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Behavior of Simply Supported Reinforced Concrete Beam with Edge Opening, With and Without Repairing

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Abstract:

This study is an attempt to find out how the reinforced concrete beams with edge opening behave under the effect of shear forces. Eight simply supported reinforced concrete beams were tested under two point loads to measure the deflections, up to specific limit that is below collapse. After that the samples were repaired by steel plates of thickness of 0.5mm with dimensions (120×30mm).These plates were sticked on the concrete beams using epoxy. The repaired beam was retested, measuring deflection versus loads up the appearance of the first crack. Three of these beam samples were strengthened by steel plates sticked to the faces of their opening. The dimensions of those plates were (150×100×0.5mm).
All results were compared with the results obtained from ANSYS 7.0 program. It was found that the results were acceptable and could be adopted to give a good view about the behavior of such samples.

الخلاصة:

هذه الدراسة تقدم محاولة لدراسة قوى القص لعتبة بسيطة الإسناد من الكونكريت المسلح و لهذا الغرض فقد اعتمدت في هذه الدراسة ثمانية نماذج ، و قد تم قياس الانحراف بعد تسليط أحمال مفردة عمودية في مواقع معينة مع مراعاة عدم الوصول إلى الفشل النهائي و الانهيار.
لقد تم اعادة الفحص بعد تقوية النماذج بصفائح حديدية ذات ابعاد (٣٠×١٢٠ ملم)وذات سمك ٠.٥ملم بوضعها إلى اعلى و اسفل الفتحة لكل نموذج و قد تم الحصول على قيم الانحراف لكل نموذج مع الحمل المسلط . من ناحية اخرى تم تقوية جوانب الفتحات لثلاثة نماذج بصفائح حديديةذات ابعاد (١٥٠×١٠٠ ملم) وذات سمك ٠.٥ملم بدلا من استخدام حديد القص قرب الفتحات. لقد تم مقارنة النتائج جميعها مع القيم المستحصلة من طريقة العناصر المحددة باستخدام البرنامج المعروف ANSYS7.0 و قد وجد إن النتائج مقبولة إلى حد كبير مع ملاحظة إن المقارنة شملت نتائج الانحراف لكل نموذج و ذلك عند الحمل الذي يولد أول تشقق تحت تأثير قوى القص.

1-Introduction

In concrete is difficult to predict accurately. In spite of many decades of experimental research and the use of highly sophisticated analytical tools, its not yet fully understood [(1)]. Furthermore; if a beam without properly designed shear reinforcement is loaded to failure, shear collapse is likely to occur suddenly, with no advance warning of distress. This is in strong contrast with the nature of flexural failure. For typically unreinforced beams, flexural failure is initiated by
Gradual yielding of tension steel, accompanied by obvious cracking of the concrete and large deflections, giving ample warning and providing the opportunity to take corrective measures. Because of these differences
In behavior, reinforced concrete beams are generally provided with special shear reinforcement to insure that flexural failure would occur before shear failure if the member should be severely overloaded [(2)].

2- General Description of Cracking Behavior for Beams Loaded in Shear plus Flexure:

To obtain a general understanding of the cracking behavior of concrete beams, the setup adopted by d Grace et al (2003) is considered, due to shear loading the simple beam loaded at the 1/3 points as shown in Fig. (1) [(3)].
Point 1 is on the neutral axis. There is theoretically no stress (normal "σ" or shear "τ"). Point (1b) is at extreme fiber in tension at the centerline of the beam (max. moment section). Not: there is no shear load (V) at (1b).
Point 2 is on the neutral axis (max. τ at max. V). there is very little applied moment at 2 or (2b) (M≈ 0). The first shear crack should form near point 2 at approximately a distance (d) from the support.

The state of stress at **points 3** and (3b) is now considered. The vertical section at these points has both moment and shear applied (M+V). if adequate flexural steel is present along the length of the beam (no flexural failure) and point 2 has been reinforced for shear (stirrups) then as the load continues to increase, eventually flexural- shear cracks will occur at (3) and (3b) (also called shear- flexure cracks.
The ACI code requirements for reinforcing sections subjected to significant shear are adopted in this study [(4)] [(5)].

