Reclaimed Concrete Slabs Strengthened using CFRP Plate Strips Under Modified Repeated Loading

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Abstract: The primary purpose of this study is to investigate the performance and residual strength of four reclaimed concrete one-way slabs. Three of the slabs were strengthened with near surface mounted carbon fiber reinforced plastic (NSM CFRP), and all of the slabs were presented in order to investigate the influence of various parameters on the structural behavior of each of the slabs. The experimental program consists of casting and evaluating a total of four samples, which are then separated into two primary categories. These groups were classified based on the manner in which they were loaded (monotonic, and modified repeated). Those slabs had a comparable shape and dimensions of 1200 mm by 600 mm by 140 mm. The experimental inquiry was expanded to include the study of many characteristics, such as the influence of increased CFRP strip thickness and the different types of loads on the maximum load capacity and load-deflection response. The results indicated that increase the added FRP strips area has a small effect on the cracked to ultimate load (**Pcr / P u**) percent, where the percent of (**Pcr / P u**) was 25 and 28 for reference slab without CFRP, and slab with CFRP of 1.2mm in thickness under monotonic load respectively, also adding CFRP strips has an effect on the ultimate load, the increase of adding CFRP strips area increased the failure load by about 3.1 for specimens slab with CFRP of 1.2mm in thickness with respect to the specimen reference slab without CFRP for monotonic load tests. The percent of **P**u (slab with CFRP of 1.2mm in thickness under repeated loads) / **P u** (slab with CFRP of 1.2mm in thickness under monotonic loads) was 91.6 %. Adding CFRP strips has an effect on the cracking load in repeated load less than in monotonic load test, where the increase of adding CFRP strips area increased the cracking load by about 37.2% for slab with CFRP of 2.4mm in thickness with respect to the specimen slab with CFRP of 1.2mm in thickness under repeated load test. Repeated loads give crashing at the

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top fiber of slab, this is due to the effect of repeated loads which causes degradation of concrete stiffness and increased crashing of concrete.

Keywords: Modified repeated load; Ductility factor; Ultimate load; CFRP strip; Near surface mounted technology.

1. Introduction

Because of the ongoing rise in the amount of trash generated from building, recycling old concrete has emerged as a subject of concern for a global scale. In addition, the expanding global construction industry is putting pressure on the search for environmentally alternatives to natural materials that are used in the manufacturing of concrete. Many studies have been conducted over the last few decades on the usage of recycled aggregate (RA), which is aggregate that has been recycled from waste materials obtained from building and demolition. These studies have been done in order to manufacture concrete products [1].

It has proven difficult to accurately measure the fatigue behavior of CFRP reinforcement because of difficulties in catching the strips in such a manner that their fatigue behavior is not hindered. Many structural applications rely on the use of carbon fiber reinforced plastic (CFRP) reinforcement, but little empirical data exists on the long-term performance of these materials when subjected to repetitive stresses. In light of CFRP's popularity, it's a bit of a surprise. Composite materials fatigue behavior research has mostly been restricted to aircraft and transportation applications, thus what is known in this area is of limited utility to the construction industry. For civil engineering applications, only a few studies have been done on the fatigue performance of CFRP reinforcement in concrete buildings **[2-7].** RC circular slabs with holes were tested by Bayar **[8]**. An annular load in the center was applied to 13 circular RC slabs (1200 mm in diameter and 75 mm in thickness) for repeated loading. All sides of the slabs were simply supported. A variety of aperture shapes (circular, square, and rectangle) and various reinforcing strategies are examined in this study. CFRP strips may significantly improve the ultimate load and deflection of circular RC slabs with holes, according to testing data. The ultimate load capacity was enhanced by (27–52) percent depending on the CFRP strengthening technique utilized.

The fatigue properties of CFRP rods with a high modulus of elasticity were studied by Yoshitake **[9].** A cantilever RC slab specimen with embedded CFRP rods with high moduli was built and tested for roughly 11 months on a moving-wheel load testing equipment. The slab was at least 160 mm thick. When the CFRP reinforced slab specimen was exposed to repeated moving-wheel loads, it was subjected to a bending moment that was negative. The cantilever RC slab with NSM CFRP rods might benefit from a moving-wheel fatigue test. At an initial load of 60 kN (32 percent greater than the intended service load), a CFRP-enhanced slab specimen lasted about 3.56 million equivalent cycles at an initial load of 3.56 million equivalent cycles. CFRP rods were found to be the cause of the cantilever slab's eventual collapse in an experimental test.

