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BEHAVIOR OF HIGH PERFORMANCE CONTINUOUS R. C. DEEP BEAMS WITH OPENINGS AND ITS STRENGTHENING

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ABSTRACT

Reinforced concrete deep beams may exist in many structural applications such as offshore structures, transfer girders, pile caps, tall buildings and water tanks. The depth of deep beams is much greater than normal in relation to their span. Since the beam is short in this case, shear deformations are more important and special design methods should be applied in this case rather than normal beam theory. Continuous deep beams are defined in the Egyptian Code of Practice (2012) [2]as those beams whose height to effective span ratio greater than 0.4. Deep beams are members with special features. In such beams, plane sections do not remain plane after bending, with significant warping of the cross-sections because of high shear stresses. The resulting strain distribution is no longer linear and flexural stresses are not linearly distributed even in the elastic range. Recently, high strength concrete, defined by the American Concrete Institute ACI318-08[3], as concrete with cylinder compressive strength greater than 60Mpa, is being widely used in the construction industry. However, limited research efforts were directed towards the study of the behavior and shear strength of reinforced high strength concrete continuous deep beams. Furthermore, sometimes web openings have to be provided in deep beams for the purpose of access or for providing services. The presence of such openings may affect the shear strength of deep beams. However, limited investigations were directed towards the study of continuous deep beams with openings. Also, strengthening simply supported deep beams using carbon fiber reinforced polymers (CFRP) was investigated by many researchers. However, limited research papers were directed towards CFRP strengthening of continuous deep beams. Experimental tests have been carried out on rectangular reinforced concrete continuous deep beams with a/d=1.17, under static loading up to failure. The study takes into consideration the following parameters: Percentage of web reinforcement (ρ_h), Positions of openings and number of openings. Also, strengthening of openings in continuous deep beams using glass fiber reinforced polymer (GFRP) was studied in this research. Test results indicated that the presence of web openings within exterior or interior shear spans had great effect on the beam capacity and its behavior. Existence of web openings within exterior or interior shear spans caused a high reduction in the shear capacity of the beams by about 35%. Therefore and whenever should be

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kept clear of the natural load path joining the loading and reaction points (solid) free from openings. Also, the strengthening of openings contains the cracks and increase the crack and ultimate load.

Finally we will compare the test results with the theoretical values for beam A1 which were evaluated using strut and tie analysis according to Egyptian code (2012). The strut–and tie method can be used for the design of Disturbed regions (D- regions) of structures where the basic assumption of flexure theory namely plane sections remaining discontinuities arising from concentrated forces or reactions and near geometric discontinuities such as abrupt changes in cross section etc. The strut – and- tie method of design is based on the assumption that the D-regions in concrete structures can be analyzed and design using hypothetical pin-jointed trusses consisting of struts and ties interconnected at nodes. The usual design practice for continuous deep beams has been to employ empirical equations which are invariably based on simple span deep beams testes. Given the unique behavior pattern of continuous deep beams, this practice is unreliable. Since continuous deep beams contain significant extents of D-regions and they exhibit a marked truss or tied arch actions, the strut- and – tie method offers a rational basis for the analysis and design of such beams. The mechanics and behavior of continuous deep beams are briefly discussed from which a strut–and–tie model for such a beam is developed.

Keywords: high performance concrete, deep beams, Percentage of web reinforcement (ρ_h), Positions of openings and number of openings.

1. Introduction

Reinforced concrete deep beams are used in structures as load distribution elements such as transfer girders, pile caps, and foundation walls in tall buildings. Although these members commonly have several supports, extensive experimental investigations have brought simple deep beams into focus. The behavior of continuous deep beams is significantly different from that of simply supported deep beams. The coexistence of high shear and high moment within the interior shear span in continuous deep beams has a considerable effect on the development of cracks, leading to a significant reduction in the effective strength of the concrete strut, which is the main load transfer part in deep beams.

Indeed, few experiments were carried out on continuous deep beams of shear span-to-overall depth ratio (a/d) greater than 1.08 [4]. The results of simple deep beams tested by Tan et al [6].and Smith and Vantsiotis [7] showed that the relative effectiveness of horizontal and vertical shear reinforcement on controlling diagonal cracks and enhancing load capacity reversed for deep beams having an a/d less than 1.0, that is, horizontal shear reinforcement was more effective for an a/d below or equal 1.0, whereas vertical shear reinforcement was more effective for an a/d lager than 1.0. Therefore, a reasonable evaluation of the influence of shear reinforcement on continuous deep beams having an a/d less than 1.0 requires further investigation.

In the construction of modern buildings, transverse openings are often provided through beams for the passage of utility ducts and pipes to better utilize the otherwise dead space below the beam so fit. Such an arrangement of building services leads to a significant reduction in the dead space and results in a more compact and economical design. For multistory buildings in particular, the savings in story height that achieved at each level gives a substantial savings in the surface area of partition walls, length of riser ducts, and overall loads on foundation.

Therefore, special strengthening should be provided around the opening to contain the width of cracks and to prevent possible premature failure of the beam.

The provision of transverse openings will, however, change the continuous deep beam behavior into a more complex behavior. It is obvious that the provision of openings produces discontinuity in the normal flow of stresses, and these results in stress concentration and early cracking around the opening. The ultimate strength of the beam may also be seriously affected.

2. Experimental work

An experimental program was conducted including twelve reinforced concrete two-span continuous deep beams. All tested beams were fabricated, instrumented and then tested to failure under the effect of two concentrated loads one being placed at each span. All beams were made using high performance concrete. The main objective of this study was to investigate the behavior of two – span continuous deep beams within the whole range of loading starting from the elastic range up to the failure of each beam. Many significant factors were considered such as:

1- Percentage of web reinforcement (ρ_h),
2- Positions and Number of openings being placed within the interior or exterior shear spans and in flexural region.
3- The effect of strengthening of two–span continuous deep beams on its behavior was considered in the case of beams provided with openings.

2.1. Materials

2.1.1 High performance concrete (H.P.C).

Concrete mix used to produce high performance concrete is given in table (1).

Table 1.
Concrete mix proportion.

concrete	**Cement** kg/m^3	**Silica-fume** kg/m^3	**Water** liter/m^3	**Superpl.** liter/m^3 **(BVS)**	**Fine aggregate** kg/m^3	**coarse aggregate** kg/m^3 **(crushed bazalt)**	f_{cu}**(kg/cm^2)**		**Slump** (cm)
							7days	**28days**	
C	500	110	132	17.5	563.59	1127.17	660	872	16

For high performance concrete (f_{cu}= 900 kg/cm2), the constituent materials were:

1- Ordinary Portland cement, its properties agreed with ECP 203.
2- Crushed Bazalt; the used crushed basalt was 20 mm nominal max. Size, 2.70 specific gravity, and 2.36 t/m^3 volume weight.
3- Local sand; the used sand is a medium type one which has a specific gravity and volume weight of 2.50 and 1.65 t/m^3 respectively.
4- Potable water was used.
5- Superplastisizer; the used additive was Addicrete BVS having a density of 1.15 t/m^3.
6- Silica fume; it is produced by EFACO (Egyptian Ferro-Alloys Company) which resulting from the reduction of high-purity quartz with coal in electric arc furnaces in the manufacture of ferro-silicon. The fume which contains between 92 and 95 percent silicon dioxide (sio2), and consists of extremely fine spherical glassy particles, is collected by

filtering the gases escaping from the furnaces. The average particle size is 0.1 mm, the specific surface area is ranging between 12 and 15 m^2/g, and the specific gravity is $2.15t/m^3$.

7- Glass fiber: is the common name for glass-reinforced plastic (GRP) or alternatively glass-fiber reinforced plastic (GFRP) Fiberglass is also known as GFK.

Glass fiber is a fiber reinforced polymer made of plastic reinforced by glass fibers, commonly woven into a mat. The plastic may be a thermosetting plastic- most often epoxy, polyester- or vinylester or a thermoplastic. The glass fibers are made of various types of glass depending upon the fiberglass use.

Glass fiber is a strong lightweight material and is used for many products. Although it's not as strong and stiff as carbon fiber it is less brittle, and its raw materials are much cheaper. Its bulk strength and weight are also better than many metals, and it can be more readily molded into complex shapes. Applications of fiberglass include, aircraft, boats, automobiles, bath tubs and enclosures, hot tubs, septic tanks, water tanks, roofing, pipes, cladding, casts, surfboards, and external door skins.

Fig. 1. glass fiber used in strengthening of beams.

Table 2.
Typical properties of fibers.

