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STRENGTHENING OF REINFORCED CONCRETE BEAMS WITH OPENINGS

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الملخص

تهدف هذه الرسالة لتقديم دراسة عملية لتقوية وتدعيم الكمرات الخرسانية المسلحة ذات الفتحات باستخدام طرق التدعيم المختلفة قبل وبعد الصب وايضا إيجاد افضل وابسط واقل تكلفة لطرق التدعيم للكمرات ذات الفتحات. تم إجراء الدراسة على 13 كمرة ذات أبعاد 120 X 300 مم وطول 2000 مم. تم تسليح جميع الكمرات بعدد 3 اسياخ قطر 10 مم تسليح سفلي و عدد 2 سيخ قطر 8 مم حديد علوى وكانات قطر 6 مم فرعين كل 150 مم علي طول الكمرة وتم اختبار الكمرات تحت تأثير نقطتين تحميل حتى الانهيار. تم تقسيم الكمرات الي ثلاث مجموعات كالتالي: المجموعة الاولي: (كنترول) تتكون من عدد واحد كمرة بدون فتحات يستخدم سلوكها للمقارنة مع الكمرات المدعمة وكمرة اخري ذات فتحة 100 x 200 مم بدون تدعيم. - المجموعة الثانية: تتكون من عدد 10 كمرات ذات فتحات 200100 x مم. تم تدعيمهم قبل الصب باستخدام كمرات مسلحة حول الفتحة و كمرات مسلحة اعلي واسفل الفتحة مع صندوق مفرغ من اسياخ الحديد بقطر 8 مم مع استخدام الشبك المعدني ايضا تم استخدام الخوص الحديدية والزوايا الحديدية واستخدام اكثر من طبقة للشبك المعدنى وكانات متعامدة علي بعضها البعض بقطر 8 مم مع اسياخ حديد قطر 8 مم عند الزوايا. - المجموعة الثالثة: تتكون من كمرة واحدة ذات فتحة 200100 x مم تم تدعيمها بعد الصب باستخدام الزوايا الحديدية والخوص الحديدية وعدد 2 طبقة من الشبك المعدنى حول الفتحة وايضا عدد 2 طبقة من الشبك معدني علي شكل حرف U . تم تحميل الكمرات المدعمة والغير مدعمة باستخدام ماكينة التحميل و تم قياس الترخيم في ثلاث مناطق (اسفل الفتحة "يمين الكمرة" – منتصف بحر الكمرة – يسار الكمرة) وذلك لأنواع مختلفة من الكمرات المدعمة وعمل مقارنة بين الترخيم لهذه الأنواع تحت الإجهادات المختلفة. تم تسجيل قيم الاجهاد للأسياخ الحديد العلوية والسفلية للكمرات وحساب الصلابة لجميع الكمرات وتم عمل مقارنة بين كل كمرة واخري. تم عمل النموذج التحليلي العناصر الغير خطية للكمرات باستخدام برنامج التحليل العناصر الغير خطية ((ANSYS 15 وتمت مقارنة النتائج العملية للكمرات المختبرة مع نتائج برنامج التحليل.

Abstract

The present study describes the result of an experimental investigation on the response of creating opening in reinforced concrete beams after and before casting using steel wire mesh, steel angles, steel straps, steel stirrups system and reinforcement beams around the opening. The beams were instrumented and tested under two-point load. The experimental program consisted of testing thirteen simply supported reinforced rectangular beams. The main parameters of study are the different methods of strengthening. The deflection, strain, failure load, failure mode and stiffness of the strengthened beams are discussed. A nonlinear finite element method NFEM analyses (Ansys15 program) was used to corroborate the results from the experimental study. Test results indicates that the best , simple and cheap technique of strengthening by recording an increase in the load capacity of 8.95 % is that strengthened by using four steel stirrups as rectangular shape with diameter 8mm and steel rods with 8mm which also gives an decrease in deflection and an increase in stiffness. The beam strengthened by reinforced beams around the opening, gives an increase in the load carrying capacity of 2.8% of the control ultimate capacity. However, beams strengthened by two numbers of steel wire mesh, steel bars like box with diameter 8 mm and reinforced beams at upper and lower of the opening, gives an increase in the load carrying capacity of 1.6 % of the control ultimate capacity. For the beam strengthened after casting an increase was obtained in the load capacity by 3.77 % for the specimen that strengthened by using four

layers of steel wire mesh, steel strip system, steel angles and clamps. The analytical results are compared with the data obtained from beam tests up to failure. Faire agreement was found between the FEA results and EXP results.

KEY WORDS:

Experimental, Analytical, Strengthening R C Beams, Rectangular opening, beam with opening, Nonlinear, FEA, ANSYS.

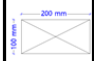
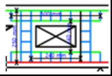
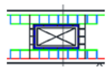
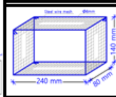
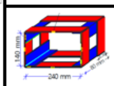
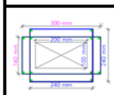
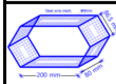
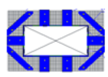
i. Introduction

Beam openings are electromechanical and architectural requirement in most modern buildings. Openings in beams become necessary to provide service lines like water supply lines, air conditioning ducts etc. to pass through in order to save the height of the room. The most favorable openings location for architectures and electromechanical is at the end of beams near support which is the most critical shear zone. The web openings of the beam result in decrease of flexural and shear strengths, flexural stiffness and increase of deflection. The reinforcement at the opening is needed to ensure the proper strength and stiffness of the beams. **Mohaisen Saad Khalf (2012)** attempted 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 beams were retested, measuring deflection versus loads up the appearance of the first crack. Three of these beams samples were strengthened by steel plates sticked to the faces of their opening. The dimensions of those plates were (150×100×0.5mm). It was found that the results were acceptable and could be adopted to give a faire view about the behavior of such samples. **Amer A. (2013)** presented the effect of in-site drilled rectangular and circular openings on flexural behavior of existing reinforced concrete beam. 10 cast in-site beams were testes with the same dimension and reinforcements under two point loading. The load, deflection, strains, crack patterns and failure modes were recorded and analyzed. The results from the performed tests were compared to study the effect of in-site drilled rectangular and circular openings on flexural behavior of existing reinforced concrete beams. The obtained results showed that the drilling of openings in the existing beams as well as the drilled openings shape decreases flexural strength and increases the vertical deflection of the beams seriously. **El-Sebai A. M. (2013)** presented a study of the effect of openings shape in-site drilling an strengthening of openings on the behavior of the existing beams. A total number of 8 cast-in-site beam specimens were tested in flexure. The specimens were divided to four groups. The first group consists of two control soli beams. The second group consists of two beams with pre-determined circular an rectangular opening in flexure zone respectively. The third group consists of two statically loaded beams to about 60% of their failure load before drilling single circular and rectangular openings in flexure zone and then continuing testing up to failure. The fourth group consists of two beams were statically loaded to about 60% of their failure load and then single circular and rectangular openings were drilled and strengthened with steel plates and tests continued until failure. The circular and rectangular openings have the same area about 2000 mm2. The beams were pre-loaded to simulate the practical drilling and strengthening processes of the loaded beams. The beams were loaded with two vertical concentrated loads up to failure. The obtained results showed that the drilling of openings in the existing beams as well as the drilled openings shape decreases flexural strength an increases the vertical deflection of the beams seriously. **El Esnawi H. H. (2013)** presented experimentally the effect of introducing opening in the shear zone on the flexural, shear capacity and behavior of reinforced concrete beam. Different conventional techniques of strengthening around the openings were used. The results were compared to a tested beam that that was pre-reinforced around the openings as well as a control beam without opening. **Nasir Shafiq (2016)** studied the behaviour of reinforced concrete (RC) beams with large openings strengthened by externally bonded carbon fibre-reinforced polymer CFRP laminates. A total of six simply supported beams consisting of two solid beams and four beams with openings were cast and tested under four-point bending. Each beam had a large opening placed symmetrically at mid-span. Test parameters included the opening shape and size as well as the strengthening configuration for the CFRP laminates. The study was conducted by way of both experimental testing and finite element analysis. The experimental results show that including a large opening at mid-span reduces the beam capacity to of 50%. In the experimental results, strength gain due to strengthening with CFRP laminates was in the range 80–90%. The finite element and experimental results were compared. **Ashwin.C.S (2017)** presented an experimental study of using carbon fibre reinforced polymer (CFRP) fabric to strengthen the beam. Thirteen RC beams were casting divided by followings: three were control beam, four beams with opening, four beams with opening strengthened by CFRP and two beams were retrofitted with CFRP. The experimental investigation was carried out under two point loading and results indicate the percentage decrease in strength due to web opening varies according to opening shape. It was observed that there was an increase in strength of beams due to wrapping of CFRP in the shear zone. The effects of strengthening on deflection, ultimate load, strain and CFRP contribution were investigated.

ii.Experimental program

The experimental work carried out in this study has been planned to investigate the efficiency of strengthening of reinforced concrete beams. Beams were strengthened by different methods using steel wire mesh, steel angles, steel straps, steel stirrups system and steel empty box from steel bar. In this experimental program, thirteen reinforced concrete beams of 120 mm×300mm cross-section and 2000 mm total length (1800 mm effective length) were casted. All beams have three normal mild steel bars 10 mm diameter as main reinforcement as a bottom reinforcement and two normal mild steel bars 8 mm as a top reinforcement. All beams were provided with two branches Φ 6 mm stirrups @ 150 mm spacing as shown in Fig. 5.1 All beams were tested under two points loading. The tested beams are shown in table [1]

[Table. 1] List of specimens and strengthening methods

Groups	Beam No.	Beam dimension	Openings dimension	key	Wire mesh	Strengthening technique
Group1Control	B1	120 x 300 x 2000 mm mm	No opening	-	------	-
	B2		 100 x 200 mm at 150 mm from support		------	-
Group 2 (Before Casting)	B3				------	Reinforcement steel beams around the opening
	B4				2 layers	Reinforcement steel beams at the upper and lower of opening and steel bars system like box with 8 mm diameter.
	B5				2 Layers	Steel bars system like box with 8 mm diameter with steel wire mesh.
	B6				4 Layers	
	B7				6 Layers	
	B8				--------	Steel angles 30x30x3mm like box with steel straps 30x3 mm.
	B9				------	Steel stirrups as a rectangular shape 8 mm with steel bars 8mm at all corners.
	B10				2 Layers	Steel diagonal box from steel bars with diameter 8 mm with steel bars diameter 8 mm at the corner.
	B11				4 Layers	
	B12				6 Layers	
Group 3 (After Casting)	B13				4 Layers	4 Steel Angles at corner of opening and steel straps around the opening " Clamp"

The beams were divided into three groups:

Group 1 - (Control beams):

Consists of control beam (B1) solid beam without opening and beam (B2) with opening without strengthening as shown in Fig. 1. And Fig.2 Strain gauges were fixed at the upper and lower steel reinforcement.

