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Effect of Wire-Mesh Type on Strengthening Reinforced Concrete Beams

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HIGHLIGHTS

- Strengthen the structural elements of the building with greater rigidity.
- Strengthen the reinforced concrete beams using a Ferro cement layer with locally available wire mesh.
- A better tension was obtained for all meshes used, but the best flexural behavior was observed for the square opening mesh.
- A better bearing capacity and deflection were obtained when the Ferro cement layer was used.
- The Ferro cement addition improved the first cracking of the strengthened beams.

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ABSTRACT

Structural strengthening is a method of application to raise the load-ability capacity of building structures to meet the building's need to carry additional and unexpected loads that were not accounted for in the main design. In this study, Ferro-cement was used for strengthening concrete beams. Three locally available wire mesh types were used with an ordinary cement mortar to strengthen reinforced concrete beams under flexural loading. The results show that using a Ferro-cement layer with wire mesh of 15 mm size square opening has the best effect on increasing reinforced concrete beams' bearing capacity and deflection more than when using the other two types of meshes. The first crack and failure load increases were 72 and 79%, respectively. In contrast, the deflection increased 70 and 51% at the first crack and failure load.

1. Introduction

The exposure of buildings to structural problems due to error in design, mistakes during the fulfillment of the structural articles, or change in the serviceability of the building leads to an increase in the applied loads over that designed for or the building subjected to an accident such as small fire that didn't cause the failure of it. All of that needs the building elements to be strengthened or repaired.

There is a significant demand to strengthen concrete structures worldwide, and there are a variety of causes for this. Deficiencies are frequently the result of deterioration due to age and exposure to the environment, increased traffic induced by a rising society, or functional changes such as a higher needed permit load [1] also, Maintenance and changing conditions may necessitate local strengthening and stiffening of structures to meet a greater ultimate load and/or more stringent serviceability requirement [2]. Raising the current capability of a non-damaged structure or a structural element to a specific level is known as strengthening [3].

Building structures is expensive, and many people find the construction process inconvenient. As a result, having durable structures with long lifetimes and low maintenance costs is desirable. One option to extend both lifetime and durability is to upgrade structures to suit changing demands or restore them to their initial level of performance [4]. Consequently, Existing concrete structures must be upgraded, repaired, or strengthened economically and effectively. Therefore, selecting an appropriate method for reinforcing an existing building is essential, and the repair and rehabilitation field needs an efficient and cost-effective restoring method [5].

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The application of the Ferro-cement layer over the structural element is considered one of the low-cost improving methods of structural strengthening and its rapid application on elements' surfaces. Also, it does not require professional workers due to its ease of processing. The American Concrete Institute (ACI) defined the Ferro-cement as "A type of thin-wall reinforced material commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of relatively small wire diameter mesh. The mesh may be metallic or other suitable materials" (ACI 549) [6].

Many researchers used the Ferro-cement to strengthen building structures and demonstrate their effectiveness. For example, Lub and Wanroij [7] studied the ability to strengthen existing RC building structures using new ways, such as the shotcrete-Ferro-cement. Paramasivam [8] investigated the possibility of strengthening the RC beams using the connected Ferro-cement laminates and found that the Ferro-cement is considered an applicable alternative strengthening component for rehabilitating reinforced concrete structures. The potential of the Ferro-cement to improve the performance behavior of the RC beams, especially at the earthquake exposure locations, due to the excellent ductility of the Ferro-cement was studied by Rafeeqi et al. [9]. The researcher found an enhancement of the RC beams' performance and greatly improved ductility at ultimate load.

Nahar et al. [10] evaluated the effect of using Ferro-cement to strengthen the RC beams and improve their properties and found that the use of Ferro-cement to strengthen and repair the RC beams gives a comparatively good performance. Chandralekha and Surendar [11] and Karuny and Eswaran et al. [12] studied the flexural strength of the RC beams after using the Ferro-cement to strengthen. The authors found that the load-bearing capacity increased, and the Ferro-cement was considered a good system that can be used to strengthen RC beams. Damaged RC beams were rehabilitated and repaired as a cost-effective solution to maintain the structures was investigated by Al-Rifai et al. [13]. He found that employing a Ferro-cement jacket is suitable to rehabilitate the damaged beams and acceptable. Shaheen et al. [14] suggested a preparation method for the RC beams with openings using the Ferro-cement laminates. They found that using the Ferro-cement laminates appeared to have positive results in strengthening and repairing the beams. They found that by applying the proposed technique, high ultimate and serviceability loads, superior fracture resistance management, high ductility, and good quality energy absorption qualities could be obtained.