ELWakkad **[10]** investigated the failure analysis of concrete beams subjected to repeated loads. An experimental test program was used to assess the performance of reinforced continuous RC beams subjected to repeated loads utilizing NSM techniques. In all, there are nine test samples, each of which is 3800 mm wide by 4000 mm long and weighs a total of 300 mm. Repetitively or with a concentrated load, the nine test specimens were subjected to the same stress. One of the test specimens was subjected to a concentrated load. Results showed that the NSM reinforcing system was found to be a significant benefit in enhancing flexibility of RC continuous beams exposed to cyclic stress, as demonstrated in the study. Cyclic loading increases the amount of deflection and rotation at intermediate support. Reinforcing materials (steel or stainless steel) can increase cracking load values by roughly 20% to 30% when applied to both upper and lower surfaces in negative and positive moment zones.

Reactive Powder Concrete (RPC) slabs under static and repetitive loads were explored by Hamid **[11].** Six RPC two-way slabs of 1000 mm length, 1000 mm width, and 70 mm thickness were tested as part of the experimental program. A different percentage of steel fibers was used in each pair, resulting in a total of three distinct steel fibers ratios (0.5 percent, 1 percent, and 1.5 percent). Static load was applied to one specimen in each pair, while five cycles of repetitive load were applied to the other (loading-unloading). (36.1% and 17.0%) and ultimate deflection (14.0%) were observed when the steel fiber volume fraction was increased from 0.5 percent to 1% and 1% to 1.5%, respectively, in static tests (33.6 percent and 3.4 percent). As a result, the specimens' stiffness and ductility were improved, particularly in the late phases of loading. Using five cycles of repeated load on the steel fiber reinforced RPC two-way slab specimens resulted in a decrease in ultimate load capacity, ultimate deflection, ultimate strain, and absorbed energy as compared to the correlating static test slabs, and it's because the loading-unloading process causes a fluctuations of stresses and more damages in concrete.

2. Research significance

Experimentation was carried out with the purpose of studying the modified repeated response of a reclaimed reinforced concrete one-way slab subjected to a four-point bending test with the intention of determining how effectively the CFRP strip reinforcement improved the performance of the one-way slab. This study's overall objective is to evaluate how well the CFRP strip reinforcement did this. During the testing, the NSM methodology was utilized, and the primary focus was on identifying how the amount and thickness of CFRP strips influenced the outcomes.

3. Test specimens and material properties

In the experiment work, four one-way slabs were casted, each of which was 1200 mm long, and 600 mm wide, and 140 mm thickness. Planned for the experimental study was to look at a number of different parameters and how they affect how well strengthened slabs bend. These parameters include the thickness of the CFRP layer, the effects of flexural strengthening, and the effects of using recycled aggregate in the mix of concrete. The specifics of the examination procedure for the sample group are detailed in **Table 1**. All experimental work carried out in Civil Engineering Department Laboratory/ AL-Nahrain University. Curing of the control specimens and the concrete slabs were done after (24hours) from casting for 28 days. **Table 2** shows the mix proportion of R2 concrete mixtures. The average of 3 control specimens was taken for compressive strength of concrete, the other properties were calculated according to ACI -code equations.

Table 1: **Details of testing slabs.**

Specimens	Type of loading	Dimension of CFRP strip (t×w) mm	Length of CFRP (mm)	No. of strips
BM	Monotonic	---	1000	---
BM1.2	Monotonic	1.2×25	1000	2
BR1.2	Repeated	1.2×25	1000	2
BR2.4	Repeated	2.4×25	1000	2

Table 2: Mix proportion of R2 concrete mixtures.

