

Flexural strengthening of the continuous unbonded post -tensioned HSC beams by precast SIFCON laminates

Mustafa B Dawood¹, Hawra Mohamed Ali M. Taher²

^{1,2} Civil Engineering Department, College of Engineering, University of Babylon, Babylon, Iraq

ABSTRACT

Slurry Infiltrated Fiber Concrete (SIFCON) is a cementitious composite with outstanding durability and mechanical characteristics. Accordingly, the current research studies the behavior of continuous unbonded post-tensioned HSC beams that were flexural strengthened with precast SIFCON laminates. Four prestressed concrete beams with dimensions (200x300) mm and 4300 mm length were fabricated have been strengthened with 30 mm thick precast SIFCON laminates gluing with epoxy and were tested to understand the influence of their strengthening with using the various length of the laminates. The results showed that the use of precast SIFCON laminates is an effective method in enhancing the capacity of load-carrying and stiffness of continuous unbonded post-tensioned HSC beams. Used various lengths of precast SIFCON laminates in hogging and sagging regions led to positively affected by delaying the first crack appearance time of the tested beams between (56.1%-60%), Increased the ultimate flexural capacity of the test beams (36.9%-43.6%), and improving in stiffness about (153.7%-243.6%). When comparing specimens unstrengthened and strengthened, the strengthening generally leads to a reduction in the crack width in central support and mid-span regions. In other words, the crack behavior was enhanced.

Keywords: Strengthening, SIFCON laminates, Unbonded Post -Tensioned, HSC.

Corresponding Author:

Mustafa B Dawood
Civil Engineering Department, College of Engineering
University of Babylon
Babylon, Iraq
eng.mustafa.balasum@uobabylon.edu.iq

1. Introduction

Civil infrastructure construction and maintenance consume a large portion of the budgets of many countries around the world. Many infrastructure projects, such as bridges, harbours, structures for water or sewers or parking garages, schools, and airports, are built to last for decades. Numerous precast prestressed concrete members have been used in the development and construction of these structures. Several factors, including as environmental attacks, prestressing loss, corrosion damage, collision and ever-increasing applied loads, influence the load-carrying capability of these parts over time. It's not always practical to demolish and rebuild structures that have structural issues. Rather, because of limited funds, strengthening and upgrading these structures might be the best option. Local damage and cracks produced in the manufacturing facility owing to poor storage, as well as incorrect shipping and handling, are other causes of girder deficiency. It is necessary to replace girders due to transportation and handling damage that occurs to girders during construction. This increases the cost. Instead of sending the girders back to the factory, a dependable and less expensive option is presented here for retrofitting them on the construction site. Various strengthening techniques are available and can be utilized to improve the serviceability and strength of an existing reinforced concrete structure [1, 2].

Structural defects must be repaired or replaced to keep structures functional. The favored means of