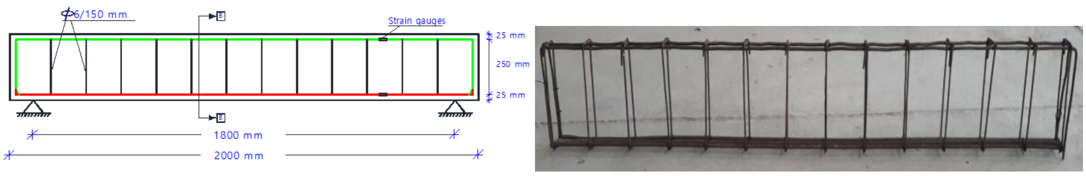


Fig. (1) Detailing of reinforcement steel for control beam (B1) without opening (solid beam).

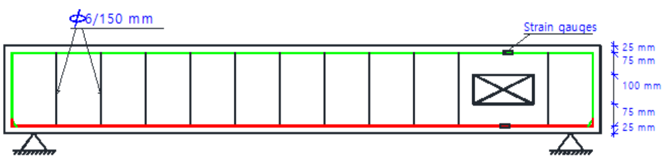


Fig. (2) Detailing of reinforcement steel for beam (B2) with opening without strengthening.

Group (2) Ten beams with openings (100 x 200 mm) at 125 mm from the support at max shear zone were strengthened by different methods using steel wire mesh, steel angles, steel straps, steel stirrups system and steel empty box from steel bar. All beams in that group were strengthened before casting. Strain gauges were fixed at upper and lower steel reinforcement.

The followings are the details of reinforcement strengthening of the beams:

Beam (B3) was provided with reinforced steel beams around the opening with diameter 8 mm where the upper and lower reinforced steel beam with length [500 mm]. The other two vertical reinforced steel beams at the both sides of opening are with length [250 mm] as shown in Fig. 3 and Fig. 4.

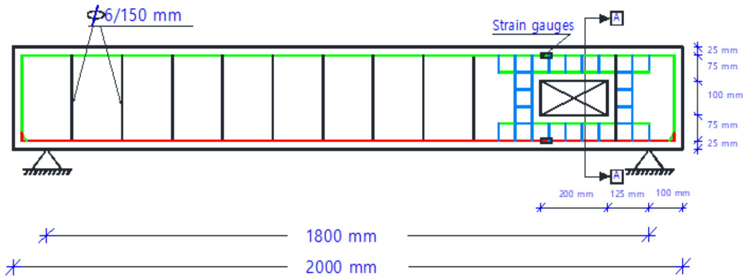


Fig. (3) Detailing of reinforcement steel for strengthened beam (B3).

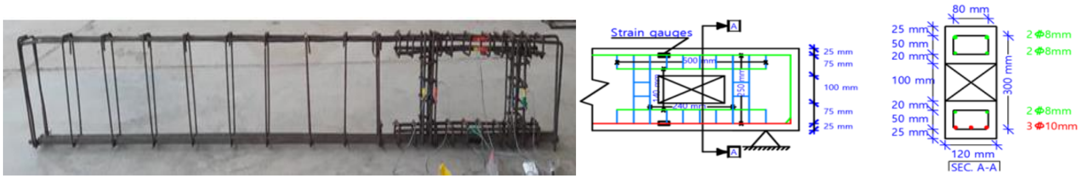


Fig. (4) Strengthened beam (B3) using steel beams around the opening.

Beam (B4) was provided with reinforced steel beams at the upper and lower of opening where the upper and lower reinforced steel beams with length [500 mm]. A steel box was used made of steel rods with diameter 8 mm with internal dimensions [240 x 80 x140 mm] and with steel wire mesh fixed around the box as shown in Fig. 5 and fig. 6.

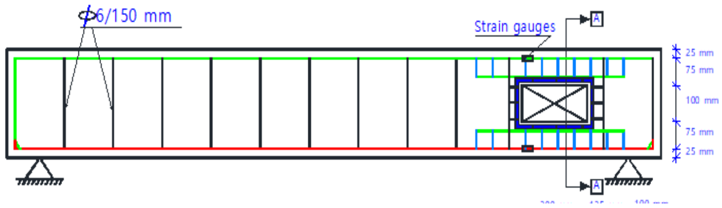


Fig. (5) Detailing of reinforcement steel for strengthened beam (B4).

Fig. (6) Strengthened beam (B4).

Beams (B5, B6, and B7) were provided with steel box made of steel bars with diameter 8mm with internal dimension [240 x 80 x 140 mm] and steel wire mesh with (2, 4 and 6) layers fixed around the box as shown in Fig. 7 and Fig. 8.

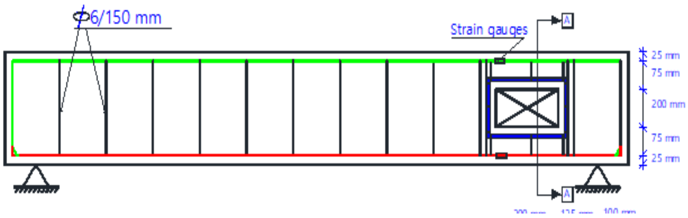


Fig. (7) Detailing of reinforcement steel for strengthened beams (B5, B6 and B7).

Fig. (8) Strengthened beams(B5, B6 and B7).

Beam (B8) was provided with steel box with internal dimension [240 x 80 x 140 mm] made from steel angles 30*30*3 mm with steel straps 30*3 mm as shown in Fig. 9 and Fig. 10.

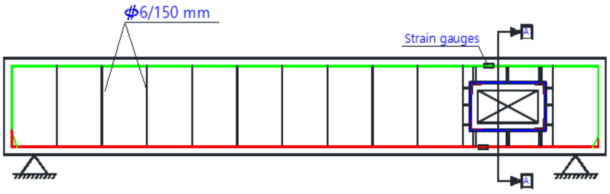


Fig. (9) Detailing of reinforcement steel for strengthening beam (B8).

Fig. (10) strengthened beam (B8).

Beam (B9) was provided with four steel stirrups 8 mm diameter as a rectangular shape with internal dimension [300*140 mm] and [240 x 240 mm] with steel bars 8mm at corner with length 80mm as shown in Fig. 11 and Fig. 12.

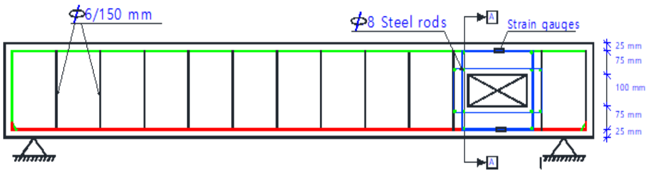


Fig. (11) Detailing of reinforcement steel for strengthened beam (B9).

Fig. (12) strengthened beam (B9).

Beams (B10, B11 and B12) were provided with steel diagonal box with internal dimension [200 x 86.5 mm] made of steel bars with diameter 8mm with steel bars diameter 8 mm and steel wire mesh fixed around the box (2, 4 and 6) layers as shown in Fig. 13 and Fig. 14.

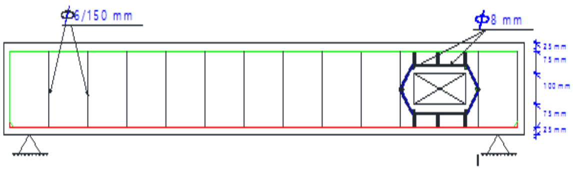


Fig. (13) Detailing of reinforcement steel for strengthened beams (B10, B11 and B12).

Fig. (14) Strengthened beams (B10, B11 and B12)

Group (3) One beam was opened after casting with opening (100*200 mm) at 125 mm from the support at max shear zone was strengthened using steel wire mesh, steel angle, steel bars and steel strip. The beam was strengthened after casting. Strain gauges were placed at the upper and lower of the steel reinforcement. Beam (B13) was provided with two layers of steel wire mesh around the opening from inside with dimension [245 x 80 x 145 mm] and other two layers of steel wire mesh as U shaped on each side of the opening. Four steel angles were placed at the corners of the opening fixed by bolts and four steel straps as U shaped were placed around the opening [30 x 3 mm] as shown in Fig. 15 and Fig. 16. Gaps and voids were filled with an epoxy resin.

