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RETROFITTING PERFORMANCE OF REINFORCED CONCRETE ONE WAY SLAB

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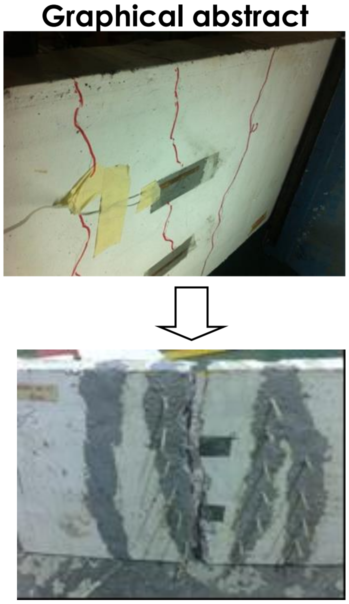
Graphical abstract



Abstract

Cracks in concrete structure have always been a big threat on the strength of the concrete. Crack is one of the common deterioration observed in reinforced concrete beams and slabs. Concrete cracking is a random process, highly variable and influenced by many factors. To restore the structural capacity of the concrete damages, retrofitting and strengthening are required. There are several techniques that are used for retrofitting and strengthening reported in the literature [1], [2], [3]. This paper investigates the strength performance of retrofitting and strengthening methods of reinforced concrete one-way slab. Flexural bending test are performed on three different concrete slab of size 1000 mm x 500 mm x 75 mm. The methods that are used for retrofit are epoxy injection and patching and for the strengthening is lamination of carbon fiber reinforced polymer. The slabs were loaded to a certain stage where the cracks were formed for retrofitting and strengthening procedure. The achieved failure mode and load capacity of the concrete slab were observed. The repaired techniques for restoring and improving the structural capacity of cracked concrete slabs were analyzed. The ultimate load achieved for the epoxy injection laminate was 19.60 kN followed by CFRP laminate and patching that were 17.64 kN and 17.03 kN respectively. While the deflection value for the three specimens were 14.42 mm, 4.49 mm and 7.036 mm.

Keywords: Concrete, Crack, Retrofit and Strengthening, Epoxy injection, Carbon Fiber Reinforced Polymer, Patch

1.0 INTRODUCTION

Cracks in concrete may accelerate the corrosion of the embedded reinforcing steel, and may reduce the service life and increase the maintenance cost of concrete structure [1]. In addition, due to the low tensile strength of concrete, the structural concrete elements deteriorate when the concrete are subjected to extreme loadings, or react to corroded reinforcing steel. Thus, some portions of the concrete components are separated resulting in a void that needs repairing. This study evaluated and identified the retrofitted material properties that are essential for concrete durability and recommended method is applied in selecting the retrofitting materials [2], [5].

The objectives of this study are to determine the maximum flexural strength of the retrofit concrete slab with different methods and to propose the best effective methods of retrofitting concrete slab with different methods of repairs.

2.0 EXPERIMENTAL SET UP

The focuses of this research study are to determine and evaluate the retrofitting of one-way spanning concrete slab under subjected loads. The methods applied for retrofitting the concrete slab are patching, injection of epoxy and lamination of carbon fibre reinforced polymer (CFRP). The concrete slabs are tested under the four point flexural bending test. The test is conducted in the Heavy Structures Laboratory, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor. The design for the sample is in accordance to the code of practice, Eurocode 2 (EC2). The size of the slab specimens are designed to be 1000 mm of length, 500 mm of width and with 75 mm thickness.

The Figure 1 shows the sketch of slab sample dimension that laid with concrete reinforcement wire mesh (BRC) of 7 mm diameter size with cross-sectional area of 200 mm x 100 mm. This experiment is carried out by preparing four samples of slab concrete. The first sample used is taken as the control specimen, while the other three samples are used for the retrofitting and strengthening methods.

The first sample of slab also known as the control sample was applied with preliminary load until it reached a failure mode. While the rest of the samples were tested under the same load until it achieved the required crack width of range from 0.5 mm to 0.8 mm opening.

