# Experimental Study of Using Ferro-Cement and Steel Plates in Repairing Reinforced Concrete Beams

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## ABSTRACT

This paper presents an experimental study of repairing reinforced concrete beams by two methods: the first one by using U-layer of Ferro-cement mortar (2 layers of ferro-mesh) and the second one by using steel plates (two approaches were used: straight layer and U-layer). The present study includes testing seven specimens of reinforced concrete beams. All beams have rectangular section of dimensions (250 mm x 150 mm) and (2 m) effective span on simple supports. The beam specimens other than control beam (B1) were divided into two groups. The first group of beams were loaded until (50%) of the ultimate load, de-loaded and repaired by the two mentioned methods (ferro-cement and steel plates), then these beams were reloaded up to failure.The second group of beams were loaded until (75%) of the ultimate load, de-loaded, repaired and reloaded up to failure. The results proved that beams repaired by ferro-cement showed improved performance, but were less efficient than those repaired by using steel plates. Also, using U-layer of steel plates in repairing reinforced concrete beams is more effective than using straight steel plates, especially for beams repaired after 75% loading of the ultimate load.

**KEYWORDS:** Repair, Ferro-cement, Steel plates, Reinforced concrete, Epoxy, Flexure.

## INTRODUCTION

Works on strengthening and/or repairing concrete structural elements have been set out not a long time ago using different materials for strengthening and/or repairing. The objective of strengthening and/or repairing is to save structural elements in order to avoid high costs of new building. Singh (1992) studied strengthening and repairing reinforced concrete beams that have been damaged by an earthquake by using epoxy injection and steel plates. His study showed that repairing and strengthening by epoxy and steel plates are not suitable for earthquake damages. A comprehensive review of studies on strengthening and repairing concrete beams between 1975 and 2003 was conducted by Engingeniz et al. (2005). Their study was on beam-column joints designed for non-seismic loads. In 2009, Balamuralikrishnan and Jeyasehar studied ten reinforced concrete beams with a span length of (3 m), loaded until failure under static loads. Two beams were used as control beams and the remaining beams were strengthened with carbon fiber reinforced polymer (CFRP). Their experimental results were compared with

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the theoretical results obtained from the ANSYS software. Their study showed an increase in load capacity for beams strengthened with CFRP. Also, in 2009, Ibrahim and Salman conducted numerical analysis using ANSYS program to perform reinforced concrete beam strengthening with carbon fiber reinforced polymer. Al-Amili et al. (2010) investigated three experimental samples with six tests to study the effect of steel fiber on the deflection of self-compacted slabs. All samples were tested with two-point loading which showed that the load on the slabs increased by (5.3%-9.6%) for the samples strengthened with steel fiber. Then, they compared the experimental results with ANSYS results and found differences less than 9%. Also, in 2010, Ravi and Arulraj carried out finite element analysis – using ANSYS – on beam-column joints retrofitted with carbon fiber reinforced polymer (CFRP) sheets. Three samples of reinforced concrete beam-column joints were modeled by ANSYS. Results showed that the deflection of joints strengthened with CFRP decreased by 75.29% compared with joints without CFRP. ANSYS package was used by Naji et al. (2011) to analyze reinforced concrete beams strengthened with different types of FRP against shear forces and the results were compared with literature data. An experimental investigation on cracked reinforced concrete beams repaired with polymer was conducted by Ahmad et al. (2012). In 2013, Khalifa and Al-Tersway used different layers of FRP to strengthen reinforced concrete beams against flexure. They noticed an increase in loading capacity for samples strengthened with FRP. Also, in 2013, Hawileh et al. developed a three-dimensional model to study the behavior of reinforced concrete beams strengthened with FRP. The influence of externally bonded aramid fiber reinforced polymer (AFRP) on the behavior of reinforced concrete beams was studied by More and Kulkarni in 2014. They proved that the load carrying capacity of beams was significantly increased as the number of layers increased. The idea of this paper focuses on using two different methods for repairing reinforced concrete beams. The first one is by using repair with steel plates and epoxy and the other one is by using repair with ferro-cement on beams with (15x25) cm cross-sectional dimensions and (2 m) span.

