Behavior of Steel Fiber Concrete Beams with Different Reinforcement Method Around Opening

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Abstract

Openings in concrete beams is preferred than using extended dropped ceilings to accommodate utility ducts and pipes. This leads to significant cost saving but unfortunately, beam strength and serviceability are affected. Experimental study of behavior of steel fiber concrete beams with different reinforcement methods around opening by using external glass fiber reinforced polymer (GFRP) or internal additional steel bars in addition to opening size is conducted. Load deflection curves and load strain curves are discussed. Beam dimensions studied are scaled to half their actual dimensions where the studied dimensions are common in beams. The authors only choose one size for all models to make it easy to compare the results. Other dimensions should be studied in the future. The only two specimens with openings that maintain ductile behavior are when adding steel fibers to concrete not containing GFRP and adding GFRP around the opening in concrete without steel fibers. When comparing a specimen with same opening dimension to another containing steel fibers without GFRP, the usage of steel fibers increases ultimate load (P_u) by 24% and deflection (Δ_u) by 69% with elastic plastic behavior and initial stiffness (I.S) increases by 17%, post cracking stiffness (P.I) decrease by 24% and energy absorption (E.A) increase by two times. On the other hand, GFRP is used in beam specimen that doesn't contain steel fibers in the concrete mixture, P_u increases by 42% and Δu increases by 88%.

Keywords Strengthening, Glass fiber reinforced polymer, Steel fibers, Ductility, post cracking stiffness, shear zone.

Introduction

Providing services like water supply, air conditioning, electricity and sewage requires using ducts and pipes. Suspending ceiling that leads to extra dead spaces on each floor is avoided especially in multistory buildings. Therefore, presence of opening in the shear zone of a concrete beam decreases both stiffness and ultimate strength. Stress concentration results in various cracks that are formed around openings.

Hence, proper strengthening is required in the surroundings of the opening. Past research investigated strengthening of rectangular openings in flexural zone of concrete beams by fiber reinforced polymers [1]. Another research discussed using GFRP to strengthen and rehabilitate concrete beams with opening in flexural area [2]. There is no doubt that opening in shear zone is more critical than flexural zone. Strengthening of concrete beams using either carbon fiber reinforced polymer or glass fiber reinforced polymer is discussed where different parameters are included. Strength is increased when using glass fiber reinforced polymer by 42%, while using carbon fiber reinforced polymer the increase is 38% [3] and [4]. Previously researchers discussed strengthening of one opening in the shear zone analytically [5]. Deep beams with openings located at the web of the beam is discussed [6]. That paper shows that flange contributes to the strength of the beam significantly. High performance and ultra-high strength performance concrete with one opening in flexure is discussed [7]. Numerical investigation is conducted including two openings that are placed nearly at the one forth from support of the concrete beams by Pertiwi [8]. Another numerical investigation is carried out by Sweeney [9] on reinforced concrete beams with one opening. The main results show that increasing web opening height to 60% of overall height of beam, ultimate load reduces by 75% of concrete beam with same dimensions without opening. Elkafrawy [10] conducted a state-of- -art review of reinforced concrete beams with web opening which includes strengthening techniques such as ferrocement. El Ame [11] carried out experimental tests on the effect of vertical opening position and size while subjecting the beams to a four-point bending tests. The results show that when the hole is located above the centroid of the beam, it exhibits a lesser deflection accompanied by absence of plastic deformation.

Hence, upon reviewing recent research work, it has become necessary to study the effect of presence of two openings in the shear zone of the beam. In addition, different strengthening schemes are carried out either by adding steel fibers and/or GFRP to concrete ingredients or using steel bars or GFRP around the opening internally. This paper aims to provide more information to fill the gap on the behavior of concrete beams with two shear zone openings. Accordingly, parameters studied include presence of opening, dimensions of opening, adding steel fibers to concrete constituents and either using GFRP or adding steel bars around the opening.