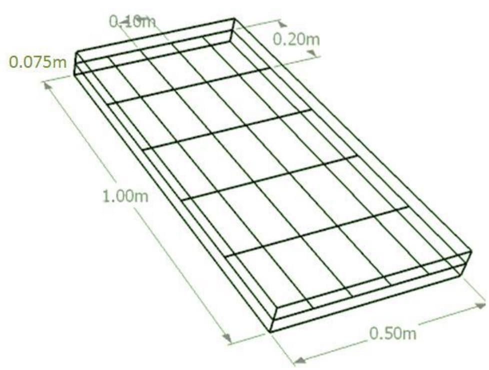


Figure 1 The dimension of the sample and concrete reinforcement wire mesh

3.0 RETROFITTING METHODS

3.1 Lamination of Carbon Fiber Reinforced Polymer (CFRP) (slab 2(S2))

The samples of the slab are grinded for a smoother surface before laminating CFRP. After the grinding process, the surface of the sample is cleaned using an air compressor. Then the surface of the slab was patched using Sikadur 31and the Epo Bond Primer was applied onto the slab to make the surface of slab free from the dust before laminating the CFRP. The proportion ratio of Epo Bond Primer for part A and part B is 2:1. In this experiment, two sheets of CFRP mat were measured in 500 mm x 500 mm per sheet. Epo Bond CF was used to laminate the CFRP mat on the surface of slab and between the two sheets of CFRP itself. The characteristic of CFRP is shown in Table 1.

Table 1 Characteristic of CFRP

PROPERTIES CFRP	DESCRIPTION
Tensile strength (MPa)	3480
Elastic tensile modulus (GPA)	230
Tensile capacity (kN/m)	380-570
Ultimate strain of (%)	1.5
Impregnation of Resin	Moderate
Work speed	Only ply per day
Durability	Long term
Thickness (mm)	0.2-0.3

Also, this binder has two parts of component, part A and part B with ratio of 2:1. Before the CFRP was attached on the surface slab, the Epo Bond CF was applied using small roller. The top surface of the CFRP sheet was covered with epoxy bond as shown in Figure 2. The sample that was retrofitted with CFRP laminate was left to be dry for 3 days to achieve good bonding between the concrete and the fiber.

Figure 2 Epoxy bond covered on the top of slab 2

3.2 Epoxy Injection (slab 3(S3))

Three flexural cracks of 0.5 mm to 0.8 mm width were observed at the middle span of the slab under a pre-load of 12.36kN. Before the injection of epoxy, the dust waste on the crack line surface was removed and cleaned properly. The concrete surface was then marked with 75 mm from center to center before placing the nozzle along the crack line. To seal the nozzle on the concrete crack line, Sikadur 31paste was used. After sealing the nozzle, the concrete slab was left for about 24 hours to make sure it is completely dry and harden. Then the epoxy was ready to be injected using hand pump where the tube pump was connected to the nozzle. Epoxy used in this experiment is Sikadur 52 that consisted of two components of part A and part B with ratio 1: 2. The Sikadur 52 component is needed to be carefully mixed for a good bonding composition. After the epoxy was transmitted into the nozzle, the nozzles were covered with a nozzle cap to prevent the epoxy from flowing out. After that the sample was left for 24 hours so that the epoxy can completely penetrate into the crack line. This is to ensure that the epoxy will fully fills the void of the crack line. Then the nozzle was grinded for a smoother surface of the concrete slab to retest the sample. Figure 3 shows that the installation of the nozzle before the epoxy was injected into the crack lines.

Figure 3 Installation of nozzle

3.3 Patching (slab 4(S4))

The load was stopped and unloaded after the sample achieved the required crack width of range from 0.5 mm to 0.8 mm opening at approximately 12.69 kN.. The sample was then grinded for a smoother surface and the air compressor was used to clean the dust waste on the surface of concrete slab. The sample is then patched at the bottom surface as shown in Figure 4 of the slab, where Sikadur 31 was used as the patching material. The Sikadur 31 materials are composed with two components of part A and part B. Both components have to be properly mixed with ratio of 3:1 to get a good paste mixture in order to obtain a good bonding between patching material and the surface of the sample. The sample was left to dry for three days.

Figure 4 The crack line was patched

4.0 RESULTS AND DISCUSSION

4.1 Visual Observation

The visual and physical observations regarding to the crack pattern of the concrete will contribute in reaching the objectives of this study which are to examine the mode of failure and the overall performance in terms of the strength, stiffness and durability before and after retrofitting methods are applied on the surface of the concrete as shown in Figure 5, Figure 6 and Figure 7.