## EXPERIMENTAL PROGRAM

### Specimens

Two groups of reinforced concrete beams in addition to the reference beam (B1) were studied. All beams have dimensions (250 mm x 150 mm) and (2 m) effective span on simple supports. Two-point loading was applied on beams. First group includes three reinforced concrete beams loaded until (50%) of the ultimate load. The first one (B2-1) was repaired with ferro-cement (with 2 layers of ferro-mesh). The second one (B2-2) was repaired with one straight layer of steel plates. The third one (B2-3) was repaired with one U – layer of steel plates. Second group includes also three reinforced concrete beams, but loaded until (75%) of the ultimate load. The first one (B3-1) was repaired with ferro-cement (with 2 layers of ferro-mesh). The second one (B3-2) was repaired with one straight layer of steel plates and epoxy. The third one (B3-3) was repaired with one U – layer of steel plates. The details of the test specimens are shown in Table (1).

### Materials

### Concrete

Ordinary Portland cement, sand and coarse aggregate with maximum size of 19.5 mm were used for all specimens. A mix design was made according to the ACI Committee 211.1.91 Manual (1997). Some trial mixtures were made to get the required concrete strength. After that, the mix proportions by weight were achieved and used in this work. The mix proportions for ($1m^3$) of concrete are given in Table (2). The average compressive strength of concrete was found to be 41 MPa.

Table (3) shows the compressive strength and splitting tensile strength results of concrete for 7 days and 28 days.

**Table 1. Test specimens and method of repair**

| Group no. | Beam symbol | Percent of loading before repair % | Description of method of repair |
|---|---|---|---|
| Control beam | B1 | 100 | Without repair |
| 1 | B2-1 | 50 | U-layer of ferro-cement (with 2 layers of wire mesh) |
| | B2-2 | 50 | One straight layer of steel plates |
| | B2-3 | 50 | One U – layer of steel plates |
| 2 | B3-1 | 75 | U-layer of ferro-cement (with 2 layers of wiremesh) |
| | B3-2 | 75 | One straight layer of steel plates |
| | B3-3 | 75 | One U – layer of steel plates |

**Table 2. Mix proportions of concrete**

| Mix proportions (kg/m$^3$) | | | |
|---|---|---|---|
| Cement | Water | Sand | Gravel |
| 560 | 225 | 680 | 790 |

**Table 3. Compressive strength and splitting tensile strength of concrete**

| Bar diameter (mm) | Equivalent bar diameter | Weight (kg/m) | Bar area (mm$^2$) | Yield strength (MPa) | Ultimate strength (MPa) | Elongation (%) |
|---|---|---|---|---|---|---|
| 6 | 5.847 | 0.21078 | 26.85 | 530 | 645 | 9 |
| 12 | 11.91 | 0.87454 | 111.41 | 515 | 625 | 11 |

**Steel Reinforcement**

All beams were reinforced by using deformed steel bars of 12 mm diameter as flexural reinforcement and deformed steel bars of 6 mm diameter as stirrups. Three samples for each bar size were tested for evaluation of reinforcing yield stress and ductility. Test results for the reinforcement bars used are shown in Table (4).

**Table 4. Mechanical properties of steel reinforcement bars**

| | | |
|---|---|---|
| Compressive Strength (N/mm$^2$) | 7 Days | 32 |
| | 28 Days | 41 |
| Splitting Tensile Strength (N/mm$^2$) | 7 Days | 3.81 |
| | 28 Days | 4.72 |

**Mortar**

Mortar with a mix proportion of 1:3 by volume with water/cement ratio of 0.4 was used to prepare ferro-mesh layers. Also, SBR liquid was used to improve the workability, physical properties and integrity of cementitious mortar and meanwhile increase its durability. The average compressive strength of mortar was found to be 23 MPa.