Nasr [15] studied the strengthening of reinforced concrete beams using a Ferro-cement layer with expanded galvanized metal steel mesh of 2.5 mm wire thickness and an opening of 15x40 mm with fixing on three sides of the beam by using tie wire and shear connectors and then casting 5 cm strengthening concrete. The concrete beam was used using a length of 2200 mm and a section of 150 x 200 mm. The experimental results showed that strengthening with Ferro-cement increased load capacity by 23%. In addition, improved crack pattern also enhanced first crack load by 50%, increased gain in ductility by 19.7%, and improved energy absorption up to 64% over the control beam. Besides that, the failure occurred due to flexure tensile.

Sirimontree et al. [16] examined the flexural behaviors of the strengthened RC beams by Ferro-cement. The authors cast three samples of Reinforced Concrete beams with similar dimensions (3000 x 200 x 350 mm) and used one of them as a reference. In contrast, both of the others were strengthened using the Ferro-cement layer with a hexagonal opening mesh thickness of 30 mm to test later. The surface of strengthening samples is purposely rough before wrapping by steel wire mesh and patched with mortar cement for the second beam. At the same time, shear connectors are provided between the concrete surface and Ferro-cement for the third beam. All of the samples are tested under a static four-point bending test. The authors found that the flexural strength increased up to 79% in the strengthened beams over the reference beam, while the ductility was higher in samples with the shear connectors.

The flexural strength of the RC beams when using the Ferro-cement laminates and the steel slag as a partial alternative to fine aggregates was investigated by Sridhar et al. [17]. The examined samples of two-volume mesh fractions were (188% and 2.35%) and two proportions of steel slag reinforcement (0% and 30%). These samples were five RC beams with 1220 x 100 x150 mm and four Ferro-cement laminates beams (galvanized square welded wire mesh 3 mm wire diameter was used and strengthened with the epoxy resin with a size of 1220 mm × 100 mm × 25 mm and). All of the samples were tested under two-point loading. The authors remarked that the Ferro-cement beams with volume fraction proportion of 2.35% and 30% steel slag led to an increase in the load-carrying capacity significantly up to 83 % under flexural load, besides the increase of the other properties such as the increase of the energy absorption capacity and ductility.

This research investigates the effect of wire-mesh type on strengthening reinforced concrete beams and chooses the best one of three available wire meshes in the local markets to form a Ferro-cement layer to strengthen reinforced concrete beams.

2. Materials

2.1 Cement

Ordinary Portland cement (Type I) was used with a specific gravity of 3.16, conforming to ASTM C150 C150M [18].

2.2 Sand

Natural sand with a sulfate content of 0.25% was used as a fine aggregate within the requirements of ASTM C33 [19]. Its grading is shown in Table 1.

Table 1: Grading of sand

Sieve Size (mm)	Sand used in a concrete mix, % passing	Sand used in mortar mix, % passing
10	------	------
4.75 (No. 4)	93.24	-----
2.36 (No. 8)	80.17	80.22
1.18 (No. 16)	64.03	64.06
0.6 (No. 30)	35.82	35.84
0.3 (No. 50)	17.28	17.28
0.15(No. 100)	0.3	0.1

2.3 Coarse Aggregate

Crushed gravel with (a 19 mm) maximum size was used. Its sulfate content is 0.047% within the requirements of ASTM C33 [19]. Its grading is shown in Table 2.

Table 2: The coarse aggregate Grade

Sieve size (mm)	%, passing
19	100
10	43.7
5	3

2.4 Water

Potable water was used for mixing and curing specimens throughout the experiments.

2.5 Superplasticizer

The high-range water-reducing admixture was used, with the commercial name GLENIUM 51. It complies with ASTM C 494 (Type F) [20].

2.6 Reinforcing Steel Bars

As longitudinal steel, deformed steel bars of 10 mm and 6 mm diameters were used. In addition, 10 mm diameter bars were used as tension reinforcement, and 6mm bars were used as compression steel and stirrups. The properties of those steel bars are shown in Table 3. Following the ACI 318 [21].