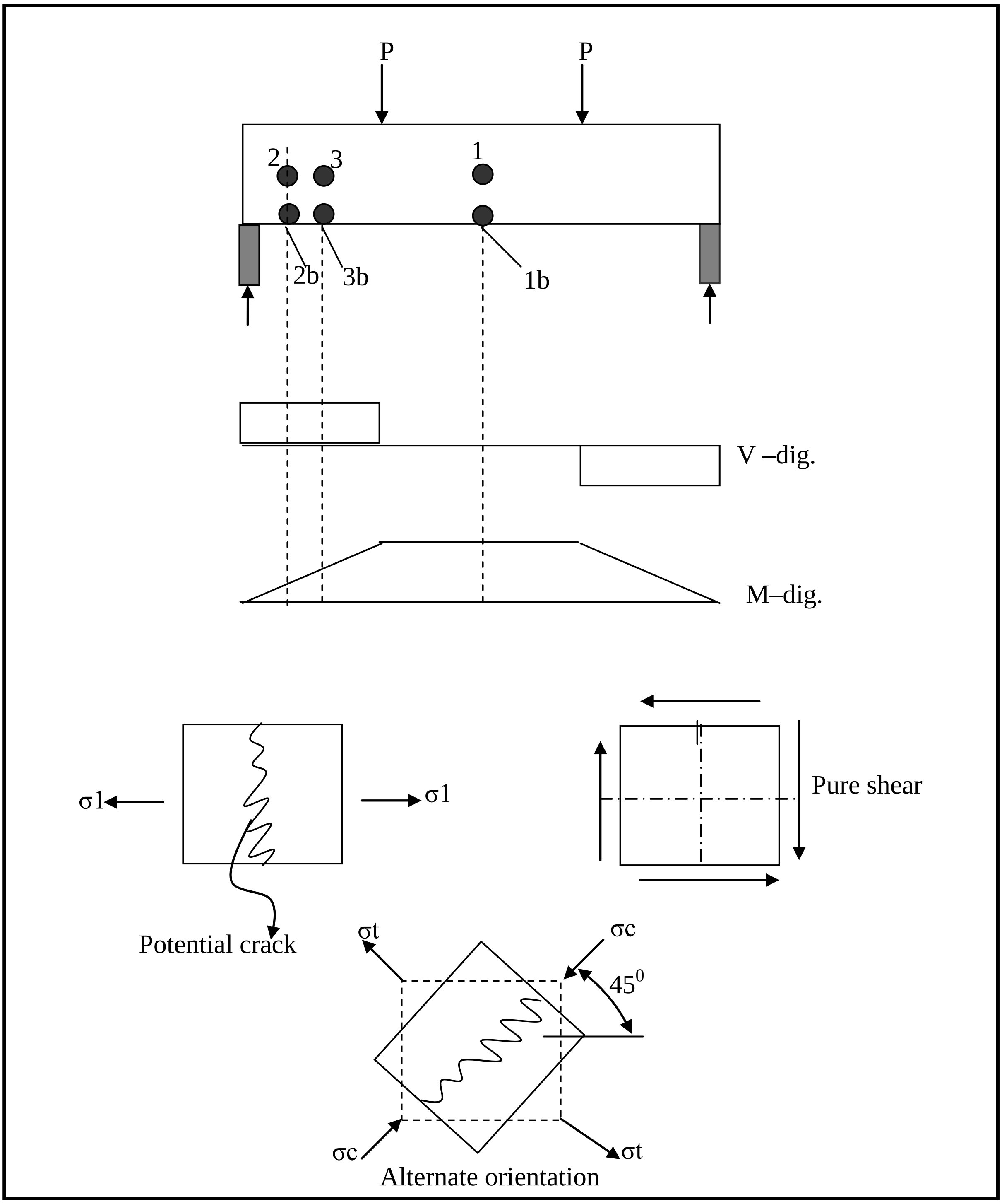

Fig (1) Cracking Behavior of Concrete due to Shear Loading

3- Experimental work:

In this study, eight reinforced concrete beams with dimensions (1300x 190x 70 mm: length × width ×height) were used. These beams has an opening with dimensions (90x90mm) as shown in Fig.(٢). The cement used was Ordinary Portland Cement (type I) which was manufactured by (Al- Sharqia) company for cement production, KSA. Natural sand from Al-Ukiaidher region was used for concrete mixes. The fine aggregate has (4mm) max. size with rounded particle shape and smooth texture. The grading of fine aggregate was within the Iraqi Specifications NO.45/ 1989. Uncrushed rounded gravels with max. size of (10mm) was used throughout this work. The grading of coarse aggregate was within the requirements of Iraqi Specifications NO.45/1984. The mix design for concrete used was (1:2:4) (cement: sand: gravel) in proportion by weight with water/ cement ratio (0.45) was used as shown in table (1).

Table (1) Mix design for all the tested concrete beams

Material	Amount Used
Cement	5.2 Kg/m^3
Coarse aggregate	0.0144m^3
Fine aggregate	0.0073 m^3
Water/Cement	0.45

The tested beams were reinforced with hot rolled mild steel bars with diameter (10mm). Two bars for each beam were used as longitudinal (tension) reinforcement. Stirrups of diameter (6mm) were used with different number and spacing for each tested beam as shown in Fig.(3a,b). On the other hand, in three beam samples, sides of the openings were strengthened by thin steel plates of 0.5mm thickness instead of using stirrups as shown in fig.(4). Twenty four hours after pouring, the beams were stripped out from moulds and cured in water containers for twenty eight days. The beams were removed from the water containers and then tested by using the compression machine. The tested beams were simply supported over an effective span of (1200mm)and loaded with two point loads, as shown in Fig.(2). The applied loads were distributed across the entire width of the upper flange using steel bars under hydraulic jack. The two point loads were applied gradually until the cracks were developed on the beam surface. A repairing plate was fixed by epoxy for all tested beams as shown in Fig.(5). The repaired beams were retuned back to the compression machine and the two point loads were applied gradually until the beams were crushed.
It may be noted that, the compression machine was calibrated by the Iraqi Central Organization for Standardization and Quality Control. The gage of the machine was reading the deflection at centre of beam with every applied load.

Five concrete cubes were tested to find the compressive strength for beams and the average value for these cubes was (20Mpa) for twenty eight days of curing.

