Effect of different strengthening techniques on the behavior of one-way continuous slab with insufficient length of development

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Abstract. The purpose of this paper is to investigate the effect of the different strengthening techniques on the behavior of continuous one-way slab with insufficient length of development of rebars at the internal joint. The insufficient length of development of rebars in the zone of negative steel reinforcement leads to a reduction in force which has dangerous consequences that affect the structure and its serviceability. This study proposed three strengthening techniques to compensate the insufficient development length which including: internal strengthening by confining the lap zone by spiral bar, externally strengthened by CFRP sheet and steel plates. Six one-way concrete slabs with dimensions of 2200 mm length, 500 mm width, and 125 mm thickness were casted and tested under static load. The main variables adopted in this study are: the length of development, type of strengthening, and presence of construction joint. All slabs were loaded to failure. Form results, it's found that the presence of construction joint and insufficient length of development of rebars at internal support of the continuous one-way slab had a tangible influence on the structural behavior, also, the insufficient length of development resulted in a deterioration of the structure, decrease in stiffness, and change in the mode failure. It was observed that the strengthening techniques used in this study able to compensate the reduction in stiffness and enhancing mode of failure. All the proposed strengthening techniques was efficient especially steel plates which gave a high increasing in ultimate load by about 16.14 % and by about 8.7-3.73% for the other.

1. Introduction

The development length is defined as the minimum length of the bar necessary to generate bond stresses sufficient to resistance the force in the reinforcing bar so that no slip or fission failure occurs and is symbolized by the symbol (d). The development length is not less than 300mm,[ACI Committee 318 (ACI 2014) ([1].For nearly 100 years, In the construction of concrete buildings, the use of steel
reinforcement to transfer stress and shear forces has become construction practice. Owing to the rebars' discontinuity that is produced in standard lengths of 6,9,12 meters, As a result, Overlap has become the conventional way of linking steel reinforcing bars [2]. The overlap load transfer mechanism moves the load by taking advantage of the relation between the steel and the concrete. Lap splicing necessitates the overlapping of two parallel bars with each other. The load from one bar is transferred to the concrete and then to the next bar. The bond is mainly affected by rib deformations on the reinforcing bar's surface [3]. Lap splicing has long been known as a direct, inexpensive method of splicing. Three types namely, lap splices, welded splices, and mechanical or coupler system may do the connection of reinforcement bars [4]. Bond is important in the response of reinforced concrete members because it allows stress to move from the steel bars to the surrounding concrete. In the study of RC structures, a perfect bond is normally assumed. This indicates that the concrete and reinforcement strains are fully compatible. This supposition true only in regions where stress transfer between the two components is negligible[5]. When pouring concrete in two phases separated by a period of time longer than the cement's setting time, a joint is needed. researcher has been study the effect structural behavior of continuous One-Way Slabs with corroded reinforcement at Internal Support strengthened with different Methods are NSM CFRP bars, CFRP strips and steel plates on the performance of reinforced concrete structural elements [6]. Have been study the effect different types and configurations of construction joints on a one-way RC concrete slab's behavior. The variables investigated are the location of the construction joints, type of construction joints (vertical, inclined, and key construction joints)[7]. Externally bonded steel plates, steel or concrete jackets, and available techniques, may be used to strengthening of established concrete structure to endure higher design loads and raise the ductility [8]. It has many advantages, including a high strength-to-weight ratio, efficient corrosion resistance, and ease of on-site handling and application in confined spaces, efficient corrosion resistance, and ease of on-site handling and application in confined spaces, FRP has proven to be the material of choice to meet these new needs. Lateral confinement has been shown to improve concrete's compression efficiency, deformability, and energy absorption capability [9] [10]. Researchers have investigated the the have been study the examines the potential of using carbon fiber reinforced polymer (CFRP) strip technique strengthening of one-way slabs and the effect of different lengths, configurations, location, quantity, shape and dimensions of CFRP sheets [11] [12]. Also, externally bonded steel plates helps in refining the structure performance by reducing deflection and increasing ultimate capacity [13]. The in situ recovery or upgrading of RC members using bonded steel plates has been proven in the field to control flexural deformations and crack width, and to increase the load-carrying capacity of the member under service load for ultimate conditions [14]. have been study to the flexural performance of one-way slabs strengthened by epoxy-bonded steel plates. the slab were strengthened with steel plates with varying the plate thickness and configuration[15].

