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Shear strengthened of R.C hollow deep beams with large opening by plates: A Review.

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ABSTRACT

This research examines the reinforcement of deep hollow concrete beams with substantial openings by plate strengthening techniques, highlighting the benefits of these apertures and their major impact on structural performance, load-bearing capacity, and durability. It also examines several methods to improve the shear strength of deep reinforced guard beams with web openings, focusing on plate reinforcement. This method involves attaching plates to the beam's surface to enhance shear stress distribution alongside contemporary techniques that use metal plates to reinforce these openings. The dissertation assesses the existing literature on the behavior of deep hollow concrete beams with significant apertures, focusing on both laboratory tests and analytical methods used to evaluate the performance of different plate designs. This is achieved using finite element method (FEM) analysis utilizing specific applications, reinforcement techniques, and fastening processes. It concludes that aperture dimensions and location are crucial to reinforced concrete deep beam stability and effectiveness. It shows how the shear span-to-depth ratio (a/d) affects load-bearing and efficacy. Innovative reinforcing methods include steel plates and fiber-reinforced polymers to strengthen ductile beams with openings. Strategic aperture placement especially near shear spans can reduce stiffness and load distribution issues. Advanced finite element modeling predicts beam performance across configurations. The results emphasize the significance of carefully designing deep hollow beams to combine utility, material efficiency, and structural robustness, providing engineers in many applications with valuable insights and solutions. This detailed study helps improve deep beam structural performance at a low cost.

1. Introduction

The ACI-Code 318M-19 defines Deep beams are members that are loaded on one face and supported on the opposite face so that strut-like compression elements can develop between the loads and the supports that satisfy (a) or (b): (a) The net span does not exceed four times the total depth of the member h (b) There are concentrated loads within a distance of 2h from the face of the support, and deep beams shall be designed with consideration of the nonlinear distribution of longitudinal stress over the depth of the beam[1].

The Canadian code CSA A23.3-14 defines deep beams as flexural members with a clear span-to-depth ratio of less than (2) [2].

The construction of contemporary structures needs many pipes and ducts to provide essential services, including water supply, sewage, air conditioning, electricity, and telecommunications networks. Figure (1) illustrates the standard pipe configuration of a high-rise structure. The pipes and ducts are often situated under the ceiling joist and are concealed by a suspended ceiling for aesthetic purposes, resulting in a "dead space." The height of this unused space on each level, which contributes to

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the overall height of the structure, is contingent upon the quantity and depth of the ducts to be integrated. The depth of the ducts or pipes may vary from a few millimeters to half a meter. An alternate configuration involves routing these ducts via transverse openings in the floor joists. This configuration of building services leads to a substantial decrease in ceiling height and facilitates a more compact design. For little structures, the savings realized using this method may be negligible relative to the overall expenditure. In multi-story structures, reductions in floor height, when multiplied by the number of stories, may lead to substantial savings in overall height, length of air conditioning and electrical ducts, plumbing risers, wall surfaces, partition surfaces, and the total weight on the foundation [3].

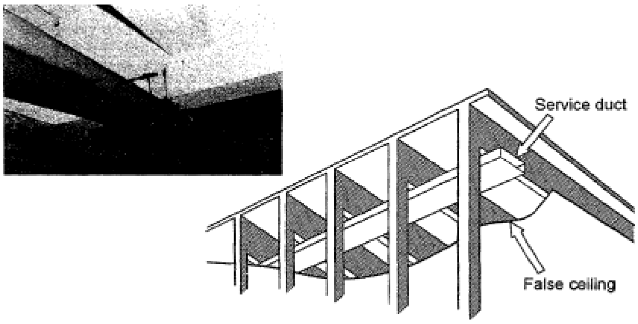
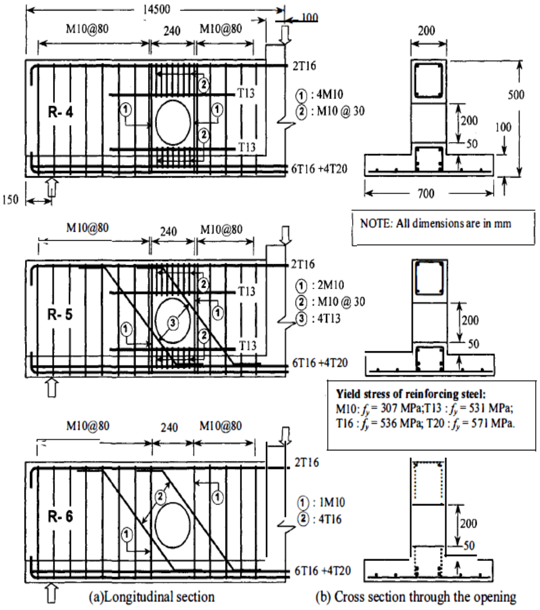


Figure (1) Typical layout of service ducts and pipes [3].

2. Previous studies of researchers

The researcher examined the effectiveness of the reinforcement and tie model in evaluating reinforced concrete beams with geometric discontinuities, especially transverse circular gaps in the web. The authors selected three previously evaluated full-size T-beams with circular holes and created a reinforcement and tie model for each of them as shown in Figure (2). The research compares theoretical predictions about ultimate strength, failure modes, and applied shear distribution across the chord components above and below the openings, and finds remarkable agreement with actual data. The model shows that diagonal reinforcement is necessary to mitigate concrete discomfort in the neck section by effectively transferring large shear across the discontinuity. These results may improve the future design of beam openings[4].



(a)Longitudinal section (b) Cross section through the opening

Figure (2) Beam and reinforcement details [4].

This study presents monotonic testing findings for four reinforced concrete deep beams, focusing on cracking patterns, load-deflection responses, failure modes, and steel reinforcement and concrete stresses. Despite different failure causes, the specimens showed similar failure loads and ultimate deflections, showing consistent performance. The yielding of longitudinal and transverse reinforcement occurred before failure, highlighting the importance of reinforcement behaviour in deep beams. Using test data, the study evaluates the ACI 318-99 Code and Appendix A of the ACI 318-02 Code shear design methods. Both design methods produced conservative shear strength estimates for single-span deep beams. The 25% conservatism of specimens STM-1 and STM-H is acceptable, and additional experimental data is awaiting. This conservatism is a significant improvement over the previous ACI technique, which generated test loads double the calculated values. [5].

The ACI code defines shear strength as the sum of concrete Vc and shear reinforcement Vs. However, this research proposes a new approach for measuring deep reinforced concrete beam nominal shear strength Vn. Thus, the authors use a strut-and-tie model to combine transverse tensile stresses on diagonal beam compressive strength, as illustrated in Figure (3). The experiment excludes early failures such as shear tensile and bearing failure and focuses on diagonal splitting and concrete crushing. Primary reinforcement, shear, and concrete tensile strength contribute to diagonal splitting resistance. Crushing resistance depends only on concrete compressive strength. The interplay of transverse tensile and compressive stresses within the diagonal beam affects deep beam shear strength, highlighting their interdependence. Experimental data and established calculation methods confirm the model's accurate, consistent, and conservative predictions across several case studies. Geometric ratios, longitudinal reinforcement levels, mesh reinforcement designs, layouts, and diagonal reinforcement are possible. The study presents a reliable tie-in and coupling method that increases deep beam shear strength understanding. [6].

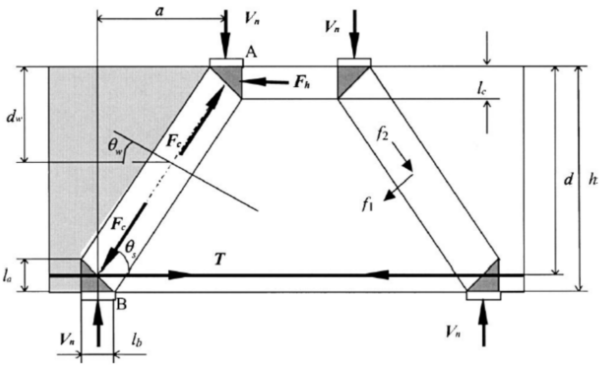


Figure (3) Strut-and-tie model for simply supported deep beams [6].

This article provides an investigation by the observer et al. on an innovative methodology for forecasting the shear strength of deep reinforced concrete beams. The model included the contributing factors of many components to the beam's stiffness against shear, including the diagonal concrete support, longitudinal and vertical reinforcement, and horizontal reinforcement, as seen in Figure (4). The model has been tested with an extensive dataset including 240 evaluations for both standard and high-strength deep concrete beams. In comparison to established methodologies like the ACI code, the suggested model offers a more precise and dependable forecast of shear strength. The study's primary results indicate that a straightforward and precise method for estimating shear strength, together with the suggested model, efficiently incorporates the ratio of shear depth to concrete strength. The model exhibits reduced sensitivity to the calculation of the angle of the slanted support. Horizontal reinforcement of the web is less efficacious than vertical reinforcement in deep beams. The suggested model and design formula provide a more efficient and precise methodology for designing deep beams than traditional techniques[7].

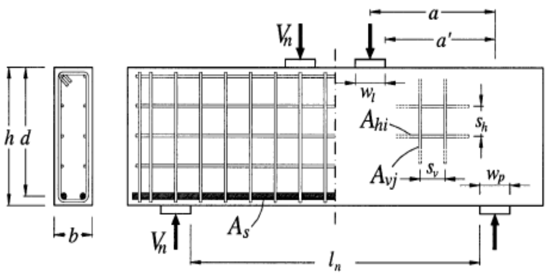


Figure (4) Geometry of reinforced concrete deep beam [7].

The study authors illustrated the efficacy of stirrups in improving the shear resistance of deep reinforced concrete beams. Prior research has often overlooked the role of stirrups in shear resistance computations. Experimental Configuration A series of tests were undertaken to assess the impact of stirrups on deep beam specimens with differing shear span ratios (a/d) and transverse reinforcement ratios (pw), as seen in Figure (5) [8].