Table 3: The properties of steel bars

Nominal Diameter (mm)	Yield Strength (fy) (MPa)	Ultimate Strength (fu) (MPa)
6	435	557
10	478	685

Table 4: Properties of wire meshes

Type	Opening, mm2	Wire dia. mm	Yield Stress, (N/mm2)	Ultimate Stress, (N/mm2)
1	225	1	410	685
2	42	0.5	424	694
3	439	0.4	292	419

2.7 Wire Meshes

Three types of wire mesh, most available in local markets and shown in Figure 1, were used in the present work. Their properties are shown in Table 4.

Type 1: PVC (smooth poly-vinyl chloride) coated galvanized welded wire steel mesh to make it more durable and protect from corrosion, with a square mesh opening.

Type 2: An expanded metal mesh of galvanized plate in rhombus mesh opening.

Type 3: Galvanized hexagonal opening wire mesh from woven stainless-steel wire.

2.8 Anchoring Grout

This grout is used in the fixing process of the wire mesh on concrete. It comprises two-component polyester resin-based anchoring grout, with the commercial name Master Flow 916 AN.

2.9 Screws

Self-drilling stainless steel screws are used with a length of 25 mm and diameter of 6 mm and used two washers of diameter 30 mm, as shown in Figure 2.

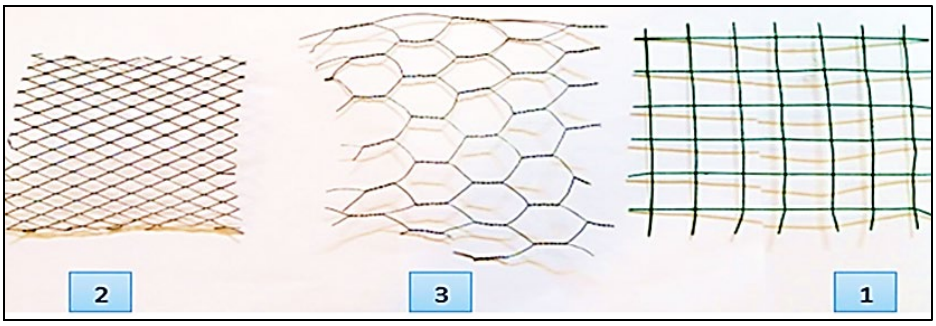

Figure 1: Wire meshes used

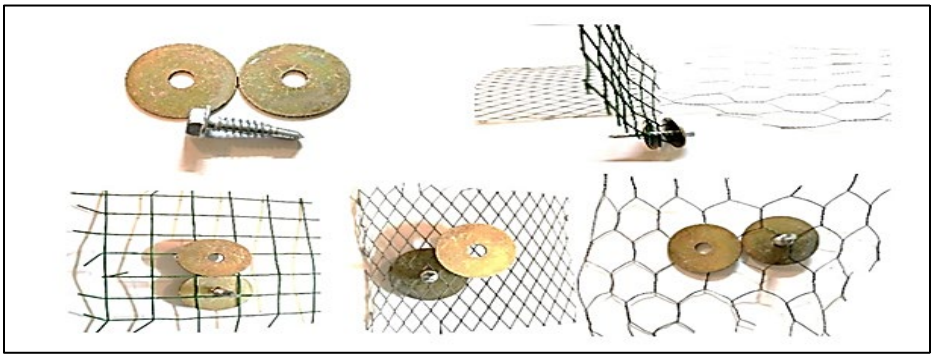

Figure 2: Screw and washers with the wire meshes used

3. Mixing and Casting

3.1 Mortar Mix Design

The adopted mix proportion (cement: sand) is 1:2 with a water/cement ratio of 0.4. The mix flow was within 100-110% required for rendering cement mortar.

3.2 Mix Design and Reinforcement of Concrete Beams

According to British Standards (BS) [22], a concrete mix was designed to give 28 days of compressive strength of about 35 MPa, and a slump of about 80 mm. The composition mix used in this study was: 1 Cement: 1.5 Sand: 2 Aggregate: w/c of 0.4. The details of the steel bars reinforcement of concrete beams used throughout this study are given in Figure 3.

