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Research Paper

Reinforced Concrete Beams with Drop-in- Ends of Vertical and Inclined Reinforcement and having Pockets Loaded by In-Plane Static Forces

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ABSTRACT

This research presents an experimental investigation on the behaviour of RC dapped end beams with loaded openings that have been strengthened initially with four different techniques including steel fibre concrete, inclined crossed bars, jacketing with steel plates and the composite section technique. Ten specimens with a rectangular opening at the midspan are tested under in-plane point load within opening. Such beams are categorized into two groups with five specimens per group. The dapped end zone of the first group is reinforced with standard vertical stirrups, while for the other groups inclined bar reinforcement has been used. Two main parameters have been considered which are the detailing of the reinforcement around the opening and the effect of inclusion of the dapped ends. The response has been discussed in terms the first cracking load, ultimate load, maximum deflection, failure modes, load-deflection curves, crack patterns, crack width, to recognize the optimum strengthening proposal of the opening. Results indicated that the modified reinforcement configurations of the dapped ends yielded better response and the ultimate load increased when adopting the composite section method in (21-23%) relative to the conventional beams. Regarding strengthening by steel SFRC method, an improvement in load capacity by (8-10%) has been observed. Whereas, strengthening with crossed inclined bars yielded an enhancement of (8.5-11%). Furthermore, using steel plates increases the load capacity by about (11-13%).

1 Introduction

The conventional geometry of the end support of the RC precast beams is the rectangular one. However, it was found that lowering the centre of gravity of the beam may improve its lateral stability and better fabrication in joints.. This can be achieved by making notches at ends of the beam. Such beams are called drop-in or dapped end beams. The use of dapped end beams may affect the cost aspect and the drift problem of the precast buildings. The applications of the drop-in ends increased gradually in precast buildings around the world and it was extended to be used in half joints, precast wall, precast footings, stairs and stepped beams, etc. [1, 2]. The corner formation at the dapped end may result in severe disturbance of flow of stresses and disturbed region (D-region) is induced. Such type of regions can be found in corbels, openings, corners,

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etc. are designed using strut and tie model (STM) [3] or for limited cases (a/d<1.0) by shear friction (PCI) method [4]. Fig. 1 shows some of the D-regions against the B-regions of uniform flow of stresses [4].

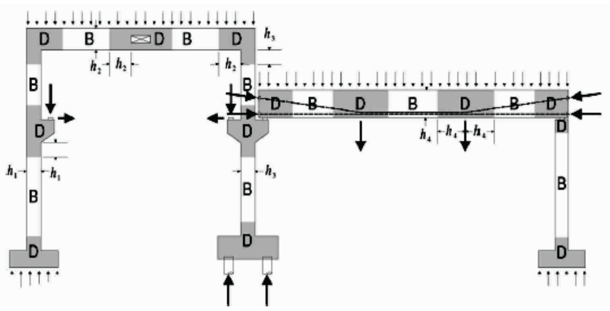


Fig. 1 – D-region and B-regions for RC members [4]

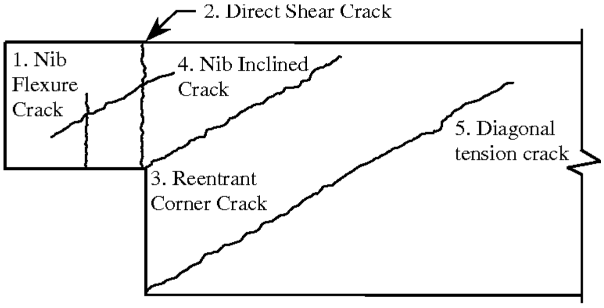


Fig. 2 – Modes of failure for DE [5]

Previous studies detected several modes of failure in dapped ends as shown in Fig.2.The system of nib reinforcement is used to resist failure modes 1, 2 and 4 whereas the hanger reinforcement is used to resist modes 3 and 5 [5].

Some studies adopted vertical (Standard) hanger reinforcement, in this regard, Mattock and Chan [6] proposed design procedure for the dapped ends (DEB) utilizing the proposed corbel design method by Mattock, 1976 [7] with using the hanger reinforcement. Lu, et al., 2003 [8] investigated some parameters that may affect the response of the high-strength concrete DEBs; including the strength of concrete, the main steel reinforcement and (a/d) values. Peng, 2009 [9] concluded that the details of hanger steel and anchorage had a great effect on ductility and increasing the shear capacity by (44 and 42%), respectively. In 2011, Yang et. al. [10] proposed a mechanism analysis based on the energy principle to estimate the shear strength of RC DEBs. the results are compared with the. Results revealed that the developed mechanism analysis yielded similar results to that obtained from the simplified STM model of ACI 318-05. Lu, et al., 2015 [11] reported that the shear strength improved` with increasing the grade of concrete and reducing (a/d) ratio. Mohammed, et al., 2019 [12] concluded that prediction of the load of failure according using ACI-318-08 and PCI method were more accurate in comparison with Euro Code2 and BS 8110.

The inclined hanger reinforcement in dapped ends has been proposed firstly by (Liem, 1983) [13]. Results revealed that capacity of DE with (45º) inclined reinforcement may be twice the strength of the specimens with vertical stirrups. Wang, et al., 2005 [14] showed that the inclined stirrups and longitudinal bent reinforcement are more effective on the shear capacity than vertical stirrups. Falcón, 2019) [15] concluded that the crack width reduced when using diagonal reinforcement compared with orthogonal reinforcement. Desnerck, et al., 2016 [16] found that the specimen designed according to STM models failed at load higher than the design load by (34.1%). Then, Desnerck, et al., 2017 [17] used the inclined dapped end reinforcement when studying the internal deficient dapped end.

The inclined configuration has been used by several researchers when strengthening the deficient dapped ends, most of the studies showed the advantage of the inclined configuration if compared with other arrangements. Taher 2005 [18] used different techniques to upgrade several defects in the steel detain of the dapped ends. Amongst were the inclined steel bolts anchoring and EB inclined CFRP stripping. Shakir et. al. [19] through studying the deficient dapped ends, examined several configurations of CFRP sheet strengthening including the inclined, horizontal and the combined arrangements. Shakir and Aliwe [20] used the NSM steel bars technique in strengthening dapped ends. Several arrangements have been considered as vertical, horizontal and inclined configurations.

