Effect of Flange Openings on T-Section Beams Performance

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Abstract

Providing an opening in beam makes cracks surrounded the opening due to stress concentration. In this study an experimental works conducted to study the behavior of reinforced HSC T-shaped beams with flange opening in bending zone. This paper shows the behavior of RC beam with opening un-strengthened by additional reinforcement. In this experimental study three beams were casted, one rectangular beam and one T-beam without opening as a reference

beam and the remaining beam was provided with one rectangular flange opening 180×360 mm at middle section. These beams were tested under one-point loading. The effect of flange opening was studied in terms of ultimate failure load, maximum deflection and failure mode. From the test results, it could be concluded that the ultimate load carrying capacity of the RC T-shaped beam with flange opening at flexural zone was reduced by about 2.30%. As well, the cracking load was reduced by about 2.94%.

Keywords: T-shaped Beams, flange openings, flexural strength.

1. Introduction

Utility pipes and ducts are necessary to accommodate essential services in a building. The types of services include air-conditioning, power supply, telephone line, computer network, sewerage and water supply. It has been practiced that pipes and ducts are usually hanged below the floor beams and covered by a suspended ceiling for its aesthetic purpose. These openings can be of different shapes and sizes as circular, square or rectangular [1]. Several studies on the probability of using the concrete flange effect on flexural and shear strength were performed. They concluded that the concrete flange of T-shaped beams contributes to increase the ultimate shear and flexural strength compared to rectangular beams that have the same web dimensions [2-4]. Researchers also found that the flange reinforcement and the dimensions affect the flexural and shear strength of the T-beams greatly, and the ductility improved with the change in the width of the flange [5]. Based on previous researches , it is clear how the flange impact enhances the behavior of the beam. The presence of an opening in the flange of a reinforced concrete beam leads to many problems in the beam behavior such as reduction in the beam stiffness, excessive cracking, excessive deflection and reduction in the beam strength [6-8]. Furthermore, sudden change in the dimension of cross section of the beam leaded to high stress concentration at the corners of opening that may lead to cracking unacceptable from aesthetic and durability viewpoints. The reduced stiffness of the beam may also give rise to excessive deflection under service load and result in a considerable redistribution of internal forces and moments.