3.3 Preparation, Casting, and Curing of Specimens

Molds for flexural strength testing were prepared with 150 mm width, 200 mm height, and 750 mm length internal dimensions. To determine concrete compressive strength, six 100 mm cubes were prepared to cast from the same concrete used for beams. All beams' specimens and cubes were left in the laboratory for 24 hours after casting. Then, they were stripped from the molds and placed in a water container filled with tap water. At 28 days' age, they were taken out of the container and strengthened, then tested according to the standard specifications.

3.4 Preparation of Concrete Surface and Fixing of Ferro-cement Layer

Four beams were used, named R1 (as a reference), M1, M2, and M3 are strengthened using one of three types of wire mesh (mentioned in Table **5**) and cement mortar to obtain the best meshes type. All beams were strengthened by applying the U wrap of wire mesh of Ferro-cement with fixing by using mechanical method (using screws) to eliminate the de-bonding of Ferro-cement and trying to reach the full maximum tensile strength of Ferro-cement.

The fixing procedure includes:

1) Cleaning of three sides of the beam then drilling the beam in width and tension face to make holes, everyone equal to 4 mm which is less than the screw diameter of 6 mm. 2 holes at the bottom of beam side and 2 holes at the top of beam side and two holes at tension face of the beam.
2) Fill the holes with grout, then enter the connector screw of diameter 6 mm in each hole using two washers to get a perfect fixed Ferro-cement mesh on the beam.
3) Applying a layer of cement mortar up to the thickness of 20 mm on the three faces of beams. After that, the beams are cured for 7 days and then tested.
   The details of the strengthened and fixing method are shown in Figure 4.

