ENHANCEMENT OF THE BEHAVIOUR OF REINFORCED CONCRETE DAPPED END BEAMS INCLUDING SINGLE-POCKET LOADED BY A VERTICAL CONCENTRATED FORCE

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Abstract:

In precast building construction, some beams are designed to support one or several concentrated loads resulting from the reactions of the attached cross beams. Consequently, the pocket beams without or with dapped ends may represent one of the innovative solutions to constitute the joints between the two attached members. In the present research work, the behaviour of dapped end beams that included rectangular opening loaded with in-plane force, have been investigated. Several detailing have been proposed, in addition the vertical stirrups, to improve the strength of the opening region including the use of steel fibre concrete (SFC), Configuration of the inclined crossed bars, jacketing with steel plates and the composite section technique with two arrangements of the reinforcement of the dapped end. Ten specimens have been tested under gradually increased vertical static loading. The tested specimens are categorized into two sets based on the configuration of dapped end reinforcement. Two variable have been considered which are the strengthening configuration of the opening region and the configuration of the dapped end reinforcement. The response has been discussed in terms several indicators including, the cracking and failure loads, maximum deflection, mode of failure, load-deflection curves, crack patterns, crack width, to recognize the optimum strengthening proposal of the opening. Results revealed that using the inclined steel bars (modified arrangement) yield better response than the conventional (standard) reinforcement (vertical stirrups) within the dapped end. For beams with pockets strengthened with crossed inclined bars, failure load enhanced in range of (8.5-11%) whereas the enhancement was in ranged in (8-10%) for the steel SFC method. Moreover, an improvement by about (11-13%) in load capacity increased when the jacketing with steel plates was applied. The maximum improvement was obtained when using the embedded rolled section within the opening with values of (21-23%).

1 Introduction

In precast grid floor systems, beams may be designed to support one or series of concentrated loads that represent the reactions of attached crossbeams. Several configurations have been proposed to achieve the joint connection between the two beams, as shown in Figure 1. In some of such arrangements, the dapped ends are used to provide several merits, including improvement of the lateral stability of the beam by lowering its centre of gravity, better fabrication between the grid system and the floor topping, improving the rigidity and resistance to drift and reducing the total height of multi-storey building. The use of dapped end beams may

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affect the cost aspect of the precast buildings. Dapped ends are used also in half joints, precast wall, precast footings, stairs and stepped beams, etc. [1], [2]. The sudden change in the cross-section dimensions (re-entrant corner) of the dapped end may result in formation a severely disturbed region (D-region). Structural members may include more types of D-regions such as corbels, openings, corners, etc. at which a considerable disturbance of the contour lines of stresses may occur leading to severe concentration of stresses. D-regions represent potential regions to initiate failure. Therefore, many studies have been achieved in this regard and several mechanisms have been proposed based on the strut and tie model (STM) [3] or for limited cases (dapped ends and corbels) on the shear friction (PCI) method [4]. Figure 2 shows some of the D-regions as well as the regions of uniform flow of stresses (B-regions). Dapped ends were recognized to fail in one of several modes as shown in Figure 3. Mode that the dapped end may follow, depends mainly on shear span/effective depth (a/d) ratio and the internal detailing of the steel reinforcement as indicated in Table (1).

Figure 1. Some joints configurations in two crossed precast beams.

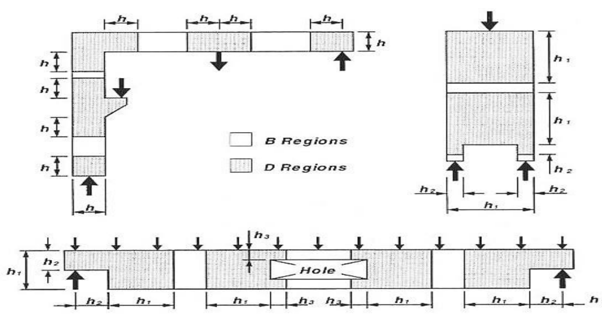


Figure 2. D-region and B-regions for RC members [5].

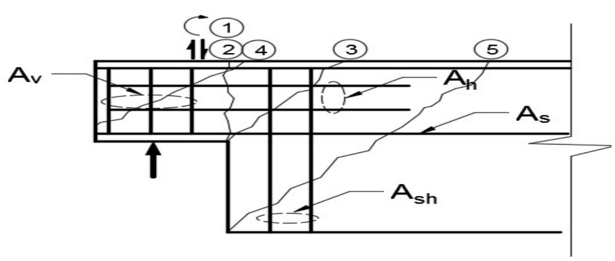


Figure 3. Modes of failure for DE [4].

Table 1. Modes of failure of dapped ends [4].*

Mode of failure (number and name)	Causes
1-Flexural (cantilever bending) Failure	Inadequate flexural + axial tension reinf.
2-Direct shear	Inadequate shear friction reinf.
3-Diagonal tension - re-entrant corner	Inadequate shear reinf.(Ash)
4-Diagonal tension - extended end	Inadequate shear reinf. (Ah+Av)
5-Diagonal tension - undapped portion	Inadequate development length beyond the potential crack

* Regarding deficient internal detailing only.

It may be observed that the mode of failure emanating from the re-entrant corner (Mode 3) is resisted by the hanger reinforcement. Some studies adopted the vertical (Standard) hanger reinforcement, others proposed the configuration of inclined steel bars. Regarding the first propoal, Mattock and Chan [6] proposed a simple design procedure for the dapped ends (DEs) that depended on the equilibrium on the planes of failure with considering the shear friction effect. Kumaraguru, 1992 [7] tested experimentally six beams with dapped ends to investigate the influence of (a/d) ratio on capacity of the dapped-end beams. Moreover, the capacity of the nib was evaluated using the PCI procedure. Test results revealed that the procedure of PCI design handbook overestimated the shear capacity.

The behavior of DEs with steel fiber concrete (f'c=60 MPa) and headed rods was investigated by Fu, 2004 [8] through testing two full-scale dapped end beams with four dapped ends. It was reported that the STM models can be used as practical tools to predict the capacities of members that included disturbed regions; the inclusion of steel fibers significantly improved the shear capacity, ductility and crack control. Furthermore, the headed rods may be considered as good anchorage and confinement of the nodal zones. 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 2012, Lu et. al. [10] considered the effect of several variables on the behavior of DEs through testing 24 RC dapped-end beams. Such variable included the effect of the compressive strength of concrete, a/d ratio and the horizontal load. Results revealed that the shear strength of DE increases with increasing the concrete strength and reducing a/d ratio and the value of the horizontal load. Oviedo et al., 2016 [11] proposed an optimal STM models based on a full optimization algorithm.