strengthening are externally-bonded carbon fiber-reinforced polymer (CFRP), external post-tensioning, epoxy-bonded steel plates, and reinforced concrete jacketing. These techniques, on the other hand, have a number of drawbacks, including the installation difficulty, the weight of the reinforcing material used, and the disruption they cause to the household during implementation (lack of fire resistance, corrosion risk). Therefore, researchers try to find new processes and materials that are simple to use while also being strong in the long term for example, SIFCON is a novel cementitious composite made possible by advances in construction material technology. It is necessary to have a dense matrix as well as tailored fiber and aggregate phases in order to achieve exceptional performance much above traditional concrete. Concrete is a common building material in civil engineering that is used to build much of the infrastructure [3, 4]. The most common building material in the world is concrete. Construction and design of RCS are geared toward long-term use. Concrete, instead, has high compressive strength and low tensile strength. Fibers have been added to reinforce concrete to help with its brittleness. Fiber-reinforced concrete is widely utilized for a wide range of applications and has a wide range of strength and stiffness characteristics. This concrete category was developed to strengthen the strength of an unusual sort of steel FRC "fiber reinforced concrete" in current times. It's made up of a steel fiber matrix with strong tensile qualities that gives the composite matrix its strength. SIFCON offers better ductility and energy absorption properties because to its high percentage of steel fiber. Steel fiber volume fraction differences were added to the primary distinctions between FRC and SIFCON (VF). Additionally, SIFCON's uneven mortar aggregates are absent from the synthesis step. Because coarse aggregates prevent mortar from penetrating the steel fiber network, they can be used. SIFCON, on the other hand, has more cement than FRC or regular concrete. Because of the larger percentage of steel fibers, the SIFCON production procedure is modified. Modern concrete is made by first pouring steel fibers into a mold that is completely filled. Afterwards, cement-based slurry infiltrates and aids SIFCON's steel fiber network. Steel fibers are warmly mixed with wet concrete in FRC before being sprinkled onto forms, as opposed to FRC. There are several parameters that affect the steel fiber volume (V_f), such as the degree of vibration, the placement technique, the size of mould, and their orientation. The aspect ratio, diameter, and shape of steel fibers can be used in the steel fiber placement process when using external vibration [5, 6]. It's possible to think of SIFCON as a subset of steel fiber-reinforced cement. Fiber volume fractions ranging from 5 to 30 percent are used to make these items. Fibers will be inserted into the shapes using this approach. The sheets are then filled with fine-aggregate and cement-rich flowable slurry that has been poured or pumped in. There are more massively powerful mechanical properties in SIFCON than in other materials, such as steel, such as flexural strength, shear, tensile, and compressive strength. SIFCON specimens have been shown to have compressive strains more than 10% but no discernible deterioration in strength. Type fiber alignment, fiber volume, and slurry strength are all important design elements to consider in the SIFCON manufacturing process. Modulus of elasticity of hardened slurry, compressive strength, tensile strength, and have an effect on the SIFCON composite [7, 8]. Steel fibers of various types are used in the manufacture of SIFCON. The most widely used types are those with crimped or hooked ends. Deformed and straight fibers were both used, as well. However, only a small percentage of the population makes use of these two sorts. In SIFCON, the fibers used must be loose (discreet or single) for fiber bed penetration, with no honeycombing or clogging. This is because shorter or smaller fibers may be packed more densely than longer ones, and a bigger volume of fiber can be obtained with tolerable vibration. As a result, agglutinant fibers must be separated before being placed in the molds, and the most usually used type is crimped fiber. Deformed and straight fibers are used in the same way, but they are not as common. As a result, the agglutinant fibers must be dissolved and separated before being placed in the molds [9-11].

2. Production of SIFCON

Several preliminary tests were carried out so as to generate a matrix of high strength with appropriate workability to penetrate rise volumes of fibers. When making SIFCON laminates, the needed fiber volume was first taken into account when selecting a matrix. After that, you'll need to figure out what volumetric ratio of steel fibers you're going to utilize. Cement (type I) and "silica fume" (SF), fly ash (FA) were employed as binder resources in the SIFCON mix, which included very fine sand with a maximum particle size of 600 m. Sika ViscoCrete® 5930-L, a new SP generation, was used in this investigation. Volume fractions of a hook steel fiber with a (0.5mm) diameter and 30mm length (11 percent), To obtain a homogenous SIFCON matrix, a unique mixing approach was used. To begin with, binders, sand, and other ingredients were mixed together in a large bowl. After that, 50% of SP mixed water has been included to dry ingredients. The balance of SP has been added-on to the wet mixture once the premixing was completed. With a duration of 10 minutes,

high-speed spinning was used to mix the final product. The first stage was to place the steel fibers in molds, and the second was to pour the slurry on top of it while vibrating. The mechanical properties of Concrete mixes in table (1), Figure (1) shown the steps of SIFCON production.

Table 1. Concrete mixes mechanical properties

Mix Name	Compressive Strength (f_c') (MPa)		Tensile Strength (MPa)		Modulus of Elasticity** (GPa)
	28days	90 days	28 days		28 days
	f_{cu}	f_{cu}	f_{ct}	f_r	E_c
SIFCON mix	139.611	151.951	23.87	39.29	56.00
HSC mix	76.638	87.781	5.34	5.91	32.895

