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OVERVIEW OF THE DIFFERENT METHODS FOR REPAIRING CONCRETE SLABS

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ABSTRACT

The objective of this research paper is to explore various techniques for repairing concrete components, specifically slabs. Based on the test results, the MA-UFRP system was found to enhance the flexural strength of the slabs by up to 43%. The average strength of the MA-UFRP reinforced slabs was 18% lower than the EB-FRP reinforced slabs with end anchoring, but only 10% lower than the EB-FRP reinforced slabs without the final anchor. When comparing The midpoint of the span divergence of the slabs reinforced with the MA-UFRP system to those reinforced with EB-FRP without end anchorage, it was discovered that the former exhibited an average increase of 56%, while the latter showed a 5% increase, and the control group exhibited only a 15% decrease.The utilization of FRP systems significantly increased the structural ability of the original slabs for retrofitting purposes, with an enhancement of up to 500% for unreinforced specimens and 200% for steel-reinforced specimens. The average stress and slab stiffness in the shear modulus of concrete when steel rods are present and (FRP) were notably lower, often by more than 30%. Additionally, the use of Georide in repairing concrete slabs has demonstrated positive outcomes. Geogrid-reinforced slabs exhibited a 25% increase in load-carrying capacity, a 6.5% increase in deflection, and a 23% increase in energy absorption. Furthermore, when compared to steel-reinforced slabs, the geogrid-reinforced slabs displayed a 25% increase in load-carrying capacity, a 6.5% increase in deflection, and a 23% increase in energy absorption.

KEYWORDS: Rpair, FRP, epoxy , CFRP , NSM , Geo-Grid , rigidity ,carbon fiber laminates (CFL), toughness.

1. INTRODUCTION

This paper aims to shed light on the methods commonly used recently in the rehabilitation and restoration of concrete slabs [1-5]. Rehabilitation engineering involves systematically applying principles from various engineering fields to create, modify, test, evaluate, and implement technical solutions for addressing the challenges faced by different structures. One approach to restore the strength of a structure is through rehabilitation [6-8]. Concrete structures generally exhibit excellent stability and durability, except in areas exposed to extreme mechanical and environmental stresses. However, from a socioeconomic standpoint, the rehabilitation of deteriorating concrete structures is particularly challenging due to the significant costs borne by users. Consequently, there is a need to generate innovative ideas for the revitalization of concrete buildings.

2. REHABILITATING AND REINFORCING CONCRETE SLABS

The process of structural rehabilitation has grown in importance and is now required to increase the effectiveness of fixing structural elements that have defects. Reinforced concrete (RC) [9] structures that have been damaged or corroded, as well as the disparity and cost of repairs, have encouraged the introduction of novel materials and techniques for structural rehabilitation. Mosallam, A.S. and Mosalam, M. Kh. [10] provided a study that evaluated the final performance of reinforced and unreinforced concrete slabs that were rebuilt and retrofitted with fiber-reinforced polymer (FRP) composite strips using analytical and experimental methodologies. Applying a water bag with high pressure, many large-scale slab specimens were treated to an even distribution of pressure in two directions. Carbon/epoxy and eglass/epoxy composite materials were used in this investigation. By applying the finite element method, the recovered slabs' behavior was anticipated. A comparison of the experimental and analytical data showed that the computerized prototypes were valid in representing findings of the work conducted to find out both the restored and the control slabs. Research outcomes showed that both FRP solutions greatly boosted the restored slabs' strength, which was about five times higher than that of the as-built slabs.