Mix No.	Cement content (kg/m³)	Sand (kg/m³)	Gravel (kg/m3)	PVC % Rep. by gravel (volume)	Super. PL. % by wt. of cement	Silica% Rep.by cement	w/c	cubic comp. strength (MPa)@ 28days
R2	460	625	945	25	2.3	15	0.45	35

The RC slabs were poured using reclaimed concrete as a binding ingredient. It was used to determine the modulus elasticity, and compressive and tensile strengths of concrete by using steel cylindrical molds with diameters of 15 cm in diameter and 30 cm in height. Reinforcing steel bars with a diameter of 10 mm were subjected to standardize testing to determine their average yield, ultimate strength, and elongation. The characteristics of the concrete and the steel reinforcements that were utilized in this project are outlined in **Table 3**. The characteristics of the CFRP strip are detailed in **Table 4**.

Table 3: Materials properties.

Material	splitting tensile strength (MPa)	Compressive strength f'_c (MPa)	Yield stress (MPa)	Ultimate tensile strength (MPa)	Modulus of elasticity (GPa)
Concrete	3.01	28.56	--	--	25.1
Steel Ø10mm	---	---	591	690	200

Table 4: **properties of CFRP strip.**

Properties	Sikadur carbondur S1012
Tensile strength (KN)	336
E-modulus (GPa)	165
Strain at break (min.) %	1.69%
Width (mm)	100
Thickness (mm)	1.2

4- Monotonic load test results

4.1 Cracks pattern, load capacity, and mode of failure

The experimental results concerning the cracking loads and the failure loads are listed in **Table 5**. The cracking pattern for specimens is shown in **figs. 1** and **2**. It is evident from these figures that flexural cracks are approximately parallel and that there are no cracks were observed near to support regions, also it is clear that cracks pattern for the slabs have similar behavior.

Table 5: Cracking and Ultimate Loads of Monotonic load test.

Specimens	Cracking Load (P cr) (kN)	% Increase in Cracking Load with Respect to Ref	Ultimate Load (P u) (kN)	% Increase in Ultimate Load with Respect to Ref	Pcr / P u (%)
BM	31.8	Ref.	127.025	Ref.	25
BM1.2	36.7	15.4	130.999	3.1	28

Figure 1: Cracks Pattern for Bottom and side Projections of Specimen (BM).

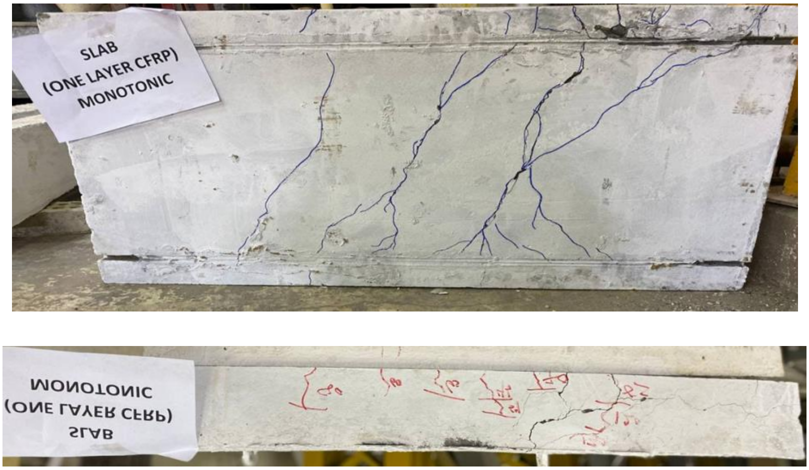


Figure 2:Cracks Pattern for Bottom and side Projections of Specimen (BM1.2).

Table 6 shows the cracking width at ultimate load of monotonic load test. The cracking width was measured by a high-definition microscope with a lens that magnifies and clarifies the micro-cracks up to 10 times. The percent of decreasing in ultimate crack width was 43 % for specimens BM1.2 with respect to the specimen BM. Adding FRP strips has a significant effect on stiffness of slabs, the increase of adding FRP strips area increased the stiffness of slabs which leads to decrease the cracking width.

Table 6: Cracking at Ultimate Load of Monotonic load test.

Specimens	Crack width at ultimate load, (mm)	Decreasing Crack width at ultimate load, (%)
BM	1.4	Ref.
BM1.2	0.8	43

4.2 Load-deflection behavior

Effect of added CFRP strips on load-deflection behavior at mid-span is illustrated in **Fig. 3**. The results for specimens BM1.2 are compared with BM (the control specimen without CFRP). From load-deflection curves, it is clear that the two slabs have the same stiffness in the elastic region while after yielding of tension reinforcement the increase of added FRP strips area is directly proportional with slab stiffness or in other words, the deflection decrease at the same load level. All proportions of mid-span deflection of tested slabs at service and ultimate loads are given in **Table 7**. Note that the service load was taken as 70% of the ultimate load.