Experimental program

The dimensions of beam specimens are chosen to be the most used dimensions (span 400cm, 60 cm depth and 30 cm width) and openings are chosen proportional to these dimensions. Seven different beams are prepared with span 200 cm, 30 cm depth and 15 cm width with upper and lower reinforcement of two bars with diameter 10 mm. Stirrups used are five bars with diameter 8 mm. Table (1) shows details of tested parameters along with specimens' numbers and names. Concrete mix design with compressive strength 275 Kg/cm^2 is shown in Table (2). Concrete is poured in molds with dimensions and reinforcements where foam is used in the position of openings and is removed after concrete hardens. The curing process continued till the concrete completed its reaction. Steel fibers added to the concrete are corrugated with length 50 mm and thickness 0.5 mm with density 7850 Kg/m^3. Only three specimens are strengthened around the opening; specimens CO15G and SO15G are strengthened with GFRP (20 cm in horizontal direction and 7.5 cm in vertical direction) as shown in Fig. 1. Meanwhile specimen SO15A is strengthened with additional 8 steel bars with diameter 10 mm as shown in Fig. 2. All specimens are tested under a two-point load at one third from the support till failure as shown in Fig. 3. Vertical deflection at the mid span is recorded by LVDT along with strains in the reinforcement bars that are measured by strain gauges placed in the bars. Both crack (Δ_{cr}) and ultimate (Δ_u) deflections are recorded accompanied with corresponding loads (P_{cr} and P_u) respectively. Load strain curves are plotted afterwards. Since the stiffness is the resistance of an elastic body to deflection or deformation by an applied force, then for a reinforced concrete beam it is important to determine initial stiffness (I.S) that is an initial slope of load-deflection curve. GFRP when used in concrete significantly improves the overall performance of concrete by enhancing tensile properties and cracking control. It is worth mentioning that energy absorption capacity is also studied in this research because toughness is generally defined as the area under load–deflection curve of a flexural beam. Thus, both concrete strength after cracking i.e., post cracking stiffness (P.I) and energy absorption (E.A) are determined for all specimens.

Table (1**)** Specimens details

Number	Specimen name	Opening	Opening dimensions	Adding steel fibers to concrete	Strengthening method	
					GFRP around opening	Additional steel bars surrounding opening internally
1	(CO15)	yes	15*15	-	-	-
2	(SW)	-	-	yes	-	-
3	(SO15)	yes	15*15	yes	-	-
4	(CO15G)	yes	15*15	-	yes	-
5	(SO15G)	yes	15*15	yes	yes	-
6	(SO35)	yes	15*35	yes	-	-
7	(SO15A)	yes	15*15	yes	-	yes

Table (2**)** Concrete mix design

Content	Quantity in m^3
Cement	350 Kg
Fine aggregate	600 Kg
Coarse aggregate	1200 Kg
Water	175 liters
Steel fiber	63.5 Kg
Admixture (Super plasticizer)	83% by volume of cement
W/C ratio	0.5

