Repair and Strengthening of Damaged RC Beams using Ferrocement Laminates

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ABSTRACT

The deterioration of concrete structures might be due to ageing, poor maintenance, corrosion due to poor environmental conditions and accidental situations like earthquakes. The need to upgrade the deteriorated civil engineering infrastructure greatly enhances with the ever increasing demands. Therefore rehabilitating and retrofitting civil engineering infrastructure has been identified as important issue to be addressed.

In this research paper, the methods of strengthening of reinforced concrete beams using ferrocement laminates are reviewed. Investigation into the methods of anchorage of the ferrocement laminates in the strengthened beams, methods of increasing the ultimate load of the original beams using ferrocement laminate and control the cracking behavior of the beams and the effect of the damage of the original beams prior for repair are examined. The results show that the strengthened beams have performed better in cracking behavior, reduction in mid-span deflection and increased in the ultimate load and the pre-cracked beams prior to repair did not affect the ultimate loads of the strengthened beams tested.

A large number of civil infrastructures around the world are in a state of serious deterioration today due to carbonation, chloride attack, etc. Moreover many civil structures are no longer considered safe due to increase load specifications in the design codes or due to overloading or due to under design of existing structures or due to lack of quality control. In order to maintain efficient serviceability, older structures must be repaired or strengthened so that they meet the same requirements demanded of structures built today and in future. It is becoming both environmentally and economically preferable to repair or strengthen the structures rather than replacement, particularly if rapid, effective and simple strengthening methods are available [1-3]. Different types of cement based materials are available in market for that job. However due to higher tensile strength to weight ratio and a degree of toughness, ductility, durability and cracking resistance that is considerably greater than those found in other conventional cement based materials Ferrocement, is ideally suited as an alternative strengthening component for the rehabilitation of reinforced concrete structures [4-7]. According to the ACI Committee 549, Ferrocement is a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortal reinforced with closely spaced layers of continuous and relatively small wire diameter mesh. Paramasivam et al. [8] reported that the purpose of the fine mesh was simply for crack control and was not relied upon to contribute to the structural strength of the member. Ferrocement laminates with skeletal bar can take significant role in strengthening reinforced concrete beams. For flexural strengthening, the ferrocement laminates were cast onto the soffit (tension face) of the beams without any change in width of the beams. In this study, the strengthening of simply supported reinforced concrete beams using ferrocement laminate attached onto the soffit was investigated.

KEYWORDS: *Reinforced Concrete Beam, Strengthening, Ferrocement*

1. INTRODUCTION

Ferrocement is a form of reinforced mortar that differs from conventional reinforced or pre-stressed concrete primarily by the manner in which the following elements are dispersed and arranged. It consists of closely placed, multiple layers of mesh or fine rods completely embedded in cement mortar.

Ferrocement reinforcement can be assembled in to its final desired shape and the mortar can be plastered directly in place without the use of form. The following definition as adopted by ACI committee " Ferrocement is a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely placed layers of

continuous and relatively small size wire mesh. The mesh can be made of metallic or other suitable materials"

Widespread use of ferrocement in construction industry has occurred during the last 25 years. The main worldwide applications of ferrocement construction to date have been for silos, tanks, roofs and mostly boats.

The objectives of the study may be listed as follows:
1. To investigate the methods of anchorage of the ferrocement laminates in the strengthened beam.
2. To examine the effect of different layer of wire mesh.
3. To examine the effect of the damage of the original beams prior for repair.

2. EXPERIMENTAL PROGRAM
The main objective of this investigation is to study the flexural behavior of concrete beams rehabilitated and retrofitted with ferrocement laminates. The experimental programme consists of casting and testing of nine RCC beams of 125mm ×250mm × 3200mm.
➢ Control beam   - 1 No.
➢ Rehabilitation of beams - 4 Nos. (loading variations done by 75% of ultimate load)
    Out of these 4 beams, 2 Nos. for each 2 layers and 3 layers wire mesh.
➢ Retrofitting of beams - 4 Nos.
    Out of these 4 beams, 2 Nos. for each 2 layers and 3 layers wire mesh.

3. TESTING OF MATERIALS
Properties of materials used for this investigation are arrived by testing of cement, fine aggregate, coarse aggregate, reinforcement and the details of the test results are given below.