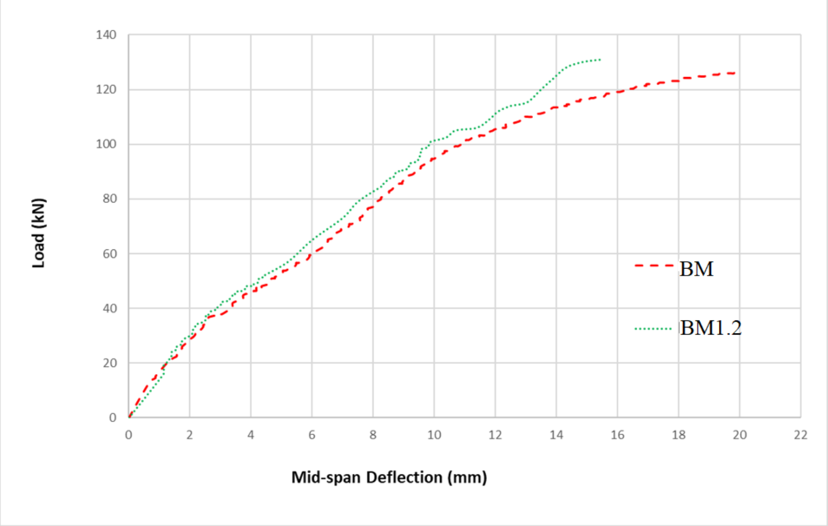


Figure 3: Effect of the added FRP strips on Load-Deflection Behavior at Mid-Span.

Table 7: Deflections at Mid-Span of Specimens at Service and Ultimate Loads.

Specimens	Deflection at Service Load (mm)	% Decrease in Deflection at Service Load	Deflection at Ultimate Load of Ref. Specimen =	% Decrease in Deflection at The Ultimate Load of Ref.	Deflection at ultimate load(mm)	% Decrease in Deflection at Ultimate Load
BM	9.29	Ref.	19.896	Ref.	19.896	Ref.
BM1.2	9.13	1.7	14.21	28.6	15.523	22

4.3 Ductility factor

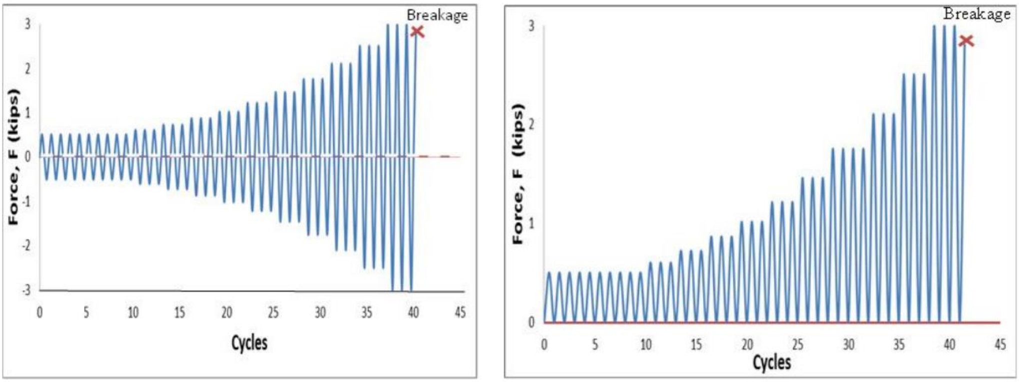
The ductility factor is the ability of structural member to sustain large deformation or in other word; it is the percentage of mid-span deflection at failure loads to the mid-span deflection at the initial yielding of tension main reinforcement bars. It is observed that increase in CFRP strips area decrease the ductility factor, as shown in **Table 8**. The ductility factors were calculated as given in **Table 8** for all specimens.

Table 8: Ductility Factor for Specimens.