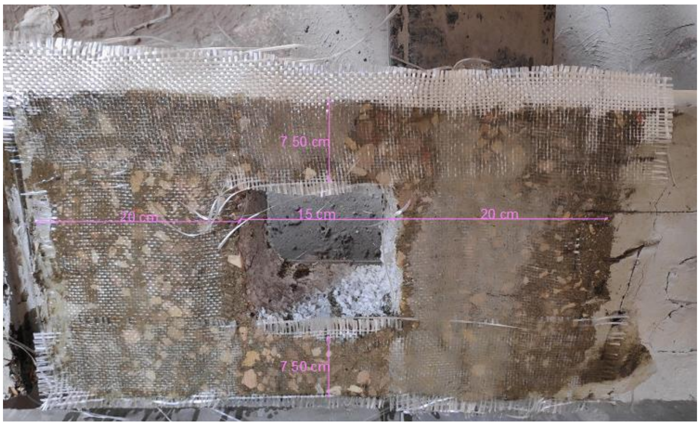

Fig. 1 GFRP strengthening dimensions around opening

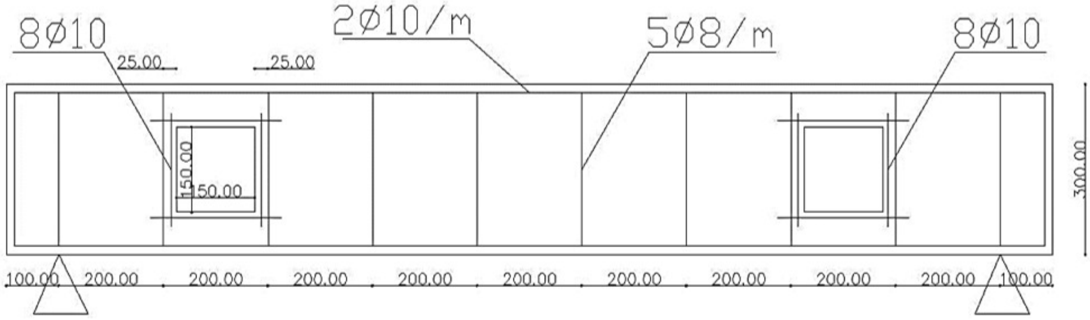

Fig. 2 Specimen dimensions and reinforcement

Fig. 3 Test setup of specimens

Test results and discussion

Main results of the experimental tests are discussed in this section. Failure mode of specimens show brittle shear failure occurs in specimen CO15. Specimen SW fails by yielding of steel bars then crushing of concrete occurs. The crack pattern of specimen reveals flexural mode as shown in Fig. 4. Yielding of steel bars afterwards crushing of concrete is noticed where crack pattern of specimen SO15 shows shear mode as shown in Fig. 5. The presence of openings affected failure mode from flexure to shear brittle. Specimens CO15G, SO15G, SO35 and SO15A fail by yielding of steel bars followed by crushing of concrete. Thus, opening dimensions do not affect failure mode.

Fig. 4 Flexural failure in specimen SW

Fig. 5 Brittle shear failure in specimen SO15

Effect of opening presence

The effect of using openings is studied by using two specimens SW and SO15. It can be seen from Table (3) that P_{cr} of beam SO15 decreased by 35% meanwhile, Δ_{cr} increased by 2.12 times but P_u decreased by 38% and Δ_u decreased by 84.5%. The behavior of SW shows elastic plastic behavior of load deflection curve, but SO15 shows brittle behavior. The Microsoft excel curve goes up till peak strength and drops vertically where post peak softening occurs as shown in Fig. 6. The load strain curve shows a very linear load -strain response for SO15 which indicates brittle failure in presence of opening. Microcracks spread faster around openings in concrete which accelerates failure. Also, I.S decreased by 7%, P.S decreased by 40% and E.A decreased by 86.7%. As a result of the presence of opening, ductility decreased.

Effect of Opening Dimensions

From Table (3) the comparison between SO15 and SO35, increasing opening dimensions, decreases P_{cr} of specimen SO35 by 39%, while P_u decreased by 49%. Nearly both specimens show the same deflection but the behavior of SO35 shows elastic plastic behavior in load deflection Microsoft excel curve as shown in Fig. 7, while SO15 tends to show brittle behavior. The curve corresponds to small deflection versus high loads up till peak strength then it drops vertically where post peak softening occurs. Ultimate load and crack load are shown in Fig.8. From Figs. 9 and 10, I.S decreased by 57%, P.S decreased by 25% and E.A decreased by 4.3%. because of the increase in opening dimensions which accordingly decreased the ductility of specimens.

Adding steel fibers to concrete

Group 1 (Specimens without reinforcement around opening)

The effect of using steel fibers is studied by studying two specimens CO15 and SO15. P_{cr} of SO15 increased by 5 % and Δ_{cr} increased by 1.2 times but P_u of SO15 increased by 24% and Δ_u increased by 69% according to Table (3) when compared to CO15. The presence of steel fibers enhances the behavior of SO15 in the post cracking stage because internal voids are filled with it, but the corresponding deflection increases. Both SO15 and CO15 show elastic plastic behavior in load deflection curve as shown in Fig.11. Brittle shear failure in SO15 can be concluded from load strain relationship as shown in Fig.12. CO15 failure occurred by yielding of steel bars followed by formation of cracks in concrete compression zone which leads to crushing. From Table (3) I.S increased by 17%, P.S decreased by 24% and E.A increased by two times compared to CO15 which indicates enhancement in ductility of specimen especially after cracking occurs.