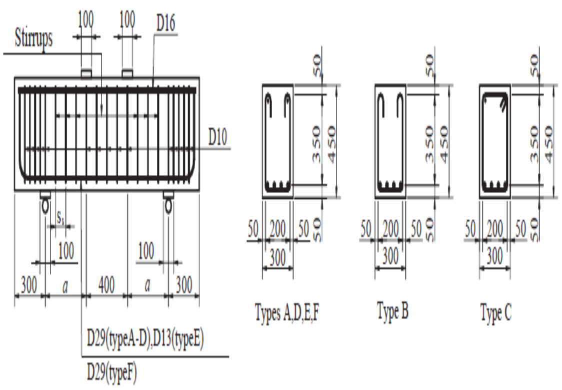
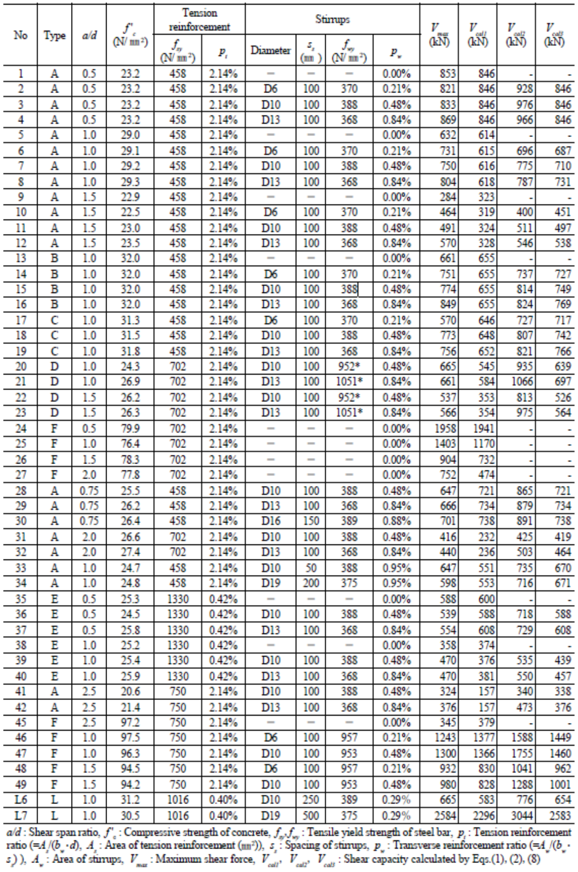


figure (5) Schematic drawing of RC deep beam specimens (Types A- F) (mm) [8].

The specimens collapsed under targeted stressors at two places. The results showed that shear span ratio Table 1 for the tested specimens and results shows that stirrups improve shear resistance more at higher shear span ratios (a/d = 1.0 and 1.5) than at lower ratios (a/d = 0.5). Research showed that the transverse reinforcement ratio (pw) significantly affects deep beam shear resistance, with larger ratios increasing it. The findings showed that stirrups with high-strength reinforcement (USD785) had similar shear strength to those with SD345. Based on experimental results, a new method for determining deep stirrup beam shear strength is presented. This method takes into account the shear span and transverse reinforcement ratios. This research underlines the need to incorporate stirrups into deep stirrups to increase shear strength, especially at high shear span ratios. The recommended method gives engineers a practical tool to measure deep stirrup shear strength. [8].



No	Type	a/d	f'_c (N/mm²)	Tension reinforcement		Stirrups				V_{max} (kN)	V_{cal1} (kN)	V_{cal2} (kN)	V_{cal3} (kN)
				f_{sy} (N/mm²)	p_t	Diameter	s_s (mm)	f_{wy} (N/mm²)	p_w				
1	A	0.5	23.2	458	2.14%	–	–	–	0.00%	853	846	-	-
2	A	0.5	23.2	458	2.14%	D6	100	370	0.21%	821	846	928	846
3	A	0.5	23.2	458	2.14%	D10	100	388	0.48%	833	846	976	846
4	A	0.5	23.2	458	2.14%	D13	100	368	0.84%	869	846	966	846
5	A	1.0	29.0	458	2.14%	–	–	–	0.00%	632	614	-	-
6	A	1.0	29.1	458	2.14%	D6	100	370	0.21%	731	615	696	687
7	A	1.0	29.2	458	2.14%	D10	100	388	0.48%	750	616	775	710
8	A	1.0	29.3	458	2.14%	D13	100	368	0.84%	804	618	787	731
9	A	1.5	22.9	458	2.14%	–	–	–	0.00%	284	323	-	-
10	A	1.5	22.5	458	2.14%	D6	100	370	0.21%	464	319	400	451
11	A	1.5	23.0	458	2.14%	D10	100	388	0.48%	491	324	511	497
12	A	1.5	23.5	458	2.14%	D13	100	368	0.84%	570	328	546	538
13	B	1.0	32.0	458	2.14%	–	–	–	0.00%	661	655	-	-
14	B	1.0	32.0	458	2.14%	D6	100	370	0.21%	751	655	737	727
15	B	1.0	32.0	458	2.14%	D10	100	388	0.48%	774	655	814	749
16	B	1.0	32.0	458	2.14%	D13	100	368	0.84%	849	655	824	769
17	C	1.0	31.3	458	2.14%	D6	100	370	0.21%	570	646	727	717
18	C	1.0	31.5	458	2.14%	D10	100	388	0.48%	773	648	807	742
19	C	1.0	31.8	458	2.14%	D13	100	368	0.84%	756	652	821	766
20	D	1.0	24.3	702	2.14%	D10	100	952*	0.48%	665	545	935	639
21	D	1.0	26.9	702	2.14%	D13	100	1051*	0.84%	661	584	1066	697
22	D	1.5	26.2	702	2.14%	D10	100	952*	0.48%	537	353	813	526
23	D	1.5	26.3	702	2.14%	D13	100	1051*	0.84%	566	354	975	564
24	F	0.5	79.9	702	2.14%	–	–	–	0.00%	1958	1941	-	-
25	F	1.0	76.4	702	2.14%	–	–	–	0.00%	1403	1170	-	-
26	F	1.5	78.3	702	2.14%	–	–	–	0.00%	904	732	-	-
27	F	2.0	77.8	702	2.14%	–	–	–	0.00%	752	474	-	-
28	A	0.75	25.5	458	2.14%	D10	100	388	0.48%	647	721	865	721
29	A	0.75	26.2	458	2.14%	D13	100	368	0.84%	666	734	879	734
30	A	0.75	26.4	458	2.14%	D16	150	389	0.88%	701	738	891	738
31	A	2.0	26.6	702	2.14%	D10	100	388	0.48%	416	232	425	419
32	A	2.0	27.4	702	2.14%	D13	100	368	0.84%	440	236	503	464
33	A	1.0	24.7	458	2.14%	D10	50	388	0.95%	647	551	735	670
34	A	1.0	24.8	458	2.14%	D19	200	375	0.95%	598	553	716	671
35	E	0.5	25.3	1330	0.42%	–	–	–	0.00%	588	600	-	-
36	E	0.5	24.5	1330	0.42%	D10	100	388	0.48%	539	588	718	588
37	E	0.5	25.8	1330	0.42%	D13	100	368	0.84%	554	608	729	608
38	E	1.0	25.2	1330	0.42%	–	–	–	0.00%	358	374	-	-
39	E	1.0	25.4	1330	0.42%	D10	100	388	0.48%	470	376	535	439
40	E	1.0	25.9	1330	0.42%	D13	100	368	0.84%	470	381	550	457
41	A	2.5	20.6	750	2.14%	D10	100	388	0.48%	324	157	340	338
42	A	2.5	21.4	750	2.14%	D13	100	368	0.84%	376	157	473	376
45	F	2.5	97.2	750	2.14%	–	–	–	0.00%	345	379	-	-
46	F	1.0	97.5	750	2.14%	D6	100	957	0.21%	1243	1377	1588	1449
47	F	1.0	96.3	750	2.14%	D10	100	953	0.48%	1300	1366	1755	1460
48	F	1.5	94.5	750	2.14%	D6	100	957	0.21%	932	830	1041	962
49	F	1.5	94.2	750	2.14%	D10	100	953	0.48%	980	828	1288	1001
L6	L	1.0	31.2	1016	0.40%	D10	250	389	0.29%	665	583	776	654
L7	L	1.0	30.5	1016	0.40%	D19	500	375	0.29%	2584	2296	3044	2583

a/d : Shear span ratio, f'_c : Compressive strength of concrete, f_{sy},f_{wy} : Tensile yield strength of steel bar, p_t : Tension reinforcement ratio ($=A_t/(b_w \cdot d)$, A_t : Area of tension reinforcement (mm²)), s_s : Spacing of stirrups, p_w : Transverse reinforcement ratio ($=A_w/(b_w \cdot s_s)$), A_w : Area of stirrups, V_{max} : Maximum shear force, V_{cal1}, V_{cal2}, V_{cal3} : Shear capacity calculated by Eqs.(1), (2), (8)

Table (1) Specimen parameters, test results and calculated capacities [8].

This study exhibits the impact of grid holes on the productivity of high-strength, deep, reinforced concrete beams. 32 deep beams were completely analyzed under two-point overhead stress, with changes in concrete strength, shear span-to-depth ratio, and opening dimensions. The objective of the study was to comprehend how these elements influence the shear strength and deflection of the beams. The test specimens, measuring 160 mm in thickness and 600 mm in depth as seen in Fig. (6) [9].

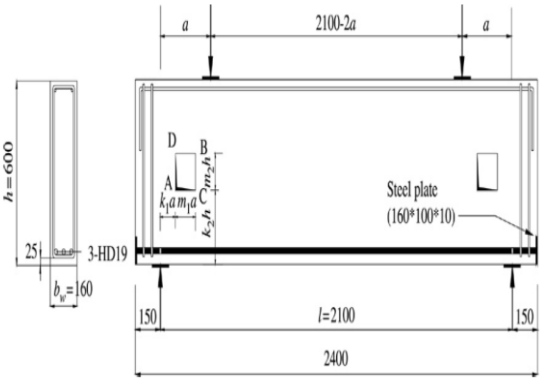


Figure (6) Typical specimen details (mm) [9].

