



Study the effect of the loss in main steel reinforcement of simply supported beams which compensated by precast concrete

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Abstract

This study is intended to experimentally investigate of the structural behaviour of simply supported reinforced concrete beams loss in main steel reinforcement which compensated by precast concrete. six simply supported reinforced concrete beams with various ratios of main steel reinforcement (ρ) equal to 0.00969, 0.00646, and 0.00323. Each two beam have same ratio of reinforcement, one of them supported by precast concrete layer. The layers made by high mechanical properties So, Slurry-infiltrated fibre concrete with 17.7 MPa tensile concrete and 87 MPa compressive strength was used to cast 3 mm thickness layers with 7.5% volume friction. The hard reinforced concrete beam and precast concrete layer were bonded together on beam's tension face to product composite segment. The result show that decrease in ratio of main reinforcement lead to reduction in ultimate load by about 28% and 58% for 0.00646, and 0.00323 as compare with reference beam with $\rho = 0.00969$. The ultimate flexural capacity of beams with bonded precast concrete segment was found to be best related to the beams without it, where they reach to 98% and 69% of reference beam flexural capacity. On the other hand, the ultimate load increased as compared with same beam without precast layers by about 31.16%, 36.0%, and 62.71% for main steel reinforcement ratios (ρ) equal to 0.00969, 0.00646, and 0.00323 respectively. Furthermore, the strength by precast layers could improve the cracking behaviour, and stiffness of the beams.

Keywords Beams · Loss in steel reinforcement · High tensile and compressive strength · Precast concrete

1 Introduction

Concrete production is in general predictable to give concern free service during its planned scheme life. On the other hand, this expectations aren't understood in several structures because the structural insufficiency, materials worsening, unexpected over loading or physical destruction [1]. To guarantee the safety, ductility, and sufficient precaution of reinforced concrete members, the ratio between concrete and reinforcement should be balanced and controlled while considering the economic aspect. as known, the main reinforced concrete members have reinforcement limitations (upper and lower), and the reinforcement ratio should be between these limits. If the ratio is not within these limits, it could influence the overall behavior of the beams in terms of safety, failure mode, ductility, stability, and durability [2].

Flexural members with a reinforcement ratio lower than the minimum limit, such as plain concrete members, may experience a sudden failure by a single localized crack without sufficient precaution, which is an undesirable failure mode according to all design codes. Structural designers prefer ductile failure in all structural members and try to eliminate sudden failure.

One type of failure is expected to take place without any warning when a reinforced concrete beam with a very light quantity of reinforcement is needed to satisfy the design, or in case of the cross section dimensions of the concrete beam are e in it causing sudden failure [3].

So, finding a new repairing method and design is vital to improve the lifetime of reinforced concrete constructions. Many investigators used fiber cementitious materials as hopeful and economical reparation technique [4], as Slurry Infiltrated Fibrous Concrete (SIFCON), a significantly particular high-performance concrete in the strength and ductility categories. It's an upgraded version of traditional fiber-reinforced concrete. SIFCON has high cementitious content and without coarse aggregate, and it may have

