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The Behavior of Punching Shear Strength on Geo-Polymer Concrete Circular Slabs with Openings: A Review

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ABSTRACT

This paper examines eco-friendly concrete, focusing specifically on geopolymer concrete and its performance in reinforced concrete circular slabs, with and without openings, as well as its strength when reinforced with CFRP sheets under punching shear conditions. Flat reinforced concrete slabs are frequently utilized in construction due to their efficiency and speed of installation, along with the continuous smoothness achieved in the arrangement of the elements. However, slab systems often lack adequate shear strength in both directions. As a result, they may suffer shear failure at the points where they intersect with columns, leading to the failure of a larger segment of the structure. Various factors can contribute to shear failure, including changes in the usage of the facility, design and construction errors, increased load, material degradation, and poor-quality standards. The placement of openings can occur in either the positive or negative moment area of the slab, giving rise to different challenges that cannot be addressed with a uniform approach. To correct structural deficiencies, carbon fiber-reinforced polymer (CFRP) sheets or strips are utilized as composite elements. The application of CFRP improves the punching shear resistance in both directions and also enhances flexural strength, ductility, and rigidity. This makes CFRP a more feasible option compared to other costly and complex methods, such as increasing the cross-sectional dimensions of columns. This paper reviews recent research on the application of Carbon Fiber Reinforced Polymer (CFRP) to boost the shear strength of flat slabs. It details the materials used for the reinforcement of these slabs and the techniques employed in their application. Furthermore, the paper summarizes the studies cited and proposes possible directions for future research.

1. Introduction

Flat plates are commonly favoured because they help lower construction costs. They are also cost-effective in terms of formwork and enable a simpler layout of flexural reinforcement. Another advantage of using a flat slab is the reduction in building story heights, which results in increased usable area within structures for a given height restriction. Additionally, flat plates can offer various other advantages, such as minimizing

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dead loads on columns and foundations [1]. Two-way shear, or punching shear, manifests as truncated pyramid-shaped surfaces extending from the column into the flat slab. This leads to a notable reduction in shear strength at the slab-column junction, which may result in separation as the slab descends.

During redistribution, nearby elements encounter increased loads, resulting in a significant transfer of weight to these components, which may not be engineered to accommodate such stress [2,3,4]. The sudden and unpredictable nature of this occurrence brings a significant disruption to the entire system. Punching shear failure is considered a significant structural failure. When flat slabs experience maximum moments due to uniform loading, you can observe flexural cracks forming around each column. As the load continues to increase, a fan-shaped crack appears, signalling the complex interplay between flexure and punching shear. Interestingly, these failure mechanisms reveal that the slab displays remarkable ductility when it comes to flexural failure. These dynamic highlights the intricate behavior of structural components under stress [5]. The shear failure mode is characterized by a limited ductility. One key aspect that can diminish the punching resistance of flat slabs is the existence of openings located close to the column. These openings can significantly weaken the structural integrity, making it crucial to consider their placement during design. This phenomenon occurs as a result of the reduction in the critical perimeter of the slab when concrete and reinforcement are removed at the opening, leading to a decrease in shear strength. Therefore, it is critical to assess the punching shear strength of flat slabs with openings at their ends accurately. Research efforts are ongoing to focus on the analysis and design aspects of reinforced concrete slabs.[6]. The use of fiber-reinforced polymers (FRP) as external shear reinforcement improves the punching shear capacity of flat slabs compared to traditional methods like bolts, rebars, or drop panels. FRPs have several advantages, such as being lightweight, strong, easy to handle, and requiring less labor. They are becoming more and more popular for strengthening and repairing structural parts, especially in slab-column connections, and efficiently improve beams and columns against flexural and shear pressures. [7]. Compared to other composite materials, CFRP's remarkable tensile strength and rigidity make it a preferred choice for strengthening. [8]. Reviewing the behavior of reinforced concrete slabs under punching shear circumstances is the goal of this research. Two sections will comprise the literature review. Shear punching is discussed and geopolymer concrete is defined in the first section. Once more, there will be two sections to the literature review. The first section discusses shear and defines geopolymer concrete. punching.

2. Geopolymer Concrete (GPC)

In the construction sector, the key factor being emphasized right now is the sustainable development of buildings. Concrete is the material most frequently utilized in construction, and it mainly comprises Portland cement [9]. Ordinary Portland Cement (OPC) is vital for concrete. Its production requires the burning of massive amounts of fuel and the disintegration of limestone, both of which release significant quantities of carbon dioxide into the environment [10] because of the problems with serviceability, economy, and sustainability brought on by the expensive restoration and rehabilitation of RC buildings damaged by steel bar corrosion. The production of steel and cement materials entails a significant amount of energy and resources.

Many academics and engineers have sought workable substitutes [11]. An inventive and sustainable substitute for conventional Portland cement in building is geopolymer cement [9, 12]. The main ingredients of the geopolymer binder are different industrial wastes or by-products that are high in silicon (Si) and aluminum (Al). Fly ash, a byproduct of burning coal, metakaolin, which is made by thermally activating kaolinite clay, and slag, a byproduct of metal smelting operations, are common materials used to make geopolymers. Liquid alkalis, including sodium hydroxide (NaOH) and sodium silicate ($Na2SiO3$), are added to these ingredients to efficiently activate them and speed up the polymerization process. This combination not only serves as a viable alternative to traditional Portland cement but also contributes to sustainability by recycling industrial waste and reducing the carbon footprint associated with cement production. The resulting geopolymer exhibits superior durability and chemical resistance, making it suitable for various construction applications [13]. Research has shown that the geopolymer industry has the potential to reduce carbon dioxide ($CO2$) emissions by as much as 80% when compared to conventional Portland cement production. This reduction is attributed to the unique chemical composition and production process of geopolymers, which utilize industrial by-products like fly ash or slag as primary materials. These processes not only minimize the reliance on carbon-intensive raw materials but also significantly lower the overall greenhouse gas emissions associated with concrete manufacturing. Consequently, the adoption of geopolymers could play a crucial role in mitigating the environmental impact of the construction industry and addressing climate change concerns by decreasing the carbon footprint linked to traditional cement production methods [14,15].

2.1 Terminology

Geopolymers are complex, stable materials composed of alumina silicates, which are reacted with alkali hydroxides or alkali silicates [16]. Joseph [17] proposed that alkaline solutions can react with silicon (Si) and aluminum (Al) powders and fly ash, metakaolin, and red mud to form binders These binders can be derived from geological source materials or industrial by-products, such as (GGBFS) Ground Granulated Blast Furnace Slag. [18], [19], [20], [21] and [22]. These polymers get their name from silica aluminate. The term "poly(sialate)" was chosen, with "sialate" acting as short for silicon-oxo-aluminate.[13] & [15]. The poly(silicate) empirical formula is given below: [23] & [24].

Mn (-(SiO2) z–AlO2) n, wH2O

Were

- "n" is the polymerization degree.
- "M” The alkali component was used.
- "w" is the hydration degree.
- "z" The value ranges from 1 to 3 based on the response chemistry.