Were categorized into three series based on concrete strength: low (L series, 24 MPa), medium (H series, 50 MPa), and high (UH series, 80 MPa). The shear extension-to-depth ratios for each series differed, with the L and H series at 0.5 and 1.0, respectively, while the UH series ranged from 0.5 to 1.5. The slots were deliberately positioned near the midpoint of the shear span (a), and their dimensions were adjusted to assess their impacts. Slot widths were measured at 0.25a, 0.5a, and 0.65a, with depths varying from 0.1h to 0.3h. Experimental studies disclosed numerous critical results about the behavior of deep slotted beams. The width and depth of slots did not notably influence the mid-span deflection during initial loading; nevertheless, they considerably impacted the deflection measurements after the emergence of diagonal fractures. The research indicated that the stiffness of slotted beams was less influenced by concrete strength compared to beams without slots. The slope of the inclined plane indicating the maximum fracture width decreased as concrete strength, slot size, and shear span-to-depth ratio increased. A crucial component found was the correlation between the shear forces at the onset of diagonal fractures and the final shear forces, which were intimately connected to the angle (θ_3) produced between the support and the edge of the web opening, as seen in Figure (7) [9].

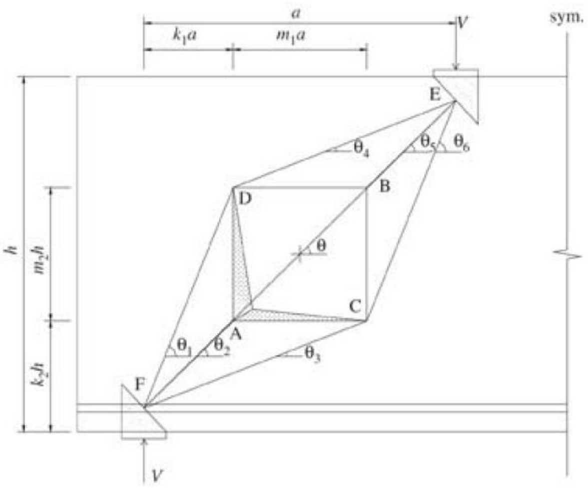


Figure (7) Identification of the symbols [9].

The research revealed that the influence of concrete strength on ultimate shear strength was reduced in deep beams with openings, indicating that in these beams, the enhancement of compressive strength had a lesser impact on total shear strength than in solid deep beams. The analytical assessments contrasted the study's findings with the equations presented by Kong and Sharpe, as well as Tan, Tong, and Tang. The findings show that these equations are appropriate for predictive modeling in deep, high-strength concrete beams with openings when the angle θ_3 is 30 degrees or more. It clarifies the structural behavior of deep, high-strength concrete beams with web holes, demonstrating that while apertures influence structural integrity, their design and positioning are crucial in ascertaining performance under load [9].

These studies evaluate how hole size and diagonal reinforcement affect the durability of fifteen deep reinforced concrete beams with holes. Every test beam was the same size. We present an effective diagonal reinforcement factor that integrates diagonal reinforcement amount and opening size, affecting beam performance from 0 to 0.318 across specimens. If this component rises, diagonal fracture breadth and rate decrease, and beam shear strength increases—practical diagonal reinforcing factors of 0.15 supplied beam shear strength over solid beams. By opening width, the test classified deep beams into T-series (0.25a) and F-series (0.5a) shear extent classes. Starting depths were 0.1h to 0.3h, where "h" indicates beam depth. Previous research has shown that apertures change the load path and considerably lower shear strength. Every aperture was supposed to be at the shear span centre. To strengthen beams, three 10 mm diameter bars angled 45° to the beam's longitudinal axis were employed as diagonal shear reinforcements in layers above and below each aperture Figure (8). 0.0–0.0152 effective diagonal reinforcement ratios and 0.0–0.318 practical diagonal reinforcement factors. For fairness, beam width, depth, applied loads, and concrete strength were standardized. Data demonstrated that diagonal fracture patterns were considerably impacted by practical diagonal reinforcing components. Beams with a factor above 0.096 have fan-like diagonal cracks before failure. Increasing this component minimized diagonal cracks and strengthened beam shear. Practical diagonal reinforcing factors above 0.15 offered beams shear strength higher than deep solid beams. According to the study, the effective diagonal reinforcement factor predicted deep beams with openings' shear strength and load transfer capacity. The numerical method, based on upper limit analysis of plasticity theory, matched experimental data, confirming its trustworthiness for structural engineering. [10].

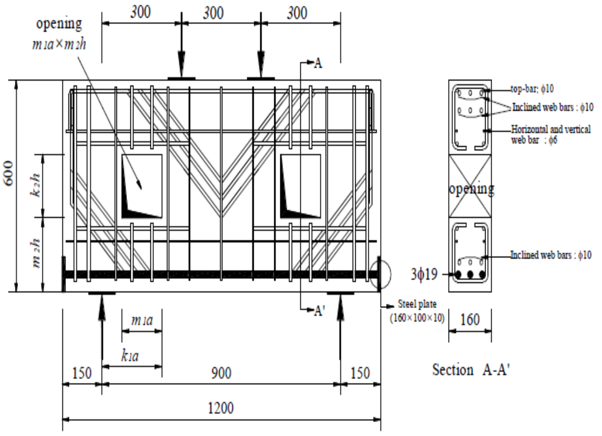


Figure (8) Specimen details and arrangement of reinforcement (all dimensions are in mm**)** [10]**.**

The examination tested the shear strength of continuous deep reinforced concrete beams with varying grid opening placements. Five specimens with circular grid apertures were examined in the experimental environment, as shown in Table (2.1). The findings demonstrated that beams, including grid apertures, preserved almost 90% of the shear strength compared to those devoid of holes. Generally, spans with openings exhibited reduced stiffness; however, one specimen (DB-4) showed comparable shear strength, stiffness, and deflection across spans, irrespective of the slot position.[11].

The article examines recent studies on concrete deep beams, emphasizing those with and without web openings. The findings of this investigation evaluate existing design codes and aim to improve a previously developed design formula for reinforced concrete (RC) and prestressed concrete (PC) deep beams. The study encompasses an experimental program investigating the impacts of varying web opening sizes, positions, and concrete strengths. The paper outlines the experimental configuration and presents the results on crack patterns, failure modes, and load-deflection characteristics. The objective is to highlight the deficiencies of current design methods based on the new test results[12].

This research examines the efficacy of externally affixed CFRP panels in augmenting the strength of deep reinforced concrete beams, including openings. Thirteen deep beams, each having a cross-section of 80 × 500 mm and a length of 1200 mm, were manufactured and subjected to four-point bending tests, as shown in Figure (9). The beams had two symmetrical square apertures inside the shear spans, and many aspects were examined, including aperture diameters, positioning, and CFRP incorporation. The findings demonstrate that the structural performance of deep reinforced concrete beams is considerably influenced by the extent of overlap of the holes during load application. The use of CFRP panels significantly improved the shear strength of the beams, with enhancements between 35% and 73%. The failure types varied: unreinforced beams collapsed suddenly owing to diagonal shear fractures, while CFRP beams also exhibited sudden failure, marked by concrete pullout and ripping or CFRP detachment, particularly in configurations with apertures at the beam's top[13].

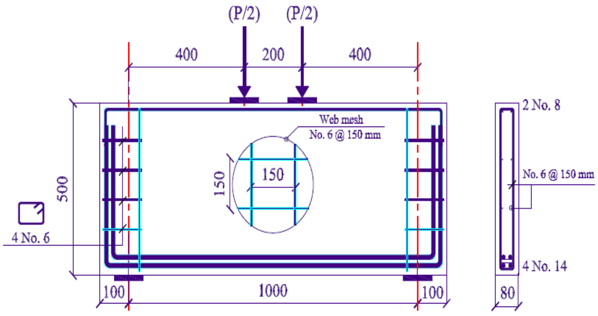


Figure (9) Details of test specimen (mm)[13].

This work experimentally examines the reinforcing of deep concrete beams using steel fibers. The study is bifurcated into two segments: the first segment examines six deep beams devoid of mesh apertures. In contrast, the subsequent segment analyzes six beams with mesh openings, all measuring 772 mm x 320 mm x 80 mm for both categories of deep concrete beams. The objective is to assess the impact of varying steel fiber diameters on the ultimate load and deflection of deep beams, taking into account variable shear extension-to-depth ratios (a/d). The primary findings demonstrate that augmenting the volume percentage of steel fibers improves the ultimate loads for both solid and mesh-opened beams. The advantageous impact of steel fibers is particularly significant at low a/d ratios. Furthermore, preserving a uniform steel fiber size for beams devoid of mesh holes enhances the ultimate loads when the a/d ratio diminishes. Conversely, beams, including lattice apertures, have little influence from variations in a/d ratios on ultimate loads and cracking. The proportional increase in ultimate loads is notably more significant when the steel fiber volume fraction rises from 0.0% to 0.5% and 1.0%[14].

This study evaluated the behavior of high-strength reinforced concrete (RC) deep beams with compressive strengths between 59 MPa and 65 MPa. Sixteen deep beams were subjected to two-point loads, all simply supported, with a shear span-to-effective depth ratio of 1.10. The specimens exhibited variation in the configuration of vertical, horizontal, and orthogonal steel bars for shear reinforcement, categorized into five series. The research concentrated on critical elements such as mid-span and loading point deflections, fracture development, failure mechanisms, and shear strengths. The results indicated that both vertical and horizontal web reinforcements substantially improve the shear capability of deep beams. Orthogonal shear reinforcement had the greatest efficacy when oriented perpendicular to the principal axis of diagonal fractures. Focusing shear reinforcement on the central portion of the shear span has enhanced the final shear strength of deep beams. Also, the test findings were juxtaposed with the predictions from the ACI 318-08 recommendations, which often produced harmful or inconsistent results, indicating that the code provisions need revision for enhanced accuracy[15].

This study examines the latest developments in reinforced concrete (RC) beams, including web apertures, which are crucial for integrating utilities such as HVAC, electrical, and networking systems in contemporary structures. It encompasses several subjects, including the categorization of openings, criteria for their placement, and the structural performance of reinforced concrete beams having these characteristics. The document examines several design techniques from the American Concrete Institute (ACI), the Architectural Institute of Japan (AIJ), and the strut-and-tie approach. It also discusses reinforcement methods for these beams using Fiber Reinforced Polymer (FRP) and steel plates. Finally, it delineates deficiencies in existing knowledge and proposes avenues for further investigation[16].