Type of fiber	Diameter (mm)	Tensile Strength kg/cm2	Young's modulus kg/cm2	Elongation (%)
Glass fiber	1.5-4	$2.5*10^4$	$8*10^5$	3.6

2.2 Test procedure

All beams were tested under two point static loading. The load was increased up to 5.0 tons. Then; the load was applied in increments each of 5.0 ton for all beams. The load was kept constant every two successive increments for five minutes. During this period, the mid span deflection was recorded, cracks propagation were traced, and readings of strain gauges were recorded. For each beam, the total duration of loading up to failure was different depending upon the openings position, strengthening of openings, and the founded of horizontal reinforcement.

2.3 Measured deformation of beams

Strains of concrete and steel were measured by means of electrical strain gauges at the shown positions in fig (2).The gauges length were 52mm and 800mm for steel and concrete respectively. The resistance was 600 ohms and gauge factor (2 ± 0.75%). Strain gauges were connected to strain indicator. The beam deflection was measured using dial gauge with accuracy of 0.01mm fixed at the position of maximum deflection for each beam as shown in fig. (2).

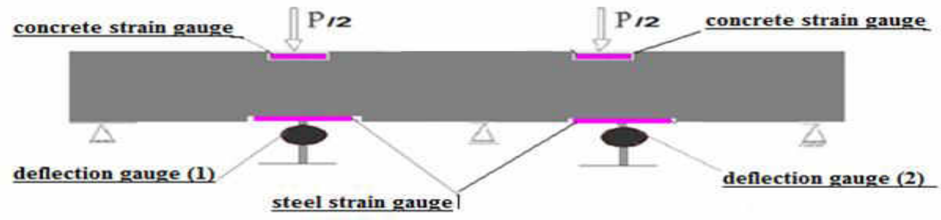


Fig. 2. Method of measuring deformation of beams.

2.4. Tested beams

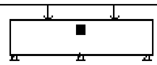
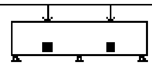
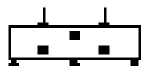
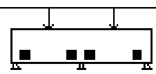
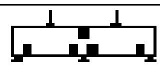
The beams were tested with main bottom steel diameter 4#18mm and main top steel diameter 2#18mm, rectangular cross section equal to 12×70 cm^2).The dimensions of all openings equal to 18*18 cm. All beams have been casted with concrete having 28 days' strengths of about 900kg/cm^2.The considered total length for all beams were 320cm as shown in figures (3, 4, 5, 6, 7, 8,9). Table (3) showed the details of the tested beams.

Table 3.
Details of the tested beams

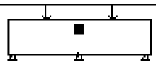
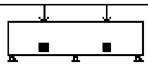
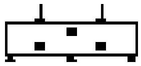
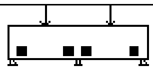
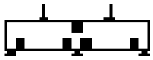
3.1. Group of beams without Openings (A).

Group A	ρ_h%	Position of Openings	Number of Openings
A1(Ref)	0.32	-	-
A2	0	-	-

3.2. Group of beams with openings (B).

Group B	ρ_h%	Position of Openings	Number of Openings
B1	0.32		one
B2	0.32		Two
B3	0.32		three
B4	0.32		four
B5	0.32		five

3.3. Group of beams with openings strengthened by glass fiber(GFRP)(C).

Group C	ρ_h%	Position of Openings	Number of Openings	ngthening of Openings
C1	0.32		one	(GFRP)
C2	0.32		two	(GFRP)
C3	0.32		three	(GFRP)
C4	0.32		four	(GFRP)
C5	0.32		five	(GFRP)

1- Group of beams without Openings (A).

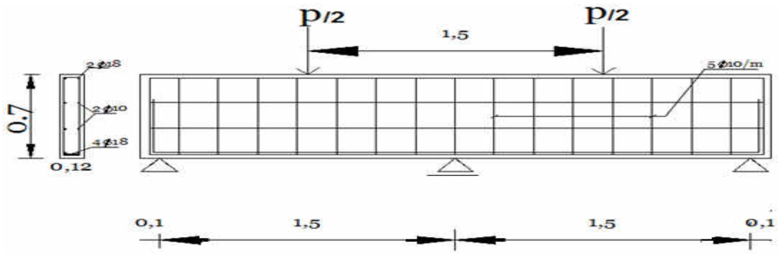


Fig. 3. Details of beam (A1).

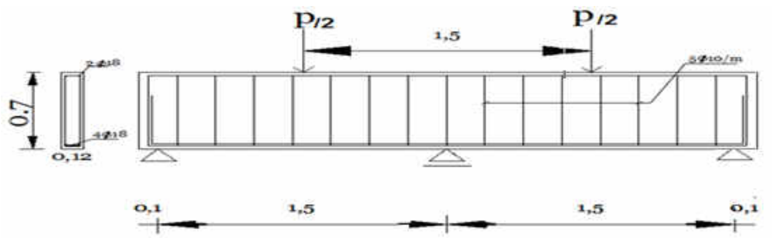


Fig. 4. Details of beam (A2).

2- Group of beams with Openings (B).

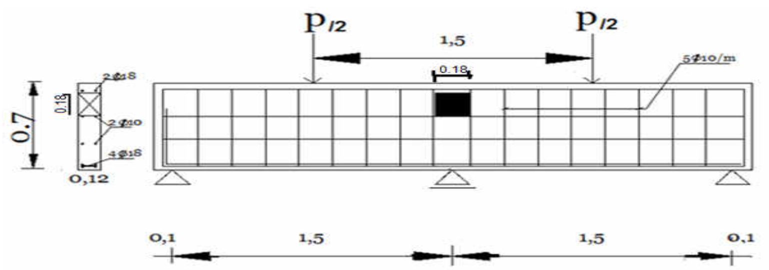


Fig. 5. Details of beam (B1).

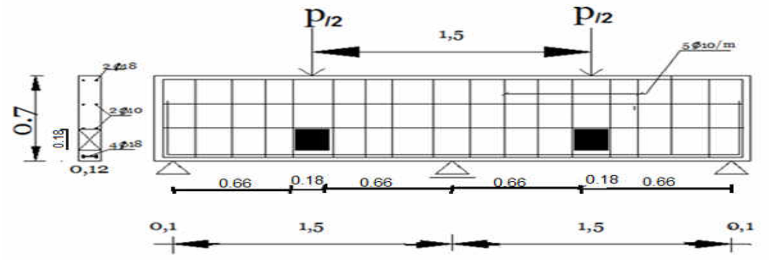


Fig. 6. Details of beam (B2).

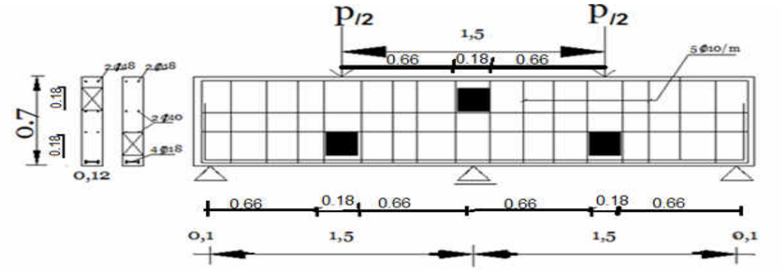


Fig. 7. Details of beam (B3).

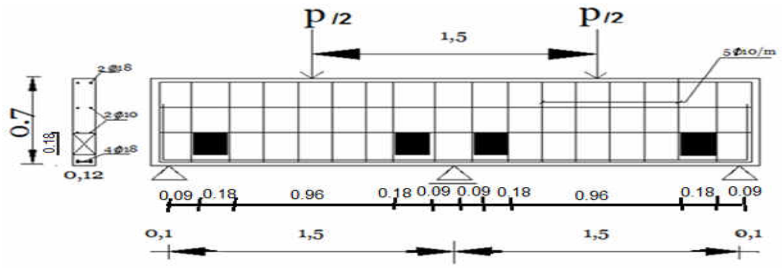


Fig. 8. Details of beam (B4).

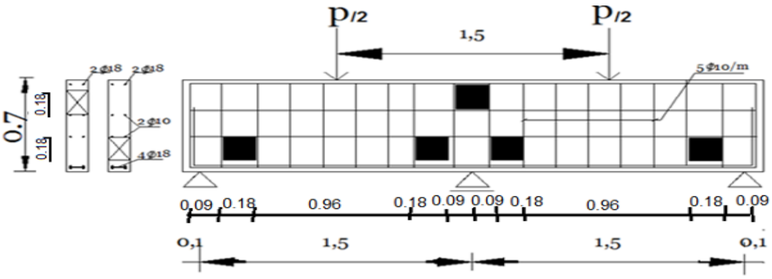


Fig. 9. Details of beam (B5).

3- Group of beams with strengthening of openings (C).