2. Experimental Program

2.1. Specimen's details

The experimental program included casting, strengthening, and testing, six one-way slabs. The dimensions of slabs were 2200 mm length, 500 mm width, and 125 mm thickness. The slabs are designed according to ACI code ,[ACI Committee 318 (ACI 2014)] [1]. With ordinary concrete at an average strength of 28 days is equal to 28 MPa. The specimens were divided as shown in table (1). The concrete
casting process was in two stages, the first stage for the first span of the slab and 7 days were stopping after these seven days the second stage was conducted to cast the second span of the slab to form the construction joint, in addition, there was a specimen with the same dimensions and reinforcement but without the construction joint which was considered as a reference. Lap splices are generally formed by lapping two bars over a certain length and connecting them together with a wire to form a continuous line at negative zone. This helps to properly transfer loads throughout the structure, Figure (1) shows the reinforcement details of the specimens. Properties of reinforcement were tabulated in table (2).

Table 1. Specimen's Details (Development Length and Proposed Strengthening)

| Specimens Symbol | Development Length (ld) | Strengthening type                   |
|------------------|-------------------------|-------------------------------------|
| S-O-1            | 0                       | Not strengthened                     |
| S-O-2            | 300                     | Not strengthened                     |
| S-O-3            | 120                     | Not strengthened                     |
| S-O-4            | 120                     | Strengthened with spiral reinforcing |
| S-O-5            | 120                     | Strengthened with CFRP strips        |
| S-O-6            | 120                     | Strengthened with steel plates      |

- S-O-1: one way slab without length of development and no Construction Joint.
- S-O-2: one way slab with sufficient length of development with Construction Joint.
- S-O-3 S-O-4, S-O-5, S-O-6: one way slab with insufficient length of development with Construction Joint.

Figure 1. Reinforcement Details
2.2. Materials

Casting was done with a normal strength concrete mixture. For each span, all specimens Ordinary Portland cement was used in casting specimens in this mixture, and the concrete compressive strength after 28 days was 28 MPa. In the concrete mix, use natural and clean sand and 19 mm max size rounded gravel as coarse aggregate. Table (3) shows the concrete mix proportions.

| Nominal steel bar diameter (mm) | Yield strength Fy (Mpa) | Tensile strength Fu (Mpa) |
|---------------------------------|--------------------------|---------------------------|
| 10                              | 475                      | 657                       |
| 6                               | 405.6                    | 552                       |

Table 2. Properties of Reinforcement

2.3. Specimens Preparation for Strengthening Installation

CFRP sheet depends on the effectiveness of the adhesion strength between concrete and CFRP sheet as the positions of CFRP sheet on the external face of the slab are prepared by grinding machine to the total level required to make the aggregate visible, then the surface is cleaned from loose particles and dust. The same procedure which was adopted for preparing the specimen surface for CFRP strips installation was followed in preparation for steel plate installation except for additional holes that were made in the slabs for bolts fix and cleaning these holes from dust as shown in the Figure (2).
2.4 Installation of Strengthening

Strengthening techniques in this study included the following techniques: spiral bars strengthening using steel reinforcement of 6 mm diameter by making it in a spiral shape of 50 mm diameter wrapped around the length of overlap with a length of 200 mm. This process took place after the first casting stage and before the second casting stage, as shown in the following Figure (3).