Sometimes, transverse web openings are necessary to pass service pipes and ducts to avoid increasing the floor height due to passing duct underneath the beams. However, another D-region may be induced at opening zone that adversely affects the strength, stiffness, deflection response and cracking pattern of the beam [21, 22]. Several studies have been published regarding strengthening of web openings included within the conventional beams. Suresh and Prabhavathy [23] used the steel fibres and steel plates. It was found that using steel fibres increased the load capacity by (5 to 30%). While when using steel fibre with steel plates (4mm) thickness increased the load capacity by (50 to 110%). Shakir, 2016 [24] investigated theoretically the strengthening of large openings using partial and full jacketing strengthening of the opening. Allam, 2005 [25] used steel plate and the CFRP sheets. Chin, et al., 2011 [26], El-Maaddawy and El-Ariss, 2012 [27] strengthened openings with CFRP composites. Fawzy, 2015 [28] used externally epoxy-bonded steel strips plate and FRP sheets in strengthening of openings. Soman and manju, 2017 [29] used BFRP and CFRP sheets. Morsy and Barima, 2019 [30] used different strengthening techniques including internal rebars, internally embedded fibre rebars, and near surface mounted utilizing FRP laminate, steel box and externally bonded FRP laminate. The proposal of using the composite section in strengthening RC corbels yielded good enhancement relative to the conventional steel bars reinforced concrete corbels [31-33]. Thus, it has been considered to improve the performance of the loaded opening region.

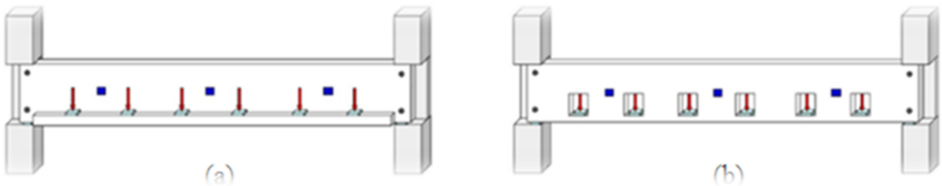


Fig. 3 Proposals to support transverse beam on a girder [34]

(a)Dimensions

(b) Beam reinforcement for Group G1

(c) Beam reinforcement for Group G2

(d)Cross section (B-B)

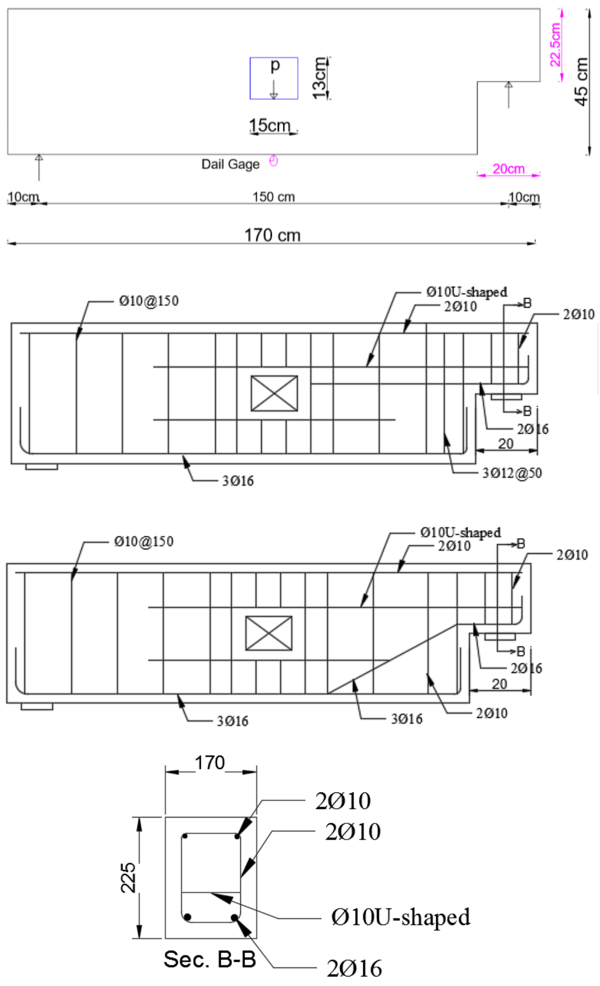


Fig. 4 Dimensions and reinforcement detailing of the tested specimens

Most of previous studies concerned with beams of unloaded openings or openings of negligible loads. However, openings may be used to accommodate the support reaction of transverse stringers in grid systems, or to support cross continuous steel beams or services ducts with heavy weights as shown in Fig. 3. Mercan et. al. 2012 [34] studied theoretically, the elastic response for slender rectangular pocket and spandrel beams.

It can be seen that there is a scarcity of studies regarding this the precast dapped end beams with heavily loaded openings. The current study aims to investigate experimentally the behaviour of such type of beams made of SCC concrete and to improve the knowledge in the area. Different strengthening techniques have been used at the opening zone. Two parameters have been considered which are the type of reinforcement of the dapped end region and the strengthening proposal at the opening zone to improve the response.

2 Experimental investigation

2.1 Description of Specimens

Ten specimens have been tested, each of overall dimensions (1700 X 450X 170) mm and c/c span of (1500mm) with rectangular openings of dimensions (150 X 130) mm located at midspan. The nib dimensions are (200 X 225) mm. All specimens having (shear span/depth) of (1.0) and have been categorized according to dapped end reinforcement into two main groups (G1 and G2) with five specimen each. The specimens of the two groups are reinforced at the dapped ends with the vertical stirrups and inclined bars respectively. Each group consisted of one control specimen, and four that are strengthened openings with different techniques. The main tensile reinforcement of the beam consisted of three bars of 16 mm diameter, whereas two bars of 12mm diameter bars are used at the compression face. Two stirrups of 12 mm diameterare used on each side of the opening. Stirrups of 10mm with spacing of150mm are used. Two bars of 10 diameter bars used at top and bottom of opening as stirrups reinforcement. Two bars of 16 mm diameter are used as main reinforcement at nib and three stirrups of 12 mm utilized in hanger region for specimens of group G1. For specimens of group G2, the vertical stirrups are reduced to two bars of 10mm diameter. The three-16 mm bars inclined dapped end reinforcement is provided by bending the nib reinforcement with a specified angle and adding one-16 mm bar. Fig. 4 show the dimensions and details of reinforcement of typical beams, respectively. Specimen designations are listed in Table 1.