The same figures of group (B) , but we strength the beams by glass fiber around the openings according to the fig. (10).where the glass fiber putted on beams around the openings and extend to distance 7.5cm from left, right, upper and lower of the opening from two sides of the beam and passing inside the opening within the width of beam.

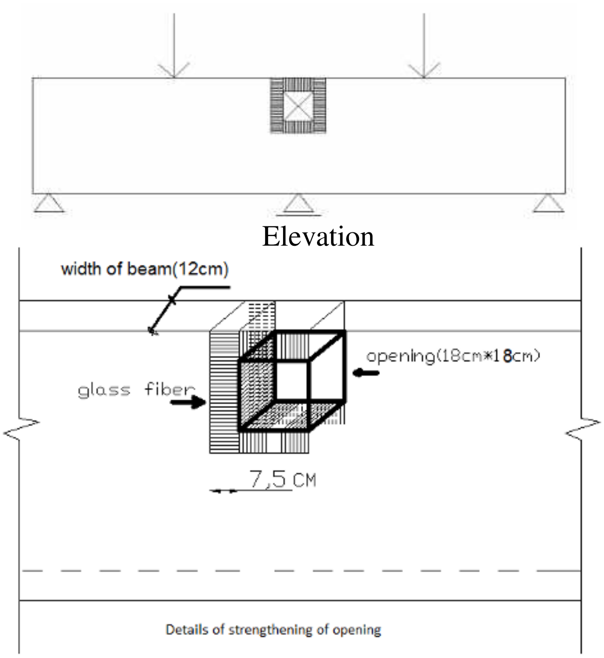


Fig. 10. Shape strength of beam by glass fiber.

3. Test result

3.1. Crack pattern and mode of failure

The crack pattern and mode of failure are explained for the tested reinforced high performance concrete (H.P.C) deep beams. Twelve high performance concrete two-span continuous deep beams were tested under static loading. The cracking and ultimate loads were recorded in table (4) and the deflection and strain for concrete and steel were given in table (5). Mode of failure for each beam was as follow:

1- Group of beams without Openings (A).

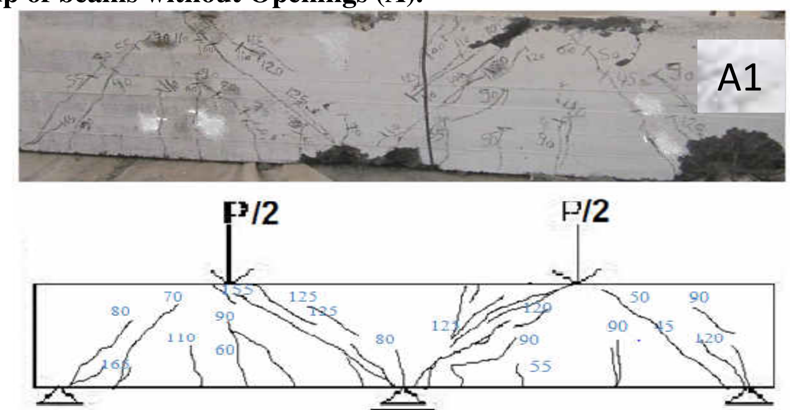


Fig. 11. Crack pattern of beam (A1).

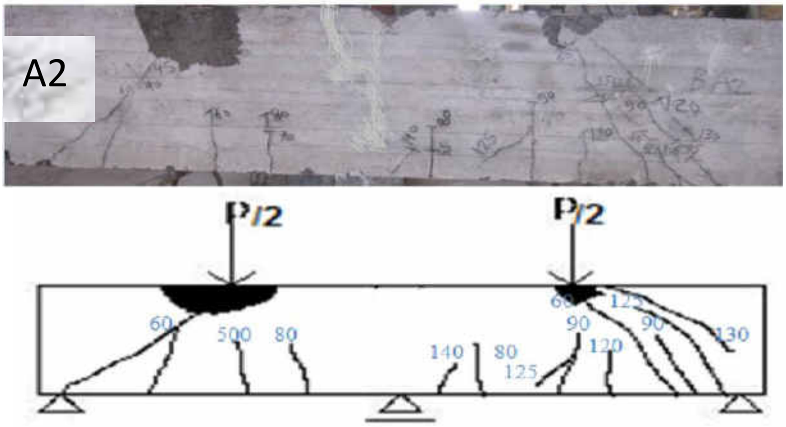


Fig. 12. Crack pattern of beam (A2).

2- Group of beams with Openings (B).

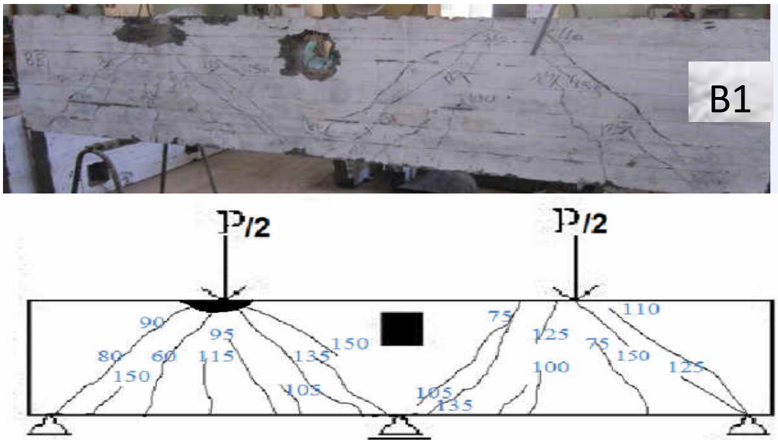


Fig. 13. Crack pattern of beam (B1).

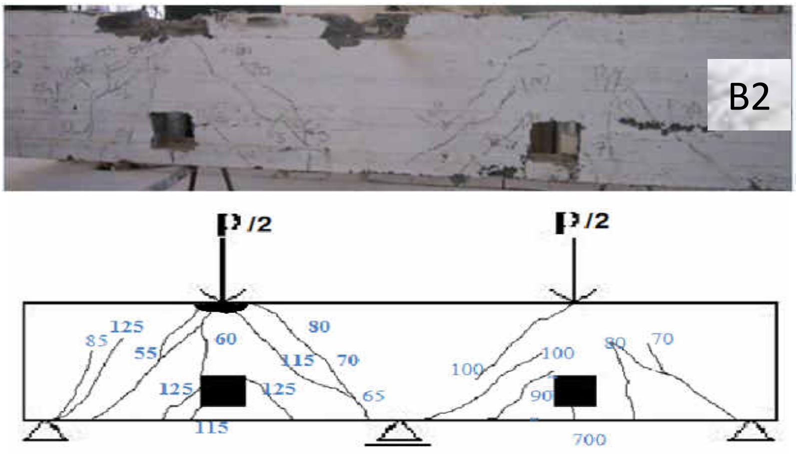


Fig. 14. Crack pattern of beam (B2).

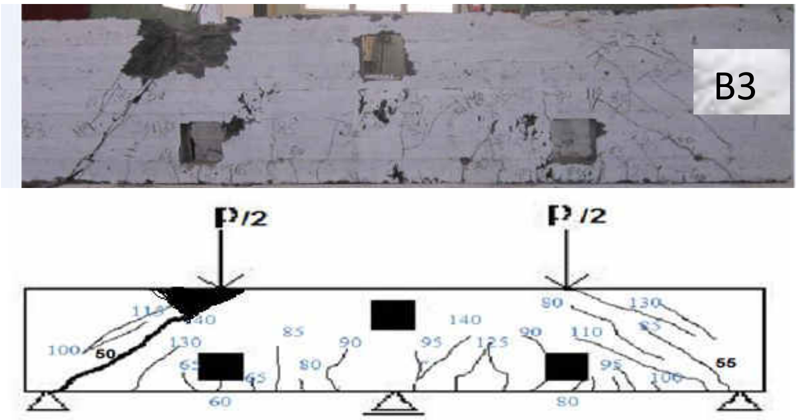


Fig. 15. Crack pattern of beam (B3).

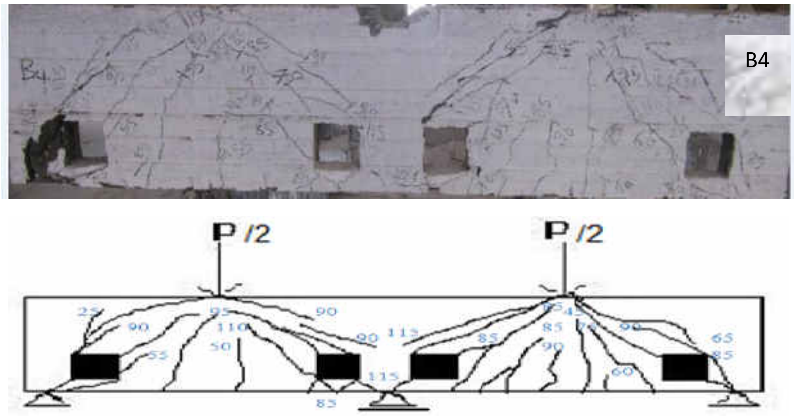


Fig. 16. Crack pattern of beam (B4).