Bonaldo, E., et al. [11] described the potential improvements and increases that composite materials could bring to the flexural load bearing capacity of reinforced concrete (RC) sections. Carbon fiber-reinforced-polymer laminates are used in near-surface mounting (NSM). NSM (Near-Surface Mounted) technique involved strengthening the laminates by securely bonding them into slits in the concrete cover on the stress face of the elements using an epoxy-based adhesive. Laboratory experiments demonstrated that NSM was a suitable method for enhancing the ability to withstand bending forces of reinforced concrete slabs. But in the case of RC slabs with low concrete strength, the increase in flexural resistance achievable through NSM was limited by the maximum allowable compressive strain in the compressed section of the slab, which aimed to prevent concrete crushing. This limitation reduced the effectiveness of the strengthening technique and restricted its application. To overcome this constraint, a solution was implemented by applying a new, slight covered of concrete pre-existing in the compressed area. However, there was a risk of spontaneous fracture in this thin concrete layer due to volumetric contraction caused by shrinkage and heat. To prevent the formation of uncontrolled patterned cracks, steel fibers were added to the concrete, resulting in steel fiber-reinforced concrete (SFRC). This inclusion of steel fibers increased the postcracking residual stress, thereby enhancing the flexural resistance of the structure. By combining the NSM technique with an SFRC overlay, the flexural resistance of the existing RC slabs was significantly enhanced.

Hamelin, P., et al. [12] the behavior of slabs reinforced with FRP was examined both theoretically and experimentally, as shown in Fig. 1. The experimental results indicate that FRP significantly enhances the resistance to punching failure, leading to a decrease in the rotation of the slab around the loaded column. The theoretical research involved the development of a numerical model using finite elements to assess the bending behavior of reinforced slabs. The model accounted for the presence of FRP strips and steel reinforcement by representing concrete is characterized as a material with three-dimensional properties, consisting of multiple layers, and exhibiting non-linear behavior. Additionally, the effects of a concrete cover on the reinforcement and repairs were investigated using the proposed model. Inspection of various case studies demonstrated that the average stress and slab stiffness between the steel rod and FRP in the concrete shear modulus are notably lower, often by more than 30%. Other authors discussed the performance of using FRP on concrete [13-16]

Fig. 1: Marking; (2) impregnating and bonding the carbon strips to the concrete slab; (3) rolling away extra glue; (4) adding more layers. [12]

El Maaddawy, T. and Soudki, kh. [17] conducted a study to evaluate the viability of employing the mechanically-anchored un-bonded fiber reinforced polymer (MA-UFRP) system in enhancing the fracture strength of reinforced concrete (RC) slabs. 6 RC Slabs with dimensions of 500 mm for width, 100 mm for thickness, and 1800 mm for length were built. These slabs were subjected to four-point bending tests until failure occurred. The tension side of each slab was filled with three No. 10 deformed steel bars, resulting in a steel reinforcement ratio of 0.8%. A first slab served as the control, while the remaining five slabs were strengthened using different fiber-reinforced polymer strengthening techniques. All strengthened slabs had an external FRP reinforcement ratio of 0.12%. Among the five strengthened slabs, two were reinforced with an externally-bonded fiber-reinforced polymer (EB-FRP) system. One of these slabs included end anchoring, while the other did not. The last three slabs that reinforced using the MA-UFRP system, with distinctive anchor positions, as depicted in Fig. 2.

