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Punching Shear Behavior for Flat Slabs with CFRP and Openings

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ABSTRACT

This study is devoted to investigate the punching shear behavior of geopolymer flat slab that have transverse web openings with CFRP. The shear reinforcement is considered one of the important solutions to increase the resistance of the slabs to the failure of the punching shear and it is also possible through the use of these collars to provide service openings next to the columns. Three molds made of wood were prepared to examine 15 samples of geopolymer concrete under concentrated conditions, Dimensions of section are of total (70*70*7 cm) and Dimensions of column (15*15*15 cm). Three groups of models comprise the models for this research: the first group looks at the impact of the column's location; the second group looks at the impact of an opening next to the column or not; and the third group looks at the impact of CFRP.The findings demonstrated that the presence of transverse web openings affects the general punching shear behavior of flat slab geopolymer reinforced concrete as a result of the reduction of concrete within the geopolymer concrete section. CFRP specimens demonstrated superior due to the inherent mechanical properties of the material. Among the various repairing procedures used, the full wrapping technique yielded the best results after the repairs.

1. Introduction

Two-way concrete slabs with consistent depths are typical flat plates, which carry loads straight to supporting columns without the need for beams, capitals, or drop panels. Due to the ease with which formwork and reinforcing bars may be arranged for the assembly of flat plates, construction time can be minimized (1). This kind of building is not only aesthetically pleasing but also has additional room. Because flat Figures are less expensive to build, they are used extensively (2). They also result in a simpler arrangement of flexural reinforcement and are economical in their formwork. Reduced building story heights, which increase usable space in buildings for a given or limited height, are another benefit of a flat Figure. Flat Figures also have many other benefits, such as lowering dead loads on the foundations and columns (3). Punching shear, also known as

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two-way action shear, is a common cause of progressive failure in flat plate constructions. It happens at the junction of the slab and the column. As a result, caution must be used when designing such slabs to avoid an unforeseen failure scenario (4).

2. Significance of the Research

For every researcher, gathering trustworthy information regarding the structural behavior of reinforced geopolymer beams is vital. This is essential to comprehend the significance of the mechanical qualities that geopolymer concrete possesses and to know how to construct a suitable foundation for the planned research program. This provides a brief overview of the structural behavior of reinforced geopolymer slabs in the current paper.

3. Geopolymer Concrete

The amount of cement produced in 1995—roughly 1.5 billion tons—was reportedly risen to 2.2 billion tons in 2010. The issue is that the cement industry contributes to some CO2 emissions; approximately one ton of CO2 is released into the environment during the production of one ton of Portland cement. Furthermore, climate change and global warming are caused by CO2 emissions. The goal has been to identify substitutes for regular Portland cement. This involves the addition of other cement-making components such as rice husk ash, fly ash, silica fumes, and granulated blast furnace slag. Polymer-floor concrete can drastically cut CO2 emissions to the atmosphere that are produced by the cement, which helps to mitigate global warming (5).

Prof. Davidovits coined the word "geopolymer" in 1978 to refer to a broad class of materials with inorganic molecular chains or network topologies that could take the role of Portland cement in concrete constructions. The final structure of the Geopolymer is mostly determined by the ratio of silica to alumina (Si: Al), with Si: Al values typically ranging from 2 to 3.5 in the majority of materials assumed to be utilized in conveyance systems (6) (7).

Technically speaking, geopolymer gel is superior to conventional cement common binding gels because of its high mechanical strength development, quick strength growth,strong chemical resistance, resistance to sulfate attack, and affordability (8).

4. Terminology

Specifically, a strong and stable substance made of alumina-silicates produced by activating alkali hydroxide and/or alkali silicate is referred to as a "geopolymer" (9).According to Davidovits [10], an alkaline liquid could be used in response to fly ash, meta-kaolin, red mud, and powdered silicon and aluminum (Al) to create binders in a geological source material or in by-product products like ground granulated blast furnace slag (GGBFS) (11), [12], [13], [14], & [15]. The chemical name of these polymers was derived from silica-aluminates. The term poly (sialate) was chosen, and "sialate" is the acronym for silicon-oxo-aluminate [16] & [17].The poly (sialate) network is made up of oxygen ion sharing, four-fold coordination of Si4 + & Al3 + ions, from semi-crystalline to amorphous [16] & [18]. The following empirical formula for poly (silicate) is given:

The following empirical poly (silicate) formula is given:

$M_n(-(SiO_2)_z–AlO_2)_n, wH_2O$

"M" denotes the alkali component employed; "n" denotes the degree of polymerization; and "w" denotes the degree of hydration [18]& [16]. Where "z" might have a value ranging from 1 to 3, contingent upon the response chemistry.