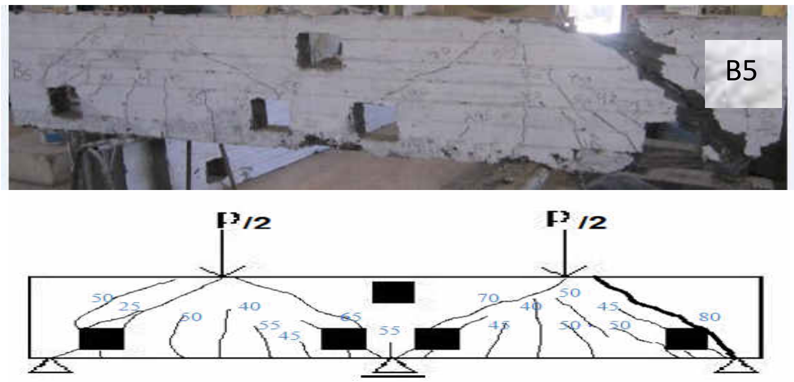


Fig. 17. Crack pattern of beam (B5).

3- Group of beams with strengthening of openings (C).

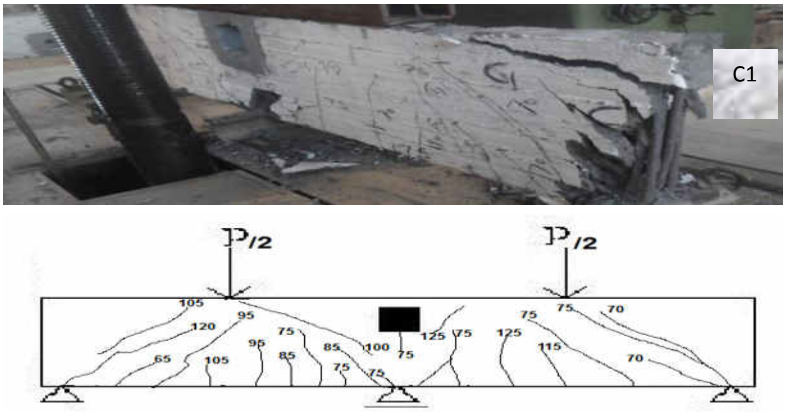


Fig. 18. Crack pattern of beam (C1).

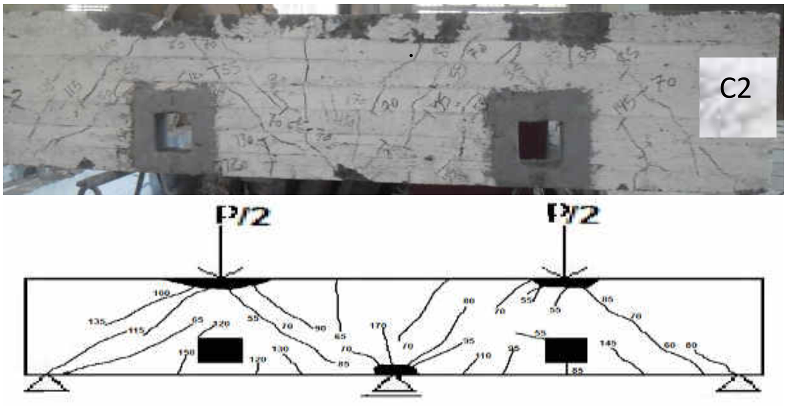


Fig. 19. Crack pattern of beam (C2).

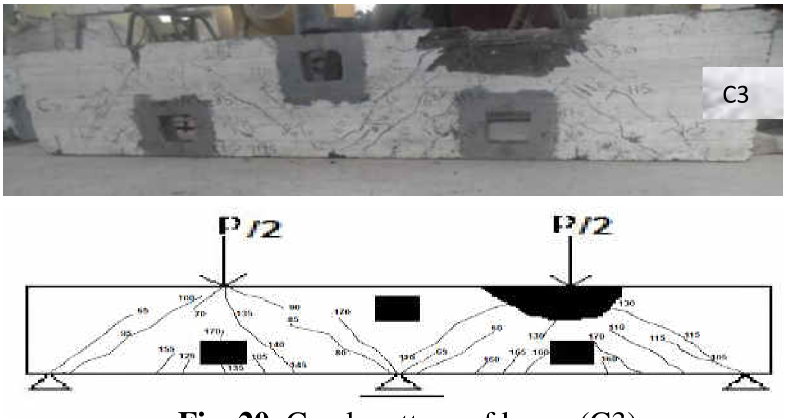


Fig. 20. Crack pattern of beam (C3).

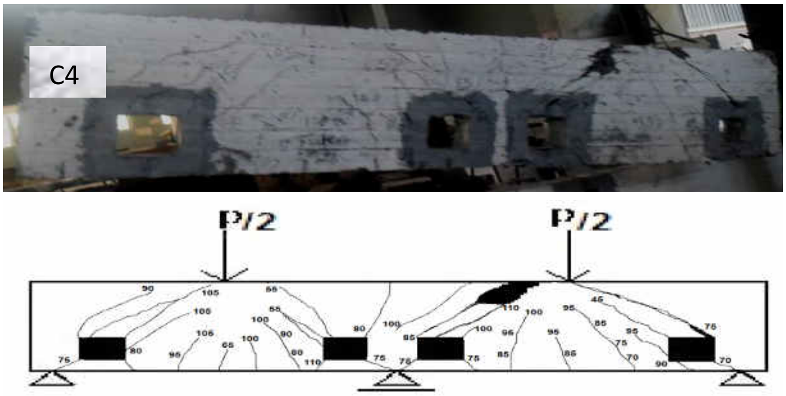


Fig. 21. Crack pattern of beam (C4).

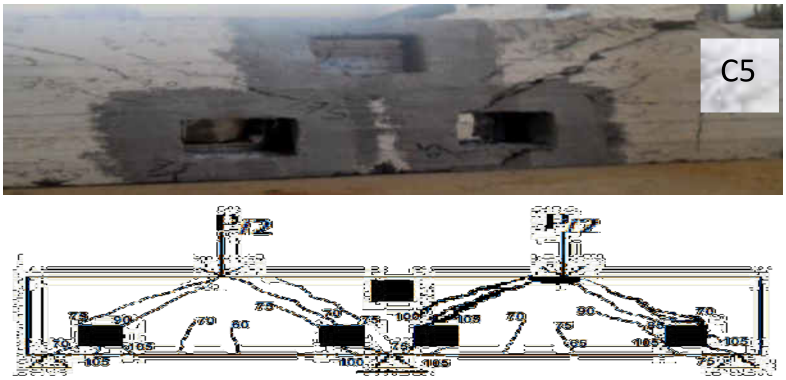


Fig. 22. Crack pattern of beam (C5).

Table 4.

Test results of high performance concrete continuous deep beams with or without openings.

Group No	Specimen	Fcu (kg/cm²)	Cracking load		Failure load Pu(kN)	Deflection		Mode of failure
			Qcr (kN)	Pcr (kN)		δcr(mm)	δu(mm)	
A	A1(Ref)	870	700	800	1750	2.2	6.5	Shear-compression
	A2	866	600	780	1700	2.35	6.83	Shear-compression
B	B1	858	550	770	1650	2.46	7.1	Shear-compression
	B2	860	550	755	1620	3.15	7.5	Shear-compression
	B3	855	500	750	1600	3.4	7.8	Shear-compression
	B4	862	250	735	1150	3.65	8	Shear
	B5	850	250	730	1045	4.0	8.2	Shear
C	C1	862	650	785	1700	2.4	6.65	Shear-compression
	C2	853	600	770	1700	2.6	6.8	Shear-compression
	C3	865	600	765	1650	2.85	7.05	Shear-compression
	C4	847	400	785	1350	3.2	7.4	Shear
	C5	856	400	785	1280	3.35	7.65	Shear

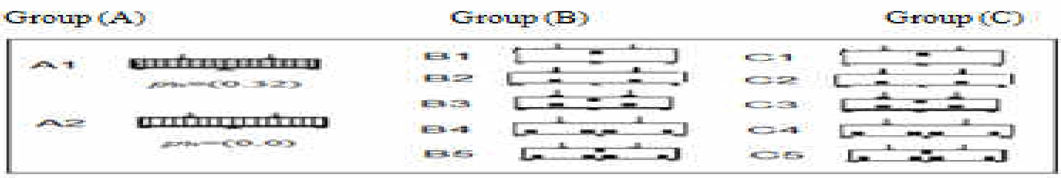


Table 5.
Results of deflections, concrete, and steel strains of the tested beams.