2.1.1 Geo-polymer Categories

Geopolymers are materials produced by the alkali activation of various industrial by-products and natural raw materials. This process results in a cement-like substance known for its durability and sustainability. The primary components used in the formulation of geopolymers include blast furnace slag, a by-product of iron production in a molten state; fly ash, a by-product of coal combustion; and thermally activated clays, which possess properties that improve binding performance. Among the raw binders that are important in the polymerization process, three materials are commonly recognized: ground granulated blast furnace slag, calcined clays (particularly metakaolin, produced through the thermal treatment of kaolinite clay), and carbon fly ash. These materials are selected for their composition, which typically contains higher concentrations of silicon (Si) and amorphous aluminum (Al). These elements are critical for forming the binding matrix and contribute to the overall strength of the geopolymer. Extensive research has been conducted on various combinations of materials in GPC mixes, examining their mechanical properties, durability, and environmental benefits. This exploration has led to a greater understanding of how different binder materials can be optimized to produce geopolymers with enhanced performance characteristics, making them a compelling choice for sustainable construction practices [25], [26], [27] & [28], including:

• Class (F) flyash (low amount of calcium)

• Natural minerals containing Al and Si

• Class (C) flyash (high amount of calcium)

• Metakaolin or Calcined kaolin

• Slag • Red mud • Albite

• Silica fume

2.1.2 Alkali-activators

The alkaline solution activates aluminosilicate base materials to produce geopolymer paste. Various options are available for alkali activators. Alkali metal hydroxides, such as sodium hydroxide, carbonates, sulfates, phosphates, and fluorides (in a few studies) can act as activators. Silicates and aluminum silicates significantly enhance the alkaline activator species. [29]. In theory, any alkali metal can engage in geopolymerization processes; however, most research has focused on the impacts of NaOH and Na2SiO3, often referred to as water glass. This combination initiates chemical reactions with the aluminum and silicon present in fly ash. These reactions produce a binding agent that unites the small particles and aggregates in geopolymer concrete [30]. Different grades of sodium silicate solutions can be obtained commercially, providing a range of weight ratios between silica and alkali (SiO2 to Na2O) from 1.60 to 3.25. A sodium hydroxide (NaOH) solution is prepared by dissolving pellets of NaOH solid or flakes in water (Shihab et al., 2018). [31]. The solution concentration, measured in terms of Molarity (M), is determined by the quantity of NaOH solids dissolved in the solution.

2.1.3 High-Range Water Reducer and Extra Water

Adding high-range water reducers (HRWR) in geopolymer concrete mixtures can improve workability, similar to how it does for regular Portland cement concrete. For geopolymer production, naphthalene sulphonate is a preferred HRWR. A study [32] using a naphthalene-based HRWR incorporated the substance at up to 4% of the fly ash weight to see what would happen. They found that when dosages exceeded 2%, compressive strength decreased slightly.

2.1.4 Slag-Based Geopolymers

Slag is a commonly used additive in concrete. The main process for transforming iron oxides into molten metallic iron takes place in a blast furnace (BF). In the BF, iron oxides (including ores, pellets, and sinter), fluxes, and fuels (like coke and coal) are continuously introduced into the furnace. The liquid slag rises above the molten iron, referred to as hot metal, which accumulates at the bottom of the furnace. Both the slag and hot metal are periodically removed from the furnace. The hot metal can either be cast into pig iron for use in foundries or directly employed in steel production. As Figure (1) shows, liquid slag exits the BF at around 1500 °C and can be cooled in the air or granulated using water [33].

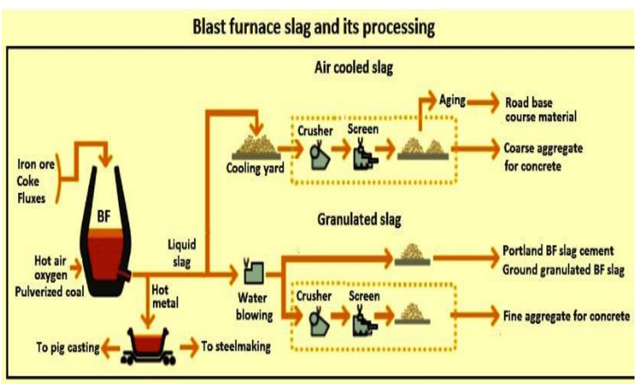


Figure 1. Processing of blast furnace slag [33].

Gases contained within the solution are extracted as a substance known as BF slag. The cooling process affects the formation of mineral crystals and determines the number and size of gas bubbles that may escape before becoming trapped during the solidification of the slag. Consequently, the slag's crystalline structure, porosity, and density are influenced by these cooling conditions, all while adhering to the specific chemical composition. Depending on the methods used for cooling, the liquid BF slag can manifest in notably different product forms. BF slag can be categorized into two main groups according to the cooling technique: air-cooled and granulated slag, as shown in Figure (2).

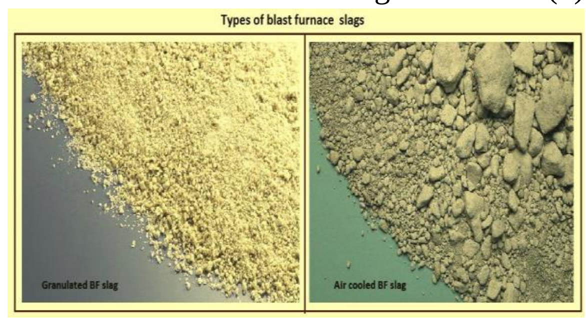


Figure 2. Types of BF slag [65].

Slag cement concrete has greater compressive and flexural strengths than regular Portland cement concrete. These enhanced strengths help meet designated safety standards for concrete mixtures and provide engineers with valuable tools to optimize the design of concrete elements. Additionally, it offers improved material properties that allow manufacturers to refine their concrete mix designs. As a result, property owners may benefit from lower life cycle costs.

3. Studies on Geopolymer Concrete (GPC)

Geopolymer concrete incorporating slag cement improves traditional concrete's compression and flexural strength, as demonstrated in Figures (3) and (4). It plays a crucial role in the creation of high-strength concrete. As much as 50% of the cementitious materials can be composed of slag cement, and typically, the concrete's 28-day strength increases with a higher percentage of slag cement. The hydration of Portland cement and water leads to the formation of calcium silicate hydrate and calcium hydroxide. CSH, generated during the hydration of Portland cement, binds the concrete and enhances its strength. Ca(OH)2, by itself, lacks strength. However, when slag cement is incorporated into a concrete mixture, it interacts with Ca(OH)2 and water to produce more CSH. This additional CSH increases the concrete matrix's density, enhancing strength [34].

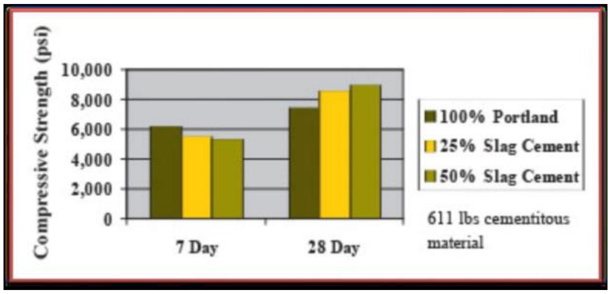


Figure 3. Effect of Slag Cement on 7 & 28-day Compressive Strength [34].

