Research Article

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Effect of concrete and reinforcement continuity on repairing mid-span zone in simply supported one-way slab

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Abstract: The flexural strength of slabs may be reduced due to accidents and environmental effects. This study focuses on the rehabilitation of the one-way reinforced concrete slab. Experimental works include five simply supported one-way reinforced concrete slabs with width, depth, and length of 400, 120, and 2200 mm, respectively. Different configurations of steel continuity between old and new concrete have been tested. Moreover, in the control specimen (steel is continued overall, the specimen and concrete are cast in one stage over the entire slab). In the other four specimens, the concrete is cast in two stages, the left and right parts representing the old concrete are cast first, and the middle part representing a new concrete is cast after that. In these four specimens, new steel is connected to old one by different configuration (original steel remain to continue, new steel connected to old one by weld, new steel connected to old one by making 90° hooks, and new steel bars is put inside bores using epoxy). After testing, the welding method of connecting new to old steel is the best one.

Keywords: reinforced concrete, one-way slab, repairing, reinforcement continuity

1 Introduction

Reinforced concrete structures may expose to accidents, and environmental effects result in cracking and loss in the flexural capacity. The one-way slab is one of the significant components of these structures. Therefore, this study focused on rehabilitating the one-way reinforced concrete slab. An experimental study was achieved in 2009 on eight reinforced concrete slabs under the membrane and bending loads [1]. The loads were stopped before failure, and the slab was unloaded and repaired using CFRP layers. Then, the load was applied until collapse. The CFRP strips increased the ultimate strength capacity. Also, in 2013, an experimental study was carried out on twenty-one one-way self-compacting reinforced concrete slabs [2]. Eighteen slabs were burning and loading till failure, then retrofitted using CFRP and loading till failure again, while three slabs were loaded and retrofitted without burning. The effect of different temperature levels, concrete compressive strength, and cooling rates were studied.

On the other hand, Allam *et al.* theoretically studied in 2013 the concrete cover effect on the strength of slabs type one way under the effect of fire [3]. In the same year, the direct shear and bending behavior of reinforced concrete slabs type one-way under explosive load have been studied [4]. The effectuation of concrete strength, a ratio of reinforcement, and length of the span were also studied. A new intelligent material named PZT was used to monitor the structural health to detect the damage properties of simply supported reinforced concrete slabs [5]. Moreover, Radonjanin *et al.* studied and evaluated the behavior of repaired reinforced concrete structures damaged by fire [6]. Slabs in this structure were strengthened by adding new reinforcement and a new concrete layer on the bottom side. The impact test effect to detect damage of lab-built reinforced concrete slabs was used [7]. These slabs' cracking was achieved by applying static load in three phases until the failure load was reached. Hamiruddin *et al.* found in 2018 that the use of reinforced concrete with fiber having high strength (HSFRC) as a rehabilitation material for a reinforced concrete slab that is damaged by heat enhances the mechanical properties (flexural strength) of the slab [8]. In the same year, a structural behavior study of reinforced concrete slabs was achieved in a way that was repaired by plastic reinforced by fiber [9]. This study was done using a computer ABAQUS code, considering the effects of fibers

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direction, layers number, and slab aspect ratio. Finally, two numerical studies were conducted on the structural behavior of reinforced concrete slabs that cracked under the effect of blast loading [10, 11].

Through the research mentioned above, there is no study to repair a one-way slab of reinforced concrete by replacing damaged concrete and steel reinforcement with new ones. Therefore, we focus on this point in our study by testing five specimens. The first specimen is a control specimen where the steel is continued over all the specimens, and concrete is cast in one stage over the entire slab. For the other four specimens, the concrete is cast in two stages, the left and right parts representing the old concrete are cast firstly, and the middle part representing a new concrete is cast after that. In these four specimens, new steel is connected to old one by different configuration (original steel remain to continue, new steel connected to old one by weld, new steel connected to old one by making 90° hooks, and new steel bars is put inside bores using epoxy).

In this work, the specimens will be described at first, then the process of casting the specimens and curing of concrete will be addressed, followed by preparing the specimens for testing, then conducting the tests and obtaining the results, and finally discussing these results.

