (a/h) ratio and the increase in overall depth under the same (a/h) ratio led to a more brittle failure with wide diagonal cracks.

The high strength concrete deep beams exhibited more significant size effects with regard to brittle behavior. It was observed that the specimens of a/h = 0.5 show less sensitive size effects than the ones of a/h = 1.0. It was also shown that the ACI Code-99 [12] gives similar safety factors on the shear strength at the first diagonal crack of high-strength concrete deep beams, but does not specify a high enough safety factor on their ultimate strength due to the size effect.

5. Review of Steel Fiber Reinforced Concrete Deep Beams

In 2004, Shah and Mishra [24] investigated the effect of presence of steel fibers in concrete and deformation characteristics of deep beams for various span to depth ratios by testing twelve simply supported deep beams. All beams had constant span length of 600 mm and width of 75 mm while the depth was varied (400, 300, 200, and 150 mm), i.e. span to depth ratio was varied (1.5, 2, 3, and 4). The content of steel fibers was 1% by volume. Failure was in the form of splitting of the beam along the diagonal cracks extending from third of depth towards the loading points.

The results indicate that the inclusion of steel fibers significantly reduces the cracking and deformation behavior of plain concrete deep beams by resisting tensile stresses. It can be seen that the ductility of the beams increases with the increase in span to depth ratio and with increasing inclusion of steel fibers. The inclusion of steel fibers reduces crack width and deflection at all stages of loading. Fiber reinforcement can increase the stiffness of concrete to resist spalling. All concrete deep beams reinforced with steel fibers exhibited large deflection at failure which indicates high ductility and energy absorption.

In 2007, Madan et al [25] studied the shear strength of a series of reinforced concrete deep beams with three steel fiber volume fractions of (0, 1.0 and 1.25%), three shear span to effective depth ratios (a/d) (0.75, 1.0 and 1.25) and three combinations of web reinforcement. A total of 18 beams were tested to failure under two-point loading. All beams had a rectangular cross section, 90 mm wide and 260 mm deep with 2 bars of 10 mm diameter as longitudinal reinforcement. The effective span to overall depth ratio was varied from 1.69 to 2.5.

Test results indicate that the fibers have significant influence on the shear strength of deep beams. The shear strength increases with increasing steel fibers volume because of the increase in their resistance to crack propagation. Also shear strength increases with decreasing (a/d) ratio. Steel fibers can replace the conventional web reinforcement in reinforced concrete deep beams. The inclusion of short steel fibers in concrete mix provides effective shear reinforcement in deep beams and provides better crack control and deformation characteristic of the beams.

In 2008, Parghi et al [26] investigated the effect of inclusion of steel fibers in concrete on crack and deformation characteristics of deep beams for various span to depth ratios through tests on eighteen simply supported beams under two point loading. All the beams had constant span and width of 600 mm and 75 mm, respectively. Each series comprised minimum four beams of different overall depths, 600 mm, 500 mm, 400 mm, 300 mm and 200 mm , such that, the span to depth ratios of these beams were 1, 1.2, 1.5, 2.0 and 3.0 respectively and the volumetric ratio of steel fibers content was 1%.

The inclusion of steel fibers in concrete deep beams reduced crack width and deflection at all stages of loading up to failure. Fibers reinforcement can increase the stiffness of the concrete and enhance the spall resistance. All beams exhibited large deflection at failure, indicating high ductility and energy absorption property. High specific surface area and good bond characteristics of fibers are very effective in controlling both deflection and crack width, causing increases in the reserve strength of deep beams.

In 2012, Vengatachalapathy and Ilangovan [27] made an experimental study that deals with the ultimate strength of reinforced concrete deep beams with and without openings in the web subjected to two point loading. Seven simply supported deep beams of dimensions 75 × 350 × 750 mm were tested. The percentage of steel fibers was varied from 0% to 1%. The experimental results show that there is an increase in the ultimate load and the first crack load for fibers reinforced concrete deep beams.

There is a 10% to 20% increase in ultimate load due to presence of steel fibers. Addition of steel fibers increases the tensile strength of concrete matrix and also increases the flexural rigidity of the beam. Also the ultimate load obtained by applying the modified Kong and Sharp's formula [28] of deep beams is compared with the experimental values. This formula provides an accurate prediction of the ultimate strength of steel fibers reinforced concrete deep beams with and without web openings.