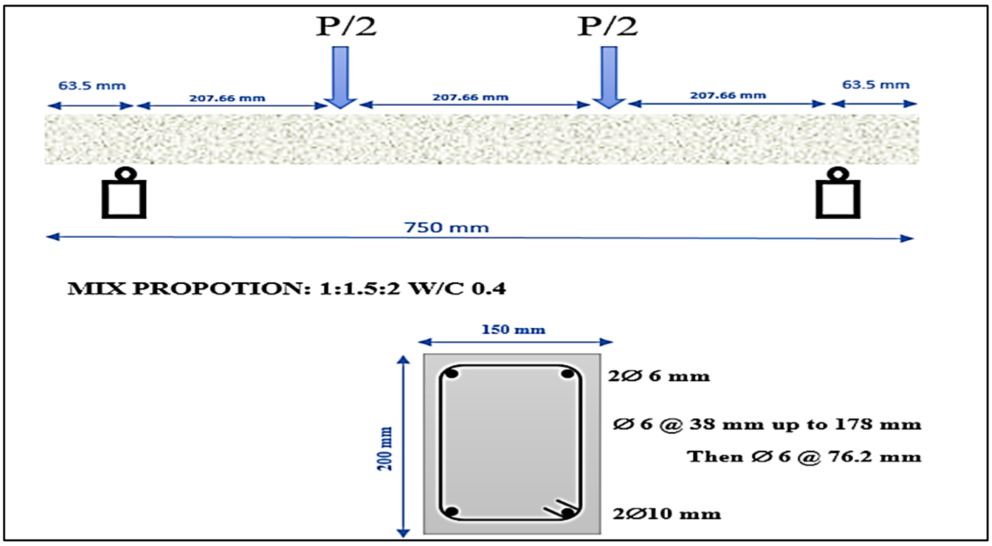

Figure 3: Details of reinforcement of concrete beams

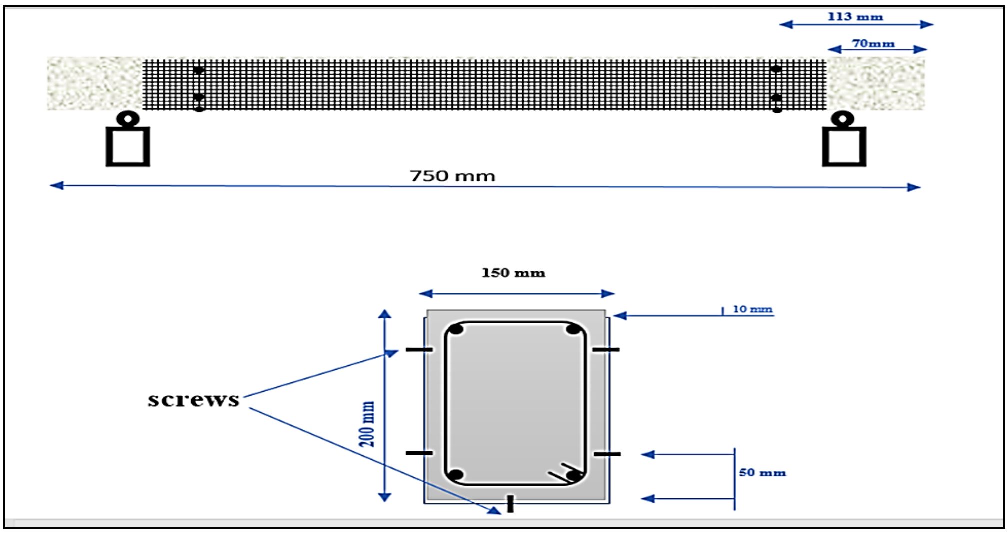

Figure 4: The details of the strengthening and fixing method

4. Tests

4.1 Compressive Strength

The compressive strength test was performed on cubes in a compression testing machine of 3000 kN capacity at 28 days, to be 37 MPa. The reported strengths are the average of three test specimens.

4.2 Testing of Beams

The beam specimens were tested using a hydraulic test machine for cracking and ultimate loads with a maximum loading capacity of (330 kN). The effective span of the beam was 623 mm. The load was applied on two points, each 104 mm away from the center of the beam towards the support. Dial gages of 0.01 mm accuracy were used for measuring the deflections under the mid-span and at load points. The dial gauge readings were recorded at different loads.

The load was applied at intervals of 500 N/S. The behavior of the beam was observed, and the first crack was identified by sight. The deflections were recorded for respective load increments until failure.

5. Results and Discussion

5.1 Testing of Beams

Table 5 and Figures 5 and 6 indicate the effect of different Ferro-cement layers used in strengthening reinforced concrete beams on their behavior under flexural loading. Results indicate that for the reference beam, with increasing applied load and nearly 54 kN, the first crack was formed in the middle of the beam, and deflection reached 0.3 mm. Then, at continuously increasing loads, more cracks appeared. Next, those cracks began to appear in a region between the support and the point of the applied load, starting from the support area toward the applied load area. Finally, those cracks crossed up near the loading point, and the specimen failed when the load increased up to 103 kN and deflected 6.8 mm, as shown in Figure 7.

Table 5: Effects of Ferro-cement type on strengthening beams

Symbol	Strengthening Ferro-cement type	First Crack		Failure	
		Load, kN	*Deflection, mm*	*Load, kN*	*Deflection, mm*
R1, Ref.	---	54	0.3	103	6.8
M1	strengthen with type 1 mesh	93	0.51	185	10.31
M2	strengthen with type 2 mesh	57	0.35	117	7.71
M3	strengthen with type 3 mesh	77	0.42	161.62	9.67