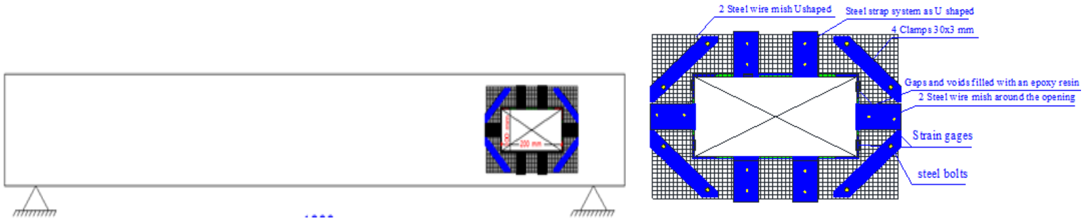


Fig. (15) Detailing of reinforcement steel for strengthened beam (B13).

Fig. (16) Strengthened beam (B13).

A. Concrete mixing design, casting and curing

The concrete mix was designed to obtain target strength of 25 N/mm2 at the age of 28 days. The concrete mix used in all specimens was designed according to the Egyptian code of practice. The average time of mixing concrete in the mixer was from 4 to 6 min from the moment of adding water. Before each casting the wood forms were prepared and lubricated with oil. During casting, a mechanical vibrator was used to compact the concrete. All beam specimens were left in forms for 12 hours then one of form sides were removed and sprayed with water. After another 8 hours all form sides and bottom form were removed and beams were covered with wet canvas for 28 days to achieve the expected strength. Six standard cubes 150 x 150 x 150 mm were casted from each concrete patch to define the concrete properties. The curing conditions for the cubes were the same the beams specimens' condition

B. Description of Forms

The forms were made of 18mm plywood to ensure plain fair face concrete. The form dimensions were 120 mm×300 mm cross-section and 2000 mm length.

C. Test setup and loading

Before starting casting and while preparing the reinforcement of beams, the strain gauges were fixed directly on the main (bottom) reinforcement, on the top reinforcement steel, on the right stirrup of the opening and on the left stirrup of the opening of all beams. Before testing, the beams were washed by a thin coat of white plaster to facilitate determination and mapping the cracks at the different stages of loading. Three LVDT of accuracy 0.01 mm (deflection) were used, one was fixed directly under the opening (on distance of 225 mm from the support near opening), the other one was fixed directly at distance of 900 mm from the support near opening and the last one was fixed directly at distance of 1575 mm from the support near opening as shown in Fig17. After the beams were accurately placed into position on the testing frame, the initial readings from the LVDT were taken before the load application.

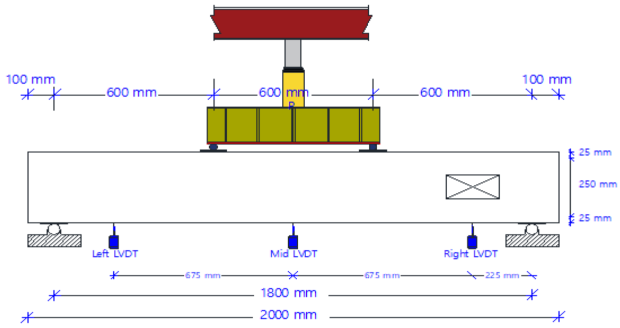


Fig. (17) Two-point load system and the position of the LVDT.

D. Test procedure

The zero load readings for the upper and lower steel reinforcement strain and the initial readings from the LVDT were recorded. The load was applied in regular increments from zero up to the failure load. At the end of each load increment, readings from the load cell and strain gauges were recorded through the data acquisition system. The tests were terminated by complete destruction of the beam specimens.

E. Measurements

The followings were measured:

i. The load readings were taken for all stages.
ii. The LVDT readings were taken for all load stages
iii. The strain gauge readings were taken for all load stages.
iv. Crack patterns at different load levels were monitored until beams failure.

iii. Finite element modeling

The present study addresses a three-dimensional nonlinear finite element analysis (FEA) modeling for the prediction of the shear behavior of reinforced concrete (RC) beams, with and without opening, strengthened with steel wire mesh, steel angles, steel straps, steel stirrups system and reinforcement beams around the opening. The nonlinear FEA was performed using the ANSYS program. Eight nodes 3-D space solid elements were used to represent the concrete. The steel reinforcements were modeled as discrete reinforcing steel bars using two nodes 3-D space link element.

A. Reinforcement concrete

Concrete and resin was modeled using 3-D (8-node) solid elements. This element is capable of considering cracking in three perpendicular directions, plastic deformation and crushing, and creep. The element is defined by eight nodes having three translation degrees of freedom at each node in the x, y and z directions.

B. Steel reinforcement

A Link180 element was used to model the steel reinforcement. Two nodes are required for this element. Each node has three degrees of freedom translations in the nodal x, y, and z directions. The element is also capable of plastic deformation.

C. Steel Plate

An eight-node solid element, Solid185, was used for the steel plates at the supports in the beam models. The element is defined with eight nodes having three degrees of freedom at each node translations in the nodal x, y, and z directions. The geometry and node locations for this element type.

D. Concrete

Concrete is considered as a quasi-brittle material. Complete stress-strain curves of concrete are needed to accurately predict structural behavior to failure and post-failure. ECP 203-2007 constructs the simplified uniaxial compressive stress-strain curve, as shown in Fig. 18, for concrete used in this finite element model. Poisson's ratio for concrete was assumed to be 0.2 for all four beams as denoted in ECP 203 2007. Typical shear transfer coefficients range from (0.0 to 1.0), with 0.0 representing a smooth crack (complete loss of shear transfer) and 1.0 representing a rough crack (no loss of shear transfer). When the element is cracked or crushed, a small amount of stiffness is added to the element for numerical stability.

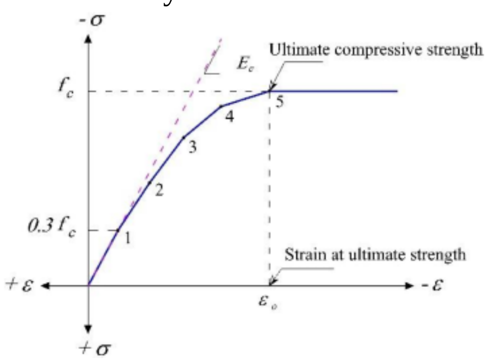


Fig. (18) Simplified compressive uniaxial stress-strain curve for concrete

E. Steel reinforcement

The reinforcement element was assumed to be a bilinear isotropic elastic-perfectly plastic material and identical in tension and compression as shown in Fig. 19. Modulus of elasticity and Poisson's ratio were taken 2 x 10^5 MPa and 0.3 for all types of steel reinforcement.

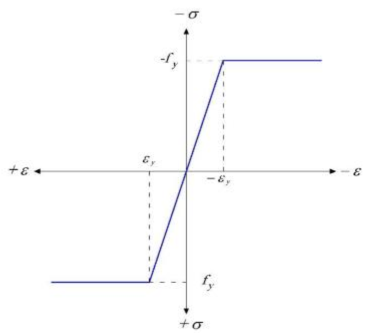


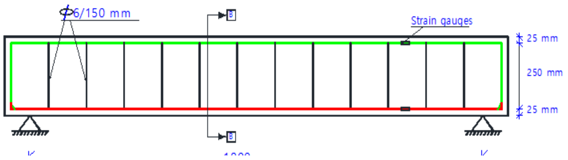
Fig. (19) Stress-strain relationship of steel rebar

F. Finite Element Model

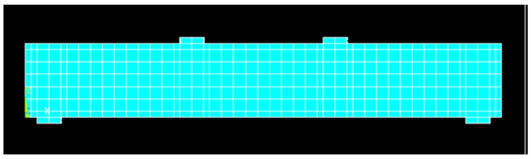
The finite element model is used to represent four beam specimens with cross section 120 x 300 mm and 2000 mm length as following:

- Fig. 20 shows the modeling and detailing of reinforcement for the modeling of control beam (B1).
- Fig. 21 shows the modeling and detailing of reinforcement for the modeling of beam (B2).
- Fig. 22 shows the modeling and detailing of reinforcement for the modeling of strengthened beam (B3).

- Fig. 23 shows the modeling and detailing of reinforcement for the modeling of strengthened beam (B9).

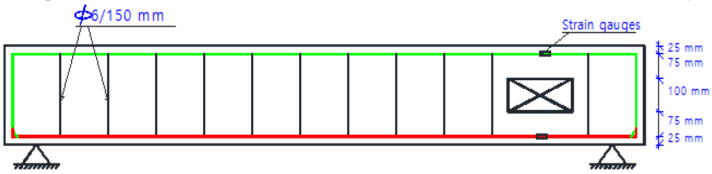


Details of control beam B1 Experimental

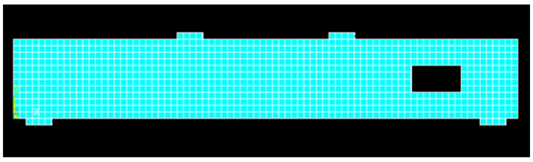


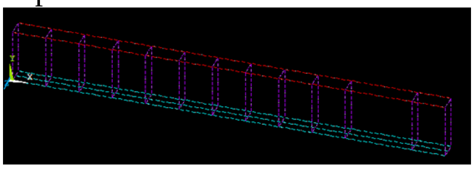
Modeling of control beam B1 Finite element modeling