Specimens	Steel Yielding Load (kN)	Yield Deflection (mm)	Ultimate Deflection (mm)	Ductility Factor
BM	76.5	7.82	19.896	2.54
BM1.2	75.1	7.1	15.523	2.20
Ductility Factor = Ultimate Deflection / Yield Deflection				

5. Repeated load test results

Over a 2.50 mm contact width in the concrete, line loading was used to apply an identical amount of pressure to the load plate's top surface. FEMA's modified load technique was used to model the recurring load (2007). There are no reversals of load in the new approach of load calculation, which exclusively employs positive loading situations (Figure 4). Rather than load reversal, which is more commonly associated with wind and earthquake disasters, this is more typical of imposed floor loads on structures or traffic loads on bridges. In cases of low cycle fatigue, when the peak amplitude of the cycle load is greater than 50% of the ultimate load of the member, and the member generally fails after less than one million cycles, this method is the best choice. Ten cycles of amplitude equal to 0.01 of the final deformation in monotonic scenario, followed by three further cycles of amplitude 1.2 times the deformation in the first stage, and so on. Each succeeding step increases the amplitude of the deformation by 0.2 (i.e., until total damage occurs), while still exposing the specimen to three cycles until total damage occurs.



(a) (b)

Figure 4: Load protocol: (a) FEMA-461 (b) modified FEMA461 (FEMA (2007)).

5.1 Cracks pattern, load capacity, and mode of failure under effect of repeated load

The experimental results under repeated load concerning the cracking loads and the failure loads are listed in **Table 9** where the percent of **Pcr** / **P u** was 35.8 and 43 for slabs BR1.2 and BR2.4 respectively. The cracking pattern for specimens under repeated load is shown in **figs. 5** and **6**. It is evident from these figures that flexural cracks are approximately parallel and that there are no cracks were observed near to support regions, also it is clear that cracks pattern for the slabs have similar behavior. **Table 10** shows a comparison in ultimate loads of monotonic and repeated load test for the same slab, where the percent of **P**u(BM1.2) **/ P u** (BR1.2) was about 1.09. Also shows the percent of change in ultimate load with respect to ref (BM). **Table 11** shows the cracking width at Ultimate Load of repeated load test.

Table 9: Cracking and Ultimate Loads under effect of repeated load.

Specimens	Ultimate Load (P u) (kN)	% Increase in Ultimate Load with Respect to Ref	Cracking Load (P cr) (kN)	% Increase in Cracking Load with Respect to Ref	Stage of Cracking Load	Pcr / P u (%)
BR1.2	120	-	43	-	7	35.8
BR2.4	137	14.2	59	37.2	7	43

Table 10: Comparison in ultimate loads of monotonic and repeated load test.

Specimens	**Ultimate Load (P u) (kN)**	**% Change in Ultimate Load with Respect to Ref (BM)**
BM	127.025	-----
BM1.2	130.999	+3.1
BR1.2	120	-5.5
BR2.4	137	+7.8
Pu(BR1.2) / P u(BM1.2)= 91.6		