3.1. Fine Aggregate
Size : passing through 4.75mm and retaining on 0.75 micron
Specific gravity   : 2.48
Fineness modulus   : 3.10
Grading zone   : II
Type   : Clean river angular sand.

3.2. Coarse Aggregate
Size : passing through 20mm and retaining on 10mm sieve.
Specific gravity   : 2.91
Fineness modulus   : 3.57
Type   : crushed granite (angular)

3.3. Cement
Specific gravity : 2.88
Brand   : OPC 53 grade

3.4. Water : Ordinary potable water free from impurities.

3.5. Mix Design
The mix proportion of 1: 1.52: 3.417 at 0.5 water cement ratio was used.

3.6. Test Results of Concrete Cubes
The concrete mix proportion designed by IS method to achieve the strength of 20 N/mm². Three cube specimens were cast and tested at the time of beam test (at the age of 28 days) to determine the compressive strength of concrete.

The average compressive strength of the concrete was 29.11 N/mm².

3.7. Reinforcement Details
Main reinforcement   : 2 Nos. of 12mm dia. HYSD bars.
Secondary reinforcement : 2 Nos. of 8mm dia HYSD bars.
Shear reinforcement   : 6mm dia at 120mm c/c.
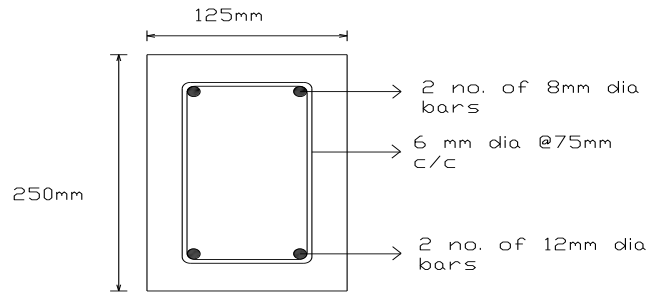
The yield strength of steel reinforcements used in this experimental program was determined by performing the standard tensile test on the three specimens of each bar. The average yield stresses of steel bars obtained were 390 N/mm², 375 N/mm² and 240 N/mm² for 12mm, 8mm and 6mm diameter respectively.

3.8. Mesh Used
Weld mesh size : 15mm x 15mm, 2mm dia.
Woven mesh : t=0.8mm, gauge=20.

The weld mesh and woven mesh are tied together, which is used as reinforcement for laminates.

4. RESULTS AND DISCUSSION
The ultimate strength for the conventional beams, rehabilitated and retrofitting beams are tabulated as follows.

Sl. No	Beam	C/S Area mm²	Layer of wire mesh	Ultimate strength in kN
1	Control	125×250	-	40
2	BTS1	125×250	2	45
3	BTS2	125×250	2	44
4	BTS3	125×250	3	47
5	BTS4	125×250	3	46
6	BTRF1	125×250	2	56
7	BTRF2	125×250	2	55
8	BTRF3	125×250	3	59
9	BTRF4	125×250	3	58

4.1. Control Beam
The ultimate load carrying capacity of the conventional beam was 40kN and the average first crack load for the control beam was 17kN. The maximum mid span deflection at collapse for the conventional beam was 23.5mm. The load vs. deflection curve is shown in the following Fig. 1.1.
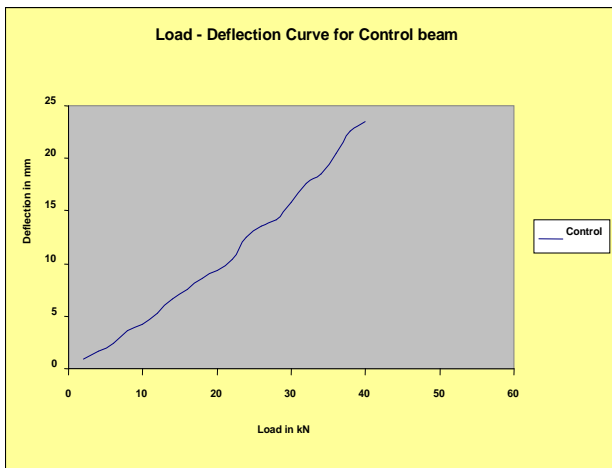
Fig.1.1. Load vs. Deflection curve for control beam

4.2. BTS1 Beam

The ultimate load carrying capacity of conventional beam was 40kN and that of this rehabilitated beam was 45kN. Therefore the rehabilitated beam shows 1.125 times increase when compared with conventional beam. The average first crack load for the control beam was 17kN whereas that of this rehabilitated beam was 20.5kN. Therefore the first crack load of rehabilitated beam was increased 1.205 times when compared to that of conventional beam.