Fig. (20) Details of control beam B1 without opening



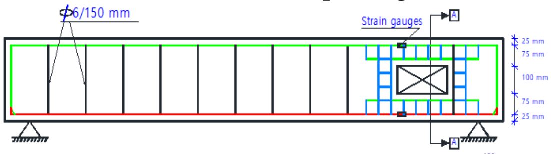
Details of beam B2 Experimental



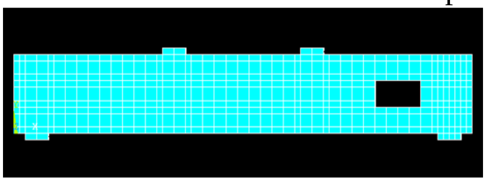


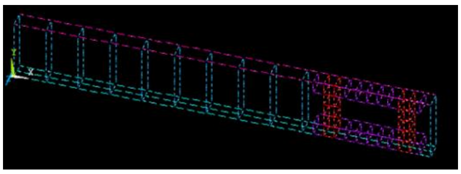
Modeling of beam B2 Finite element modeling

Fig. (21) Details of beam B2 with opening without strengthening



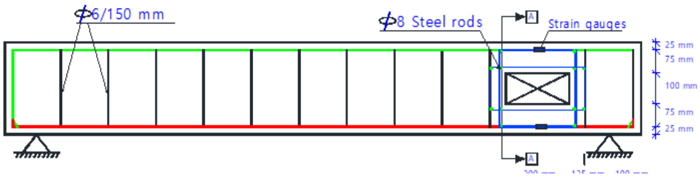
Details of beam B3 Experimental



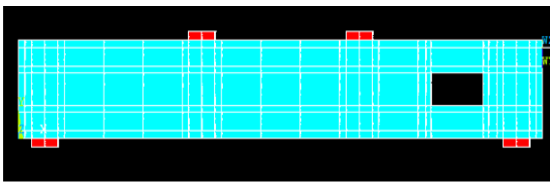


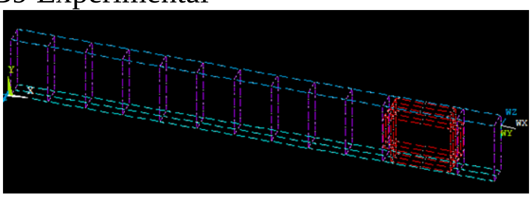
Modeling of beam B3 Finite element modeling

Fig. (22) Details of strengthened beam B3 with opening strengthened by reinforced beams around the opening.



Details of beam B9 Experimental





Modeling of beam B9 Finite element modeling

Fig. (23) Details of strengthened beam B9 with opening strengthened four steel stirrups as rectangular shape with diameter 8 mm and steel rods with 8 mm

iv. Results and analysis of test result

Table 2 shows the failure load and the maximum deflection at three points (left and mid span as well as under the opening) for non-strengthened and strengthened beams.

A. Results and analysis of experimental test result

Fig. 24 and Fig. 25 show the relationship between load and deflection for control beam (B1) without opening and (B2) beam with opening without strengthening as well as strengthened beams (B3) [using reinforced beams around the opening] and (B4) [by using steel bars like box of diameter 8 mm, steel wire mesh (2 layers) and reinforced beams at upper and lower of the opening].

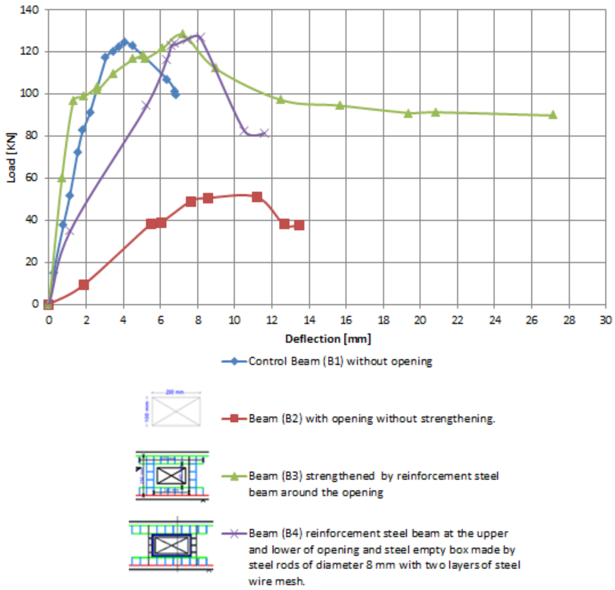


Fig. (24) The load-deflection relationship (Under opening) Control beam (B1) without opening, Beam (B2) with opening without strengthening, strengthened beam (B3) and strengthened beam (B4)

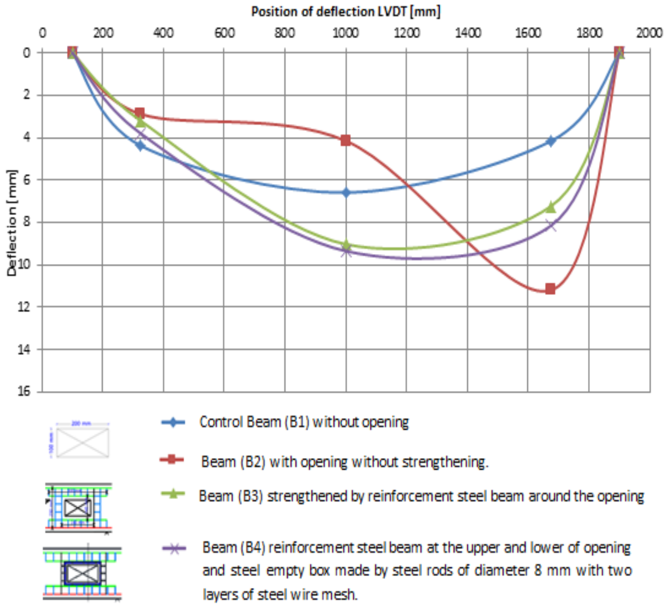


Fig. (25) The deformation shape for Control beam (B1) without opening, Beam (B2) with opening without strengthening, strengthened beam (B3) and strengthened beam (B4)

Fig. 26 to Fig. 27 show the relationship between load and deflection for control beam (B1) without opening and (B2) beam with opening without strengthening as well as strengthened beams (B5, B6 and B7) using steel box made by steel rods with diameter 8mm and steel wire mesh (2, 4 and 6) layers.

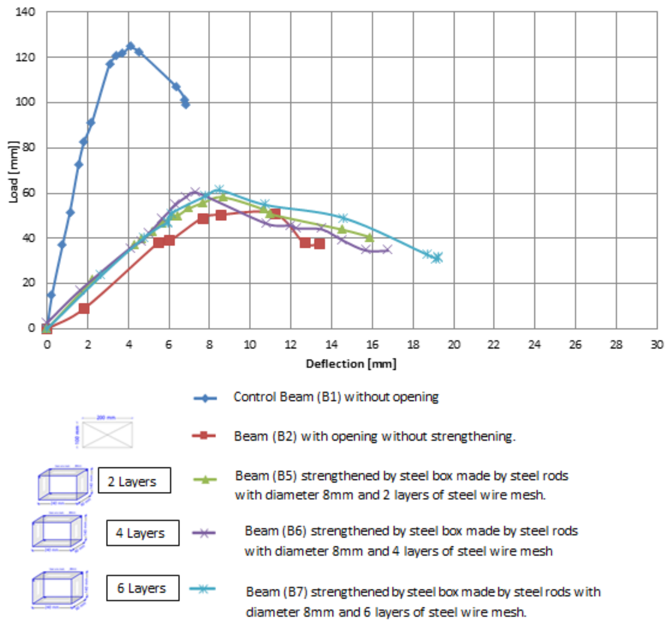


Fig. (26) The load-deflection relationship (Under opening) for control beam (B1) and beam (B2) with opening without strengthening as well as strengthened beam (B5, B6 and B7).

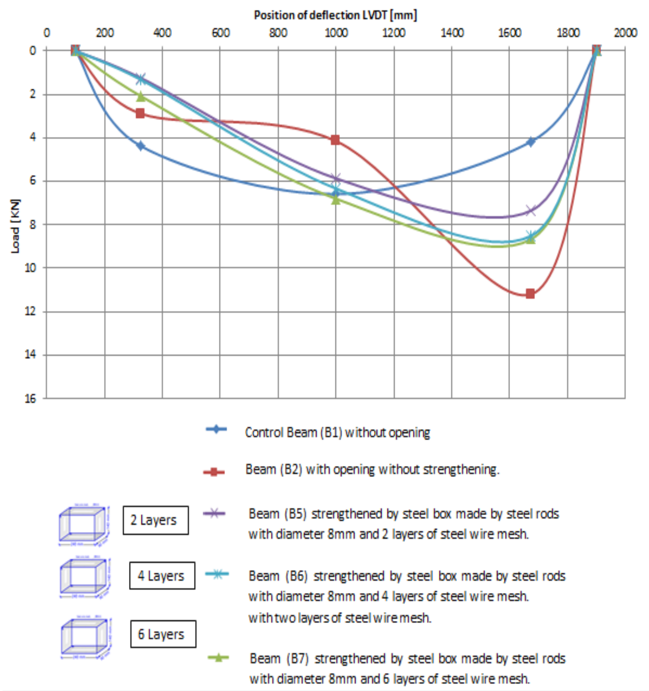


Fig. (27) The deformation shape for control beam (B1) and beam (B2) with opening without strengthening as well as strengthened beams (B5, B6 and B7)

Fig. 28 and Fig. 29 show the relationship between load and deflection for control beam (B1) without opening and (B2) beam with opening without strengthening as well as strengthened beam (B8) using steel straps 30 x 3mm and steel angle 30 x 30 x 3 mm and strengthened beam (B9) using four steel stirrups as rectangular shape with diameter 8 mm and steel rods with 8 mm.