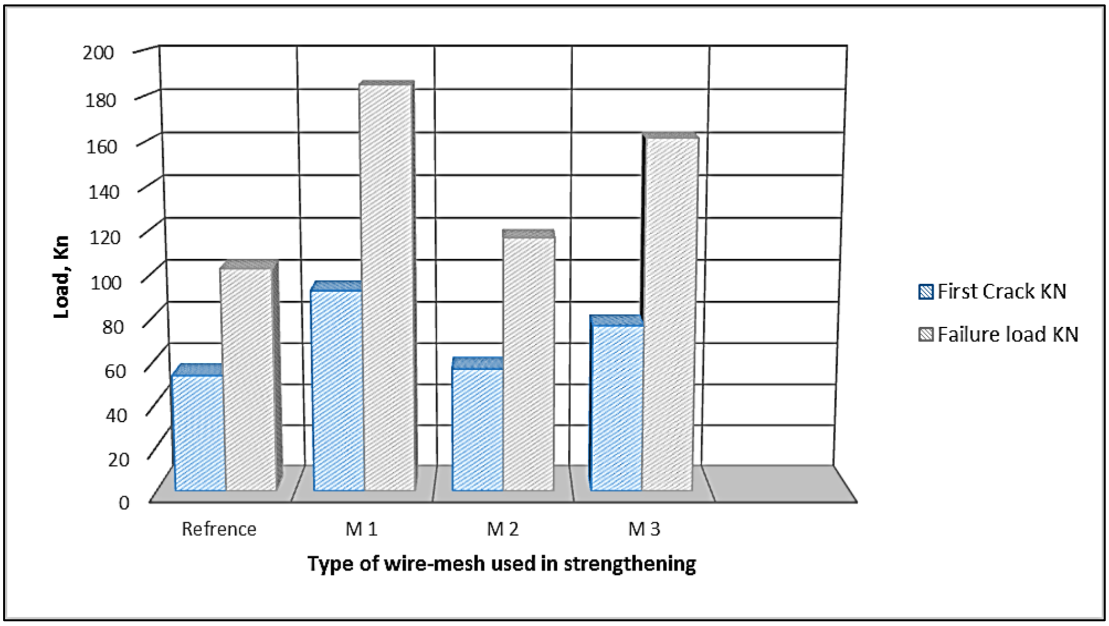

Figure 5: Effects of Ferro-cement type on bearing capacity of Reinforced concrete beams

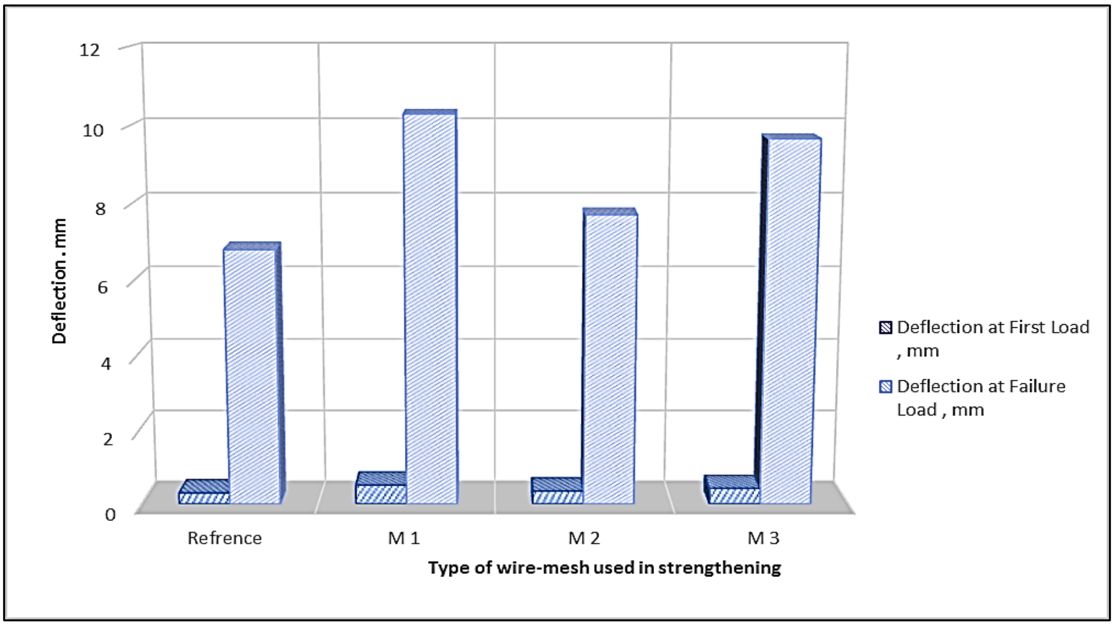

Figure 6: Effects of Ferro-cement type on the deflection of Reinforced Concrete beams

Figure 7: Failure Cracks in the reference beam

It was noticed that there was no debonding between any of the three types of Ferro-cement layers from reinforced concrete beams due to the applied loading.

To strengthen a beam with mesh type1, the first crack was formed in the right-hand side of the beam at a load of 93 kN and deflection of 0.51 mm. At continuously increasing loads, more cracks appeared. These cracks began to appear in a region between the support and the point of the applied load with increasing load. Finally, the shear crack in the right-hand side of the beam appeared. These cracks occurred in the Ferro-cement layer, then concrete and shear cracks crossed near the loading point, and then the specimen failed with a load of 185 kN and deflection of 10.31 mm.

This specimen shows improvement up to 72 % at first crack load and 79 % at failure load, and deflection increased up to 70% and 51% at first crack and failure load, respectively, from the reference beams, which is comparable with ACI 549 [8].