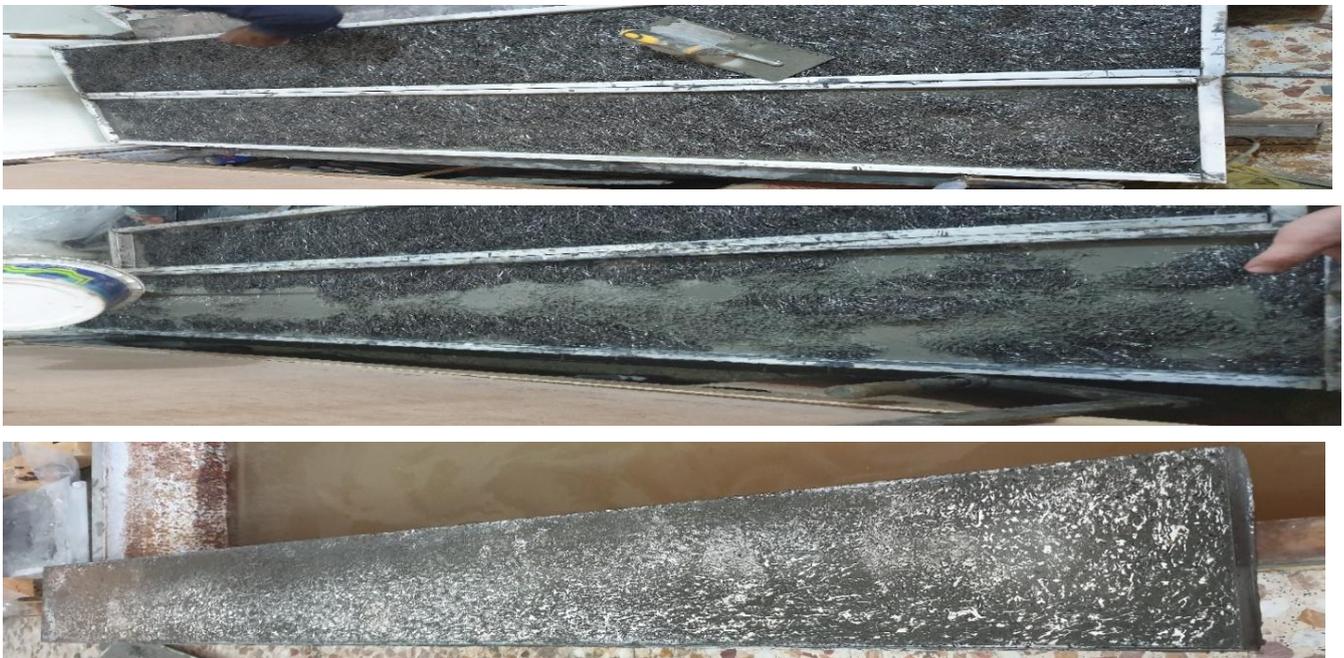


Figure 1. The steps of SIFCON production

3. Description of specimens

Four prestressed high strength concrete beams, one unstrengthened beam serves as a control beam for the other three strengthened beams in the sagging and hogging zones, with a variable length of precast SIFCON laminates. under two focused point loading in the middle of each span, and measuring (4.3) meters in length with a rectangular cross section of (200 x 300 mm). The 1860 MPa ultimate strength prestressing steel was made up of seven low relaxation strands with a 141.9 mm² surface area. The diameter of the deformed steel bars used was 10mm. The compression zone was reinforced with two 10 mm diameter bars, and the tensile zone should be reinforced with two 10 mm diameter bars. A sufficient amount of steel was used for shear reinforcement to prevent shear failure before flexural failure. Bars with a diameter of 10 mm were employed in the shear span of flexural beams as closed stirrups with a 100 mm c/c spacing to ensure shear failure. The stirrups, on the other hand, were removed from the zone of greatest shear stress. As may be observed in Figure (2), the beam's cross-section and Figure (3), the strand profile and steel arrangement (3). PC manual and ACI318-19 were used to create these trusses [12, 13]. Tested specimen details in table (2).

