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Load-Deflection for Epoxy Repaired High Strength Reinforced Concrete Beams

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Abstract

This paper presents an experimental investigation to predict the load-deformation behavior of High Strength reinforced concrete beams that failed in flexure and were repaired by epoxy injection.

Four simply supported reinforced concrete beams with dimensions of (120*230*2550mm) were investigated after repairing with epoxy resin injection method. Beams B_1 and B_2 have tensile steel ratio of 0.0099, while Beams B_3 and B_4 have tensile steel ratio of 0.0177.

Deflections were measured at first third, second third from the support and at mid span for all beams by using dial gauges.

The behavior achieved for resin injected high-strength reinforced concrete beams was similar to that of the original beams. However, the cracks do not re-open after retesting. Instead, new nearby cracks are developed and the repaired beams showed a greater ductility than the original beams.

الخلاصـــــــة

يقدم هذا العمل بحثاً عملياً عن سلوك العتبات الخرسانية المسلحة المصنوعة من الخرسانة عالية المقاومة الفاشلة بالأنثناء و المُصلّحة بوساطة حقن التشققات (بالايبوكسي).

*تم استخدام أربعة عتبات خرسانية مسلحة عالية المقاومة بسيطة الاسناد. بأبعاد(١٢٠*٢٣٠* ٢٥٥٠ ملم) حيث تمت دراستها بعد إصلاحها بطريقة الحقن بالأيبوكسي. العتبات B_1 و B_2 ذات نسبة حديد تسليح تساوي (٠٠٩٩و٠) بينما العتبات B_3 و B_4 فكانت نسبة حديد التسليح فيها (١٧٧ و٠).*

تم قياس الهطول عند الثلث الأول والثاني من المسند وعند منتصف الفضاء للعتبة قبل وبعد الأصلاح من خلال مقاييس مدرجة.

طريقة التصليح من خلال الحقن بالأيبوكسي أظهرت تصرفاً لعلاقة الحمل-الهطول مشابهة لتلك العلاقة التي ظهرت للعتبات قبل عملية الأصلاح بهذه الطريقة مع فروق طفيفة ، أن التشققات لم تظهر مرة أخرى بعد الاصلاح بينما تشكلت تشققات جديدة قريبة. و بصورة عامة ، فان السلوك الإنشائي للعتبات الخرسانية ذات المقاومة العالية المصلحة كان مشابها لسلوك العتبات الاصلية مع مطيلية أعلى.

1. Introduction

Over the last two decades, the use of high-strength concrete has been on the increase. The main benefit of using high-strength concrete stems froms the reduction in cross sections and consequently their self-weight. This is particularly useful in high-rise buildings. For many years, concrete with compressive strength in excess of 41 MPa was available at only a few locations. However, in recent years, the applications of high-strength concrete have increased, and high-strength concrete has now been used in many parts of the world. The growth has been possible as a result of recent developments in material technology and demand for higher-strength concrete [1].

Selection of repair procedures is based on the careful evaluation of the extent and cause of cracking. Depending on the nature of the damage, one or more repair methods may be selected. For example, tensile strength may be restored across a crack by injecting it with epoxy or other high-strength bonding agent. Cracks as narrow as (0.05mm) can be bonded by the injection of epoxy. The technique generally consists of establishing entry and renting ports at close intervals along the cracks, sealing the crack on exposed surfaces, and injecting the epoxy under pressure. Crack injection is a costly operation, but it is commonly used as a repair method itself, or as preparation for other strengthening schemes. However, this type of repair assumes that the injected cracks have restored the bulk concrete capacity of the beam. If the strength of the epoxy, or bond, is compromised significantly, the concrete strength will not be restored to the expected levels. The purposes of repair are to improve the function and performance of the structure, restore and increase the strength and stiffness, improve appearance of the concrete surface, provide water tightness, prevent access of corrosive materials to the reinforcement, and improve the durability performance of the structure [1].

2. Experimental Program

The experimental work of this study consists of casting, testing up to failure in flexure, repairing and retesting four rectangular reinforced high-strength concrete beams. Details of the work stages mentioned above are presented in this section. All four beams had span length of (2650mm) and cross-sectional dimensions of (120mm) by (230mm). These beams had tensile reinforcement as follows:

Beams reinforcement of (B_1 and B_2) consisted of two (12mm) diameter rebars, reinforcement of (B_3 and B_4) consisted of two (16mm) diameter rebars, while compressive reinforcement varied for all beams. The shear reinforcement for all beams consisted of single stirrups of (8mm) diameter at (100mm) center to center throughout the span of the beam. Details of the test specimens are shown in **Fig.(1)**.

