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Shear Strength and Behavior of Reinforced Concrete T-Beam with Openings in Both Web and Flange

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Abstract

The main objective of this research is to study the shear strength and behavior of reinforced concrete T-beam with openings in the web and flanges. The effect of number and location of openings on the shear strength and behavior of the beams is compared with theoretical equations. The experimental program includes casting and testing of thirteen reinforced concrete T-beams, one of which was cast without any openings, while, the others were cast with openings in the web and/or the flanges under mid span point load. The specimens have constant cross section, with 350 mm flange width, 70 mm flange thickness, 150 mm width of the web, 350 mm over all depth of the beam, and 1800 mm clear span. For all the beams the span and steel reinforcements were kept constant. Variables in this study are the location and number of 50mm diameter openings at distance d=300 mm, and 2d=600 mm from the edge of the beams in both the web and/or the flanges. Experimental results showed that, opening in the webs at distance (d) from supports are more effective on the strength decreasing value of the T-beams than others with an opening in the flange at the same distance from the supports. Beams with one opening in webs and/or flanges at distance (d) from supports are more effective on the strength decreasing value of the T-beams than others with two and four openings in the webs and flanges at distance (2d) from the supports. The presence of the web openings at distance (d) from supports reduces the shear capacity about (30.67% to 33.33%) in comparison with control beam, and about (6.67% to 9.33%) for beams with web opening at distance (2d) from the supports. The presence of flange openings at distance (d) from supports reduces the shear capacity about (17.33% to 30.67%) in comparison with control beam, and about (9.33% to 22.67%) for beams with flange opening at distance (2d) from the supports. Beams with opening in both flanges and webs, the presence of openings at distance (d) from supports reduces the shear capacity about (22.67% to 28%) in comparison with control beam, and about (6.67% to 12%) for beams with openings at distance (2d) from the supports.

Introduction

In the slab-beam-girder structure system, the beams are usually built monolithically with the slab. Hence, the portion of concrete slab, effectively connected together with a beam, can be considered as the flange projecting from each side of the beam. At the same time, the part of the beam at the bottom of the slab is working as the web of T-shaped beam or simply T- beams. In the construction of modern buildings, a network of pipes and ducts is necessary to accommodate essential services like water supply, sewage, air-conditioning, electricity, telephone, and computer network. Passing these services required creating openings in web and/or Flanges of T-beams after or before construction. It is obvious that inclusion of openings in beams alters the simple beam behavior to a more complex one. An abrupt change in the sectional configuration 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.

Experimental Study

Experimental Program

The experimental program includes casting and testing of thirteen reinforced concrete T-beams with opening in both the web and the flanges under central point load in the structural laboratory. The specimens were T- shape in cross section, for all the beams span and steel reinforcements were kept constant. The main variables in this study are the location and number of 50 mm diameter openings in both the web and the flanges.

Specimen Details

All specimens had a constant T- shape cross section of [Length (L) = 2000 mm, width of flange (bf) = 350 mm, depth of the flange (hf) = 70 mm, width of the web (bw) = 150 mm, total depth of the beam (h) = 350 mm]. Figure. (1) shows an overview of dimensions with the layout of reinforcement for all beams,