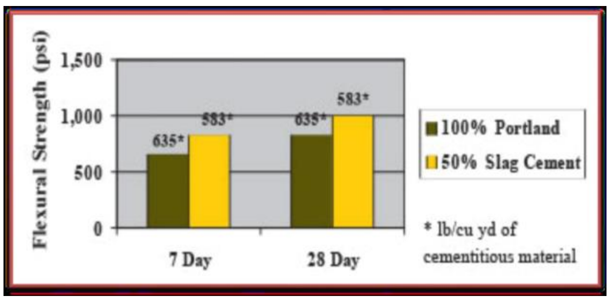


Figure 4. Effect of Slag Cement on seven and 28-day Flexural Strength [34].

Karunanithi et al. [35], Experiments conducted focused on geopolymer concrete based on reinforced slag, with the aim of investigating both mechanical properties and performance of slag and steel pipe inclusions Detailed analysis of (EDX) and (SEM) inclusion consistently revealed wollastonite in the concrete matrix, which indicated its incorporation during mixing. To evaluate the effectiveness of steel pipes in slag-based geopolymer concrete, tests, including punch shear tests and impact resistance evaluation, were conducted. The results indicated that the concrete mix designated as GCF22, characterized by a binder-to-total aggregate ratio of 0.22 and a fine-to-coarse aggregate ratio of 0.6, exhibited superior performance when blended with 1.0% steel fibers, as demonstrated in Figures (5). In particular, GCF22 demonstrated a notable shear stress capacity of 11.9 N/mm² during the punching shear test. This performance was further corroborated by the impact test, where the energy absorption capacity of the GCF22 mixture was quantifiably impressive. The mixture achieved an energy absorption value of 3541.41 N·m at the point of initial cracking, signifying a significant increase in toughness, while also recording a post-peak toughness of 349.48 N·m. Based on these observations, it is evident that the inclusion of 1.0% steel fibre is an optimized proportion that enhances the mechanical attributes of geopolymer concrete. Therefore, the GCF22 mixture is recommended as a superior choice for applications where enhanced shear strength and energy absorption are critical.

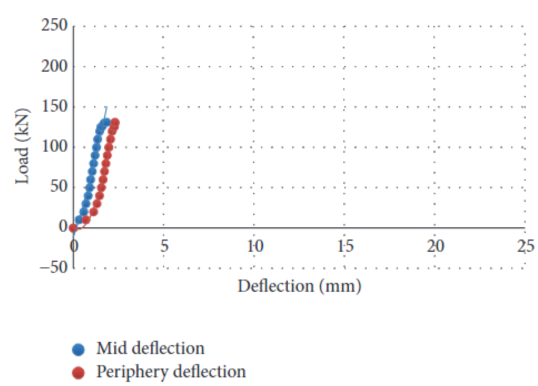


Figure 5. Punching shear values for control mix concrete

Marwa A. Sadawy et al. [36] The study presented a detailed investigation of the behavior of reinforced and fiber-reinforced open GPC slabs under punching shear conditions using a combination of experimental and analytical methods. In total, 24 square reinforced concrete slabs were analyzed, each incorporating a square column with dimensions of (100 mm x 100 mm x 300 mm). The slabs maintained a consistent size of (1000 mm x 1000 mm x 100 mm) throughout the study. The research focused on several critical variables, including the specific type of concrete utilized, the strategic positioning of the openings relative to the column, and the volume ratio of steel fibers integrated into the concrete mixture. To accurately simulate and analyze the connections between the reinforced slabs and the columns, the researchers utilized the finite element analysis software ANSYS V14.5. The study's results revealed a substantial enhancement in the ultimate load capacity of the slabs when steel fibers were incorporated into the geopolymer concrete formulation. The fiber-reinforced geopolymer concrete slabs demonstrated a markedly higher maximum load capacity in comparison to traditional Portland cement-reinforced concrete slabs. This significant improvement in performance is visually represented in Figure (6), which illustrates the comparative load capacities of both materials under similar conditions. The findings underline the potential advantages of using fiber reinforcement in geopolymer concrete applications, particularly in scenarios where enhanced structural integrity is paramount.

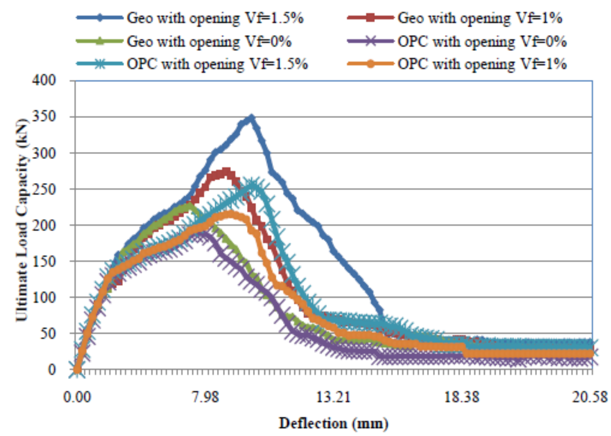


Figure 6. Load-Central Deflection (slabs with opening)

M. Ali Sadawy [37] In this study, the characterization of (GGBS)-enhanced GPC is experimentally investigated. The study investigates the effect of different steel fibers on the flexural strength, split tensile strength, compressive strength and elastic parameters of hardened geopolymer concrete. It also examines fresh geopolymer concrete's workability, setting time, and flow properties. Furthermore, a corrosion test was performed on the reinforced GPC. The mixture was prepared using an alkaline solution with a GGBS ratio of 0.5, and steel fibers were added in different volume fractions (0%, 0.5%, 1.0%, and 1.5%). The experimental results indicate that including steel fibers enhances the compressive and tensile strengths of steel-reinforced geopolymer concrete compared to standard geopolymer concrete without fibers. As the concrete matured, both its mechanical properties and corrosion resistance were observed to increase. The incorporation of steel fibers led to improvements in compressive and flexural strengths during the early stages, which also contributed to a rise in split tensile strength. The results indicated that an increase in geopolymer content was associated with enhanced corrosion resistance over time, as illustrated in Figure (7).