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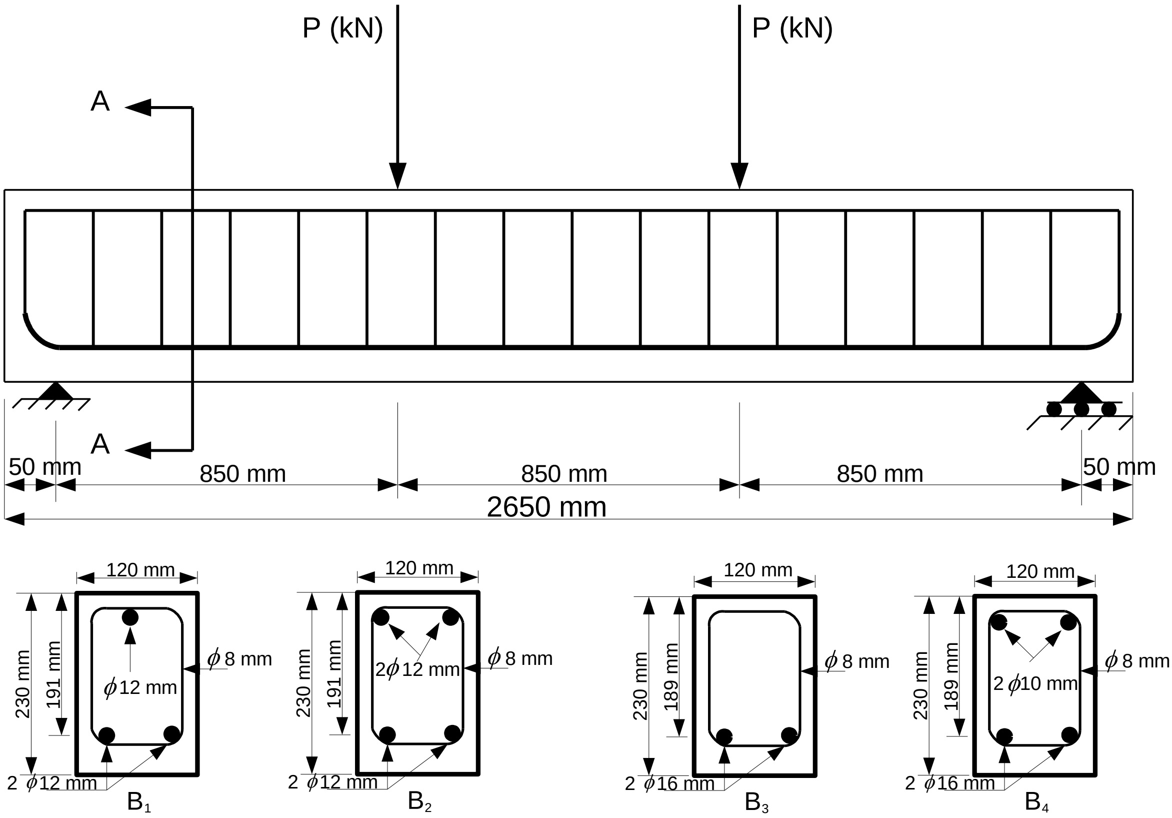

Figure (1) Details of test specimens

Tables (1), **(2)**, and **(3)**, show that properties of reinforcement, proportion of mix, and measured compressive strength respectively.

Table (1) Properties of reinforcement#

Nominal Diameter (mm)	Measured Diameter (mm)	Area (mm^2)	Length (mm)	Elongation %	Modulus Elasticity (GPa)	f_y (MPa)	f_u (MPa)
8	8.01	50.4	200	11.4	213	532.4	602.7
10	10.0	78.5	200	11.9	210	611.9	725.8
12	12.1	114.9	200	14.0	215	534.3	634.5
16	15.97	200.2	200	12.5	204	594.6	784.4

 # Testing was made at the Laboratory of Materials in Baghdad University, College of Engineering

Table (2) Concrete mix proportions

W/C ratio	Water (kg/m^3)	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	S. P.# (kg/m^3)
0.27	162	600	664	996	24

 # Superplasticizer

Table (3) Measured and predicted compressive strength

Beam No.	Nominal $f'_c)_{28}$ MPa	Measured $f'_c)_{28}$ MPa	Nominal $f_{cu})_{28}$ MPa	Measured $f_{cu})_{28}$ MPa
B_1	70	69	87.5	79
B_2	70	67	87.5	77
B_3	70	62	87.5	82
B_4	70	68	87.5	80

2-1 Epoxy Resin

A two part, solvent-free, low viscosity, named Conbextra EP10 epoxy injection resin is used for repairing the beams. It has many advantages such as suitability for hot climates, excellent bond to concrete, and no-shrinkage. The properties of Conbextra EP10 (according to the manufacturer) are listed in **Table (4)**.

Table (4) Properties of epoxy (Conbextra EP 10)

Property	Typical Results
Compressive Strength*	70.0 MPa @ 20 °C 93.0 MPa @ 35 °C
Tensile Strength*	26.0 MPa @ 35 °C
Flexural Strength*	63.0 MPa @ 35 °C
Young Modulus in Compression	16.0 GPa
Pot Life	90 Minutes @ 20 °C 40 Minutes @ 35 °C
Specific Gravity	1.04
Mixed Viscosity	1.0 Poise @ 35 °C

***** *At 7 Days*

3. Testing Procedure

3-1 Beam's Test Procedure

The beam under test was simply supported over a span of (2550mm). Two equal point loads were applied to the third-points of the beam by a pair of hydraulic jacks. First third, second third from the support and mid-spam deflections of the beam were measured with dial gauges. The load is applied in small increments and the dial gage readings are taken every 4kN until failure occurs. After each increment of loading, the deflections were recorded and the propagation of cracks was examined, detected and their widths are recorded at several levels of loading. **Plate (1)** shows the loading arrangement used throughout the tests.