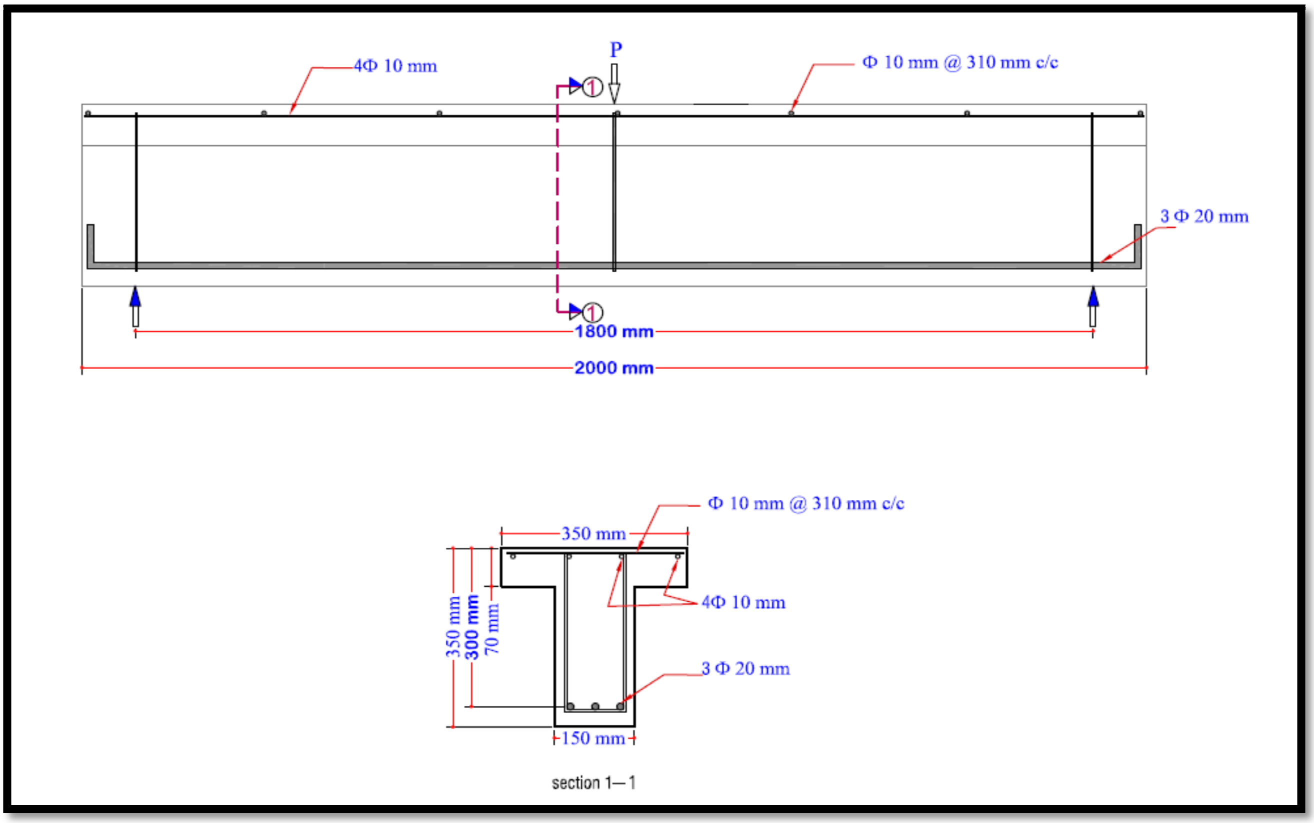


Figure 1. Detail of reinforcement and dimensions of beams

Variables:

Location and number of openings of 50 mm diameter were variables taken to study their effects on shear strength and behavior of reinforced concrete T-beam of constant cross section under a central point loads and as follows:

Twelve reinforced concrete T- beams were cast with openings in different location of flange and webs, and control beam was cast without any opening as shown in Table (1) and Figure. (2)

Table (1) number and location of openings in flange and webs

No.	Sig.	Number and distance of opening in web from edge of beam	Number and distance of opening in flange from edge of beam
1	A0	No opening (control beam)	No
2	A1	One opening, 700 mm	No
3	A2	One opening, 400 mm	No

4	A3	Two openings from each side, 700 mm	No
5	A4	Two openings from each side, 400 mm	No
6	A5	No	One opening, 700 mm
7	A6	No	One opening, 400 mm
8	A7	No	Two openings from each side opposite direction, 700 mm
9	A8	No	Two openings from each side opposite direction, 400 mm
10	A9	One opening, 700 mm	One opening, 700 mm
11	A10	One opening, 400 mm	One opening, 400 mm
12	A11	Two openings from each side, 700 mm	Two openings from each side opposite direction, 700 mm
13	A12	Two openings from each side, 400 mm	Two openings from each side opposite direction, 400 mm