(a) Before retrofit (b) After retrofit

Figure 5 Retrofitting by lamination of CFRP

(a) Before retrofit (b) After retrofit

Figure 6 Retrofitting by epoxy injection

(a) Before retrofit (b) After retrofit

Figure 7 Retrofitting by patching

The figures above illustrated the concrete cracks behavior where the retrofitting by lamination of CFRP whereby a shear crack that appeared under the line load and failed into the diagonal shape of concrete crack. The crack occurred at the surface without CFRP lamination. The retrofitting of the concrete slabs with epoxy injection and patching techniques depicted a flexural crack as it failed.

4.2 Load and Deflection Before and After Retrofit

Figure 8 shows the different in load and deflection for the three samples of slabs before and after retrofitting. Lamination of CFRP noted as slab 2 (S2), epoxy injection as slab 3 (S3) and patching as slab 4 (S4). The lamination of CFRP sheets have the highest in different of percentage of load repaired which is 46.03 percent. Followed by the epoxy injection technique that is 36.96 percent and the last one is patching technique which is 25.51 percent. For the different of deflection of before and after retrofit give the result that the lamination of CFRP is the smallest of deflection where it achieve the negative of difference in deflection compared to the others having the deflection of 87.87 percent and 69.87 percent for S3 and S4 respectively.

The stiffness of the concrete after retrofit decreased compared to the before retrofit. But for slab 2(S2) there is an increment for the stiffness since the percentage of the deflection decreased compared with the other slabs. Also, S2 have the biggest different percentage in load before and after retrofit means that the strength capacity, stiffness and durability of the concrete slab increased.

Previous study, Katsumata *et al*., [6] reported that debonding of the CFRP often discovered at the surface of the concrete. From the observation, debonding occurs after cracking of the concrete takes place and it is usually form near the cracks and propagates in both directions even when a stress gradient exists in CFRP or concrete. Pieces of cement paste are often stuck to the bonding of CFRP. Thus this observation recommends that debonding strength may be influenced by the concrete tensile strength. In the debonding range, the stress transfer capacity between CFRP and concrete is very high where the debonding of CFRP does not work effectively for strengthening. Therefore, the debonding stage for S2 occurred slowly.

Panel	Load		Different load before and after (%)	Deflection		Different deflection (%)
	Before	After		Before	After	
S2 (Lamination CFRP)	9.52	17.64	46.03	10.86	4.493	- 58.63
S3 (Epoxy injection)	12.36	19.60	36.96	1.75	14.42	87.87
S4 (Patching)	12.69	17.03	25.51	2.12	7.03	69.87

Figure 8 Maximum Load and deflection before and after retrofitting

Figure 8 show that the graphs of load against deflection between the three methods of retrofitting slab structures. Figure 8 generalizes that the ultimate load for the each applied methods of the sample. As shown in that table, S2 has 17.64 kN of ultimate load, S3 is 19.606 kN of ultimate load and for the S4 is 17.036 kN of ultimate load capacity. Recognize that ultimate load of the epoxy injection is the highest among the others and the second one highest is lamination of CFRP and the lowest is patching at soffit of the slab. Though, the S3 is the highest one, the percentage different among the S3 and S2 is just 10 percent and for the different percentage among the highest and the lowest ultimate load is about 13 percent. For the different percentage between S2 and S4 is about 3 percent. The deflection values for three of the samples at maximum load are 4.493 mm, 11.631 mm and 6.912 mm for S2, S3 and S4 respectively. The S2 ultimate load occur at an early stage of load compare with the other samples. Though, the strength degradation does not occur as soon as compared to the S3 and S4. Observed that, the lamination of CFRP (S2) , epoxy injection (S3) and patch (S4) have similar elastic region. During the elastic state, S2 shows the concrete resist most of the load and started to crack and its give in highest value of load as compared to the S3 and S4.