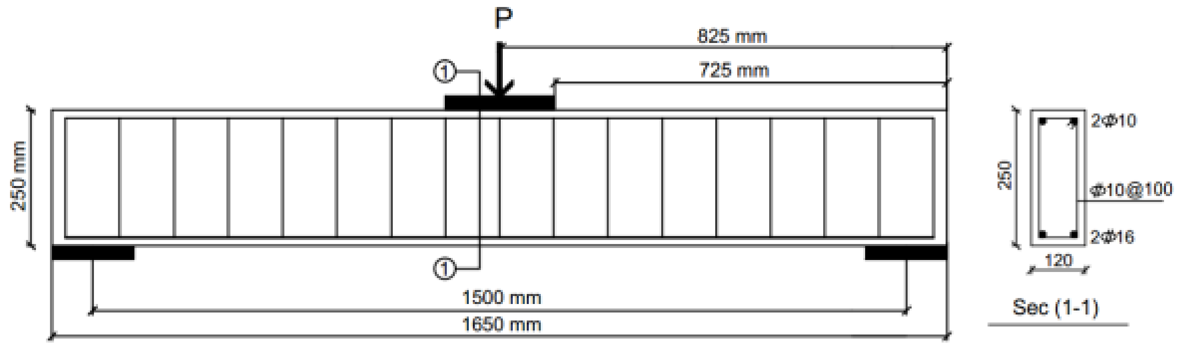
2. Experimental Program

2.1 Specimen Details

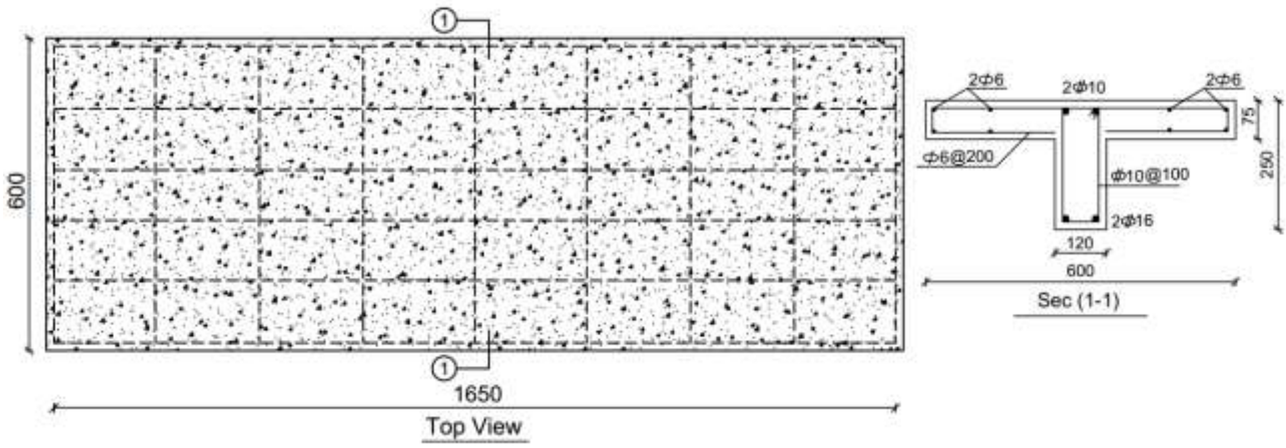
The objective of this program was to study the effect of the flange and the flange opening, on the beam flexural behavior under static loading. A total of three HSC beams with reinforcement ratio =1.5%, divided into one rectangular beam as a reference beam and T-beam without openings and the remaining beam was provided with one rectangular flange opening 180×360 mm at middle section were casted and tested in this experimental program. The dimensions of the tested beams were 1650 mm long, with a clear span (distance between supports) of 1500 mm and 250 mm total thickness, 120 mm web width and slab (75 mm thickness and 600 mm width). To focus on the flexural strength behavior of the beams and reduce the shear contributions, the shear span-depth (a/d) =3 [9]. The details of the tested beams are shown in Table 1 and Fig. 1.

Table 1 Layout of beams specimens

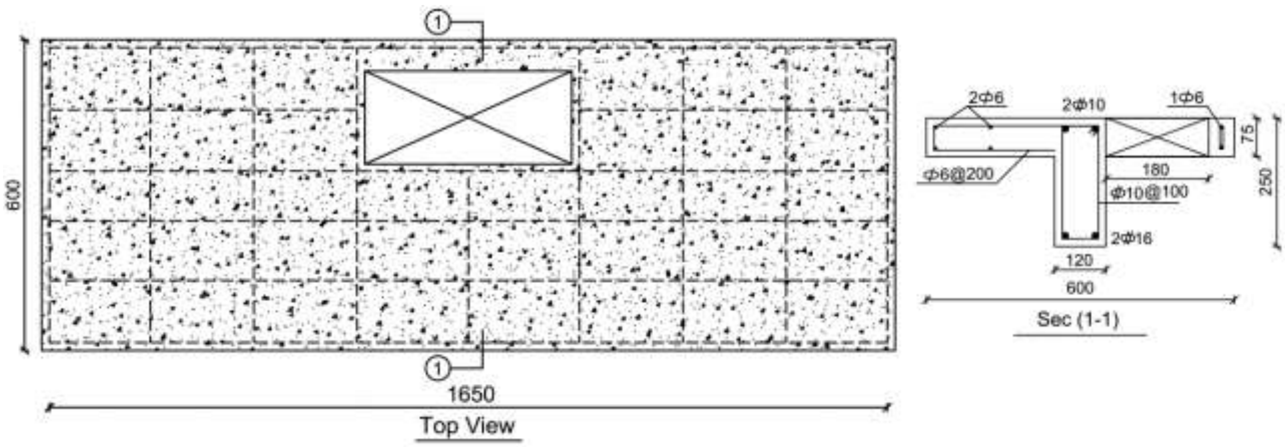
Beam	Dimensions (mm)	Opening a (mm)	Opening b (mm)	Bottom Reinforcement (As)	Top Reinforcement (As')	Stirrups
R-1.5	Web 120×250	-----	-----			
T-1.5		-----	-----	2Φ16	2Φ10	10Φ10/m
TS-1.5	Flange 75×600	180	360			