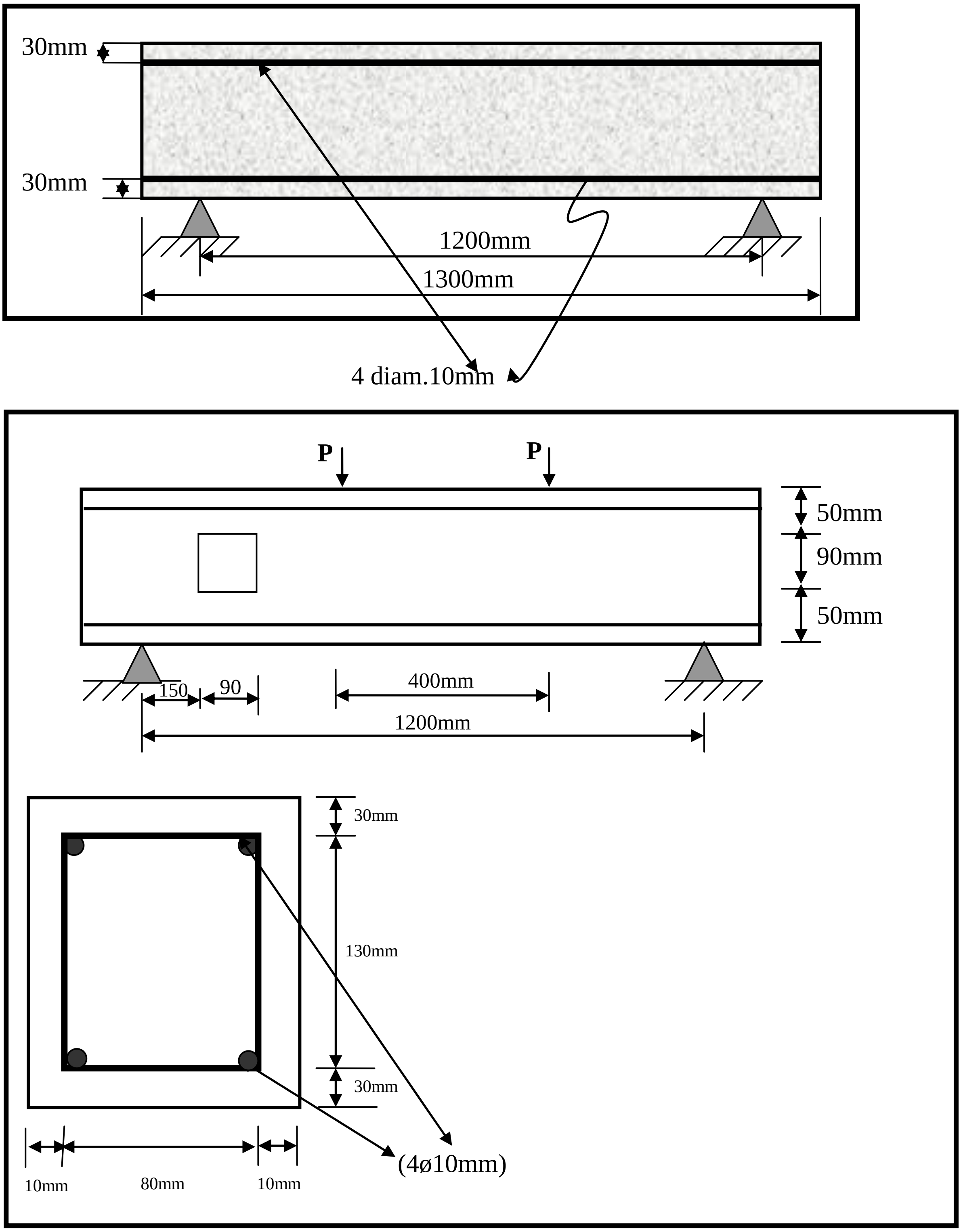

Fig. (2) the tested reinforced concrete beam with and without opening

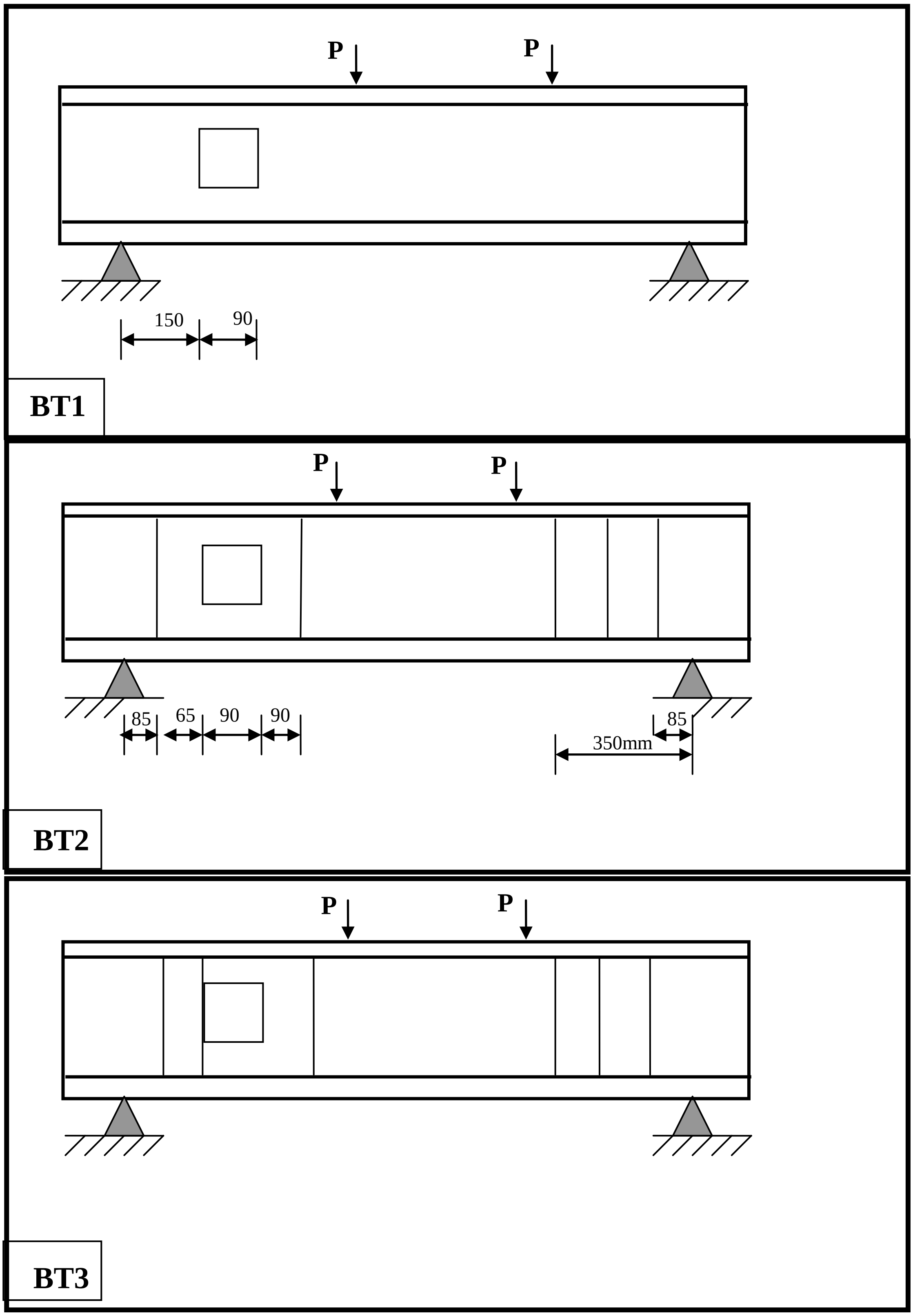

Fig. (3a) Reinforced concrete beams without repairing plate

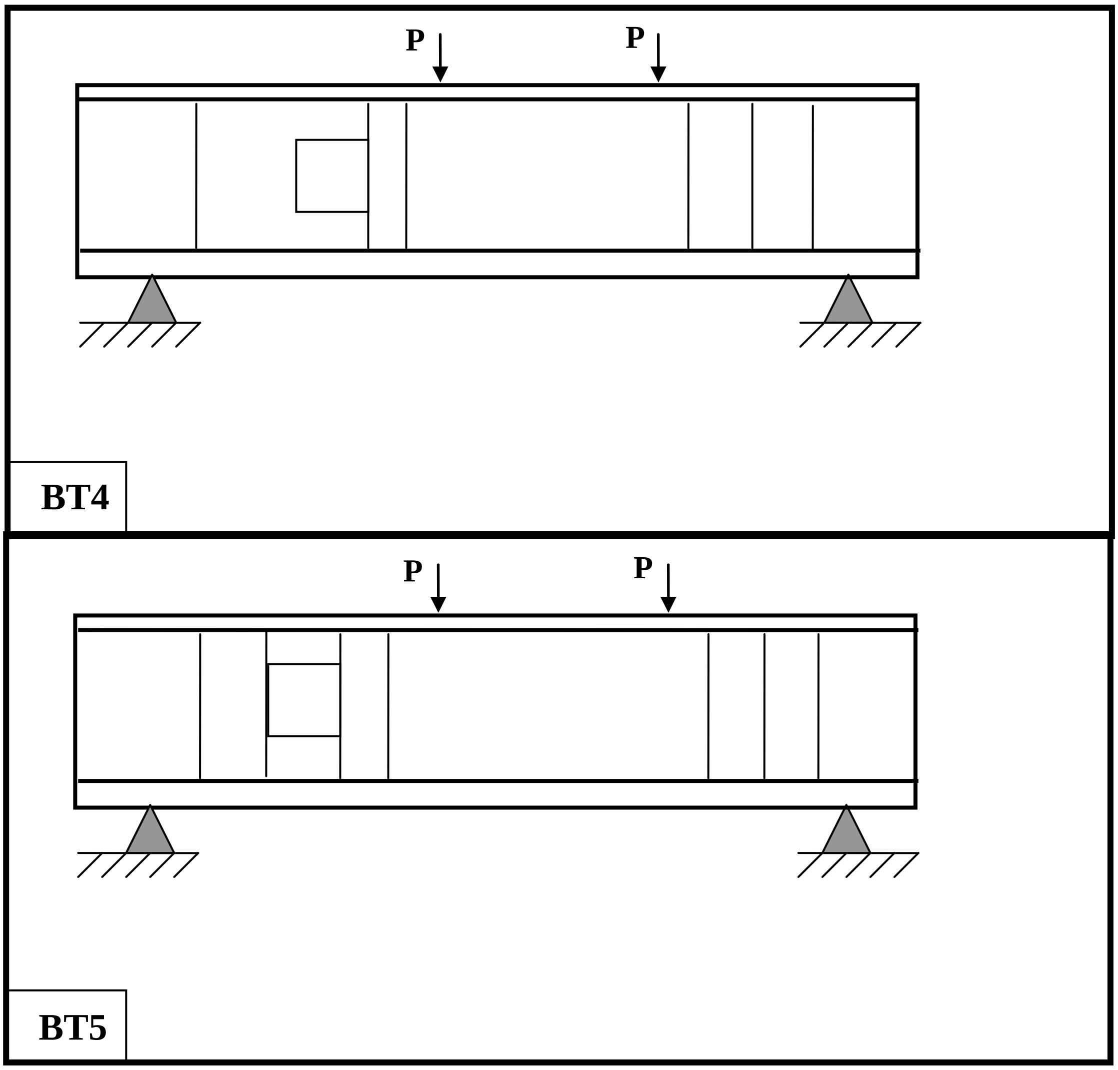

Fig.(3b) Reinforced concrete beams without repairing plate

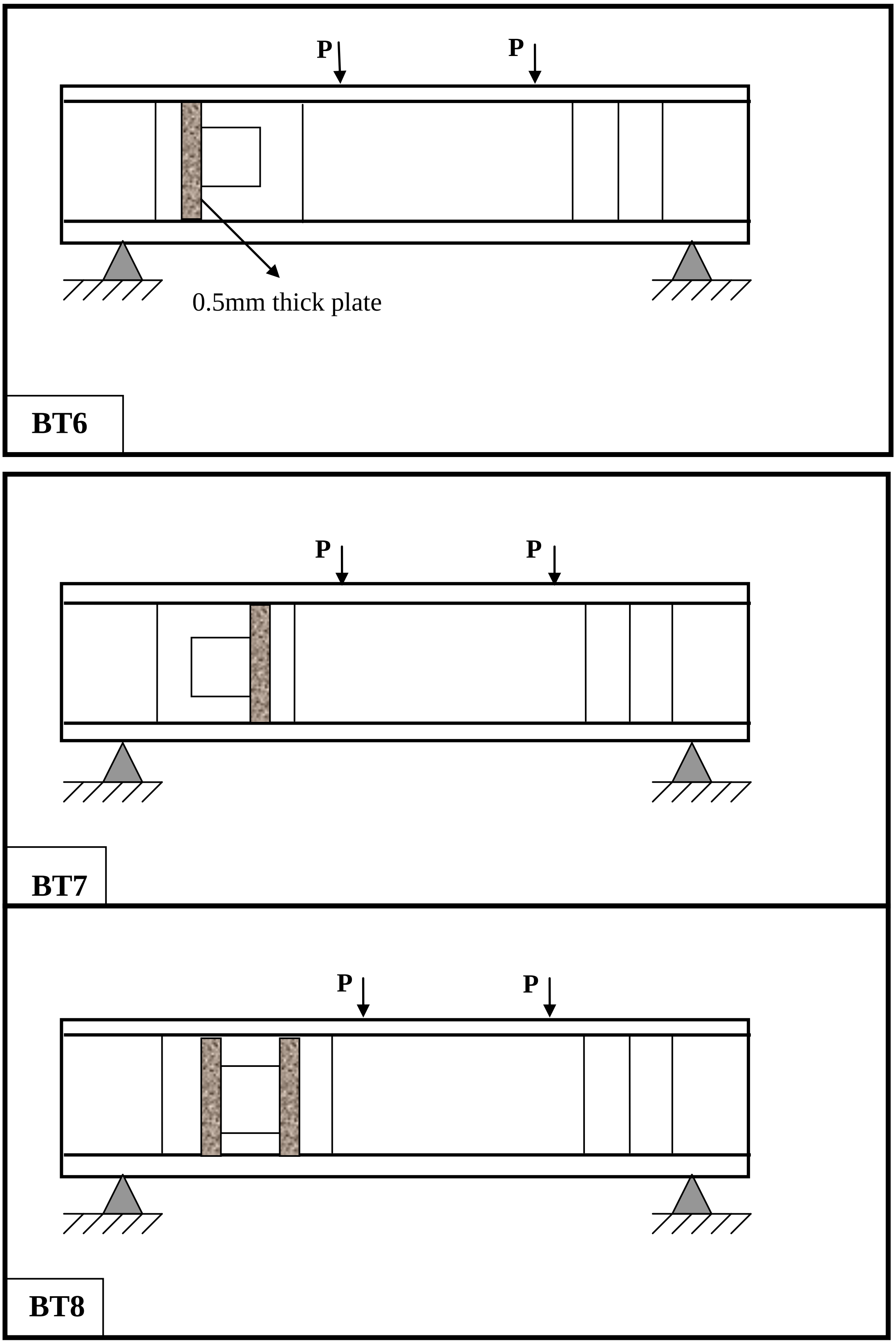

Fig (4) Reinforced concrete beams using a repairing steel plate

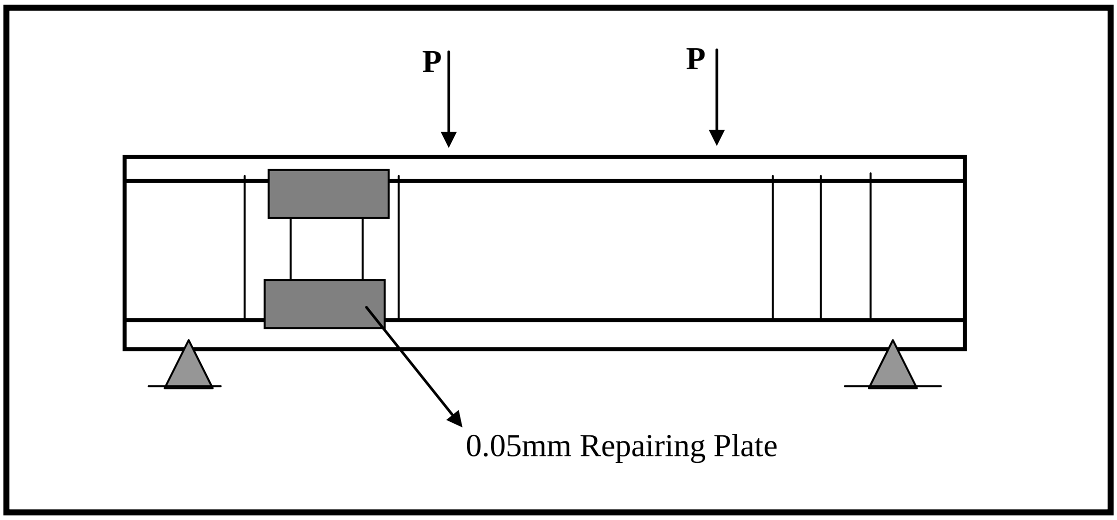

Fig. (5) Repairing plate for all tested beams .

4- Finite Element Software:

A successful analysis of an engineering problem needs the existence of an efficient code translation of the existing solution algorithm to be used by a digital computer. Finite element solutions are good examples of the fact due to the required target memories and tedious computations. For the present work purposes, it is sufficient to use a general purpose programme, since neither special circumstances are met nor special aims are to be accomplished.

4-1 ANSYS 7.0:

In this work, a use has been made of ANSYS 7.0 (6) which is an interactive finite element programme for the analysis of linear and nonlinear structural systems. Further analyses like heat conductions and fluid-structure analyses could be conducted using ANSYS. However it's structural analysis capability that concerns us in this paper. Static and dynamic analyses are achieved by a combination of one, two and three- dimensional elements.

4-2 Adopted Elements:

The present study adopts several elements to simulate the reinforced beam and repaired beam as follows:

- **Solid 65 (Three- Dimensional Reinforced Concrete Element) :**

This is used for the three- dimensional modeling of solids with or without reinforcing bars (rebar).

- **Shell 43:**

This is well suited to model linear warped, moderately- thick shell structures (this element would be using for steel plate simulation).

- **Contact 52 (Point-to- Point Contact):**

This represents two surfaces which may maintain or break physical contact and may slide relative to each other.

5- Discussion of the Results and Conclusions

The curves and tables below give a good picture of the behavior of reinforced concrete beams with an opening at one of its supports , under flexural forces and shear forces in particular.
From Table (2) and Fig.(6) to Fig.(8) , its clear that the cracks appears at first near the opening. This is in accordance with the intuitive expectation that suggests sections near the opening to be critical ones. A good indications for the benefits gleaned out of using of embedded plates to improve shear resisting of sections close to the openings

Table (2) load –Deflection values for beams without repairing plate

Beam No.	Load (KN)	Deflection Experimentally (mm)	Deflection Theoretically (mm)
B1	0	0	0
	5	0.34	0.266
	10	0.54	0.451
	15	0.82	0.675
B2	0	0	0
	5	0.34	0.289
	10	0.5	0.435
	15	0.67	0.568
	20	0.97	0.825
	25	1.27	1.093
	27.5	1.8	1.557
B3	0	0	0
	5	0.07	0.057
	10	0.14	0.116
	15	0.4	0.326
B4	0	0	0
	5	0.15	0.125
	10	0.25	0.208
	15	0.8	0.69

Beam No.	Load (KN)	Deflection Experimentally (mm)	Deflection Theoretically (mm)
B5	0	0	0
	5	0.24	0.195
	10	0.4	0.328
	15	0.72	0.599
	20	1.35	1.18
	25	2.2	1.788
	28	2.3	1.914
B6	0	0	0
	5	0.2	0.166
	10	0.35	0.291
	15	0.75	0.631
B7	0	0	0
	5	0.33	0.268
	10	0.352	0.438
	15	0.85	0.698
B8	0	0	0
	5	0.02	0.016
	10	0.05	0.044
	15	0.25	0.208
	20	0.54	0.446
	25	0.95	0.8
	30	1.45	1.236