**Ferro-Mesh**

Locally available woven rhombic ferro-mesh with an opening size of 15 mm, having wire diameter of 1mm, was used.

Figure (1) shows a sample of the ferro-mesh used in the present study.

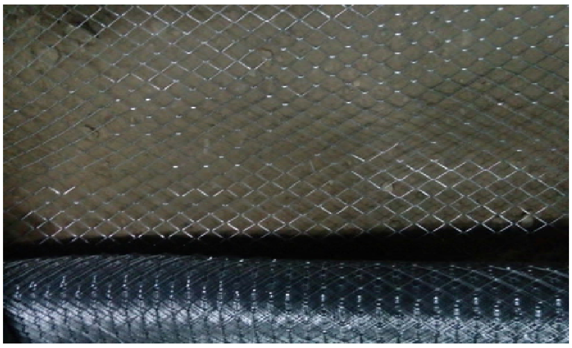

**Figure (1): Ferro-mesh used in the present study**

**Epoxy**

Two types of epoxy were used in this study. The first type is Quickmast 108 from DCP Company. This type was used to bond mortar of ferro-cement with reinforced concrete beams. The second type is NanoGrout SG from Conmix Company. This material was used to bond the steel plates with reinforced concrete beams. The main properties of Quickmast 108 and NanoGrout SG are shown in Tables (5) and (6), respectively.

**Table 5. Technical properties of Quickmast 108**

| Property | Value | |
|---|---|---|
| Tensile strength | 7 days | 35 N/mm$^2$ |
| Compressive strength | 7 days | 69 N/mm$^2$ |
| Bond strength (old to new system) | 7 days | > 13 N/mm$^2$ |
| Elongation | > 20% | |
| Water absorption | < 0.1% | |
| Full cure | 7 days at 25° C<br>5 days at 35° C | |
| Minimum time (overlay) | After 2 hrs or when becoming tacky | |
| Pot life | 7-9 hrs at 25° C<br>4-6 hrs at 25° C | |
| Colour | Green | |
| VOC | < 10 gm/lit | |

**Table 6. Technical properties of NanoGrout SG**

| Property | Value | |
|---|---|---|
| Component | Two: Part A-Base<br>Part B- Hardener | |
| Mixed form | Paste | |
| Colour | Grey when mixed | |
| Compressive strength | 1 day | 45-50 N/mm$^2$ |
| | 7 days | 70-80 N/mm$^2$ |
| Flexural strength | 7 days | 20-35 N/mm$^2$ |
| Tensile strength | 7 days | 15-25 N/mm$^2$ |
| Bond strength | 7 days | 20 N/mm$^2$ |
| Pot life | 45-70 mins. (2 kg mixed material) | |
| Water penetration | Nil | |
| Chemical Resistance | Resistant to alkalis, fuels, acids, oils,… etc. | |

**Steel Plates**

Steel plates of 1.0 mm thickness were used in this study. Two approaches were used to repair the reinforced concrete beams. The first approach was by using one straight layer of steel plates attached to the bottom face of the beam by epoxy resin (NanoGrout SG). The second approach was by using one U-layer of steel plate wraps about the beam with epoxy resin (NanoGrout SG). Table (7) shows the main properties of steel plates.

**Table 7. Properties of steel plates**

| Thickness (mm) | Length (mm) | Yield strength (MPa) | Ultimate tensile strength (MPa) | Elongation % |
|---|---|---|---|---|
| 1 | 1800 | 280 | 355 | 14 |

**Beams Fabrication**

The details of reinforcement of the tested beams are explained in Figure (2). The reinforcements of all beams are (2 Ø 12 mm) in the tension face, (2 Ø 6 mm) in the compression face and the stirrups are (Ø 6 mm @ 125 mm). The beams B2-1 and B3-1 were repaired by ferro-cement layer with 2 layers of ferro-mesh (chicken wires) and using the epoxy material (Quickmast 108) to bond ferro-cement layer with RC beams. The other beams B2-2, B2-3, B3-2 and B3-3 were repaired by using steel plates with epoxy material (NanoGrout SG) as shown in Figure (2). The same mix proportions were used in all beams.