2 Experimental works

To understand the effect of concrete and steel rebar continuity on the structural behavior of rehabilitated one-way reinforced concrete slab, five slabs will be tested under two points loading at civil engineering department of University of Babylon.

2.1 Description of specimens

Five simply supported one-way slabs of reinforced concrete are tested. The specimens have dimension and cross-section properties, as shown in Figures 1-5.

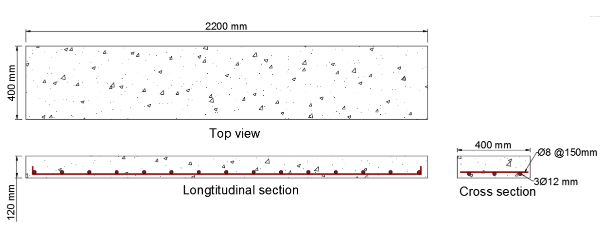

Figure 1: Dimensions and details of specimens OWS1.

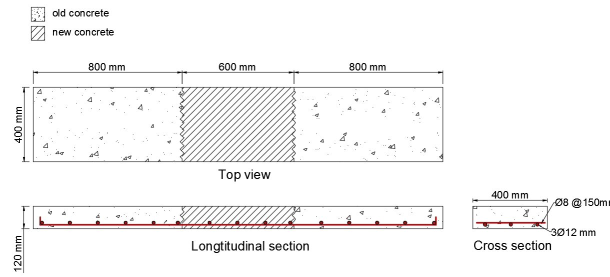

Figure 2: Dimensions and details of specimens ROWS2.

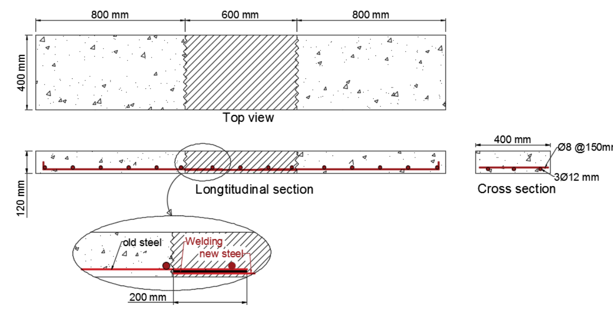

Figure 3: Dimensions and details of specimens ROWS3.

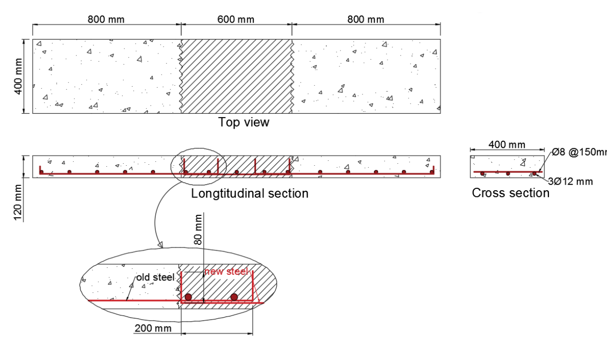

Figure 4: Dimensions and details of specimens ROWS4.

In the specimens (OWS1 and ROWS2), the middle third of the reinforcement's slab was the original one (as shown in Figures 1 and 2). In the specimen (ROWS3), the middle third reinforcement is a new mesh connected to the original mesh of the other two-thirds by welding (Figures 3 and 6a). In specimen (ROWS4), the new reinforcement connects to the old one by using a hock with an angle of 90° (the hock is made in old and new reinforcement steel), as shown in Figures 4 and 6b. In specimen (ROWS5), the new reinforcement mesh is fixed by making a bore in old concrete (20

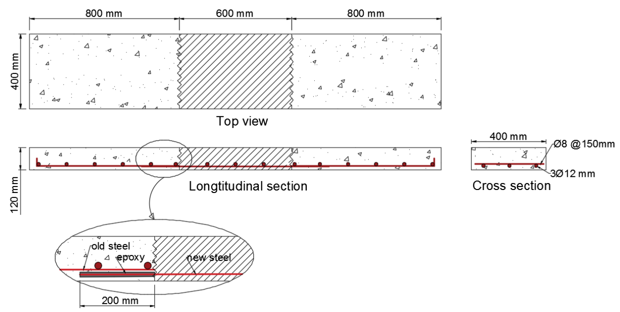

Figure 5: Dimensions and details of specimens ROWS5.

cm) and using epoxy to fix the new bar (see Figures 5 and 7).

