EFFECT OF EXISTING FLANGE OPENINGS AND COLD JOINTS ON STRENGTH OF RC T-BEAMS

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ABSTRACT

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 vertically required creating openings in slab (Flanges of T-Beams) after or before construction.

New researches show that the concrete flanges provide a certain level of shear resistance above a certain width. Therefore, due to existing of these openings or cold joints in slab (Flange) and abrupt changes in the sectional configuration, opening corners are subject to high stress concentration that may lead to reduction in stiffness of the T-Beam and produced cracking and excessive deflection.

In the present research, shear behavior of reinforced concrete T-Beams which contains vertical opening (Flange openings) or cold joints at the flanges are studied as well as the effect of openings or cold joints locations. Eight beams were tested, one of which were constructed without any openings or cold joints (reference beam), while, the others were constructed with openings or cold joints in different locations.

Experimental results show that the presence of flange openings reduce the shear capacity about (22% to 32%) for beams containing one opening and about (17%-39%) for beams containing two openings. For beams containing cold joints, the shear capacity decreased about (27%) in comparison with reference beam.

الخلاصة

يعتبر نظام البلاطات و العتبات من اكثر النظم المستخدمة في انشاء الارضيات و السقوف الخرسانية، وفي معظم هدة المنشات تكون بلاطة الارضيات و السقوف جزءا متكاملا (Integral Part) من العتبة الحاملة وهكذا، يصبح مقطع العتبة على شكل حرف (T)

هناك بعض المتطلبات الخدمية، مثل مد شبكة انابيب تجهيز الماء الصافي او التاسيسات الصحية او الكهربائية او منظومات التدفئة و التبريد تتطلب عمل فتحات بالاتجاه العمودي لسقف كل طابق. في معظم الحالات تخترق هدة الشبكات البلاطات الخرسانية عند الاطراف و التي تمثل الشفة (Flange) في العتبات الخرسانية المسلحة ذات المقطع(T) مما يجعل وجود هدة الفتحات اماكن ضعف تتركز فيها الاجهادات.

اثبتت الدراسات الحديثة ان وجود الشفة (Flanges) يساعد بدرجة معينة على زيادة مقاومة القص في العتبات الخرسانية المسلحة ذات المقطع(T) عند مقارنتها مع العتبات الخرسانية المسلحة المستطيلة.

اعدت هدة الدراسة لتقييم تاثير وجود الفتحات او المفاصل (في منطقة الشفة) على سلوك القص في العتبات الخرسانية المسلحة ذات المقطع(T)، تم اجراء سلسلة من الفحوصات المختبرية على ثمانية عتبات خرسانية مسلحة ذات مقطع(T)، كانت العتبة الاولى بدون اية مفاصل او فتحات (العتبة المرجعية) اما البقية فكانت تحتوي على مفاصل انشائية او فتحات في مواقع مختلفة.

اظهرت النتائج المختبرية نقصان في مقاومة القص بحدود (22%-32%) في العتبات التي تحتوي على فتحة واحدة في الشفة، ونقصان بحدود (17%-39%) في العتبات التي تحتوي على فتحتين في الشفة.

بالنسبة للعتبات التي تحتوي على مفاصل انشائية، اظهرت النتائج المختبرية نقصان في مقاومة القص بحدود (23%) عند مقارنتها مع العتبة المرجعية.

KEY WORDS: **T-Beam, Flange, Opening, Cold joints, Shear, Slab, Concrete**

INTRODUCTION

Reinforced concrete system normally consists of slab and beams that is placed monolithically and as a result T-Beams (T-Shaped Beam) created and the two parts act together to resist the applied loads.

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. Usually, these pipes and ducts are placed underneath the beam soffit or penetrate vertically the slabs and, for aesthetic reasons, are covered by a suspended ceiling or by special decoration, Figure (1).