In 2018, Hassan and Mhebs [29] present the experimental and analytical investigation of the behavior of high strength hybrid reinforced concrete deep beams under monotonic and repeated two-point load. The idea of hybrid in this work is different. Two types of concrete were used in beam but not in cross-section. The first type was the Fibrous High Strength Concrete (FHSC) at shear spans for enhancing shear capacity against cracking due to diagonal strut failure (by adding Steel Fiber (SF) in that regions), while the second type was the Conventional High Strength Concrete (CHSC) at the mid-portion between the two strengthened shear spans.

From the experimental test results, when beam cast with fibrous with SF of 1% concrete along entire length, the ultimate load of 10.96% increased as compared with hybrid beam. And it was observed to increase as much as 32.78% as compared with beam cast from conventional high strength concrete under monotonic loading. Under repeated loading of 75% control ultimate load, the ultimate load for beam cast with fibrous concrete along entire length increased as much as 15.32% as compared with hybrid beam. And it was seen to increase 36.17% as compared with the beam cast from conventional high strength concrete. The percentage increase in ultimate load of hybrid (SF ratio 1%) deep beam cast with high strength concrete became 97.3% as compared with the identical beam cast with normal strength concrete under monotonic loading and (98.21%) under repeated loading (load 75% control beam load). The percentage increase as ultimate load for hybrid beam cast with SF ratio 1% was 9.62% as compared with hybrid beam with SF ratio 0%. As the web reinforcement increased from 0 to 0.004 and from 0 to 0.006, the percentage increased in the ultimate load as 28.07% and 57.89%, under monotonic loading as 26.14% and 59.09%, under repeated loading.

6. Review of Self Compact Concrete (SCC) Deep Beams

In 2010 Shah and Modhera [30] investigated the behavior and shear strength of SCC deep beams through testing eight simply supported beams under two points loading. All beams have 600 mm constant span and 100 mm width. Each series comprised four beams of different overall depths: 600 mm, 500 mm, 400 mm, and 300 mm such that span to depth ratios of these beams were 1, 1.2, 1.5 and 2 respectively. Using of steel fibers with 0.5 % volumetric ratio in construction of SCC deep beams was studied.

It was found that as depth of the beam increased, diagonal crack became predominant. The effective span to depth ratio has a significant influence on the ultimate shear strength and failure mode but marginal influence on the diagonal cracking strength. For all beams considered, the diagonal cracking strengths were between (65 % to 75 %) of the ultimate strength.

In 2011 Mohammad Hassani et al [31] tested six high strength SCC deep beams (f′c ranges from 79.1 MPa to 97.2 MPa) having dimensions of 200 × 500 × 1500 mm with a wide range of tension and shear reinforcement ratios. The results show that, at ultimate limit condition, the strain distribution on concrete surface along mid-span is no longer parabolic. In deep beams, several neutral axes were obtained before ultimate failure is reached. As the load increases, the number of neutral axes decreases and at failure load it reduces to one. Failure of deep beams with longitudinal tensile steel reinforcement less than that suggested by the ACI Code was occurred by flexure and accompanied by large deflections without any inclined cracks. As the longitudinal tensile steel reinforcement increases, failure due to crushing of concrete at nodal zones was clearly observed. As the tensile reinforcement percentage increases, number of cracks increases with reducing crack length and crack width.

In 2012 Mohammad Hassani et al [32] discussed the results of eight simply supported high strength SCC deep beams (f′c ranges from 79.1 MPa to 97.2 MPa) having various ratios of web reinforcement and tensile reinforcement with dimensions of 200 × 500 × 1500 mm. The results show that beam ductility decreases with increasing in tensile reinforcement ratio. The effects of width of load point and support point are more important than the effect of tensile reinforcement ratio in preventing premature failure.

The failure modes of tested beams were: the widening of the diagonal strut cracks, the premature localized crushing of concrete at the load and support points and the ultimate shear failure. Three of tested beams failed before yielding of tensile bar due to crushing of concrete at support points. The strain distribution was nonlinear due to shear deformation that is insignificant for normal beam but is very significant for deep beams. Also, it is found that the strain of tensile bars in the tension zone is more significant than the strain in compression zone.