Group 2 (Specimens with external glass fiber reinforced polymer (GFRP) around opening)

The effect of using steel fiber in Specimens with external glass fiber reinforced polymer (GFRP) around opening is discussed on comparing two specimens CO15G and SO15G. Table (3) shows that using steel fibers in Specimens with external glass fiber reinforced polymer (GFRP) around opening increased P_{cr} of beam SO15G by 14.6% and similarly, P_u increased by 49% when compared to CO15G where steel fibers fill concrete voids accordingly higher strength is observed. The load deflection curve of both specimens CO15G and SO15G show brittle behavior where the curve goes up to peak strength and drops vertically where post peak softening occurs as shown in Fig.13. The presence of steel fibers in SO15G concrete along with GFRP increased toughness of specimen despite of the linear elastic nature of GFRP. Table (3) shows I.S decrease by 18%, P.I increase by 25% and, EA shows an increase by up to 35% when compared to specimen CO15G. This indicates that improvement in ductility occurs after cracking.

Reinforcement method around opening

Reinforcement by external glass fiber reinforced polymer (GFRP) around opening in Specimens without steel fibers.

The effect of using GFRP around openings was studied through specimen CO15G. P_{cr} of CO15G increased by 76% along with increasing Δ_{cr} by 29% when compared to specimen CO15. Likely, P_u increased by 42% and Δ_u increased by 88% as a result of the comparison with CO15 according to Table (3). This improvement highlights the role of GFRP since adhering it to the beam enhances the strength. It is worth noticing that using GFRP as a strengthening means resulted in brittle behavior of CO15G due to stiffness of GFRP. It can be concluded that failure is caused by yielding of steel bars followed by crushing of concrete and not in vicinity of the opening where strengthening is added. Table (3) indicates an increase in I.S by 36%, while P.S decreases by 16% and energy absorption by 1.7 times.

Reinforcement by external glass fiber reinforced polymer (GFRP) around opening in Specimens containing steel fibers.

From Table (3), using GFRP with the presence of steel fibers increased P_{cr} of SO15G by 91% and Δ_{cr} increased by 1.19 times when compared to SO15. On the contrary, P_u decreases by 14% and Δ_u increases by 13%. SO15G tends to be more elastic than SO15 which shows that both steel fibers and GFRP enhances behavior of specimen. I.S decrease by 5%, while P.I increases by 38%. and energy absorption increases by 22%. GFRP shows more ductile behavior in the cracking stage, on the other hand this effect becomes less in the post cracking stage.

Reinforcement by internal additional steel bars in specimens containing steel fibers

From Table (3), effect of internal steel bars around opening was that the P_{cr} for SO15A increased by 93 % and Δ_{cr} increased by 85% than SO15. P_u increase by 34% and Δ_u increase by 21%. Meanwhile, identical behavior is shown in load strain relationship for specimens SO15 and SO15A because their failure cracks occur in shear zone or steel bars area respectively and not around the opening. As can be seen in Table (3), I.S decreases by 15%. P.S failure increases by 40% and EA increases by 41%.Effect of different reinforcement method around opening by using external glass fiber reinforced polymer (GFRP) or internal additional steel bars

The effect of using internal steel bars around opening is that Δ_{cr} decreased by 84 % when compared with using external glass fiber reinforced polymer (GFRP) SO15G. Accordingly, P_u and Δ_u increased by 16 % and by 6 % than SO15G. On the other hand, SO15G shows elastic behavior when compared with SO15A which is attributed to the role of bridging of fiber at the crack surfaces. From Table (3), it can be seen that I.S index decreases by 89% but the same P.S, while EA increases by 15%.