Results indicate that the meshes with square openings (type 1) are more efficient than the other types of meshes. This is because their wires are oriented in the directions of the maximum stresses [8] and have a larger mesh diameter and a higher modulus that leads to higher stiffness than other meshes—shown in Figure 8.

Figure 8: Cracks in reinforced concrete beam strengthened with type 1 Ferro-cement layer

For the beam strengthened with mesh type 2, the first crack was formed in the middle of the beam at a load of 57 kN and deflection of 0.42 mm. At continuously increasing loads, another crack appeared. These cracks began to appear in a region between the support and the point of the applied load. Then another shear crack appeared on the right-hand side of the beam. These cracks occurred in the Ferro-cement layer than in concrete, and crack crossed up near the loading point, and then the specimen failed in the load of 117 kN and deflection of 7.71 mm. This specimen has shown less improvement than the specimen of mesh type 1 because the opening of meshes used are too small and caused a decrease in the adhesion area between cement mortar and beam face. The result shows an increase of up to 5 % at first crack load and 14 % at failure load, and deflection increased up to 16 % and 13 % at first crack and failure load, respectively, from the reference beams, as shown in Figure 9. For the beam strength with mesh type 3, the first crack was formed in the middle of the beam at a load of 77 kN and deflection of 0.51 mm. At continuously increasing loads, more cracks appeared, and these cracks began to appear in a region between the support and the point of the applied load. These cracks occurred in the Ferro-cement layer, then concrete and cracks were crossed up near the loading point, and then the specimen failed with a load of 161.62 kN and deflection of 9.67 mm.

Figure 9: Cracks in reinforced concrete beam strengthened with type 2 Ferro-cement layer

This specimen showed improvement up to 42 % at first crack load and 56 % at failure load, and deflection increased up to 40 % and 42 % at first crack and failure load, respectively, from the reference beams. In addition, these woven mesh wires are not initially straight because the weave has the smallest diameter, leading to Faster failure and less resistance ACI 549 [8], as shown in Figure 10.

Figure 10: Cracks in reinforced concrete beam strengthened with type 3 Ferro-cement layer

Table 6 below is for a comparison of the results of the present work. In all the previous studies mentioned earlier, the comparison was in terms of deflection and bearing capacity. However, each study had different results due to different properties of wire mesh used like the metal of wire used and diameter and opening of wires, tensile strength, and modulus of elasticity of mesh. Besides that, the method used to strengthen and thickness the Ferro-cement layer. Furthermore, the properties and dimensions of reinforced concrete beams affect the result of each study.

Table 6: Comparison of the effect of Ferro-cement type used in the present study and other studies on the strengthening of reinforced concrete beams

Study	Strengthening technique	Deflection increases at failure, %	Failure load increase, %
The present study	strengthen with type 1 mesh and 20 mm thickness of cement mortar	51.6	79.6
	strengthen with type 2 mesh and 20 mm thickness of cement mortar	13.4	13.6
	strengthen with type 3 mesh and 20 mm thickness of cement mortar	42.2	56.9
Nasr [1]	strengthened using U warp of Ferro-cement laminate of expanded galvanized metal steel mesh with a thickness of 25 mm and an opening of 15x40 mm. Fixing on three sides of the beam by using tie wire and shear connectors at three sides of the beam, With the addition of 5 cm of concrete cover.	19.7	23
Sirimontree et al. [2]	Reinforced concrete beams strengthened with an external steel bar and U warp of Ferro-cement layer with hexagonal opening mesh fixed using shear connectors, with the thickness of 30 mm.	26	79
Sridhar et al [3]	Pre-cast Ferro-cement laminate was used galvanized square welded wire mesh, 3 mm wire diameter was used with the size of 1220 mm × 100 mm × 25 mm and strengthening with the epoxy resin and at three sides of the beam.	46.43	83

6. Conclusions

The main conclusions from the present research are listed below:

1) The strengthening of reinforced concrete beams with any of the three studied types of Ferro-cement layer increases the flexural capacity and deflection at first crack and failure.
2) The use of Ferro-cement mesh (type 1) with a square opening has the best effect on increasing the bearing capacity of reinforced concrete beams and their deflection more than the other two types of meshes. As a result, the first crack and failure load increases were 72 and 79%, respectively. In contrast, the deflection increased 70 and 51% at the first crack and failure load.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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