(a) Beam (R-1.5)



(b) Beam (T-1.5)



(c) Beam (TS-1.5)

Fig. 1. Details of the Experimental Specimens (unit. mm)

2.2 Materials

In manufactured of the test specimens, Table 2 presented the details of the concrete mix design. The used coarse aggregate was gravel with maximum size of 10 mm. The coarse and fine aggregate were mixed together to achieve well graded aggregate. Ordinary Portland cement from Al Arish factory was used which matched with the specifications of the Egyptian Code ECP [10] (203-2017). Ten percent by weight of the Portland cement was substituted by silica fume to increase the concrete strength and produce the target concrete compressive strength 56 Mpa. A superplasticizer (Type G) was used to enhance the workability of the concrete mix due to using a very low water/cementitious ratio, under the commercial name of (Sikament ®- R 2004). The specimens were casted in wooden forms and three standard cubes 150×150×150 mm and two cylinders 150×300 mm were prepared for each batch to test the strength of the beams.

Two types of steel reinforcement were used in manufactured beams for this work. For transverse reinforcement of diameters (6 mm), mild steel (characteristic yield strength of 240 Mpa), were used for slab reinforcement, see Fig. 1. While for the main longitudinal reinforcement bars of diameters (10 mm and 16 mm), high grade steel (characteristic yield strength of 400 Mpa), were used. Reinforcement of each diameter were exposed to direct tension testing to obtain the actual mechanical properties for instance ultimate strength and yield strength are reported in Table 3.

Table 2 Mix Design Proportions (Constituents and Mix Proportions, Kg/m^3)

Cement	Coarse Aggregate	Fine Aggregate	Silica Fume	Water	Superplasticizer
550	1050	677	55	160	11 Liter/m^3

Table 3 Mechanical properties of tested reinforcement and specification

Property	Specification*		Tested	
Grade	24/35	40/60	24/35	40/60
Shape	plain	deformed	plain	deformed
Yield stress (N/mm^2)	Min 240	Min 400	311	542
Ultimate stress (N/mm^2)	Min 350	Min 600	429	710

2.3 Instrumentation and Test Setup

After preparing the test setup and before loading, zero loading of steel strain and vertical concrete displacements were recorded and checked. Three dial gauges were used to measure vertical deflection of the beams. The first one was located at the middle of the span and others at distance 375 mm from the supports. The beam was tested as a single point loading system using a hydraulic jack attached to the loading frame as shown in Fig. 2. The beams have been tested at ages of 28-days. The beam specimens were placed on the testing machine and adjusted so that the centerline, supports, point load and dial gauges were in their correct location. Loading was applied slowly, at the end of each load increment, the crack initiation, path and tip were outlined after the load had become steady, using a marker. The load was applied gradually with constant rate of loading during the test. The readings of measurements devices were recorded in paper sheet at every increment of load recorded by load cell. The cracking load was recorded once the first crack noticed. The crack pattern development was recorded after each load increment.