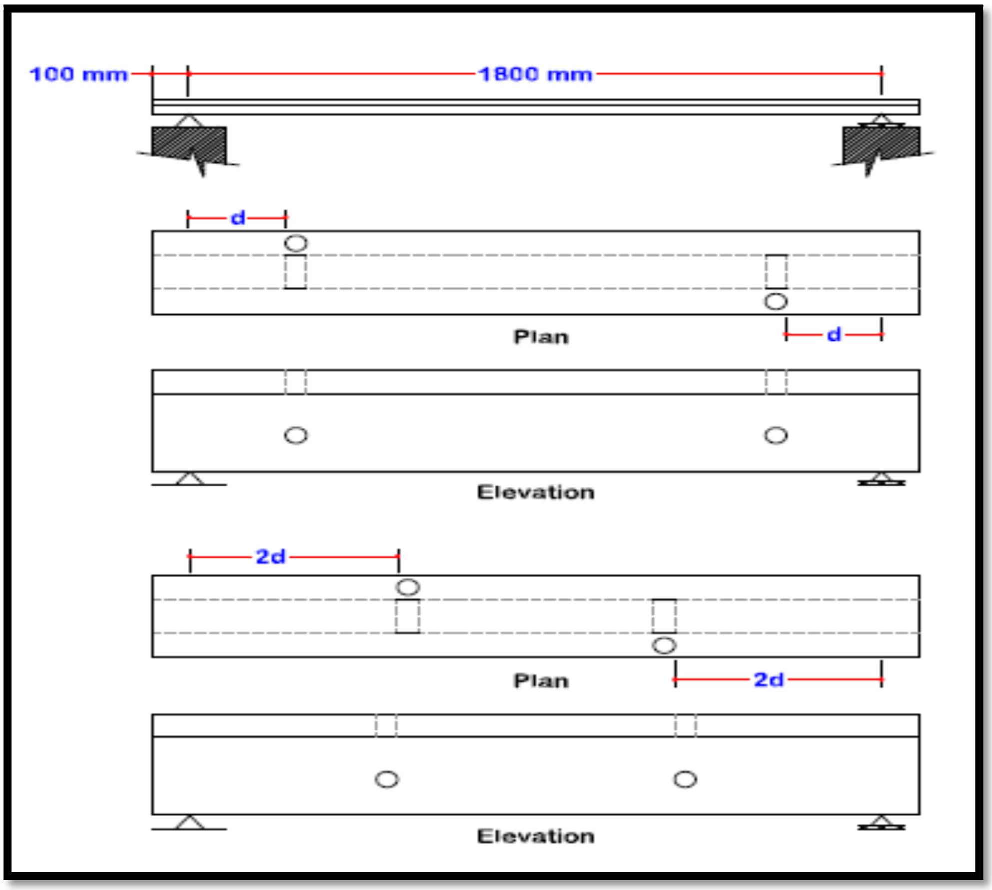


Figure 2. Number and location of openings in flange and web

Materials

The materials used in this study; are cement (Ordinary Portland Cement) Tasluja type, natural Darbandikhan sand as fine aggregate, natural Gravel from Darbandikhan with 12.5 mm maximum size as coarse aggregate, tap water was used for washing of materials, mixing, and curing of concrete, and reinforcement bars deformed steel bars with nominal diameter of 20 mm were used as flexural reinforcement, and deformed steel bars with nominal diameter of 10mm were used as temperature and shrinkage reinforcement placed at the top of the beam. Table (2) shows the properties of steel reinforcement bars, Table (3) shows the properties of concrete.

Table (2) Properties of steel reinforcement bars.

No.	Bar dia. (mm)	Yield strength, F_y, MPa	Ultimate strength fu, MPa	Elongation (mm/mm)
1	20	620	727	14.2 %
2	10	550	671	11 %

Table (3) properties of concrete

Group	Beam Sign.	Mix proportion by weight	W/C	f_{cu} MPa	f'_c MPa	f_{sp} MPa
1	A0	1 : 2.27 : 2.86	0.5	38.2	30.56	2.943
1	A5	1 : 2.27 : 2.86	0.5	38.2	30.56	2.943
1	A6	1 : 2.27 : 2.86	0.5	38.2	30.56	2.943
1	A8	1 : 2.27 : 2.86	0.5	38.2	30.56	2.943
2	A1	1 : 2.27 : 2.86	0.5	37.6	30.08	2.907
2	A2	1 : 2.27 : 2.86	0.5	37.6	30.08	2.907
2	A3	1 : 2.27 : 2.86	0.5	37.6	30.08	2.907
2	A7	1 : 2.27 : 2.86	0.5	37.6	30.08	2.907
3	A9	1 : 2.27 : 2.86	0.5	36.65	29.32	2.846
3	A10	1 : 2.27 : 2.86	0.5	36.65	29.32	2.846
3	A12	1 : 2.27 : 2.86	0.5	36.65	29.32	2.846
4	A4	1 : 2.27 : 2.86	0.5	37.5	30	2.893
4	A11	1 : 2.27 : 2.86	0.5	37.5	30	2.893
			Average	37.55	30.04	2.902

Casting of concrete

The moulds of four beam were placed on a level surface and oiled, then the reinforcement cage was placed in the mould and fixed in such a way that no movement occurred during casting and vibrating. One of the beams was cast without any opening (control beam) and the other beams were cast with opening in webs and/or flanges as mentioned in Table (1), befor casting procedure, plastic pipes with exterior diameter of 50 mm were placed in the required opening position inside the moulds.