Table (3) Crack (P_{cr}), Ultimate Loads (P_u) and Corresponding Deformations (Δ_{cr} and Δ_u) in addition to Initial Stiffness (I.S), Post cracking stiffness (P.I) and Energy Absorption

Number	**Specimen**	**P_{cr} (kN)**	**Δ_{cr} (mm)**	**P_u (kN)**	**Δ_u (mm)**	**I.S**	**P.I**	**E.A**
1	CO15	21.01	0.66	50.78	3.95	19.8	8.95	218.15
2	SW	34.54	0.7	102.49	43.01	25.01	11.28	4935.3
3	SO15	22.178	1.49	63.25	6.68	23.23	6.75	656.62
4	CO15G	37.08	2.63	72.15	7.46	26.94	7.47	596.04
5	SO15G	42.5	3.27	72.5	7.61	21.92	9.34	805.32
6	SO35	13.5	1.51	32.11	6.77	9.8	5.05	628.49
7	SO15A	43	2.77	84.79	8.14	19.64	9.47	928.66

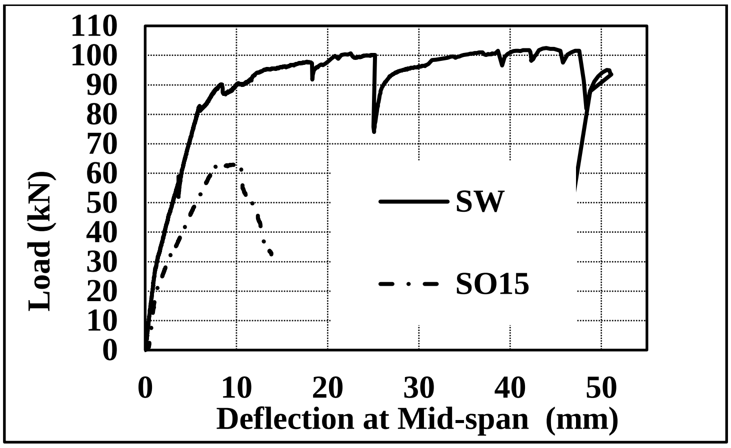

Fig. 6 Load deflection curve for SW and SO15 specimens

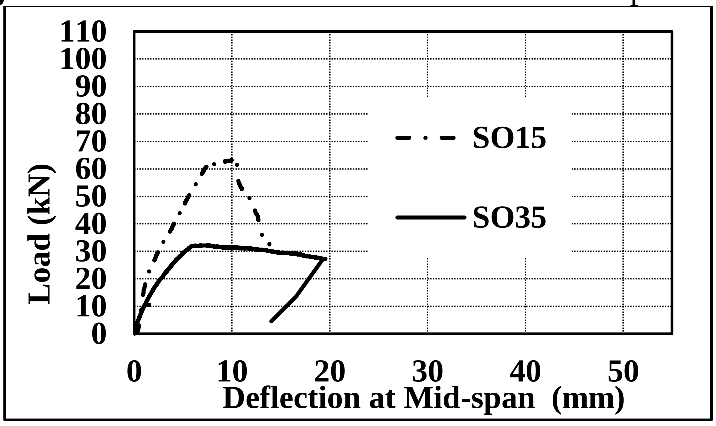

Fig. 7 Load deflection curve for SO15 and SO35 specimens

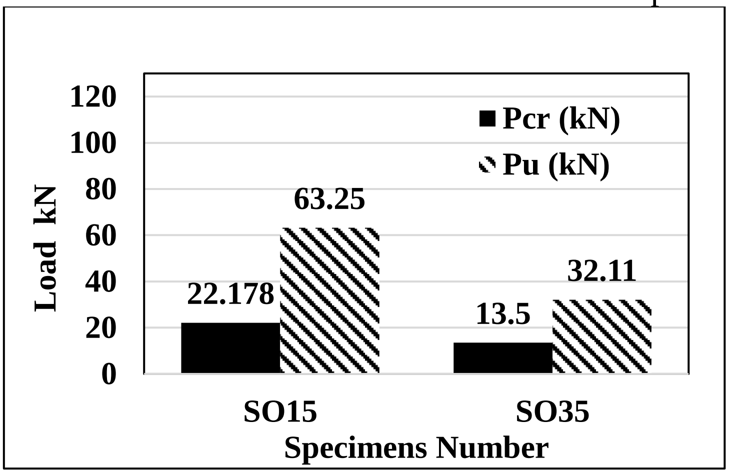

Fig. 8 Crack and ultimate load for SO15 and SO35 specimens

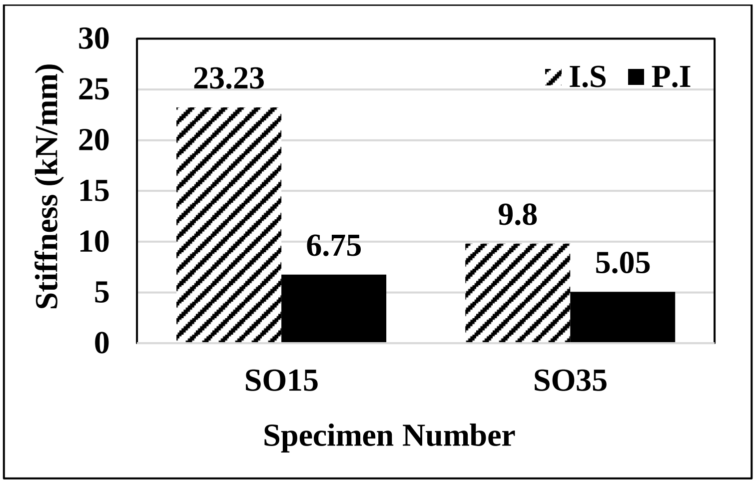

Fig. 9 Initial and post cracking stiffness for SO15 and SO35 specimens

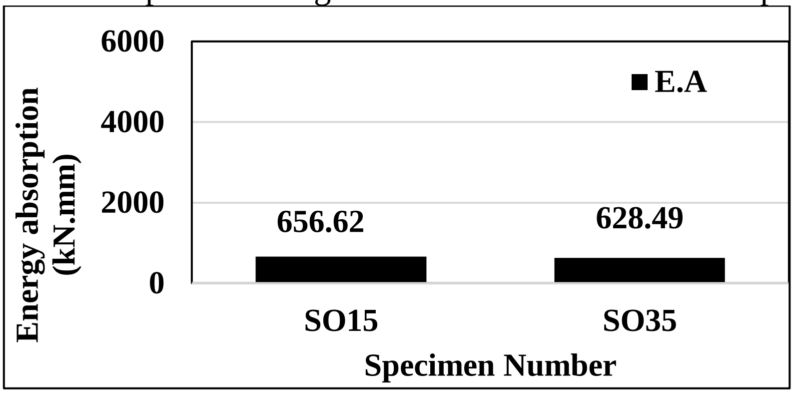