Extensive gaps in RC deep beams may impede load transmission via concrete struts, resulting in a substantial decline in strength and serviceability. This research investigates the performance of two reinforced concrete deep beams and two steel fiber-reinforced concrete SFRC beams with wide apertures subjected to incrementally higher concentrated loads. The border sections of the RC beams near the supports were strengthened with steel cages. A reinforced concrete beam with enhanced boundaries exhibited a ductile failure mechanism and attained greater ultimate strength than anticipated using strut-and-tie models (STMs). Conversely, the SFRC beams, including a 1.5% volume percentage of fibers, surpassed the design load, showcasing significant post-peak residual strength and displaying ductile failure methods while lacking intricate S-T-M details[17].

The experiment examines the performance of five deep reinforced concrete beams, each measuring 1200 mm in length, 300 mm in height, and 150 mm in width, as seen in Figure (10), subjected to two-point focused loads with a shear-to-depth ratio of 1.52. Four beams possess hollow cores rebuilt using carbon fiber reinforced polymer (CFRP) laminates, applied in single or double layers on one or both sides, comparing two hollow geometries: circular and square. Laboratory experiments were performed on these supported beams to assess load deflection, concrete stress, and fracture patterns. The research encompasses parametric studies examining the impacts of hollow apertures, their geometries, materials, and configurations of CFRP laminates (single, double, and lateral horizontal stirrups). The primary findings demonstrate that incorporating hollow sections diminishes strength capacity by about 13% and elevates deflection and concrete stress by around 18% and 24%, respectively, compared to solid sections. CFRP markedly increases the bearing capacity by 33% to 66% and decreases deflection under the same loads by about 26%. Moreover, augmenting the beam sides with CFRP strips to counter horizontal shear enhances strength by about 20%. Using two CFRP strips on hollow sections may attain strength capabilities equivalent to or exceeding those of solid sections[18].

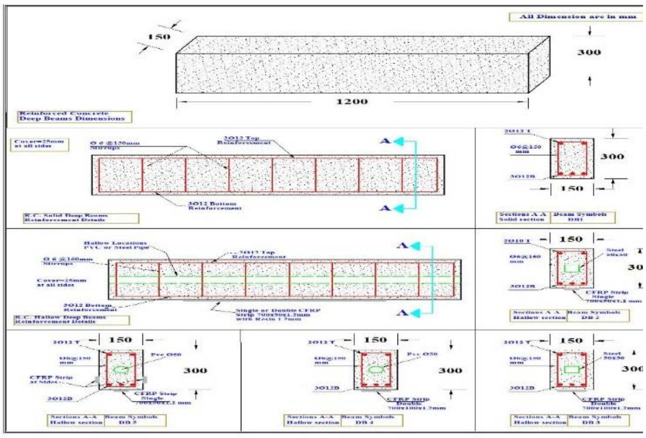


Figure (10) Details of Reinforced Concrete Deep Beams [18].

It examines the impact of various web apertures on the flexural performance of reinforced concrete beams. Nine rectangular beams were evaluated, and our results indicated that diagonal reinforcement around the holes effectively alleviated early failures attributed to Verendel action, as anticipated from the bending moment and axial force interaction diagrams. Using longitudinal reinforcing bars and full-depth stirrups next to the apertures, in conjunction with short stirrups in the tendons, mitigated the risk of both beam-type and frame-type shear failures. Many apertures extended the plastic failure process compared to beams with just a single opening[19].

This research tested 16 reinforced concrete deep beams, half receiving loads via columns and the other via bearing plates. The study examined force-transfer processes, concrete compressive strength, and horizontal-vertical stirrup ratios. Results indicated that with stable shear span-to-effective-depth ratios, beam shear strength rises with concrete compressive strength and stirrup ratio. Critical flexural sections were found at load-bearing plate centroids and load column faces. Based on these force-transfer processes, the paper provides an analytical technique to forecast deep beam shear strength. The suggested technique predicted reinforced concrete deep beam shear strength better than the ACI 318-08 strut-and-tie model based on test results[20].

High-strength concrete (HSC) deep beams with different web opening sizes and positions were tested in this article. It examines new variables. The paper outlines the experimental setup, failure loads, and commonly seen fracture patterns in samples tested, comparing experiment results with design technique predictions shows these methods commonly underestimate or overestimate HSC deep beam strength. Web openings reduce ultimate strength, yet existing design methods do not account for it. To overcome these issues, the authors offer a novel design equation verified by experiments and prior research. The newly presented equation is more accurate and reliable. The manuscript says future studies should examine other web opening forms and places[21].

This research describes an experiment employing externally applied fiber-reinforced polymer (FRP) composites to increase deep-reinforced concrete beam shear strength. Six 1500 mm × 120 mm × 500 mm deep beam specimens were evaluated before and after reconstruction. The research used carbon/epoxy and glass fiber/epoxy laminates. The experimental findings were compared to established analytical models, including ACI 440, to determine their ability to predict shear behavior in reinforced concrete beams enhanced with glass fibers. Carbon fiber-reinforced polymer (CFRP) laminates raised the ultimate strength of reinforced beams by 30-% to 58-%. The research also showed that the shear extension-to-depth ratio (a/d) affects beam shear failure modes and shear strength enhancement[22].

A new AI model called EMARS (Evolutionary Multivariate Adaptive Regression Splines) estimates the shear strength of deep reinforced concrete beams. Adaptive Multivariate Regression Splines (MARS) are used to learn and fit the curves, and the Artificial Bee Colony (ABC) optimization method is used to find the best parameter values and minimize the estimation errors. We built the model using 106 literature-based experimental datasets. We tested EMARS against BPNN, RBFNN, and SVM data mining algorithms. The accuracy of shear strength estimation was compared with four well-established mathematical methods, ACI-318 (2011), CSA, CEB-FIP MC90, and Tang's method, and the results showed that EMARS outperformed other models and methods for calculating the shear strength of deep reinforced concrete beams[23].

Modern deep reinforced concrete beams contain multiple openings for power lines, communication networks, and air conditioning ducts. These openings may weaken the beams, causing excessive cracking, deflection, and loss of stiffness. Several studies have examined these slotted beams and their reinforcement options. FRP sheets, which have better tensile strength, stiffness, corrosion resistance, and fatigue performance, are a potential option. Despite the increasing popularity of FRP sheets among academics and engineers to address structural problems, there is little literature on their application to reinforce deep-slotted reinforced concrete beams. This review examines eleven FRP strengthening experiments on deep-slotted reinforced concrete beams. The results suggest further study and progress in this field[24].

The study's objectives present a laboratory study aimed at augmenting the shear strength of deep reinforced concrete beams with holes using externally bonded SGFRP composites. The research indicated that SGFRP may fail due to inadequate bonding with the beam surface; however, this issue may be mitigated by implementing a mechanical anchoring system, particularly the mechanical expansion bolt (MB) configuration. In the experiments, 29 deep reinforced concrete beams were assessed under a three-point loading configuration, as shown in Figures (11 and 12), taking into account variables such as the dimensions and geometry of the apertures, the thickness and composition of SGFRP, and the concrete's strength. The findings indicated that the SGFRP approach, using well-bonded SGFRP composites, significantly enhances shear strength and alters the failure mode from non-bonding to slant crack rupture. Although thicker SGFRP reinforcements often enhance shear strength, they also pose a danger of anchor withdrawal and bond failure. The U-shaped arrangement of SGFRP on the lateral and inferior surfaces of the beams is the most effective. Furthermore, SGFRP reinforcement has shown reduced efficacy in high-strength concrete beams compared to low-strength beams[25].

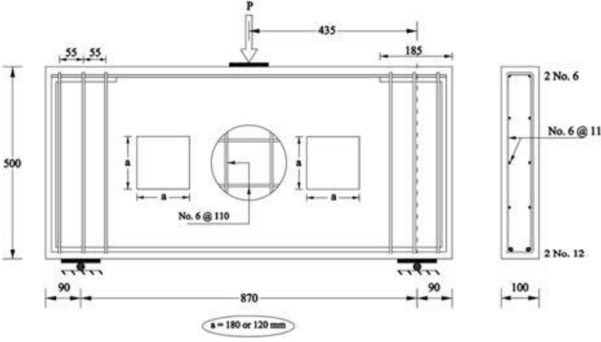


Figure (11) Group A, B, E and F Beam Detailing (units in mm)[25].

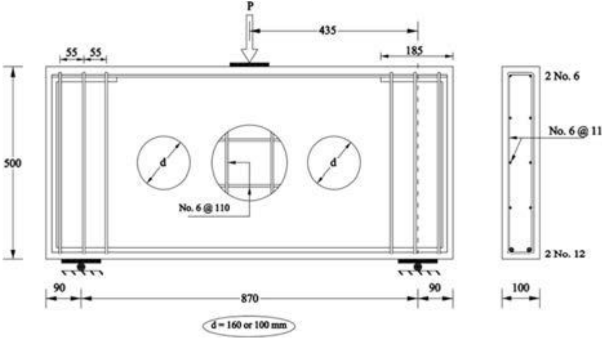


Figure (12) Group C and D Beam Detailing (units in mm)[25].

Standard beam assessment is inadequate for deep beams because of nonlinear stress distributions caused by abrupt changes in geometry or loading. The brace-and-tie model (STM) is a rational and direct method for predicting the strength of reinforced concrete deep beams, conceptualizing them as truss-like structures composed of diagonal concrete supports and tension ties, as seen in Figure (13). Numerous brace-and-tie model methodologies exist; moreover, they often need more clarity and complexity in shear strength computations. This study introduces shear strength prediction methodologies enhancements via a comprehensive experimental database, including 406 deep beam tests. Multiple linear regression analyzes several brace-and-tie model variants and six sophisticated efficiency factor formulations. The document contains regression diagnostics and validation methodologies, supplemented by two numerical examples for demonstration[26].

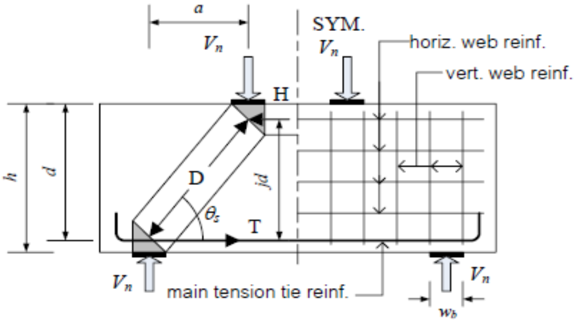


Figure (13) STM of a simply supported deep beam[26].