Group No.	Beam No.	δ_u (mm)	ϵ_{cu} x 10^{-5}	ϵ_{suB} x 10^{-5}	ϵ_{suT} x 10^{-5}
A	A1(Ref)	6.50	175	150	144
	A2	6.83	190	214	178
B	B1	7.10	121	132	110
	B2	7.50	140	162	150
	B3	7.65	150	210	202
	B4	8.0	161	225	212
	B5	8.2	170	233	225
C	C1	6.65	156	148	141
	C2	6.80	184	160	171
	C3	7.05	228	175	208
	C4	7.40	232	180	230
	C5	7.65	248	205	260

3.2. Deflection characteristics.

The measured values of maximum deflection are plotted versus the applied load from starting the loading up to failure as shown in figures from (23) to. (25).

3.2.1. Group of beams without Openings (A).

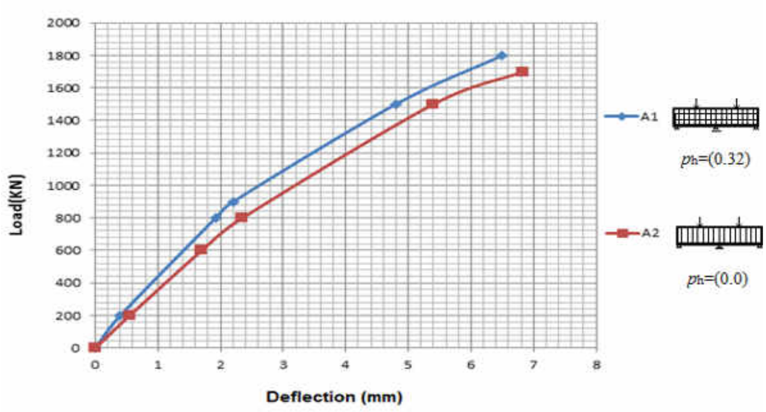


Fig. 23. Load - Mid Span Deflection relationship for beams in group (A).

3.2.2. Group of beams with Openings (B).

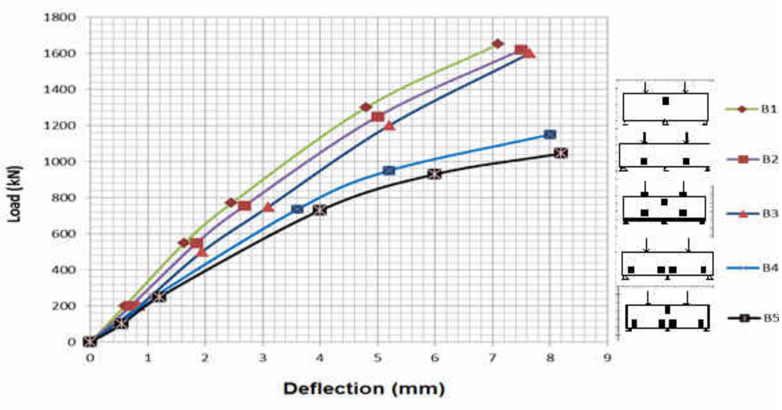


Fig. 24. Load - Mid Span Deflection relationship for beams in group (B).

3.2.3. Group of beams with strengthening of openings (C).

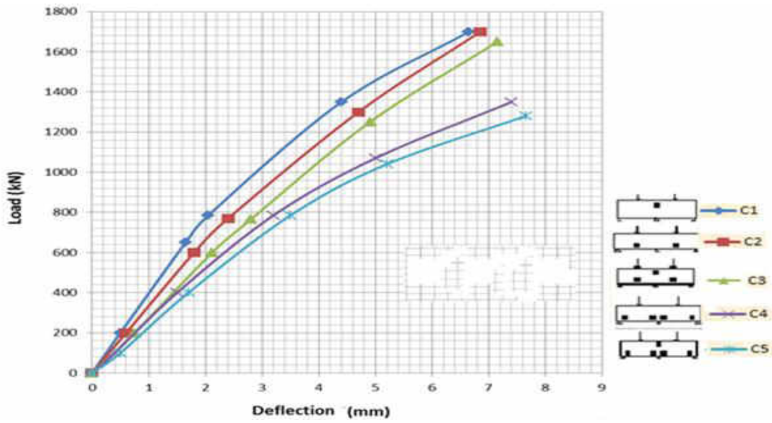


Fig. 25. Load - Mid Span Deflection relationship for beams in group (C).

3.3. Concrete strain distribution.

Figures (26) to (28), shows the behavior of the concrete strain in compression for all beams. The results indicated that all specimens presented almost have the same trend where the load increased, the strain also increased.

3.3.1. Group of beams without openings (A).

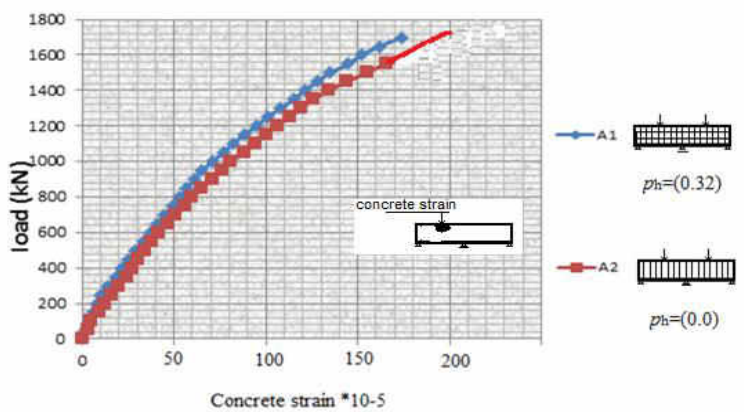


Fig. 26. Max-Concrete Strain versus applied load for beams in group (A).

3.3.2. Group of beams with Openings (B).

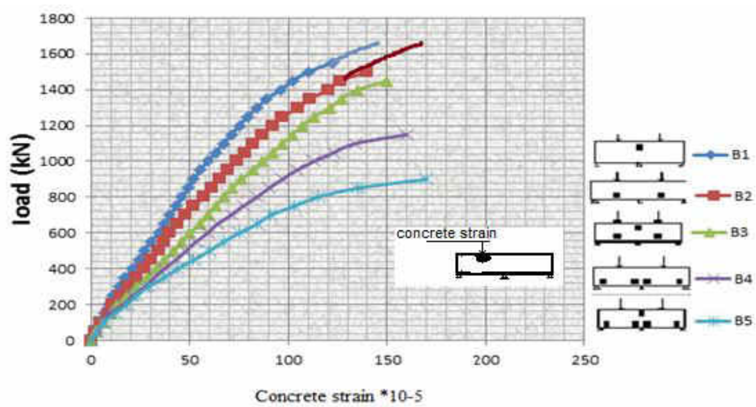


Fig. 27. Max-Concrete Strain versus applied load for beams in group (B).

3.3.3. Group of beams with strengthening of openings (C).

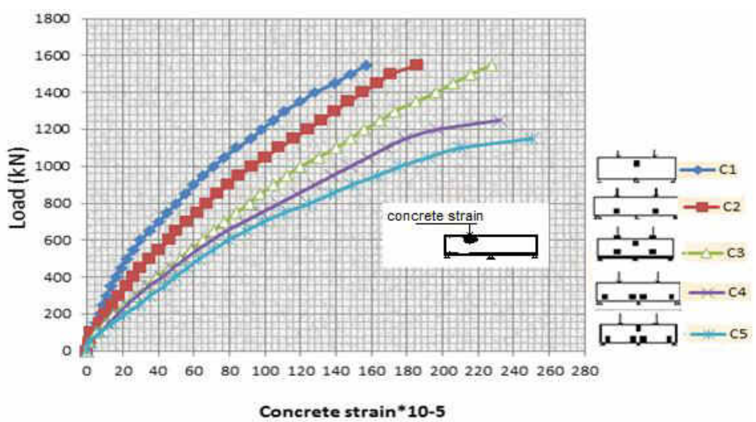


Fig. 28. Max-Concrete Strain versus applied load for beams in group (B).

3.4 Steel strain distribution.

Figure (29) to (31), shows the behavior of the steel strain in tension for all beams. The results indicated that all specimens presented almost have the same trend where as the load increased, the strain also increased.