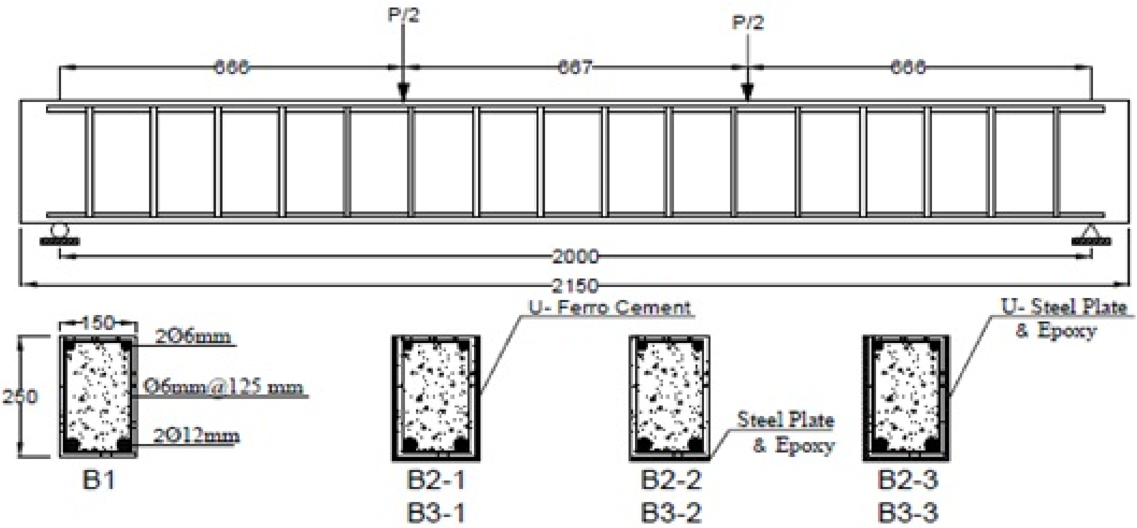


**Figure (2): Details of reinforcement of the tested beams**

## TEST RESULTS AND DISCUSSION

All beams were tested under static two-point loading as shown in Fig. (3). Concentrated loads were applied at third points of the beams gradually at increments of (6 kN) up to specific load before the repair process.

The test for the control beam (B1) was continued until failure, then ultimate load and maximum midspan deflection were recorded and given in Table (8). At successive load increase, visible flexural cracks were initially observed within the tension zone at the midspan of the beam. At large loads, these cracks extended with the formation of new cracks at different orientations, as shown in Fig. (4).


**Figure (3): Loading arrangement of the control beam (B1)**

**Table 8. Cracking and ultimate loads of the control beam (B1)**

| First cracking load $F_{cr}$ (kN) | Ultimate load $F_u$ (kN) | Max. midspan deflection (mm) | $F_{cr}/F_u$ % |
|---|---|---|---|
| 31 | 90 | 14.63 | 34.4 |


**Figure (4): Control beam (B1) after failure**

The load-deflection curve for control beam (B1) is shown in Fig. (5). This curve can demonstrate a certain tendency in which, at early stages of loading, the beam behaves elastically with no visible cracks, which explains the behavior of the beam before the first cracking load. At a further stage, the beam tends to shift from elastic behavior and turns rather to possess a non-linear behavior with visible minor tension cracks beyond which (at the third stage) yielding occurs and the beam behaves plastically.