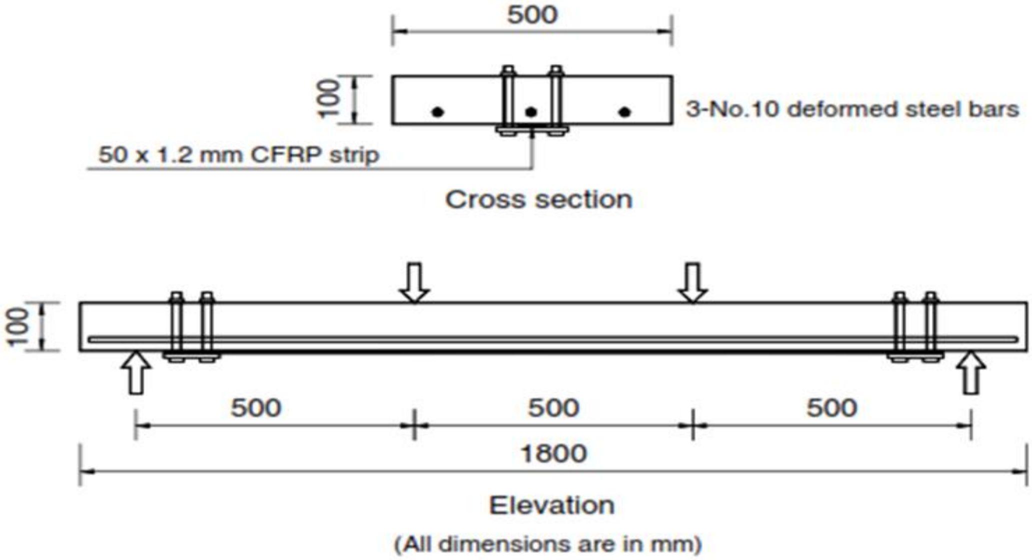


Fig. 2: Standard test specimen with anchorage at the end [17]

DRAGOŞ BANU et al. [18] approaches were given, such as inadequate maintenance, steel reinforcement corrosion, exceeding the concrete-reinforced component, and other unique circumstances. The methods mentioned above are recognized as traditional since they have been around for a despite using solely conventional building supplies like concrete and steel. The five tactics that have been used most successfully worldwide, both historically and today, are briefly summarized here. Combinations of technology and economic circumstances force one of these techniques to be the only viable choice. Figs 3 through 7, show the several approaches to strengthening slabs.

Fig. 3: using the grout pouring technique to mend cracks [18]

Fig. 4: Crack shape before reservation [18]

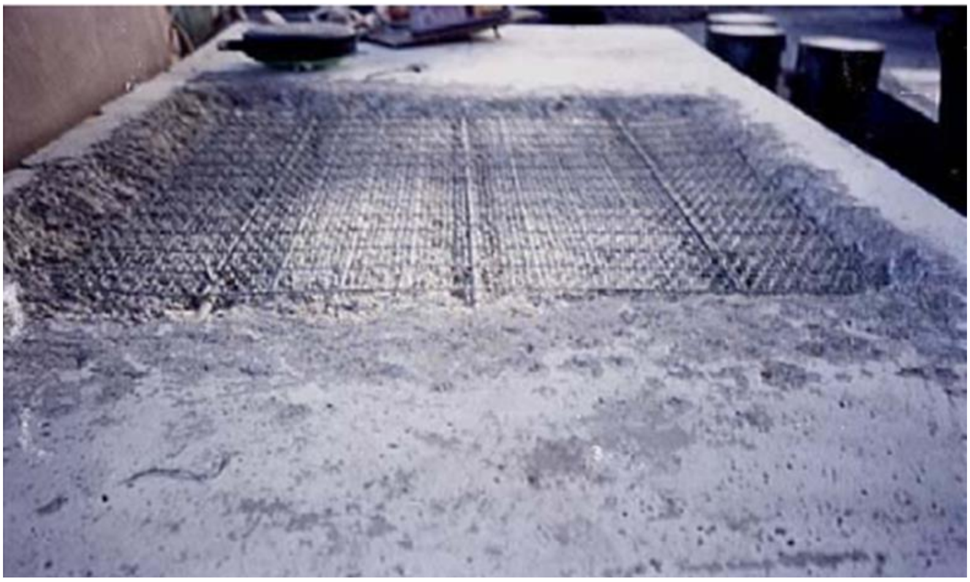


Fig. 5: Wired mesh used for repair [18]