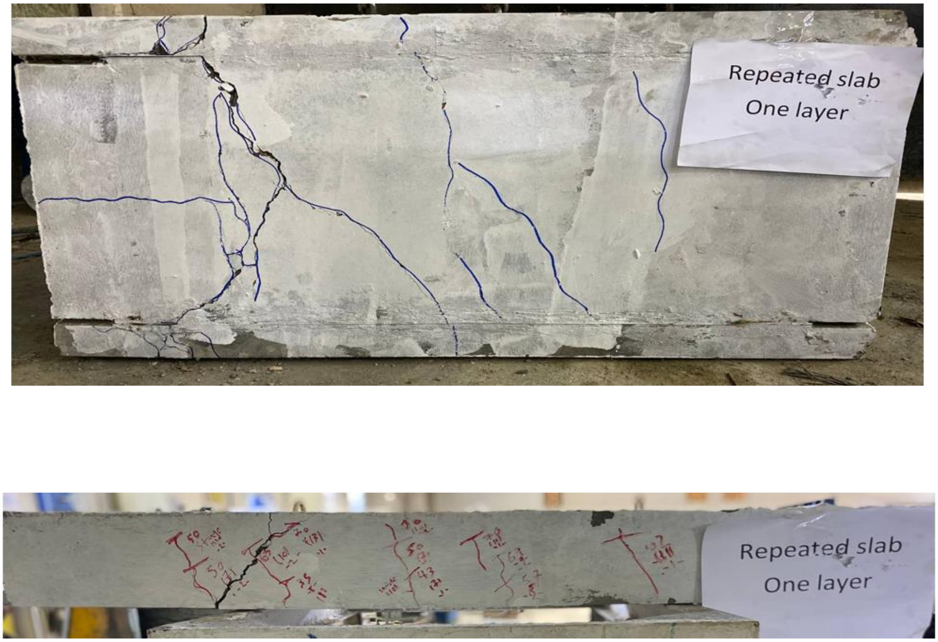


Figure 5: Cracks Pattern for Bottom and side Projections of Specimen (BR1.2), under repeated load test.

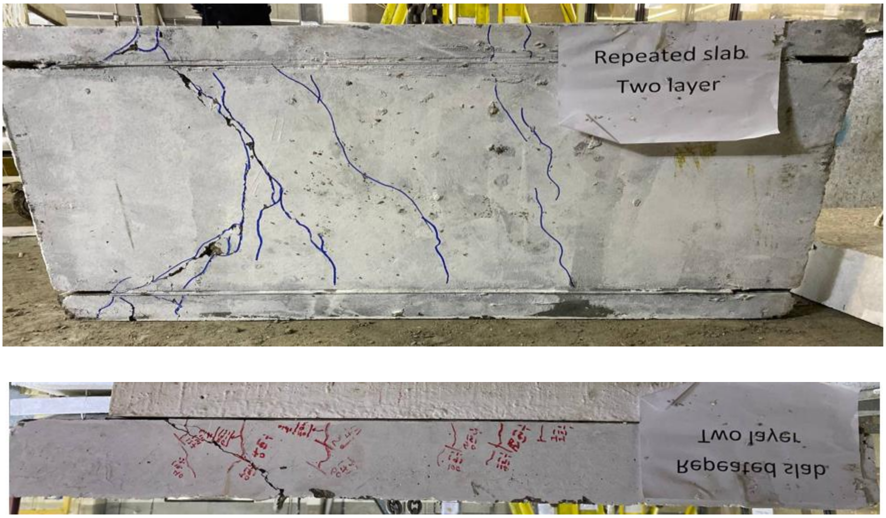


Figure 6: Cracks Pattern for Bottom and side Projections of Specimen (BR2.4), under repeated load test.

Table 11: Ultimate crack width under effect of repeated load.

Specimens	Ultimate crack width, (mm)	decreasing in Ultimate crack width, (%)
BR1.2	2.2	Ref.
BR2.4	1.9	13.6

5.2 Load-deflection behavior under effect of repeated load

The vertical deflection at the center had recorded at each load increment of the repeated load test program. **Table 12** shows the deflections at Mid-Span of Specimens at Ultimate Loads under repeated load. A comparison between repeated and monotonic test is illustrated in **Figure 7**.

Table 12: Deflections at Mid-Span of Specimens at Ultimate Loads under repeated load.

Specimens	Ultimate load Pu (kN)	Ultimate Deflection (mm)	% Increase in Deflection at Ultimate Load
BR1.2	120	14.3	Ref.
BR2.4	137	14.99	4.8

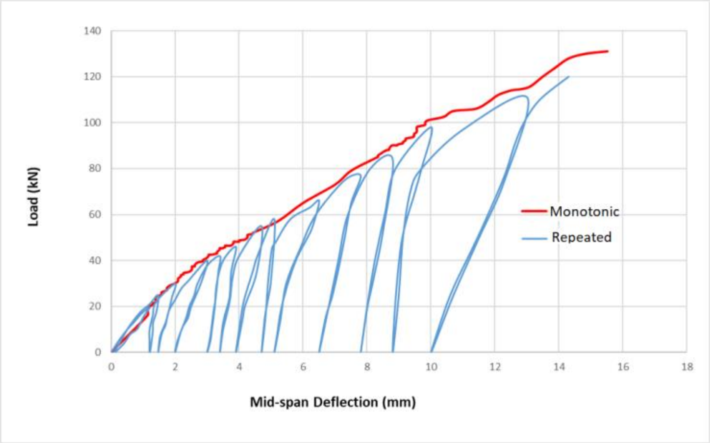


Figure 7: Comparison between repeated and monotonic test on Load-Deflection Behavior at Mid-Span for BM1.2 and BR1.2 slabs.