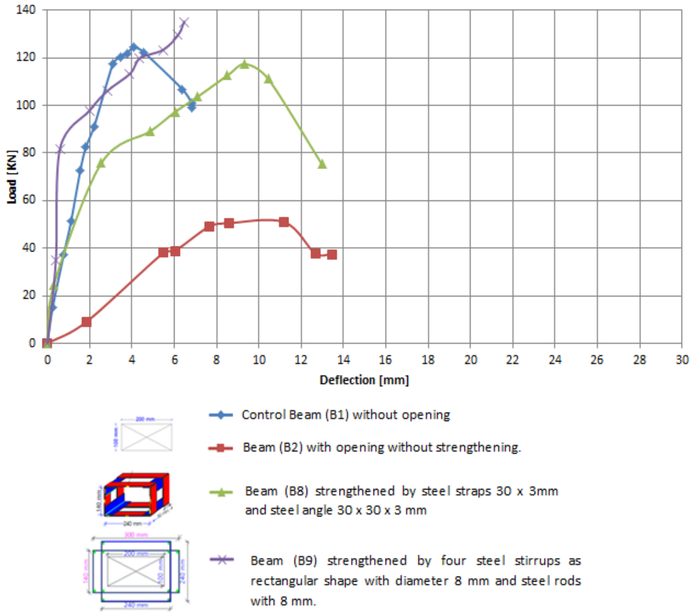


Fig. (28) The load-deflection relationship (at Under opening) for control beam (B1) and beam (B2) with opening without strengthening as well as strengthened beams (B8 and B9).

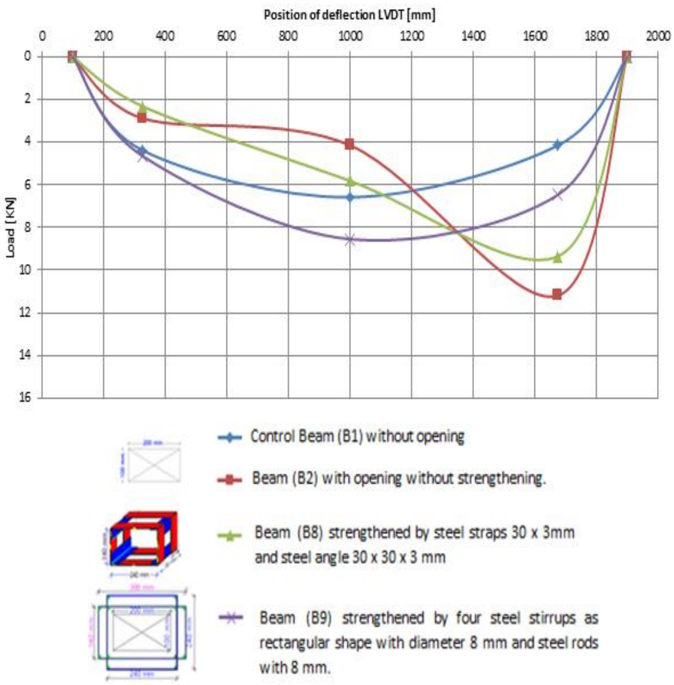


Fig. (29) The deformation shape for control beam (B1) and beam (B2) with opening without strengthening as well as strengthened beams (B8 and B9).

Fig.30 and Fig 31 show the relationship between load and deflection for control beam (B1) without opening and (B2) beam with opening without strengthening as well as strengthened beams (B10, B11 and B12) using layers of steel wire mesh (2, 4 and 6), steel stirrups system with diameter 8 mm and steel rods with diameter 8 mm.

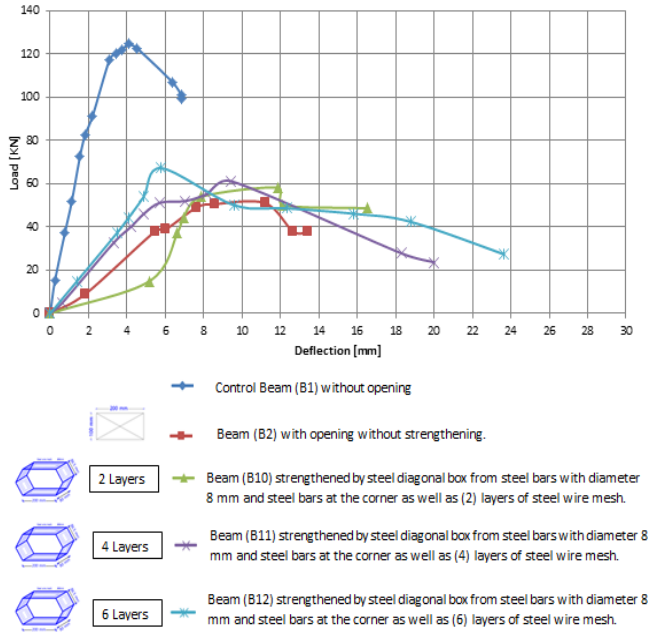


Fig. (30) The load-deflection relationship (at Under opening) for control beam (B1) and beam (B2) with opening without strengthening as well as strengthened beams (B10, B11 and B12).

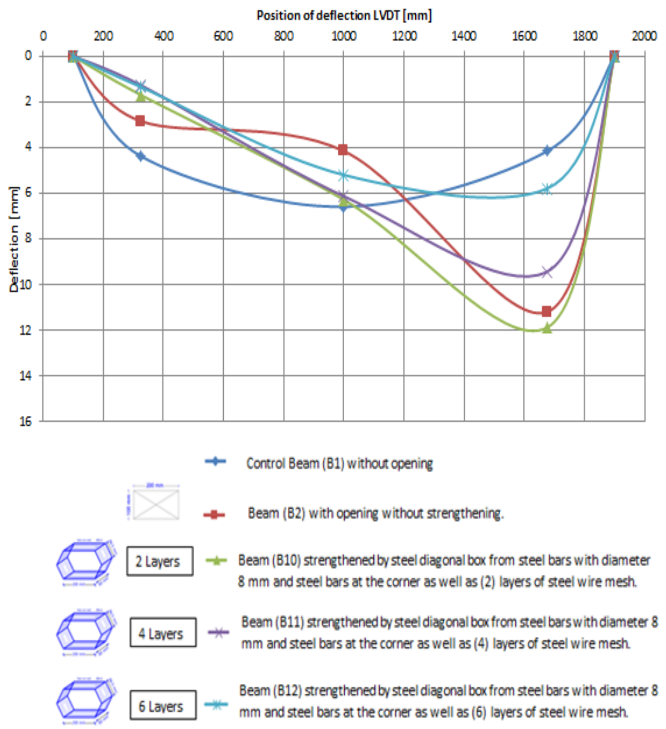


Fig. (31) The deformation shape for control beam (B1) and beam (B2) with opening without strengthening as well as strengthened beams (B10, B11 and B12) at failure load.

Fig. 32 and Fig. 33 show the relationship between load and deflection for control beam (B1) without opening and (B2) beam with opening without strengthening and strengthened beam (B13) using four layers of steel wire mesh, steel strip system, steel angles and clamps.

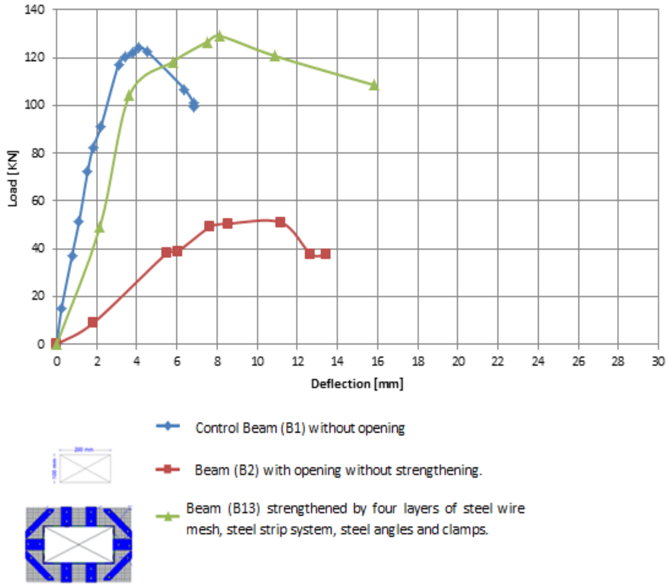


Fig. (32) The load-deflection relationship (at Under opening) for control beam (B1) and beam (B2) with opening without strengthening as well as strengthened beam (B13).

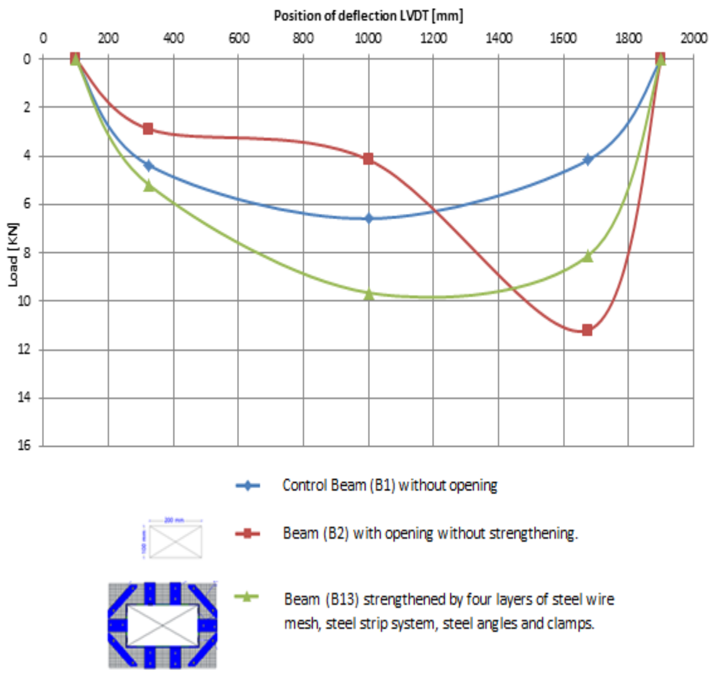


Fig. (33) The deformation shape for control beam (B1) and beam (B2) with opening without strengthening as well as strengthened beam (B13) at failure load.