Reinforced concrete deep beams serve an important purpose in high-rise structures for load-bearing; nevertheless, introducing openings for accessibility and amenities may result in structural complications. This study examines the behavior of deep beams with openings, emphasizing symmetric placements next to the supports. The research analyzed circular apertures (Ø150 mm, Ø200 mm, Ø250 mm) and square (150x150 mm, 200x200 mm, 250x250 mm). All beam specimens had a cross-section of 100 mm x 500 mm and a length of 1200 mm, and they underwent testing under four-point bending until failure occurred. The findings indicated that circular holes decreased beam capacity by (30–35) %, but square openings resulted in a substantial strength reduction of (40–80) % relative to solid beams, highlighting the influence of apertures on beam performance[27].

The behavior of transverse circular apertures was studied on eleven basic spans reinforced self-compacting concrete deep beams under two symmetrical top loads. The research studied shear span to effective depth ratio (a/d), opening sizes and placements, and inclined reinforcement around openings while maintaining overall dimensions, flexural reinforcement, and concrete compressive strength. Results showed that openings near the center of the shear span significantly affect beam behavior, independent of a/d ratio or opening size. Cracking and load capacity were lowered by large diameter apertures at the top or bottom away from the load path. Inclined reinforcing around apertures improved ultimate load capacities and deflection responsiveness[28].

Carbon Fiber Reinforced Polymers (CFRP) are evaluated to enhance the shear strength of deep beams. Eight reinforced concrete deep beams were constructed and evaluated. Two control beams lacked shear reinforcement, while the other six were categorized into three groups: one received conventional steel web reinforcement. In contrast, the others were equipped with CFRP sheets in varying orientations. Shear crack and failure loads were quantified. Both CFRP and steel-reinforced beams exhibited increased load-carrying capacity, with CFRP delaying shear failures and improving serviceability. CFRP beams oriented perpendicular to shear cracks had the most significant increase in strength. In novel designs, CFRP laminates may enhance shear strength and substitute steel web reinforcement. The study compares CFRP-reinforced beams with traditional reinforcement to demonstrate the cost-effectiveness of CFRP for structural rehabilitation[29].

Deep beams are structural components that transmit substantial loads to their supports via compression forces. In construction, utility pipes and ducts often need gaps in the web of reinforced concrete beams, potentially resulting in problems such as diminished stiffness, increased cracking, deflection, and lower strength. This work experimentally examines the enhancement of reinforced concrete deep beams using circular holes. Eight beams were fabricated and tested under a 50-ton point load, including those with one opening, two openings, and a control group. Each beam had a cross-section of 180 mm by 400 mm and a length of 820 mm. Essential factors included opening dimensions, placement, web reinforcement, proportion of steel fibers, and the inclusion of CFRP sheets. All beams failed owing to diagonal compression shear, with the first fractures manifesting as flexural cracks; however, no fractures were recorded up to 45-% of the maximum load. The beam with two circular apertures supported around 79-% % of the ultimate load, while the beam with a central hole did not affect capacity. Steel fiber-reinforced beams did not enhance load capacity; however, beams with specialized cranked reinforcement had a 33-% improvement. Also, steel fibers' use decreased fracture width compared to the other beams[30].

This research examined the use of steel plates to enhance the strength of reinforced concrete (RC) deep beams, including web holes. Thirteen beams were subjected to two-point loading tests, exhibiting diverse opening geometries, including square, circular, and rectangular (horizontal and vertical). Each beam included a cross-section of 100 mm by 400 mm and a length of 1000 mm, with two symmetrically positioned apertures inside each shear span. The study revealed that the structural performance of deep beams was considerably influenced by the degree of disruption to the inclined compressive strut resulting from the apertures. The ultimate load capacity decreased by about 20.5-% for square apertures, 18.-3% for circular openings, 24.7-% for horizontal rectangular openings, and 31.7-% for vertical rectangular openings compared to a solid reference beam. Reinforcing these apertures with steel plates significantly enhanced shear strength, yielding improvements of roughly 9.3-%, 13.2-%, 8.8-%, and 11.88-% for the corresponding opening configurations; moreover, integrating stud connections into the reinforcement plates enhanced strength, with improvements of 16.9%, 17.8-%, 14.3-%, and 26.9-%, respectively. A numerical simulation using the finite element software ANSYS 11 revealed that an increase of 25-50% in the shear span-to-effective depth ratio (a/d) led to a decrease in ultimate load capacity by 18-24%.In contrast, reducing the dimensions of square apertures by 25-50% resulted in an enhancement of load capacity by 11-17%. Moreover, augmenting the thickness of reinforcement plates from 4mm to 6mm and 8mm resulted in a load capacity enhancement of 4-10%. Ultimately, using eight stud connections rather than four in each reinforced square aperture enhanced the total capacity by around 11-% [31].

This research examines the structural integrity of reinforced concrete deep beams utilized in offshore structures, foundations, and load-bearing walls when they include web apertures for HVAC or accessibility. Openings like these may reduce the beam's shear strength, creating safety issues. The research analyzes two reinforcing methods: steel reinforcement bars at the apertures and SGFRP layers surrounding them to reduce strength loss while widening them. Nonlinear finite element analysis uses ANSYS 16. The study also uses mechanical anchoring devices to strengthen FRP sheet-concrete bonding to prevent failure[32].

This research analyzes the performance of self-compressing reinforced concrete girders with circular apertures, emphasizing the impact of various configurations of externally bonded carbon fiber reinforced polymer (CFRP) on their shear strength enhancement. Six simply supported deep girders, measuring 150 × 400 × 1400 mm, were fabricated and subjected to testing under two-point failure loads, each including two circular apertures with a diameter of 110 mm, as seen in Figure (14)[33].

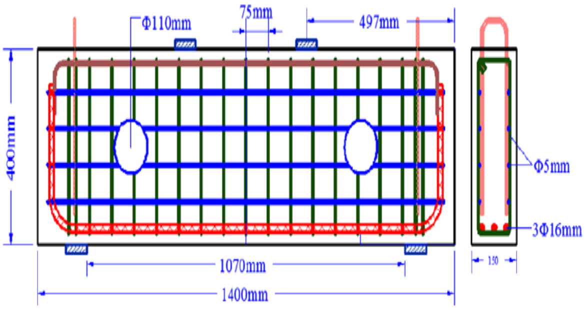


Figure (14) Reinforced concrete deep beam [33].

All girders exhibited identical shape, compressive strength, and shear-to-depth ratio of a/d = 1. The research studied variables such as fiber orientation, the application of longitudinal and vertical CFRP laminates, and the area of applied CFRP, as seen in Figure (15). Experimental results indicated that circular apertures in the load use decreased the ultimate stiffness and strength by about 50% relative to solid girders. Nonetheless, the use of CFRP markedly enhanced the ultimate load capacity and augmented the rigidity of the deep girders, including apertures[33].

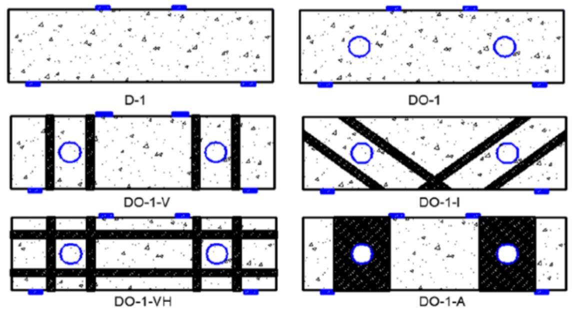


Figure (15) Strengthening Schemes of the Tested Deep Beams [33].

This research indicates a novel way to improve the performance of deep beams in reinforced concrete (RC) by using light steel panels to strengthen the vertical web instead of traditional reinforcement bars. Nine reinforced concrete deep beams were subjected to a four-point load test, with shear-to-effective depth ratios (a/d) varying from 0.75 to 1.75. The packages were categorized into three groups: the first group used conventional vertical web reinforcement, while the second and third groups utilized light steel panels arranged as chips and sheets, respectively, as seen in Figure (16). All beams measured 1200mm in length, with a clear extension of 900mm and a rectangular cross-section of 150mm in width and 300mm in depth. Results show that mild steel plate layouts substantially enhanced the ultimate load capacity by 15.4% to 28.26% and the viscosity factor by 6.06% to 30.56%, in comparison to traditional steel bars. Finally, light steel beams exhibited a reduced CT increase under strain, decreasing by 10.11% to 32.08%[34].

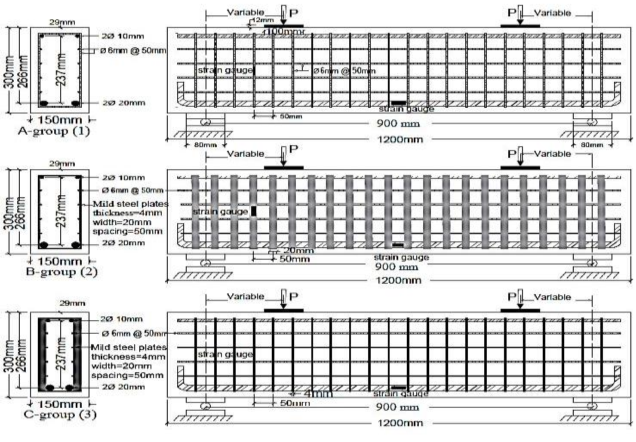


Figure (16) Sketch of tested specimens [34].

Our study examines the impact of web openings on deep beam durability, which is often used in construction for structures such as water tanks and multi-storey buildings. Ten deep packages, consisting of a control package free of slots and eight with large openings within shear extensions, were evaluated. The main factors analyzed were the shear-to-depth ratio, along with the dimensions and location of the vents. Results showed that deep beams with openings showed a significant reduction in load carrying capacity, reaching 66% in some cases. Samples with openings located at the internal limits of shear extensions showed only an 11 per cent increase in loading capacity at failure compared to those with openings at the center. These samples showed a 10% to 33% reduction in mid-range deviation under service loads compared to control packages. According to these results, it is recommended to place any slots required towards the internal limits of shear extensions to enhance the strength of the structure[35].