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additives materials like fly ash and silica fume [5]. Numerous researchers studied the properties of SIFCON in particular the flexural behavior, ductility factor, and stiffness, which reflected a good effect on the concrete constructions [6], [7] investigated the effect of using external SIFCON layers with 5.5% volume fraction, on the flexural behaviour of the reinforced concrete beams (RC). The Layers casted and bonded through epoxy at the lowest surface of reinforced concrete beams then they tested till failure. The results presented a rise in flexural strength and stiffness of beams. [8] investigated the consequence of using externally bonded layers as flexural strengthening on RC beams. Beams repairing with 20mm SIFCON thick layers, were casted and bonded at the tension face of the reinforced concrete beams. Results show that strengthened beams have flexural strength more than beams without strengthening reach to 53.48% . [4] studied the flexural performance of RC beams using SIFCON with volume fraction equal to 9%. The SIFCON placed in top, bottom, and top and bottom of the beams and under flexural cyclic load. The results conclude that beams containing SIFCON in the bottom cover of concrete, which have high ultimate load, ductility factor, and energy absorption. On the other hand, they found that conventional beams show similar performance of beams with SIFCON in the compression region. [9] enhanced the ultimate load by used 25 mm thickness of SIFCON layers, which were bonding to the bottom surface of the beams by epoxy glues. However, of hook-ended steel fibers. The beams show an improved in flexural capacity reach to 47% and 72.40% for layers have volume fraction equal to 6% and 8% of hook-ended steel fibers, respectively. [10] studied the performance of shear-deficient of RC beams which repaired after tested to failure, by use external SIFCON covers at the shear span to increase shear capacity of the beams. The results indicated that this method and improved the shear strength of beam and prevented the brittle shear failure. [11] investigated the influence of use 20 mm thickness of precast SIFCON layers at bottom, two side, and three side of beams. The layers made with hooked end steel fibers with volume fraction equal to 7% and 10%. The results indicated that SIFCON layers can considerably improve the cracking behavior through increasing the first cracking load and development more finer cracks, in addition to enhance the behavior of the feeble structure. [12] studied the effect of the SIFCON sections position (bottom, top ,bottom, and jacket) with different thickness: 15 mm, 25 mm, and 35 mm on flexural behavior. The test results displayed that increasing in the thickness of SIFCON section can advance strength reached to 1148%, and ductility increased by about 2.54.

The research studied the structural behaviour of simply supported reinforced concrete beams with various ratios of main steel reinforcement (0.00969, 0.00646, and 0.00323), which supported by precast concrete layer. Precast SIFCON

concrete layer was used as strengthening method by bonded it to bottom tension face of the reinforced concrete beams as try way to replace the loss in steel reinforcement.

2 Experimental study

2.1 Details of specimens

The experimental program included the testing of six specimens with various ratios of main steel reinforcement were used (0.00969, 0.00646, and 0.00323), the details are shown in Table 1 and Fig. 1 . All specimens were geometrically identical with an overall length of 1300 mm and a cross section of (200mm×150mm). The beams casted by normal concrete and have a curing for 28days. In the same time three layers of SIFCON concrete were casted separately and curing for 28days also to strength beams. The cross-section of the all layers was [1300mm x 100 mm] with 30mm thickness and 7.5% steel fibres.