The validity of the proposed models was studied by comparison of test results of five specimens designed by the proposed models with those of four specimens designed using the conventional STM. It was reported that specimens based on the proposed models exhibit better structural performance in terms of crack growth, ductility, modes of failure and a load capacity. In 2019, Mohammed et al. [12] tested experimentally several full-scale DEs with two grades of engineered cementitious composites (ECC), namely 85 Mpa and 105 Mpa. It was recommended not to use the diagonal reinforcement as a full substitution for the hanger reinforcement. Because that, the bottom corner of the full-depth beam may experience severe damage due to the loss in confinement at an un-dapped zone. In a review study on dapped ends, Shakir [13] reported that some studies concluded that the prediction of the failure load using ACI-318-08 and PCI methods were more accurate compared to Euro Code2 and BS 8110 regulations. In 1983, Liem [14] adopted the inclined configuration of hanger reinforcement instead of the conventional vertical stirrups. Results revealed that capacity of DE reinforced by inclined bars with 45° was doubled compared to that with vertical stirrups. Wang, et al., 2005[15] adopted the inclined stirrups and longitudinal bent as the reinforcement of dapped ends. Results showed that the proposed arrangements of reinforcement are more effective on the shear capacity than vertical stirrups. Moreover, semi-empirical equations for shear strength have been derived based on the test results. The predicted results showed good agreement with the experimental ones. Falcón, 2019 [16] concluded that the orthogonal and inclined mechanisms which represent the configurations of reinforcement of the DEs are efficient to develop the full strength. Moreover, it was reported that the distribution of hanger reinforcement over several layers reduces the member's strength because of the increased span to-depth ratio, Desnerck, et al., 2016 [17] found that the specimen designed according to STM models failed at a load higher than the design load by 34.1%. Then, Desnerck, et al., 2018 [18] performed experiments on 12 half-joint beams considering the effects of several defects including inefficient internal detailing, lack in anchorage and initial damage at anchorage zone.

The inclined alignment was adopted in several studies to upgrade the deficiently reinforced dapped ends. Most studies emphasized that it is advantageous to use the inclined configuration if compared with other arrangements. Taher 2005 [19] used several techniques in upgrading the internal defects of the dapped ends. Amongst were the use of anchored inclined steel bolts and EB inclined CFRP stripping. Shakir et. al. [20] examined several strengthening configurations for the dapped ends using CFRP sheet. Such configurations included the inclined, horizontal and the combined arrangements. Shakir and Alliwe [21] adopted the NSM steel bars technique in strengthening inadequately reinforced 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 when passing duct underneath the beams. Consequently, D-regions may be induced at opening zone, that adversely affect the strength, stiffness, deflection response and cracking pattern of the beam [22], [23]. Several studies were conducted considering the strengthening of openings in the reinforced concrete beams. Suresh and Prabhavathy, 2014 [24] 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 of 4 mm thickness increased the load capacity by 50 to 110%. Shakir, 2016 [25] investigated theoretically the strengthening of large openings using partial and full jacketing strengthening of the opening. Allam, 2005 [26] used steel plate and the CFRP sheets. Chin, et al., 2011 [27], El-Maaddawy and El-Ariss, 2012 [28] strengthened openings with CFRP composites. Fawzy, 2015 [29] used externally epoxy-bonded steel strips plate and FRP sheets. Soman and Manju, 2017 [30] used BFRP and CFRP sheets. Morsy and Barima, 2019 [31] 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 disturbed regions (corbels) yielded good enhancements [32], [33], [34]. It is to be mentioned that the behaviour of dapped end is similar to the corbel [6]. Thus, it is adopted, in the present study, as one of the proposals to improve the performance of the severely loaded openings.

In some cases, web openings may be introduced in beams 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 Figure 4. Mercan et. al. 2012 [35] studied theoretically, the elastic response for slender rectangular pocket and spandrel beams. Hamad and Shakir, 2021[36], studied experimentally the behavior of self-compacting reinforced concrete beams with in-plane loaded openings that were strengthened by several techniques. The recorded enhancement in capacity ranged in 8-21%. Shakir and Hamad 2021 [37] investigated experimentally the behaviour of RC pocket beams with without or with dapped ends. It was reported that inclusion of the dapped ends within the pocket beams reduced the capacity in range of 9%–12%, and that the composite section proposal yielded the highest enhancements of 21% and 23% for the pocket beams without and with dapped ends respectively.

Figure 4. Pocket beam [35].

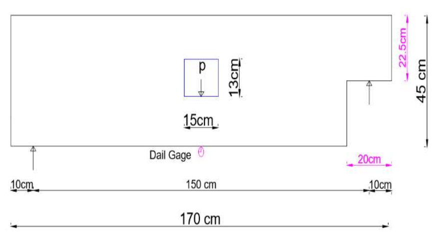
It can be seen that there is a scarcity of studies regarding the precast dapped end beams with heavily loaded openings. The current study aims to investigate experimentally the behaviour of such type of beams made of SCC concrete and to improve the knowledge in the area. Different strengthening techniques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

2 Experimental Program

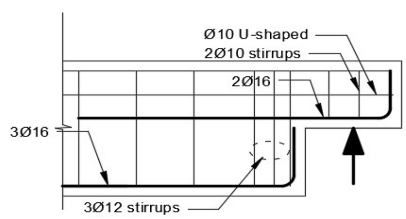
2.1 Details of Specimens

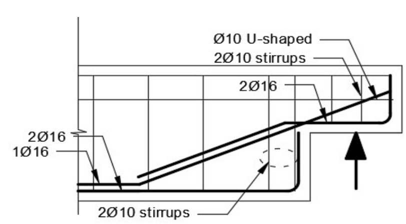
In the present research work, the behaviour of single-pocket beams with dapped ends have been investigated. Ten specimens were tested experimentally under a system of in-plane concentrated static loading within the openings. The overall length of a typical specimen was 170 cm with (c/c) span of 150 cm. The cross section dimensions were 17 cm in width and 45 cm in depth. Each of the tested specimens included rectangular openings at midspan of 15 cm × 13 cm. The dimensions of the recess end was 20 cm × 22.5 cm, Figure 5a. All specimens had shear span/overall depth ratio (a/h) of 1.0.The tested specimens are grouped into two sets according to the configuration of reinforcement of the dapped end with five specimens for each group, one control specimen, and four that are strengthened openings with different techniques.