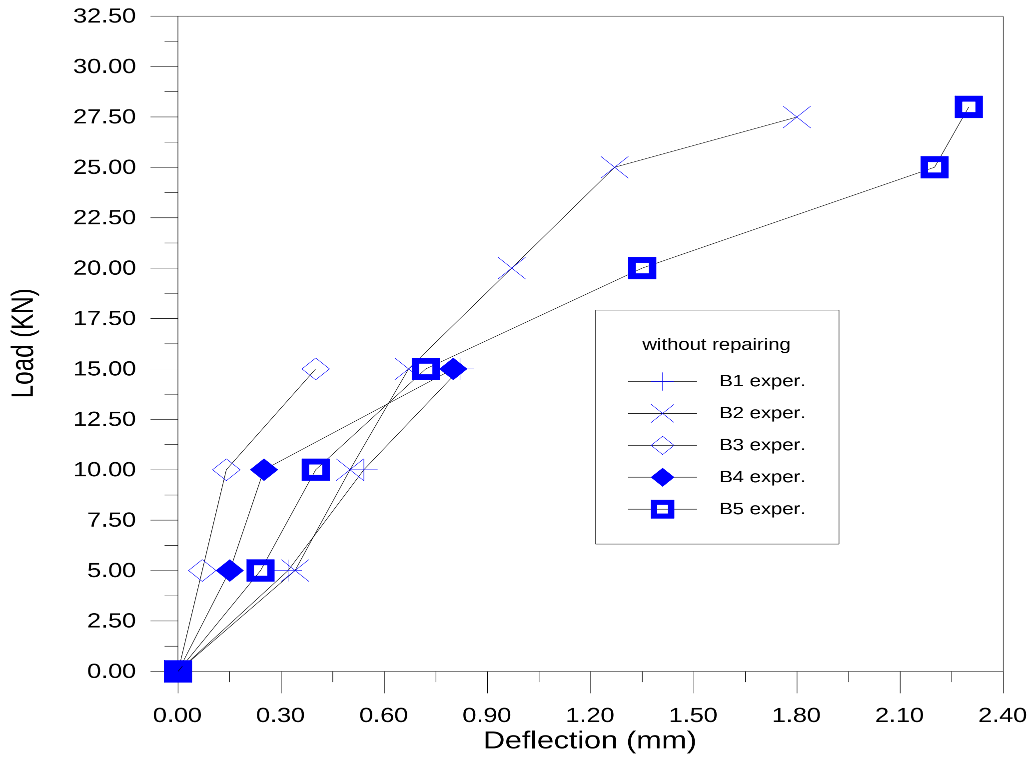

Fig (6): load deflection curve for beams with stirrups (tested results)

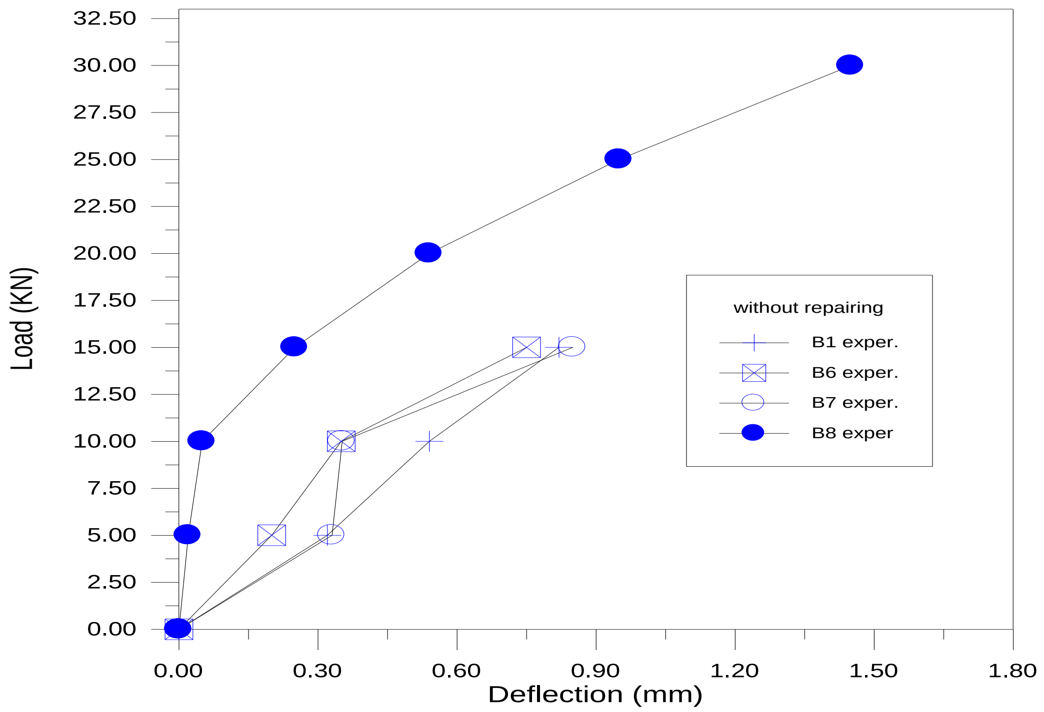

Fig (7) load deflection curve for beams with plate reinforcement. (tested results)