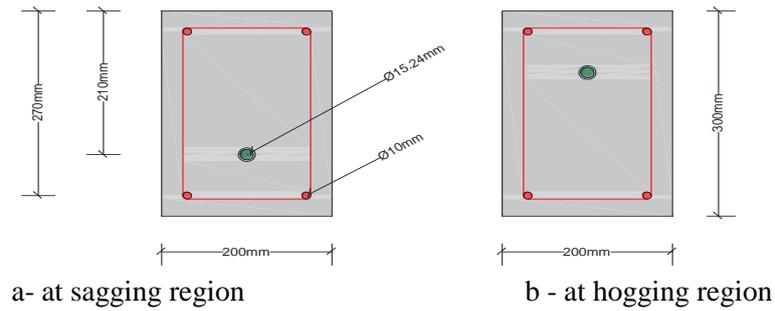


Figure 2. Cross section dimensions

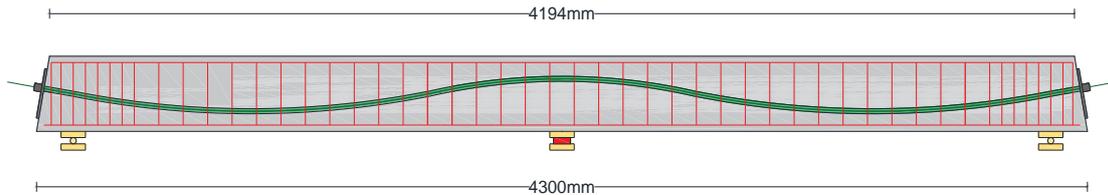


Figure 3. Reinforcement and tendon profile of beams

Table 2. Tested Specimen Details

Beam Name	Laminate length	
	At sagging	At hogging
FB1	-	-
FB3	0.9L	0.8L
FB9	0.7L	0.8L
FB10	0.9L	0.6L

*L=Span length

4. Techniques for strengthening in the workplace

It was critical to keep the beam surface dust-free prior to applying the SIFCON laminate. The rough surface of the beam was smoothed with the use of a hand grinding machine. Additionally, the SIFCON laminate's surface was buffed to remove any roughness. The beam and SIFCON laminate had their surfaces smoothed down, and then they were carefully cleaned. The beams and laminates needed to be cleaned because epoxy can only work correctly if the surfaces are clear of pollutants such as dust, debris, water (if necessary), oil, and grease. The bonding faces were then coated with a thin layer of sika-331 epoxy paste and held together with weights. The epoxy has been allowed to cure for 14 days on the composite beam. Epoxy reinforcement technique for sturdiness.



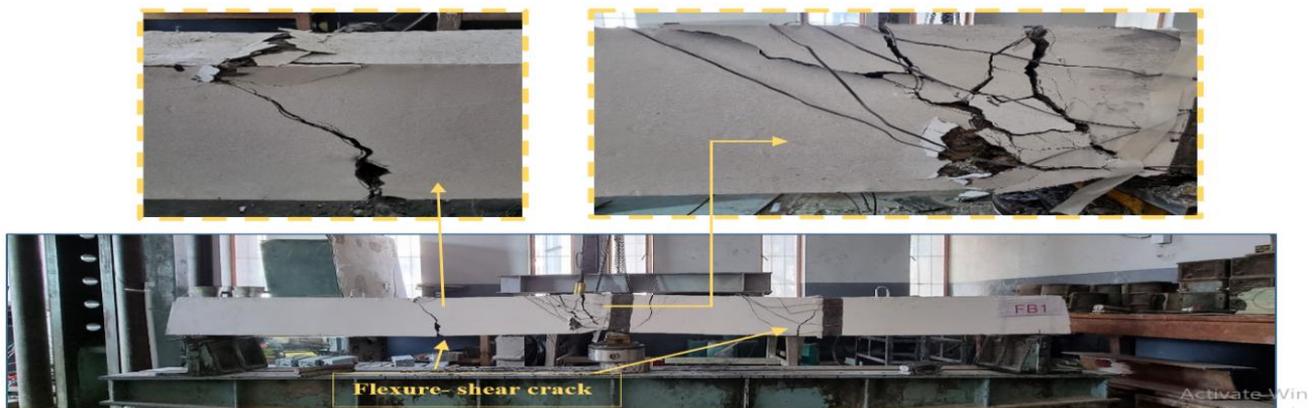
Figure 4. Preparation SIFCON laminate to strengthening