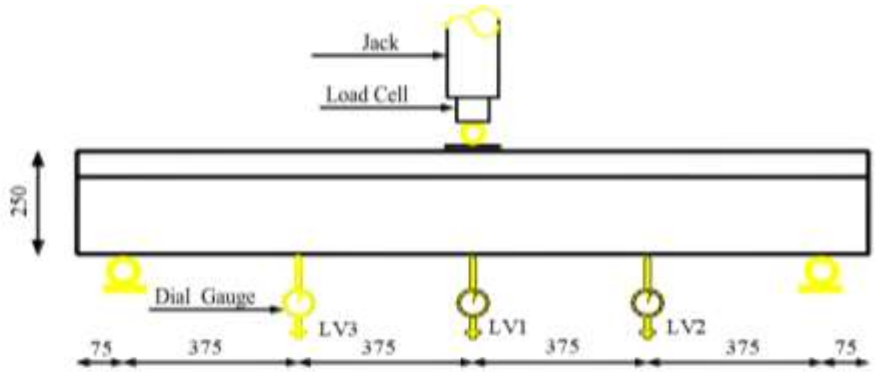


Fig.2 Test Setup

3. Experimental Results

3.1 Crack Pattern and Mode of Failure

3.1.1 Effect of Flange on T-section Behavior

Fig. 3 shows the crack patterns of the tested beams. All beams failed in flexure as they were designed. For beams (R-1.5) and (T-1.5), the earliest flexural cracks, for both beams, developed in the pure moment zone perpendicular to the direction of the maximum principal stress induced by pure flexure. Then, as the load increased, the flexural cracks extended upward and were very close to the top surface of the rectangular beam, while for T-beam, the flexural cracks continued from the web to the bottom of the flange without crushing the flange till beam failure. Finally, it noted that flanges in T-beam resulted in a concentration of the cracks in the flexural region and increasing the shear cracks, but the mode failure did not change, and it is still a flexural failure. As well, raising the value of first crack load by 24.20%. The results presented in this section concluded by You et al., (2017) [11].

3.1.2. Effect of Flange Opening on T-section Behavior with μ = 1.5%

Fig. 3 shows the cracking patterns for beams (T-1.5) and (TS-1.5) after failure. All beams failed in flexure as they were designed. The first cracks started at the constant moment region and continued to propagate as the applied load was increased. Cracks then started to appear outside of the constant moment region. At high load levels no more flexural cracks were formed, but the existing cracks continued to widen as the beams increasingly deflected, and a few diagonal flexural shear cracks started in the shear regions. Prior failure; the cracks continued from the web to the flange without crushing the flange till beam failure, crushing of the concrete near the positions of applied loads had occurred due to high concentrated stresses under load and presence of weak locations in the flange (openings). Finally, It was noted that decreasing the flange width (openings) resulted in an increase in the cracks spacing, decrease in the number of the cracks in the flexural region, but the failure mode is still flexure.