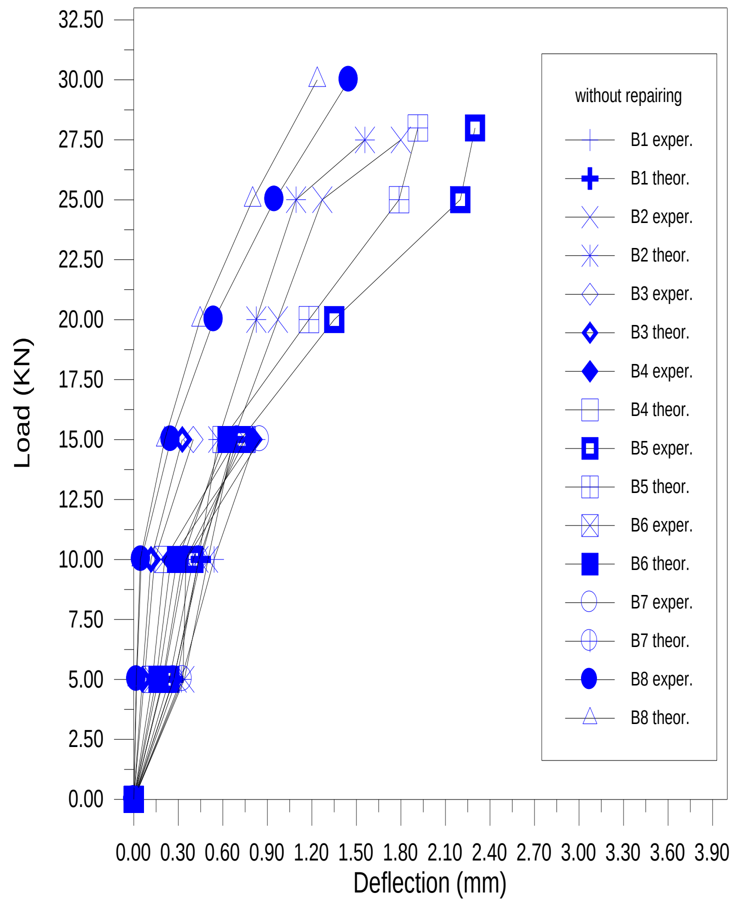

Fig (8) load – deflection curve for beams without repairing plate

On the other hand it is clear that the beams after repairing have the same behavior and the cracks would be appear at first time near the opening. Table (3) and Fig (9) to Fig.(11), below give a good indication for this fact.

Table (3) load –Deflection values for beams with repairing plat

Beam No.	Load (KN)	Deflection Experimentally (mm)	Deflection Theoritically (mm)
B1	Collapse at the first exerting of load so no repairing		
B2	0	0	0
	5	0.34	0.287
	10	0.54	0.457
	15	0.77	0.644
	20	1.05	0.874
	25	1.3	1.09
	30	1.7	1.43
	35	2.05	1.71
B3	0	0	0
	5	0.35	0.296
	10	0.6	0.507
	15	0.98	0.816
	20	1.8	1.542
	25	2.7	2.3
B4	0	0	0
	5	0.54	0.47
	10	1	0.841
	15	1.3	1.11
	20	2.2	1.88
	25	2.6	2.22
B5	0	0	0
	5	0.37	0.32
	10	0.72	0.62
	15	1.1	0.939
	20	1.35	1.182
	25	1.77	1.152

Beam No.	Load (KN)	Deflection Experimentally (mm)	Deflection Theoritically (mm)
B6	0	0	0
	5	0.41	0.35
	10	0.72	0.626
	15	1.36	1.183
	20	3.1	2.593
B7	0	0	0
	5	0.52	0.443
	10	0.7	0.606
	15	1	0.832
	20	1.3	1.11
	25	1.6	1.385
B8	0	0	0
	5	0.67	0.58
	10	0.73	0.625
	15	1.3	1.16
	20	1.55	1.341
	25	2.1	1.78

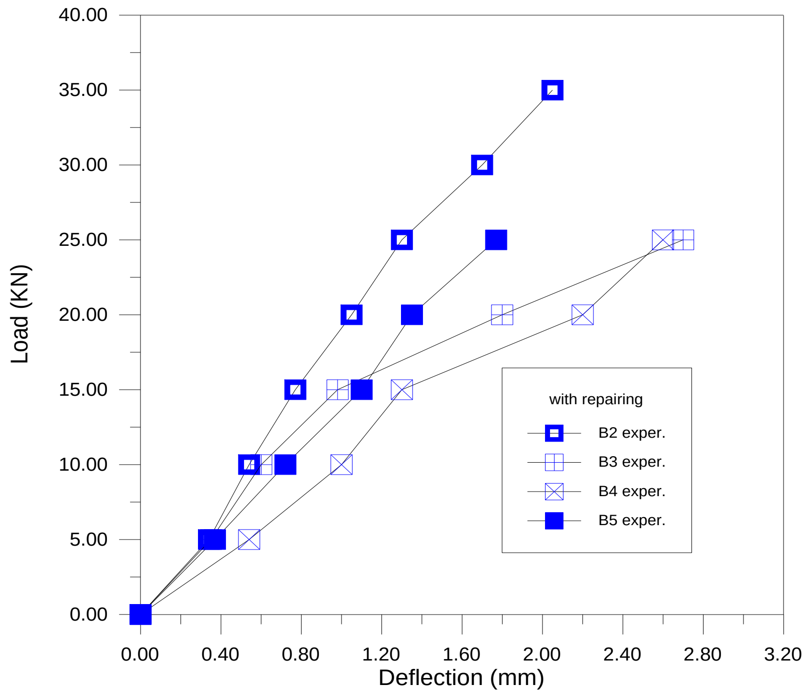

fig (9) load deflection curve for beams with stirrups (with repairing) (tested results)

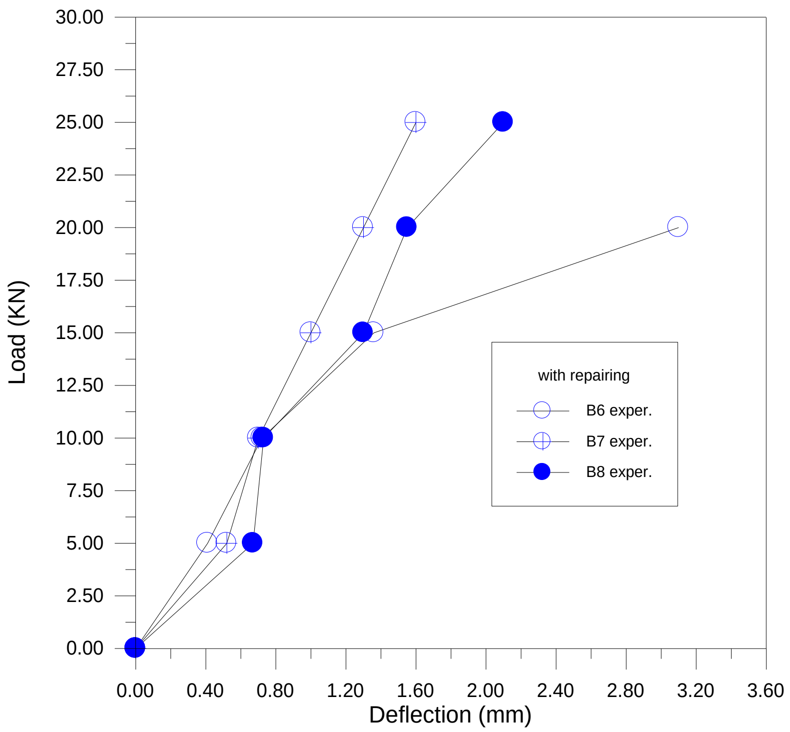

Fig. (10) load deflection curve for beams with plate reinforcement (with repairing).(tested results)