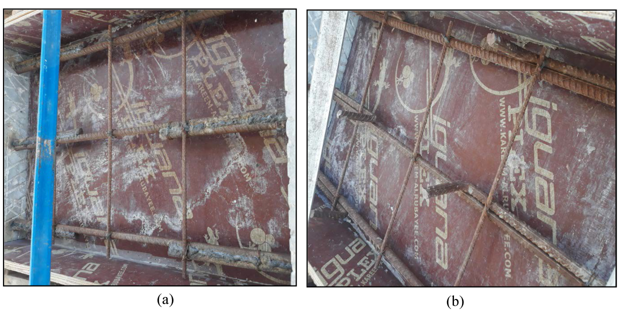

Figure 6: New to old steel bonding by: a) welding and b) making a hook with 90° angle.

2.2 Casting and curing of specimens

Slab (OWS1) is the control specimen, and its concrete is cast in one stage. On the other hand, in all other specimens, the concrete is cast in two stages, i.e., the concrete of the left and right third is cast firstly, and then after the middle third is cast. In the first casting stage, concrete with cylindrical strength (33 MPa) is used for all specimens. Concrete with cylindrical strength (30 MPa) is used in the second casting stage for specimens ROWS2, ROWS3, ROWS4, and ROWS5.

In the two stages of casting and after 24 hours, the specimens are marked and covered by wetted gunny bags until 28 days. A scarifying device using a rotating disc wheel is used for cleaning and roughing the old concrete surface before using a quick mast from DCP Company (see Figure 8), which would be put before 30 minutes from casting a new concrete (second stage of casting).

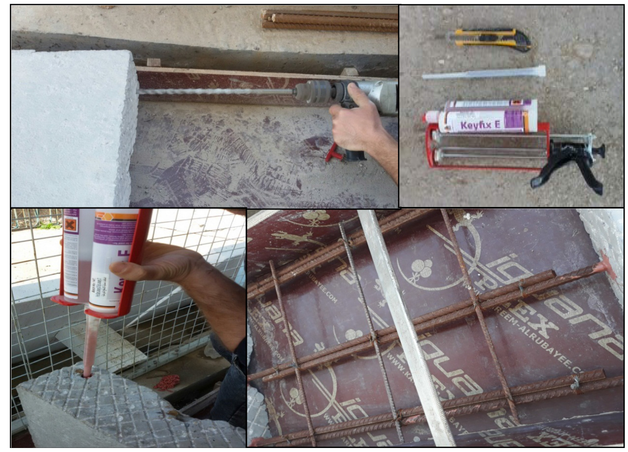

Figure 7: New steel mesh fixing by using epoxy.

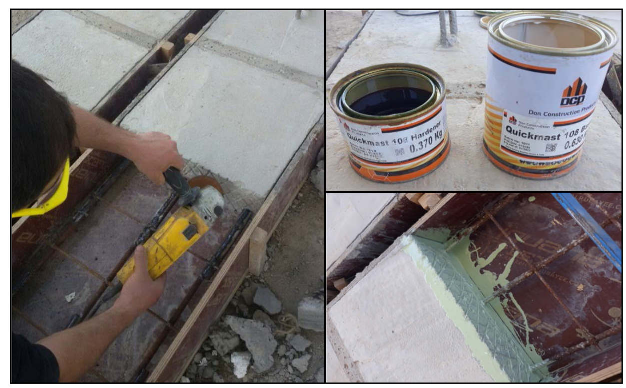

Figure 8: Preparing old concrete surface.

2.3 Test of specimens

A load of two points is applied for all specimens. One dial gage is placed at mid-span under the slab to record deflection when the load is applied up to failure (see Figures 9 and 10).