2.2 Materials properties

Sulphate resisting cement (C) type (V) in which test results [35] listed in Table 2 is used in this work,. Washed and surface dried natural sand that is imported from Al-Najaf zone is used as fine aggregate (FA). Washed and dried surface coarse aggregate (CA) of Al-Nibaey region is utilized, the max. size (20 mm), is used. However, for SFRC, max. size of (14 mm) has been used. Table 3 shows the test results of the sieve analysis of aggregate which compared with the limit of the Iraqi specification (IQS 45/1984) [36]. Clean water (W) is used for casting and curing in this experimental work. Limestone Powder (LP) passed the sieve size of 0.125 mm is used as a filler material in SCC to improve the segregation resistance and increase the amount of powder (cement + filler) [37]. Epsilon HP 580) [38] is used as Super plasticizer (SP) to produce a concrete with low water content and high workability. Steel bars of Ø10, Ø12 and Ø16 diameters reinforcement having yield stresses of 576, 590 and 600 MPa respectively and ultimate strengths of 674, 684 and 693 respectively. The respective values for the rolled steel section, which is used in the composite bottom chord, are 333 and 453 respectively. Whereas for the steel plates, the values are: 586, 716 MPa respectively. The tests of steel bars are achieved according to ASTM A615-4 [39] while for the rolled section and steel plate the tests are done based on ASTM E8/E8M − 16a [40]. Moreover, Micro steel fibres type WSF0213 made by a company in Jiangxi Province (Mainland), China (Length=13mm, diameter=0.2mm, tensile strength=2600 MPa) are used in SFRC concrete in order to enhance shear strength, improve the ductility. Mix constituent materials are listed in Table 4.

2.3 Fresh and Hardened Concrete Tests

The Slump Flow and T500 Tests, Fig. 5, are performed to estimate the flow ability and the rate of the flow of the casted SCC. Such tests are achieved based on ACI237R-07 [3]. Moreover, J-ring Test ASTM (C1621/C1621M) [41], it is used to measure the passing ability of SCC mixture.

For the tests of the hardened concrete (mechanical properties), for each mix three cylinders with dimensions (100x200) mm that had been utilized to evaluate the compressive strength (f'c) [42], and three cubes with dimensions (150x150x150) mm have been used to find the cube compressive strength (fcu)[43]. Three (100x200) mm cylinders are utilized to find the splitting tensile strength (ft)[44].Cylinders with dimensions of (150mm x 300 mm) are used to determine the modulus of elasticity (Ec)[45]. All the mechanical tests are done after wet curing period of 28 days. Fig.6 shows the specimens under test. Results of these tests are recorded in Table 5.

Table 1- Designations of specimens test in the present work

Beam designation		Detail of opening strengthening
Group G1 (vertical stirrups)	G1-CONT	None
	G1-FIB	Steel Fiber
	G1-cross	Inclined Crossed bars
	G1-PLT	Steel Plates
	G1-TEE	Composite bottom chord with WT-Rolled Steel
Group G2 (Inclined bars)	G2-CONT	None
	G2-FIB	Steel Fibre
	G2- cross	Inclined Crossed bars
	G2-PLT	Steel Plates
	G2-TEE	Composite bottom chord with WT-Rolled Steel

Table 2- Cement Physical and Mechanical Properties

Physical Property		Result	Limits IQ.SNo.5/1984
Initial Setting (minute)		85	>45
Final setting (minute)		285	<600
Fineness (Blaine), in m^2/kg		289	>250
Compressive Strength (Mpa)	3 days 7 days	17.6 26.9	≥15 ≥23

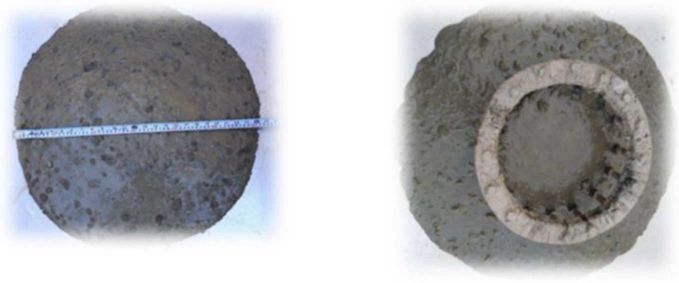
Table 3- Grain Size Distribution of Aggregate

Sieve size (mm)	Fine aggregate		Coarse aggregate		
	Acc. (%)	Limits* (%)	Acc.%(Max. size=14 mm)**	Acc.%(Max. size=20 mm)	Limits* (%)
0.15	2	(0-10)			
0.30	16	(8-30)			
0.60	42	(35-60)			
1.18	60	(55-90)			
2.36	90	(75-100)			
4.75	95	(90-100)	4	5	(0-10)
10			75	42	(50-85)** / (30-60)
14			98		(90-100)
20				96	(95-100)

*According to (IQS 45/1984) [36], ** For steel fibre concrete

Table 4- Details of concrete mixes (kg/m^3)

Material	C	FA	CA	LP	W	W/C	SP(L)	SF%
SCC	400	962	780	75	125	31%	6	0
SFRSCC	400	962	780	75	125	31%	6.8	1



a)Slump Flow Test b) J-Ring FlowTest

Fig. 5 Self-compacting concrete tests

(a) (b) (c) (d)

Fig. 6 Hardened concrete tests (a) Cylinder Compressive strength (b) Cube compressive strength (c) Splitting test (d) Modulus of elasticity

Table 5 - Results of the mechanical properties of SCC and SFRSCC

Type of mix	Fcu*(MPa)	fc'** (MPa)	ft# (MPa)	Ec‡(MPa)
SCC	56	50	4.16	26315
SFRSCC	61	58	4.7	33824

*BS 1881-116 1983 [43] ** ASTM C39/ C39-15a [42] #ASTM C496 /C496-11[44] ‡ASTM C469 / C469M-14[45]