5. Experimental setup

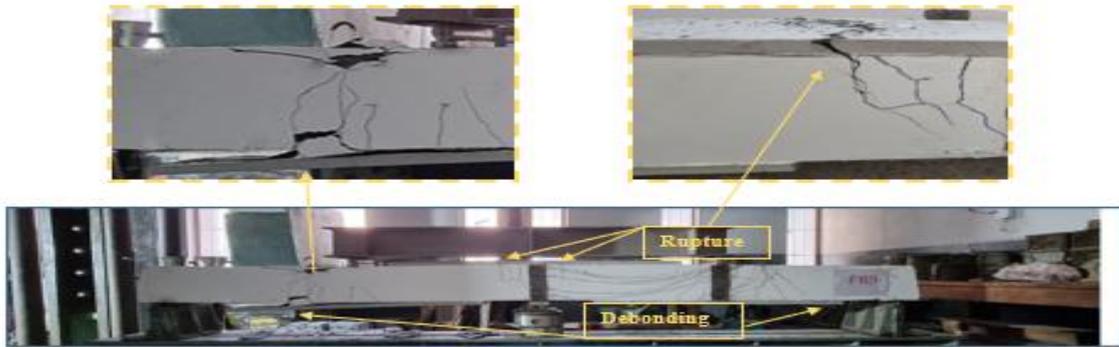
A continuous beam was tested by applying two focused point loads in the middle of each span on all specimens and real-size laminates. The beam clear span of 2000 meters for each span. All tests were carried out by seeing and documenting the loads, vertical displacements on the beams and laminates to see how they performed structurally. To ensure that the loading speed was consistent throughout all tests, a loading control system was used. The specimens had their loads increased to the point of failure. The displacements were tracked using two LVDTs at mid of each span. It's important to know where the LVDTs are in relation to each other since they calculate the opposite-direction displacements depending on how much load is applied to each span.

6. Results and discussion

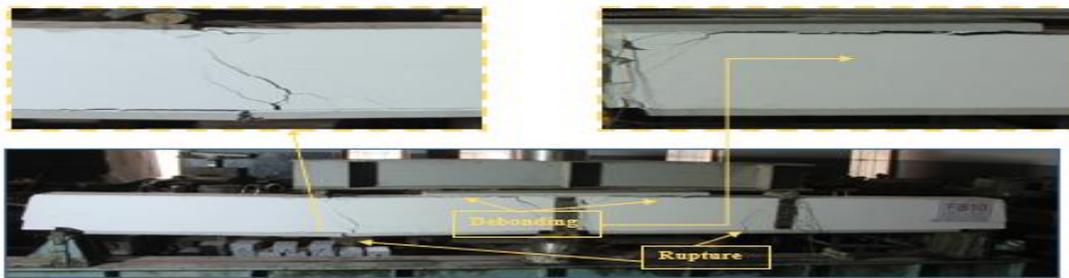
FB1 beam is a control beam (without strengthening) for the other test specimens that are designed to fail in flexure. The first apparent flexural crack located at the highest moment area at the cracking load (247.1kN). With tiny increasing in the load, the few number of cracks increased wider. Formerly, on higher load, the cracks existed at the mid-span (at the load of 261.9 kN), as an individual crack in each span. The flexural cracks at the mid of the span changed their direction and propagated towards the loading point (flexure shear crack) FB1 beam arrived at an ultimate load at (438.2 kN) with flexure mode of failure (crushing of concrete) as shown in figure (5-a). FB3 was strengthened with precast SIFCON laminates glued by epoxy that have a length to span ratio (0.8L) at the hogging region and (0.9L) at sagging regions. The first crack happened at the mid support at the cracking load (395.3kN) by increasing the load, the first crack happened at the mid-span (at the load of 401.1 kN). The cracking load at the mid support and the mid-span increased compared to FB1. The number of cracks increased at mid-span more than FB1beam and reduce their number at the mid-support. With the increased loads, the separation initiated at the end of the SIFCON laminate then extended inward at the hogging region. Then, a rupture in the SIFCON laminate happened in the mid span region. The FB3 beam reached a final load at (629.3 kN) with cracking concrete, rupture SIFCON laminate in the mid-span, and debonding on the SIFCON laminate at the hogging region, as shown in figure (5-b). FB9 beam is a specimen that is strengthened with precast SIFCON laminates glued by epoxy that have a length to span ratio (0.8L) at the hogging region and (0.7L) at sagging regions. The initial crack occurred at the mid support at the cracking load (385.9kN). by increased load, the first crack occurred at the mid-span (at the load of 399.2 kN). The cracking load at the mid-span and the central support significantly increased comparing with to FB1 but less than FB3. Beam FB9 reached an ultimate load at (600.6kN) with the mode of failure crushing of concrete, rupture of SIFCON laminate at central support region, and laminate debonding initiated at the end of the laminate at sagging region as shown in figure (5. c). FB10 beam specimen was strengthened with precast SIFCON laminates glued by epoxy that have a length to span ratio (0.6L) at the hogging region and (0.9L) at sagging regions. The first crack occurred at the mid support at the cracking load (392.3kN) by increased load, the first crack occurred at the mid-span (at the load of 406.6 kN). The cracking load at the central support and the mid-span increased significantly compared to FB1but less than FB3 at the central support. Beam FB10 reached an ultimate load at (600kN) with the mode of failure crushing of concrete, rupture of SIFCON laminate at mid-span, and debonding laminate initiated at the end of the laminate as shown in figure (5.d). Figure (6) compares the applied load to midspan deflection curves of beams FB1, FB3, FB9and FB10.