This research investigated reinforced concrete (R.C.) deep beams with retrofitted ferrocement laminate web apertures. Twelve simply-supported deep beams were strengthened with ferrocement in different arrangements, included for both sides and centring around the apertures, and tested under a central point load. The three provided control samples without strengthening. The type and quantity of steel wire meshes, plaster mortar thickness, mortar strength, and opening placement relative to bending and shear zones were studied. Retrofitting with ferrocement improved deep beams with apertures. Openings decreased ultimate load-carrying capacity by 31% in the shear zone and 16% in the flexural span. Retrofitted beams with shear apertures had 85%, 19%, and 65% higher ultimate failure load, ductility ratio, and uncracked stiffness than unretrofitted beams[36].

The shear size impact refers to the reduction in shear strength of reinforced concrete (RC) beams as the depth of the beam rises. This impact is affected by boundary conditions, especially the dimensions of load-bearing plates or columns. This research categorized several deep beam experiments to separate the influence of bearing plate dimensions on shear size effects. Results demonstrate that deep beams with constant bearing plate dimensions show more pronounced shear size effects compared to those with variable plate dimensions. The research uses non-linear analytic software (ATENA) and a cracking strut-and-tie model (CSTM) to precisely forecast shear size effects and extend maximum beam heights to 4 meters. The research identifies two primary factors contributing to the shear size effect in reinforced concrete deep beams: the bearing plate size impact, which diminishes the relative strut width owing to differing plate dimensions, and the beam depth effect, which lowers shear transfer strength as beam depth rises. Additionally, the research evaluates the ACI 318-14 shear transfer model (STM), indicating its inadequacy in considering the influence of beam depth. This omission may lead to decreased safety for enormous deep beams compared to smaller ones. Therefore, suggestions for integrating the beam depth effect into STM design are presented[37].

This study intends to scientifically and statistically evaluate the effect of inclined reinforcement on reinforced concrete (RC) deep beams, including differently shaped web apertures, as seen in Figure (17). Twenty beams with similar geometric dimensions underwent two-point loading. The analyzed components included the quantity of inclined reinforcement, the form of the aperture (circular, square, rectangular, and a novel variant with fillet edges), and the shear span-to-depth ratio. The research presented the effective inclined reinforcement factor, which connects the quantity of inclined reinforcement to opening size; an increase in this factor enhanced beam performance by diminishing fracture width and augmenting ultimate load. Significantly, beams with rectangular apertures and fillet edges exhibited a superior load enhancement relative to those with sharp edges. Beams with square, circular, or filleted apertures exhibited greater ultimate loads than solid beams when the effective inclined reinforcement ratio was above 0.085 for a shear span-to-depth ratio of 1.0 and 0.091 for 0.6. The efficacy of inclined reinforcement in improving beam performance increased as the shear span-to-depth ratio decreased. Furthermore, the final load forecasts derived from plasticity theory show strong concordance with empirical findings[38].

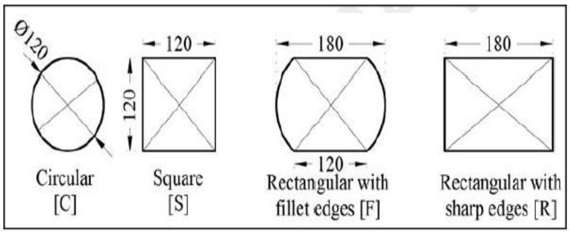


Figure (17) Opening shapes and dimensions (All dimensions in mm) [38].

This study examined web-opening reinforced high-strength self-compacted concrete (RHSSCC) deep beams. To test the impacts of opening size (75 mm and 50 mm), form (square, circular, and a novel rhombus), and placement relative to the neutral axis (higher or lower) and load route (inside or outside the load path), 61 deep beams were manufactured. The research analyzes load-deflection curves, fracture patterns, absorbed energy, and beam performance with symmetrical, unsymmetrical, and centred web apertures[39].

This research conducts an experimental and computational investigation of the impact of web opening dimensions and configurations on the load-bearing capacity and serviceability of reinforced concrete deep beams. Five full-scale simply supported deep beams, including two substantial web holes in shear zones, were subjected to failure testing, with a shearing span-to-depth ratio of 1.1. The square apertures were symmetrically positioned at either the midway or the internal borders of the shear span, measuring 200 mm and 230 mm as shown in figure (18). The findings indicated that the shear capacity of deep beams is markedly influenced by the dimensions and positioning of the apertures, with losses in shear capacity of up to 66% seen. The ABAQUS finite element software facilitated numerical calculations, yielding load-carrying capacity estimations that exceeded experimental data by 5-21%. The finite element estimates for the onset of diagonal and flexural cracking exhibited a maximum variability of just 17%. When service loads were applied, the numerical forecasts for midspan deflection were 9-18%

higher than the values extracted from experiments[40].

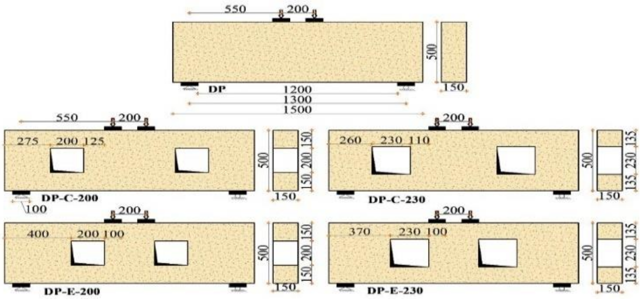


Figure (18) Configuration of experimental specimens [40].

This work examines a research gap concerning the behaviour of flanged deep beams with transverse apertures since the majority of current literature mainly concentrates on rectangular deep beams. The authors performed trials on sixteen deep beams, including twelve with flanged sections (some featuring apertures) and four reference beams with rectangular sections. The shear span-depth ratio was established at 1.10, with web apertures of a uniform depth (120 mm) and differing lengths (120 mm, 240 mm, and 360 mm), as seen in Figure (19). The study evaluated the influence of the flange on strength, stiffness, and deformation capacity, examining outcomes related to cracking patterns, failure modes, load-deflection behaviour, deformation distribution, and stresses in reinforcement. The results indicated that flanged sections substantially enhance strength and stiffness, a consideration that should be included in design regulations. A finite element analysis (FEA) was performed, showing a significant correlation with experimental data, especially with predictions derived from modified compression field theory (MCFT). The research enhances the comprehension of deep beams with openings and underscores the need to use flanged sections in structural design[41].

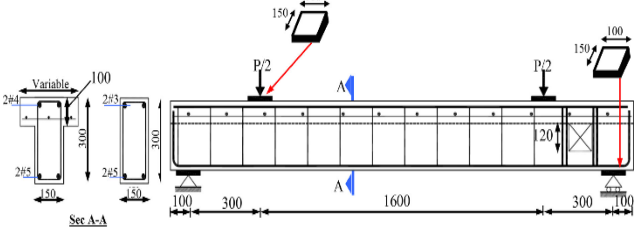


Figure (19) Beams geometry and details of reinforcement (all dimensions are in millimeters)[41].

This research studies the behaviour of nine reinforced high-strength self-compacted concrete (RHSSCC) deep beams, including longitudinal apertures of diverse forms, dimensions, and placements. A deep beam is defined by its depth exceeding one-fourth of its clear span, and the holes are essential for housing conduits and other mechanical components. The study examined two types of apertures (square and circular) and their positioning in the compression or tension zones of the beams, using diameters that were one-sixth and one-quarter of the beam's depth. Essential performance indicators, including load capacity, deflection, absorbed energy, and fracture patterns, were documented and examined. The findings show that longitudinal holes diminish the load-bearing capability of RHSSCC deep beams. Larger holes led to a more pronounced decrease in capacity. Furthermore, apertures situated in the compression zone resulted in a more significant reduction in capacity than those in the tension zone. However, the configuration of the holes had a negligible impact. The research emphasizes the influence of longitudinal openings on the structural efficacy of deep beams[42].

The present work reviews the performance of reinforced concrete deep beams, often used in high-rise structures and bridges, with a specific focus on shear stresses. In contrast to conventional beam theory, deep beams function as two-dimensional elements when subjected to substantial shear stresses. The research utilizes finite element modelling using ANSYS to examine five models of deep beams under four-point loading conditions. Four of these models use longitudinal holes fortified with carbon fiber reinforced polymer (CFRP) to augment their strength relative to unperforated beams. Multiple aspects, such as the shape of the apertures, the quantity of CFRP layers, and their configuration, are analyzed. The results demonstrate that the finite element analysis closely correlates with experimental outcomes, indicating that CFRP efficiently reinstates the strength of deep beams, which mostly fail owing to shear[43].

Due to their large depth-to-span ratios, deep beam shear strength is important. This research examines gagger plates, closed-form steel plates, as an alternative shear reinforcing option to steel stirrups. Three deep beams were cast and tested under four-point bending, one as a reference with regular closed stirrups and the other two having 4 mm thick and 20 mm wide gagger plates either in-plane or out-of-plane. Steel-plate-reinforced beams outperformed the reference beam in mechanical behaviour. In terms of strength, service stiffness, ductility, and toughness, the in-plane design beat the out-of-plane and reference beams[44].

This dissertation focuses on how externally prestressed strands improve the shear strength of reinforced concrete (RC) deep beams with significant gaps. Nine beams (150 × 400 mm, 1600 mm length) were tested under three-point bending to failure. The beams were divided into three strengthening groups: Group I (no strengthening), Group II (horizontal external strands), and Group III (vertical external strands), as shown in Figure (21). Three opening ratios (0.4, 0.6, and 0.8) were tested using two huge rectangular apertures symmetrically around the beam's centre. The horizontal prestressed strand system increased shear strength by 32–53% and reduced tension reinforcement strain by 60–91% across all opening ratios. The vertical strand technique increased stirrup strain by (142–158%) but did not affect tension reinforcement strain. The researchers also adjusted a strut and tie model (STM) analytical solution to reflect strengthening approaches. The beams' shear strengths, with and without strengthening, converged to 0.93 on average. [45].