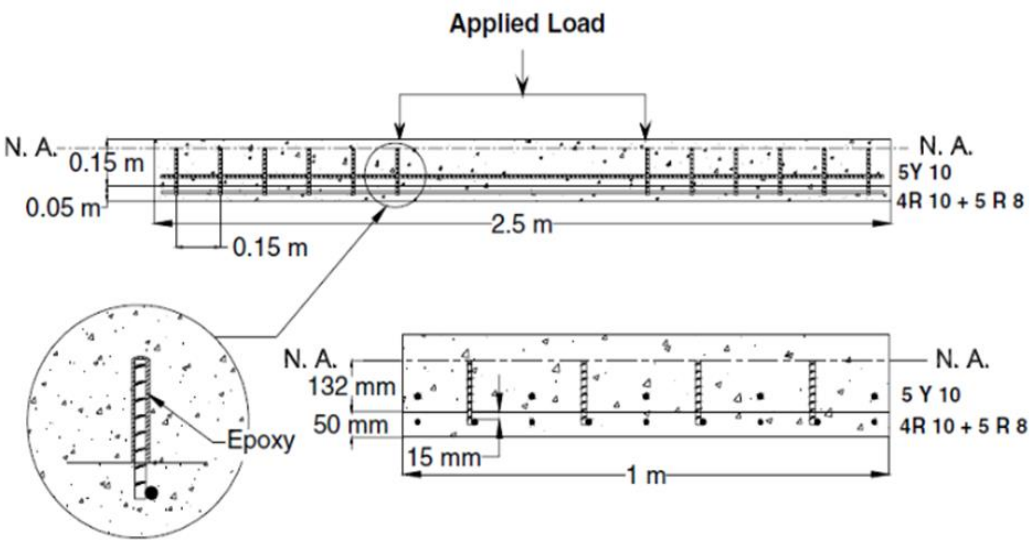


Fig. 6: Section enlargement technique [18]

a *b*

Fig. 7: Strengthening by increasing the area of the slab: (a) cracked pattern prior to restoration; (b) a surface that has been roughened and steel supplied [18]

Inacio, M. M. G., et al. [19] The work being presented describes the experimental research conducted to look into a strengthening method that involves adding extra shear reinforcement to flat slabs under punching. Eight examples were strengthened using prestressed vertical bolts and three different anchoring techniques: small buried anchorage, tiny anchorage on surface, and huge anchorage on top. A reference specimen that had not been reinforced was also inspected. Collapse mechanisms, shear reinforcement impact and real punching loads were contrasted in compliance with EC2, ACI 318-11, and MC2010 requirements. Test results showed by employing microscopic incorporated anchoring plates is a realistic and efficient technique to boost punching capacity. Additionally, there was a method that enhanced the appearance of the finished reinforced construction.

Abbas, H., et al. [20] carried out experiments involving the penetration of RC concrete slabs reinforced with externally attached carbon-fiber reinforced-polymer sheets and textile-reinforced mortar (TRM), as illustrated in Fig. 8. Count of 12 RC slab illustrations were tested, consisting of two different concrete grades (39.9 and 63.2 MPa) and two strengthening systems (CFRP and TRM). The slabs were supported by two opposing edges. In the course of the load-displacement experiments, two peak loads were observed in the reinforced slabs, while the control slab exhibited a single peak followed by a plateau. The second peak, also referred to as the plateau, was attributed to the combined effects of aggregate interlock and the dowel action of the rear face rebars and reinforcing layers. The dowel action of the rear face rebars and strengthening layers (initial peak) did not impact the final punching load. However, the energy absorption (approximately 66% for CFRP and 22-56% for TRM) and the second peak load (increasing by 190-276% for CFRP and 55-136% for TRM) exhibited significant increases. Additionally, the ultimate punching load (first peak) of the reinforced slabs increased by 9-18%. Furthermore, the researchers developed an analytical model to predict The sheer power of the punch of the reinforced slabs, and it demonstrated a strong correlation with the experimental results. For more details about CFRP [21-26]

Fig. 8: Strengthening of slabs with externally bonded CFRP sheet [20]