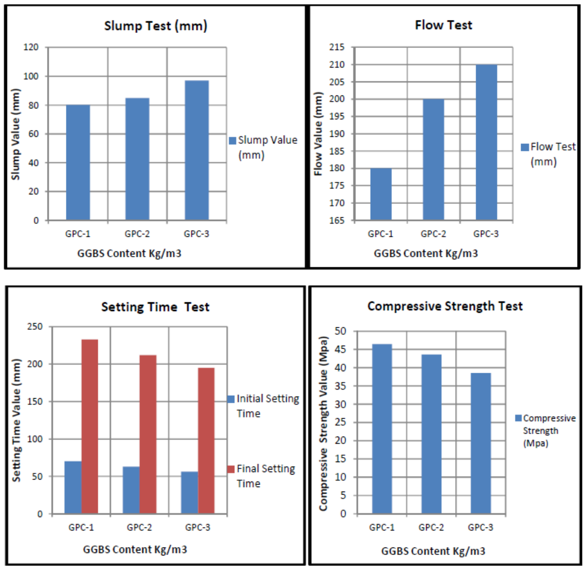


Figure 7. Fresh properties as a consequence of GGBS content

Sarwar Hasan Mohammad et al. [38] The study examines the performance of sixteen two-dimensional slab (GPC) concerning punched shear deflections under monotonic cyclic loading conditions This examines variables such as reinforcing elements, reinforcement percentage, concrete properties and concrete grade. For the tested specimens, the failure mechanisms and crack patterns were found to be similar in terms of reinforcement parameters. Reinforced fiber-reinforced polymer bars showed lower compressive strength than steel bars despite the same compressive strength number. The results indicated that increasing the concrete strength and the reinforcement ratio led to an enhancement in punching shear capacity and a reduction in deflections for both cyclic and monotonic loads. GC slabs' punching shear performance was superior to that of ordinary concrete (OC), even when both types were reinforced using basalt FRP (BFRP) bars. The ultimate load capacity of the slabs was observed to be lower under cyclic loading compared to static loading. However, the reduction in capacity for slabs reinforced with FRP was minimal. The slabs with FRP reinforcement demonstrated better fatigue performance than those reinforced with steel bars under cyclic loading conditions. The data collected from our experiments also served as a valuable tool for evaluating the reliability of current punching shear capacity equations. This analysis allowed us to gain deeper insights into their effectiveness and accuracy.

A.Serag Faried[39] The study provided an interesting investigation of the response of reinforced concrete to shear impact forces, effectively affecting their behavior under stress. The literature review is conceptually divided into two sections, emphasizing the importance of experimental and theoretical studies on the behavior of opened reinforced fiber-reinforced geopolymer concrete slab. This exploration draws from a wealth of existing research, considering key factors like the specific type of concrete, the strategic placement of openings with columns, and the influence of the steel fiber volume ratio. One exciting proposal from this research is to leverage experimental findings to create a robust computational model to assess the punching shear performance of these innovative GPC slabs with openings. The findings are impressive: incorporating geopolymer concrete enhances compressive strength and boosts various mechanical properties. However, it’s important to note that introducing an opening in the slab tends to diminish its ultimate load capacity. Intriguingly, the results are clear when we compare the punching shear capacity of geopolymer-reinforced concrete slabs to that of Ordinary Portland Cement

(OPC) slabs—regardless of their opening status. Geopolymer concrete outshines OPC, showcasing superior punching resistance and highlighting its potential for more resilient structures.

4. Shear Punching

In flat slabs that lack beams to connect the supporting columns, the manner in which loads are distributed becomes crucially important. These slabs directly experience a high degree of load concentration over a relatively small area, creating significant structural implications. This concentration intensifies the shear stresses in the slab-column connection zone, highlighting the critical nature of this region in maintaining structural integrity. When the forces on the slab become excessively concentrated, they can lead to a structural failure known as punching shear. This type of failure occurs at critical points where the applied load is most intense, particularly around the vicinity of the column support. Punching shear is characterized by a brittle failure in which the slab essentially 'punches through' due to the inability of the material to withstand the high shear stress. The effects of punching shear can be visually represented in a diagram, such as the one depicted in Figure (8), which illustrates the localized failure pattern around the column supports and underscores the importance of properly designing the slab-column connection to prevent such occurrences. Proper reinforcement and design considerations are essential to mitigate the risks associated with punching shear and ensure the safety and longevity of flat slab structures [40].

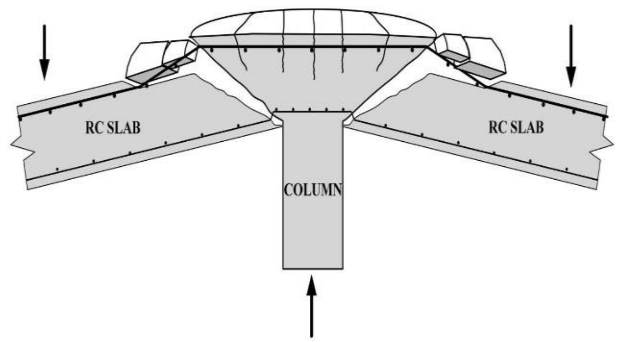


Figure 8. Failure due to punching in the connection area of the slab columns. [40]

A physical separation occurs between the slab and the column if the punch fails. This difference seriously undermines the balanced order maintained by these parties. As a result, the whole structure can collapse because loads are transferred to other members that are not intended to withstand high pressures. Because concrete is a brittle material, punching failures can occur suddenly. Consequently, it is important to evaluate the vertical column-supported slabs during the design phase carefully. It is necessary to reinforce the slab adjacent to the column by reinforcing systems to avoid slab failure due to punching shear. Recent design codes specify broken or straight reinforcing bars under the slab to allow the probability of continuous failure of the structure due to unexpected loads will be increased be installed, even where design calculations indicate that punching shear reinforcement is not so it is necessary

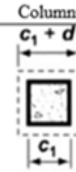
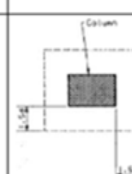
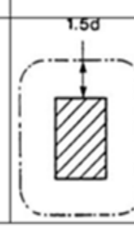
Figure 9. Typical punching shear failure (Piper's row car park, Wolverhampton, UK,1997, built in 1965) [41]

4.1 Punching Shear Failure Analysis

Punching shear failure in flat plates occurs at the joint between the slab and the column, posing a serious threat to the overall structural stability, which could ultimately result in collapse. A number of experimental investigations have assessed the punching shear strength at this vital connection point. Table 1 provides an overview of several of these investigations and guidelines, including ACI 318 [42], BS 8110 [43], and Eurocode 2 [44]. The identification of the location of the critical section is a contentious issue among current design codes, as indicated in Table 1. For example, ACI 318 [42] defines a significantly smaller critical section in comparison to BS 8110 [43] or Eurocode 2 [44]. Punching cracks emerge from the merging of micro-cracks at the upper part of the slab. These micro-cracks form through the thickness of the slab before failure occurs, eventually resulting in a punching crack that extends to the corner of the slab-column intersection [45].

Alexander and Simmonds [46] have outlined two conventional modes of punching shear failure. When a structure experiences symmetrical loading, the failure surface appears as a truncated cone surrounding the column (refer to Figures 10 and 11.a). In contrast, when the load is unevenly distributed, a combination of punching shear and flexural failure takes place, as shown in Figure 11.b. In this scenario, damage is primarily concentrated on the side of the column that bears the greater load, while the other side may exhibit little to no damage, although significant torsional cracks can occur in the nearby regions.