5.3 Ductility factor under effect of repeated load

It is observed from **Table 13** that the increase in CFRP strips area decrease the ductility factor in repeated load test just like monotonic test.

Table 13: Ductility Factor for Specimens under repeated load.

Specimens	Ultimate Load (***kN***)	Yield Deflection (mm)	Ultimate Deflection (mm)	Ductility Factor
BR1.2	120	6.8	14.3	2.1
BR2.4	137	7.8	15	1.92
Ductility Factor = Ultimate Deflection / Yield Deflection				

6. Conclusions

A- Monotonic load test

1. Increase CFRP strips area has a small effect on the cracked / ultimate load (**Pcr** / **P u**) ratio. Where the ratio of (**Pcr** / **P u**) was 25 and 28 for BM, and BM1.2 respectively.
2. The Experimental test results indicated that adding CFRP strips has a significant effect on the ultimate load, the increase of adding CFRP strips area increased the failure load by about 3.1 for specimens BM1.2 with respect to the specimen BM.

3. The effect of added CFRP strips on the central deflection at **service** load is approximately small, where the central deflection decreased by about (1.7 %) for BM1.2 with respect to the specimen BM.
4. The effect of added CFRP strips on the central deflection at **ultimate** load is significant, where the central deflection decreased by about (22 %) for BM1.2 with respect to the specimen BM.
5. Increase the adding CFRP strips area decrease the ductility factor, where the ductility factor value was 2.54 and 2.20 for BM and BM1.2 respectively.

B- Repeated load tests

1. The percent of **P**u (BR1.2) repeated loads / **P u** (BM1.2) monotonic loads was 91.6 %.
2. Adding CFRP strips has an effect on the ultimate load in repeated load less than in monotonic load test, where the increase of adding CFRP strips area increased the failure load by about 14.2% for specimens BR2.4 with respect to the specimen BR1.2 under repeated load test.
3. Adding CFRP strips has an effect on the cracking load in repeated load less than in monotonic load test, where the increase of adding CFRP strips area increased the cracking load by about 37.2% for specimens BR2.4 with respect to the specimen BR1.2 under repeated load test
4. Repeated loads give crashing at the top fiber of slab, this is due to the effect of repeated loads which causes degradation of concrete stiffness and increased crashing of concrete.
5. The ductility factor in case of repeated load was, 2.1 and 1.92 for BR1.2 and BR2.4 respectively.

7.REFERNCES

[1] Guo, H., Shi, C., Guan, X., Zhu, J., Ding, Y., Ling, T. C., ... & Wang, Y. (2018). Durability of recycled aggregate concrete–A review. *Cement and concrete composites*, *89*, 251-259.

[2] Adimi, M. R., Rahman, A. H., and Benmokrane, B. (2000). “New method for testing fiber-reinforced polymer rods under fatigue.” J. Comp. Constr., 10.1061/(ASCE)1090-0268(2000)4:4(206), 206–213.

[3] Braimah, A., Green, M. F., and Campbell, T. I. (2006). “Fatigue behavior of concrete beams post-tensioned with unbonded carbon fiber reinforced polymer tendons.” Can. J. Civ. Eng., 33(9), 1140–1155.

[4] El-Ragaby, A., El-Salakawy, E., and Benmokrane, B. (2007a). “Fatigue analysis of concrete bridge deck slabs reinforced with E-glass/vinyl ester

FRP reinforcing bars.” Composites Part B, 38(5–6), 703–711.

[5] El-Ragaby, A., El-Salakawy, E., and Benmokrane, B. (2007b). “Fatigue life evaluation of concrete bridge deck slabs reinforced with glass FRP composite bars.” J. Compos. Constr., 10.1061/(ASCE)1090-0268 (2007)11:3(258), 258–268.

[6] Abdulkareem, B. F., & Izzet, A. F. (2022). Residual post fire strength of non-prismatic perforated beams. In *IOP Conference Series: Earth and Environmental Science* (Vol. 961, No. 1, p. 012002). IOP Publishing.

[7] Al-Azzawi, A. A. (2017). Free vibration of simply supported beam on elastic foundations. *Al-Nahrain Journal for Engineering Sciences*, *20*(2), 353-357.