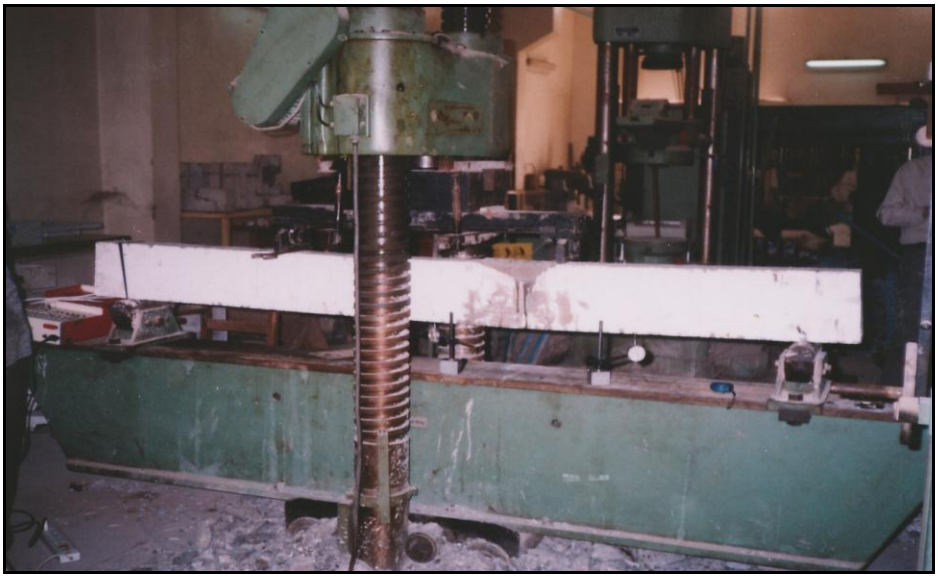

Plate (1) Loading for the test

3-2 Beam's Repair Procedure

The following steps are followed in the epoxy injection repair process for each failed beam:

1. After flexural failure, the cracks and their neighboring areas are cleaned from dust, debris and other contaminants by applying compressed air using electrical blower to ensure good penetration of the resin and proper bond of the crack paste.
2. Surface ports are then fixed along the considered crack. The port has an opening at the top for the epoxy to enter and a flange at the bottom bonded to the concrete. The ports are placed 10-15cm apart. The port is fixed in its proper position by applying an epoxy paste to the flange portion of the port taking care not to cover the hole, and then tacking it in place.
3. Epoxy paste is then used to seal over the surface ports and the exposed cracks. The paste is extended 20-30mm on either side of the crack with 2-3mm thickness to prevent resin seepage. The beam is then left for 30-45 minutes to ensure complete curing of the paste.
4. The two components of epoxy resin are then mixed in a metal batch using a mechanical stirrer at a proportion of 1(base): 3(hardener) by volume, according to the manufacturer's instructions.
5. A mechanical injection gun is fed with the mixed epoxy and the injection process started. The injection process began by pumping epoxy into the lowest port until the epoxy began to flow from the port above it. The first port was then plugged with a cap, and the process was repeated until the crack has been completely filled and all ports have been capped. Low pressure was used in injecting epoxy into the cracks. A curing period of about 24 hours was provided to the injected epoxy [2].
6. After the injected epoxy has cured, the ports were removed by striking with a hammer and the surface seal was chipped. Only the major cracks were treated in this way. The minor cracks, being less than (0.05mm) were too fine for complete penetration of the structural epoxy [3]. The crushed concrete in the compression zone of the beam was repaired in a

similar manner. The repaired beams were left at ambient temperature for one day and then tested to failure as before. **Plates (2)**, **(3)** and **(4)** show that test procedure of beams and epoxy injection respectively.

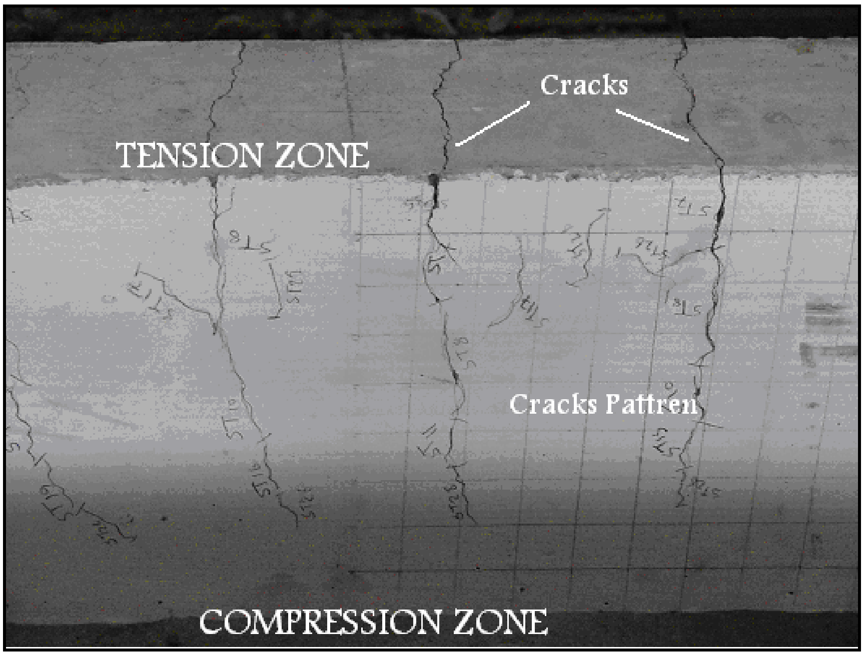

Plate (2) Set-up of epoxy injection [cleaning the cracks]