3.4.1. Beams without openings (A).

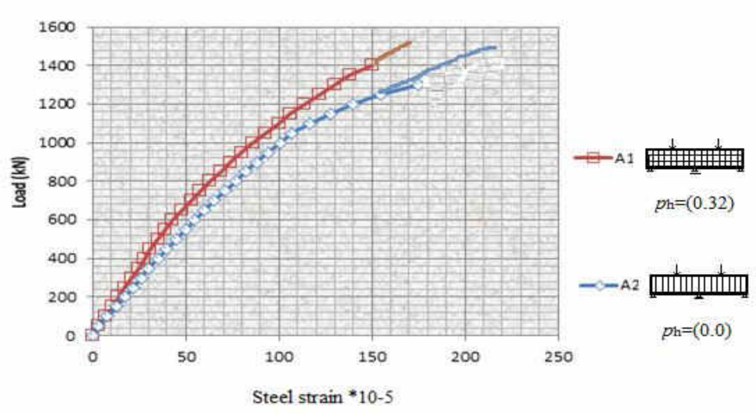


Fig. 29. Steel Strain Distribution for beams in group (A).

3.4.2. Group of beams with openings (B).

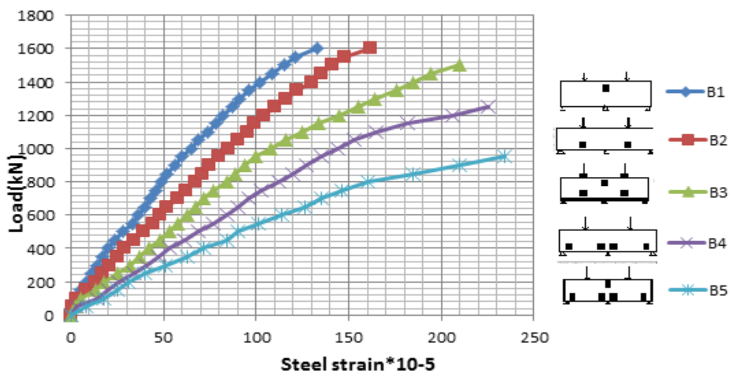


Fig. 30. Steel Strain Distribution for beams in group (B).

3.4.3. Group of beams with strengthening of openings (C).

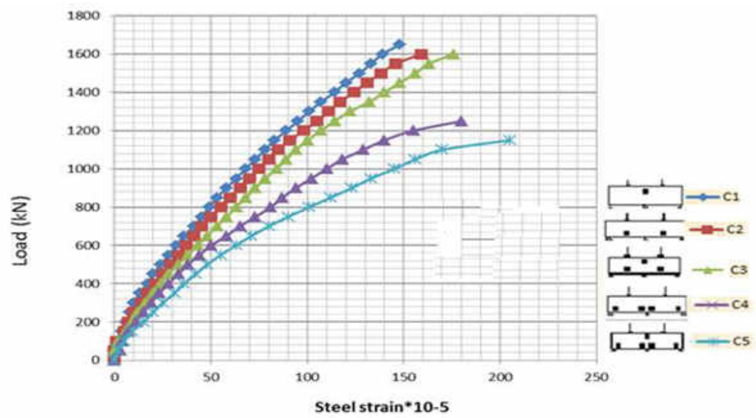


Fig. 31. Steel Strain Distribution for beams in group (C).

4. Discussion of test result

This item describes and interprets the analysis of the obtained test results of the HPC deep beams. Twelve high strength concrete two-span continuous deep beams were tested under static loading. The analysis includes the relationship between the value of cracking and ultimate loads, deflection, concrete strain; and steel strain for tested beams. The characteristic of tested beams at cracking, ultimate load, deflection and strain are given in tables (4) and (5). the values of the experimental measured parameters of beams are shown in figures (11) to (23).From item (3.1), it is obvious that, all beams failed in shear or shear compression, in spite of the different of shape of beams according to founded of openings, openings position and strengthening of openings. In the early stages of loading, no flexural cracks were observed in the region of bending moment or shear zone as the applied load increased. With a further increase of load, diagonal cracks formed in the shear span area; and bending moment area and developed towards the loading points.

The failure modes of beams in groups A & B and C are presented in tables (4), (5), the most common failure for the tested beams is a diagonal tension failure accompanied with compression failure. The shear failure in deep beams is always initiated by splitting action.

Diagonal tension accompanied with compression failure was observed in group A and beams (B1,B2,B3,C1,C2,C3).while diagonal tension only was observed in beams (B4,B5,C4,C5) according to openings and its positions.

Structural concrete members can be divided into two regions: Bernoulli regions (B-regions) and disturbed regions (D-regions). B-regions are the areas of structural concrete members that linear strain distributions are assumed to be valid. D-region is assumed to extend a distance equal to the largest cross- sectional dimension of the member away from a geometrical discontinuity or large concentrated load (5).

In solid deep beams, the first flexural cracks generally appeared in the B-region (Bernoulli assumption is valid) in the range of 10% to 25% of maximum load, and these are followed by independent diagonal cracks in D-region (disturbed zone) in the range of 40% to 75% of maximum load. With the increase in load, the flexural cracks did not develop anymore and inclined cracks newly appeared in the strut direction. The beam ultimately failed at concrete struts joining the load points and supports.

In deep beams with openings in shear region, the first diagonal cracks occurred near the bottom and top corners of openings. These cracks gradually developed towards the load points and Flexural cracks appeared in the B-region in the range of 50% to 80% of maximum load and developed toward corner of the opening.

In deep beams with openings in moment region, it behaved like a solid beams.

The presence of openings has a considerable effect on pattern of cracks and modes of failure when openings founded in shear zone. When the openings founded in moment zones the failure happened due to diagonal tension accompanied with compression. But when openings founded in shear zones the failure happened due to diagonal tension only.

The strengthening of openings with (glass fiber reinforced polymer) has a considerable effect on pattern of cracks and modes of failure, the strengthening of openings contain the width of cracks and increase the cracking loads and ultimate loads.

The effect of each parameter individually can be explained as follows:

4.1 Cracking and ultimate load (p_{cr}, p_u).

4.1.1. Effect of percentage of web reinforcement ($\rho_{h\ \%}$).

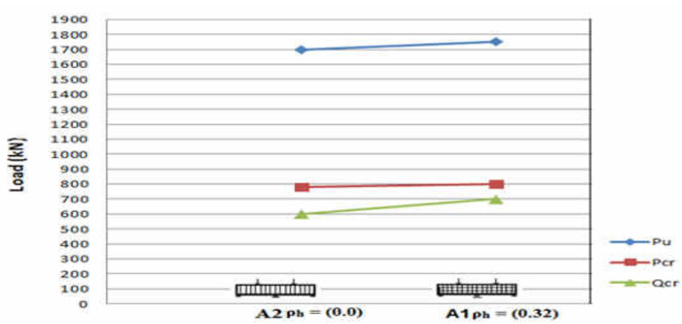


Fig.(32): Web reinforcement ratio (ρ_h %)

4.1.2. Effect of number and position of openings.

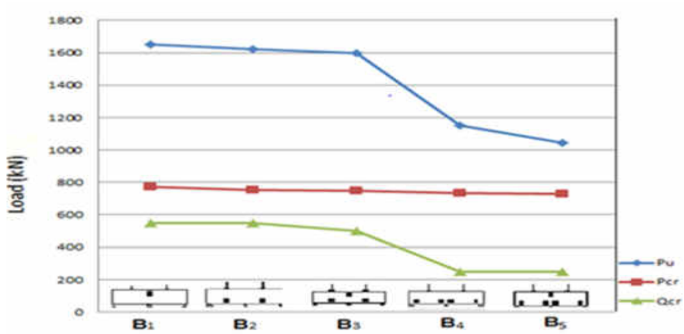


Fig.(33). Effect of openings(number and position)

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4.1.3. Effect of strengthening of openings (C).

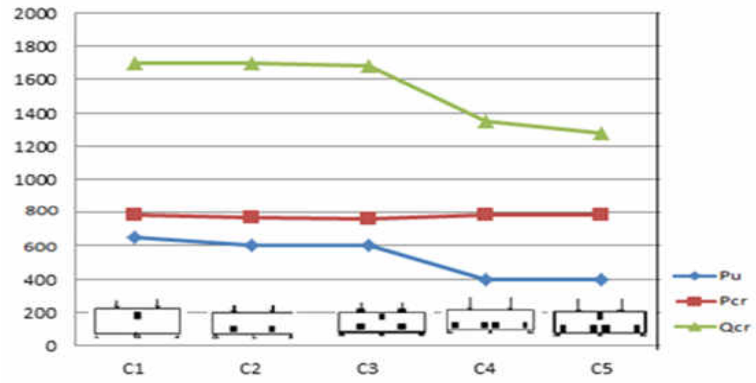

Fig.(34): Effect of the strengthening of openings

4.2. Comparison between solid deep beam (A1) (Reference) and tested beams.

Results for beams have different in web reinforcement ratio and beams have openings in shear region or in flexural zone with respect to results for beam (A1) are included in table (4) and shown in Figs (35) to (37). Tests indicated that the crack and ultimate loads have high reduction when openings located in shear region. While openings in flexural zone has not significant effect on ultimate and cracking loads. Also, the ratio of web horizontal reinforcement has small effect on ultimate& cracking loads and the cracks. The test results indicated that the deflection of the beams has small different between all tested beams. Where all the beams have the same strength of concrete. Also, the results observed that the values of deflection small comparison with the values of loads and span. These results observed the significant effect of high strength concrete.