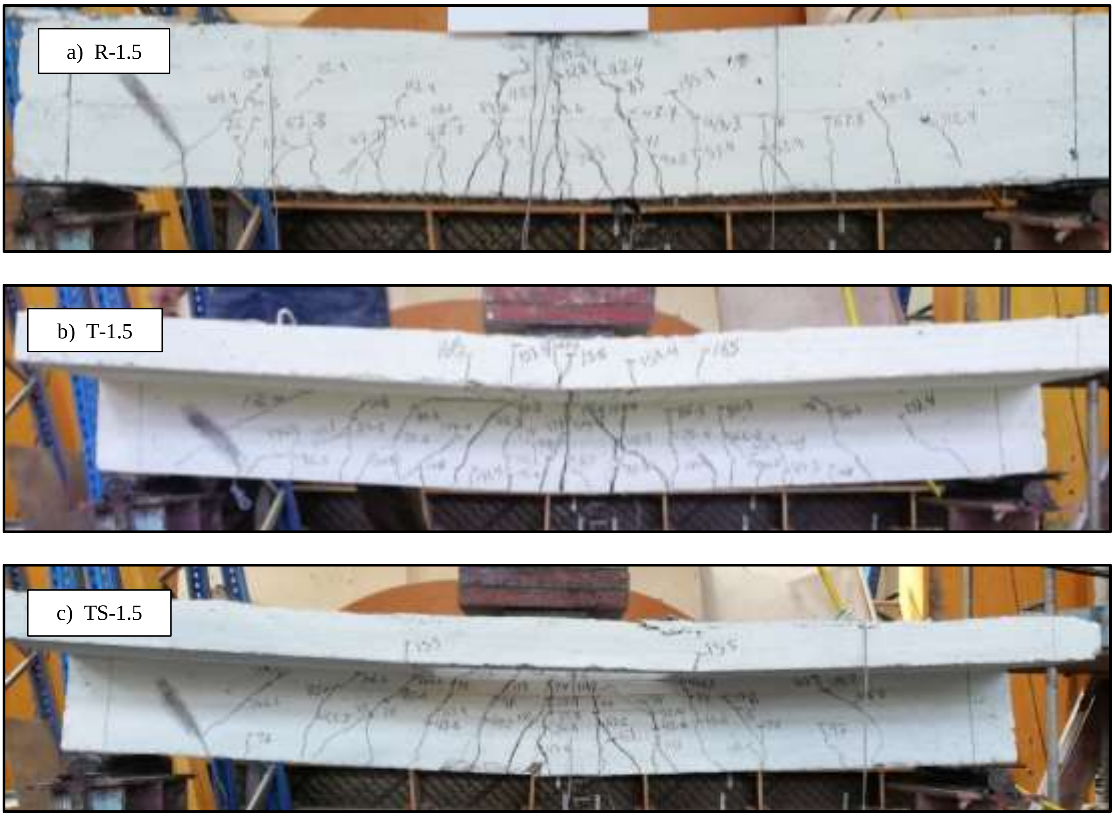


Fig.3 Crack Pattern of Tested beams

3.2 Load-Deflection Relationship

Table 4 shows the load and corresponding deflection at first cracking, yielding and ultimate load, while Fig. 4 and Fig.5 show the deflection load curves at mid-span of all tested beams.

Table 4 Experimental Results of Tested Beams

Specimen Label	Cracking Stage		Yield Stage		Failure Stage		Ductility Calculated
	P_{cr} (kN)	Δ_{cr} (mm)	P_y (kN)	Δ_y (mm)	P_{max} (kN)	Δ_{max} (mm)	µd (%)
R-1.5	35.30	1.51	118.86	7.09	138.75	15.21	2.15
T-1.5	43.84	1.16	136.23	6.53	173.31	18.13	2.78
TS-1.5	42.55	1.37	133.49	6.67	169.74	17.87	2.68

3.2.1 Effect of Flange on T-section Behavior

Fig. 4 shows that flanges in T-beams led to an increase in the ultimate load of the tested beams, and a reduction of the overall deflection. The ultimate load for the rectangular beam (R-1.5) was 138.75 KN at a maximum deflection 15.21 mm, while the overall deflection for the T-beam (T-1.5) was 5.4 mm (less than half of the maximum deflection of R-beam) only under the same load. The increasing in the ultimate load of T-beam (T-1.5) was 24.90% over that of the R-beam (R-1.5). Finally, flanges in T-beams led to a general improvement of the flexural behavior of studied beams as reflected by increase in the ultimate load capacity and reduction in overall deflection. This agrees with Halicka and Jabonski (2016) [12] in their study of MSC composite T-beams.

3.2.2 Effect of Flange Opening on T-section Behavior with µ = 1.5%

As shown in Fig. 5, at the beginning, all curves were identical and the tested beams exhibited linear behavior and the initial change of slope of the load-deflection curves occurred between (42 KN to 44 KN), which may be indicated the first crack loads. Beyond the first crack loading, the load-deflection responses were followed by another linear behavior with a reduction in the beam stiffness due to the formation of more cracks until the yielding of tension reinforcement occurred. The latter event was associated with a considerable reduction in the beam stiffness. Behavior of reference T-Beam (T-1.5) exhibited greater loads and deflections in comparison with the other beams. This beam had the greatest stiffness due to absent of openings in flange.