Plate (3) Epoxy injection for beams

Plate (4) Epoxy injection for beams

3-3 Retesting after Beam Repair

After the repair process is completed, the repaired high strength concrete beams are retested to evaluate the efficiency of the repair work. Loading arrangement and test procedure of the repaired beams are the same as those described for the original beams.

4. Test Results

Failure of the original beams was caused by yielding of the tensile steel then it followed by concrete crushing in the compression zone. The deflections for first, second third and mid-span were measured until failure stage. The constant moment region was traversed by several wide cracks especially at the middle third of the span.

After the epoxy was injected for these several cracks, and the whole process of repairing was completed the load-deflection behavior of the repaired high strength reinforced concrete beams was similar to that of the original beam before the injection of epoxy repairing. The repaired cracks did not reopen. Instead, the repaired high strength reinforced concrete beams showed failure mode different from the original beams before the repairing, new cracks were formed, and some of these cracks being adjacent to the old repaired ones. At failure, concrete crushing occurred away from the epoxy-repaired region.

Figures (2), **(3)**, **(4)**, and **(5)**, show the load deflection for beams (B_1, B_2, B_3 and B_4) at first third of beam span. **Figures (6)**, **(7)**, **(8)**, and **(9)**, show the load deflection for beams (B_1, B_2, B_3 and B_4) at second third of beam span. **Figures (10)**, **(11)**, **(12)**, and **(13)**, show the load deflection for beams (B_1, B_2, B_3 and B_4) at mid span of beam. It is obvious from the recorded data that the strength of the repaired beams was not softer than that of the original beams for high-strength concrete.

Comparison of the load-deflection curves indicates that the integrity of the beams was really restored by epoxy injection. The results show that the repaired high strength reinforced concrete beams exhibited greater flexural rigidity at high intensities of load.