The second one including two CFRP strips 700 mm long and 50 mm wide were used, each located 133 mm from the side edge of the plates. The distance between the two strips was 133 mm. Two-component of epoxy adhesive is used for bonding. Then, an epoxy mixture is prepared on the surface with a thickness of approximately one mm. Presetting is performed on the face of the slab after joining the CFRP strips with some manual pressure along it to get rid of air bubbles trapped between the CFRP sheets and the surface of the concrete. Fig (4) shows the steps of installation of CFRP strip.
Two steel plates (700 mm x 50mm x 4mm) were fixed on the tension face above the internal support area, and each located 133 mm from the side edge of the plates and the distance between the two plates is 133 mm with a bolt 14 mm diameter. Epoxy adhesive is used to fully interact with the steel bolts between the steel plate and the concrete. Moreover, it is used to fill the gaps around the steel bolts in the holes. The specimens are pre-drilled according to a specific distribution and separated from each other by 120 mm. Figure (5) shows steel plate. Properties of CFRP sheets and steel plates were tabulated in table (4).
2.5 Bonding materials

Cempatch AB is an easy to use, one component acrylic liquid polymer for construction joints, designed as a catalyst for bonding new layers of concrete to old. Sikadur®-330 is a 2-component, thixotropic epoxy-based impregnating resin and adhesive. two components have to be mixed in a ratio of 1:4 in order to use it. MARMOLIT : The strong cream glue is a mixture of unsaturated polyester modified resin and unsaturated polyester orthophalic modified resin dissolved in monomer styrene, was used to repair the steel plate to the concrete surface.

| Density (g/cm³) | 1.82 |
|----------------|------|
| Laminate Nominal Thickness (mm) | 0.167 |
| Laminate Tensile Strength (average) (N/mm²) | 3500 |
| Laminate Modulus of Elasticity in Tension(average) (kN/mm²) | 225 |

### Table 4. Properties of CFRP Sheet

| Properties of steel plate |
|---------------------------|
| Nominal thickness (mm) | 4 |
| Yielding Stress fy (MPa) | 400.7 |
| Tensile Strength fu (MPa) | 525 |

3. Testing of Procedure

specimens were painted white to highlight the first appearance and development of cracks, test slabs were placed over the base of the universal testing machine by crane carefully in such a way that prevents any unnecessary movement (see Fig. 6). Testing began with the initial loading, after that, small increments of loading were applied, and corresponding measurements were recorded. After cracks appear, the first crack was recorded and marked. As loads increased, cracks also developed in the midpoints of the negative region as well as in the positive region. Testing was continued until to failure and a ultimate load were recorded. The deflection was measured at the center of spans using the dial gauges placed below the tension face (underside) the specimens. When reached advanced loading stages, the load was applied at a slow rate until the specimen failed and when the indicator from load stops to record further load or return values, the deflection increased very quickly.
4. Experimental Results

The load-deflection response at the point of loading, cracking load, ultimate load, and failure patterns were all used to evaluate the tested specimens. Cracks could be classified according to the appearing area which is a negative crack that appears in the negative moment zone on the top face above the internal support and positive cracks at the positive moment zone at the bottom face in the middle of the spans. A summary of the specimen's test results was tabularized in table (5).

Table 5. Test Results

| Specimens | Failure load (kN) | \(P_f/P_{Fr}\) | Load at First Negative Crack kN | Load at First Positive Crack kN | Mode failure                  |
|-----------|-------------------|----------------|-------------------------------|-------------------------------|-------------------------------|
| S-0-1     | 185               | 1.15           | 40                            | 83                            | Shear failure                 |
| S-0-2     | 165               | 1.05           | 30                            | 55                            | bond failure                  |
| S-0-3     | 161               | —              | 25                            | 40                            | bond failure                  |
| S-0-4     | 175               | 1.078          | 50                            | 74                            | flexural tensile failure      |
| S-0-5     | 167               | 1.037          | 36                            | 55                            | Debonding of CFRP             |
| S-O-6     | 187               | 1.161          | 41                            | 51                            | flexural tensile failure      |

- \(P_f\) = Failure load, \(P_{Fr}\) = Failure load of reference slab
4.1 First Cracking and Ultimate Loads

A general interpretation of the obtained results showed that the first cracking load in the slab (S-O-3) was less than the strengthened slabs due to the contribution of CFRP sheet and steel plates in increasing of gross moment of inertia that led to increasing cracking moment of section. Table (5) presented the first cracking load attained from the experimental work and the comparison with the slab (S-O-3). For load Capacity, all the strengthened slabs gave a major increase in the ultimate load-carrying capacity when compared with that for the reference slab (S-O-3) specimen. There was a noticeable improvement of strengthened slabs. The increase in the ultimate load ranges from 3.7% to 16.1%. The highest increase in the ultimate load capacity was attained by steel plate strengthening. For the internal strengthening by spiral bars, the increase in the ultimate capacity was about (8.7%), while the strengthening by CFRP sheets led to increasing load carrying by about 3.7% due to the depending of CFRP sheet that led to accelerate the failure.