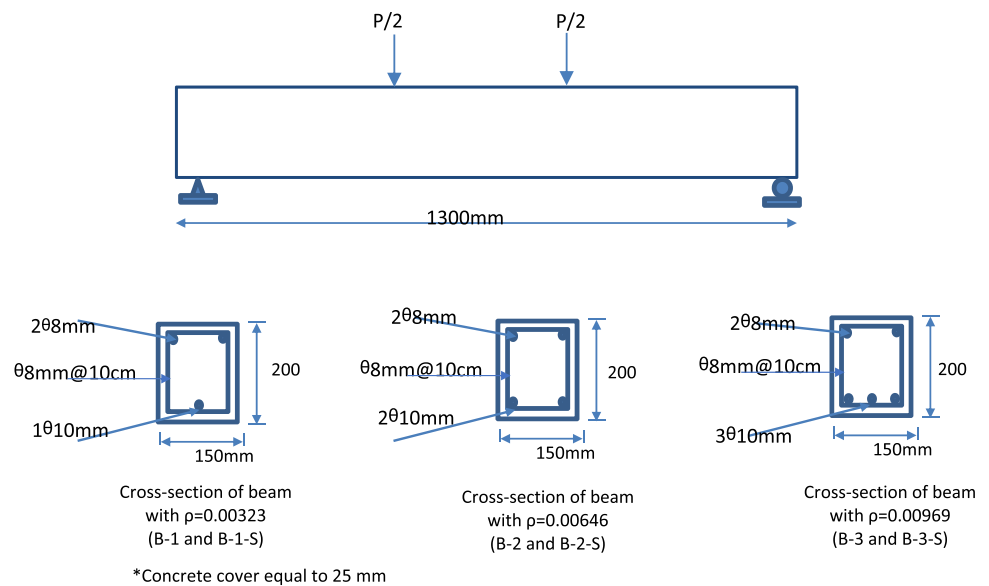
2.2 Materials characteristics

Ordinary Portland cement is used in the research. Natural sand used as fine aggregate for normal concrete, while a crushed gravel with maximum size 14 mm was used as a coarse aggregate. For SIFCON, There is no standard specifications yet, there for its use the same type of fine aggregate in normal concrete that passing over (600 mm) sieves to verify complete infiltration through steel fibre. Also, Hyperplast (PC200) superplasticizer, [13] Type G, was used to manufacture the SIFCON concrete to advance the workability of the slurry and flow through the dense fiber. On the other hand, The steel fiber used is hooked ends with length of (33mm) and diameter equal to (0.6mm) and according to the manufacturer data, the density and tensile strengths were 7800 kg/m³ and 1200 MPa respectively. It is following [14] requirements. Deformed steel bars of Ø8 mm and Ø 10 mm used to reinforcing beams where the yield and ultimate strengths are 460MPa and 555MPa, respectively. Whereas, the modulus of elasticity of all steel bars is 200

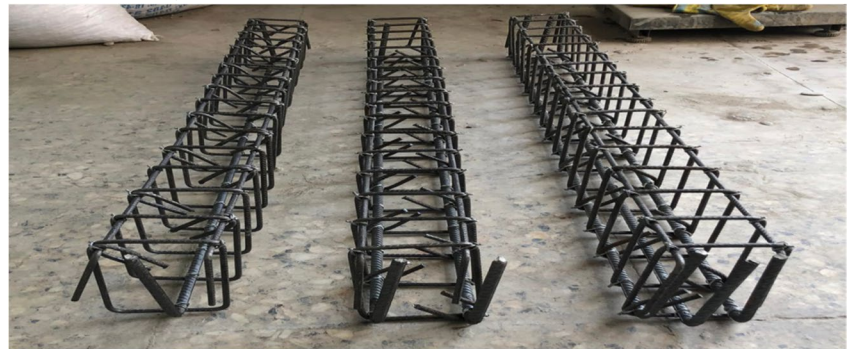
Table 1 Details of Beams

Specimens	Main reinforcement	Main steel reinforcement ratio (ρ)	Strengthening
B-3	3 ϕ 10	0.00969	-
B-3-S	3 ϕ 10	0.00969	layer of SIFCON
B-2	2 ϕ 10	0.00646	-
B-2-S	2 ϕ 10	0.00646	layer of SIFCON
B-1	1 ϕ 10	0.00323	-
B-1-S	1 ϕ 10	0.00323	layer of SIFCON

Fig. 1 Reinforcement details of beams



*Concrete cover equal to 25 mm



GPa. Finally, NanoGrout SG epoxy base adhesive with paste form was used to bonding precast concrete components and its conform with [15] type IV. Also, bolts are used to fasten the SIFCON layer with RC beams and NanoGrout-SG epoxy with pourable consistency to filling the holes of bolts.

3 Concrete mix design and mixing procedures

Normal concrete was utilized to casted the reinforced concrete beams. It was designed according to [16]. A mix by weight of cement, sand and gravel (1:1.47:2.84), and 0.39 water cement ratio are used. At the same time, the layers of SIFCON were casted separately as shown in Fig. 2. The

proportion of SIFCON (sand: cement) by weight was (1:1), while the water/cement ratio is 0.3 by weight. The hook-ended steel fiber content of 7.5 % which used. The SIFCON sufficient mixing was essential to achieve the required performance and consistency. For SIFCON, the first part was prepared the slurry by mixing cement and sand in clean mixer for 2 min., then (2/3) of the mixing water was added to the dry materials then mixed to 2 min. After that superplasticizer with (1/3) of mixing water were add to the mixer and mixed to 10 min. to get a homogenous slurry. In the second part, the steel fiber is placed randomly in the molds and infiltrated with the slurry. and the casting will be in layers, thickness of each layer is about (20-30)mm.

On the other hand, after 28 days of casting, the compressive, splitting tensile, Modules of Elasticity tests of the

Fig. 2 SIFCON layer casted



concrete are done, the average concrete compressive strength of normal concrete and SIFCON at 28 days are 32.7 MPa and 87 MPa, respectively, the tensile strength are 3.3 and 17.7 MPa, while Modules of Elasticity are 24.9 and 33GPa respectively.