The maximum mid span deflection at collapse for the conventional beam was 23.5mm whereas it was 22.34 for rehabilitated beam. The average mid span deflection for the rehabilitated beam with mesh was 0.05 times lower than that of conventional beam. The load vs. deflection curve is shown in the following Fig.1.2.
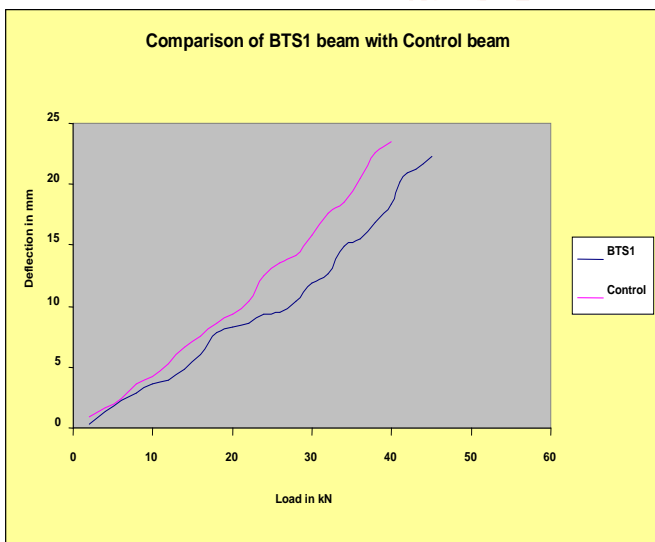

Fig.1.2 Load vs. Deflection curve for control and BTS1 beam.

4.3. BTS2 Beam

The ultimate load carrying capacity of conventional beam was 40kN and that of this rehabilitated beam was 44kN. Therefore the rehabilitated beam shows 1.10 times increase when compared with conventional beam. The average first crack load for the control beam was 17kN whereas that of this rehabilitated beam was 21kN. Therefore the first crack load of rehabilitated beam was increased 1.235 times when compared to that of conventional beam.

The maximum mid span deflection at collapse for the conventional beam was 23.5mm whereas it was 21.92mm for rehabilitated beam. The average mid span deflection for the rehabilitated beam with mesh was 0.07 times lower than that of conventional beam. The load vs. deflection curve is shown in the following Fig.1.3.
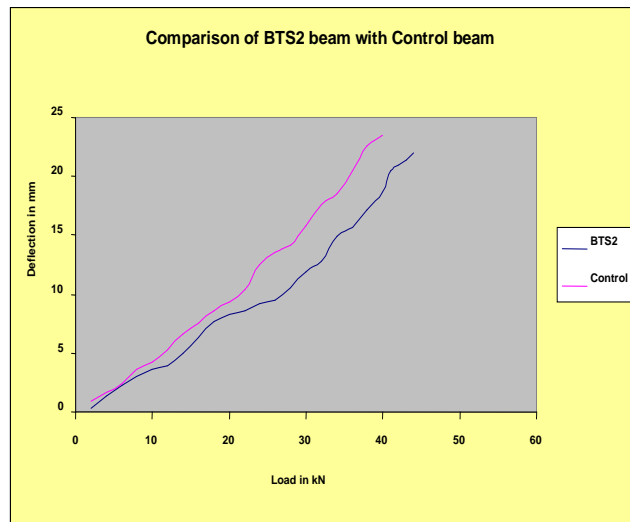

Fig.1.3. Load vs. Deflection curve for control and BTS2 beam.

4.4. BTS3 Beam

The ultimate load carrying capacity of conventional beam was 40kN and that of this rehabilitated beam was 47kN. Therefore the rehabilitated beam shows 1.175 times increase when compared with conventional beam. The average first crack load for the control beam was 17kN whereas that of this rehabilitated beam was 20kN. Therefore the first crack load of rehabilitated beam was increased 1.17 times when compared to that of conventional beam.