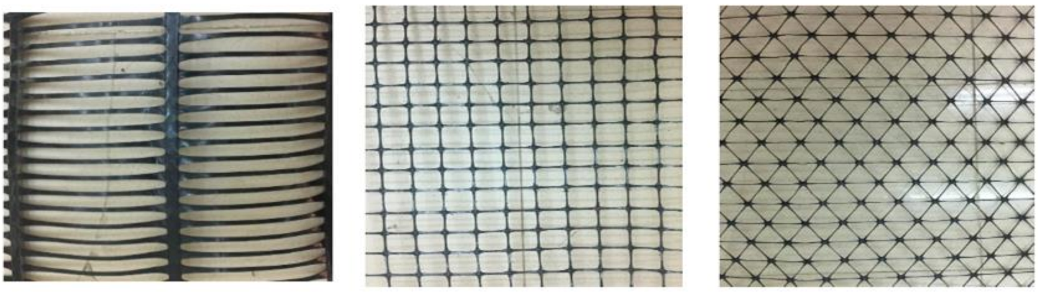
Reddy,p.M. et al. [27] investigate the practicality of Making use of geogrid as supplementary shear reinforcement in (RC) beams and columns. The findings revealed that as the quantity of transverse reinforcement increased, the rate of rigidity and toughness degradation in Typically restricted beam examples decreased. Additionally, the inclusion of geogrid confinement had a positive impact, leading to increased beam strength and achieving flexural failure with minimal shear reinforcement. Behavior of geogrid [28-30]

Gabr, A.S. [31] examined the application of geo-grid to one-way reinforced concrete slabs as a reinforcing material. One reference slab and six RC slabs fortified with various types of Geo-Grid are tested as part of the experimental program. Two line loads have been applied to the specimens during testing. Based on experimental findings, geo-grid could be a useful substitute material for conventional confining methods when it comes to strengthening reinforced concrete slabs. Ultimately, the tested slabs were analyzed using an ANSYS tool to create a Finite Element model and the theoretical and experimental results were then compared [32,33].

Zheng, X., et al. [34] explored different configurations of carbon-fiber-laminates (CFL) [35] and thin steel plates (SP) to determine the optimal hybrid strengthening setup. Four-point bending tests were performed on nineteen RC slabs in all in various arrangements. The loads of the interior reinforcement bars, CFL, SP, load versus deflection curves, stiffness of the reinforced specimens, and failure mechanisms were all analyzed. The test results proved the effectiveness of the CFL-SP hybrid fortifying method. Maximum increases above the control slab in extendable capacity and stiffness were, on average, 204.2% and 91%, respectively. Furthermore, the slabs improved with CFL-SP composite material had greater steel yielding and breaking loads compared to those reinforced only with FRP or steel plate. More efficient use of FRP material was made, and adding steel plate to the reinforced RC slabs boosted their rigidity. The overlap-type hybrid bonding approach, which joins CFL as inner plates and steel as outside plates, was determined to be the ultimate hybrid strengthening system across all configurations. In Fig. 9, an alternative anchor is displayed at the conclusion of the reinforced slabs.

Fig. 9: Different anchor at the end of strengthened slabs [34]

Arab, M. [36] examined the feasibility of using geogrids [37] to reinforce high-strength self-compacted concrete slabs (HSC), aiming to enhance its malleability and strength at tensile. Two different approaches were employed to modify the surface of the geogrids and improve their adherence to the cement matrix. The first approach involved physically attaching sand to the geogrid surface, while the second approach utilized a chemical method of submerging the surface in polycarboxylate. The study also described the types of geo-grids used (uniaxial, biaxial, and triaxial) and the number of layers (10) employed. In comparison to untreated specimens, the test findings showed that chemical therapy increased the overall load-carrying capability of the evaluated slabs by about 8.5% for just one sheet of geogrid and 13% for two layers. These improvements were observed in slabs that had two layers of geogrid in addition to steel reinforcement. Interestingly, it was found that although the addition of geogrids significantly increased the ductility of the slabs, it reduced their ultimate external loading capacity.