2.4 Strengthening Systems

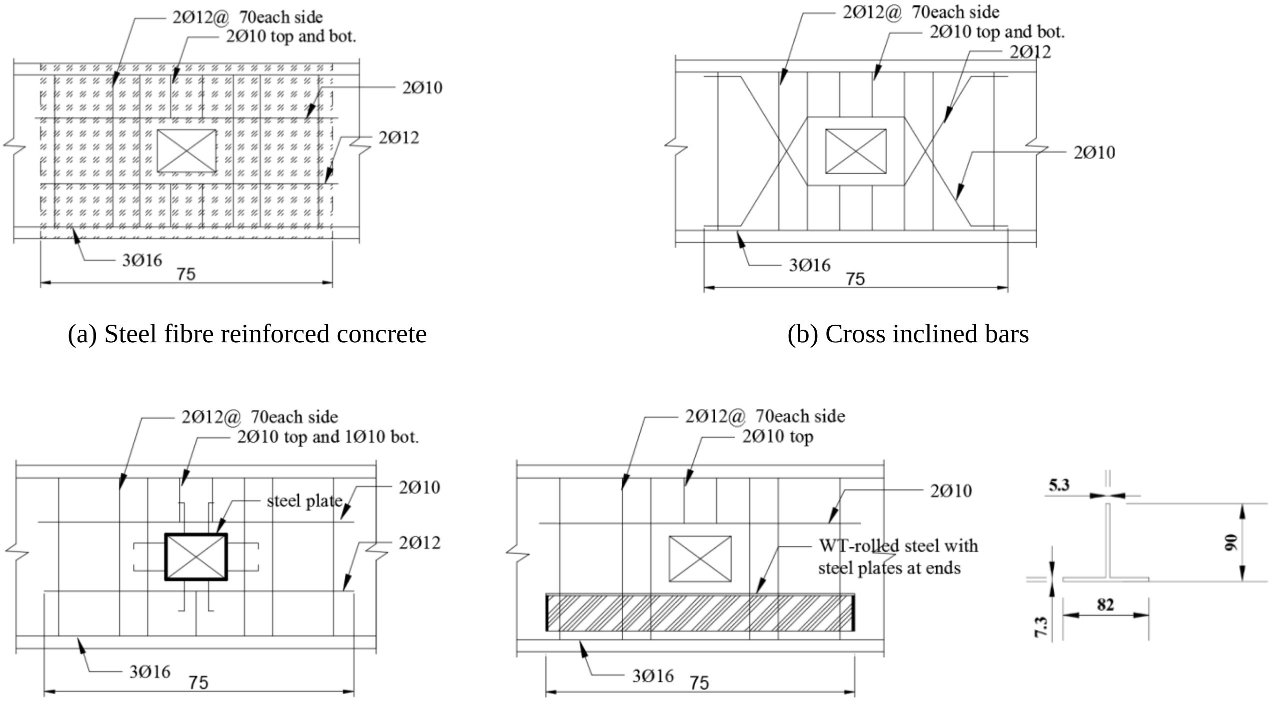
Four strengthening proposals are used to improve the performance of beams at the opening zone. They are:

1-Using SFRC within area of (275) mm on both side of the centre of the opening. The use of fibers in concrete may improve the shear, flexural and compressive strengths. Also, improve that efficiency of stress transfer away from point of application.

2- Crossed inclined steel bars (as rhombus shape) around the opening. The aim of this configuration is to interrupt the diagonal cracking that are emanating within the bottom chord of the opening and to resist the tendency of the longitudinal separation of the beam at the level of opening

3- Jacketing the interior faces of the opening with steel plates of (2.85mm) thickness. the plate jacketing serve three roles. One is to improve shear strength and cracking resistance at corners, acted as longitudinal reinforcement to the top and bottom chords and provide better distribution of the concentrated force on the opening.

4- Inclusion of WT-rolled section within the bottom chord of the opening.Fig.7 shows the detailing of the various configurations. Also, Fig.8 shows the cage of steel reinforcement of the tested specimens.



(a) Steel fibre reinforced concrete

(b) Cross inclined bars

(c) Steel plate jacketing

(d) WT-rolled steel in the bottom chord

Fig. 7 – Strengthening configurations for the pockets of the tested specimens

(a) Group (1)

(b) Group (2)

Fig. 8 – Reinforcement of Dapped and Beams with openings

2.5 Testing Procedure

After a curing stage of 28 days, the specimens are painted with white colour so that cracks can be easily detected. The beams are positioned in the hydraulic machine. Rubber and steel platesare used to prevent the local crushing concrete.Load steps are applied by (15 kN) increments before first cracks appear. Then, loading steps increased to about (10 kN) up to failure. At each stage of loading, the reading of the dial gauge is recorded. The initiation and propagation of cracks is traced. The test was carried out at laboratories of the Engineering Consulting Bureau of Kufa University using (2000kN) hydraulic testing machine. Fig. 9a shows the testing machine and Fig.9bshows a specimen under test.

(a)

(b)

Fig. 9 – Loading setup (a) The testing machine (b) specimen under test

3 Results and Discussion

The response of the tested specimens has been studied in terms of crack patterns mid-span deflection, cracks width for the test specimens.

3.1 Crack Patterns and cracking history

3.1.1 Group G1: pocket beams with dapped ends of vertical reinforcement

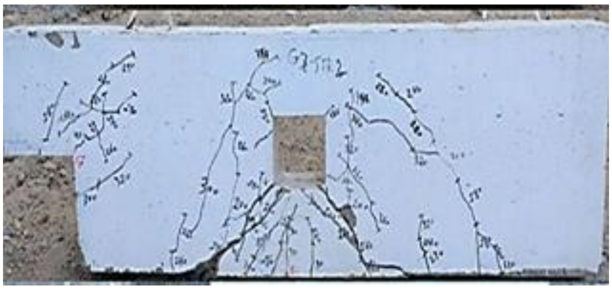
Fig.10a shows the map of cracking for specimen G1-CONT at failure. It can be seen that the location of the loaded opening, which is severely, disturbed region (D-region) at the maximum moment location resulted in initiating the first crack as flexural crack at a small load of 50 kN. At load of 60kN, the first diagonal shear crack initiated at the re-entrant corner. The existence of dapped end resulted in development another D-region that relatively high concentration of stresses occurred and that cracks tend to propagate through, then reducing the ultimate load, stiffness and rigidity of the specimen. More cracks formed at both sides of opening, continued to widen, and propagated toward the top compression zone. While, few diagonal cracks may be recognized at the nib zone (small thickness). The opening reinforcement contributed in spreading the stresses induced and more concrete block contributed in resistance. At load level of 300kN, some horizontal crack initiated at mid-depth of the opening revealing that some tendency for separation about to occur and that the vertical stirrup reinforcement is not efficient enough to accommodate stresses as in the case with unloaded opening.

At a load level of 330 kN, the specimen failed by developing a diagonal cracks at corners of the opening causing diagonal shear mode failure. The small intensity of cracks at the top chord of the opening reveals that more capacity could be obtained provided that the resistance of the bottom chord is improved. Thus, it is expected that if the diagonal cracking in both of the disturbed zones (re-entrant corner and opening region) are interrupted by diagonal reinforcement, better performance might be obtained. Also, it is obvious that the cracks within the mid distance between opening and re-entrant corner have the largest width. This reveals that the crack propagation of both region occurred independently of the other with uniform rate. It is clear that most of cracks are diagonally oriented towards the top cord of opening rather transferred to the sides of opening. In general, for these beams, the diagonal shear mode of failure at the bottom of corners opening is dominant.