The reinforcement of the dapped ends for Group (G1) represented the standard (vertical) hanger reinforcement and consisted of 3Ø12 mm @50 mm, Figure 5b. Whereas, that for the specimens of Group (G2) that represents the inclined arrangement consisted of 2#10 mm at 100 mm in addition to three bent bars of ø16 mm, Figure 5c. Two of such bars are the bent main steel nib reinforcement and one is the mid bar of the bottom steel of the undapped portion. The main tensile reinforcement of the beam consisted of 3Ø16 mm bars. Whereas, 2Ø10 bars are used at the compression face. 2Ø12 mm stirrups are used on each side of the opening. Ø10@150 mm bars are used as stirrups. 2Ø10 mm bars are used at top and bottom of opening as stirrups reinforcement. 2Ø16 mm bars used as main reinforcement at nib end. Figure. 5 shows the dimensions and details of reinforcement of typical beams, respectively. Also, specimen designations are listed in Table (2). Regarding the detailing at opening zone, the control specimen of each group included 2#10 mm as vertical stirrups on both sides of the opening. The other specimens are reinforced by several arrangements, which are using the inclined crossed bars, using steel fiber concrete, jacketing by steel plates and adopting the composites section with an embedded rolled steel within the bottom chord of the opening.



a) Dimensions of the pocket beams





b) Standard reinforcement of the dapped end *c) Modified reinforcement of the dapped end*

Figure 5. Dimensions and reinforcement of the control beam.

2.2 Materials properties

The constituent materials of the concrete mix used in the present study consisted of cement, fine and coarse aggregate, some additives, steel fibers and mixing water. Sulphate resistant Portland cement (C) type (V) provided from Karbala Cement Factory, Iraq, named (Al- Jesser). Cement has been tested physically and chemically to comply the requirement of the IQS 5/1984 specification [38]. The chemical and physical test results are listed in Tables (3) and (4), respectively. Washed and surface dried natural sand with grading indicated in Table (5) that is taken from Al-Najaf zone is used as fine aggregate (FA). Washed and dried surface coarse aggregate (CA) of Al-Nibaey region with maximum size 20 mm (for specimens with SFC at openings, the maximum size was 14 mm). Table (6) shows the test results of the sieve analysis of the coarse aggregate (IQS 45/1984) [39]. Clean water (W) is used for casting and curing the tested specimens. 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 increasing the amount of powder (cement + filler). Epsilon HP 580) [40] is used as a super plasticizer (SP) to produce a concrete with low water content and high workability. Samples of the steel bars of Ø10 mm, Ø12 mm and Ø16 mm diameters reinforcement are tested and the average of three samples per size are shown in Table (7). Moreover, samples of the rolled steel and the steel plates are tested to find their yield stress and tensile strength.

The tests of steel bars are achieved according to ASTM A615-4 [41]. While, for the rolled section and steel plate the tests are done based on ASTM E8/E8M − 16a [42]. Moreover, Micro steel fibres (Length=13 mm, diameter = 0.2 mm, tensile strength = 2600 MPa) are used in SFRC concrete in order to improve the shear strength, ductility and cracking resistance. Mix constituent materials are listed in Table (8).

Table 2. Designations of specimens test in the present work.

	Beam designation	Detail of opening strengthening
Group G1	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	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 3. Cement Chemical Analysis [38].

Oxide	Test result (%)	Limit(%)
CaO	61.64	---
SiO_2	19.89	----
Fe_2O_3	4.6	----
AL_2O_3	3.18	----
MgO	2.54	≤0.5
SO_3	2.04	≤2.5
C_3A	0.643	≤3.5
L.O.I	2.64	≤4
I.R.	0.8	≤1.5
L.S.F.	0.963	0.6-1.02

Table 4. Cement Physical Properties [38].

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	17.6	≥15
	7 days	26.9	≥23

2.3 Fresh and Hardened Concrete Tests

The tests of fresh concrete are checked to confirm that the concrete mix satisfies the requirements of the self-consolidating concrete (SCC). These tests are the Slump Flow and T500 tests that are performed to estimate the flow ability and the rate of the flow of the casted SCC. Testing was achieved according to ACI237R-07 [43]. While, J-ring test was carried out according to ASTM (C1621/C1621M) [44]. It is used to measure the passing ability of SCC mixture. Regarding the hardened concrete, cylinders with dimensions (100 mm × 200 mm) have been used to determine the compressive strength (f'c) [45]. Furthermore, cubes with dimensions (150 mm × 150 mm × 150 mm) have been used to find the cube compressive strength (Fcu) [46]. Three (100 × 200) mm cylinders are tested to find the splitting tensile strength (ft) [47]. Furthermore, cylinders with dimensions of (150 mm × 300 mm) are used to determine the modulus of elasticity (Ec) [48]. Results of the fresh and hardened concrete tests are depicted in Tables (8) & (9), respectivek.

Table 5. Grain size distribution of fine aggregate [39].

Sieve size (mm)	Acc. (%)	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)

Table 6. Grain size distribution of coarse aggregate [39].

Sieve size (mm)	Acc.% (Max. size=14 mm)	Acc.%(Max. size=20 mm)	Limits (%)
4.75	4	5	(0-10)
10	75*	42	(50-85)* / (30-60)
14	98		90-100)
20		96	(95-100)

Table 7. Properties of steel used in the present study.

Steel type	Yield stress(N/mm^2)	Ult. strength(N/ mm^2)
Bars #10 mm	576	674
Bars #12 mm	590	684
Bars #16 mm	600	693
Rolled steel	333	453
Steel plate	586	716

Table 8. 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
SFC	400	962	780	75	125	31%	6.8	1

Table 9. The results of the Test SCC.

Test	Results	Limits
Slump Flow (mm)[43]	615	(450-760)
T500 (sec)[43]	2.5	(3-5)
J-ring.(mm)[44]	36	(25-50)

Table 10. Results of the mechanical properties of SCC and SFC.