The maximum mid span deflection at collapse for the conventional beam was 23.5mm whereas it was 20.36mm for rehabilitated beam. The average mid span deflection for the rehabilitated beam with mesh was 0.134 times lower than that of conventional beam. The load vs. deflection curve is shown in the following Fig.1.4.
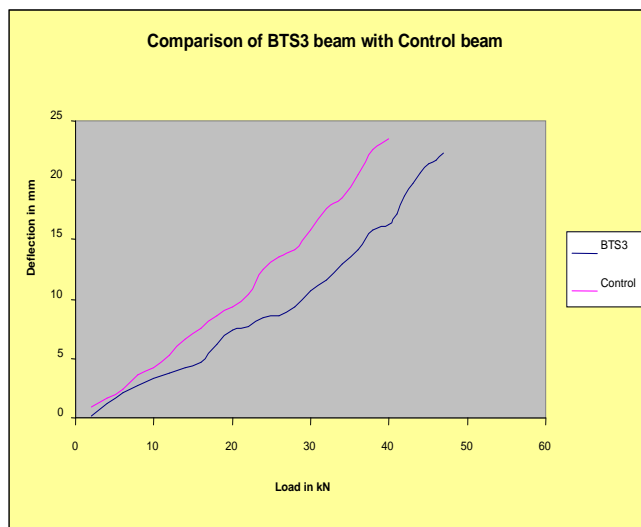

Fig.1.4. Load vs. Deflection curve for control and BTS3 beam.

4.5. BTS4 Beam

The ultimate load carrying capacity of conventional beam was 40kN and that of this rehabilitated beam was 46kN.

Therefore the rehabilitated beam shows 1.15 times increase when compared with conventional beam. The average first crack load for the control beam was 17kN whereas that of this rehabilitated beam was 20.5kN. Therefore the first crack load of rehabilitated beam was increased 1.2 times when compared to that of conventional beam.

The maximum mid span deflection at collapse for the conventional beam was 23.5mm whereas it was 20.74mm for rehabilitated beam. The average mid span deflection for the rehabilitated beam with mesh was 0.117 times lower than that of conventional beam. The load vs. deflection curve is shown in the following Fig.1.5.
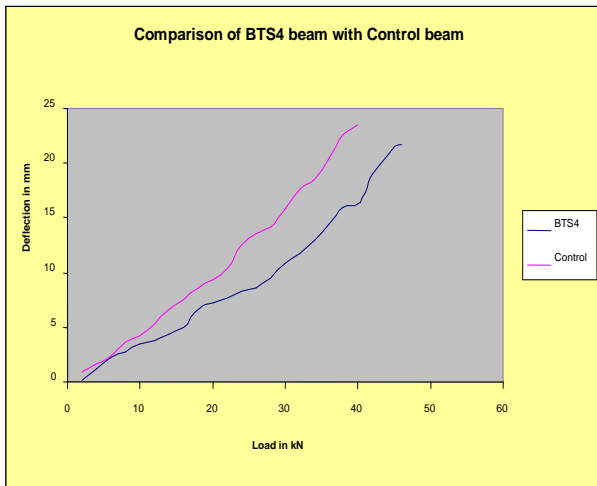

Fig.1.5. Load vs. Deflection curve for Control and BTS4 beam.

4.6. BTRF1 Beam
The ultimate load carrying capacity of conventional beam was 40kN and that of this retrofitted beam was 56kN. Therefore the retrofitted beam shows 1.4 times increase when compared with conventional beam. The average first crack load for the control beam was 17kN whereas that of this retrofitted beam was 23.5kN. Therefore the first crack load of retrofitted beam was increased 1.38 times when compared to that of conventional beam.