Fig. 10 Energy absorption for SO15 and SO35 specimens

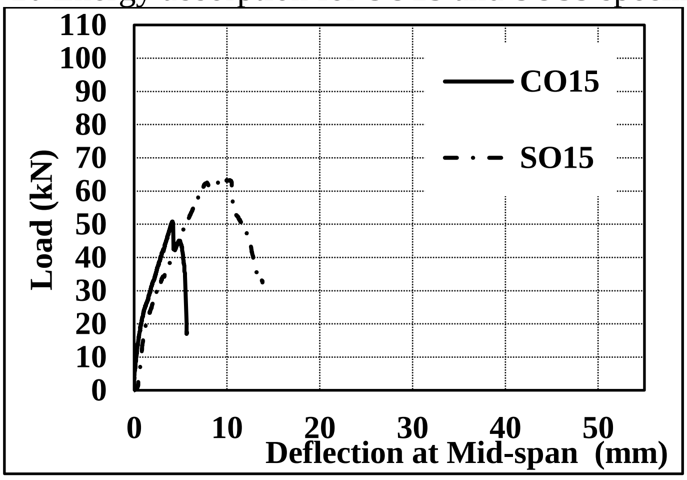

Fig. 11 Load deflection curve for SO15 and CO15 specimens

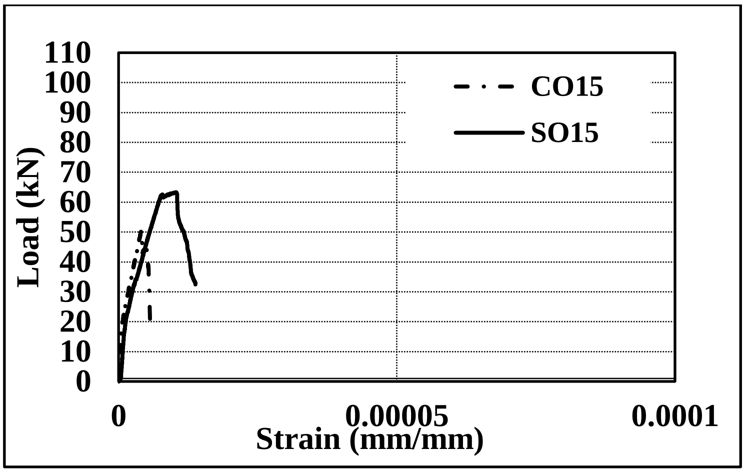

Fig. 12 Load strain curve for SO15 and CO15 specimens

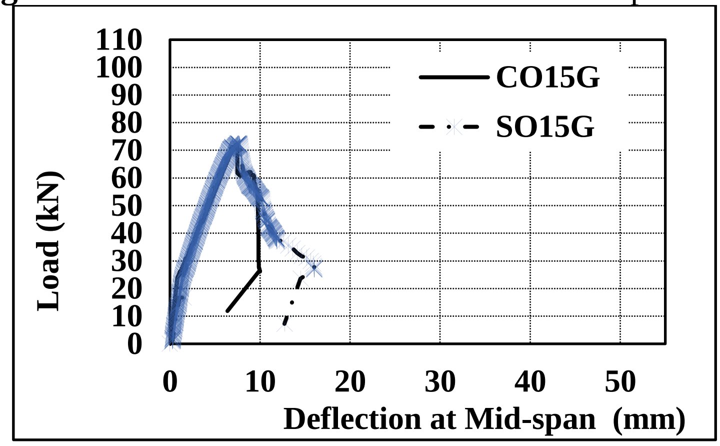

Fig. 13 Load deflection curve for SO15G and CO15G specimens

Conclusions

There is no doubt that presence of an opening and/or increasing the opening dimensions leads to decrease in ductility, also brittle behavior replaces elastic plastic behavior as a result. Authors choose the most common beam dimensions in the study where the dimensions are scaled to half its actual dimensions. Only one size of beams is studied to highlight the effect of different reinforcement methods. Numerical study including other dimensions should be studied in the future. Several factors are tested to overcome the influence of openings on concrete beams. The disadvantage of adding steel fibers to concrete specimens with or without GFRP is ductile behavior specially in the post cracking phase with a small, alarming deflection although an increase in P_u by up to 49% is observed. Two techniques are used to strengthen beams around the opening by GFRP in specimens with or without steel fibers. The advantage is more ductile failure in specimens with GFRP where P_u increases by 42% in specimens without steel fibers and by 14% in specimens with steel fibers. The advantage of adding GFRP to specimen is that EA increases by 1.7 times in specimens without steel fibers and by 22% in specimen with steel fibers. The disadvantage of strengthening by internal steel bars around opening in specimens containing steel fibers is brittle failure despite of noticing that P_u increases by 34% and EA increases by 41%. Strengthening by steel bars when compared to strengthening with GFRP causes P_u and Δ_u to increase by 16 % and by 6 %

respectively despite the brittle failure. At the end, to achieve ductile behavior along with enhanced strength and EA, it is recommended to use GFRP around the opening.

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