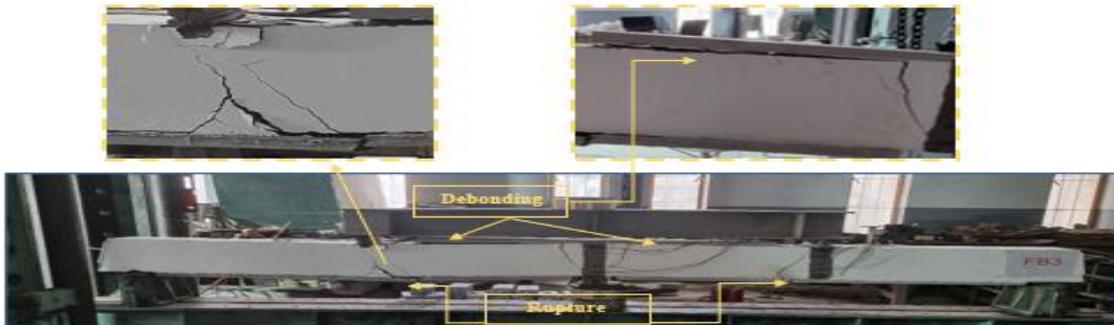
a



b



c



d

Figure 5. Tested beams

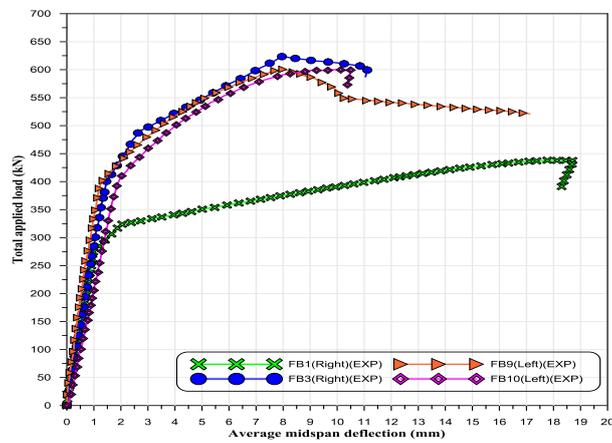


Figure 6. Load - midspan deflection curves of tested beams

7. Conclusion

This research reports the findings of an experimental study to explore flexural strengthening of the continuous unbonded post-tensioned HSC beams by precast SIFCON laminates. Accordingly, the following are observed:

- The production method of full-scaled SIFCON laminate is not complicated. The most essential advantage of prefabrication is having the chance to decide its properties such as length, height. In that approach, the standards of quality that leads behavior will be high, and the cost is predicted to be low compared to certain other techniques of strengthening.
- The findings of the experiment show that prestressed concrete continuous beams can be strengthened by employing externally bonded precast SIFCON laminates bound with epoxy resin. In the hogging and sagging regions, epoxy resin-glued precast SIFCON laminates of various lengths delayed the first crack appearance time by 56.1%-60%, increased test beam ultimate flexural capacity by 36.9%-43.61%, and improved stiffness by 153.7%-243.6%, and the mid-span deflection was reduced at ultimate load due to the application 46% -58.2%.
- With regards to the effect of laminate length, increasing the length of laminates increases stiffness and flexural strength.
- Although strengthening was successful in preventing the sudden failure, it resulted in separate failures of the Epoxy resin that was used to bind the precast SIFCON laminate at the ends of the structure.
- Generally, when comparing specimens that have been unstrengthened and those that have been strengthened, the strengthening results in a reduction in crack width in the central support and mid-span regions. To put it another way, the crack behavior was improved.