The maximum mid span deflection at collapse for the conventional beam was 23.5mm whereas it was 26.76mm for retrofitted beam. The average mid span deflection for the retrofitted beam with mesh was 1.138 times higher than that of conventional beam. The load vs. deflection curve is shown in the following Fig.1.6.
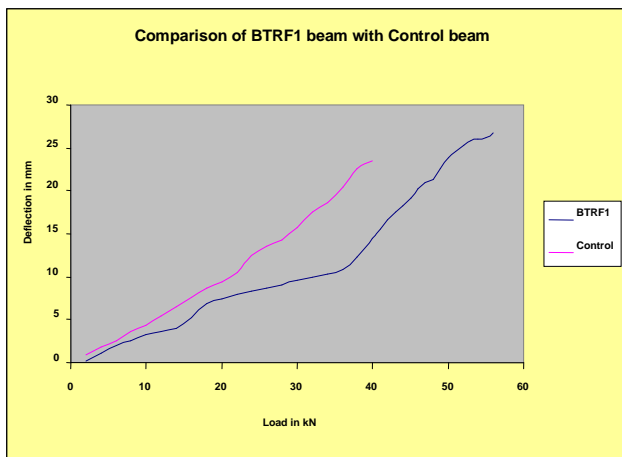

Fig.1.6. Load vs. Deflection curve for control and BTRF1 beam.

4.7. BTRF2 Beam
The ultimate load carrying capacity of conventional beam was 40kN and that of this retrofitted beam was 55kN. Therefore the retrofitted beam shows 1.375 times increase when compared with conventional beam. The average first crack load for the control beam was 17kN whereas that of this retrofitted beam was 24kN. Therefore the first crack load of retrofitted beam was increased 1.41 times when compared to that of conventional beam. The maximum mid span deflection at collapse for the conventional beam was 23.5mm whereas it was 26.94mm for retrofitted beam. The average mid span deflection for the retrofitted beam with mesh was 1.15 times higher than that of conventional beam. The load vs. deflection curve is shown in the following Fig.1.7.
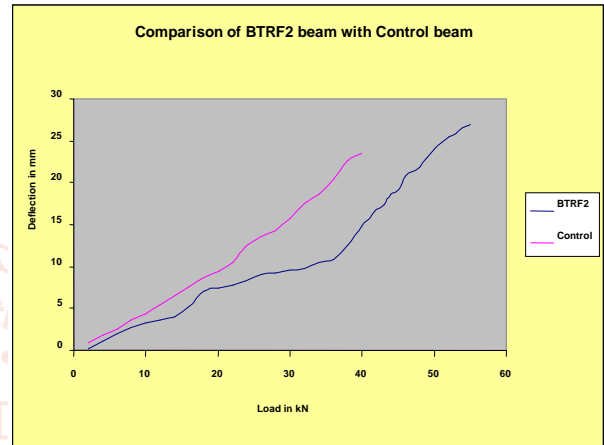

Fig.1.7. Load vs. Deflection curve for control and BTRF2 beam.

4.8. BTRF3 Beam
The ultimate load carrying capacity of conventional beam was 40kN and that of this retrofitted beam was 59kN. Therefore the retrofitted beam shows 1.475 times increase when compared with conventional beam. The average first crack load for the control beam was 17kN whereas that of this retrofitted beam was 24.5kN. Therefore the first crack load of retrofitted beam was increased 1.44 times when compared to that of conventional beam. The maximum mid span deflection at collapse for the conventional beam was 23.5mm whereas it was 24.67mm for retrofitted beam. The average mid span deflection for the retrofitted beam with mesh was 1.05 times higher than that of conventional beam. The load vs. deflection curve is shown in the following Fig.1.8.
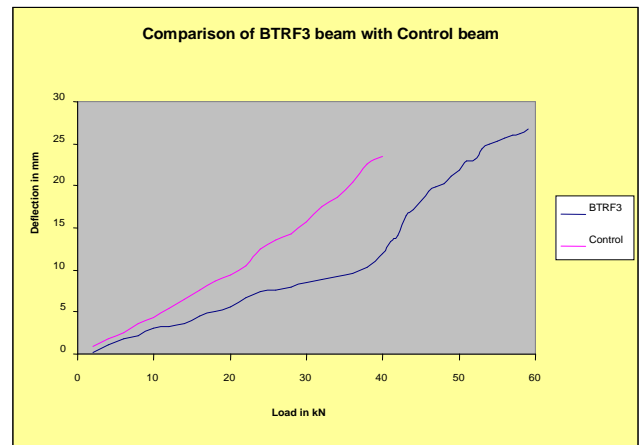

Fig 1.8 Load vs. Deflection curve for control and BTRF3 beam.