Measurement and Instruments

All thirteen reinforced concrete T-beams were tested using hydrolic jack with a capacity of 500 KN, deflection was measured at mid span of the beam using digital dial gauge with an accuracy of 0.001 mm, and electronical method was used for measuring concrete strain by using Linear Variable Displacement Transducers (LVDT) with accuracy 0.001 mm.

Testing Procedure

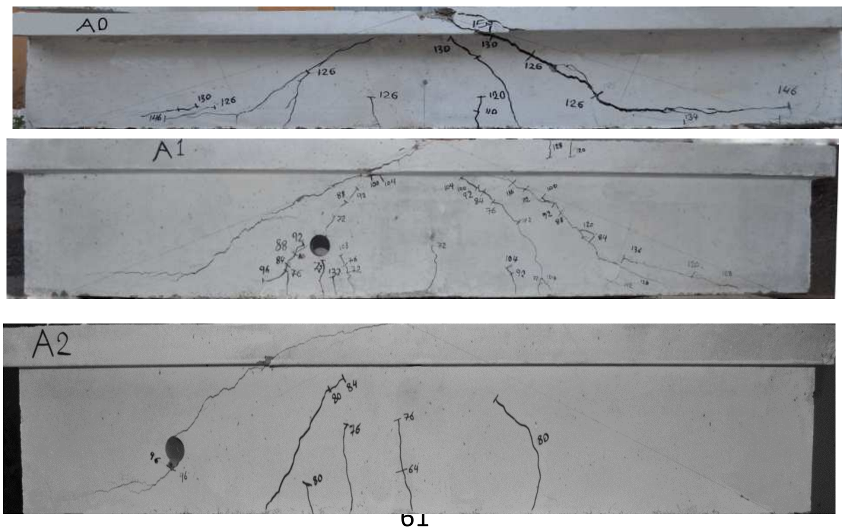
All beams were tested as simply supported beam and loaded by a single point load at mid span. Mid span dial gauge for reading deflection and (LVDT)s reading for concrete strains were recorded for zero load, and then the load was applied incrementally at range of 4kN. For each interval, all readings were carried out and recorded, Also the crack development was marked on one side of the beam. For each beam the first flexural crack and shear crack load were recorded, the procedure continued till the beam failure.