5. Studies on Geopolymer Concrete (GPC)

The geopolymer concrete based on low-calcium fly ash has been examined by Hardhat and Range, 2005, with an emphasis on the development of short-term characteristics and the impact of varying the mixture's component proportions. Because geopolymer concrete samples have reduced creep and shrinkage, better resistance to sulfur salt attack, and excellent resistance to acidic media, their compressive strength is quite strong. Raising the mass ratio of Na_2SiO_3 to NaOH, increasing the molarity of the NaOH solution, raising the curing temperature range from 30°C to 90°C, and rising the Fly ash-based geopolymer concrete has a high compressive strength because of its 4- to 96-hour (4-day) cure period. This kind of concrete works better and avoids fine fly ash agglomerations during mixing when a naphthalene-based superplasticizer is added to roughly 4% by weight of fly ash (19).

Sofi et al., (2007) , evaluated the elastic modulus of the GPC. It was found that it is comparable to the conventional portland cement concrete, most of the geopolymer concrete's mechanical properties depend on mix design and method of curing (20).

The impact of various parameters on the short-term engineering qualities of fresh and hardened low-calcium Geopolymer-based Fly Ash mortar was investigated by Hardjito et al. (2008). They discovered that the higher compressive strength ranges are obtained when the concentration of alkaline liquid is increased, curing is allowed to occur for one day at 65°C, and the activator to FA mass ratio is 0.4. The results for the compressive strength of the mortar cubes measuring 50x50x50 mm ranged from 1.6 MPa to 20 MPa.
(21).

- (Raijiwala et al., 2012) investigated how alkaline activators affected durability and strength. Large amounts of sodium hydroxide are available, although potassium hydroxide has a higher alkalinity than NaOH. The same quantity (50% NaOH + 50% KOH) was applied as an alkaline activator at three different temperatures (60, 80, and 100 degrees Celsius) in order to prepare geopolymer concrete. Tests for compression, indirect tensile, bending, tensile, and durability were conducted on fly ash, which is produced by a hot local power plant. The outcomes demonstrated that the mix of the aforementioned at 80 °C has an advantageous impact on the Geopolymer concrete's strength and longevity (22).
- El-Salakawy et al. tested a total of six full-size RC slabs, five of which featured slabs with apertures of varying configurations near the column. The square holes in the prototypes were aligned parallel to the sides of the column, and they came in two sizes: one that matched the size of the column exactly, and another that was 40% smaller. According to the data, the ultimate load

drops by 30% for the larger aperture and by 12% for the smaller one (23).

- Yooprasertchai et al. reported the results of trials on 14 flat specimens to investigate the impact on punching shear strength of apertures of different numbers (2 and 4), shapes (circular, square, and rectangular), and distances (1 and 4 times the thickness of the slab from the face of the column). Round holes were shown to have the least impact on punching capacity out of all the forms studied. Additionally, placing apertures four times the thickness of the slab away from the column face did not appreciably reduce the punching capacity. Additionally, increasing the number of openings from two to four resulted in a significant drop in punching capacity. Using the descriptive formulae for ACI 318 and Eurocode 2, all specimen punching capacities were estimated. The average ratio of analytical to experimental results and the standard deviation of ACI equations were shown to be more accurate (24).

To predict how openings in slab-column connections with shear stud reinforcement (SSR) would affect the punching shears failure, Guan used a non-linear Layered Finite Element Method analysis. conduct. Six parametric tests in all examined all twenty-one (21) models by varying parameters such as column aspect ratios and the size and location of the openings. He included empirical forecasts into the comparison, which have been supported by the American Concrete Institute and the Standards Association of Australia. Determining the ideal hole and column sizes for flat Figure devices required this investigation, which was a critical first step (25).