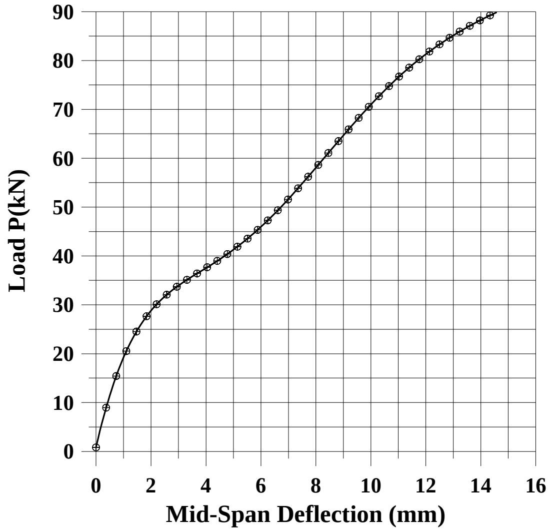


**Figure (5): Load-deflection curve of the control beam (B1)**

Group (1) of beams were loaded until 50% of the ultimate load, de-loaded and repaired by two methods: the first method by using ferro-cement mortar (2 layers of ferro-mesh) and the second method by using steel plates as shown in Fig. (6). Then, these beams were reloaded up to failure. The load deflection curves for this group of beams are shown in Fig. (7). This figure proved that beam (B2-1) repaired with ferro-cement mortar showed improved performance, so that the ultimate load capacity increased by 18% and at the same time, the ductility of this beam increased, which can be explained from increasing midspan deflection by 58% in comparison with the control beam. The increase in the ultimate load capacity occurs for the reason that the stiffness of the beam was increased due to using ferro-cement layer.

Beam (B2-2), repaired with one straight layer of steel plates, showed an increase in the ultimate load capacity by 24% with respect to the control beam, while beam (B2-3) repaired with one U – layer of steel plates showed the largest increase in the ultimate load capacity of 100% as a result of increasing the flexural strength and shear resistance of the beam.


**(a) B2-1 (ferro-cement)**


**(b) B2-2 (straight layer of steel plates)**

**(c) B2-3(U-layer of steel plates)**

**Figure (6): Group (1) of repaired beams**

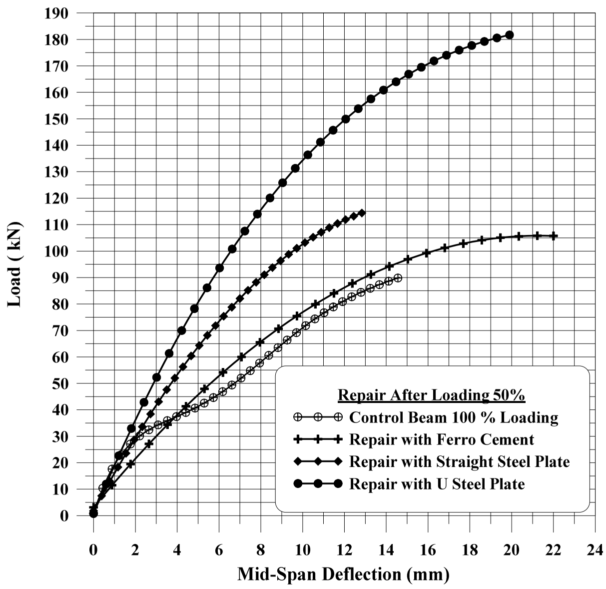


**Figure (7): Load-deflection curves of group (1) of beams (after 50% loading)**

Fig. (8) shows the load-deflection curves for group (2) of beams. The beams in this group were loaded until 75% of the ultimate load, de-loaded and repaired by the same two mentioned methods. After that, these beams were reloaded up to failure.