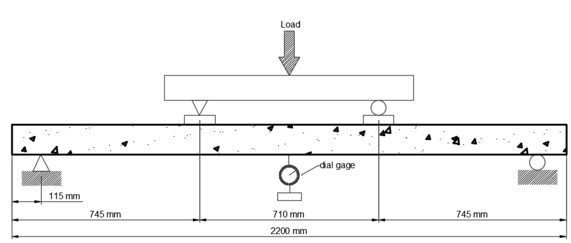

Figure 9: Flexure test.

Figure 10: Flexure test machine.

3 Results

The following sections will present the load-deflection curves, first cracking load, ultimate load, failure modes, and cracking patterns.

3.1 Curves of load-deflection

For all specimens, the curves of load-deflection are shown in Figure 11. Also, the relationship between the external applied load and deflection at mid-span is shown. The first cracking load, failure load, mid-span deflection at failure load, and failure type of all specimens are shown in Table 1 and Figures 12 and 13.

According to Figure 9, the ultimate flexural moment at mid-span will be equal to (0.315 P_u). And for the control specimen OWS1:

The effective depth d = 95 mm

As = 339 mm^2

P = 339 / 400 × 95 = 0.0089

$M_u = \phi \rho b d^2 f_y (1 - 0.59 \rho f_y / f'_c)$ Eq. 1 [12]

$0.315 P_u = 0.9 \times 0.0089 \times 400 \times 95^2 \times 420 (1 - 0.59 \times 0.0089 \times 420 / 33) \times 10^{-6}$

$P_u = 35.98$ kN

Furthermore, this will be approximately 68% of the experimental failure load of specimen OWS1 (52.6 kN). Table 2 shows the differences in failure load and mid-span deflection at failure load for all specimens concerning with OWS1. The slab OWS1 fails at load (52.6 kN) and mid-span deflection (35.5 mm), while the ultimate theoretical capacity is (24.5 kN). The specimen ROWS2 fails at load (53.2 kN) and mid-span deflection (37.1 mm). The specimen ROWS2 behaves the same as OWS1, which means that the bonding agent used between the old and new concrete made a good connection. The slab ROWS3 appears failure at load (49.2 kN) and deflection (23.9 mm). The differences in failure load and the mid-span deflection concerning with OWS1 are (-6% and -33%), respectively. For slab ROWS4, failure happens at load (30.3 kN) and deflection (15.1 mm), which are less than that for OWS1 by (42% and 58%) respectively. The ROWS5 shows failure at load (20.2 kN) and deflection (10.6 mm), which is less than from OWS1 by (62% and 70%) respectively.

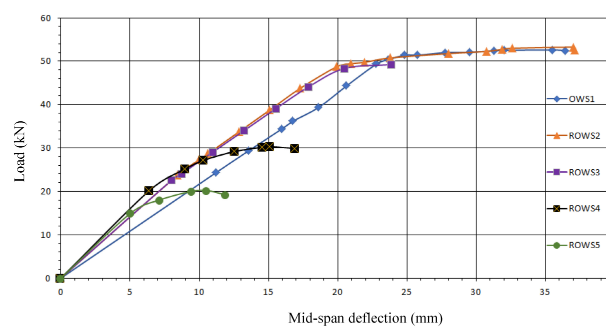

Figure 11: Load-deflection curve for all specimens.

3.2 Cracking pattern

In the slab OWS1, the first crack is appeared at load (6.6 kN) in the region between mid-span and the point of applied load (see Figure 14). After the first crack, another crack appears at the region of the opposite point load. At loads (12 and 13 kN), new cracks appear at the region between mid-span and point load on the opposite side of the first crack. After that, cracks are propagated in the region between two applied load points. The slab failure is a flexural failure at load (52.6 kN) with deflection (35.5 mm), and the position of failure is at the mid-span zone.

On the other hand, the slab ROWS2 shows its first crack at load (9.4 kN) in the region between mid-span and the right point of applied load, as shown in Figure 15. After

Table 1: First cracking load, failure load, and mid-span deflection at failure load of specimens.