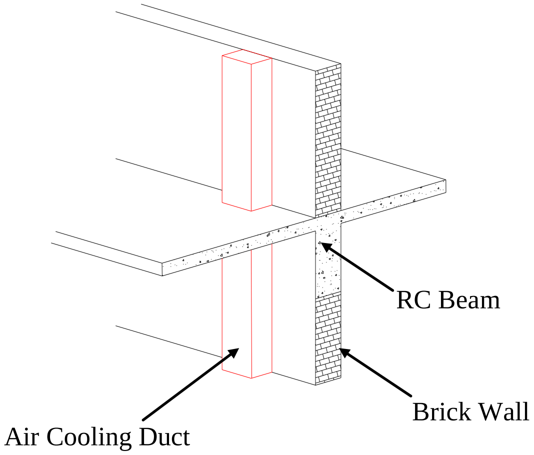

Fig. (1) Air Cooling Duct through the Slab (Flange)

Passing these ducts through vertical (or transverse) openings in the floor beams leads to a reduction in the dead space and results in a more compact design multiplied by the number of stories can represent a substantial saving in total height, length of air-conditioning and electrical ducts, plumbing risers, walls and partition surfaces, and overall load on the foundation.

It is obvious that inclusion of openings in T-beams alters the simple beam behavior to a more complex one. Due to abrupt changes in the sectional configuration, opening corners are subject to high stress concentration that may lead to cracking unacceptable from aesthetic and durability viewpoints.

Since the strength of concrete in tension is considerably lower than its strength in compression, design for shear becomes of major importance in all types of concrete structures.

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 in a continuous beam unless special reinforcement is provided in sufficient quantity with proper detailing, the strength and serviceability of such a beam may be seriously affected.

Several researches are interest in transverse openings (web openings) in the rectangular floor beams under the effect of flexural or torsion loads, (Mansure, M. A., 2006) and (Dainel H.R., and McMullen A.E, 1977).

New researches show that the concrete flanges provide a certain level of shear resistance above a certain width, (Giaccio et. al., 2003). Also, the current codes of practice such as(ACI 318-08), do not include an increase in shear strength resulting from the inclusion of a flange.

Generally, shear mode of failures are divided into four categories of failure and depends mainly on shear span to effective depth ratio, (Wang, C. K. and Salmon, C. G., 1994). The possible modes of failure are (1) Shear-tension failure; (2) Shear-compression failure; (3) Flexural failure; (4) Arch-rib failure.

In the present research, shear behavior of reinforced concrete T-Beams which contains vertical opening (Flange openings) or cold joints at the flanges will be studied as will as the effect of openings or cold joints locations.

EXPERIMENTAL STUDY

Experimental Program

Tests were carried out on eight T-Shaped beams, simply supported under the effect of single point loading. All beam specimens were reinforced with tension (flexural) bars at bottom. To eliminate the shear resisting contribution of stirrups and to ensure the specimens to fail in shear mode of failure, the tested beams were made without shear reinforcement (stirrups).

The variables were the number and location of slab (flange) openings and cold joints. The span, cross-section, concrete strength, and reinforcement were kept constant for all tested specimens.

Specimen Details

Each beam is designated in a way to indicate the T-Shaped beam, the dimensions and properties of tested specimens are shown in Table (1) and Figure (2), the locations of cold joints and openings are shown in Figure (3). Based on the classification presented by (Wang, C. K. and Salmon, C. G., 1994), all tested beams are classified as short beams ($1 \prec a/d \prec 2.5$).