4 The prepared of strengthening specimens

After 28 days of curing, the pre-cast SIFCON layer and normal concrete are glued together at tension face to product composite section. The bonding face of normal concrete beam and SIFCON layer were roughen by steel wire brush and then washed by water to eliminate the dust. Then, the two parts of the epoxy adhesive (NanoGrout SG- Paste) was equipped and put on the two bonding faces of concrete to fixing them together and follow by applied weights to certain contact. The glued section is left for seven days before

testing to advance the bonding strength of epoxy. For more bonding between normal concrete surface and SIFCON layer, extra bolts were installed. A pourable form of epoxy is used to fill the bolt holes after they have been cleaned, drilled, and filled. Fig. 3, 4 and 5 illustrated the strengthening steps.

5 Loading arrangement and testing

The specimens are simply supported and tested under static load through two symmetrically concentrated loads, placed at one third span by using a hydraulic machine with 1000 kN capacity. The load cell fixed above rigid steel beam which used to distribute the pressure force on the tested specimen as two-point loads. A dial gauge of 0.01mm/div sensitivity was installed at the bottom center of the beams used to estimate vertical deflection as shown in Fig. 6.

Fig. 3 Preparation bonding surface of beams



Fig. 4 Fixing Precast SIFCON layer with beam by epoxy, bolts, and applied weight



Fig. 5 **A** the bolts positions at the bottom face of beam, **B** Location of precast SIFCON layer related to cross section of strengthen beam

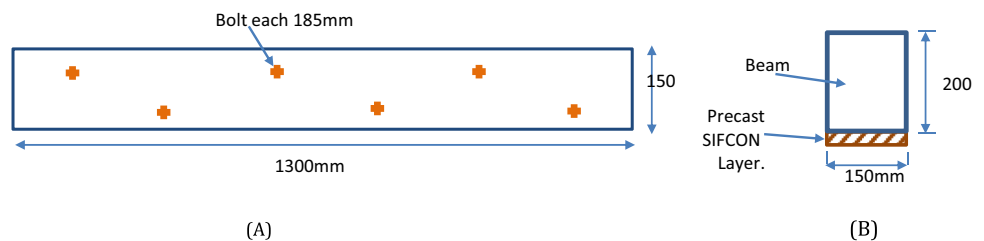


Fig. 6 Specimen under test

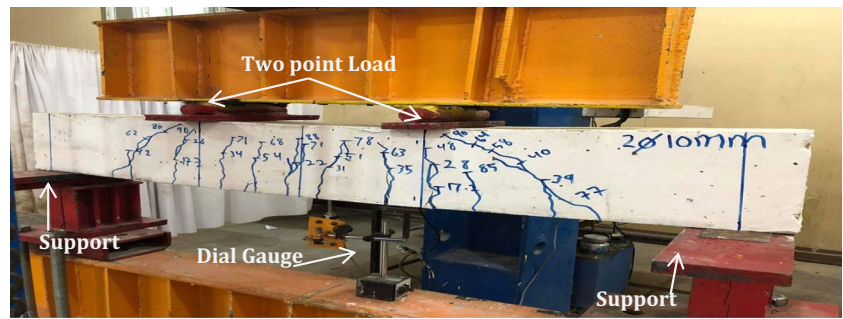


Table 2 Test result of the specimens

Specimens	(ρ)	Flexural first crack (kN)	Shear first crack (kN)	Ultimate Load P_u (kN)	$P_{u_{unstr}}/P_{u_{B-3}}$ ¹	$P_{u_{str}}/P_{u_{B-3}}$ ²	$(P_{u_{str}} - P_{u_{unstr}})/P_{u_{unstr}}$ % ³
B-3	0.00969	20	39	138			-
B-3-S	0.00969	33	110	181		1.31	31.16
B-2	0.00646	17	39	100	0.72		-
B-2-S	0.00646	25	106	136		0.98	36.00
B-1	0.00323	17	35	59	0.42		-
B-1-S	0.00323	22	90	96		0.69	62.71