Specimen symbol	Specimen description	1st cracking load (kN)	Failure load (kN)	Mid-span deflection at failure (mm)	Failure type
OWS1	One way reinforce concrete slab, specimen (1) (control)	6.6	52.6	35.5	Flexural failure
ROWS2	One way reinforce concrete slab, specimen (2)	9.4	53.2	37.1	Flexural failure
ROWS3	Concrete is casting in two stages, and steel reinforcement is not damaged	5.9	49.2	23.9	Bond failure
ROWS4	One way reinforce concrete slab, specimen (3)	9.5	30.3	15.1	Bond failure
ROWS5	Concrete is casting in two stages, and new reinforcement is added and welded to the original one	8.9	20.2	10.5	Bond + flexural failure

Table 2: Difference in first cracking load, failure load, and mid-span deflection at failure load of specimens concerning with control specimen (OWS1).

Specimen symbol	The difference in first cracking load %	The difference in failure load %	The difference in mid-span deflection at failure %	The difference in first cracking load %
ROWS2	42	1	4	42
ROWS3	-11	-6	-33	-11
ROWS4	44	-42	-58	44
ROWS5	35	-62	-70	35

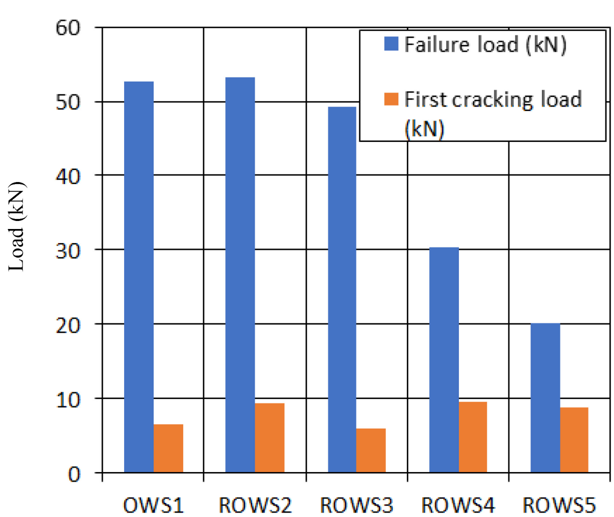

Figure 12: Failure and first cracking loads for all specimens.

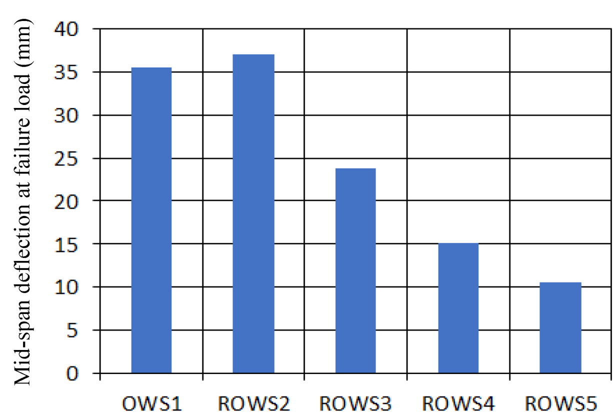

Figure 13: Mid-span deflection at failure loads for all specimens.

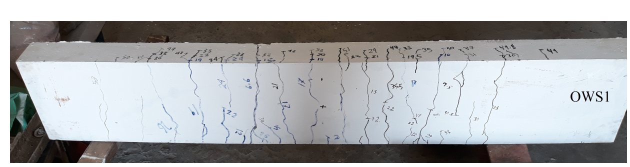

Figure 14: Bottom crack pattern of slab OWS1.

the first crack, cracks appear at the bond region between new and old concretes. After that, cracks propagate in all regions of the maximum positive moment. Slab ROWS2 is failed by flexure at load (53.2 kN) and deflection (37.1 mm). The slab ROWS2 shows approximately the same behavior as slab OWS1.

Figure 15: Bottom crack pattern of slab ROWS2.

Moreover, the first crack in slab ROWS3 appears at load (5.9 kN) at mid-span, as shown in Figure 16. After the first crack, a new crack near it appears at load (14.5 kN). Then, a crack at the bond region appears at load (15.8 kN). After that, cracks are propagated in the mid-span region. Finally, a crack at the left bond region is appeared at load (34 kN) and leads to failure at load (49.2 kN) and deflection (23.9 mm). The behavior of slab ROWS3 is weaker than OWS1 and ROWS2.