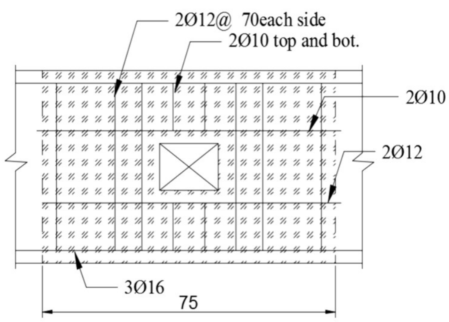
Type of mix	F_{cu}*(N/mm^2)	f_c'** (N/mm^2)	$f_t^{\#}$ (N/mm^2)	$E_c^{\ddagger}$(N/mm^2)
SCC	56	50	4.16	26315
SFC	61	58	4.7	33824

*BS 1881-116 1983[45] ** ASTM C39/ C39-15a[46]
#ASTM C496 /C496-11[47] ‡ASTM C469 / C469M-14[48]

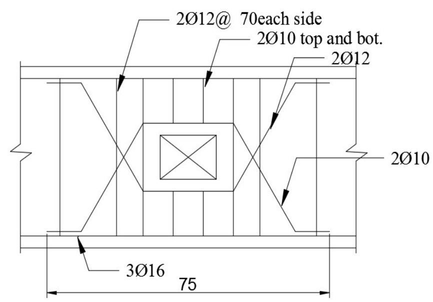
2.4 Strengthening Systems

Four strengthening proposals are used to improve the opening zone. They are:

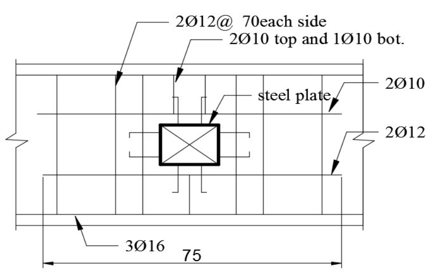
1. Using SFC within a distance of 275 mm on both side of the centre of the opening. Two mixers have been used for specimens with steel fiber concrete, one for each type of concrete. Steel plates have been fixed at 20 mm from each side of the opening before placement of concrete. The steel plates have some details to simplify removing from concrete Then, the two mixes are placed simultaneously to avoid movement of plates. The plate are removed gradually with advance of filling the forms. The use of SFC may result in more homogious concrete, better control on the cracking initiation and propagation, enhancing compressive, shear and tensile resistance Then, increase the loading capacity, toughness and ductility of traditional concrete.
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 2.85 mm thickness.The use of plate jacketing may improve the shear strength and cracking resistance at corners of the opening and provides better distribution of the concentrated force on the opening region.
4. Inclusion of WT-rolled section within the bottom chord of the opening. Then, shear and flexture resistance may be improved significantly. Moreover, better load transfer may be obtained. Also, the composite section may improve the rigidity of the opening region leading to reducing the midspan deflection of the dapped end pocket beams. Figure 6 shows the detailing of the various configurations. Also, Figure 7 shows the cage of steel reinforcement of the tested specimens.



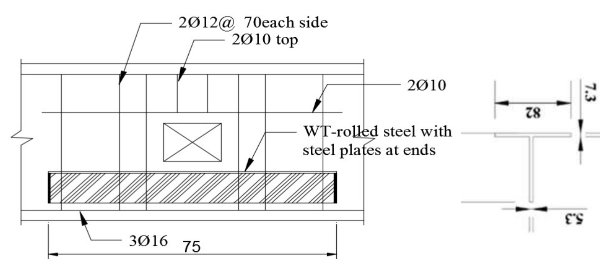
a) Steel fibre reinforced concrete



b) Cross inclined bars



c) Steel plate jacketing



d) WT-rolled steel in the bottom chord

Figure 6. Strengthening proposals for the opening region.

a) Group (1)

b) Group (2)

Figure 7. Reinforcement of Dapped end Beams with openings.

2.5 Testing Procedure

After a curing stage of 28 days, the specimens were painted with white colour so that cracks can be easily detected. The beams are positioned in the hydraulic machine. Rubber and steel plates, are used to prevent the local crushing concrete. Load steps are applied by 5 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 are traced. The test was carried out at laboratories of the Engineering Consulting Bureau of Kufa University using 2000 kN hydraulic testing machine. Figure 8a shows the testing machine, and Figure 8b shows a specimen under test.

a) *b)*

Figure 8. 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

The full map of cracking propagation at failure for the speciemn G1-CONT is depicted in Figure 9a. Taking a glance on the recorded values, it can be observed that the first cracking intiated at load level of 50 kN, within the bottom face of the beam at the midspan or exactly under the bottom chord of the opening. Based on equilbrum conditions, this region represents the location at which maximum bending moments occur. At the same time, the openings are severly disturbed regions where concentration of stresses occur at corners. At load of 60 kN, the first diagonal shear crack initiated at the re-entrant corner which in turns represents another D-region. The rapid propagation of stresses within the two D-regions may affect the general performance of the beam in terms of stiffness, load capacity, rigidity of the beam and resistance to defomations. This effect depends mainly on the detailing of the reinforcement at these regions and the adequacy of the reinfocement arrangement to transfer stresses to the less disturbed regions. Futher loading resulted in development the flextural crack vertically. At load of 55 kN, the first cracking initiated at the opening corners. Such cracking developed diagonally due to the interaction between the maximum bending moment with the maximum shear force. More cracks formed at both sides of opening, continued to widen, and propagated toward the top compression zone. It can be seen that the portion ABCD of the beam which represent the directly loaded part, tends to act as a beam supported by the vertical stirrups (crossing the diagonal crack) at both sides. Moreover, it is clear that few cracks developed at the top chord because that most of the energy of the beam at opening is disspated by the cracks developed at the bottom chord. Due to the tensile resistance of the vertical stirups, more cracking developed around the opening. At 300 kN, horizontal cracks initiated at mid-depth of the opening that acted to split the beam horizontally, revealing that the opening reinforcement is inadequate to accomamudate and transfer stresses from the loaded opening to other parts of the specimen. Regarding the re-entrant corner, the first cracking after being initited, it developed digonally with progressive loading. More cracks developed between the two D-regions (dapped end and opening) due to the increased cruvature resulting from the deteriorated strength at both D-regions. Thus, it can be concluded that providing efficient resistance against the diagonal cracking and the horizontal splitting at opening may improve the general behavior of the beam and significant enhancement in load capaciy and reducition in the rate of deflection may 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.