Table (1) Properties of Test Beams

Beam Designation	Dimensions (mm)				a/d	Reinforcement	Number and Location of Openings or cold joints
	b_f	t_f	t_w	h			
TB-1*	220	50	60	250	2.17	$2\phi 8$	None
TB-2							One opening at L/3 (350mm) from the beam edge
TB-3							Two adjacent openings at L/3 (350mm) from the beam edge
TB-4							Two opposite openings at L/3 (350mm) from the beam edge
TB-5							One opening at L/2 (500mm) from the beam edge

TB-6							Two adjacent openings at L/2 (500mm) from the beam edge
TB-7							One cold joint at L/3 (350mm) from the beam edge
TB-8							Two opposite cold joints at L/3 (350mm) from the beam edge

* Reference Beam (T-Beam without Openings or Cold joints)
** Diameter of Opening is (50mm)

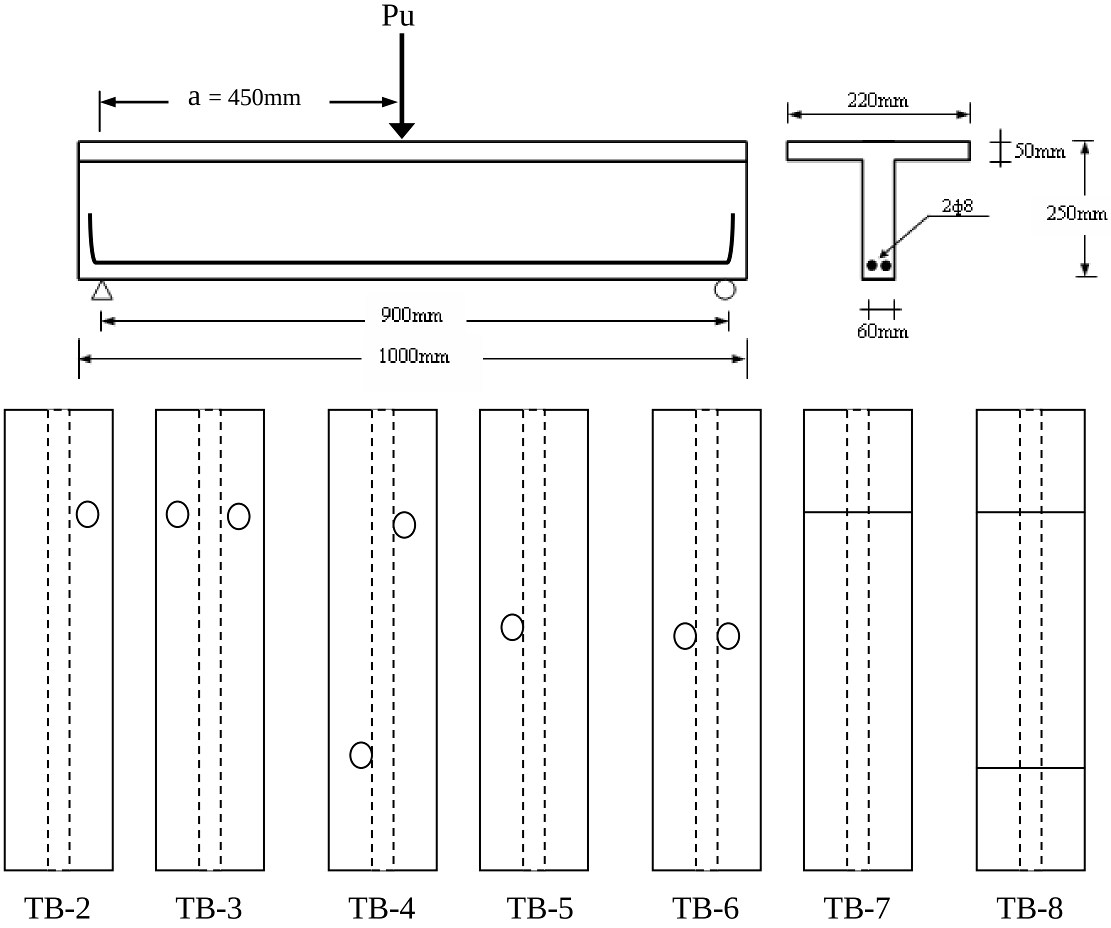

Fig. (3) Locations of Cold joints and Openings (Top View)

Materials

In manufacturing the test specimens, the properties and description of used materials are reported and presented in Table (2); and the concrete mix proportions are reported and presented in Table (3).