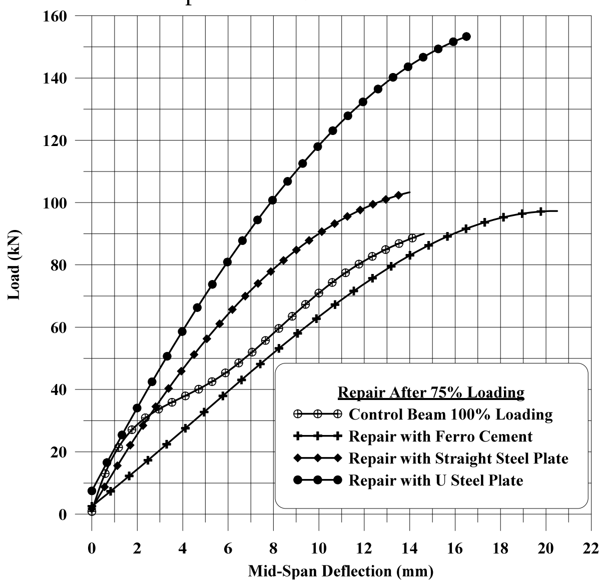


**Figure (8): Load-deflection curves of group (2) of beams (after 75% loading)**

The results showed that using steel plates to repair theses beams is more effective than using ferro-cement due to great increase in the stiffness of the beams, especially when using one U – layer of steel plates as in beam (B3-3). This beam showed an increase in the ultimate load capacity reaching 70%, while beam (B3-2) showed little increase in the ultimate load capacity by 14% only.

Figs. (9-12) shows the effect of using U-ferro-cement, straight layer of steel plates and U-layer of steel plates in the repair of reinforced concrete beams, respectively.

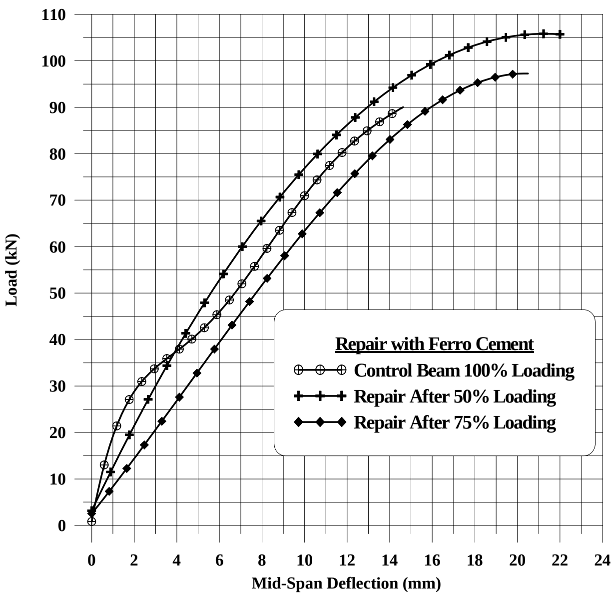


**Figure (9): Effect of ferro-cement repair**

From these figures, it can be noticed that the influence of repair by the two used methods in the present study was relatively little for beams repaired after 75% loading because of great decrease in the stiffness and strength of these beams before the repair process. The modes of failure for the repaired beams are shown in Fig. (13).