References

- [1] H. M. Afefy, K. Sennah, and A. Cofini, "Retrofitting actual-size precracked precast prestressed concrete double-Tee girders using externally bonded CFRP sheets," *Journal of Performance of Constructed Facilities*, vol. 30, no. 2, p. 04015020, 2016.
- [2] M. B. Dawood and H. M. A. M. Taher, "Various methods for retrofitting prestressed concrete members: A critical review," *Periodicals of Engineering Natural Sciences*, vol. 9, no. 2, pp. 657-666, 2021.
- [3] M. B. Dawood and H. M. A. M. Taher, "Utilizing Slurry Infiltrated Fibrous Concrete (Sifcon) In Rehabilitation and Strengthening Structures of Reinforced Concrete: Literature Review and Recommendation."
- [4] I. A. Aljazaery, S. K. Al_Dulaimi, H. T. Salim, "Generation of High Dynamic Range for Enhancing the Panorama Environment," *Bulletin of Electrical Engineering*, vol. 10, no. 1, 2021.
- [5] N. M. Al-Abdalay, H. A. Zeini, and H. Z. Kubba, "Investigation of the Behavior of Slurry Infiltrated Fibrous Concrete," *Journal of Advanced Research in Fluid Mechanics Thermal Sciences*, vol. 65, no. 1, pp. 109-120, 2020.
- [6] A. Ghazi, S. Aljunid, S. Z. S. Idrus, R. Endut, N. Ali, A. Amphawan, A. Fareed, A. Al-dawoodi, and A. Noori, "Donut Modes in Space Wavelength Division Multiplexing: Multimode Optical Fiber Transmission based on Electrical Feedback Equalizer," in *Journal of Physics: Conference Series*, 2021, vol. 1755, no. 1, p. 012046: IOP Publishing.
- [7] H. Yazıcı, S. Aydın, H. Yiğiter, M. Y. Yardımcı, and G. Alptuna, "Improvement on SIFCON performance by fiber orientation and high-volume mineral admixtures," *Journal of materials in civil engineering*, vol. 22, no. 11, pp. 1093-1101, 2010.
- [8] H. Alrikabi, N. A. Jasim, "Design and Implementation of Smart City Applications Based on the Internet of Things," *International Journal of Interactive Mobile Technologies (IJIM)*, vol. 15, no. 13, pp. 4-15, 2021.

- [9] S. S. Khamees, M. M. Kadhum, and A. A. Nameer, "Effects of Steel Fibers Geometry on the Mechanical Properties of SIFCON Concrete," *Civil Engineering Journal*, vol. 6, no. 1, pp. 21-33, 2020.
- [10] H. F. Khazaal, H. T. S. ALRikabi, and M. S. Farhan, "EVALUATION OF THE EFFECT OF LENGTH ON THE PERFORMANCE OF RECTANGULAR TO RECTANGULAR WAVEGUIDE TAPER," *Al-Qadisiyah Journal for Engineering Sciences*, vol. 10, no. 4, pp. 536-549, 2017.
- [11] A. Ghazi, S. Aljunid, S. Z. S. Idrus, A. Fareed, C. Rashidi, and A. Al-dawoodi, "Comparison of Laguerre-Gaussian and Hermite-Gaussian Modes for Optical-CDMA over Multi-Mode Fiber," in *IOP Conference Series: Materials Science and Engineering*, 2020, vol. 767, no. 1, p. 012011: IOP Publishing.
- [12] A. M. Command, *PCI DESIGN HANDBOOK*, 7 TH EDITIO ed. 2010.
- [13] A. 318, "318M-19," *Building Code Requirements for Reinforced Concrete and Commentary*,, p. 261, 2019.