Table (2) Description of Construction Materials

Material	Descriptions
Cement	Ordinary Portland Cement (Type I)
Sand	Natural sand from Al-Ukhaider region with maximum size of (4.75mm)
Gravel	Crushed gravel with maximum size of (12mm)
Reinforcing Bars	(ϕ 8 mm) deformed steel bars, having (424 MPa) yield strength (f_y)
Water	Clean tap water

Table (3) Proportions of Concrete Mix

Parameter	Quantity
Water/cement ratio	0.45
Water (Liter)	168
Cement (kg/m^3)	420
Fine Aggregate (kg/m^3)	600
Coarse Aggregate (kg/m^3)	1200

Test Measurements and Instrumentation

Hydraulic universal testing machine (MFL system) was used to test the beams specimens as well as control specimens. Central deflection has been measured by means of (0.01mm) accuracy dial gauge (ELE type) and (30mm) capacity. The dial gauges were placed underneath the bottom face of each span at mid.

Test Results of Specimens

Test results of mechanical properties of specimens are summarized in Table (4). Compressive strength for cylinders was carried out on concrete with ASTM-C39. Tensile strength (Split cylinder) test were carried out in accordance with ASTM-C496 and tensile strength in flexural (modulus of rupture) were carried out in accordance with ASTM-C78

Table (4) Mechanical Properties of Concrete

Property (MPa)	Value
Cylinder compressive strength (f_c')*	32
Split cylinder (f_{ct})**	3.5
Modulus of rupture (f_r)***	3.3

*Average of three samples by using (152x305mm) cylinders. ** Average of three samples by using (152x305mm) cylinders.
*** Average of three samples by using (100x100x500mm) prisms.

Test Procedure

All slab specimens were tested using universal testing machine (MFL system) with monotonic loading to ultimate states. The tested beams were simply supported over an effective span of (900mm) and loaded with a single-point load; Figure (4) shows the setup of beam specimens.

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 gauge were in their correct or best locations.

Loading was applied slowly in successive increments. At the end of each load increment, observations and measurements were recorded for the mid-span deflection and crack development and propagation on the beam surface.

When the beams reached advanced stage of loading, smaller increments were applied until failure. They fail abruptly without warning (sudden failure) and the diagonal cracks that develop becomes wider and as a result, the load indicator stopped recording any more and the deflections increased very fast without any increase in applied load.

The developments of cracks (crack pattern) were marked with a pencil at each load increment.

Fig. (4) Setup of T-Beam specimens

RESULTS AND DISCUSSION

As mentioned before, the main objectives of this study are to examine or assess the shear behavior of reinforced concrete T-shaped beams containing openings or cold joints at different locations of beams flanges.

During the experimental work, ultimate loads, load versus deflection at mid-span for each beam were recorded. Photographs for the tested beams are taken to show the crack pattern and some other details.

The recorded data, general behavior and test observations are reported as well as recognizing the effects of various parameters on the shear behavior.

General Behavior

Photographs of the tested beams are shown in Figure (5) and test results are given in Table (5). All beams of this category were designed to fail in shear, which was characterized by sudden failure and diagonal wide cracks which extended from supports towards the load or openings or cold joints locations. The general behavior of the tested beams can be described as follows:

At early stages of loading, several cracks initiated in the mid span of tested beams (flexural cracks), with further loading, these cracks extended upwards and became wider in shear span. One or more cracks propagated faster than the others and reached the compression flange (near applied load or openings or cold joints), where 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 or cold joints).

As expected, the main cracks (diagonal cracks) for all tested beams commenced at the shear span and all beams exhibited sudden failure. It is may be noted that, at advanced stage of loading, some parts of tested T-Beams were crushed and subjected to defragmentation , this is may be due to high concentrated of stresses and absents of steel reinforcement to hold these parts in the transverse direction.

Mode of Failure

The experimental evidences show that the diagonal cracks extended horizontally along the tension reinforcement and eventually, the failure take place due to crushing failure in the concrete near the compression face (near applied load) and this mode of failure called “Shear-Compression” failure.