Kim et al. (2008) tested four large-scale slabs (3000×3000×90 mm), comprising one unstrengthen slab, one slab strengthened with non-prestressed CFRP sheets, and two slabs with prestressed CFRP sheets. The study examined the flexure of two-way slabs strengthened with or without prestressed CFRP sheets. At the center span, the slabs were simply supported and exposed to a constant patch stress. Additionally, a nonlinear three-dimensional (3D) FEA using ANSYS 2004 software was used to forecast the tested slabs' flexural responses. It was also anticipated that the materials would join perfectly. For non-prestressed and prestressed CFRP sheets, they discovered that there was an increase in flexural strength of up to 25% and 72% (32 and 80% in the FEA), respectively. They discovered that the control slab's failure was extremely ductile; in contrast, the strengthened slabs showed a stepwise failure as a result of the CFRP sheets' partial rupture or delamination. The effectiveness of prestressing CFRP compared to non-prestressed CFRP was successfully confirmed by Kim et al.'s study (26).

- An experimental investigation on the flexural strengthening of reinforced concrete (RC) slabs with various CFRP systems employing various externally bonded reinforcing (EBR) techniques was presented by Tan et al. (2003). Similar-sized slabs of 6300 x 1000 x 220 mm were created using ready-mix concrete and allowed to cure in a typical laboratory setting. Every slab was reinforced with steel bars in the transverse direction and with deformed steel bars in the longitudinal direction. The study's findings demonstrate that the CFRP EBR improved the strengthened slabs' flexural strength while lowering their deflections and crack widths. By using CFRP laminate Figure prestressing, the load capacity was significantly raised and the deflection and crack forms were significantly decreased; the slab reinforced with NSM tapes demonstrated the best performance. There were two failure modes identified: the CFRP's reinforcement delamination and rupture (27).

6. Applications of Geopolymer Concrete

6.1 The pavement

A weighbridge at the Port of Brisbane received a number of pavement slabs made of geopolymer concrete placed in November 2010.the slabs are composed of class 32 MPa concrete and are located in a hostile maritime environment. (28)

6.2. Tanks of water

In March 2011, two 2.4 m height by 10 m diameter tanks were filled. Ordinary concrete with a compressive strength of around (32) MPa, a maximum coarse aggregate size of 10 mm, 20% fly ash, and 80% Portland cement make up the first basin. tank number two is constructed of geopolymer concrete of grade 32 MPa with aggregate particles as small as 10 mm. (29).

7. Objectives

The present study aims are:

1. The introduction of novel eco-friendly concrete materials employing geopolymer concrete, which is made from precursors and alkali activators and has been shown to be a promising alternative to ordinary Portland cement in building. Portland cement can emit fewer greenhouse gases since the Geopolymer binder generates 70–80% less carbon dioxide than Portland cement.

2. Using recycled concrete waste from construction and demolition sites—which would otherwise be dumped in landfills—as a source for aggregate offers the possibility of both economic and environmental advantages.

3. By enhancing the geopolymer concrete's qualities with iron filings, the community may dispose of these materials more responsibly by lowering the pollution they bring to the environment.

4- Examining the mechanical characteristics of geopolymer concrete using recycled material from concrete

5. Examining the bearing load capacity of wall panels made of geopolymer concrete that are subjected to an eccentric t/6 axial uniform load from the wall thickness under fixed supported conditions.

6. Deriving suggested formulas for the mechanical characteristics and bearing load capacity of wall panels made of geopolymer concrete.

7. Studying the influence of the existence of the opening near the column.

8. Numerous variables, including the usage of CFRP strips with various designs as a strengthening strategy, have been the subject of numerous research. Nonetheless, early CFRP debondin was the most frequent reason for failure.
The main goal of this study is to examine, both computationally and experimentally, the impact of flexural strengthening on two-way

slabs reinforced with CFRP strip and bars under monotonic, evenly distributed loads that have fixed support for all edges. There is a dearth of prior research to confirm that CFRP bars can substitute conventional reinforcing in concrete slabs and strengthened by CFRP strip with different layouts under a monotonic uniformly distributed load that gives the same or more strength capacity, less deformations, and mode of failure (30).