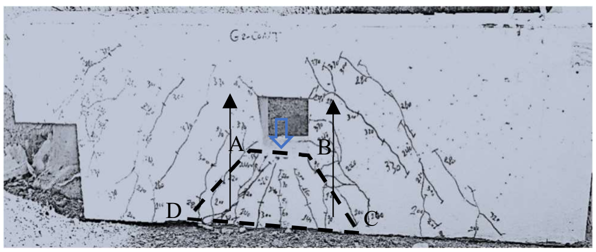
The beam failed at load 330 kN, following a failure mode of diagonal shear. The first proposal to improve the performance of the opening region is using the SFC as discussed in Sec. 2.4. The cracking pattern of the specimen G1-FIB is shown in Figure 9b. First cracking initiated at the re-entrant corner of dapped end within a load of 65 kN. It is expected that the steel fibers improved the bridging action between the two sides of the crack, and consequently, improving the load transfer to more parts of concrete on both sides of the opening. Then, a better stress redistribution in the specimen occured preventing the localization of failure caused by the concentration of stresses within the opening region. Comparing with G1-CONT, more intensity of cracks may be noticed at the opening zone and far sides of opening. 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 content (1%) at opening region was not enough to develop the required strength for the pocket beams. Regarding the dapped end, it can be observed the cracking development from the re-entrant corner is similar to the mode of the direct shear. This may be attributed to the improved strength within opening compared to spacimen G1-CONT and relatively small shear span-to-depth of nib end (a/h) value. It is clear that the detailing of the dapped end is effcient to control the development of damage at this region. The specimen failed at a load of 356 kN with diagonal shear at corners of the opening, recording an enhancement of about 8% compared to the control beam. Based on the defect of the first proposal of strengthening, another method has been considered, which included the use of inclind bars configuration (or crossed bars). This arrangement aimed to improve the stress transfer at opening region and to strengthen the corners.

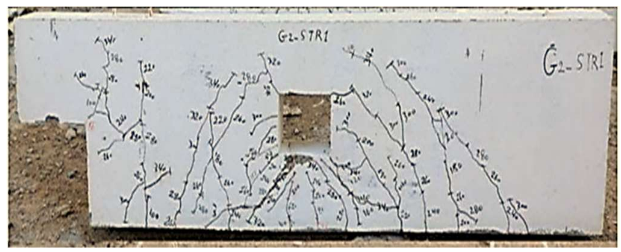
The deailing of this cofiguration G1-cross is depicted in Figure 6b, while Figure 9c shows the cracking pattern. Here, the first crack initiated at the opening zone (as in specimen G1-CONT) as a flexural crack at 55 kN. At a load level of 67 kN, the crack initiated at the re-entrant corner and developed as a diagonal crack with angle of about 45^{o}. When the load reached 358 kN, the beam failed at opening by diagonal cracking i.e. the ultimate load increased about 9% compared to the control beam. It can be observed that the the diagonal legs restricted the widening of the diagonal cracks emanting from the corners of the opening to some limits. Also, the inclind bars acted to connect the top and bottom layers of the beam as in the vertical stirrups. Then, it resist the tendency for horizontal separation. Moreover, It can be seen that the downward inclined steel bars are ineffective in resisting the applied load and diagonal cracking. Then, it may not contribute in enhancing the strength of the pocket beams because that most of cracking developed parallel to the inclined legs. However, these legs resist crack widening at the top corners of the opening. It is to be mentioned that the NSM steel bars with semi-rhombus configuration may be adopted when the function of opening was changed from being unloaded to be loaded. Other techniques as using steel fibers, plate jacketing, and composite section method may not be used with the hardened concrete.

The third proposal to improve the strength of the opening region includes jacketing the interior faces of the opening by steel plates as detailed in Sec. 2.4 The map of cracking propagation of specimen G1-PLT is shown in Figure 9d. It is expected that the shear connectors on both sides of the opening and the top chord constitute the machinsim of load transfer to both sides of the opening. Also, the steel plate controlled the development of the diagonal crack from the corner of the opening. The same scenario as in the control specimen, the first crack is initiated at mid span as a flexural crack (at a load of 58 kN) followed by development of the daigonal crack at a load 65 kN, from the re-intrant corner of the dapped end. At a load level of 365 kN, the beam fully damaged with diagonal shear at the opening. i.e. improvement in ultimate capacity by 10.6% was recorded. It is expected that using more embedded length for shear connectors may enhance the effeciency of stress transfer. In addition, It can be seen that some localization of cracking occured referring to a weak transfer of stresses than the beam G1-FIB. However, the jacketing resulted in more capacity than using the steel fiber concrete or the inclinde bars. This may be due to the better distributuion of load on the plate and the effect on controlling the crack initiation from the corners besides the incroporation of more concrete portion in resistance by the shear connectors.

The last proposal that has been studied in the present work was adopting the composite section concept by embedding a WT-shaped rolled section within the bottom chord of the opening. The detialing of the model are indicated in Fig. 6d. It is well known that the composite section has several advantages compared to both the reinfoced concrete and the rolled steel sections separately. Such metrits include increased strength for a given cross sectional dimension, gearter resistance to impact loads, depth and weight of steel beam required is reduced, higher stiffness, less deflection and wider openings may be included. Figure 9e depicts the map of cracking propagation of specimen G1-TEE. The first crack initiated as a flexural crack at the opening region within a load level of 65 kN. The first crack developed diagonally at the re-entrant corner at a load 70 kN, and extended with an angle of 45^{o}. With progress in load, more cracks developed at both D-regions. However, the vertical development of cracking and widening (around the opening) is restricted by the high stiffness and rigidity of the composite section. Consequently, More cracks developed horizontally and more volume of concrete may contribute in resisting the concentrated load. It is to be mentioned that the emnhancement in rigidity resulted in reducing the deflection and curvature values. The beam failed by the diagonal shear mode at the dapped end with a load of 405 kN recording increment of about 23%. Compared to specimens G1-CONT, G1-FIB, it is obvious that incorporating the rolled steel shifted the mode of failure from diagonal shear failure at corners of opening to diagonal shear at the dapped end with crushing of the compression zone. It can be seen that due to the inceased strength of the opening region, an increase in the rate of propagation of cracks at the opening region 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.



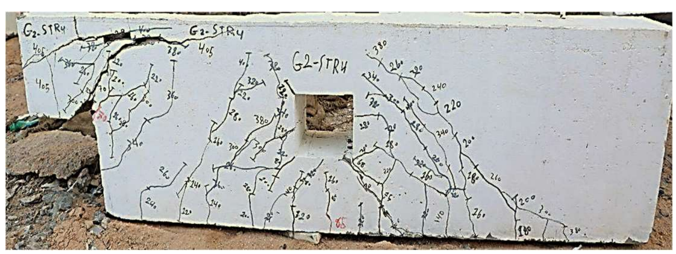
a) Specimen G1-CONT



b) Specimen G1-FIB

c) Specimen G1-cross

d) Specimen G1-PLT



e) Specimen G1-TEE

Figure 9. Crack pattern of the specimens of group G1

For the tested specimens, it is clear that the cracking at the dapped end resulted in more curvature of the beam. Then, more stresses induced 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, higher stiffness at opening against excessive curvature was produced. Thus, higher failure load of 405 kN has been recorded. The capacity of the pocket beams may be improved by reducing the shear and tension effect at the opening and vertical tension at the dapped region by applying prestressing technique. This technique was used by Nanni and Huang [49] and Botros [50] to improve the performance of the dapped end beams without openings. It may be adopted for beams having several pockets without serious reduction in performance.