Table 6.

Comparison between A1 (Ref) and tested beams results.

Series No.	Beam No.	Q_{cr}/Q_{crRef}	P_{cr}/P_{crRef}	P_u/P_{uRef}	$\delta_{cr}/\delta_{crRef}$	δ_u/δ_{uRef}
A	A1(Ref)	1	1	1	1	1
	A2	0.86	0.98	0.97	1.07	1.05
B	B1	0.79	0.96	0.94	1.12	1.09
	B2	0.79	0.94	0.93	1.43	1.15
	B3	0.71	0.94	0.66	1.55	1.18
	B4	0.36	0.92	0.6	1.66	1.23
	B5	0.36	0.91	0.97	1.82	1.26
C	C1	0.93	0.98	0.97	1.09	1.02
	C2	0.86	0.96	0.97	1.18	1.05
	C3	0.86	0.96	0.96	1.3	1.08
	C4	0.57	0.98	0.77	1.45	1.14
	C5	0.57	0.98	0.73	1.6	1.18

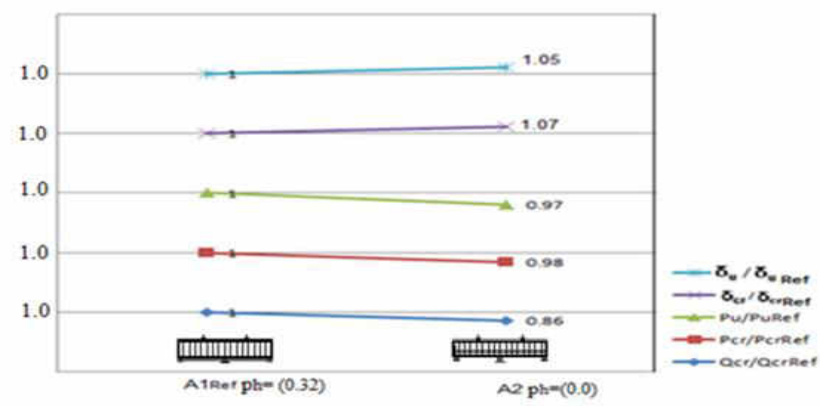

Fig.(35).Effect of web reinforcement ratio (ρ_h)

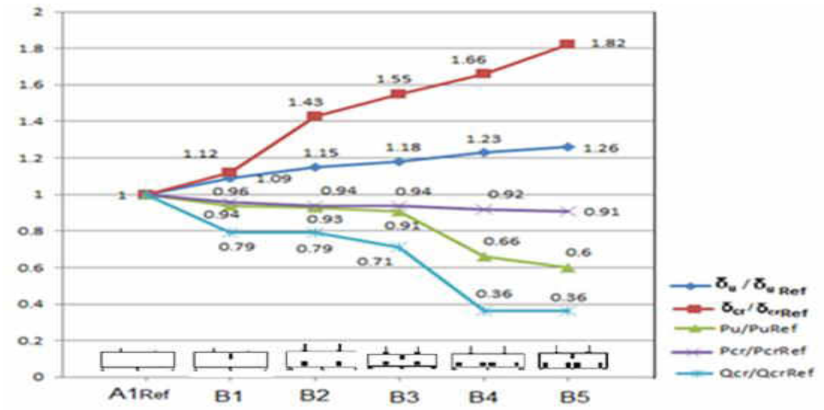

Fig.(36).Effect of Openings(numbers and positions)

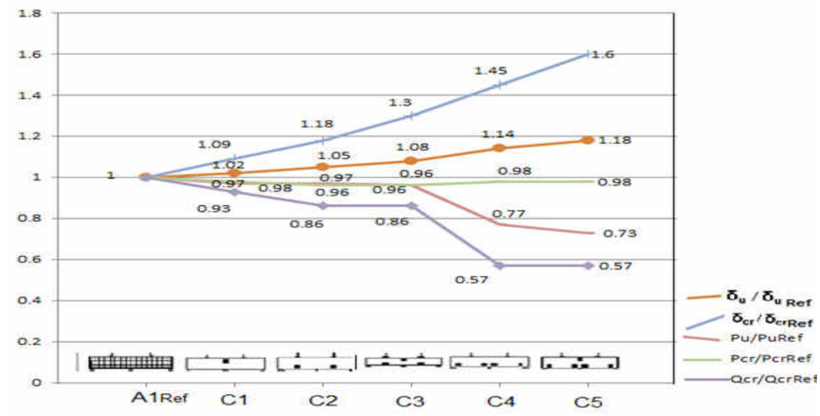

Fig.(37): Effect of Strengthening of Openings

Comparison between the test results and the theoretical values for beam A1 which were evaluated using strut and tie analysis according to Egyptian code (2012).

4.3. Analysis of continuous solid deep beam by strut and tie model

The strut–and tie method can be used for the design of Disturbed regions (D- regions) of structures where the basic assumption of flexure theory namely plane sections remaining discontinuities arising from concentrated forces or reactions and near geometric discontinuities such as abrupt changes in cross section etc. The strut – and- tie method of design is based on the assumption that the D-regions in concrete structures can be analyzed and design using hypothetical pin-jointed trusses consisting of struts and ties interconnected at nodes . The usual design practice for continuous deep beams has been to employ empirical equations which are invariably based on simple span deep beams testes.

Given the unique behavior pattern of continuous deep beams, this practice is unreliable. Since continuous deep beams contain significant extents of D-regions and they exhibit a marked truss or tied arch actions, the strut- and – tie method offers a rational basis for the analysis and design of such beams. The mechanics and behavior of continuous deep beams are briefly discussed from which a strut–and–tie model for such a beam is developed.

4. 3.1. Analysis of continuous deep beam (A1) (Ref) by Strut and Tie model

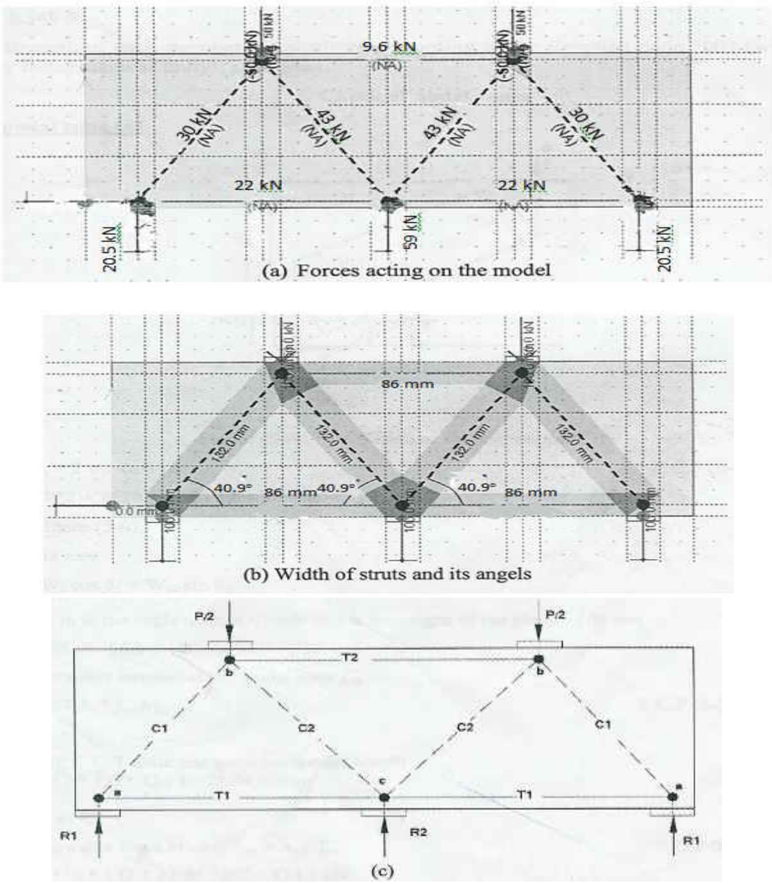

Fig. 38. Strut and tie model for continuous solid deep beam.