Fig. 10b shows the crack pattern of specimen G1-FIB at failure instant. First cracking is initiated at a load 65 kN at re-entrant corner of dapped end. The addition of steel fibres led to improving the shear strength of opening region, the specimen failed at a load level of 356 kN with diagonal shear failure at corners of opening, with an enhancement of about (7.88%) compared to control beam. Comparing with G1-CONT, more intensity of cracks can be noticed at the opening zone and far sides of opening with reducing cracks spacing. This may refer to the fact that presence of steel fibersyielded better stress redistribution in the specimen and prevented the localization of stresses. It can be observed that the horizontal cracking on both sides of the opening developed from the top corners within higher level of loading. The small enhancement in capacity reveals that the use the steel fibers at opening region only, is not adequate, enough to develop the required strength for the pocket beams with dapped ends unless the strength of the dapped end to be b improved significantly.

(a) Specimen G1-CONT

(b) Specimen G1-FIB



(c) Specimen G1-cross

(d) Specimen G1-PLT

(e) Specimen G1-TEE

Fig. 10 – Crack pattern of the specimens of group G1

Fig. 10cillustrates the crack pattern of specimen G1-cross at failure. The first crack initiated at the opening zone as flexural crack at a load level of 55kN. At a load level of 67kN. The crack formed at the re-entrant corner and extended with angle about 45^{o}. Progressing in loading, the cracks appeared at both of sides of opening extending towards to the top chord. When the load reached about 358 kN, the beam failed by upward diagonal cracking i.e. the ultimate load is increased about (8.48%) compared to control beam. Small number of cracks formed at opening zone compared to beams G1-CONT and G1-FIB. Also, it can be observed that the cracks are developed away from the opening region indicating that the diagonal bars of the cross steel resulted in restraining of the widening of crack growth at opening zone and spreading of cracking away from opening towards dapped end. However, it seems that the downward bars did not affect the cracking at opening significantly as in the case of beams with unloaded opening.

It can be seen that the downward inclined steel bars are parallel to the diagonal cracking, and then there is no significant influence on the rate of crack propagation. Thus, it is expected that use only upward bars with quantity equals to the total area of strengthening steel may improve the results significantly. It is to be mentioned that the NSM steel bars with semi-rhombus configuration may be adopted when the function of opening from being unloaded to become loaded. Other techniques as using steel fibers, plate jacketing, and composite section method may not be used with the hardened concrete

Map of crack propagation of specimen G1-PLT at failure is depicted in Fig. 10d. the first crack is initiated at a load level of 58 kN at nearly mid span as a flexural crack. At a load 65 kN, the diagonal shear cracks appeared at re-entrant corner. With further loading, the diagonal cracks appeared at sides of opening and at the nib zone. At a load level of 365 kN the beam fully damaged with diagonal shear failure mode. It can be concluded that steel plates improved ultimate shear strength by average ratios of (10.6%) relative to the beam G1-CONT. It can be noticed that the intensity and concentration of cracks at nib zone are more than the beam G1-CONT and the spacing between cracks at bottom chord of opening is reduced. Also, the cracks formed at both sides of opening propagated towards top chord of opening. Thus, allowing to accommodate more stresses. Consequently, more cracks developed at the dapped end emanating from the re-entrant corner. In addition,It can be seen that using steel plates resulted a lower efficient transfer of stresses than the steel fibre which it is using in the beam G1-FIB.

Fig. 10e shows the map of cracking propagation of specimen G1-TEE. The first crack initiated as a flexural crack appeared in middle region with a load level of 65 kN. At a load 70 kN, the diagonal crack noticed at the re-entrant corner of dapped end and extended with angle about (45^o). The crack formed at point near the support of the dap grew diagonally at a load level of 260 kN, such crack continued to widen and propagate simultaneously with the diagonal shear cracks at the bottom corner of opening until causing diagonal shear failure at the extended end dap end at failure load of 405 kN. It can be concluded that the steel WT-section results in increasing the load of capacity about (22.73%). This is because that the steel WT-section produced high stiffness at opening region and made the cracks propagation over a larger area of the specimen. Compared to specimens G1-CONT, G1-FIB, it is obvious that incorporating the rolled steel changed mode of failure from diagonal shear failure at corners of opening to diagonal shear failure at the extended end with crushing of the compression zone. In addition, it is yielded high resisting for loading. Moreover, It can be seen that an increase in the rate of propagation of cracks at the nib zone and the opening zone and developed away from opening zone towards the support when compared to specimens G1-cross and G1-PLT. This may be attributed to the WT- rolled steel contributed in transferring the stresses induced at the opening zone (as in steel fibers) such that more concrete areas contributed in resisting the applied loads and to prevent the local failure.

For the tested specimens, it is clear that the cracking at the dapped end resulted in more curvature of the beam. Then, more stresses around opening for specimens without enough stiffness against curvature i.e. specimens G1-FIB, G1-PLT and G1-cross. The recorded ultimate load was in small range (356-365) kN. While for specimen G1-TEE, Good stiffness at opening against excessive curvature. Thus, higher load of 405 kN has been recorded.

Capacity of the pocket beams can be improved by reducing the shear and tension effect at the opening and vertical tension at the dapped region by applying prestressing force on the beam. This technique has been used in several studies Warner &Diliger [46], Nanni& Huang [47] and Botros [48], to improve the performance of the dapped end beams without openings. This technique may assist in production of beams having several pockets and without serious reduction in performance.

3.1.2 Group G2: pocket beams with dapped ends of inclined reinforcement.

Fig. 11a displays the history of crack propagation of the beam G2-CONT. First flexural crack is observed at the opening region at a load level of 55 kN. With progress in loading, the shear cracks occurred at a load level of 60 kN at the corner of opening. At a load 65 kN, the diagonal shear crack is formed at the re-entrant corner and extended with angle about (45^o). The cracks are formed at sides of opening and extended towards top chord of opening and more cracks are observed at nib zone. The cracks at the bottom corners of the opening continued to propagate until causing the failure of the specimen at a load level of 355 kN with separation of the bottom chord of the opening.