Table 1. Current Design Methods for Punching Shear

Design Method	PSS (MPa)	Critical Section b_o For Rectangular Columns	Limitations
ACI318-19 [29]	$V_c = 0.33\sqrt{f'_c}$ $V_c = (0.167 + \frac{0.33}{\beta_c})\sqrt{f'_c}$ $V_c = (0.167 + \frac{3.32d}{b_o})\sqrt{f'_c}$		$\sqrt{f'_c} \leq 70MPa$ the maximum shear stress does not exceed (1/3 $\sqrt{f'_c}$) MPa
BS 8110 [30]	$V_c = 0.27k(100\rho_t)^{1/3} f_{c,cube}^{1/3}$ $k = \sqrt[4]{400/d}$ $\rho_t \leq 0.03$		the design of shear for concrete strength (f_{cu}) not greater than (40 N/mm²). ($100\rho_t$) should not be over than (3). ($\sqrt[4]{400/d}$) should not be below (0.67) for structural elements that is not equipped with shear reinforcement, and not less than (1) for members with shear reinforcement
Eurocode 2 [31]	$V_c = 0.18k(f_c 100\rho_t)^{1/3}$ $k = 1 + \sqrt{200/d} \leq 2.0$ $\rho_t \leq 0.02$		

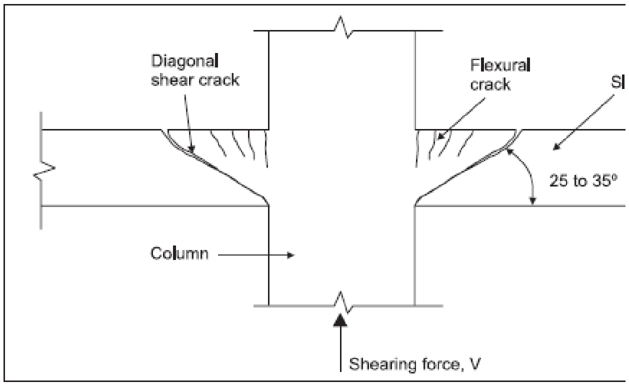


Figure 10. Failure Surfaces at Flat Plate Punching [46]

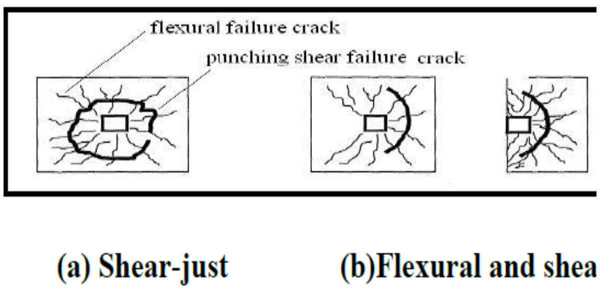


Figure 11. Failure Modes and Cracks [46]

4.2 Slabs with Opening

Punching shear failure can be a significant concern in reinforced concrete (RC) flat slabs, particularly in the regions where the slab meets the column. This phenomenon arises when shear stresses become elevated, leading to a precarious situation that can compromise the slab's integrity. Understanding this dynamic is crucial for ensuring safe and durable construction These shear stresses become more significant when there are openings and unbalanced moments present. Openings reduce the amount of concrete available to help resist these shear stresses, while unbalanced moments—resulting from the slab's configuration, loading factors, and the existence of openings—intensify the applied shear stresses. Openings are typically created for purposes such as ventilation, air conditioning, heating, and electrical needs, and for architectural design, they are generally placed near columns, further diminishing the volume of concrete available to counteract punching shear. When an opening is located within four times the slab's thickness, the critical shear perimeter (bo) is modified according to the recommendations in ACI 318 [42]. The critical shear perimeter is defined by the region enclosed by two tangents drawn from the center of the column to the edges of the openings, as shown in Figure (12). Regarding the punching shear capacity of flat slabs, both ACI 318 [42] and Eurocode 2 [47] agree that the maximum distance from the edge of the column at which an opening can still impact the capacity is four times the slab thickness (4h) and six times the effective depth (6d), where "h" represents the thickness of the slab and "d" indicates the effective depth.

Genikomsou and Polak [48] Study indicates that when openings in slabs are positioned more than four times the slab's height (4H) away from the edge of a supporting column, their punching shear strength rivals that of slabs without any openings. This finding uncovers an intriguing potential for design flexibility, allowing for innovative architectural solutions while maintaining structural integrity. This finding suggests that such a placement of openings does not significantly compromise the structural integrity of the slab. Moreover, these results align with the criteria established by ACI 318 [42], indicating that the design parameters for positioning openings in slabs can be safely adhered to without negatively impacting their performance.

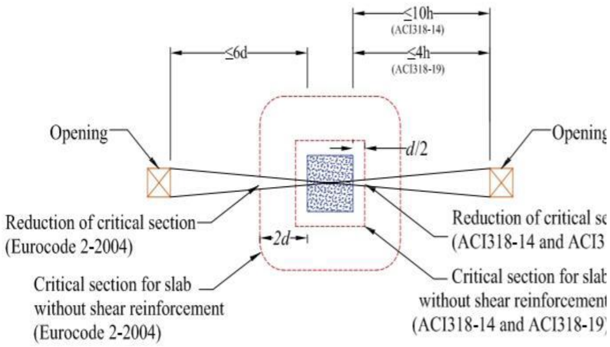


Figure 12. Critical Section Perimeter and Opening [42,47]

yooprasertchai et al. [49] To investigate the variation in the number of openings (2 or 4), their shapes (rectangular, rectangular, and circular), and the distances (1 and 4 times the slab thickness from the column tip), samples were 14 types of planar analysis that affected the punching shear force. The findings indicated that the circular opening had little effect on punch ability. Furthermore, placing the openings more than four times the distance of the structural weight from the end of the column did not significantly affect the impact force, however, as the number of openings increased from two to four, a significant decrease in punching power was observed. To determine the punching capacities of all specimens, we utilized the equations outlined in ACI 318 [42] and referenced Eurocode 2 [47]. This approach allowed us to accurately assess the strength and performance of the materials in question. The average ratio of experimental results to analytical outcomes and the ACI equations' standard deviation exhibited greater accuracy.

El-Salakawy et al. [50] The study involved a comprehensive examination of six full-size reinforced concrete slabs, focusing on structural integrity when subjected to various loading conditions. Five of these slabs were designed with strategically placed openings located near the support columns. The configurations of these openings varied, but each was crafted as a square hole aligned parallel to the edges of the column. These prototypes featured two distinct sizes of openings: the first set had apertures that matched the dimensions of the column precisely, while the second set included openings that were 40% smaller than the column. analysis of the data collected from these tests found that the presence of large openings significantly reduced the ultimate loads of the slab, especially for the ultimate loads of slabs with large openings reduced by 30%. In contrast, slabs with smaller openings showed a significant reduction in load capacity, with a decrease of 12%. These findings highlight the effect of opening size on the structural performance of reinforced concrete with respect to adjacent support columns.

Guan [51] This study used a comprehensive nonlinear layered finite element method (LFEM) approach to investigate the effect of openings in slab-column connections, including shear stud reinforcement (SSR), on punched shear failure behavior. The research comprised six parametric studies that analyzed twenty-one distinct models. These models were developed by systematically varying several critical parameters, including the dimensions and strategic placement of the openings as well as the aspect ratios of the columns under consideration. To enhance the robustness of the findings, the study incorporated empirical forecasts recommended by the Standards Association of Australia and the American Concrete Institute. This integration of empirical data into the analysis provided valuable benchmarks for comparing and validating the numerical simulations conducted throughout the research. The outcomes of this detailed investigation were instrumental in identifying the ideal sizes and configurations for openings and columns within flat plate systems, contributing to improved structural integrity and performance in engineering design. The study's insights are expected to guide future designs and construction practices, minimizing the risks associated with punching shear failure in reinforced concrete structures.