4.2 Crack Patterns and mode failure

All specimens were gradually loaded until the initiation of cracking. The first visible crack began a load of 40 kN at the negative bending moment region for the specimen (S-O-1). After increasing the load, the first crack appeared in the positive region at load 83 kN. For slab with sufficient length of development (S-O-2), the first visible crack was appeared at the negative bending moment region at load about 30 kN, the first crack appeared in the positive region at load 55 kN while for a slab with insufficient length of development at load 25 kN at negative bending moment region, the first crack appeared in the positive region at load 40 kN, and for a slab with strengthening confining by spiral bars at 50 kN after increasing the load stage, the first crack appeared in the positive region at load 74 kN. The flexural cracks in slabs then propagated toward supports, under increasing load. For the strengthened slab with CFRP sheets, the first crack at negative bending moment region at 36 kN. Due to load increment, these cracks spread, around the CFRP laminates and expanded rapidly. The first crack appeared in the positive region at load 55 kN. And for a slab with strengthening by steel plates at 41 kN at a Negative bending moment region after increasing the load stage, the first crack appeared in the positive region at load 51 kN. The slabs' failure mode is shown in Fig. (7) to Fig. (12).

4.3 Deflections

Deflection measurements for all slabs were documented at different stages of loading before failure. Two dial gauges have been placed at the center of each span to measure the deflection of slabs. Fig.13 to Fig.18 show the comparison of load deflections curves of each span for all tested slabs in this study. Fig.19 shows the comparison of load deflections curves for all tested slabs. It was observed that the insufficient length of development in of rebars at internal joint caused a decrease in stiffness and an increase in deflection at the same stage of loading. compared to the control slab (S-O-3), the presence of spiral bars, CFRP sheets, and steel plates gave good results of enhancing the structural behaviour of slab by increasing load carrying capacity and decreasing deflection.
Figure 7. failure mode of S-O-1 specimen

Figure 8. failure mode of S-O-2 specimen

Figure 9. failure mode of S-O-3 specimen

Figure 10. failure mode of S-O-4 specimen
Figure 11. failure mode of S-O-5 specimen

Figure 12. failure mode of S-O-6 specimen

Figure 13. Load-Deflection Curve of S-O-1 Specimen

Figure 14. Load-Deflection Curve of S-O-2 Specimen
Figure 15. Load-Deflection Curve of S-O-3 Specimen

Figure 16. Load-Deflection Curve of S-O-4 Specimen

Figure 17. Load-Deflection Curve of S-O-5 Specimen

Figure 18. Load-Deflection Curve of S-O-6 Specimen

Figure 19. Load-Deflection Curves of Specimens
5. Conclusions

1. The insufficient length of development of rebars at internal joint caused a tremendous effect on the structural behaviour of one-way continuous slab in addition to the cracks pattern and their propagating in the positive and negative moment zones.

2. For the specimens with insufficient length of development of rebars at the internal joint without strengthening, bond failure will dominate the failure mode with low load capacity.

3. With regards to the ultimate load, the specimen strengthened by CFRP strips technique gives higher increasing in the load carrying capacity by about (3.72 %).

4. In general, high ultimate loads were achieved for slabs strengthened internally with spiral reinforcing compared with reference un-strengthened slab by about (8.7 %)

5. The overall behavior of the specimen strengthened with steel plates is improved by improving the mode of failure, stiffness, cracks pattern, provides the highest load carrying capacity with respect to all other strengthening techniques, so this technique of strengthening can be used as an alternative technique for the slabs containing insufficient length of development of rebars at the internal joint.

6. All the proposed strengthened technique was able to compensate strength losses due to insufficient length of development and the presence of construction joint and improving the structural behavior of the member.

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