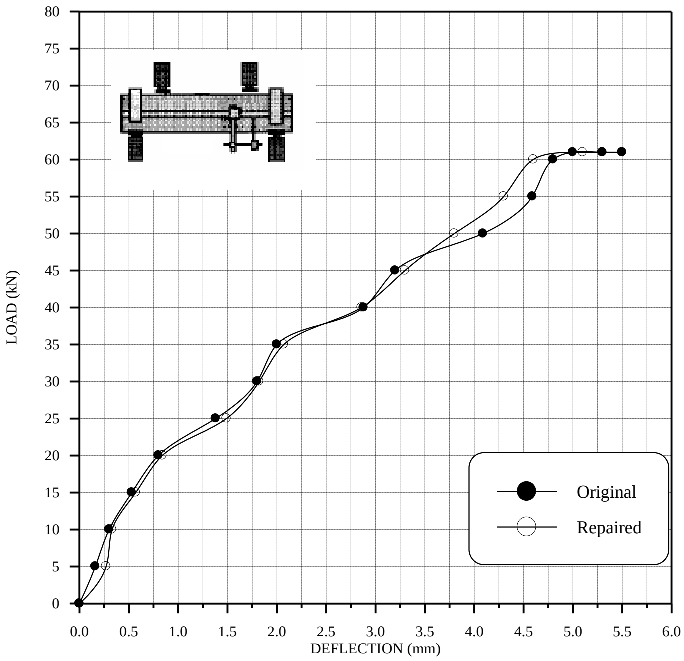

Figure (2) Load-deflection behavior at first third from the support of Beam B1

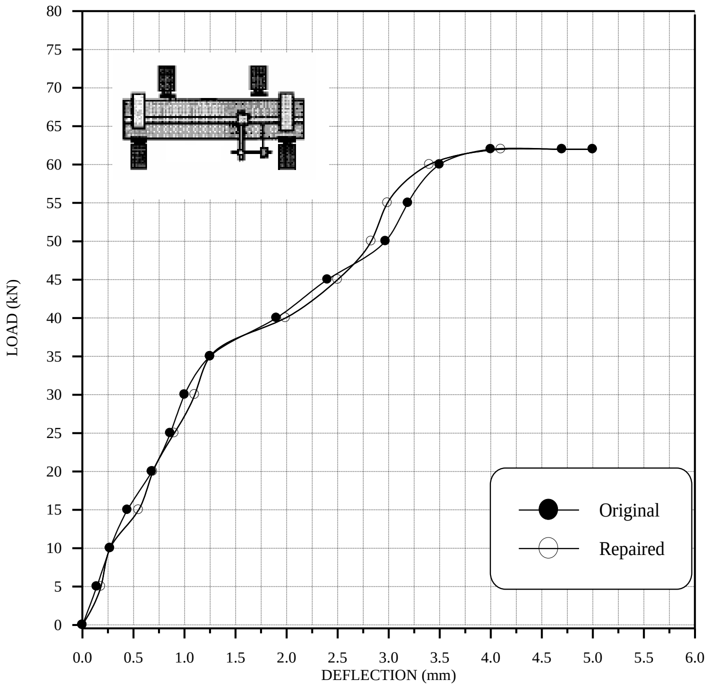

Figure (3) Load-deflection behavior at first third from the support of Beam B2

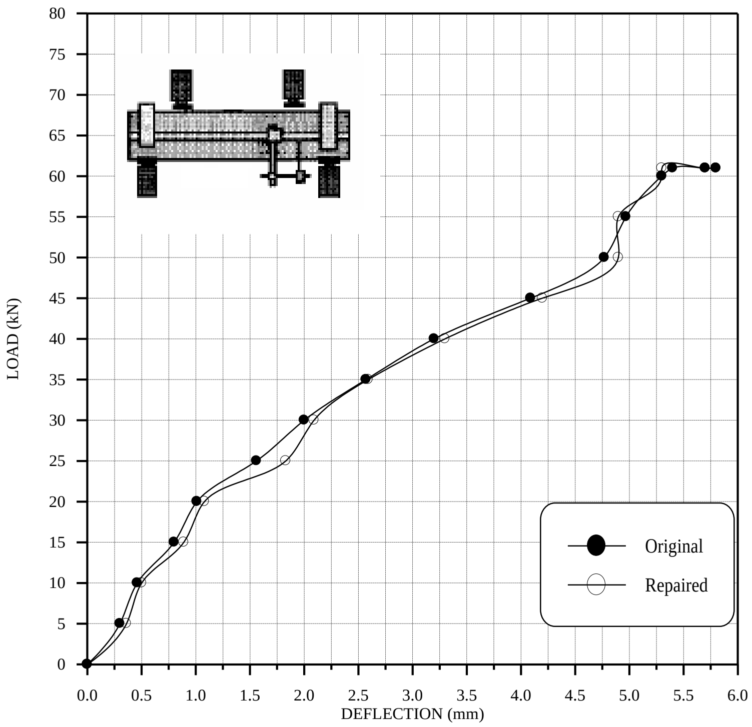

Figure (4) Load-deflection behavior at first third from the support of Beam B3

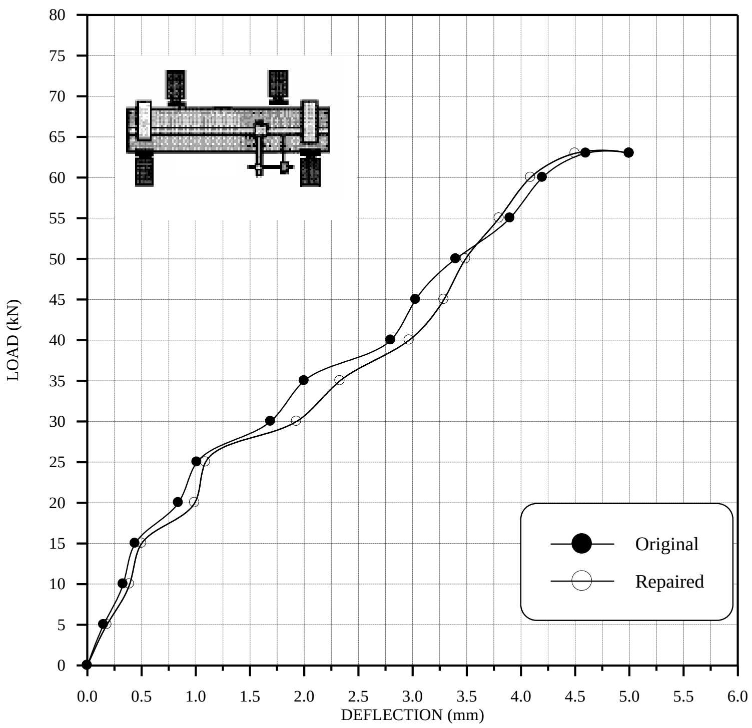

Figure (5) Load-deflection behavior at first third from the support of Beam B4

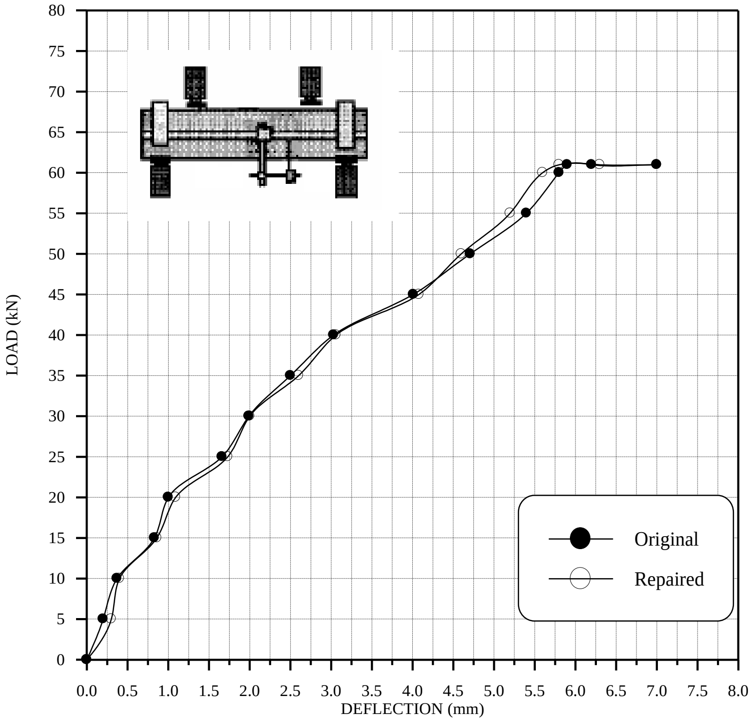

Figure (6) Load-deflection behavior at second third from the support of Beam B1

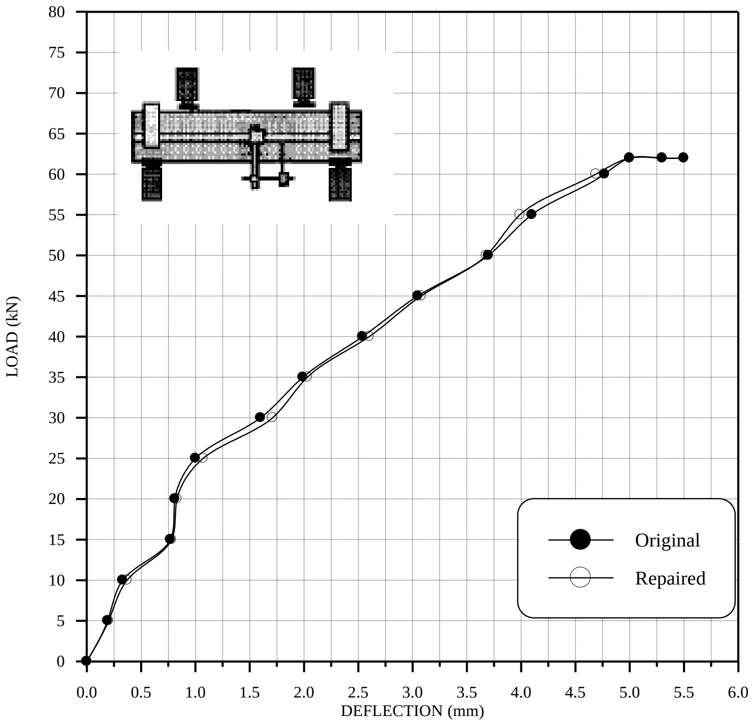

Figure (7) Load-deflection behavior at second third from the support of Beam B2