8. Shear Punching

Punching shear is a flat slab phenomena where a cone-shaped perforation is created from the top of the slab by targeted support reactions. Punching shear was undesirable in structural concrete flat slab constructions because of its brittle character, which might cause a building to gradually collapse, even though punching shear failure is typically preceded by flexural failure [37]. Punching shear design technique presumed that the slab experiences hogging moments in both principal directions above the column. This meant that the slab could be either constant or the slab-column link could be momentarily resistive.
Punching shear around the columns was therefore crucial for shear in flat slab constructions.

9. Punching Shear Failure Analysis

Punching shear failure is recognized as a serious risk to flat slab structures due to its abrupt and brittle nature [31]. As a result, several scholars have looked at practical modeling techniques for figuring out shear forces and capabilities [32] & [43]. A recent parametric study [34] on punching shear in plates verified that a nonlinear 3D FEA employing "8-node brick components" can accurately forecast the shear capabilities. They discovered that increasing concrete strength, slab thickness, column size, or reinforcement ratios all improve ability, albeit they can also lead to more delicate breakdowns. Moreover, studies like the one conducted by [35] & [36] have led to comparisons between various shear reinforcing technologies and reinforcement techniques.

10. Materials

10.1. Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS):Properties of Ground Granulated Blast Furnace Slag that used was shown in Table 1.

Table.1: Ground granulated blast furnace slag properties

Model Number:	S95
SLAG:	Hot
COLOR:	Light Grey
FINENESS:	490-510 m^2 /kg
Type:	Powder

10.2. Sodium Hydroxide

Combining sodium hydroxide (NaOH) or potassium hydroxide (KOH) with either potassium silicate or sodium silicate was the most popular alkaline activator used in geopolymerization (39). The kind and strength of the alkali solution had an impact on the raw material's dissolution. There were two forms of sodium hydroxide available: flake and pellet. It is advised to combine the two solutions to create the alkaline liquid at least 24 hours before using.(40)

10.3. Sodium Silicate Na2SO3

According to Palomo et al. [41], the kind of activator used had a significant impact on the polymerization process. When soluble silicate—either sodium or potassium silicate—is added to the alkaline activator, reactions happen more frequently than when alkaline hydroxides are used alone. According to Xu and Van Deventer's work [42], the reaction between the source material and the solution was boosted when sodium silicate solution was added to the sodium hydroxide solution as the alkaline activator. According to Tempest et al. [43], the sodium silicate activator dissolved quickly and started to bind the particles of the base material.

10.4. Reinforcing Bars

The investigation made use of 8 mm distorted bars. Table .2 provides an illustration of the test results. The current work in the construction materials laboratory, civil engineering department, Mustansiryah University, adheres to ASTM A615 standards (44)

Table 2 . Tension tests results for steel bars within this study

Nominal diameter mm	Normal diameter mm	Yield stress MPa	Yield strain mm/mm	Ultimate strain mm/mm	Ultimate strength MPa	Elongation %
8	7.90	517	0.00201	0.167	654	10

*Engineering Consulting Office / University of Al – Mustansiriyah

The reinforcing mesh involves of 8 mm diameter deformation bars placed in a single layer with an intermediate thickness of the wall panels. The c/c spacing of bilateral bars 110mm in both direction, clear side cover is 20 mm according to ACI 318 – 14 (45)

10.5. Carbon Fiber

Fiber-reinforced polymers, often known as fiber-reinforced plastics, are a class of composite materials that combine fiber and matrix. The reinforced material used, CFRP rebar, has a high specific strength and good mechanical performance. It was mostly used in pre-stressed constructions. Table.٣ lists the characteristics of CFRP (46)

Table 3. Comparisons of CFRP Material Properties Between Material Tests and Manufacturer Specified Values

Materials	Material Tests by Changhyuk Kim	Manufacturer Specified Typical Test Values
Elastic modulus (ksi)	15600	15300
Rupture strain	0.0096	0.0093
Rupture stress (ksi)	150	143