The results obtained from this model may be summarized as follows

Table 7.
Summarized theoretical results of beam (A1).

Strength of nodes, kN		Strength of struts, kN		Strength of ties, kN	
Nodal zone a (exterior support)	Nodal zone c (interior support)	Exterior strut C1	Interior strut C2	Tie T1	Tie T2
3184	**1226**	**2228**	**1554.4**	**2688.2**	**3080.2**

The table indicates that the failure in the model occurred at load P = 1226 kN at the middle support due to the high value of the interior reaction R2. The strength of the interior strut was close to the failure of the model.

The theoretical results which were evaluated according to Egyptian code indicated that the continuous solid deep beam (A1) achieved theoretical failure load less by about 30% than experimental failure load. (Pth/ Pexp) = (1226 / 1750) = (0.70).

5. Conclusions

Test results of twelve two-span reinforced concrete deep beams, with or without web openings are reported. All test specimens had the same cross-section, main longitudinal top and bottom reinforcement. The main parameters considered were the Percentage of web reinforcement (ρ_h), position, Number of the web openings, and strengthening of openings.

Based on the results obtained from the experiments, the following conclusions may be drawn:

1- Test results indicated that the presence of web openings within exterior or interior shear spans had great effects on the beam capacity and its behavior. Existence of web openings within exterior or interior shear spans caused a high reduction in the shear capacity of the beams. Therefore and whenever should be kept clear of the natural load path joining the loading and reaction points.
In these tested beams. The first visible diagonal cracks generally appeared at the top and bottom corners of web openings towards the load points and supports at different load levels.

2- The formation of diagonal cracks in continuous deep beams started at mid-depth along the line connecting the loading plate and the supporting plate then propagated gradually towards both the loading plate and the supporting plate accompanied by the formation of other lines of parallel diagonal cracks. Finally, for continuous solid deep beams failure occurred by shear along the strut connecting a concrete crushing under the loading plate or supports.

3- If the openings were clear of the natural load path e.g. within mid span region, the test results showed that these beams behaved almost in a manner similar to the companion solid beams. Therefore, these regions are suitable for providing openings when required.

4- Solid continuous deep beams showed more distributed cracks than beams with openings within exterior or interior shear spans, where dangerous cracks would be situated above and below the openings. Therefore, the regions above and below the openings should be well protected.

5- In the design of the majority of solid deep beams, it is usually necessary to consider shear for the ultimate state only. In the design of deep beams with openings, however, shear may also be important considerations for the serviceability limit state of cracking. Continuous deep beams of the present study showed severe cracks before failure, therefore, serviceability limits should be considered in the design.

6- Test results observed that the horizontal web reinforcement ratio (ρ_h) has significant effect on behavior of cracks. But has not significant effect on ultimate loads.

7- Test results indicated that the strengthening around the openings by GFRP has significant effect when openings located at shear region where the strengthening enhancement the cracking loads and the failure loads. Also, the strengthening contains the cracks around the openings. But has not significant effect if the openings in moment region.

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سلوك الكمرات الخرسانية المسلحة العميقة المستمرة ذات المقاومة العالية والفتحات وتقويتها

الملخص العربى

تتناول هذه الرسالة دراسة معملية لاثنتي عشرة كمرة مستمرة الارتكاز علي ثلاث ركائز مصنعة من الخرسانة عالية المقاومة. الهدف الرئيسي من هذا البحث هو دراسة السلوك الخاص بالكمرات العميقة والمستمرة ذات البحرين المتماثلين وذلك تحت تأثير الأحمال الكبيرة بداية من المرحلة المرنة منتهية بحد الانهيار. ومن أهم المتغيرات التي تم دراستها في هذا البحث هي : نسبة حديد التسليح الأفقي في الكمرات بدون فتحات وكذلك عدد الفتحات وأماكن وجودها سواء في منطقة أقصي اجهادات قص بالقرب من الركيزة الوسطي اوالطرفية اومنطقة أقصي اجهادات شد وذلك لدراسة تأثير وجود الفتحات علي الكمرات العميقة والمستمرة ذات الخرسانة العالية المقاومة ,علاوة علي ذلك تم دراسة تأثير تدعيم الكمرات المزودة بفتحات وتقويتها باستخدام شرائح ألياف الزجاج التي تم التدعيم بها أفقيا وراسيا حول الفتحات من الخارج.

جميع الكمرات تم تصنيعها وتجهيزها للاختبار تحت تأثير حملين متماثلين اعلي منتصف كل بحر من بحري الكمرة المستمرة.

جميع الكمرات تم تصنيعها من الخرسانة عالية المقاومة ذات مقاومة تصل الي حوالي 900 كجم /سم2

جميع هذه الكمرات تم اختبارها معمليا مع اخذ القياسات المطلوبة والمتاحة لذلك وهي :قياس سهم الانحناء وكذلك قياس نسبة الاستطالة الحادثة في كل من الحديد الرئيسي السفلي والعلوي بالإضافة الي الخرسانة , علاوة علي ذلك تم دراسة الشروخ وتدوين أحمال أول شرخ وكذلك تتبع مسار الشروخ وأشكالها مع كتابة أحمال الانهيار وتحديد شكل الشرخ النهائي ومكانه الذي سبب انهيار الكمرة .

وقد اظهرت النتائج ما يلي :

1- توضح النتائج أن وجود الفتحات في منطقة القص الداخلية اوالخارجية له تأثير كبير علي كفاءة وسلوك الكمرات. حيث أن وجود الفتحات في منطقة القص يسبب نقص حاد في مقاومة الكمرات تصل الي نسبة 35 % , ولذلك يجب جعل المنطقة التي تربط بين الحمل والركيزة مصمتة كلما أمكن ذلك. حيث انه في هذه الكمرات تم ملاحظة أن الشروخ القطرية عموما تظهر في الجانب العلوي والسفلي للفتحات في اتجاه المسار الذي يربط بين الحمل والركيزة .

2- أوضحت النتائج أن الشروخ القطرية في الكمرات العميقة المستمرة تبدأ في منتصف الارتفاع لهذه الكمرات خلال المسار الذي يربط بين الحمل والركيزة , ثم بعد ذلك تمتد تدريجيا ناحية الحمل والركيزة مصحوبة بشروخ قطريه موازية لها , وفي النهاية يحدث الانهيار في الكمرات العميقة المستمرة نتيجة القص خلال الضاغط مصحوبا بتفتت للخرسانة في منطقة الضغط .

3-عند وجود الفتحات بعيدا عن مسار الحمل أي في منطقة العزوم أوضحت نتائج الاختبار أن هذه الكمرات تكون شبيهة تقريبا بالكمرات المصمتة, وبالتالي فان هذه المنطقة وهي منطقة العزوم مناسبة لوضع الفتحات كلما أمكن ذلك.

4- أوضحت الكمرات العميقة المستمرة المصمتة توزيعا للشروخ أكثر من الكمرات المزودة بالفتحات في منطقة القص حيث ظهرت شروخ خطيرة أسفل واعلي الفتحات , ولذلك فان هذه المناطق حول الفتحات يجب تدعيمها وتقويتها.

5- في تصميم الكمرات العميقة المصمتة يتم في العادة مراعاة أقصي قوه للقص فقط, لكن في تصميم الكمرات العميقة ذات الفتحات يجب اخذ قوة القص في مرحلة التشغيل في الاعتبار حيث أظهرت هذه الدراسة أن هناك العديد من الشروخ تم ملاحظتها قبل الانهيار,وبالتالي فان مرحلة التشغيل يجب أخذها في الاعتبار في التصميم

6- أوضحت النتائج أن نسبة حديد التسليح الأفقي له تأثير واضح علي شكل الشروخ ولكن ليس لها تأثير يذكر علي حمل التشغيل والانهيار في الكمرات بدون فتحات.

7- من نتائج هذه الدراسة تم ملاحظة أن تقوية الفتحات باستخدام شرائح ألياف الزجاج له تأثير فعال عندما تكون الفتحات في منطقة القص , حيث تعمل التقوية علي تحسين حمل الشروخ وحمل الانهيار, بالاضافه الي أن التدعيم يقاوم الشروخ حول الفتحات , ولكن النتائج بينت أن تقوية الفتحات التي تقع في منطقة العزوم ليس له تأثير يذكر علي شكل الشروخ أوعلي حمل الانهيار., وأوضحت أيضا الدراسة المعملية أن التدعيم قد حسن سلوك الكمرة المزودة بفتحات في منطقة القص الي17 % زيادة ولكنها كانت اقل بنسبة 25 % عن الكمرات العميقة والمستمرة الخالية من وجود الفتحات.