(a) Specimen G2-CONT

(b) Specimen G2-FIB

(c) Specimen G2-CROSS

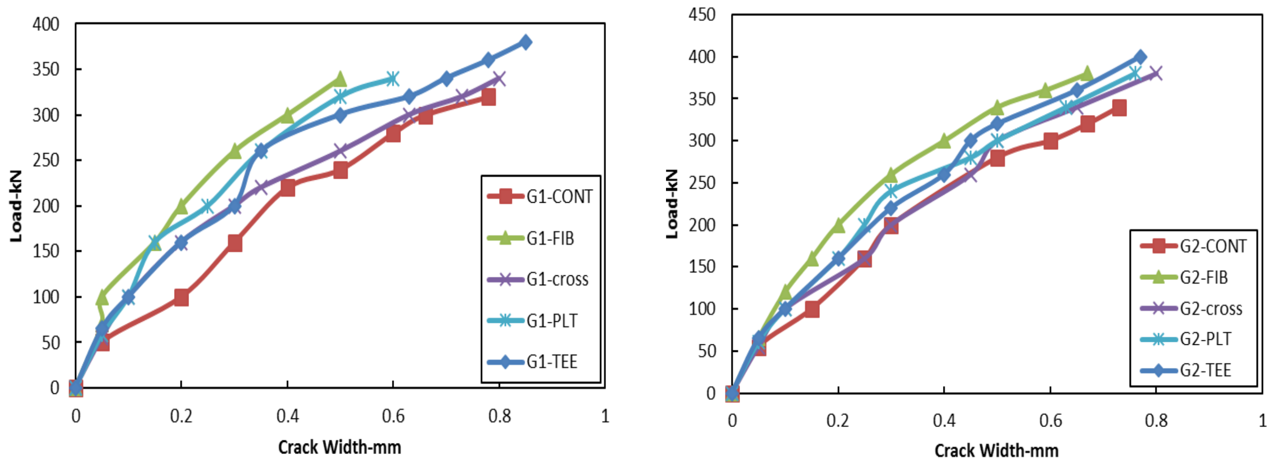
(d) Specimen G2-PLT

(e) Specimen G2-TEE

Fig. 11 – Crack pattern of the specimens of group G2

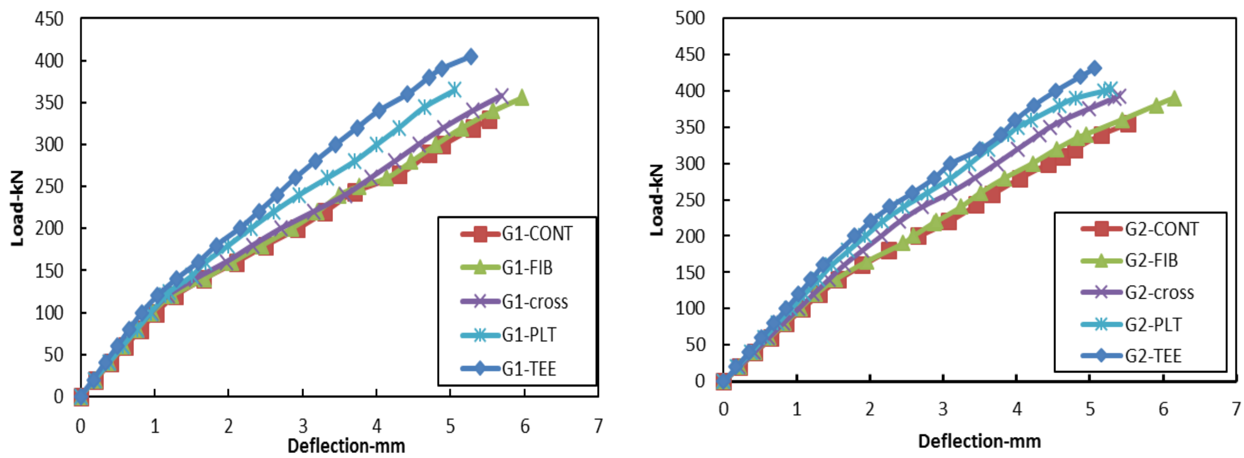
It can be seen that specimen G2-CONT resisted more load than specimen G1-CONT and the mode of failure is different. Also, the intensity and concentration of cracks at the top chord of the opening and at the dapped end region are more than beam G1-CONT. It can be explored that the bent bar yielded improvement in performance of the dap end rather than using vertical stirrups. Fig. 11b shows the crack pattern fro specimen G2-FIB at failure. It is observed that the first flexure crack initiated at a load about 65 kN at mid span region. When the applied load reached 70 kN, the diagonal shear crack developed from re-entrant corner with an increment about (7.7%) with respect to control beam G2-CONT. With further loading, the cracks are widened and propagated towards the top chord of opening. When the applied load reached 200kN, the cracks observed at nib zone. Failure occurred by separation of the bottom chord of the opening at a load level of 390 kN, the results indicated that fibre steel strengthening is increasing the ultimate load about (9.86%) compared to control beam. It can be observed that the intensity of cracks formed at both sides of the opening and oriented diagonally to the top chord more than specimen without steel fibre (G2-CONT). This may be attributed to advantage of the using steel fibresimproved the capacity of transmitting the stresses hence, assisted in preventing the localization of stresses and then improved the strength of beam. The crack patterns for the specimen G2-cross is shown in Fig. 11c. First flexural crack observed at mid span at an applied load of 55kN. At load 60kN, the diagonal shear cracks appeared at the bottom corner of opening. The first crack initiated at the re-entered corner at an applied load of 68kN. Furthermore, new shear cracks grew on far sides of opening and continued to widen and propagated toward the top chord of opening. The maximum recorded load is 393kN with increments of about (10.7%) more than the control specimen. The failure occurred by separation of the bottom chord of the opening. It is clear that the rate of cracking is reduced at both sides of opening and the dapped end region when compared to specimensG2-CONT and G2-FIB. Because that the inclined legs restrained the widening of cracks and reduced the number of cracks. Moreover, the use of bents bar improved the performance of the dapped end and yielded high resisting for loading.

The crack pattern for beam G2-PLT is shown in Fig. 11d. The first flexural crack showed at load 60kN at mid span region (flexural crack) with slight improvement in cracking load of about (9.1%) compared with control beam. With increasing load, the diagonal shear crack is occurred at the corner of opening at an applied load 65 kN. While the diagonal shear crack is started at re-entrant corner at load 70 kN and extended with angle about (45º). The recorded max load is 402 kN withseparation of the bottom chord of the opening, with increment of (13.24%) over control specimen G2-CONT. Also, it can be seen that the cracks propagated through nib zone and opening region lower than control beam and beam with steel fibre.i.e. localization of stresses at opening. This refers to less efficient transfer of stresses provided by steel plates. This may be attributed to the studs need to be passed more distance.