11. Preparation Alkaline Solution for Geopolymer

11.1. Preparing NaOH Solution

NaOH and Na2SiO3 make up the solution for geopolymer concrete. Flaky, highly pure sodium hydroxide (98 percent or higher) can be dissolved in distilled water to create a solution with the right concentration. Depending on the solution's concentration, the mass of the solid sodium hydroxide changes. Table .٤ shows more details for the used sodium hydroxide solution in the present work according to ASTM E291-09 (Hardjito and Rangan, 2005) (47)

Table 4. Amounts of NaOH Solids for 1 Kg of Solution (47)

Molarity (mole/L)	NaOH Weight Concentration (w/w %)	Weight NaOH Flakes (g)	Weight of Water (g)
8	26.2	262	738

11.2 Preparation of the Alkaline Liquid

Sodium silicate solutions come in different grades and can be purchased commercially. For this work, a solution with a mass of 2.4 and a ratio of SiO2 to Na2O was utilized. SiO2 makes up 32.5% of the mass of the components, Na2O makes up 13.4%, and water makes up 55.1%. NaOH is added to the Na2SiO3 solution after it has been made as a solution.

An alkaline liquid is created when sodium hydroxide solution (NaOH) and sodium silicate solution are combined. The two solutions should be combined to create the alkaline liquid at least 24 hours before (48).

12. Mixing Procedure for Geopolymer Concrete

The primary distinction between Portland cement concrete and geopolymer concrete is the binder. The alkaline solution (Na2SiO3 and NaOH) and the silica and aluminum oxide in the Metakaolin combine to generate a Geopolymer paste, which is then combined with additional components to create Geopolymer concrete. The process of mixing significantly affects the strength and workability of Geopolymer concrete. Numerous researchers claimed that the traditional methods used to create Portland cement concrete could also be applied to the production of geopolymer concrete (48,49).

The recycled concrete aggregate (fine and coarse aggregate) are first mixed together in dry form in a bucket mixer for three minutes, and then the aggregates are prepared on a saturated surface in the dry state SSD.

After adding the cement, or metakaolin, stirred for two minutes. The 65% super plasticizer was mixed with extra water for at least two minutes and then added to the alkaline liquid, which was added to the 65% super plasticizer (which had been mixed with 35% water and added to the dry materials in the mixer tray) over the course of five minutes. Subsequently, the concrete was mixed for two minutes with the addition of 35% super plasticizer and iron filings, also known as steel fiber. Compaction of the concrete is a highly skilled process that involves a vibrating table

13. Sample Curing

In contrast to traditional thermal curing, specimens of geopolymer concrete in this kind of curing are kept at room temperature in the laboratory until the day of the test as. While regular concrete is cured for 28 days in a treatment water tank, the type of curing is thought to be a very important factor determining the strength of geopolymer concrete (Davidovits) and (Tosheva and Valtchev) (50).

14. Application of CFRP Strip to Slabs Specimens The CFRP was first cut to the required length then the concrete surface was prepared when the CFRP was ready for application. The adhesive (mixed two-component epoxy (Sikadur-32LP)) at which mixture took a single uniform colure then applied on the tensile face of slab specimen using putty spatulas between the lines that were laid out for the CFRP location. Care was taken to ensure that a uniform layer of adhesive was laid out. The adhesive was also applied in a similar method to one of the sides of the CFRP strip. Each CFRP strip was then applied to the slab. The Strip was pushed firmly into the adhesive to remove any voids in the adhesive and ensure a uniform application. The slab strength reached full strength of epoxy after seven-day curing time passed then slabs was ready for testing.

15. Conclusion

1. The general punching shear behavior of slab geopolymer RC beams is decreased by the presence of transverse web holes because of the reduction of concrete within the GC section.
2. Because of their intrinsically low service load values, slab geopolymer reinforced concrete slab with a single transverse web aperture are less rigid than solid materials.
3. When the number of CFRP strips rings is increased, it was found that the local buckling failure of the strengthened specimens decreases and converges.
4. The original structural behavior of the repaired GC slab can be restored by using FRP sheets and the boundary conditions specified in the current research.
5. The primary factor contributing to the suggested techniques' effectiveness is the composite's significant strength, which is made up of epoxy and bonded FRP.
6. Predominant failure in these geopolymeric concrete flat plat was flexural plus punching.

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