However, Fig. 34 shows the ultimate load for all specimens and Fig. 35 shows the stiffness values of all specimens

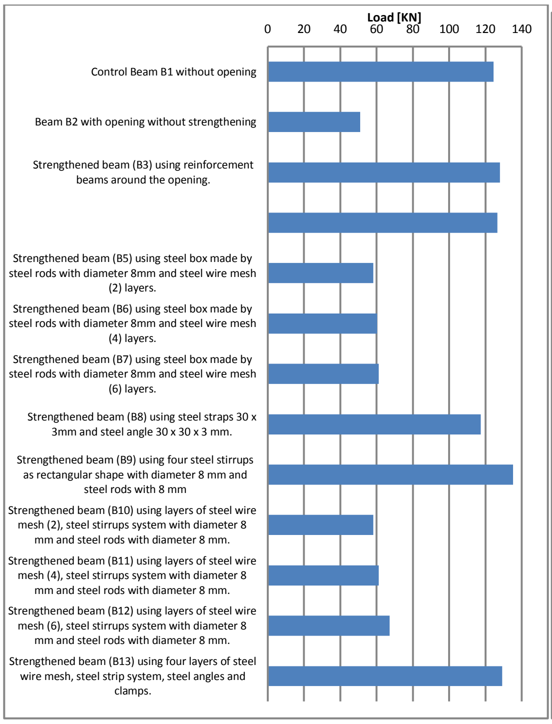


Fig. (34) The ultimate load for all specimens

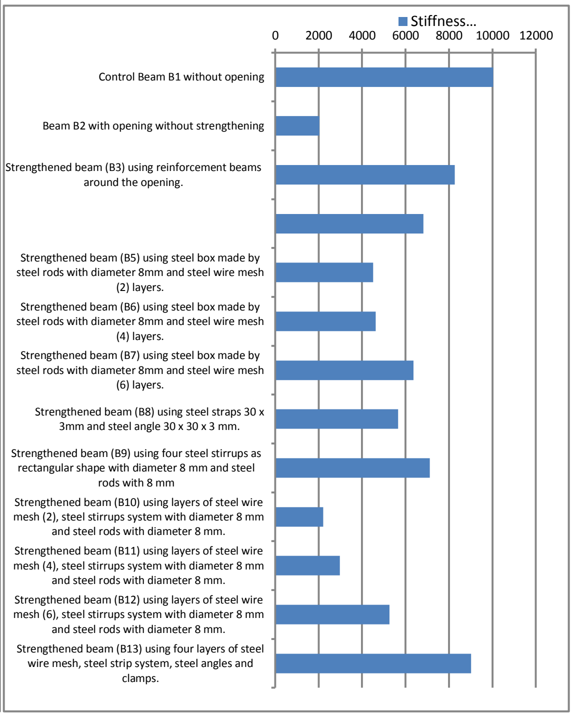
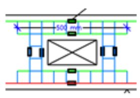
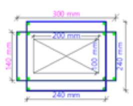


Fig. (35) The stiffness values for all specimens

B. Results and analysis of experimental and finite element model result

The comparison of the maximum failure load obtained from experimental (EXP) and finite element (FEA) analysis as shown in Table (3).

Table (3) shows the comparison of the maximum failure load obtained from experimental (EXP) and finite element (FEA) analysis as shown in

Specimen No.	Opening	key	Experimental		Finite Element Analysis	
			Load at first crack KN	Failure load KN	Load at first crack KN	Failure load KN
B1	-------------	-	49,54	124,5	42.5	117.823
B2	100 x 200 mm at 150 mm from support (max shear)	-	30.54	52,01	31.98	57.3778
B3			50.84	128.0	44.1	122.629
B9			47.24	135.2	45.8	136.281

- ***Control beams***

Fig 36 shows the comparison between the experimental results and FEA results of deformation shape for the control beam (B1) without opening.

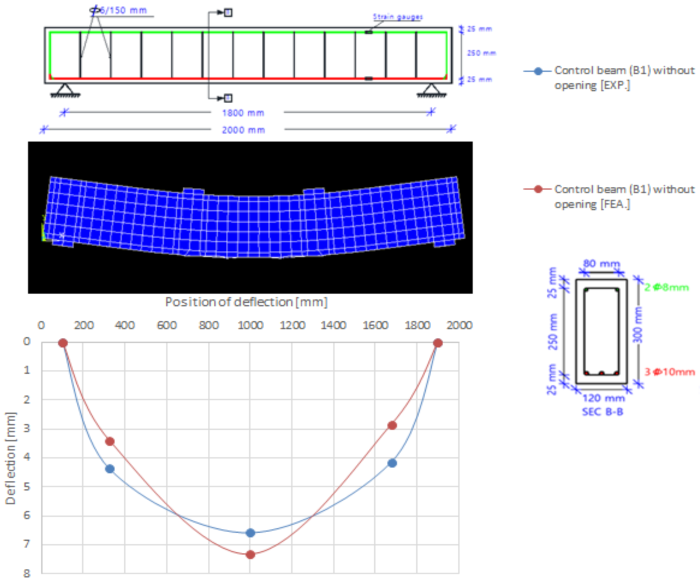


Fig. (36) The comparison between the experimental results and FEA results of deformation shape for the control beam (B1) without opening.

Fig 37 shows the comparison between the experimental results and FEA results of the load-deflection relationship for the beam B2 with opening without strengthening. Fig 38 shows the comparison between the experimental results and FEA results of deformation shape for the control beam (B2) with opening without opening.

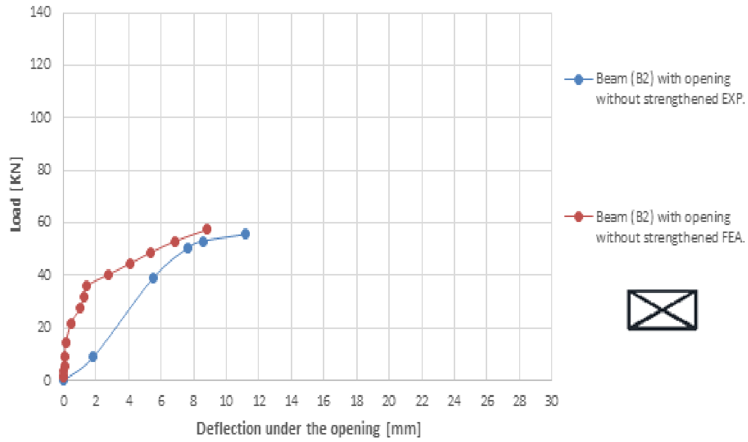


Fig. (37) The comparison between the experimental results and FEA results of the load-deflection relationship for the beam B2 with opening without strengthening

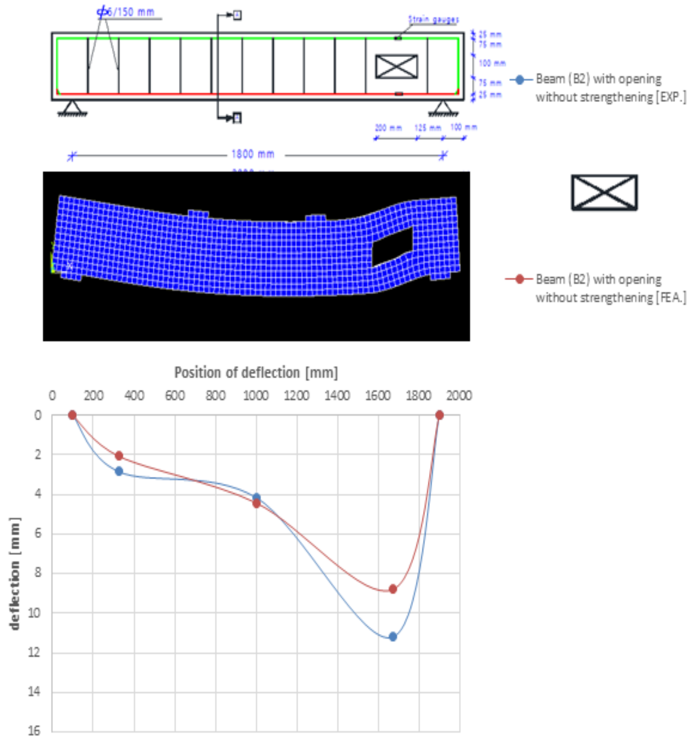


Fig. (38) The comparison between the experimental results and FEA results of deformation shape for the control beam (B2) with opening without strengthening.

- **<u>Strengthening beams</u>**

Fig 39 shows the comparison between the experimental results and FEA results of the load-deflection relationship for the strengthened beam B3 with opening strengthened by reinforced beams around the opening. This figure shows that the experimental result of the strengthening beam B3 gives maximum load capacity by 128 KN. However, the finite element results gives maximum load capacity of 122.629 KN. Fig 40 shows the FEA deformation shape for the strengthened beam B3 at the position of the left-point, mid-point and under the opening.