4.9. BTRF4 Beam

The ultimate load carrying capacity of conventional beam was 40kN and that of this retrofitted beam was 58kN. Therefore the retrofitted beam shows 1.45 times increase when compared with conventional beam. The average first crack load for the control beam was 17kN whereas that of this retrofitted beam was 25kN. Therefore the first crack load of retrofitted beam was increased 1.47 times when compared to that of conventional beam. The maximum mid span deflection at collapse for the conventional beam was 23.5mm whereas it was 24.42mm for retrofitted beam. The average mid span deflection for the retrofitted beam with mesh was 1.04 times higher than that of conventional beam. The load vs. deflection curve is shown in the following Fig.1.9.
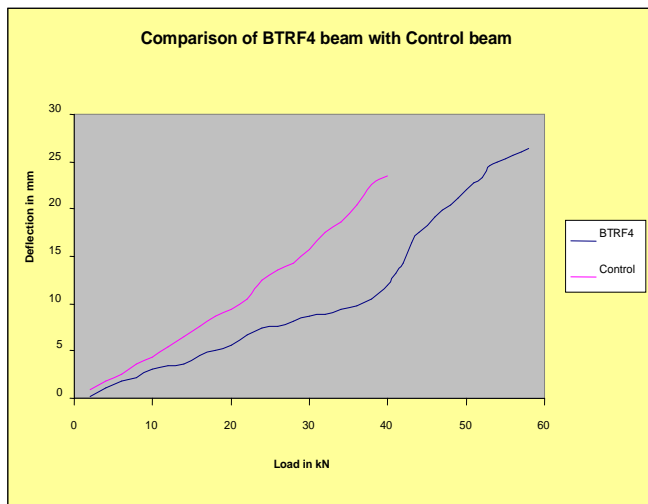

Fig.1.9. Load vs. Deflection curve for control and BTRF4 beam.

4.10. General Discussion

During the second stage of loading for rehabilitated beams, a careful examination of the failed specimens showed that the reinforced concrete and the ferrocement acted monolithically. The application of the ferrocement laminate has given adequate confinement for the reinforced concrete beams and hence during the failure stage splitting of concrete did not occur.

Fig. 1.10 shows the typical load vs. deflection curve for the control specimen and rehabilitated specimens. Fig. 1.11 shows the typical load vs deflection curve for the control specimen and retrofitted specimens. Fig. 1.12 shows the typical load vs deflection curve for the control specimen and for rehabilitated and retrofitted specimens. It may be noted from those figures, the slope of the curve was found to be steeper in case of rehabilitated and retrofitted beams, which indicate the stiffness of the rehabilitated and retrofitted beams was higher than the control specimen. Also the deflections of rehabilitated beams were lesser than the control specimen for the corresponding load. In case of retrofitted beams also the deflections were lesser than control specimen for the corresponding load. Generally, using ferrocement laminates will give the higher ultimate load than the conventional beam.
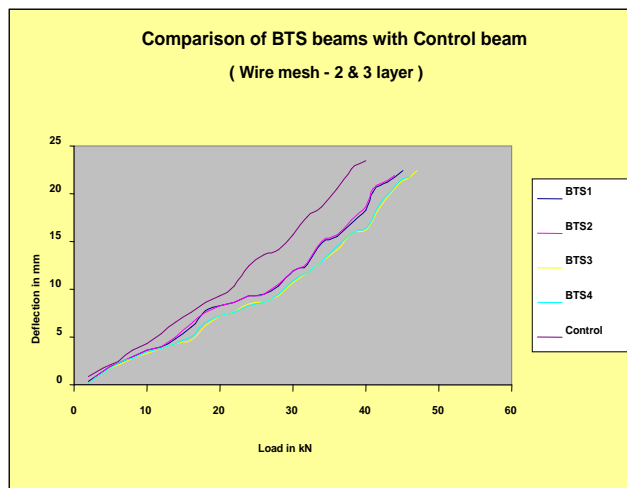