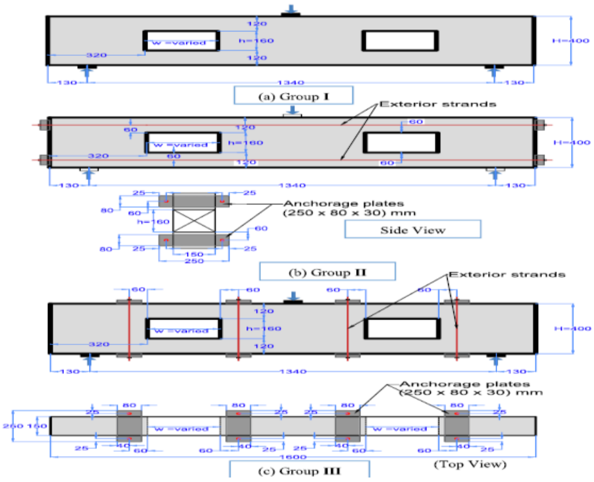
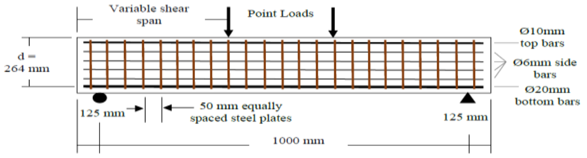


Figure (20) The layout of tested beams (all dimensions are in mm)[45].

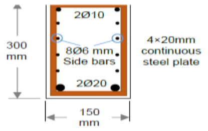
This research covers transverse apertures in reinforced concrete beams, which are needed for water, sewage, and electrical ducts and pipes. These apertures provide practical purposes but weaken the beam, causing complicated behaviour based on size, shape, and position. An experimental program used fourteen RC beams with wide holes and externally bonded steel or CFRP plates to find answers. The beams were four-point bent to assess their performance with and without strengthening. CFRP plates improved beam flexural and shear strength more than steel plates, particularly at varied opening positions[46].

The present paper analyzes the use of non-corrosive fiber-reinforced polymer (FRP) reinforcements instead of steel to extend the longevity of concrete construction. FRP has corrosion resistance, a high strength-to-weight ratio, ease of production, and electromagnetic insulation. Concrete deep beams with and without apertures, internally reinforced with hybrid FRP, are studied under static loading. Sixteen regular and high-strength concrete deep beams were tested. Eight beams were strengthened with steel and eight with hybrid FRP. The research examined concrete type, web opening location (top, middle, and bottom), and FRP reinforcing arrangement. The static load-bearing capabilities and failure mechanisms of deep beams with different web apertures were compared to theoretical models. The study on hybrid FRP reinforcements reached significant findings due to a high connection between experimental and analytical data[47].

This report describes an attempt to improve deep beams reinforced with steel plates' shear and flexural performance. As illustrated in Figure (20), three identical 1250 mm long, 300 mm deep, and 150 mm wide standard strength concrete beams were built. Two 20 mm bars with top and bottom reinforcement strengthened each beam for shear failure. The researchers reinforced the web using 4 × 20 mm steel plates formed into closed rectangular stirrups with the longer side oriented horizontally inside the beam section. Four-point bending tests were performed on beams with effective shear span-to-depth ratios of 0.75, 1.25, and 1.75. Experimental findings showed that reducing the a/d ratio improved deep beam shear strength, stiffness, and toughness[48].



(a) Longitudinal details



(b) Section

Figure (21) Details of beam dimensions and reinforcement of the deep beams[48].

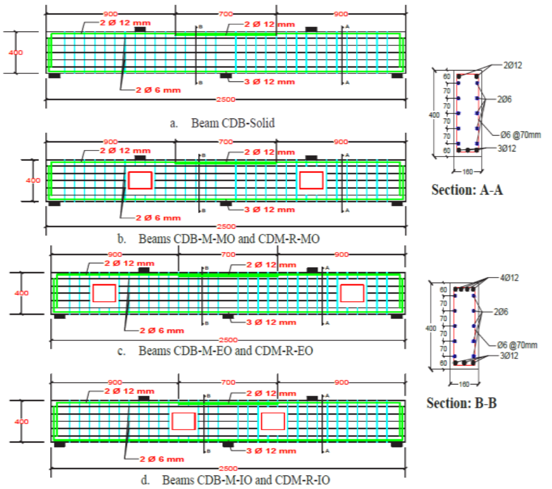
Deep reinforced concrete beams are extensively used in coastal projects, foundations, bunker walls, and load-bearing walls in structures; nonetheless, they often need apertures for doors, windows, and systems such as ventilation and air conditioning ducts. These apertures may diminish the shear capacity of the beams, hence elevating substantial safety issues. Research was performed on deep beams, including various sorts of apertures. Three beams, each with a cross-section of 150 mm × 500 mm and an overall length of 1.2 m, were fabricated and subjected to testing under two-point stresses. Each beam included two symmetrical apertures positioned centrally throughout the span, with one aperture located in each shear span. The findings demonstrated that the maximum load of the beam with long square apertures decreased by 4.032-% in comparison to the beam with long circular openings. Ultimately, both beam types collapsed due to shear, exhibiting shear fractures as the principal failure mechanism[49].

Transfer girders, wall footings, foundation pile caps, and floor diaphragms employ reinforced concrete deep beams. Retrofitting for shear weaknesses is essential since deep beams are more likely to collapse. This research examines how steel plates strengthen RC deep beams with web holes. Point loading was applied to eight deep beams with horizontal rectangular apertures. Each beam was 700 mm long and 100 mm x 350 mm, with two symmetrical apertures in each shear span around the inclined compressive strut's midway. The experiments used 10 mm steel plates for reinforcement. Horizontal rectangular holes decreased the beam's ultimate shear capacity by 7.68% compared to a solid reference beam. Reinforcing the holes with steel plates increased shear strength by 9.68%. Studs enhanced shear strength by 15% in strengthening plates compared to naked apertures[50].

A series of nonlinear finite element (FE) studies were used to evaluate reinforced concrete deep beam design with wide apertures. ATENA software was used to create three finite element models reflecting distinct design methodologies: Kong and Sharp (1978), Mansur (2006), and ACI 318-14's Strut and Tie Method (STM). Different reinforcing features were used to compare the structural behaviour of a transfer deep beam with wide apertures. Results showed that All three models showed the same service load deflection. The designs of Mansur (2006) and STM lowered stiffness at loads above the ultimate design load, whereas Kong and Sharp's technique decreased stiffness closer to the ultimate load. The deep beam built by Mansur cracked under more significant stresses than Kong and Sharp's beam. The Kong, Sharp, and Mansur models failed owing to severe shear fractures, whereas the STM specimen recovered. Three models met deflection restrictions. The research found that all three design methods give sufficient ultimate load capacity. Mansur, Kong, and Sharp needed the same reinforcement, but

STM needed more. Mansur's approach was notable for using less steel reinforcement and attaining a larger failure load. Crack widths should be controlled using reinforcing[51].

It discusses how big holes affect deep continuous reinforced concrete beams (RCCDBs) under static and repetitive loads. Figure (22) shows seven deep continuous reinforced concrete beams, one solid beam under static load and others with different configurations of large openings in the outer, inner, and middle spans, subjected to static loads and fifteen cycles of repeated loading. From 30% to 70% of the static test's ultimate load, repeated loading was applied. All beams, including those with 160 x 160 mm holes (representing 40-% of total depth), underwent a five-point bending test. The findings revealed that beams having substantial holes in the inner shear spans reduced ultimate load by 36-% compared to the solid beam. The ultimate load reduction for beams with extensive holes was 6-% after repeated loading[52].



a. Beam CDB-Solid

b. Beams CDB-M-MO and CDM-R-MO

c. Beams CDB-M-EO and CDM-R-EO

d. Beams CDB-M-IO and CDM-R-IO

Figure (22) Details of steel reinforcement for typically tested beam (all dimensions are in mm)[52].

Reinforced concrete (RC) deep beams with circular apertures retrofitted with aramid, carbon, and glass fibers are examined in this study. The primary objective was to determine how FRP types and stacking (1, 2, and 3 layers) affect beam load-bearing. The geometric and rebar properties of the beams were constant after testing. Deep RC beams were tested with four-point loads. Depending on layer count, FRP reinforcement increased maximum load capacity by 65% to 94%, CFRP by 87% to 130%, and GFRP by 133% to 196%. Layers reduce GFRP sheet separation from the beam surface. When the beams failed, CFRP sheets debonded at the supports around the circular hole despite having superior energy absorption and load capacity compared to AFRP and GFRP. However, AFRP and GFRP-refitted beams did not separate. SEM images showed rougher fracture surfaces of GFRP and CFRP specimens than the control specimen, indicating a stronger concrete bond[53].

This field trial examines the efficacy of shear stirrups and carbon fiber-reinforced polymer (CFRP) reinforcement in enhancing the shear strength of deep beams. Six deep beam samples, measuring 150 mm × 300 mm × 1000 mm with a span of 750 mm, were categorized into three groups, regular concrete (NC), ultra-high-performance fiber-reinforced concrete (UHPFRC), and UHPFRC beams reinforced with CFRP strips. Each group included two beams—one devoid of shear stirrups and one equipped with them—subjected to four-point force until failure. The findings indicated that shear stirrups significantly improved the shear strength, ultimate load, and deformation capacity of the NC beams. The UHPFRC beams demonstrated enhanced shear strength relative to the NC beams despite a decrease in deformation capacity. The CFRP reinforcement somewhat enhanced the shear strength of the UHPFRC beams by 16%, but their stretching capacity significantly increased, with displacement and power flexibility indices increasing by 49% and 185%, correspondingly[54].

This study examines how opening size and placement affect deep beam performance. The research uses a strut and tie model to incorporate reinforcement in deep beams with apertures, as there are no design code recommendations. The research includes numerical and experimental components. Eight reinforced concrete deep beams were tested under vertical loads. Seven had web apertures of various sizes and positions, while one was a reference beam. The beams had fixed diameters of 150×150 mm and 300×300 mm apertures, with horizontal locations ranging from 0.11 to 0.4 of the span. Experimental cracking patterns, failure modes, and load-deflection behaviour were compared to finite element software computational calculations. Further parametric research explored how reinforcement location around apertures affected beam behaviour. The study findings showed that large web holes interrupting the compression strut considerably decreased beam capacity, whereas smaller openings did not influence beam strength[55].

This research examines prestressed deep beams, especially full-scale T-section beams with huge web holes. Most studies have focused on reinforced concrete deep beams, but this is the first to examine prestressed variations. Experimental and computational studies were used to analyze the shear strength of regular reinforced and partly prestressed deep beams to determine how prestressing affects performance and how opening depth affects beam depth. All seven deep beams tested had the same shear span-to-depth ratio, concrete compressive strength, and web reinforcement ratios. They experienced a concentrated mid-span load till collapse. The key factors were web opening depth and prestressing strand position. Results showed that increasing web apertures considerably lowered beam shear capabilities. However, placing prestressing strands above web holes increased shear capabilities. A numerical investigation employing three-dimensional finite element models in Abaqus software accurately simulated and predicted prestressed deep beam performance,supporting experimental results[56].