Al-Shammari [52] The study investigated the effect of hole transfer in thin reinforced concrete plates with central columns and also proposed a method for reinforcing holes with steel Reinforced concrete was developed of nine thin reinforcement (RC) plates, each 850 mm long, 470 mm wide, and 50 mm thick which density, with an average compressive strength of 30 MPa and each slab was 75 mm by 75 mm. The analysis examined various parameters, focusing on whether the opening was reinforced and the distance from the opening to the column, measured at intervals 0d, 2d, 4.5d, and 7d, with (d) tests used to model the effective depth of the slab. The results showed that the point of failure in the slabs occurred at the point of maximum ultimate load for slabs without openings and at the point of minimum ultimate load for unreinforced open slabs A significant feature was observed when the apparent distance between columns and openings was 4.5 d. In addition, the ultimate weights of specimens at 0.0d, 2d, 4.5d, and 7d improved by 19.44%, 19.51%, 35.13%, and 13.46%, respectively, when the opening was reinforced with steel plates, the test results were based on that comparative analysis

Ridha [53] Two-way slab specimens with different pores (SCC) were tested to investigate the effect of punching shear force on their behavior. Seven slabs were made and divided into two groups: group A had four slabs, one without an opening (S1), three with a square opening (S2, S3, and S4), and Group B with three slabs (S5), S6, and S7) with circular openings. The study examined various variables, including the position and size of the opening (rectangular or circular) in the case of a punching failure. The constants include the type of concrete used (self-hardening) and the proportion of reinforcing steel. The results showed that an opening significantly affects the ultimate load of the slab specimens. In particular, the ultimate punch shear strength of the slabs with the larger openings was lower than the slabs with smaller openings, especially the initial load of slab S1 for square openings at the edges in groups A and B, respectively (S2, S3, S4) in, S5, 1999). S6, 2019) compared to slabs They were found to be 38.9%, 44.4%, 33.3%, 30.6%, 38.9%, and 44.4% lower. and S7). Overall, the size and location of the opening had a significant effect on load reduction.

Oukaili and Salman [54] Six tests were conducted on thin reinforced concrete plates with openings adjacent to the connection between slabs and columns. The aim of the tests was to evaluate the effect of these openings on punching shear behavior at slab and column connections. Key variables examined included opening size and placement. One specimen showed a single opening, and the other five had an arrangement of openings around the pillars. All specimens were made of concrete with an average density and compressive strength of about 30 MPa. The openings were square and showed the parallel sides of the columns. Three different opening sizes were tested: one the same size as the cylinder (150 mm x 150 mm), another 67% the size of the column (100 mm x 100 mm), and the third 150% larger than the column (225 mm x 225 mm). Openings reduced the punching shear force compared to the control solid slab, with values ranging from 11.43% to 29.25%. In addition, a decrease in stiffness was observed, ranging from 0.31% to 83.00%, influenced by the dimensions and position of the openings relative to the columns

4.3 Reinforced Concrete Slabs with and without Opening Using (CFRP) sheet

A wealth of literature has emerged on enhancing slabs with the innovative use of Carbon Fiber Reinforced Polymer (CFRP) strips. This cutting-edge material has opened up new possibilities in structural engineering, offering robust solutions for strengthening existing infrastructures.

In 1999, **Brosens** [55]. The swimming pool roof slab, constructed in 1974, is located in Kalmthout, Belgium. This architectural structure consists of an intricate system of pre-stressed concrete beams that support prefabricated reinforced concrete panels. A layer of cast-in-situ concrete further enhances these panels, providing additional strength and durability. Recent laboratory analyses revealed significant issues contributing to the deterioration of the roof. Key findings pointed to the presence of chlorides and carbonation within the concrete, both of which have detrimental effects on structural integrity. An examination of the concrete cover over the embedded reinforcement bars indicated it was unsatisfactorily shallow, measuring approximately 6 mm. This insufficient cover has allowed for the corrosion of steel reinforcement, leading to a severe compromise in safety standards. The swimming pool environment naturally heightens the risk of such deterioration due to elevated chloride concentrations and moisture levels, posing substantial risks to any steel components externally attached to the structure. In response to these alarming findings, a systematic approach was adopted to halt the progression of corrosion and maintain the structural soundness of the roof slab. To combat the corrosion, the original steel rebar embedded in the concrete slab was carefully extracted. This decisive action eliminated the sources of further deterioration within the concrete itself. As part of the repair process, Carbon Fiber Reinforced Polymer (CFRP) reinforcement was utilized; this material was meticulously bonded to the surface of the existing concrete, effectively assuming the load-bearing responsibilities that the original concrete slab could no longer support. Following the installation of the CFRP, the concrete surface was meticulously re-leveled using high-performance epoxy mortar to ensure an even and stable substrate. To enhance the aesthetic appeal and conceal the extensive repairs, a brand-new false ceiling was installed, effectively masking the underlying structural enhancements. This comprehensive approach not only restored the safety and functionality of the swimming pool roof but also ensured its longevity in a challenging environment, as illustrated in Figure (13).

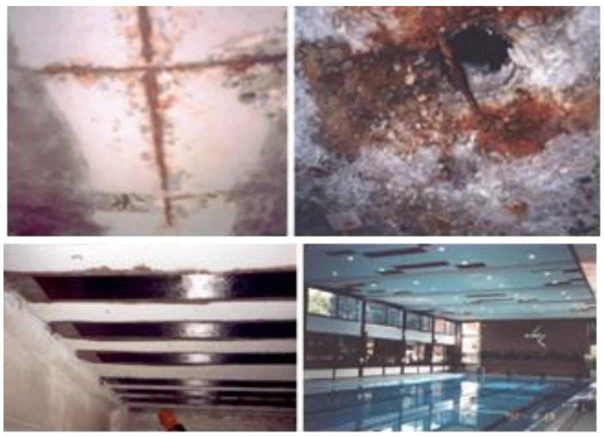


Figure 13. Concrete damage on roof slab of a swimming pool and repairing CFRP strengthening.[55]

In 2000, **(Gemert)** [56] Renovated the north side of a former school building in Leuven, Belgium, converted into the municipal library by the increased loads related to the new project Material analysis to evaluate the overall quality and condition of the building in order to provide flooring the bearing capacity of the lower elements has increased from 3 kN/m² to 6 kN/m², resulting in a characteristic value of 22.1 MPa. A tensile test was conducted to measure the surface tensile strength of the concrete, yielding a value of 2.96 MPa. The position and thickness of the metal reinforcement were determined using electromagnetic waves. The long-term reinforcement in the ribs consisted of two bars, each 16 mm in diameter, and no steel columns were found. An experimental study showed that external CFRP sheets used on one side of the slab as shear reinforcement were almost as effective as those on both sides Two CFRP sheets were placed on one side of the ribs. Figure (14) shows the work done and the final result of this method.