Fig 1.10 Load vs. Deflection curve for rehabilitated beams and control beam.
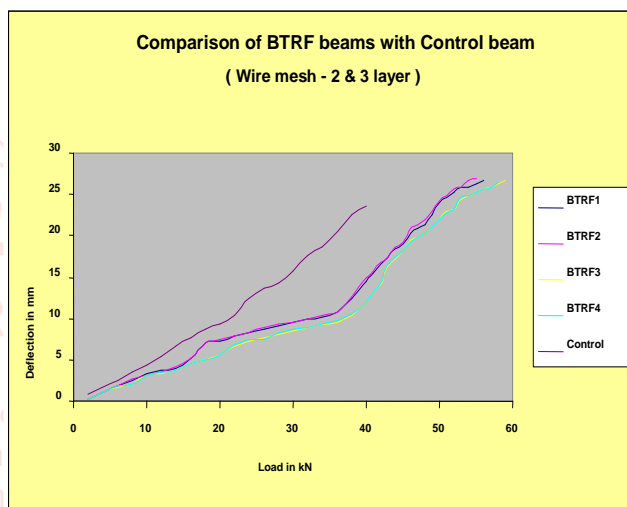

Fig 1.11 Load vs. Deflection curve for control beam and retrofitted beams.
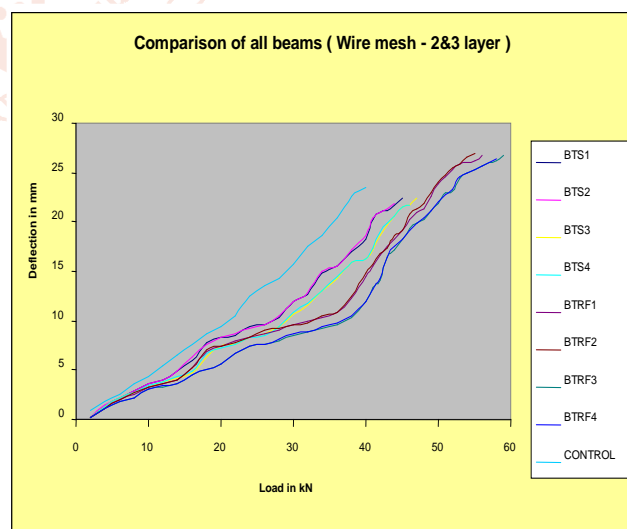

Fig 1.12 Load vs. Deflection curve for control beam and all other beams.

5. CONCLUSION

In this experimental programme, 9 Numbers of reinforced concrete beams were cast and tested up to failure. Out of nine, one is control beam; four beams are rehabilitation beams and the remaining four are retrofitting beams. The rehabilitation beams were loaded upto 75% of ultimate load

to distress them. Then the beams were rehabilitated with ferrocement laminates with double layer at the tension face insitu with epoxy resin. Also for retrofitted beams were retrofitted with ferrocement laminates with double layer at the tension face insitu with epoxy resin. The rehabilitated beams and the retrofitted beams were tested up to failure. Then the behavior of the tested beams was studied. From this study, the following observations were made.

➢ The specimens BTS1, BTS2, BTS3, BTS4, BTRF1, BTRF2, BTRF3 and BTRF4 exhibited 12.5%, 10%, 17.5%, 15%, 40%, 37.5%, 47.5% and 45% higher ultimate strength than that of conventional beam respectively.
➢ The specimens BTS1, BTS2, BTS3 and BTS4 exhibited 0.95, 0.93, 0.87 and 0.88 times lower deflection than that of conventional beam respectively.
➢ The specimens BTRF1, BTRF2, BTRF3 and BTRF4 exhibited 1.14, 1.15, 1.05 and 1.04 times higher deflection than that of conventional beam.
➢ The specimens BTS1, BTS2, BTS3, BTS4, BTRF1, BTRF2, BTRF3 and BTRF4 exhibited 1.20, 1.24, 1.18, 1.21, 1.38, 1.41, 1.44, and 1.47 times higher first crack load than that of conventional beam respectively. This shows that the load causing initial crack is more for rehabilitated and retrofitted beams than that of conventional beam.
➢ The application of ferrocement layer has given adequate confinement for the reinforced concrete beams and hence during the failure stage splitting of concrete did not occur.

While seeing the test results, it is proved that Ferro cement laminates are the cheap, cast in-situ solution for rehabilitating the distressed structural members. Its external strengthening behaviour is also quite satisfactory. But, care should be taken that proper adhesive should be used with bondage without air gap. Further, ferrocement laminates should be as thin as possible to avoid delaminating problems.

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