¹ $P_{u_{str}}$ = Ultimate load for strengthening specimens

² $P_{u_{unstr}}$ = Ultimate load for unstrengthening specimens

³Increasing of ultimate load for unstrengthening specimen with similar specimen with strengthening

6 Result and discussion

6.1 Flexural capacity

The test result of the specimens used in the study are shown in Table 2, its contain the values for cracking load, ultimate load, and increased in load. Fig. 7 and 8 clarify the tested beams behavior in relation to the experimental load and mid-span deflection. It's clear from figure the reduction in stiffness and capacity due to decrease in main reinforcement, where the ultimate load reach to 28% and 58% for ratios equal to 0.00646, and 0.00323 as compare with reference beam with $\rho=0.00969$. However, It is clear from the results that precast bonded concrete (SIFCON layer) have good effect on the flexural behavior of beams. The cracking behavior improved by development more finer cracks and increased the first crack load as compared with same beam without precast layers, where the beams B-3-S, B-2-S, B-1-S reach to 65%, 47%, and 29.5%, respectively, for main steel reinforcement ratios (ρ) equal to 0.00969, 0.00646, and 0.00323 respectively. This can be attributed to the fact that steel fibers provided more resistance to crack propagation. Moreover, The ultimate load of beams with bonded precast concrete segment was found to be best related to the beams without it, where they reach to 98% and 69% of reference beam flexural

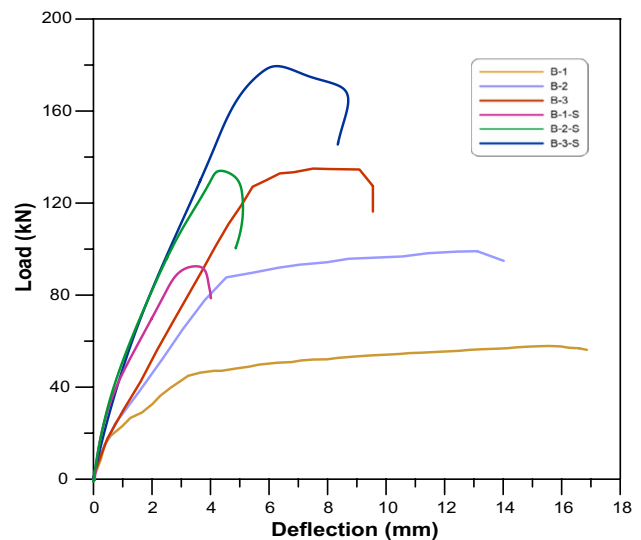


Fig. 7 Load–Deflection Curves of strength and unstrengthening beams

capacity. On the other hand, the ultimate load increased as compared with same unstrengthen beam by about 31.16%, 36.0%, and 62.71% for main steel reinforcement ratios (ρ) equal to 0.00969, 0.00646, and 0.00323 respectively. It can be concluded that bonded precast SIFCON layer lead to improve the structural behavior significantly, especially

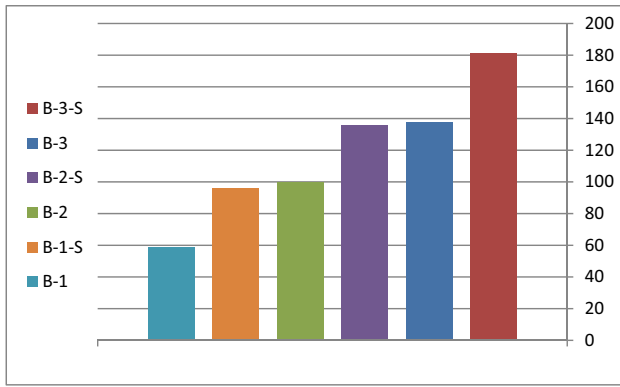


Fig. 8 Ultimate load of strength and unstrengthening beams

that with low tension reinforcement ratio. This is mainly due to the using of precast SIFCON layer with high tensile and compressive strength, there for the beam get an additional capacity, which enhances the maximum applied load as well as raises the load deflection curve.