At ultimate stage, it was found that slight decrease in ultimate load and increase in deflection for beams (TS-1.5) was observed by comparing with (T-1.5). Therefore, the ultimate load decreased by about 2.06% and deflection decreased by about 1.43% for beam (TS-1.5). At maximum allowable deflection stage (Δ_{max}= 6mm), it was observed that presence one opening, (TS-1.5), led to reduce the applied load for by about 0.63% than the control beam (T-1.5). This is may be due to presence of openings which lead to decreasing of beam stiffness and as a result, slight decreases in the applied load and increases in deflection take place.

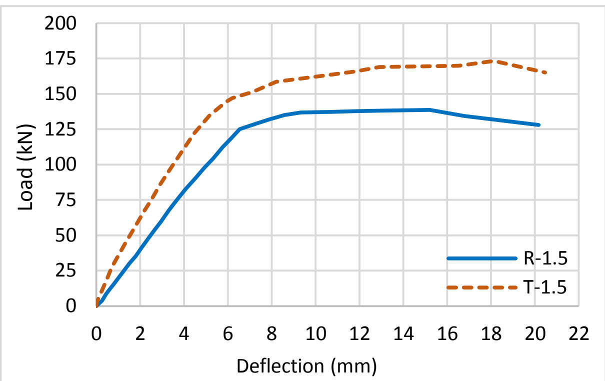


Fig. 4 load-deflection curves for Control Beams

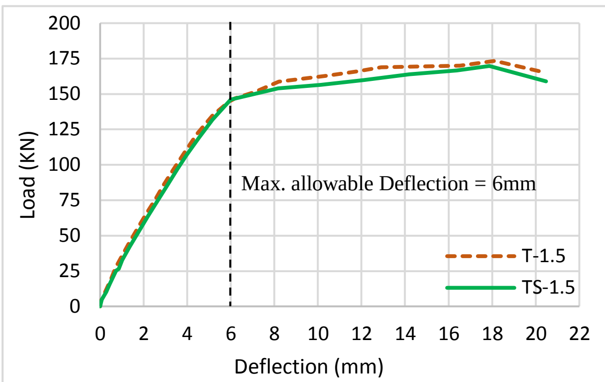


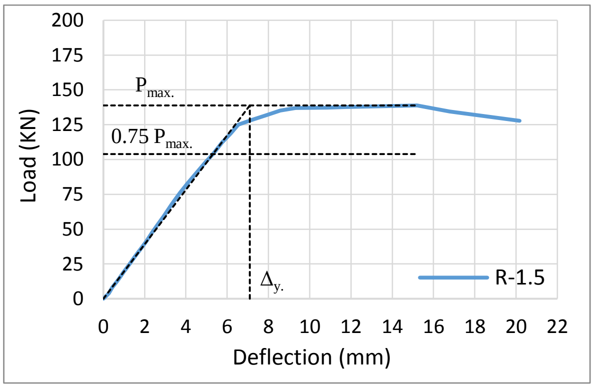
Fig. 5 load-deflection curves of Beams with µ = 1.5%

3.3 Ductility

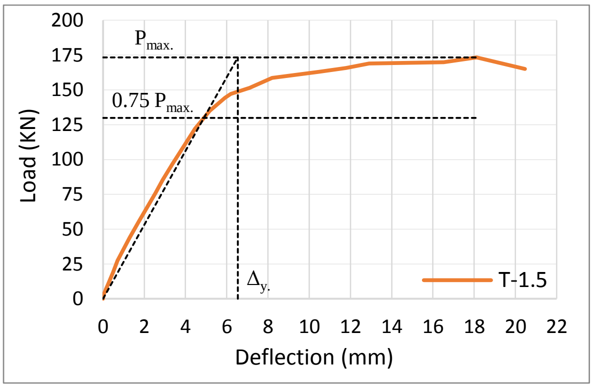
Ductility is a desirable structural property because it allows stress redistribution and provides warning of impending failure. It is defined as the ability of a material to deform plastically before fracturing [13]. In this research, Deflection Ductility Index μ_d, was explored, which is defined as the ratio between the maximum deflection to the deflection at the yielding load using the Eq. (1) [14]. Table 4 shows the Deflection Ductility Index μ_d results for the tested beams.