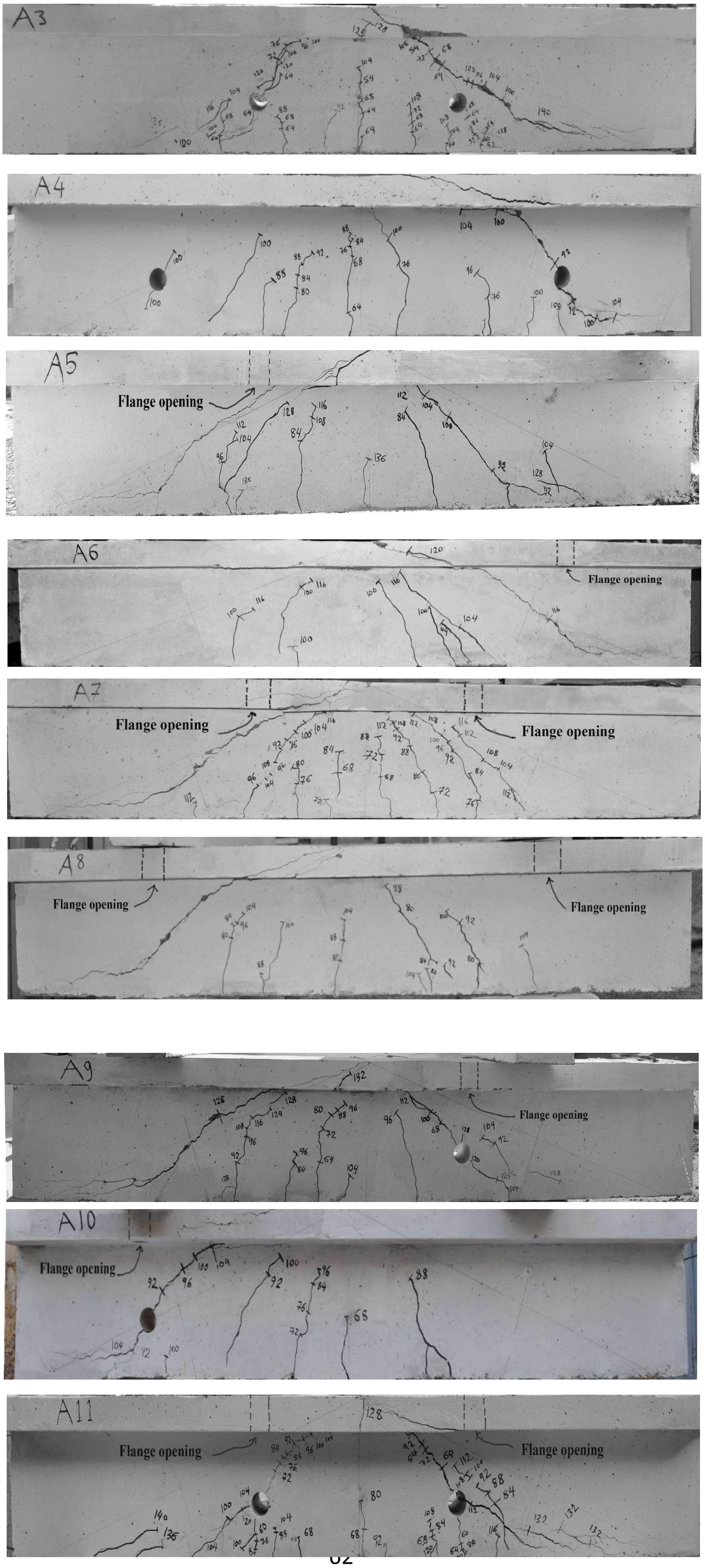
Experimental Results

All the beams were loaded to failure, for all beams, the first flexural cracks were appeared at early load increments at mid span in the region of maximum bending moment which were vertical cracks extended upward and stopped at a certain distance from the top of the beam flange, with further increase of load, new flexural-shear cracks were observed in the right and/or left of the beam span which were developed between the loading point and supports. After forming cracks, the inclined cracks developed and propagated toward the support and central point load, the failure took place due to crashing in the concrete under the applied point load and this mode of failure is called shear compression failure. A summary of 1st cracking load, failure load, and mode of failure are shown in Table (4.), Figure. (3) Shows Crack Pattern of Tested T-beams.

Table (4) Summary of Results of the Tested T-beams

Sign.	No. of openings	Distance from the supports (mm)	1st flex. Crack. load (kN)	1st Shear Crack. load (kN)	Failure load (kN)	Mode of failure
A0	0	-	110	126	150	
A1	1 (in web)	600	72	72	136	
A2	1 (in web)	300	64	80	100	
A3	2 (in web)	600	64	64	140	
A4	2 (in web)	300	64	92	104	Shear comp. Failure
A5	1 (in flange)	600	84	92	136	
A6	1 (in flange)	300	100	104	124	
A7	2 (in flange)	600	68	92	116	
A8	2 (in flange)	300	80	92	104	
A9	1 (in web), 1 (in flange)	600	64	68	132	
A10	1 (in web), 1 (in flange)	300	68	92	108	
A11	2 (in web), 2 (in flange)	600	68	72	140	
A12	2 (in web),2 (in flange)	300	64	72	116	




A3
A4
A5
Flange opening
A6
Flange opening
A7
Flange opening
Flange opening
A8
Flange opening
Flange opening
A9
Flange opening
A10
Flange opening
A11
Flange opening
Flange opening