(**a**) Uniaxial (**b**) Biaxial (**c**) Triaxial

Fig. 10: Geogrid types [36]

Huang H, et al. [38] investigated the impact of various factors such as fiber volume fraction, surface configuration, bar diameter, and anchoring length. Specifically, the focus was on analyzing the stress-slip correlations and bonding properties of Hybrid concrete with fiber reinforcement (HFRC) and glass-fiber-reinforced polymer (GFRP) rebar, which consists of polypropylene, aramid, and carbon fibers. A total of 48 samples were tested, including 12 samples of regular concrete (OC) and 36 samples of HFRC with embedded GFRP bars, using pullout testing. The results of the experiments indicated that the combined effects of carbon, polypropylene, and aramid fibers significantly enhanced the binding interactions between the GFRP bars and HFRC. A bond-slip constitutive model was developed to describe The actions of (GFRP) bars in each case (HFRC) and (OC), and it exhibited good agreement with the experimental results.

Vijay, T. J., et al. [39] looked at the behavior The study focused on examining the conduct of reinforced concrete (RC) slabs when subjected to static and dynamic loads. While there is limited research on the behavior of RC slabs using unconventional reinforcement methods, an experimental investigation was conducted to specifically study the impact response of geogrid-reinforced concrete slabs. Six RC slab specimens were subjected to drop weight impact tests, each featuring a unique combination of steel and geogrid reinforcement layers. The investigation primarily focused on parameters such as the maximum deflection caused by each impact, impact energy, impact ductility index, and failure mechanisms.The findings revealed that RC slabs reinforced with geogrid layers on both sides, in addition to the traditional reinforcement, exhibited enhanced resistance to concrete crushing by distributing the impact stress over a larger area. This particular configuration of reinforcement also enabled the slabs to withstand higher impact forces, resulting in increased influence both the ductility index and energy.

Rajesh Kumar, k. [40] study concentrated on investigating the basic properties of concrete and geosynthetic materials. The greatest load area and the moment of the geogrid reinforcement in flex slabs were found using formulas and calculations derived from the study's application of the limit state design technique. Concrete samples, such as cubes, prisms, and slabs, were individually adorned with different types of textiles and biaxial geogrid. The results showed that when paired with concrete, the geogrid performed favorably. The flexural behavior of samples with steel reinforcement and those with geogrid was compared. The results of the flexural tests on geogrid-reinforced flexural members were good. The geogrid-reinforced slabs showed a 25% a rise in the capacity to carry loads, a 6.5% increase in deflection, and a 23% increase in energy absorption when compared to steel-reinforced slabs. The study demonstrated an environmentally friendly way to reinforce concrete and provided a practical solution to the corrosion problems that are common in the building sector.

3. CONCLUSIONS

The present investigation yields the subsequent findings: -

i. By utilizing FRP systems, the structural capability of the slabs as they were constructed was greatly boosted for upgrading applications, up to 500% for un-reinforced exhibits and 200% for specimens with steel reinforcement.

ii. The flexural resistance of the existing RC slabs was markedly elevated by applying the combined strengthening way of an NSM CFRP laminate and an SFRC overlay.

iii. The four-point bending experiments conducted on concrete slab strips that were both reinforced and unstrengthened.

iv. The average stress and slab stiffness in the shear modulus of concrete amid FRP and a steel rod are significantly lower, frequently by more than 30%.
v. The slab's flexibility was up to 43% improved by the MA-UFRP system.
vi. The MA-UFRP system reinforced slabs had an average strength that was 18% less than the EB-FRP method strengthened slabs using anchoring, but only 10% less than the EB-FRP system strengthened slabs not having an end anchor.
vii. The maximum load at which the strengthened slabs failed due to punching increased by 9-18%. Moreover, there was a significant increase in energy absorption, with CFRP (Carbon Fiber Reinforced Polymer) showing an increase of approximately 66% and TRM (Textile Reinforced Mortar) showing an increase of 22-56%. Additionally, the second peak load exhibited a substantial increase, with CFRP showing an increase of 190-276% and TRM showing an increase of 55-136%.
viii. Geogrid-reinforced slabs demonstrated a 25% increase in load-carrying capacity, a 6.5% increase in deflection, and a 23% of energy used increased.
ix. The application of chemical treatment resulted in an approximate 8.5% increase in the ultimate fractional loading capacity of the tested slab compared to untreated specimens when using one geogrid layer, and a 13% increase when using two geogrid layers.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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