$$\text{Ductility Index } (\mu_d) = \frac{\Delta_{max}}{\Delta_y} \tag{1}$$

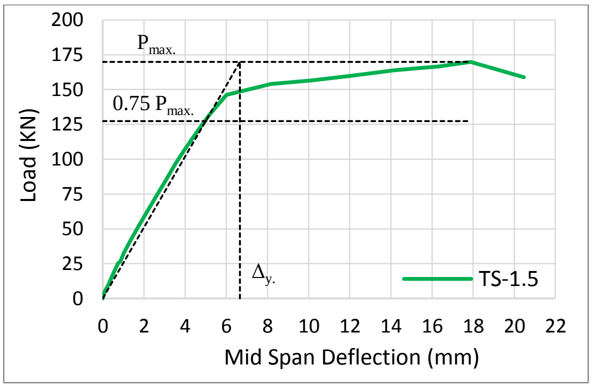
where Δ_{max} is the deflection at the maximum load; Δ_y is the deflection at the yielding of tensile reinforcement (calculated as shown in Fig. 6).



(a) Beam (R-1.5)



(b) Beam (T-1.5)



(c) Beam (TS-1.5)

Fig. 6 Yield Deflection of the Tested Beams

3.3.1 Effect of Flange on T-section Behavior

Fig. 7 shows that flanges in T-beams led to an enhancement of the ductility of the tested beams. For example, flanges led to increasing the ductility by 29.30% compared to the beam (R-1.5). Finally, flanges in T-beams led to a general improvement of the ductility behavior of studied beams as reflected by increase in the energy absorbed and total deflection occurred until failure. This agrees with Anas Yosefani (2018) [15] in his study about beams that contain high-strength reinforcement and high-grade concrete.

3.3.2 Effect of Flange Opening on T-section Behavior with μ = 1.5%

Fig. 7 illustrates the ductility indices of HSC beams (T-1.5 and TS-1.5) with the same main reinforcement ratio and various locations of slab openings. The slab openings had no considerable influence on the ductility for reinforced HSC beams with the main reinforcement ratio 1.5% where, the ductility decreased by 3.60% for beam (TS-1.5) compared to the beam (T-1.5).

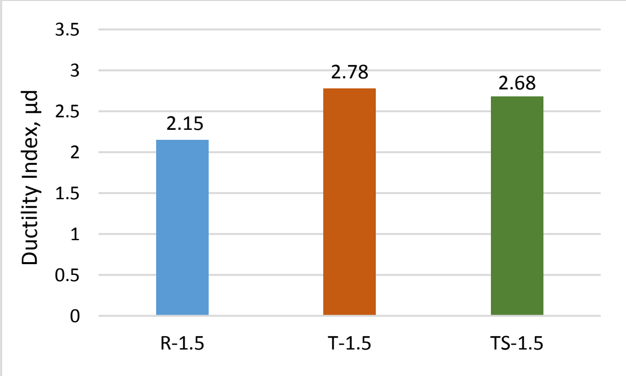


Fig. 7 Deflection Ductility Index, μ_d

3.4 Concrete Strain

3.4.1 Effect of Flange on T-section Behavior

Fig. 8 shows the relation between deflection at mid-span and concrete compressive strain for beams (R-1.5) and (T-1.5). At ultimate stage, it was found that the concrete compressive strain, increased with increasing the applied load and all beams failed at a concrete compressive strain ranging from 900 to 1554 µε. By studying at maximum deflection stage, it was found that the beams reached to compressive strain ranging 583 to 1489 µε which higher than their strains at the first cracking load by 235.9% and 187.2 %for the beams (R-1.5), (T-1.5), respectively. Generally, Flanges in T-beams led to a reduction of the maximum concrete strain by 42.08% than the rectangular beam. This agrees with Thamrin et al., (2016) [16] who included the effect of flange in his model for predicting the shear-flexural strength of slender reinforced concrete T-beams which confirms that the flange of T sections significantly decreases the strain quantity in the compression zone. Consequently, the tensile strain of reinforcement in T-sections are higher than tensile strain in rectangular sections.