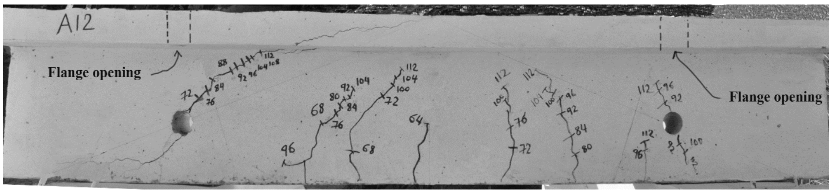
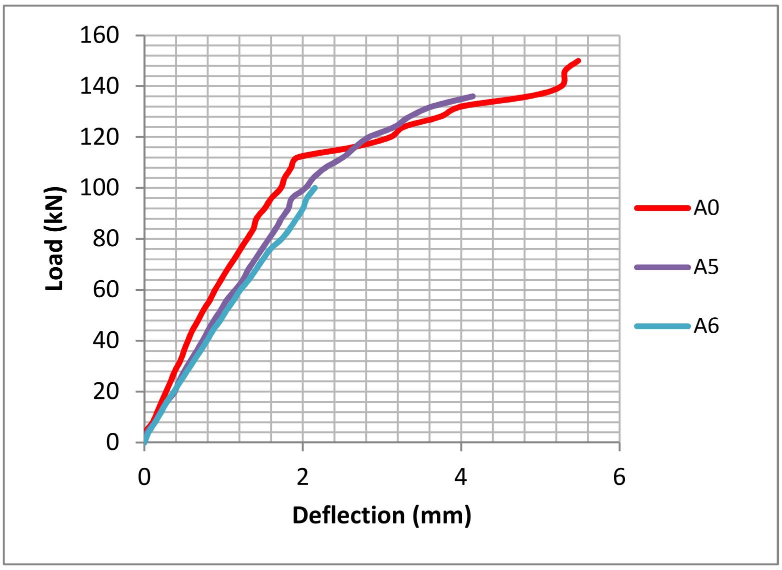
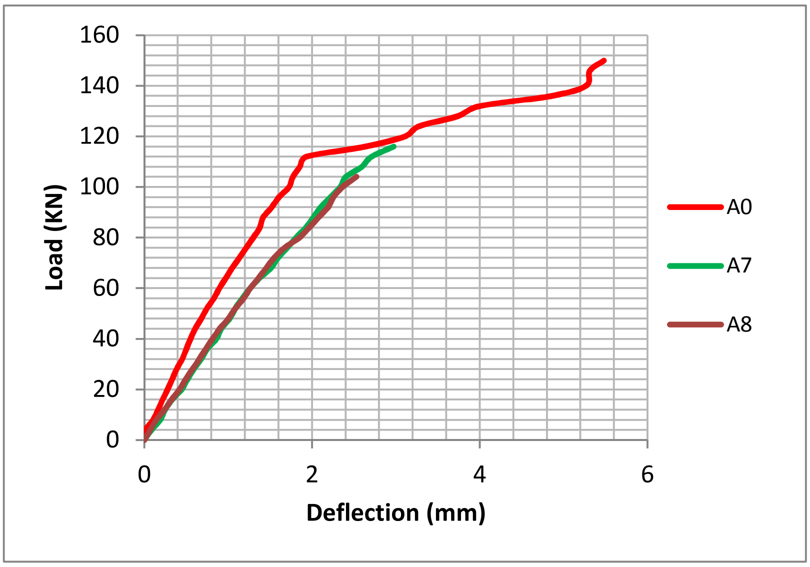


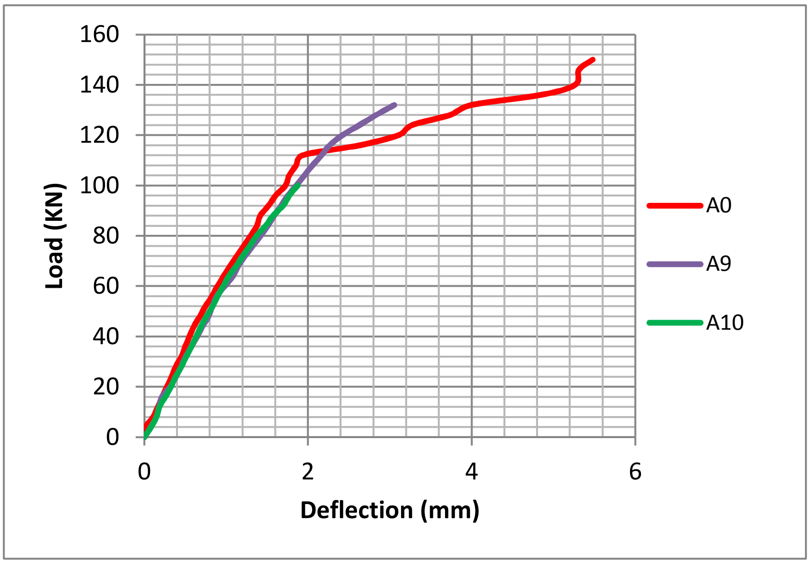
Figure 3. Crack Pattern of Tested T-beams

Load Deflection Relationship

The relationship between applied load and mid span deflection for all tested T-beam is presented in Figures. (4). The behavior of the control T-beam (A0) exhibits grater load carrying capacity in comparison with the other T-beams with opening in both webs and flanges (A1) to (A12). This beam A0 had a greatest ductility due to absent of openings