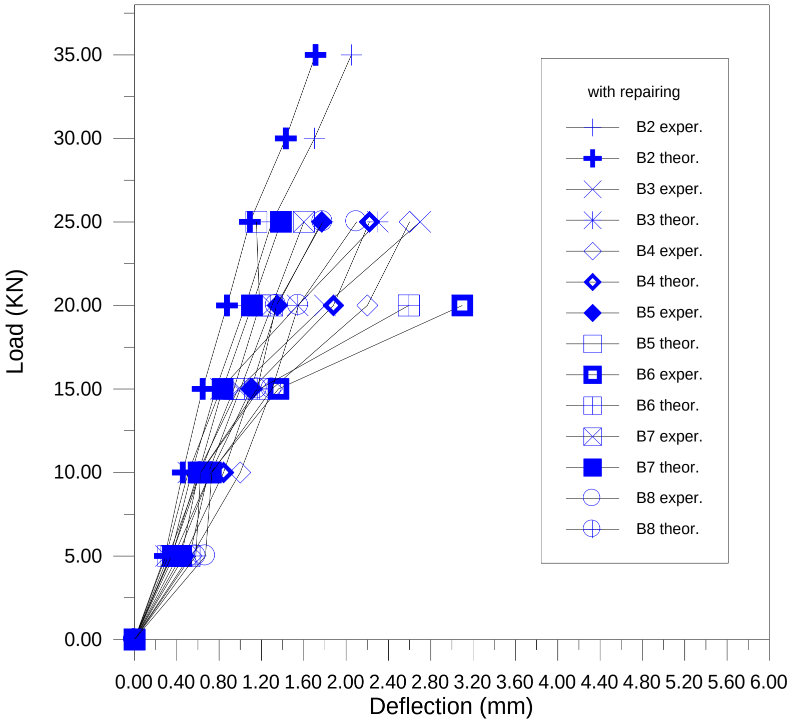

Fig (11) load – deflection curve for beams with repairing plate

Table (4) give an indication for the load value at which the first crack appears.

Table (4) The Comparison of the deflections that occurs at the load which caused first cracks

Beam NO.	Load at First Cracks (kN)	Deflections at First Cracks Experimentally (mm)	Deflections at First Cracks Theoretically (mm)
B2	10	0.54	0.457
B3	10	0.6	0.507
B4	10	1	0.841
B5	10	0.72	0.62
B6	10	0.72	0.626
B7	10	0.7	0.606
B8	10	0.73	0.625

The lesson learned from the above mentioned figures and tables is that the beams which used embedded plates instead of the rebar stirrup near the opening make the samples with less progressive cracks near that opening and is a suitable way to strengthen the weak edge of the opening

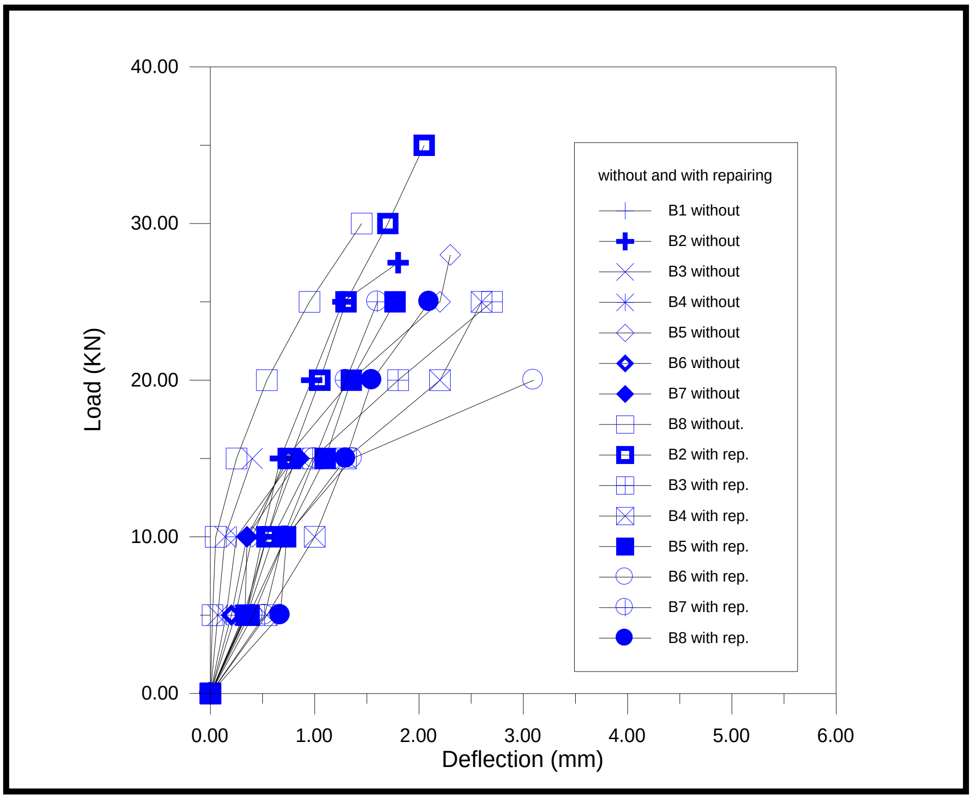

Fig (12) load – deflection curve for beams with and without repairing plate

From Fig (6) to Fig.(12) , it is found that:

1- For reinforced concrete beam with and without repairing , the cracks appear at first near opening which means that this positions is the most critical part of the beam which should be paid the most part of the designer's attention.

2- The capacity of beams before and after repairing for shear force resistance is so close if the deflection is taken the criterion, which means that the repairing is successful technique for such a case.

3- The deflections obtained by a sophisticated finite element method were not more than 15% away from the experimental results. This makes this analysis an acceptable substitute for experiments.

4- From Table (4), it is found that the first cracks appear in most of samples at the same load, which means that the parameters which were taken for all samples were close.

5- It is found that the use of steel plate to strength the side edge of opening reduces cracks near opening more than the use of stirrups.

6- References:

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Appendix of Photo of Experimental Work

Beam without Repairing Plate

Reinforcement of beams

Two point load applied to beams

Repairing Plat under and above the open

Crushing of beams