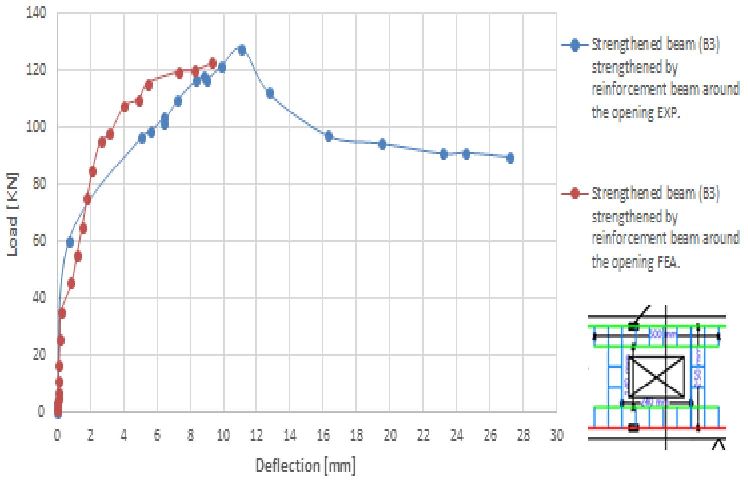


Fig. (39) Comparison between the experimental results and FEA results of the load-deflection relationship for the strengthened beam B3 with opening strengthened by reinforced beams around the opening.

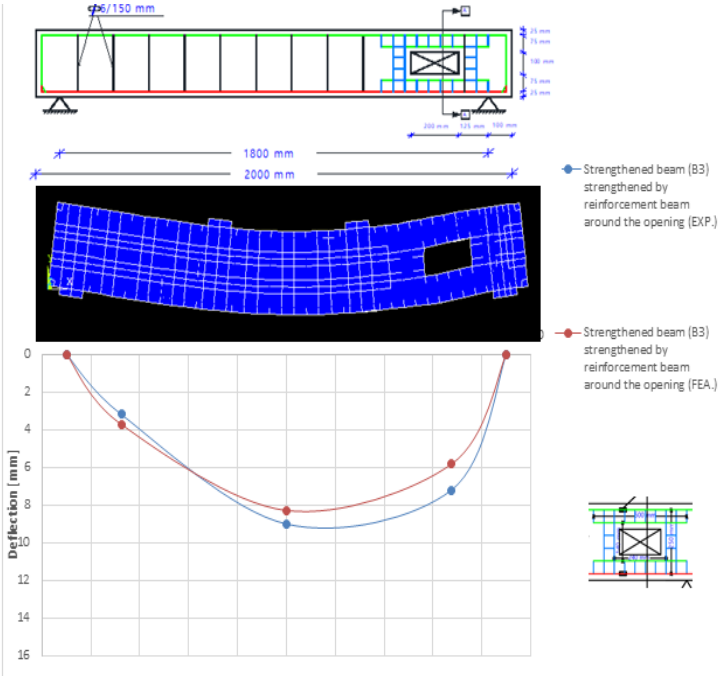


Fig. (40) The FEA deformation shape for the strengthened beam B3 with opening strengthened by reinforced beams around the opening showing the position of the left-point, mid-point and under the opening.

Fig 41 shows the comparison between the EXP results and FEA results of the load-deflection relationship for the strengthened beam B9 with opening strengthened by using four steel stirrups as rectangular shape with diameter 8 mm and steel rods with 8 mm. This figure shows that the experimental result of the strengthened beam B9 gives maximum load capacity of 135.199 KN. However, the finite element results gives maximum load capacity of 136.281 KN. Fig 42 shows the FEA deformation shape for the strengthened beam B9 at the position of the left-point, mid-point and under the opening.

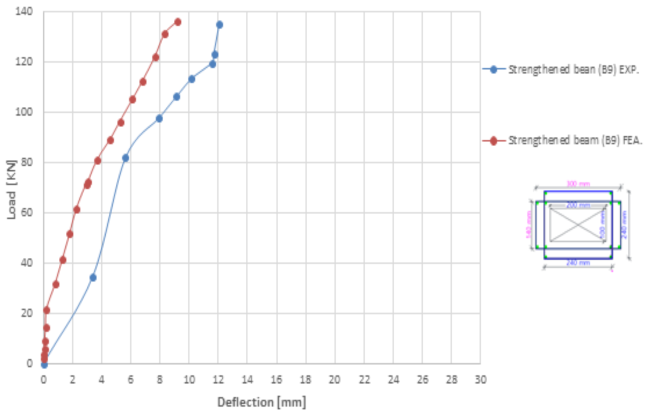


Fig. (41) Comparison between the experimental results and FEA results of the load-deflection relationship for the strengthened beam B9 with opening strengthened by using four steel stirrups as rectangular shape with diameter 8 mm and steel rods with 8 mm.

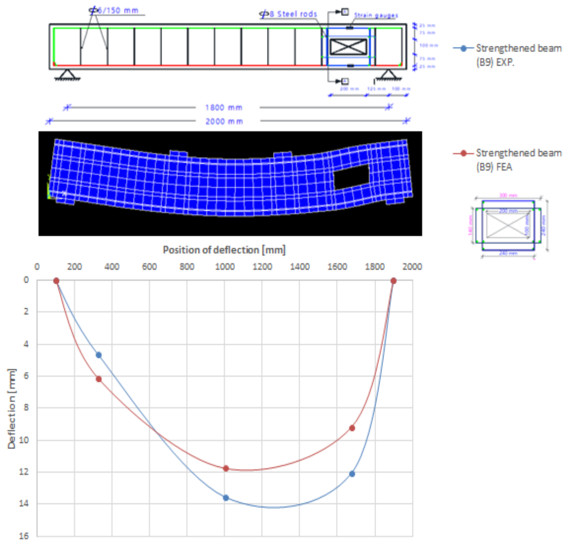


Fig. (42) The FEA deformation shape for the strengthened beam B9 with opening strengthened by using four steel stirrups as rectangular shape with diameter 8 mm and steel rods with 8 mm showing the position of the left-point, mid-point and under the opening.

Fig 43 shows the comparison of deformation shape model of the FEA results for the control beam B1 without opening, beam B2 with opening without strengthening, the strengthened beam B3 with opening strengthened by reinforced beams around the opening and strengthened beam B9 with opening strengthened by using four steel stirrups as rectangular shape with diameter 8 mm and steel rods with 8 mm.

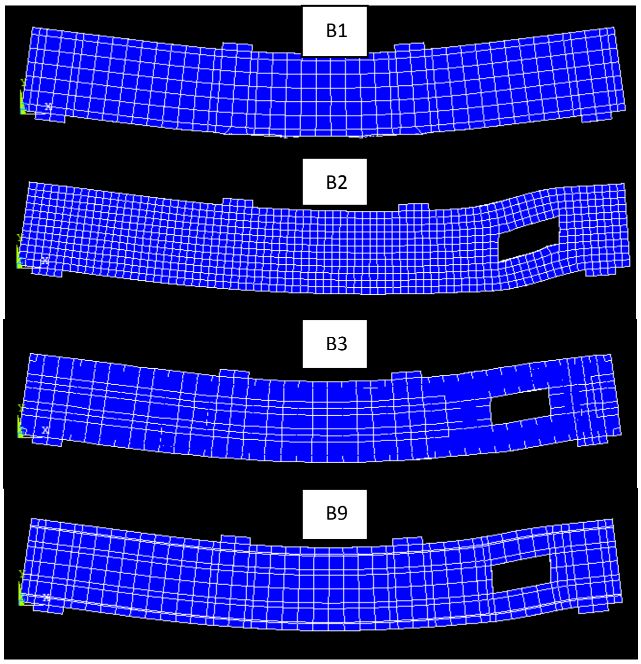


Fig. (43) Comparison of the deformation shape deflection at failure load between control beam without opening, beam (B2) with opening without strengthening, strengthened beam (B3) as well as strengthened beam (B9)

Fig 44 shows the comparison of deformation shape of the FEA results for the control beam B1 without opening, beam B2 with opening without strengthening, strengthened beam B3 with opening strengthened by reinforced beams around the opening and strengthened beam B9 with opening strengthened by using four steel stirrups as rectangular shape with diameter 8 mm and steel rods with 8 mm. This figure shows that the close agreement of the deformation shape between the EXP result and FEA result for the strengthening beam B3 and B9 with control beam B1 (without opening).