In 2012 Choi et al [33] made an experimental study to investigate shear

behavior and performance of deep beams made with SCC by testing four deep beams under two point loads. Two of them were made with SCC and two with normal concrete (NC). The beams had dimensions of 180×360×1700 mm with shear span to effective depth ratio (a/d) of 1.43. It was found from the tests that the SCC specimen having a normal shear reinforcement condition exhibited a slightly higher load carrying capacity than the corresponding NC specimen, while the SCC specimen having congested shear reinforcement condition showed a similar load carrying capacity to the corresponding NC specimen.

For all specimens, diagonal shear cracks appeared within the range of 33 % to 41 % of ultimate load appeared at both sides of the layers parallel to the inclined compression strut and extended simultaneously in both directions downward to the support and upward to load positions of the specimens. Finally, sudden shear-compression failure was observed in all tested deep beams.

In 2012 Heiza et al [34] made a new shear strengthening technique for reinforced self-compacting concrete deep beams and the results were compared with some traditional techniques. An experimental test program consisted of sixteen specimens of reinforced self-compacting concrete deep beams of 100×500×1200 mm dimensions strengthened with different materials such as steel, glass, and carbon fiber reinforced polymers (GFRP and CFRP) was executed. Externally bonded layers (EBL) and near-surface mounted (NSM) reinforcement were used as two different techniques.

The new technique for shear strengthening increases the load capacity in the range between 36% and 55% depending on the anchorage length of GFRP rods. Shear strengthening using NSM reinforcement increases the ultimate load capacity more than the EBL technique when using the same material. In case of strengthening by vertical NSM intertwined roving GFRP rods, anchoring the rods through the web thickness in the transverse direction increases the ultimate load capacity by about 55%. Using vertical NSM steel or CFRP strips in transverse direction to the face gives better results than using it in parallel direction.

In 2012, Hassan [35] studied the behavior of reinforced SCC simply supported deep beams. The experimental program consisted of casting and testing 20 SCC deep beams of 1400 mm long, 150 mm wide and having an overall depth of 400 mm. The studied parameters were shear span to effective depth ratio, amount and arrangements of web reinforcement (horizontal only, vertical only and both) and shape of web openings. The effect of these parameters on cracking and ultimate loads, load- midspan deflection response and average concrete surface strains had been studied.

The results indicate that as the shear span to effective depth ratio decreases, the value of the failure load is noticeably increased. It was found that the failure load increases as horizontal, vertical and both of the two former web reinforcement ratios increase. The failure loads of beams having two symmetrical square, circular and rhombus openings of the same equivalent size of 0.58 % of the volume of the beam measured center to center of supports (50mm *x* 50mm *x* 150mm) located along lines joining the supports and the points of load application (50 %of the shear span) are 46.3 %, 43.3 % and 41.8 %, respectively, lower than the failure load of the solid beam.

In 2014, Sultan et al [36], testing twelve reinforced concrete simply supported deep beams cast using self-compacting concrete (SCC) with steel fibers to evaluate their shear behavior and strength. All tested beams have dimensions of (100 × 330 × 1050) mm and have been subjected to two point loads. The parameters considered are shear span to effective depth ratio (a/d), concrete compressive strength (f′c) and steel fiber volumetric ratio (Vf). Test results indicated that the increase in (a/d) ratio from 0.6 to 1 leads to decreases in cracking and ultimate shear strengths by average ratios of 25.1 % and 20.6 % respectively. Increasing (f′c) to the twice of the origin value leads to increases in the cracking and ultimate shear strengths by average ratios of 13.9 %and 48.1 %respectively. Using steel fibers in SCC deep beams improves cracking and ultimate shear strength by average ratios of 33.1 %and 11.4 % respectively when 0.4 % of steel fibers is used while they improve these shear strengths by average ratios of 64.4 % and 23 % when 0.8 % of steel fibers is used. The analytical work includes derivation of new equation for predicting ultimate shear strength of fibrous SCC deep beams depending on regression analysis of test results.