Figure 14. Hybrid strengthening of a ribbed floor slab and application of the CFRP sheets.[56]

In 2003, (**Nanni and Iball)** [57] A comprehensive testing program was carried out involving three distinct reinforced concrete (RC) slabs to thoroughly evaluate their behavior under various conditions, specifically focusing on the effects of a centrally located square opening. The study consisted of three different specimens: the first acted as a control and had no openings at all, allowing for baseline performance metrics; the second specimen included the square opening but did not incorporate any additional strengthening measures, which provided insight into the inherent weaknesses that openings introduce; and the third specimen also featured the square opening, but with an innovative enhancement: it had three plies of carbon fiber reinforced polymer (CFRP) applied to the tension face surrounding the opening. The outcomes of the testing revealed significant findings regarding the performance of the slabs. The application of externally bonded CFRP laminates markedly increased both the overall stiffness and the flexural capacity of the slabs that included openings. This enhancement suggests that utilizing CFRP laminates for positive-moment strengthening in slabs with cutouts is not only effective but also a practical solution for improving structural integrity. Additionally, the study indicated that further enhancements could be achieved by incorporating CFRP anchoring techniques, which would potentially elevate the effectiveness of the strengthening measures applied. Overall, the results convey a promising direction for future applications in structural engineering, particularly in the design and retrofitting of flat slabs with openings.

In 2005, (**Enochsson**) [58] The study examined the laboratory results of slabs strengthened under uniformly distributed loads using analytical and numerical methods The study included the use of CFRP sheets to slab a reinforced open reinforcement and compared their performance with conventional steel-reinforced frames, with and without openings, with dimensions (2600×2600×100 mm) and a compressive strength of 40 MPa. Sample designations include “H” for the homogeneous strip, S for small opening (0.85×0.85 m), “L” for large opening (1.20×1.20 m), “w” for smooth, s for reinforced steel, and c for reinforced CFRP, and the numbers 45 for strength and 90 for strength applied at 45° angles applied in two orthogonal directions of the opening, and for slabs reinforced with both systems of 45 and 90, respectively shown in Figures (15) and (16).

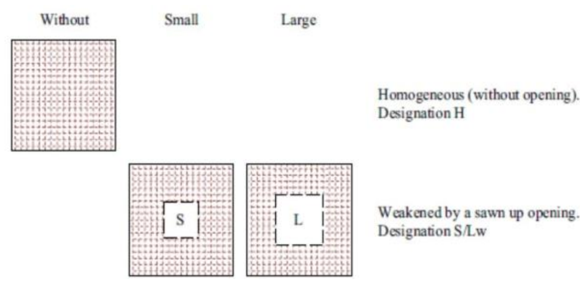


Figure (15). Experimental program. An opening drawn with solid lines is cast, and with dashed lines is sawn up (Enochsson, 2005) [58]

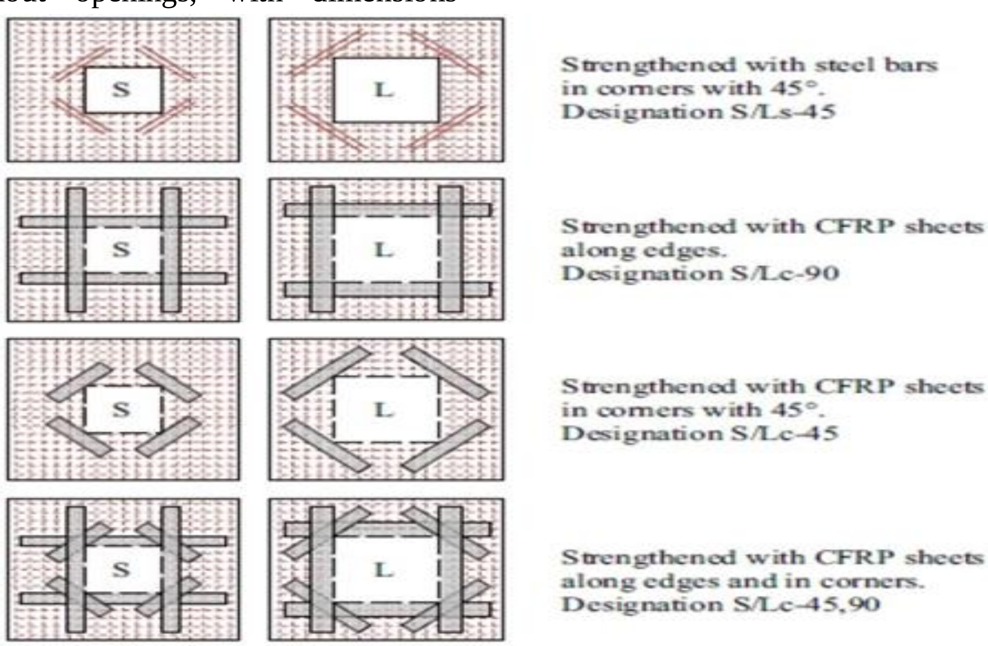


Figure (16). Experimental program. with dashed lines is sawn up (Enochsson, 2005) [58]

Numerical analysis results were compared with experimental observations, which showed that the load-deflection curve and steel stress evolution for the three slabs agree well. The main differences are in the elastic region noted and in the onset of the nonlinear response.

In 2009, (**Al-Wetaifi**) [59] Two-way slabs made of reinforced concrete, measuring 1050 mm x 1050 mm x 30 mm, were tested. Each slab specimen exhibited a compressive strength of 27.05 MPa and a steel coefficient of 0.00983. The slabs were divided into four groups (A, B, C, and D). Group “A” consists of slabs without openings, group “B” consists of open slabs at the common column fabric, and Group C consists of open slabs at the common column spacing and centerline, whereas Group “D” featured openings situated in the common area at the junction of the middle strips. The size of the opening is 60 mm. x 60 mm. Twenty-six of the thirty slabs tested were reinforced with CFRP sheets. The first set of concrete slab specimens from each group (A, B, C, D) was not reinforced and was identified as the type used for comparison purposes, labeled A-1, B-1, C-1. 1, and D-1

In 2009, (**Elsayed et al**.) [60] A study investigated the enhancement of two-way reinforced concrete (RC) slab with and without cutouts by a non-adhesive reinforcement method using mechanically bonded fiber-reinforced polymer (FRP) strips. The results showed about 30% and 66% higher yield and ultimate load in slabs without cutouts as compared to control samples, Increase in ultimate load For slabs with cutouts reinforced specimens exhibited up to 17% increase in crack load, 10% increase in yield load and up to 33% in ultimate load a last compared to their control counterparts.