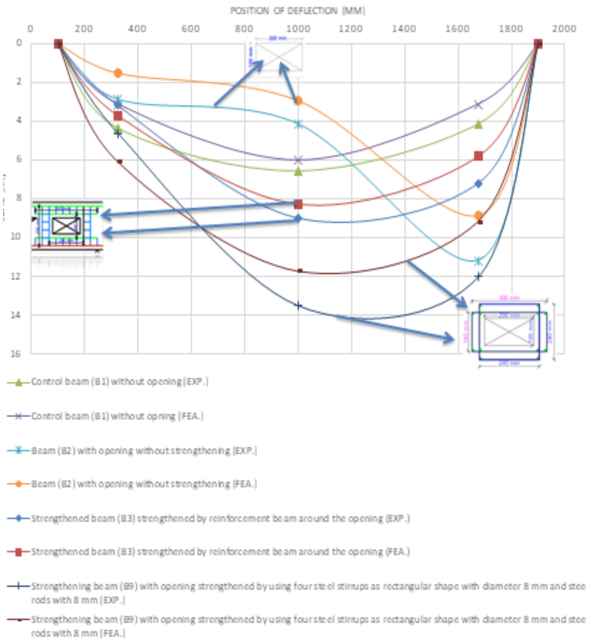
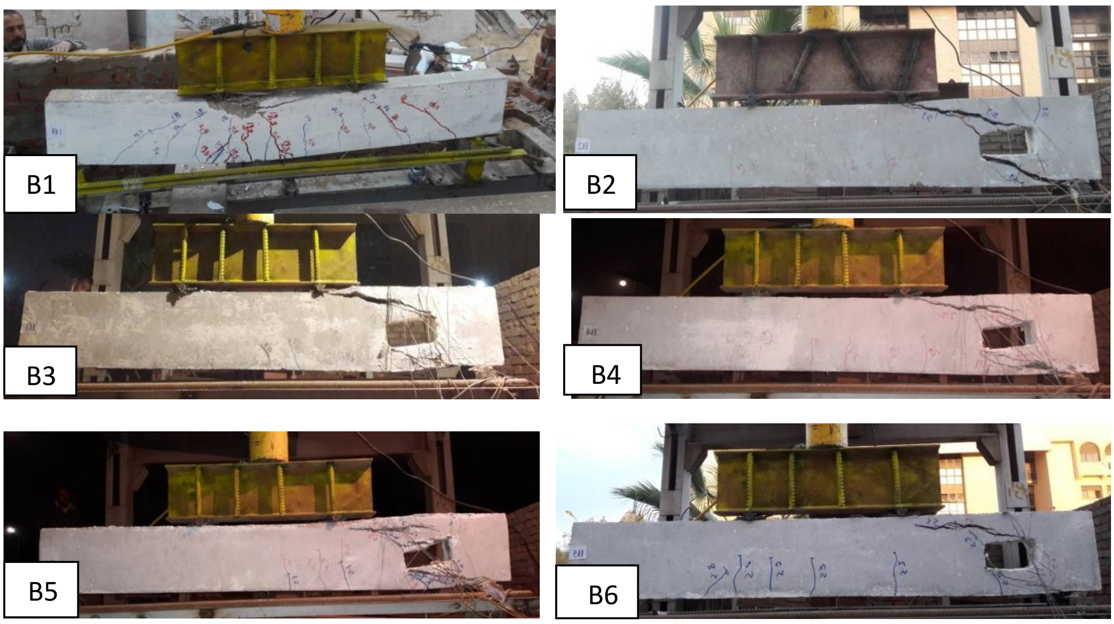


Fig. (44) Comparison of the deformation shape between control beam without opening, beam (B2) with opening without strengthened and strengthened beam (B3) as well as strengthened beam (B9).

v. <u>Failure modes:</u>

For all tested specimens, strengthened and non-strengthened, failure has been occurred at the corner of opening as shown in the figure [Fig.45], However, Fig. 46 shows the comparison of the failure between the EXP and FEA.



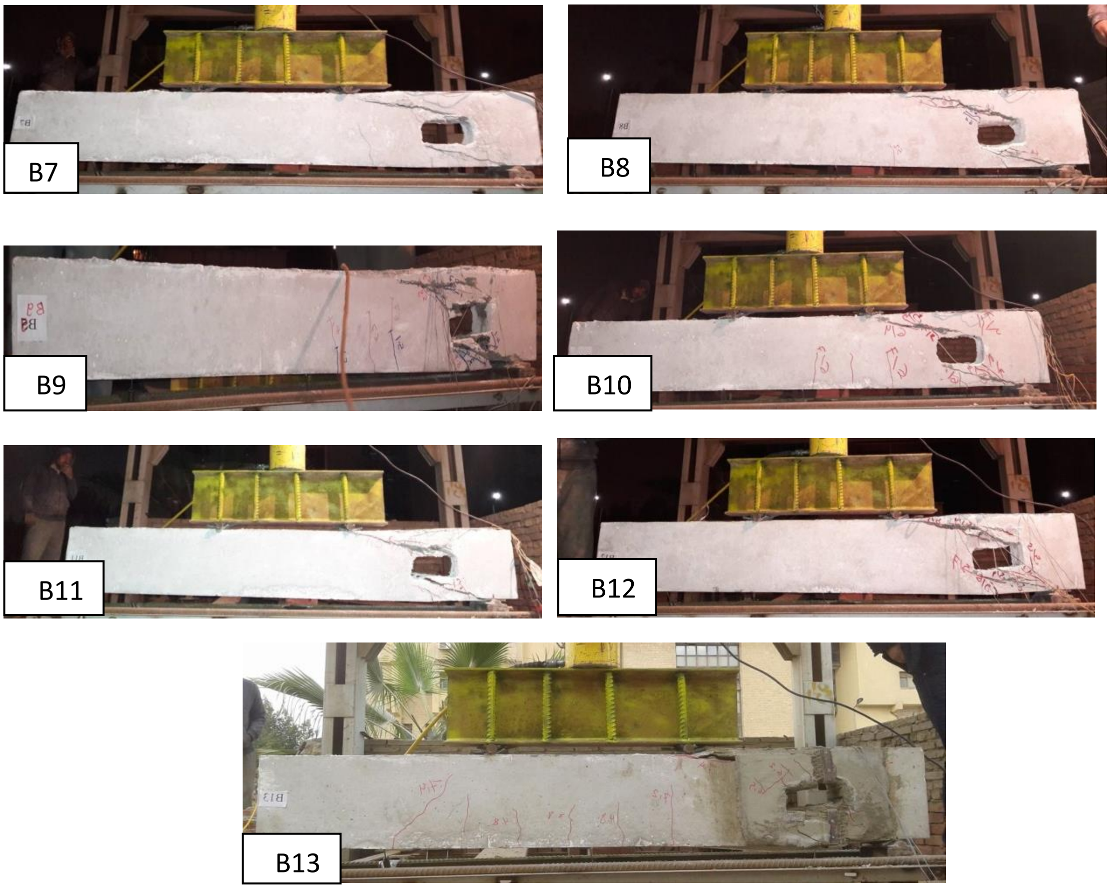
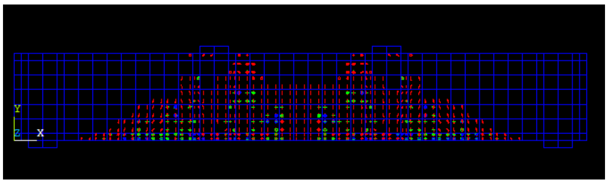
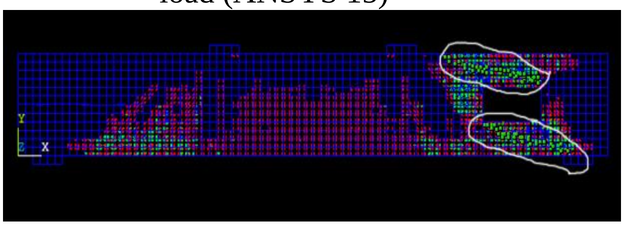


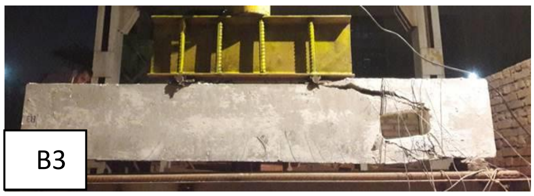
Fig. 45 Failure mode of all strengthened and non-strengthened beams

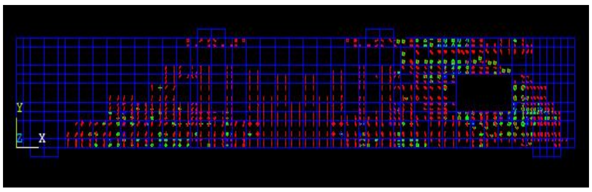


Crack pattern of control beam (B1) without opening. Cracks pattern for Control beam (B1) by FEA model at failure load (ANSYS 15)

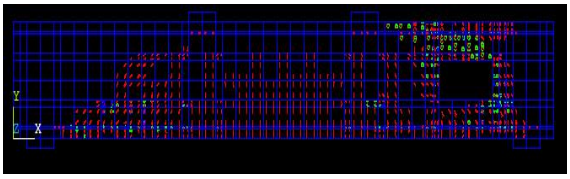


Failure mode of specimen control beam (B2) with opening without strengthening.





Failure mode of specimen strengthened beam (B3) with opening strengthened using reinforced beams around the opening.



Failure mode of specimen strengthened beam (B9) with opening strengthened using four steel stirrups as rectangular shape with diameter 8 mm and steel rods with 8 mm after testing under two points loading.

Cracks pattern for strengthened beam (B9) by FEA model at failure load (ANSYS 15)

Fig. 46 The comparison of failure mode between EXP results and FEA results for control beam (B1) without opening, beam B2 with opening without strengthening and strengthened beam B3 as well as strengthened beam B9.

vi. CONCLUSIONS:

From the present study, the followings have been concluded:

i. The more effective, best and simple technique is that beam strengthened before casting by using four steel stirrups as rectangular shape with diameter 8 mm and steel rods with 8 mm. An increase was obtained in the load capacity by 8.59% of the control ultimate capacity and has an acceptable value of stiffness .

ii. For beams strengthened by reinforced beams around the opening, gives an increase in the load carrying capacity of 2.8% of the control ultimate capacity. However, beam strengthened by two numbers of steel wire mesh, steel bars like box with diameter 8 mm and reinforced beam at upper and lower of the opening, gives an increase in the load carrying capacity by 1.6 % of the control ultimate capacity and an acceptable value of stiffness.

iii. For all beams strengthened by steel wire mesh (2,4 and 6 layers) that strengthened before casting, a decrease was obtained in the load capacity by 46% and 54% of the control ultimate capacity. This technique gives a decrease value of stiffness and increase in deflection .

iv. For beam strengthened by four layers of steel wire mesh, steel strip system, steel angles and clamps that strengthened after casting, an increase was obtained in the shear strength by 3.7% of the control ultimate capacity. This technique gives a maximum stiffness. The deformation shape of this technique is close to the deformation shape of the control beam without opening.

v. Strengthening reinforced concrete beams with opening increases the stiffness and improves serviceability of the beams.

vi. Faire agreement was found between the finite element results and the experimental results.

vii. References:

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