Load (kN)
Deflection (mm)
A0
A5
A6


Load (KN)
Deflection (mm)
A0
A7
A8


Load (KN)
Deflection (mm)
A0
A9
A10

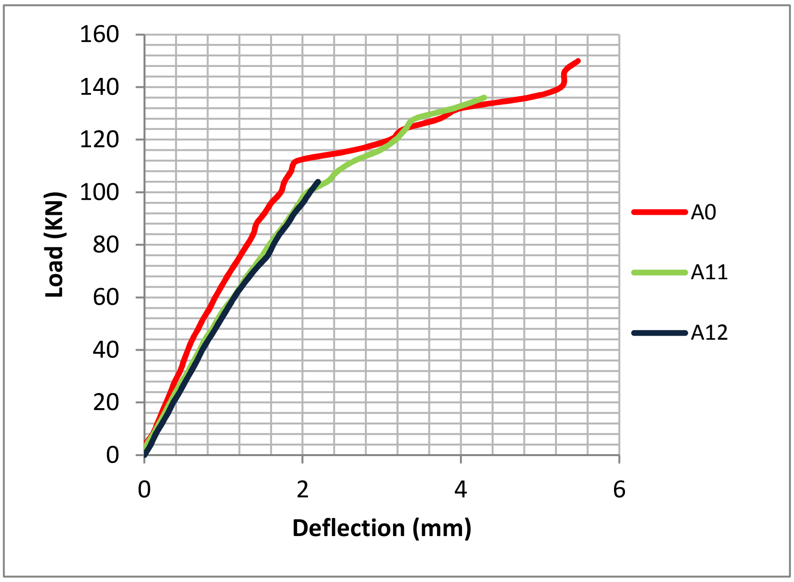


Figure 4. Load deflection relationship for T-beams

Theoretical Analysis

There is not an exact equation to compute the shear strength of reinforced concrete T-beam, only empirical equations are proposed to design the shear strength of reinforced concrete beam. In this study, the test results are compared with these equations, which include; shear strength of reinforced concrete beam, shear strength of reinforced concrete T-beam, and shear strength of reinforced concrete beam with opening. Based on the test result, a modified equation from Zararis's equations is proposed to compute the shear strength of reinforced concrete T-beam with opening in both flanges and webs. The following equations were used to compare the test results:

1. ACI 318M14 equation for predicting shear strength of reinforced concrete beam for non-prestressed member without axial force.

   $$V_c = \left(0.16\sqrt{f_c{}'} + 17\rho_w \frac{V_u d}{M_u}\right) b_w d \text{......} (1)$$

   This equation gives underestimated results.

2. Ioannis P. Zararis et al. equation for computing shear strength of reinforced concrete T-beam,

   $$V_{cr} = \left(1.2 - 0.2\frac{a}{d}\, d\right) \times \frac{c}{d}\, f_{ct}\, b_{ef}\, d \text{ .... } (2)$$

   Where:

   $$1.2 - 0.2\frac{a}{d}\, d \geq 0.65 \text{ ... ... } \quad (\text{d in meter})$$

   $$b_{ef} = b_w\left[1 + 0.5 \times \frac{h_f}{d}\left(\frac{b}{b_w} - 1\right) / \frac{c}{d}\right] \text{ ...... } (2.1)$$

   $$\left(\frac{c}{d}\right)^2 + \left[1.5\,\frac{h_f}{d}\left(\frac{b}{b_w} - 1\right) + 600\,\frac{\rho + \rho'}{f_c{}'}\right] \times \frac{c}{d} - 600\,\frac{\rho + \frac{\rho' d'}{d}}{f_c{}'} = 0 \text{ ... . } (2.2)$$

   This equation is under estimate and safe.

3. M.A. Mansur. equation for computing shear strength of reinforced concrete beam with web opening. $V_c = \frac{1}{6}\sqrt{f_c{}'}\, b_w\,(d - d_0)$ ... . (3)

This equation gives underestimated results

4. Proposed modified equation for Zararis's equation for predicting the shear strength of reinforced concrete T-beam with opening in both flanges and web

$$V_c = 1071.4\left[\left(1.2 - 0.2\frac{a}{d}\, d\right) \times \frac{c}{d}\, f_{ct}\, b_{ef}(d - d1d0)\right]^{0.3676} \text{ ... ... } (4)$$

$$d1 = \left(\frac{(0.5 * L - x')}{d}\right) \text{ .... } (4.1)$$

Proposed modified P.Zararis equation (4) could estimate the shear strength of reinforced concrete T-beam with and without opening in webs and flanges more accurately and safely comparing with other equations. Figure (5) show details of parameters.