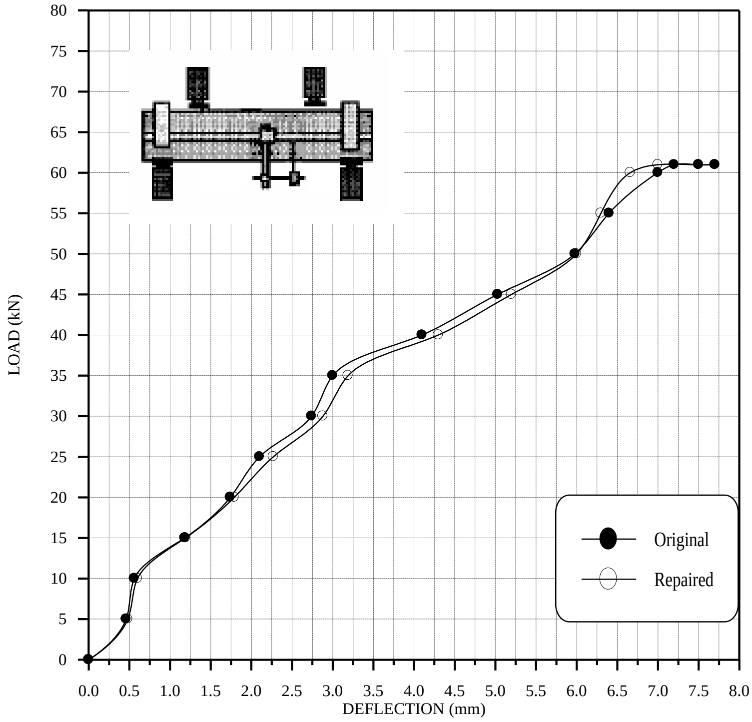

Figure (8) Load-deflection behavior at second third from the support of Beam B3

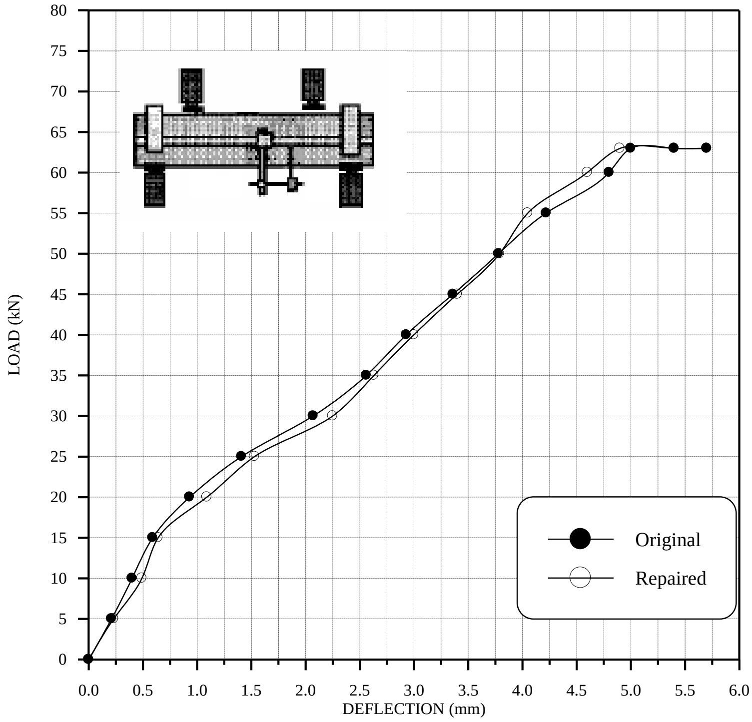

Figure (9) Load-deflection behavior at second third from the support of Beam B4

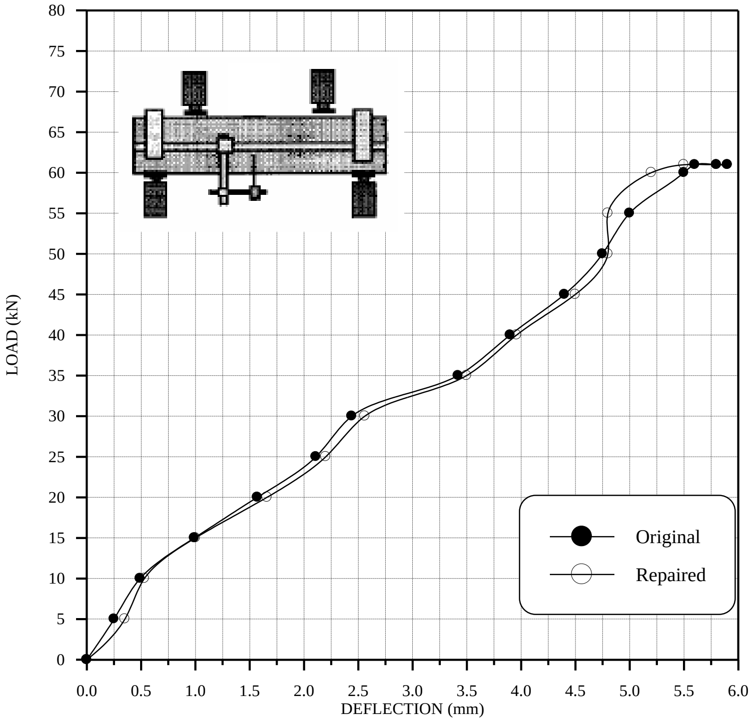

Figure (10) Load-deflection behavior at mid span of Beam B1

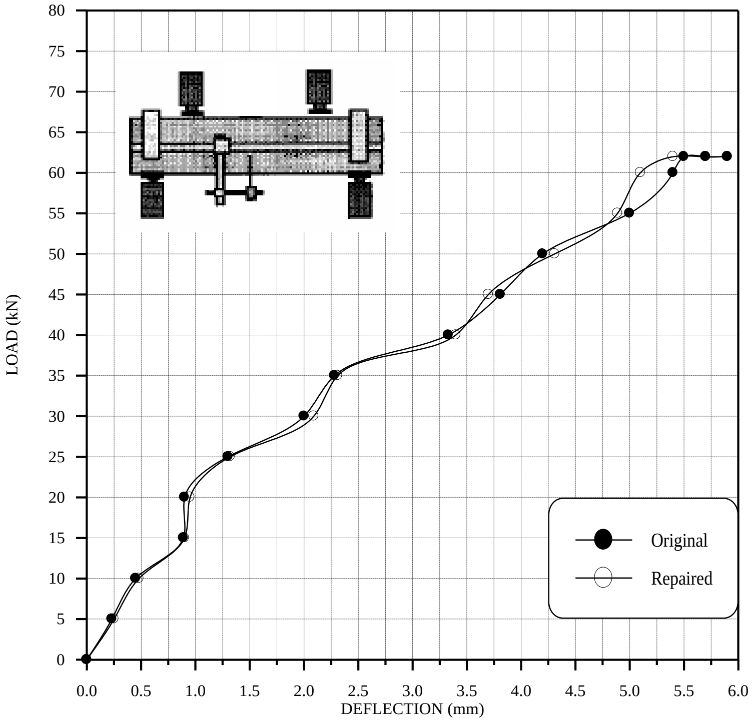

Figure (11) Load-deflection behavior at mid span of Beam B2

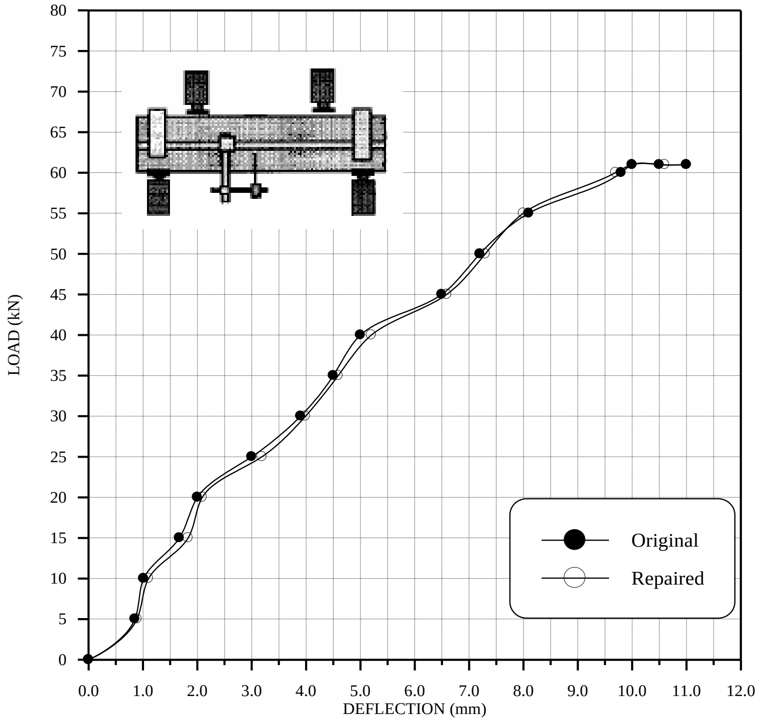

Figure (12) Load-deflection behavior at mid span of Beam B3

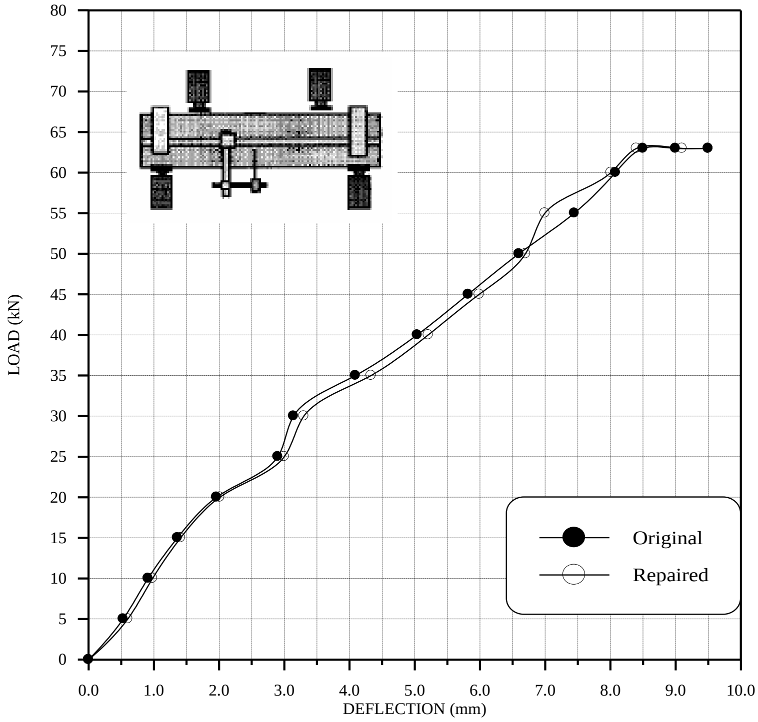

Figure (13) Load-deflection behavior at mid span of Beam B4

5. Conclusions

Based on the results of this study, the following conclusions can be drawn:

1. Load deflection curves of the repaired beams were similar or improved compared with the original beams.
2. The crack injection process using a manual injection gun is done successfully and easily for cracks whose widths range from 0.5 to 1.0 mm and easier for wider cracks. For crack widths less than 0.5 mm, the process is done with some difficulty because these small widths of diagonal cracks limit penetration of the epoxy resin into the cracks.
3. The repair process restores the integrity of the high-strength reinforced concrete beams that show greater ductility compared with the original beams.
4. The flexural strength of the repaired beams is not less than that of the original beams.
5. For high-strength reinforced concrete beams the failure load in general where approaching is higher the repaired beam than that in the original beams.
6. The repaired cracks did not reopen and the repaired beams failed due to formation of new cracks.
7. The structural behavior of the four repaired high strength reinforced concrete beams by epoxy injection is similar to original beams. Failures in both cases are characterized by flexural behavior.

6. References

1. E. G., Nawy, ***"Fundamentals of High Performance Concrete"***, John Wiley and Sons, New York, 2001, 441 pp.

2. ACI Committee 503, ***"Use of Epoxy Compounds with Concrete"***, American Concrete Institute, 1993, 28 pp.

3. Zhang Dong, and Wu Keru, ***"Fracture Properties of High-Strength Concrete"***, ASCE Journal, Vol. 13, January-February 2001, pp. 86-88.