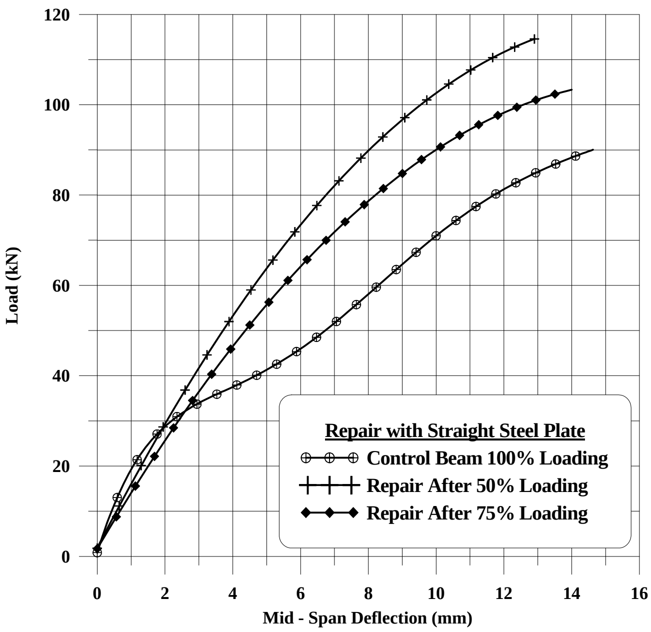


**Figure (10): Effect of straight steel plate repair**

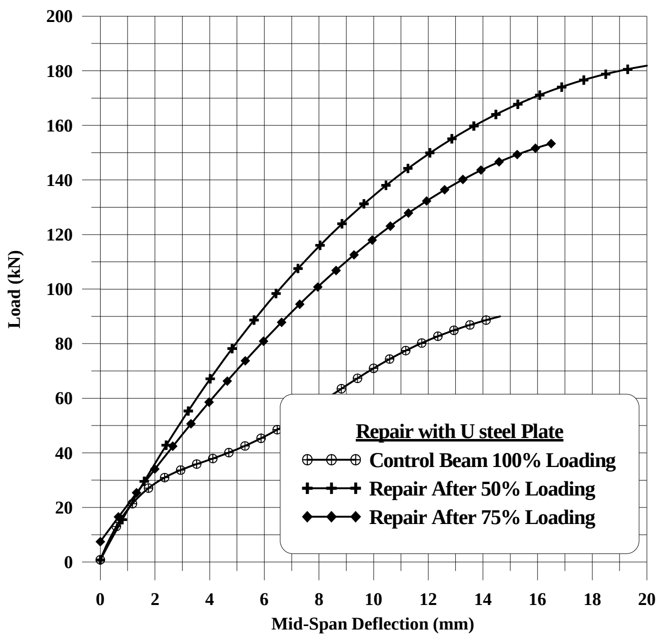


**Figure (11): Effect of U-steel plate repair**

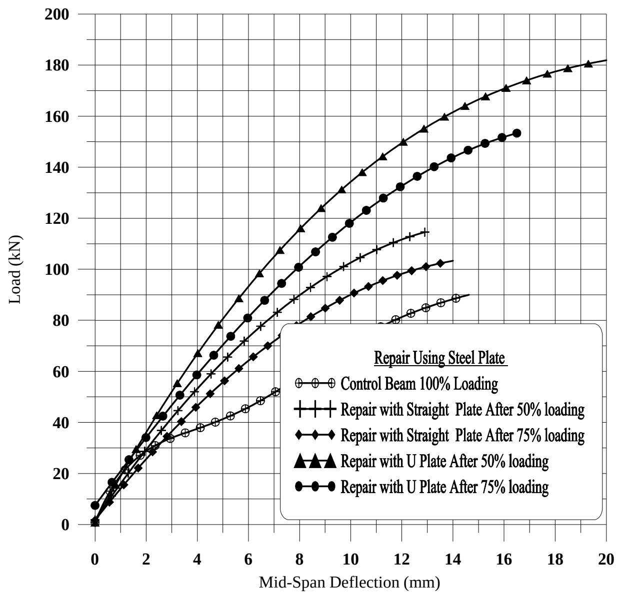


**Figure (12): Effect of repair by using steel plates**

**(a) Flexural failure and debonding of ferro-cement layer of beam B2-1**

**(b) Flexural and shear failure of beam B2-2**

**(c) Debonding of steel plates and crushing of concrete at the load points of beam B2-3**

**Figure (13): Modes of failure of the repaired beams**

## CONCLUSIONS

Based on the experimental results obtained in the present study, the following conclusions can be drawn:

1- After the cracks appear in the reinforced concrete beams and before the stage of failure, these beams can be repaired well by using ferro-cement mortar or steel plates.

2- Ferro-cement mortar used in the repair of reinforced concrete beams showed improved performance, so that the ultimate load capacity increased by 18% as a result of the increase in the stiffness of these beams.

3- Using straight layer of steel plates to repair the beams leads to an increase in the ultimate load capacity by 24%, while using U – layer of steel plates leads to the largest increase in the ultimate load capacity reaching 100% as a result of the increase in the flexural strength and shear resistance.

Using steel plates in repairing reinforced concrete beams is more effective than using ferro-cement, especially for beams repaired after 75% loading of the ultimate load.

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