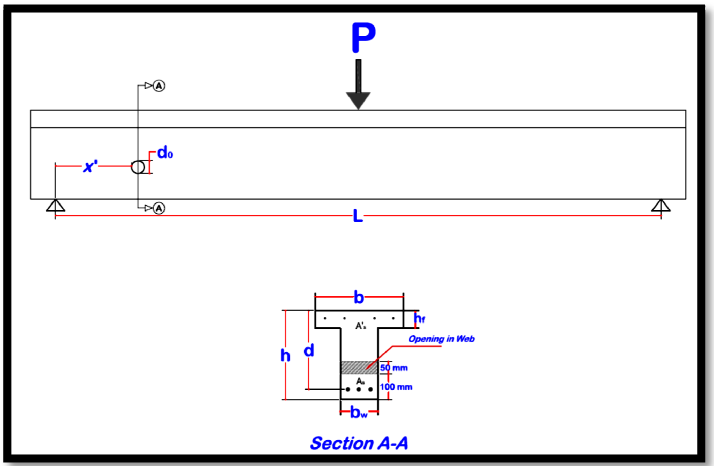


Figure 5. parameters of the proposed equation.

Conclusions

Based on the experimental results and theoretical analysis of thirteen reinforced concrete T-beams in this study and the shear strength of reinforced concrete T-beam with openings at distance d=300 mm, and 2d=600 mm from the edge of the beams in both flange and web, the following conclusions can be drawn:

1. Openings at distance (d) from the support are more effective than others, the location of the openings has a greater effect on the mid span deflection and strength of the tested T-beams rather than the number of openings because of the symmetry in the cross sectional properties of the beams, loading, and diameter of openings,
2. Opening in the web at distance (d) from supports are more effective on the strength decreasing value of the T-beams than others with an opening in the flange at the same distance from the supports and those with one opening in webs and/or flanges,
3. Opening in the webs and flanges at distance (d) from supports are more effective on the strength decreasing value of the T-beams than others with two and four openings in the webs and flanges at distance (2d) from the supports,
4. The presence of the web openings at distance (d) from supports reduce the shear capacity about (30.67% to 33.33%) in comparison with control beam, and about (6.67% to 9.33%) for beams with web openings at distance (2d) from the supports,
5. The presence of flange openings at distance (d) from supports reduce the shear capacity about (17.33% to 30.67%) in comparison with control beam, and about (9.33% to 22.67%) for beams with flange opening at distance (2d) from the supports,
6. Beams with opening in both flanges and webs, the presence of openings at distance (d) from supports reduce the shear capacity about (22.67% to 28%) in comparison with control beam, and about (6.67% to 12%) for beams with opening at distance (2d) from the supports,
7. ACI 318M14 equation underestimates the tested values for all tested beams, also for those with opening in flanges and webs, and provides too much factor of safety,
8. Ioannis P. Zararis et al. equation could estimate shear strength of reinforced concrete T-beam without opening, while for T-beams with openings a modification is required as proposed in equation,
9. M.A. Mansur. equation underestimates the tested values for all tested beams, also for those with opening in flanges and webs, and provides too much factor of safety,

10. Proposed modified P.Zararis equation could estimate the shear strength of reinforced concrete T-beam with and without opening in webs and flanges more accurately and safely comparing with other equations.

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Notations

As: Area of tension bar reinforcement (mm^2)
a/d: shear span to effective depth ratio
b: Flange width (mm)
b_{ef}: the effective width (mm)
b_w: Web width (mm)
c: the depth of the compression zone (mm)
d: effective depth (mm)
d: effective depth (mm)
d_0: Diameter of opening in web (mm)
f_c': Compressive strength of concrete (N/mm^2)
f_{ct} the tensile strength of concrete (N/mm^2)
f_y: Tensile strength of steel bars (N/mm^2)
f_{yv}: the tensile strength of the shear reinforcement (N/mm^2)
h_f: the flange thickness (mm)
L: Span length of the beam (mm)
V_c: Nominal shear strength provided by concrete (N)
V_{cr}: shear strength provided by concrete (N)
x': distance of opening from the support of the beam (mm)
ρ_v:the shear reinforce