6.2 Cracking pattern and failure mode

The spread of cracks is observed during the test as shown in Fig. 9. The strengthening specimens indicated no debonding between tension face of beam and precast concrete layer and operated as one unit during the test. The bonding were depending on chemical agent (epoxy) and mechanical interlocking providing by surface roughness

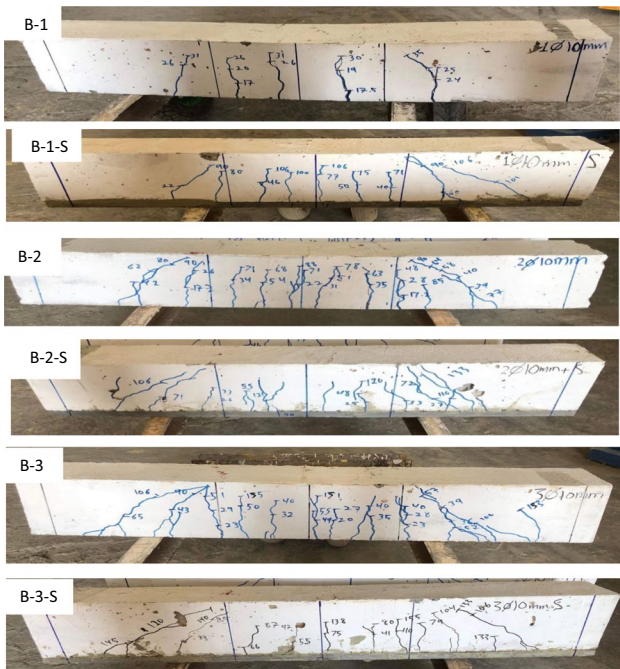


Fig. 9 Cracks pattern of specimens

and bolts. That demonstrates the influence of bolts in improving the bond capacity and prevent any slip. The failure mode of beams B1 and B2 was flexural failure at low ultimate load due to low amount of tension reinforcement, while the B3 has shear-flexural failure. The flexural and shear cracks are formed at the locations where the bending moment and the shear stress are higher in magnitude.

The strengthening beams are failed in a shear-flexural mode. The failure in the strengthening beams was ductile and crack is propagated slowly in the precast SIFCON segment, therefore no sudden failure was happened and the beam carries a high level of load after failure. This behavior is caused by the fibers ability to reduce the development of crack and macro-cracks. Moreover, the fibers geometry (hook-ends) leads to improve the bond-strength between fibers and matrix.

6.3 Stiffness criteria

It is the load needed for cause a one unit of deformation in a member. The slope of the secant drawn to each cycle in the hysterical curve at loading 0.75 times the maximum load of that cycle was measured as stiffness criteria [17]. It is obvious from Fig. 7 and Table 3 the low stiffness of beams B-1 and B-2 due to low tension reinforcement. On the other hand, it's clear that linear part of the ascending load – deflection curve of strengthening beams became longer. So, it can be concluded that using precast bonded SIFCON segment improve the stiffness reaching to 41.51%, 63.20% and 138.64% for strengthening beams B-3-S, B-2-S, and B-1-S, respectively as compared to similar unstrengthening beams. The reason for this enhancement was using precast SIFCON, which is limiting the cracks development and this can retention high stiffness.

Table 3 Stiffness of the specimens

Specimens (ρ)	0.75Pu (kN)	Deflection at 0.75 Pu (mm)	Stiffness K (kN/mm)	(K _{str} - K _{unstr}) / K _{unstr} % ¹	
B-3	0.00969	103.5	4.1	25.24	-
B-3-S	0.00969	135.75	3.8	35.72	41.51
B-2	0.00646	75	3.6	20.83	-
B-2-S	0.00646	102	3	34.00	63.20
B-1	0.00323	44.25	3.3	13.41	-
B-1-S	0.00323	72	2.25	32.00	138.64

¹K_{str}= Stiffness for strengthening specimens

K_{unstr}= Stiffness for unstrengthening specimens

*Increasing of stiffness for unstrengthening specimen with similar strengthening specimen

7 Conclusion

From the test results, the following conclusions transpire:

1. Decrease ratio of tension reinforcement lead to reduction in flexural capacity.
2. Using precast bonded concrete segment with high mechanical properties like SIFCON, get an additional capacity to beam and can improve flexural behavior.
3. Precast bonded SIFCON layer can enhance the crack's mechanics due to the fibers ability to bridge and transform the micro cracks and macro one.
4. By comparison to the reference specimen, the first cracking load increased by around 29.5%—65%.
5. The ultimate flexural loads of strengthening beams by concrete segment increased by 31.16%, 36.0%, and 62.71% as compared with the corresponding unstrengthening beam with ratio of tension reinforcement equal to 0.00969, 0.00646, and 0.00323, respectively.
6. Precast bonded concrete (SIFCON layer), working as an external reinforcement, rewarded partly the loss in the main steel reinforcement and increase the moment arm, therefore its increase the flexural capacity beam.

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Declarations

Competing interests The authors declare no competing interests.

References

1. Sharma S, Pahuja A, Rao B, Kumar N, and Sharma A (2016) NDT and Diagnostic Study of Corrosion Damaged RC Structures to Enhance Their Service Life-Case Studies. *Concrete Solutions: Proceedings of Concrete Solutions, 6th International Conference on Concrete Repair, Thessaloniki, Greece*
2. Ameer MS, Azad AM (2022) Minimum Flexural Reinforcement Steel Ratios of High-Strength Concrete Beams. *Adv Civil Eng* 19. <https://doi.org/10.1155/2022/5612790>. Hindawi
3. Bosco C, Carpinteri A, Debernardi PG (1990) Minimum reinforcement in high-strength concrete. *J Struct Eng ASCE* 116(2):427–437
4. Bhattacharjee J (2016) Rehabilitation/Retrofitting of Concrete Structures Along with Case Studies. in 2nd International Conference of CEU-16, Dubai, UAE
5. Deepesh P, Jayant K (2016) Study of Mechanical and Durability Properties of SIFCON by Partial Replacement of Cement with Fly Ash as Defined by an Experimental Based Approach. *Int J Innov Res Sci, Eng Technol* 5(5):8568–8574
6. Nandhini V, Selvi K (2017) Strengthening Factor for RC Beams by Using Precast SIFCON Lamination. *Indo-Iran J Sci Res* 1(1):31–37
7. Balamuralikrishnan R, Jeyasehar C (2009) Retrofitting of RC Beams with Externally Bonded SIMCON Layers. *Open Civil Eng J* 3:34–40
8. Koya C (2017) Retrofitting of RC Beams with Externally Bonded Layers - A Comparative Stud. *Int J Innov Res Sci Eng Technol* 6(4)
9. Sandanshiv J, Dubey S, Bachhav S (2016) Experimental Study on Retrofitted RC Beams with Externally Bonded SIFCON Layers. *Int J Adv Res Since Manag Tech* 3(5):1–10
10. Shannag J, Barakat S, Jaber F (2001) Structural Repair of Shear-Deficient Reinforced Concrete Beams Using SIFCON. *Mag Concr Res* 53(6):391–403
11. Dhamak Y, Wakchaure M (2015) Use of Precast SIFCON Layers for Strengthening of RC Beams. *Int J Eng Comput Sci* 4(9):14261–14266
12. Hameed DH, Salih SA, Habeeb GM (2020) Strengthening of concrete by using hybrid sifcon sections. *Cement, Wapno, Beton* 25:114–125
13. ASTM C494–19 (2019) Standard Specification for Chemical Admixtures for Concrete. *Am Soc Test Mater Int*
14. ASTM A820 (2004) Steel Fibers for Fiber-Reinforced Concret. American Society for Testing and Material International, Annual Book of ASTM Standards
15. ASTM C 881 (2002) Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete. American Society for Testing and Material International, Annual Book of ASTM Standards, pp 1–3
16. Committe ACI (2002) Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete. *ACI Manual Concrete Pract* 1:1–25
17. Muthuswamy KR, Thirugnanam GS (2014) Structural Behaviour of Hybrid Fibre Reinforced Concrete Exterior Beam-Column Joint Subjected to Cyclic Loading. *Int J Civ Struct Eng* 4(3):262–273
18. Balaji S, Thirugnanam G (2017) Behavior of Reinforced Concrete Beams with SIFCON at Various Locations in the Beam. *KSCE J Civ Eng* 22(1):161–166

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