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

The test results of the speciemens of Group G1 revealed that the first cracking at the dapped end initiated within a load level slightlly more than that when the first cracking occur at the opening region.Thus, the detailing of reinforcement at the dapped end may control the capacity of the whole beam regardless the strength enhancement at the opening region. Moreover, it is aimed to reduce the cost of production of the dapped end and elemeinate the detailing of reinforcement with maintaining the capacity without severe drop. The modfied arrangement is based on using the inclined bars instead of the vertical stirrups. The required reinforcement may be provioded by bending the nib main tensile reinforcemnt down by a suitable angle to extend through the dapped end region to the undapped portion beyond the path of Crack 5 in Figure.3. If more bars are needed, some of the tensile reinforcement of the undapped portion may be bent to extend though the dapped end region to the extended end.

The proposed arrangement may eleminate the need for the hanger reinfocement significantly and making use of the main flextural steel of the dapped end undapped portions without any deficiency in preformance. Figure 10a shows the history of crack propagation of the specimen G2-CONT. The first flexural crack has been recognized within the opening region at a load 55 kN. At slightly more load (65 kN), the diagonal shear crack appeared at the re-entrant corner and developed with angle about 45º. With futher loading, more cracks developed horizontally within the body of concrete. The cracks at the bottom corners of the opening continued to propagate until causing the failure of the specimen at a load 355 kN as a diagonal crack penterated the bottom chord and causing separation form the body of the beam. It can be seen that specimen G2-CONT accomudated higher load than specimen G1-CONT. Also, the intensity and concentration of cracks at the top chord of the opening and at the dapped end region are more. It can be explored that the bent bar yielded improvement in performance of the dap end rather than using vertical stirrups. Figure 10b displays the crack pattern for specimen G2-FIB which incroprated the SFC within the opening region and the modified model of dapped end reinforcement.

The first crack initiated as a flextural crack at a load 65 kN at opening region. When the applied load reached 70 kN, the diagonal shear crack appeared at the re-entrant corner with an increment about 8% compared to control beam G2-CONT. With progress in loading, the cracks widened and propagated towards the top chord of opening. Failure occurred by diagonal shear at the bottom chord of the opening at 390 kN. The results indicated that using SFC improved the ultimate load about 10% compared to control beam. It can be observed that the intensity of cracks formed at both sides of the opening and that oriented diagonally to the top chord more than specimen without steel fibers (G2-CONT). This may be attributed to the advantage of the using steel fibres in improving the capacity of stress transfer. Hence, assisted in preventing the localization of stresses and then improved the general performance of the beam. For the specimen that includes the use of inclined bars arrangement in both the dapped end and opening regions.

The crack patterns for the specimen G2-cross is shown in Figure 10c. As in most tested specimens, the first crack initiated as flextural crack within the bottom chord of the opening at 55kN. The first crack at the re-enterant corner initiated at a load of 68 kN. The specimen failed by diagonal cracking at the bottom chord of the opening recording a maximum load of 393 kN with increments of about 11% more than the control specimen. It is clear that the rate of cracking is reduced at both sides of opening and the dapped end region when compared to specimens G2-CONT and G2-FIB. Because that the inclined legs restrained the intensity and rate of widening of cracks. Moreover, the use of bent bars improved the performance of the dapped end and yielded high resisting for loading.

The crack pattern for the specimen G2-PLT is shown in Figure 10d. The first crack has been recognized at load 60 kN at opening region as a flexural crack with slight improvement in cracking load of about 9% compared to the control beam. The diagonal shear crack developed at the corner of opening at load 65 kN. While the diagonal shear crack intiated from the re-entrant corner at load 70 kN and extended with angle about 45º. The specimen failed by a diagonal shear mode at the bottom chord recording a failure load of 402 kN. i.e. increment of about 13% relative to the specimen G2-CONT. Also, it can be seen that the number of cracks propagated within the nib zone and opening region was lower than control beam and beam with SFC at the opening .Then, some localization of stresses at opening occurred. This refers to less efficient transfer of stresses provided by steel plates. This may be attributed to the shear connectors that may need to be embedded more distance on both sides of the openeing.

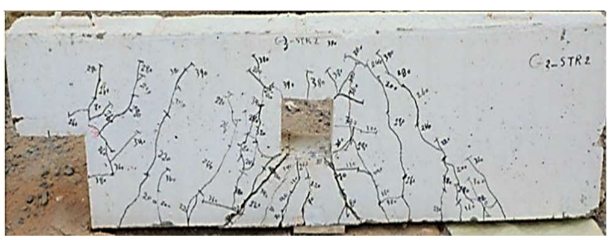
For specimen G1-TEE, it was obtained that the test terminated with diagonal cracking emanted from the re-entrant corner.Thus, the modified reinfocement improved the strength of the dapped end region and, higher loads may be accomudated.

The crack pattern for specimen G2-TEE is depicted in Figure 10e. It can be seen that the first crack deveoped as usual, at mid span of the beam (opening region) at load level of 65 kN. The diagonal shear crack initiated at 70 kN at bottom corners of the opening. At load 75 kN, the first crack appeared at the re-entrant corner. The specimen failed at a load level of 431 KN by diagonal shear crack at 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 developed vertically towards the compression face and some crushing occured at the top chord.