In 2011, (**Shather**) [61] A total of eleven reinforced concrete square slabs (1050 mm x 1050 mm x 75 mm) featuring square openings were examined using standard strength concrete. The slabs included three different sizes of openings: 333 mm x 333 mm,250 mm x 250 mm, and 500 mm x 500 mm. Each slab was tested under a concentrated point load until failure was observed. The loading system consisted of a crossed frame supported by four square wooden pads, applying concentrated four-point loads. Two slabs with openings were reinforced using steel bars as control specimens, while nine slabs were reinforced with Carbon Fiber Reinforced Polymer (CFRP) bars. The results showed that the deflections of concrete slabs reinforced with FRP bars were 21% to 29% higher than those reinforced with steel. The observed differences could be attributed to lower parameters of elasticity and bond characteristics of FRP reinforcement ho Slabs with open centers reinforced with CFRP exhibited linear behavior before cracking, significant decrease in stiffness after cracking and evolved to bilinear response Experimental results showed that the shape of the square openings significantly influenced the behavior of two-dimensional reinforced concrete slabs. The load-carrying capacity of medium-exposures is reduced by 42% compared to small-exposures with the same FRP strength ratio, while large-exposures are reduced by about 52%.

In 2012, (**Mohammed.**) [62] A study evaluated the effectiveness of carbon fiber-reinforced polymer (CFRP) and steel fiber in restoring the load capacity of slabs after openings were created in areas experiencing positive moments. Eight slabs of self-compacting concrete, measuring 450×450×40 mm, were created to evaluate the effectiveness of CFRP reinforcement and steel fiber in improving load capacity after opening. The study analyzed two strengthening methods for slabs with openings: externally bonded CFRP strips and the incorporation of 1% steel fiber by volume. Both methods were found to enhance the load-carrying capacities of the slabs. CFRP is more effective than the steel fiber method, allowing slabs to regain their total load capacity and even increase it by 30%. The inclusion of steel fiber enabled the slabs to regain 20% of their total capacity. Additionally, CFRP and steel fiber reduced cracks at the interior surfaces of the openings, with CFRP specifically preventing cracking at the inner corners.

In 2014, (**Bayar and Diyar**) [63] The objective of this study was to evaluate the effect of carbon fiber reinforced polymer (CFRP) strips on circular reinforced concrete (RC) slabs with three circular openings RC slabs, each 1200 mm in diameter and 75 mm thick, by annular force is applied at the center supported at all edges Again and retested under load. The study explored various experimental factors, including different opening shapes (square, rectangular, and circular) and multiple strengthening methods. Results showed that CFRP strips significantly improved the slabs' performance, enhancing both ultimate load capacity and deflection. The ultimate load capacity increased by 27% to 52%, depending on the specific strengthening method used. Two distinct strategies for strengthening were employed, as illustrated in Figure (17).

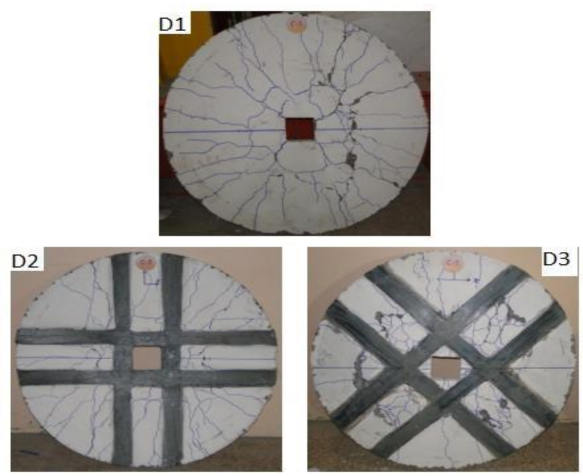


Figure 17. Type of Strengthening "Bayar and Diyar" [63]

In 2015, (**Abed H. A.**) [64] Sixteen reinforced concrete slab specimens were tested in the experimental work, each measuring 1050 mm x 1050 mm, with a depth of 80 mm, a series of material evaluations were conducted to determine the properties of the concrete and reinforcement. Each slab was subjected to uniformly distributed loads while simply supported at all four edges, simulating realistic conditions to assess their structural performance and load-bearing capacity. These slabs were categorized into six distinct groups. Specimen group (1) consisted of a slab without any openings and no reinforcements. Group (2) comprised three slabs, each featuring one central opening measuring (200×200 mm). Group (3) included three slabs that had two central openings that converged, each measuring (140×140 mm). Group (4) consisted of three slabs with two central openings that diverged, each sized at (140×140 mm). Group (5) contained three slabs exhibiting two converging diagonal openings, each measuring (140×140 mm), and group (6) included three slabs with two diverging diagonal openings, also sized at (140×140 mm).

In 2020, **(Bashar S. Mohammed et al.)** [65] This study focused on the structural behavior of concrete slabs, including openings reinforced with carbon fiber-reinforced polymer (CFRP) sheets. To investigate this, a total of ten concrete slabs, each 1000 mm long, 530 mm wide, and 25 mm thick. Among these slabs, nine were designed with strategically placed openings that simulate common architectural features, while one slab was maintained as a control specimen without any openings for comparative analysis. In the experimental setup, the CFRP sheets were applied in several distinct configurations, specifically utilizing single, double, and triple layers of reinforcement. This approach aimed to assess how varying the thickness of the CFRP application influences the overall structural integrity and performance of the slabs. The results of the experimental testing revealed that slabs reinforced with a triple layer of CFRP exhibited the highest resistance to applied loads, significantly outperforming the other configurations. Furthermore, an increase in the number of CFRP layers was consistently associated with a notable decrease in deflection values, highlighting the efficacy of CFRP as a reinforcement material for enhancing the load-bearing capacity and minimizing deformation in slabs with openings. This research offers valuable insights into the potential for utilizing CFRP in structural applications, particularly in scenarios where maintaining structural performance is critical after creating openings in concrete slabs.

5. Conclusion

This research comprehensively analyzes the performance of reinforced concrete slabs specifically under the conditions of punching shear, a critical factor influencing the structural integrity of concrete systems. One of the most pressing challenges encountered by the construction industry today is the design and construction of concrete structures that are not only durable but also environmentally sustainable. In this context, geopolymer cement emerges as a pioneering material, offering a viable alternative to the traditional Portland cement used in construction. The literature review of this research is systematically divided into two main sections. The first section highlights prior studies that have established a foundation for understanding the behavior of concrete under punching shear. It emphasizes the necessity for both experimental and theoretical investigations aimed at elucidating the performance characteristics of reinforced geopolymer concrete circular slabs that incorporate an opening. This study will meticulously examine various parameters influencing slab performance, including different types of concrete materials, the size and strategic location of the openings within the slabs, and the implications of the column's position and dimensions on the overall behavior of the concrete structure. The anticipated experimental findings from this research are poised to contribute significantly to the development of a sophisticated numerical model. This model will enable a thorough assessment of the punching shear behavior exhibited by reinforced and enhanced concrete slabs featuring openings, all while utilizing geopolymer concrete as the construction material. Notably, geopolymer concrete has consistently demonstrated superior mechanical properties when compared to traditional materials, illustrated by its increased compressive strength and overall structural resilience. Nonetheless, it is crucial to address that the inclusion of an opening within the slab can reduce its ultimate load-carrying capacity. Despite this drawback, research findings reveal that the punching failure strength of reinforced concrete slabs made from geopolymer cement—regardless of the presence of openings—exceeds that of ordinary Portland cement (OPC) slabs tested under similar loading conditions. This observation underscores that geopolymer concrete offers enhanced resistance to punching shear, reaffirming its position as a more robust alternative to conventional OPC in construction applications.

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