In 2016, Ali et al [37] studies the behavior of self-compacted concrete (SCC) deep beam and the parameters affecting the ultimate capacity. Eighteen specimens represented by ANSYS 11 program to study the effect of several variables like the percentage of shear span to effective depth ratio (a/d), areas of the web openings, web openings shape, concrete compressive strength (f'c), horizontal stirrups and vertical stirrups on the ultimate capacity of SCC deep beams. The finite element model uses Solid65 to model the SCC deep beams and link180 to model steel reinforcement. All beams are simply supported and tested under two concentrated point loads. All beams have the same dimensions and reinforcement. They have an overall length of 1200 mm, a height of 440 mm and a width of 110 mm. Conclusions showed that reducing the shear span to effective depth ratio (a/d) from 1.2 to 0.8 leads to an increase in ultimate capacity by 20%. The deep beams ultimate capacity increases by 9% after reducing the size of the square opening by 30.5%. The circular openings are recommended more than other web openings shape.

7. Review of Reactive Powder Concrete (RPC) Deep Beams

In 2014 Hassan [38] presents an experimental investigation consisting of casting and testing twelve rectangular simply supported reinforced concrete deep beams. Three of the tested beams are made with conventional concrete (CC), three with ultra-high performance concrete (UHPC) and six as hybrid beams of the two concrete (UHPC &CC). UHPC is used in compression in the hybrid beams. The effect of these parameters on the behavior of the test beams included deflection, failure mode, and ultimate loads were investigated. Experimental results have generally shown that stiffer load-deflection behavior is obtained with the increase of UHPC layer thickness (hR/h) and steel fibers volumetric ratio (Vf) for hybrid beams with UHPC in compression.

The results showed that 0.5 % of steel fibers increases the ultimate load by a range of 6.75 % to 44.23 % (the average of increase is 25.49 %). While using of 1 % of steel fibers increases the ultimate load with a range of 25.67% to 62.98 % (the average of increase is 44.33 %). The enhancement is larger in UHPC beams when compared with CC beams.

In 2015, Sinan et al [39] investigated the behavior and shear strength characteristics of reactive powder concrete (RPC) deep beams subjected to concentrated loads. Eighteen RPC deep beam specimens with the dimensions of 1400×300×110mm made with RPC were cast and tested. Important variables were investigated including the volume fraction of steel fibers, shear span/effective depth ratio, vertical web reinforcement ratio, horizontal web reinforcement ratio and percentage of silica fume powder. The addition of steel fiber had a significant effect on the cracks width and its propagation rate. Increasing the steel fibers content from 0% to 2% increases the deep beam capacity by 12.6%.

8. Conclusions

From the previous review on experimental studies of reinforced concrete deep beams and their predecessors, it can noted that the researches aimed to investigate the behavior of deep beams and study several parameters that affect their capacity. From literature one can note the following prominent remarks concerning the effect of these parameters:

1. The ultimate strength and diagonal cracking capacity of deep beams are not significantly influenced by span to depth ratio (L/d). Where the ultimate shear strength is slightly decreases with increasing (L/d) ratio.
2. The ultimate strength and diagonal cracking capacity are significantly influenced by shear span to depth ratio (a/d) which is considered as one of the important parameters that govern failure of deep beams by shear mode or flexural mode. The increase in this ratio decreases the deep beam shear capacity.
3. The concrete compressive strength (f'_c) has a significant influence on shear capacity of deep beams whereas the behavior of them does not much differ when using high strength concrete from using normal strength concrete.
4. The vertical shear reinforcement has a significant effect on shear capacity of deep beams, while the horizontal reinforcement has little effect on it especially when the value of (a/d) is large.
5. Presence of steel fibers in construction of concrete deep beams is useful in increasing the shear capacity, improving the cracking behavior and decreasing the deformations.
6. The depth of deep beams has a significant influence on their shear capacity where it increases the cross section area and reduces the (a/d) ratio.
7. The increase in main tension steel reinforcement improves the shear capacity especially when the value of (a/d) is small whereas this increase becomes non beneficial when the value of (a/d) is large. Also the extreme increase in this reinforcement is nonbeneficial in enhancing the shear capacity.
8. The presence of openings in deep beams negatively affects their shear capacity especially when these openings are close to the strut region that joins between the load and support positions.

Abbreviations

A list of symbols should be inserted before the references if such a list is needed

a	Shear span
d	Effective depth of beam
E	modulus of elasticity
$f'c$	Cylinder comprissve strength
L	Length of beam
Vf	Steel fibers volume fraction
ε_{cu}	Concrete ultimate strain
CC	Conventional concrete
NC	Normal concrete
RPC	Reactive powder concrete
SCC	Self-compact concrete
STM	Strut and tie method
UHPC	Ultra high performance concrete

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