This may be attributed to that the steel section improved stiffness 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. It is expected that making the stirrups to be perpendicular with the crack orientation may improve the loading capacity. It is obvious that the cracking pattern and the mode of failure are different for specimen G2-TEE when compared to specimens G2-cross and G2-PLT. It is clear that the failure occured either because of exhausing strength of the rolled section or that some slip occured between the rolled section and concrete due to the exessive damage of concrete. Then, the test is terminated with the same mode as the specimens of Group 2. It can be seen that the intensity and concentration of cracks at dapped end zone for specimen G2-TEE is lower than specimen G1- TEE. This is attributed to the fact that G2-TEE includes the bent bar yielded better performance of the beam.

a) Specimen G2-CONT

b) Specimen G2-FIB

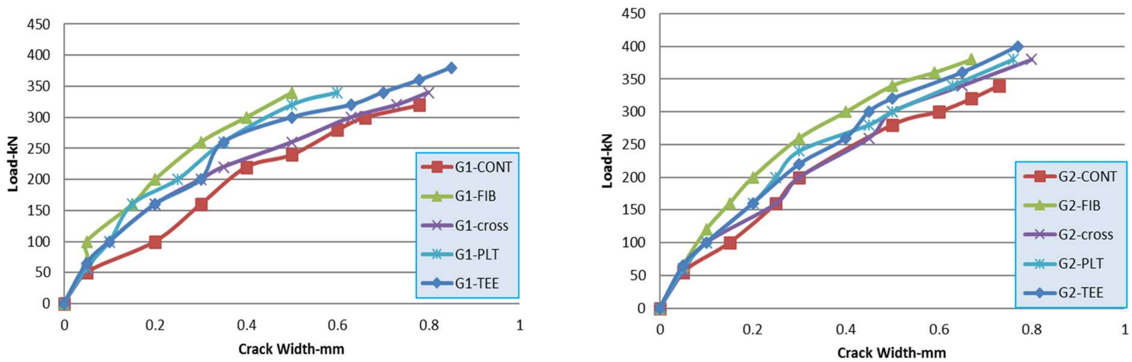


c) Specimen G2-cross

d) Specimen G2-PLT

e) Specimen G1-TEE

Figure 10. Crack pattern of the specimens of group G1.



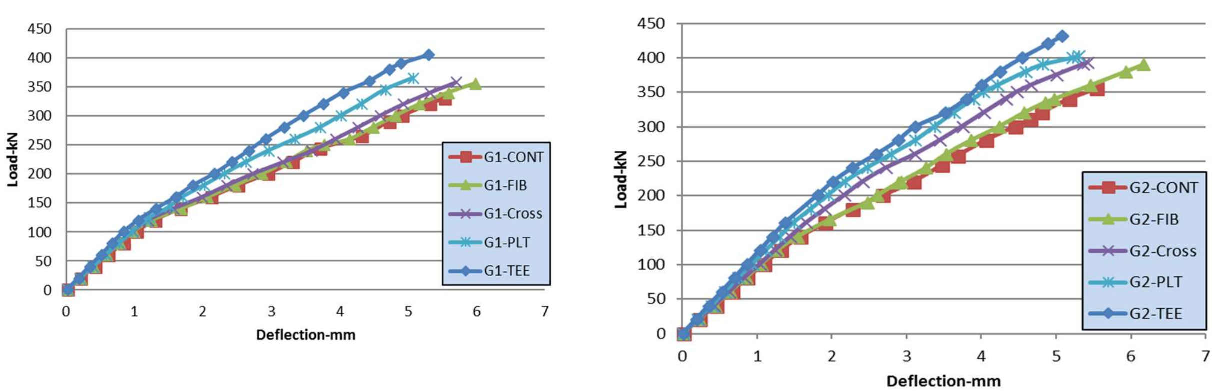
a) *b)*

Figure 11. History of cracking development (a) Group 1 (b) Group 2.

Figure 11 shows the rate of widening of the first crack for the two groups. It is obvious that the specimens with SFC at opening yielded the smallest crack width. Thus, it is expected that combining the composite section with the SFC may enhance the response considerably. Moreover, it can be seen that the use of inclined bars (G1-cross) and (G2-cross) yielded the highest values of crack width.

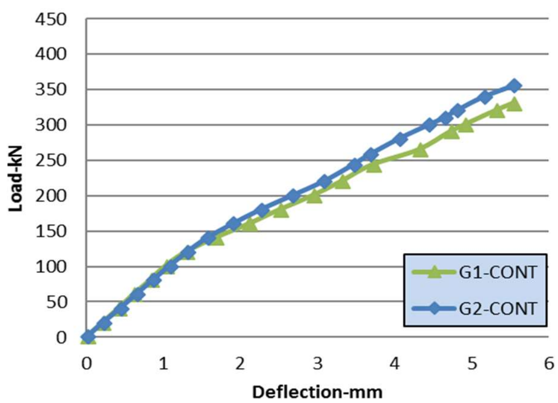
3.2 Load–Midspan Deflection

Figure 12 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. 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.

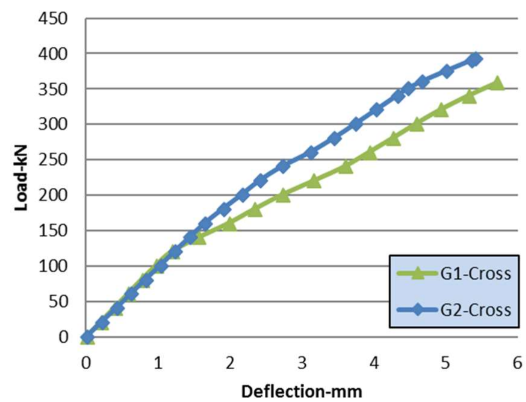


a) Group G1 *b) Group G2*

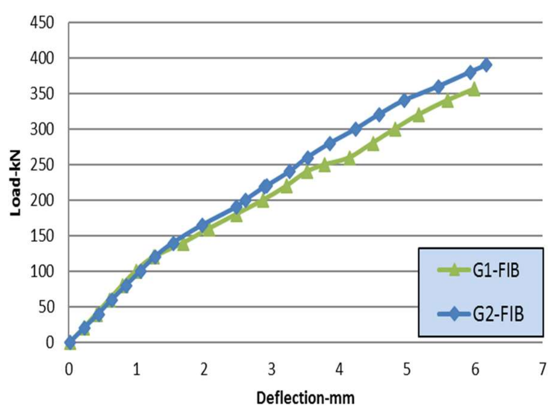
Figure 12. Load-deflection curves of the two groups.