(a) (b)

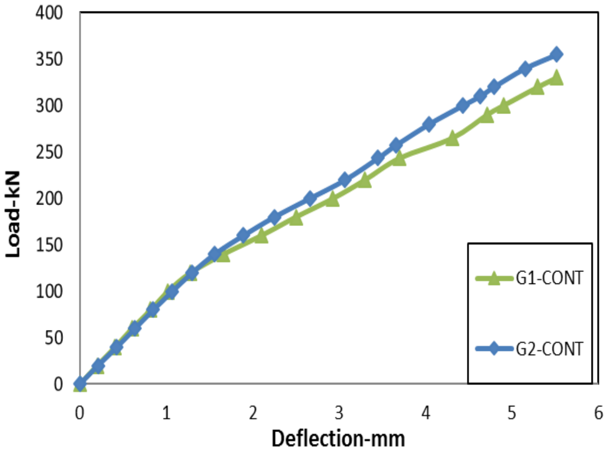
Fig. 12 – History of cracking development (a) Group 1 (b) Group 2



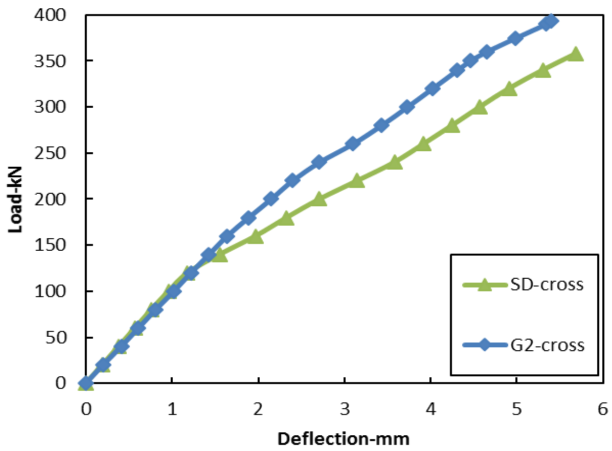
(a) Group G1 (b) Group G2

Fig. 13 – Load-deflection curves of the two groups

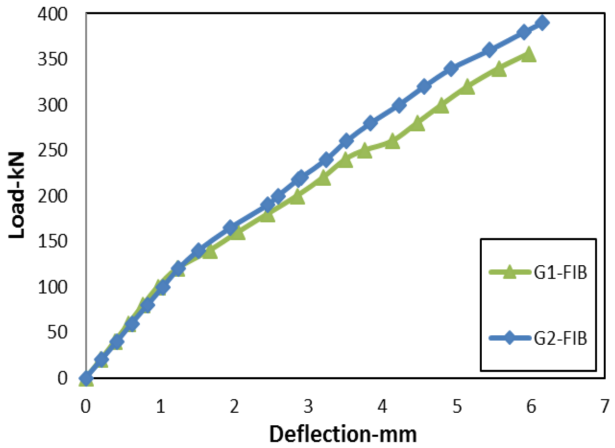
The crack pattern for specimen G2-TEE is depicted in Fig. 11e. The first flexural crack is observed at mid span of the beam at bottom chord of opening at a load level of 65 kN with an increment of about (18.2%) over reference specimen. With increasing load, the diagonal shear cracks initiated at load value of about 70 kN at bottom corner of opening. At load75kN,the first crack appeared at the re-entrant corner. The specimen failed at a load level of 431 KN with separation of the bottom chord of the opening with some crushing at top chord. The ultimate load of beam increased approximately (21.41%) than control beam. Compared to specimens G2-CONT and G2-FIB, it is noticed that the cracks are stationed in the middle third of the beam at both sides of the opening and propagated toward the top chord of opening.



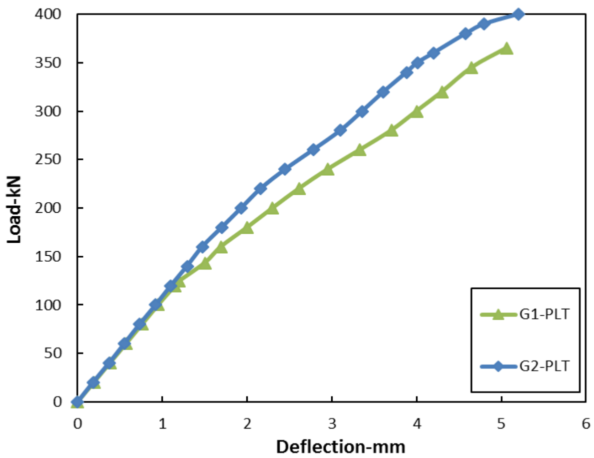
(a)Control specimens



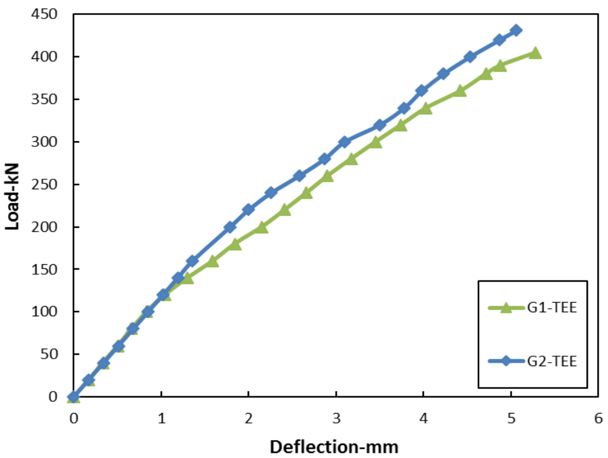
(b) Specimens strengthened with crossed bars



(c) Specimens with steel fibers concrete



(d) Specimens strengthened with plates



(e) Specimens strengthened with rolled steel

Fig. 14 – Comparisons of the load-deflection curves of the respective specimens of the two groups

This may be attributed to that, the steel section improved stiffness of beam and strength of the bottom chord considerably. Thus, more resistance is provided and more strength of the concrete of the compression area exhausted up to crushing. The Number of cracks increases up to a load level that some slippage occurred that produced wide horizontal crack at mid depth of the beam to separate the composite and non-composite section from each other. Thus, it is expected that making the stirrups to be perpendicular with the crack orientation. It is obvious that the entire cracking pattern and the mode of failure are different for specimen G2-TEE when compared to specimens G2-cross and G2-PLT. In addition, the cracks intensity are increased with the composite configuration with some tendency of horizontal separation through the mid depth of the beam can be noticed. It can be seen that the intensity and concentration of cracks at dapped end zone for specimen G2-TEE is lower thanspecimen G1- TEE and the failure mode is separation of the bottom chord of the opening with some crushing at top chord. This is attributed to the fact that G2-TEE includes the bent bar yielded better performance of the beam.

Fig. 12 shows the history of growth of the first crack for the two groups.it is obvious that the specimens with SFRC at opening yielded the smallest crack width. Thus, it is expected that combining the composite section with the SFRC may enhance the response considerably.