3.4.2 Effect of Flange Opening on T-section Behavior with µ = 1.5%

Fig. 9 shows the relation between deflection at mid-span and concrete compressive strain for beams (T-1.5) and (TS-1.5). At ultimate stage, it was found that the concrete compressive strain, increased with increasing the applied load and all beams failed at a concrete compressive strain ranging from 900 to 1154 µε. By studying at service stage, it was found that the beams reached to compressive strain ranging 583 to 1132 µε which higher than their strains at the first cracking load by 187.2 % and 231.34% for the beams (T-1.5) and (TS-1.5) respectively. Generally, Flange openings in T-beams led to an increase of the maximum concrete strain by 24.49% than the control T-beam.

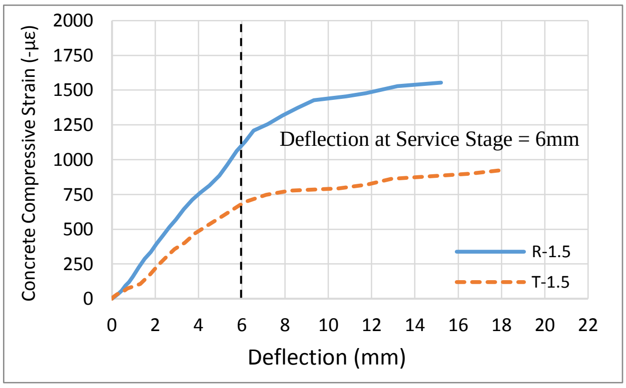


Fig. 8 Concrete Compressive Strain-Deflection curves for Control Beams

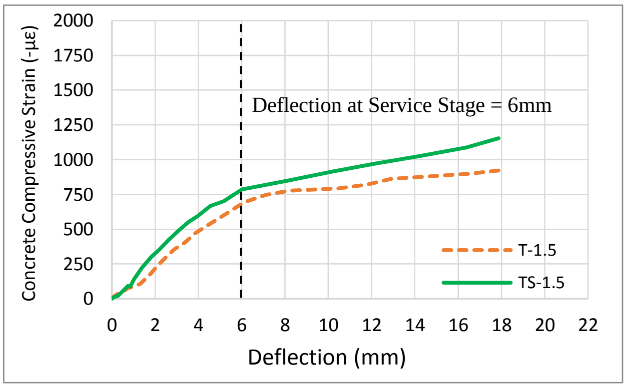


Fig. 9 Concrete Compressive Strain-Deflection curves for beams with µ = 1.5%

4. Conclusion

This research studied the experimental behavior and flexural strength of HSC T-beams with and without slab openings. The following conclusions were drawn based on this study:

1. Flanges in T-beams led to a general improvement of the flexural behavior of studied beams as reflected by increase in the ultimate load capacity (about 25%) and reduction in overall deflection.

2. For tested beam with single slab opening, (TS-1.5), the ultimate flexural strength was decreased by about 2.30% in comparison with solid T-beam. Presence of opening lead to concentrated stresses around the opening and caused decreasing in the load carrying capacity. This evidence shows the contribution of flanges to increase the ultimate flexural capacity of T-Beams in comparison with rectangular sections.

3. Flanges in T-beam resulted in a concentration of the cracks in the flexural region and increasing the shear cracks, but the mode failure did not change, and it is still a flexural failure. As well, raising the value of first crack load by 24.20%.

4. Decreasing the effective flange width (openings) resulted in an increase in the cracks spacing, decrease in the number of the cracks in the flexural region, but the failure mode is still flexure.

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