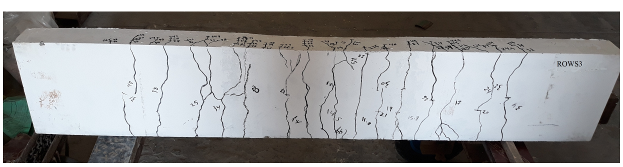

Figure 16: Bottom crack pattern of slab ROWS3.

At load (9.5 kN), the first crack in slab ROWS4 appears at mid-span, and other cracks at the bond region are appeared at load (16 kN) (see Figure 17). After that, cracks along steel bars appear, and more inclined cracks are propagated in the hook regions. A flexural tensile failure happens in the bond region at load (30.3 kN) and deflection (15.1 mm). This slab is weaker than OWS1, ROWS2, and ROWS3.

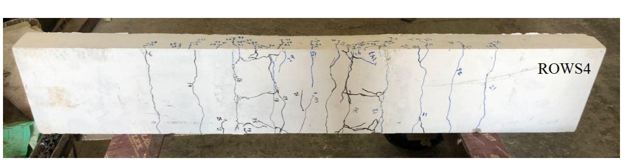

Figure 17: Bottom crack pattern of slab ROWS4.

Lastly, the ROWS5 shows the first crack at load (8.9 kN) at the epoxy bond region, and this crack towards upward (50 mm) and reaches (90 mm) upward at load (16 kN). Then, cracks appear at two sides of the bond regions and mid-span. Finally, cracks are appeared along the steel bars (see Figure 18). A flexural tensile failure happens in the bond region at load (20.2 kN) and deflection (10.5 mm). This slab is weaker than all other slabs.

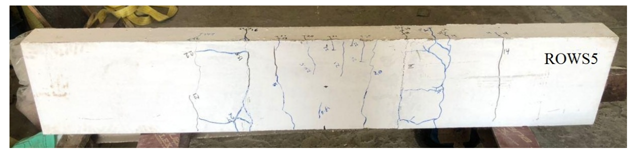

Figure 18: Bottom crack pattern of slab ROWS5.

The results of specimens ROWS3, ROWS4, and ROWS5 prove that the rehabilitation method adopted weld connection between old and new steel bar reinforcement is the best method.

4 Conclusions

This research is focused on finding the best method to rehabilitate simply supported one-way reinforced concrete slab. From the experimental results, it is found the following:

1) For specimen ROWS2, in which the original steel rebar continues overall specimen span, but the concrete is cast in two stages, there is an increase in failure load and mid-span deflection at failure by about 1% and 4%, respectively, concerning with control specimen OWS1.

2) For specimen ROWS3, new steel is connected to the old one by weld, and the concrete is cast in two stages; there is a decrease in failure load and mid-span deflection at failure about 6% and 33%, respectively, concerning with control specimen OWS1.

3) For specimen in which new steel is connected to the old one by making 90°hooks, and the concrete is cast in two stages, ROWS4, there is a decrease in failure load and mid-span deflection at failure by about 42% and 58% respectively, concerning with control specimen OWS1.

4) For specimen ROWS5 in which new steel bars are put inside bores using epoxy and the concrete is cast in two stages, there is a decrease in failure load and mid-span deflection at failure by about 62% and 70%, respectively, concerning with control specimen OWS1.

From above, the best rehabilitation technique that achieved the best reinforcing continuity is the welding technique. Moreover, the rehabilitation of reinforced concrete slab type one way will be through removing the damaged concrete and clean the surface of old concrete and reinforcing bars. If the reinforcing bars are in good condition, the next step of rehabilitation is applied. Otherwise, it is replaced by a new one connected to the old one by welding. The next step is to use a good bonding agent on old roughened and clean surfaces of concrete. Finally, to cast new concrete with strength equal to or higher than the original concrete.

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Conflict of interest: The authors state no conflict of interest.

Data availability statement: The datasets generated during and analyzed during the current study are available from the corresponding author on reasonable request.

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