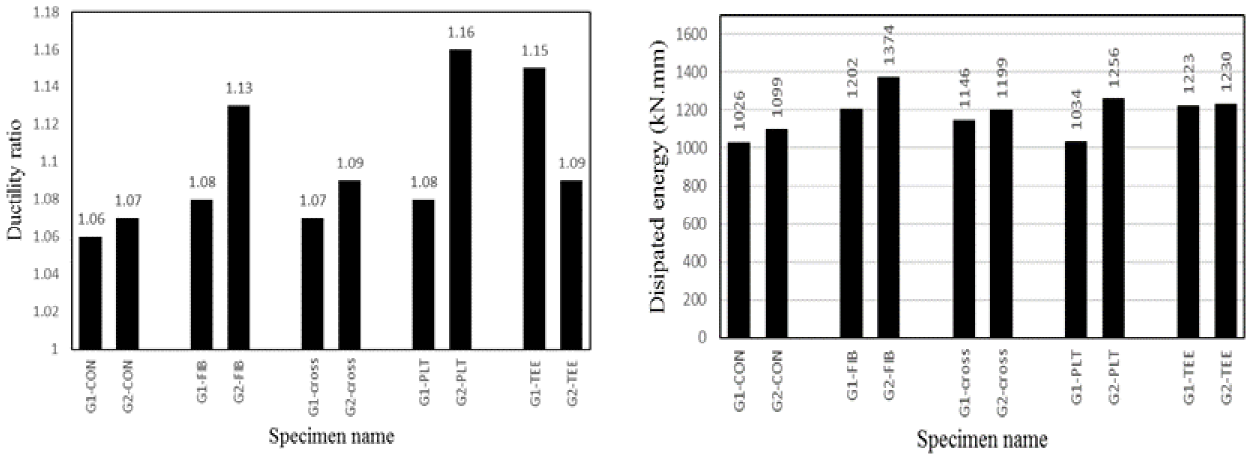
3.2 Load–Midspan Deflection

Fig. 13 shows the load- mid span deflection curves of the two group G1 & G2. It can be noticed that the proposed strengthening configurations improved capacity by (8.5-21.37%) and (10- 24%) respectively It is clear that the strengthening of the bottom chord by the Tee-section yielded the optimum results and that both of the crossed inclined bars and using SFC within opening yielded small improvement in response. This may be due to the ineffective arrangement of some of the inclined bars (for specimens G1-cross & G2-cross) and due the small content of the steel fibers (for specimens G1-FIB and G2-FIB). However, the jacketing plate provided better improvement in capacity if compared with the cross links and SFC proposals.it is obvious that the stiffness for all specimens of each group is the same up to load of 150 kN which corresponds to (20-30) % of the failure load. Beyond which the specimens with the composite bottom chord G1-Tee &G2-Tee showed relatively stiff response compared with other specimens, which yielded stiffness, ranged between the control specimen and the highest value. In other means, It can be seen that all the methods of strengthening did not affect the behavior (stiffness=slope of the tangent to the load-deflection curve) up to 150 kN which may be considered to represent the elastic range. After this stage cracking developed around the loaded opening in a rate and configuration depends upon the detailing of the strengthening method. It is found that the Tee-rolled steel section for both groups yielded the least rate of degradation and that the strengthening material acted with the concrete as one unit more than the other methods. This action may be attributed to welding the two vertical stirrups on both sides of the opening to the steel section. this prevented largely the slip of the rolled steel inside the concrete then provide good composite section of the bottom chord in addition to a partial action of the top chord. Furthermore, the rolled steel provided good bearing area to transfer the load away from point of application. The top vertical stirrups also resisted the horizontal separation action due to the high tension forces on both sides of the opening. It is very clear that not all these features are provided in each one of the other methods. The control specimen included lowest rate of resistance to local buckling, stress transfer and has no composite action. Thus, it can be seen that the stiffness of specimens ranged between the composite configuration (Tee-configuration) and the control specimen. It is worthy to be mentioned that specimen of full-scale need to be tested with the same methods of strengthening.it is expected that larger difference may be obtained. It is to be mentioned that for the post-introduced loaded openings, the only technique to be used from the four adopted proposals is the NSM crossed inclined bars.

Fig. 14 shows comparisons between the loading histories for the respective specimens of the two groups.it is clear that the specimens with the modified dapped end reinforcement yield higher capacity and stiffness although that the area of the vertical stirrups has been reduced by 54%.Thus, it is expected that more reduction can be done by passing the main reinforcement of the beam diagonally to the top of the nib end, and bending some of the main steel in the nib. This may assist in using minimum area of vertical stirrups in the dapped region.

3.3 Toughness and ductility

Fig.15a shows the ductility and toughness for the two groups. It can be seen that for all of the specimens, except those with composite section at the bottom chord, the specimen with modified dapped reinforcement gained higher ductility compared to the respective specimen from group G1. The reduction in ductility for specimen G2-Teemay be attributed that the failure is shifted to the dapped end while for all other specimens failure occurred at opening. Fig.15bshows the toughness values of the two groups.It can be noted that the specimen from a specimen from group G2 yielded higher or at least equal to that of the respective specimen of the first group. It can be concluded that the modified configuration of the dapped reinforcement improved the response of the beams with dapped ends and loaded openings.



(a) (b)

Fig. 15 – Ductility and toughness results of the tested specimen (a) ductility (b) toughness

4 Conclusion

The present study focused on the behavior of RCBeams with drop-in- ends of having openings loaded with in- plane static forces with considering two alternatives for the dapped ends reinforcement. Ten specimens were tested experimentally up to failure. The main conclusions that have been obtained are summarized as follows:

Introducing web openings within RC or steel girders to support the cross beams may be considered as one of methods to reduce the overall height of the floors has an advantage over the inverted T- beams by eliminating the torsional moment caused by the out-plane loading. Moreover, it is found that adapting the conventional reinforcement of opening may result adversatively severe localization of stresses around the opening for the loaded opening greater than the case for the unloaded opening. Then, reducing the capacity and partial failure of the beam may occur.

For the beams strengthened by steel fibre reinforced concrete around the opening yielded improvements in the load carrying capacity, ductility and toughness ranged from (8-10)%, (2-5)% and (17-25)%, respectively, compared to specimen control specimens. Regarding the specimens strengthened by the crossed steel bar making a semi- rhombus shape around the opening yielded enhancement in the ultimate capacity, ductility and toughness ranged from (8.5-11)%, (0-2)% and (9-12)%, respectively, compared to beam control specimens. Furthermore, it was concluded that strengthening opening with jacketing by steel plates improved the load carrying capacity of beams, ductility and toughness ranged from (10.7-13)%, (2-8)% and (1-14)%, respectively, compared to specimen control specimens. Also, the technique of strengthening of openings with the WT-rolled steel recorded enhancement in the load capacity of beams, ductility and toughness ranged in (21-23)%, (2-8)% and (12-14)%, respectively, compared to specimen control specimens.

The present work may be extended to include several topics regarding the pocket beams without or with dapped ends as the effects of the cyclic and dynamic loads, elevated temperature and fire effects, location and number of pockets, size of the pockets, shear span-to-depth ration.

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