The load becomes higher because of the modulus of elasticity behaviour of the fiber itself that was laminate at the soffit of the slab. In the plastic region (B-C), the graph interpret that the load seems to increased a little bit and uniformly before its reach the fractured state and fail. The loads failed and descending uniformly due to the behaviour of lamination CFRP caused the transverse crack appear at the side of the slab. The shear cracks are formed and do not indicate any warning before debonding and collapse. The lamination of CFRP influenced the failure mechanism where the slab failed in ductile fracture. Its failure satisfied the characteristic features of the ductile fracture which are large amount of plastic deformation prior to the fracture, shear slips may be present, fracture may appear to be fibrous or have a silky structure and crack growth will be slow. The concrete slab S2 and the S4 reach its yield state a similar point. But both S2 and S4 slab have a lower deflection compare to S3 means that its require more time to reach the yielding point. After the reinforcement steel undergoes the yielding state, the load of the S3 increased until its reach the ultimate load before the degradation of strength takes place at point D.

In the plastic region (B-D), the reinforcement steel experience a strain hardening where the steel become stronger through the plastic deformation as the load increase. In addition, the slab 3 reach the its ultimate load due to the mechanical properties of the epoxy resin used in the retrofitting. S3 having more crack lines compared to S2 and S4. The epoxy is injected to fill the void along the crack lines. The epoxy resin properties of Sikadur 52 itself help the concrete slab to achieve its high load. The epoxy resin has a good bonding and high durability compared to the methyl methacrylate and polyester resins. Besides that, this resin is low in its viscosity which helps it to penetrate much easier into the hairline crack and filling the void exist. As the cracks formed, the concrete strength, durability and stiffness are reduced significantly. For the slab 4 (S4), the concrete yield faster compared to S2 and S3 where the load is the lowest among the slabs. When the load was applied, the concrete slab reached its yield point much faster when there is a stress imposed towards the slab. This is because of the crack that had already existed when the concrete slab is loaded for the first time before retrofiting. The retrofit method applied on this sample is patching the bottom of the surface crack. The cracks are sealed along the surface crack using the epoxy adhesive that is Sikadur 31 paste. Compared to the others slab sample, S4 has the lowest ultimate load that is slightly below the ultimate load of S2 and S3. Besides the concrete slab for S2 it also experienced brittle fracture as the crack is only sealed on the surface of the slab because of the paste properties of Sikadur 31 that cannot penetrate through the internal crack. Figure 9 shows load against deflection for the different retrofitting method.

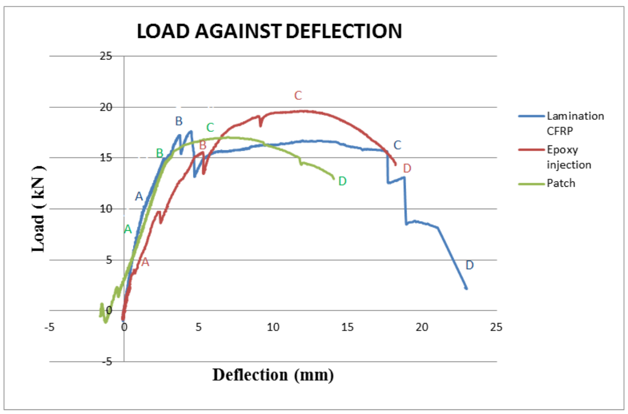


Figure 9 Load against deflection for the different retrofitting method

5.0 CONCLUSION

In this study, appraise that the injection of epoxy has greater strength compared to the lamination of CFRP. But the concrete is low in durability and stiffness compared with the lamination of CFRP which the strength can further increase. The concrete slab retrofitted by patching has restored the concrete strength much lesser compared to the other two specimens. Based on to the overall evaluation, the lamination of CFRP is considered to be the best method because of several criterias that deserve it to be the most effective retrofitting method although its maximum load is lower than the epoxy injection. From the discussion that has been made, the lamination of CFRP can repair and strengthen the concrete slab, in which it can sustain higher load capacity and increase in its stiffness besides improving its strength. The ultimate load for the CFRP laminate slab is slightly lower than the Epoxy injection slab due to the shear failure occurred. The shear failure takes place because of the uncovered surface of concrete slab with carbon fiber reinforced polymer sheet. This problem has disrupted the result of flexural strength that affects the concrete slab ultimate strength. If this problem can be encountered, there is no doubt that the ultimate loads for the methods can be increased.

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