[8] Al-Sulayvani, B. J., & Al-Talabani, D. N. (2015). Strengthening and repair of circular RC slabs with openings using CFRP strips under repeated loading. *Construction and Building Materials*, *84*, 73-83.

[9] Yoshitake, I., & Hasegawa, H. (2021, December). Moving-wheel fatigue durability of cantilever bridge deck slab strengthened with high-modulus CFRP rods. In *Structures* (Vol. 34, pp. 2406-2414). Elsevier.

[10] ELWakkad, N. Y., & Heiza, K. H. M. (2019). Failure Analysis of Strengthened Continuous Reinforced Concrete Beams under Repeated Load.

[11] Hamid, H. A., & Mohammed, S. D. (2018). Behavior of reinforced reactive powder concrete two-way slabs under static and repeated load. *Civil Engineering Journal*, *4*(6), 1178-1192.

تقوية الألواح الخرسانية المعاد تدويرها باستخدام شرائح ألواح CFRP تحت تاثيرالحمل المتكرر المعدل

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المستخلص: الغرض الأساسي من هذه الدراسة هو فحص الأداء والقوة المتبقية لأربعة سقوف خرسانية أحادية الاتجاه تم استصلاحها. تم تقوية ثلاثة من السقوف بالبلاستيك المقوى بألياف الكربون المركب بالقرب من السطح ، وتم تقديم جميع السقوف من أجل التحقق من تأثير العوامل المختلفة على السلوك الهيكلي لكل سقف. يتكون البرنامج التجريبي من صب وتقييم ما مجموعه أربع عينات ، والتي يتم فصلها بعد ذلك إلى فئتين أساسيتين. تم تصنيف هذه المجموعات بناءً على الطريقة التي تم تحميلها بها (رتيبة ، و بشكل متكرر). كان لهذه السقوف شكل وأبعاد قابلة للمقارنة تبلغ 1200 ملم × 600 ملم × 140 ملم. تم توسيع البحث التجريبي ليشمل دراسة العديد من الخصائص ، مثل تأثير زيادة سماكة شريط CFRP وأنواع الأحمال المختلفة على أقصى سعة تحميل واستجابة انحراف الحمل. أشارت النتائج إلى أن زيادة مساحة شرائح FRP المضافة لها تأثير ضئيل على نسبة التشقق إلى الحمل النهائي (**Pcr** / **P u**) ، حيث كانت النسبة المئوية 25 (**Pcr / P u**) و 28 للبلاطة المرجعية بدون CFRP ، والبلاطة مع CFRP بسماكة 1.2 مم تحت حمولة رتيبة على التوالي ، كما أن إضافة شرائط CFRP له تأثير على الحمل النهائي ، فقد أدت زيادة مساحة شرائح CFRP إلى زيادة حمل الفشل بحوالي 3.1 لبلاطة العينات مع CFRP بسماكة 1.2 مم فيما يتعلق إلى للبلاطة المرجعية للعينة بدون CFRP لاختبارات الحمل الرتيبة. كانت نسبة **Pu** (لوح بسماكة 1.2 CFRP مم تحت الأحمال المتكررة) / **P u** (لوح مع CFRP بسماكة 1.2 مم تحت أحمال أحادية اللون) كان 91.6٪. إضافة شرائح CFRP لها تأثير على حمل التشقق في الحمل المتكرر أقل من اختبار الحمل الرتيب ، حيث أدت زيادة مساحة شرائح CFRP إلى زيادة حمل التشقق بحوالي 37.2٪ للبلاطة ذات السماكة المصنوعة من البلاستيك المقوى بألياف الكربون 2.4 مم فيما يتعلق بالعينة بلاطة مع CFRP بسماكة 1.2 مم تحت اختبار الحمل المتكرر. تؤدي الأحمال المتكررة إلى تحطم الجزء العلوي من البلاطة ، ويرجع ذلك إلى تأثير الأحمال المتكررة التي تسبب تدهور صلابة الخرسانة وزيادة تكسرها.

الكلمات المفتاحية: تحميل متكرر معدل ؛ عامل ليونة ؛ تحميل النهائي؛ شريط CFRP ؛ التكنولوجيا المركبة على السطح القريب.

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