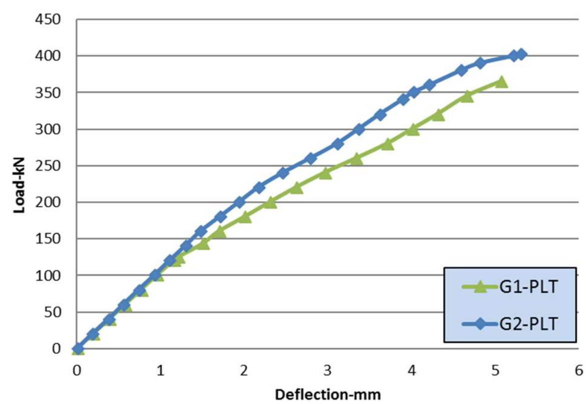
a) Control specimens



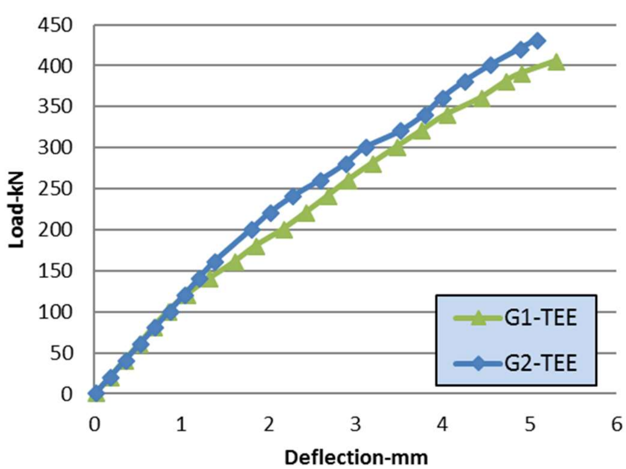
b) Specimens strengthened with crossed bars



c) Specimens with steel fibers concrete



d) Specimens strengthened with plates



e) Specimens strengthened with rolled steel

Figure 13. Comparisons of the load-deflection curves of the respective specimens of the two groups.

Figure 13 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.

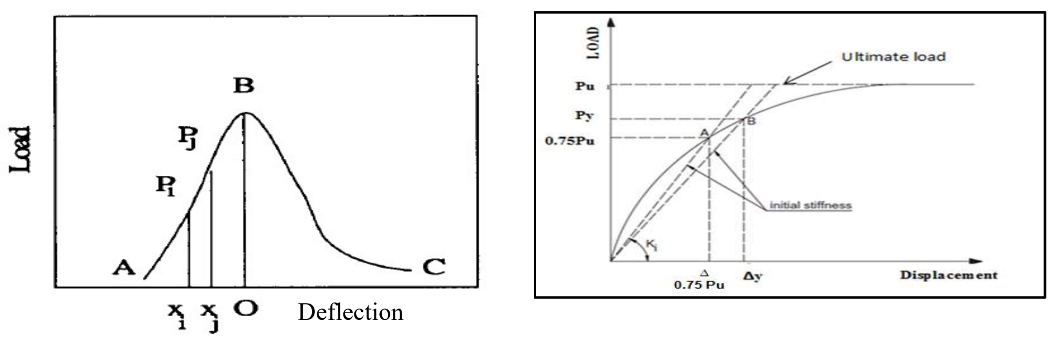
3.3 Toughness and ductility

Toughness is the ability of a material to absorb energy and plastically deform without fracturing. The flextural toughness equals to the area under load-deflection curve [51], as shown in Figure 14a. The ductility is defined as, the ability to resist inelastic deformation without a reduction in ultimate load until failure [52]. The flextural toughness and ductility index are calculated from equations (1) and (2), respectively:

$$T = \sum \frac{(P_i + P_j)}{2} * (x_j - x_i) \quad (1)$$

$$\mu_\Delta = \frac{\Delta_u}{\Delta_y} \quad (2)$$

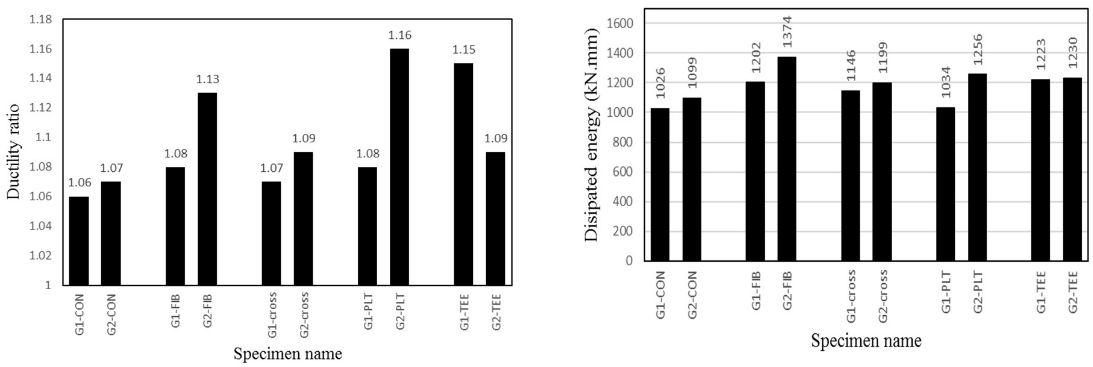
$\mu\Delta$: Ductility index; Δu: deflection at ultimate load; Δy: that represent the deflection corresponding to load level of (0.75 Pu), Figure 14b.
Figure 15a shows the ductility and toughness for the two groups. It can be seen that for all of the specimens, except those with composite section at the bottom chord, the specimen with modified dapped reinforcement gained higher ductility compared to the respective specimen in group G1. The reduction in ductility for specimen G2-Tee may be attributed that the failure is shifted to the dapped end while for all other specimens failure occurred at opening.



a) Flexural Toughness *b) Ductility index*

Figure 14. Definitions of flexural toughness and Ductility index.

Figure 15b shows the toughness values of the two groups,it can be seen that the specimen from a specimen in group G2 yielded higher or at least equal to that of the respective specimen of the first croup.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)*

Figure 15. Ductility and toughness results of the tested specimen a) ductility b) toughness.

4 Conclusion

The main conclusions that have been obtained will be summarized in the following points: -

1. The general mode of failure for the pocket beams loaded with a vertical force was diagonal shear failure at the opening region. However, For the pockets strengthened by the WT-rolled steel the failure was shifted to be as a diagonal shear emanting from the re-entrant corner of the dapped end.

2. 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 the control specimens.

3. 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 control beam specimens.

4.The strengthening the 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, relative to the coressponding control specimens.

5.The technique of strengthening 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 the control specimens.

6. It can be observed that the modified arrangement of reinfocement of the dapped ends contributed in production of beams with higher load capacity. Moreover, more economic detailing has been obtained. i.e. the hanger reinforcement was reduced by 53%

7. Based on the PCI method of shear-friction, a modified shear-friction equations may be proposed to design the opening region, taking into account the bending moment at junction between the chords of the opening with the solid part of the beam.

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