Most researchers establish the form and size of the servicing apertures in reinforced concrete (RC) deep beams, which may reduce beam strength when they interfere with the internal load flow. This research attempts to illustrate that a correctly constructed aperture may increase beam strength by strengthening diagonal struts without deflecting the beam soffit. The study includes mathematically and experimentally evaluating supported RC deep beams with different opening configurations under a central load. Beams with a star-shaped aperture had the highest average normalized peak load of 432 kN and a soffit deflection of 1.21 mm, compared to 377 kN and 1.79 mm for solid beams. Ideally, the opening arrangement should match the internal diagonal strut profiles. A descriptive numerical study employing a triangular opening system showed that diagonal strut openings with an aspect ratio of 2–3 increase strut and beam strength and reduce deflection[57].

Ultra-high-performance Fiber-Reinforced Concrete (UHPFRC) deep beams with web apertures between stirrups are tested for shear capability. All beams were built from the same 1.5% steel fiber volume fraction UHPFRC mix. Figure (23) shows tests of eight simply supported deep beams with similar cross-sections and longitudinal reinforcement to determine the effects of opening height, breadth, placement, and stirrup ratio. The tests employed stirrup spacing far larger than ACI 318's limit for conventional reinforced concrete. However, it met Egyptian code (ECP 203) standards. The research examined French (AFGC) and Korean (KCI) shear design equations. Data showed that opening features dominate UHPFRC deep beam shear capacity. Comparing a solid reference beam to a square aperture at the natural load route with a height of 20% of the beam's entire height reduced shear capacity by 43%. Shear capacity fell by 21% when the aperture width was increased symmetrically by 75%, but only 5% when one side was increased by 125%. For constant opening sizes and locations, raising the stirrup ratio by 80% increased shear capacity by 17.1%.The ultimate shear strength of UHPFRC beams with openings of 20% and 40% of the beam height could be predicted safely using AFGC equations if the opening height was removed from the beam's adequate depth. KCI equations have a 6% higher safety factor than AFGC models[58].

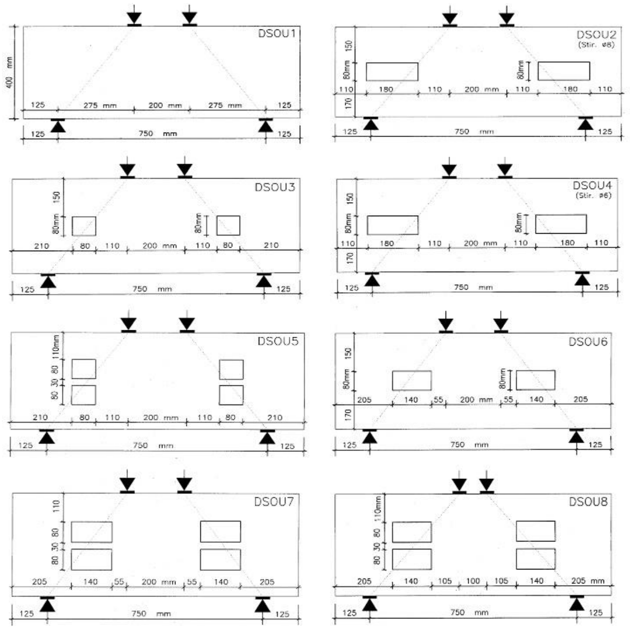


Figure (23) Size and locations of web openings[58].

To maintain strength and efficiency, this research emphasizes unique strengthening methods for concrete deep beams with big holes. It analyzes how changing orientations of metal plates impact the structural behaviour and load-carrying capability of deep beams using Abaqus FEM software. A complete sensitivity analysis and calibration against experimental data are included, with four different cases applying a 500 kN load following beam model validation. One design (case 3) had the lowest deflection and maximum load-carrying capability. The second design (case 4) employed less costly materials than case 3, making it cheaper. The research examined different concrete strengths for performance and cost-effectiveness after choosing case 4. The model can carry higher loads with less deflection, making it a feasible and safe structural option for beams with wide apertures[59].

Studied openings in the lateral sides of deep beams were investigated. Experimental tests were conducted on twenty concrete beam specimens, each 1100 mm long, 100 mm wide, and 400 mm deep. A single concentrated load was applied at the center of the shear span-to-depth ratio (a/d = 1), and all specimens were deep beams, with one specimen as a reference. Eleven specimens were experimentally tested with different circular and rectangular lateral openings. In addition, four specimens were subjected to theoretical analysis. We used six specimens with rectangular openings, using steel plates of different thicknesses for both internal and external reinforcement. The remaining specimens had circular openings. The openings were reinforced using three distinct reinforcement methods. The experimental results indicated that the presence of openings significantly reduced the load-bearing capacity and stiffness of the tested beams. Furthermore, there was a significant difference in the effect of the size, location, and shape of openings on the performance of the beams. The results indicated that the concrete beam specimens with rectangular openings and externally reinforced with fasteners showed superior performance[60].

This study examines deep beams with holes in their webs and the techniques for strengthening them to ensure structural integrity and efficacy. It examines many methodologies, including the use of externally bonded composites and fiber-reinforced polymers (FRP). The research investigates the failure causes of these beams, their load and deflection responses, improvements to their shear capacity, and the effects of opening size and positioning. Collectively, these results provide significant insights into the reinforcement of deep beams, enhancing comprehension within the domain of structural engineering[61].

This study included the casting and evaluation of thirteen specimens of reinforced concrete continuous deep beams. Of these, one functioned as a reference without any openings, whilst three acted as references for various opening configurations. Nine of the surviving samples were reinforced using Near-Surface Mounted (NSM) technology with three distinct configurations horizontal, vertical, and inclined. The findings indicated that reinforcing the specimens markedly improved their load capacity, rigidity, and ductility. The beams with angled reinforcement exhibited the most significant enhancement in load capacity, with increases between 19% and 30%. The horizontal reinforcement produced enhancements of 7% to 26%, whilst the vertical reinforcement achieved gains in load capacity ranging from 7% to 22%[62].

This research looks into the performance of deep-reinforced concrete beams with apertures that are reinforced with galvanized corrugated steel sheets (GCSS) and galvanized flat steel sheets (GFSS). An experimental program was executed on ten deep beam specimens with diverse opening configurations reinforced by GCSS and GFSS around the apertures. The primary characteristics examined were the kind of galvanized steel sheets (corrugated vs flat) and various aperture shapes (circular and square) and dimensions. The findings demonstrated that the use of galvanized steel altered the failure mechanism of the reinforced beams, shifting from the early shear failure seen in unreinforced beams. The beams augmented with galvanized steel sheets exhibited superior initial stiffness, energy absorption capacity, and ultimate load capabilities relative to the control beam. Furthermore, finite element modelling (FEM) was performed using ABAQUS software to replicate the experimental behaviour, with the predictions corroborated by test findings. A parametric analysis using the validated finite element method was conducted to evaluate the influence of galvanized plate thickness and opening size ratio on the shear strength of deep beams. The results indicated that shear strength improves with plate thickness and a suitable opening ratio of 0.33 is advised for the practical use of deep beams reinforced with galvanized steel sheets[63].

The researchers stated that in this study, a two-dimensional model was used using the finite element program, which was designed to analyze deep reinforced concrete beams with grid openings and strengthened using the DE FRP shear strengthening technique. The researchers studied the verification process of the experimental results and data of deep reinforced concrete beams with grid openings with the modeling results using the finite element program. These results showed that the finite element models that were worked on and developed captured the experimental results very well. These results were that a ratio of 0.99 was achieved between the maximum experimental and predicted load capacity through the validation of the finite element model. The grid openings were strengthened using CFRP bars with a diameter of 12 mm in the beams to strengthen their maximum load capacity, and this reinforcement increased the maximum load capacity of deep reinforced concrete beams with grid openings by 16%. The researchers relied on the results of other researchers (Yang et al., 2006), where the load was applied using four points with dimensions of 2400*160*600 mm and the targeted shear distance a=300 mm, noting the classification of the deep beam section according to (a/d=ratio less than 2.5) and three 19 mm diameter reinforcing steels were used in the tension zone with a value of Fy=420 MPa and the compressive strength of the concrete cylinder equal to 80.4 MPa. The design was without shear extensions for the beam so that it would be without steel shear connections with the use of rectangular mesh openings with dimensions of 150*180 mm along the shear. The comparative results between the experimental beams and the theoretical numerical results of the finite element model were that the maximum load for the experimental beams was 678.2 kN, while for the finite element models it was 676.6 kN. In conclusion, the addition of CFRP bars increases the ultimate load by 16% for deep reinforced concrete beams containing web openings[64].

4. Conclusions

1-The study underscores the substantial impact of web holes on the shear strength and load-bearing capacity of reinforced concrete deep beams, demonstrating a clear relationship between the dimensions of the openings and structural integrity.

2-The study demonstrates that innovative reinforcement methods, including steel plates, CFRP laminates, and fiber-reinforced polymers, substantially enhance the structural performance of deep beams with apertures.

3-The judicious placement of apertures, particularly next to shear spans or the neutral axis, may significantly mitigate adverse effects on beam stiffness and load distribution.

4-Finite element modelling techniques have shown to be reliable tools for predicting the performance of deep beams, closely aligning with actual results across many configurations

5-The findings validate the importance of modifying the shear span-to-depth ratio (a/d) in improving the performance of deep beams, emphasizing its function in mitigating failure modes.

6-Material Composition and Reinforcement The integration of material properties, including high-strength concrete and reinforcement methods, enhances load-bearing capacity while reducing deflection and fracture risk.

7-The amalgamation of mechanical anchoring and diagonal reinforcement is crucial for augmenting the shear resistance and overall ductility of the beams.

8-Research indicates that the formation of a longitudinal hollow in deep reinforced concrete beams results in reduced bearing capacity relative to solid deep reinforced concrete beams. This is accompanied by a decrease in concrete volume, hence lowering material costs.

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