Fig. (5) Crack Patterns for T-Beams

Ultimate Strength (P_u)

The recorded ultimate loads of the tested beams are presented in Table (5). As expected, test results show that the reference beams (TB-1) has the maximum ultimate strength in comparison with the rest beams. This may be due to combination of ability of flanges to sustain larger compressive force at advanced stages of loading and absent of any leak (openings or joints) in the flange. The compression flanges can carry any load increment prior to failure, and this depends mainly on the ultimate compressive strength of the concrete in the flange.

For tested beams (TB-2) and (TB-5), which had one opening in flanges, the decreased in shear strength was (22%-32%). The presence of openings in compression flange lead to decrease the stiffness of tested beams, and this leads to an decrease in carrying capacity.

For tested beams (TB-3), (TB-4) and (TB-6), which had two openings in flanges, the decrease in shear strength were (39%), (17%) and (17%) respectively.

For tested beams (TB-7) and (TB-8), which had one or two cold joints in flanges, the decrease in strength was (27%), which indicated that an increase in number of cold joints (adding another cold joint in opposite direction) not affected on the reduction of ultimate capacity.

Generally, it can be seen that the tested beams containing a certain number of openings or cold joints in the flanges exhibit smaller ultimate strength than other beams (which made fully without any openings).

Table (5) Ultimate Loads and Mode of Failure of Tested Beams

Specimens Designation	Ultimate Load (Pu) (kN)	Shear Force (kN)		Mode of Failure
		V_u	$(V_u)_i / V_u$	
TB-1 *	41	20.5	1	Shear-Compression Failure
TB-2	32	16	0.78	
TB-3	25	12.5	0.61	
TB-4	34	17	0.83	
TB-5	28	14	0.68	
TB-6	34	17	0.83	
TB-7	30	15	0.73	
TB-8	30	15	0.73	

* Reference Beam, V_u =20.5 kN

Effect of Openings and Cold joints on Ultimate Strength

As shown in Table (5), presence of openings or cold joints in compression flange lead to decreases the stiffness of tested beams due to removed concrete parts, and this leads to decrease in carrying capacity.

Due to abrupt changes in the sectional configuration, opening corners are subject to high stress concentration that may lead to reduction in stiffness of the T-Beam and produced cracking and excessive deflection, see Figures (6) and (7).

Effect of Openings and Cold joints location on Ultimate Strength

As shown in Table (5), when the flange's opening shifted from (L/3) to (L/2) (see TB-2 and TB-5), the ultimate shear strength decreased from (22%) to (32%). When the openings shifted towards the applied load (from (L/3) to (L/2)), rapid progressive of cracks were take place due to passing of openings directly within the path of diagonal cracks.

The decreasing in ultimate load was (27%) for both (TB-7) and (TB-8), which have one and two cold joints respectively. This means that the location of cold joint not affected on ultimate capacity of tested beams.

Deflections

Load-deflection curves of the tested beams at mid-span at all stages of loading up to failure are constructed and shown in Figures (6) and (7).

As shown in Figures, 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 (6 kN to 15kN), which may be indicated the first crack loads. Beyond the first crack loading, each beam behaved in a certain manner. Behavior of reference T-Beam (TB-1) exhibited greater loads and deflections in comparison with the other beams. This beam had the greatest stiffness due to absent of openings and cold joints in flange.

Load-deflection curves for the tested beams (TB-2, TB-3, TB-4, TB-5 and TB-6) exhibits smooth increase in both applied loads and deflections. Presence of flange openings caused decreasing in the load carrying capacity beyond the first cracking and this was reflected on the corresponding deflections. For T-Beams (TB-7 and TB-8), slight increase in ultimate deflection of beam (TB-8) was observed by comparing with (TB-7). This is may be due to presence of two cold joints in the beam (TB-8) which lead to decreasing of beam stiffness and as a result, slight increases in deflection take place.

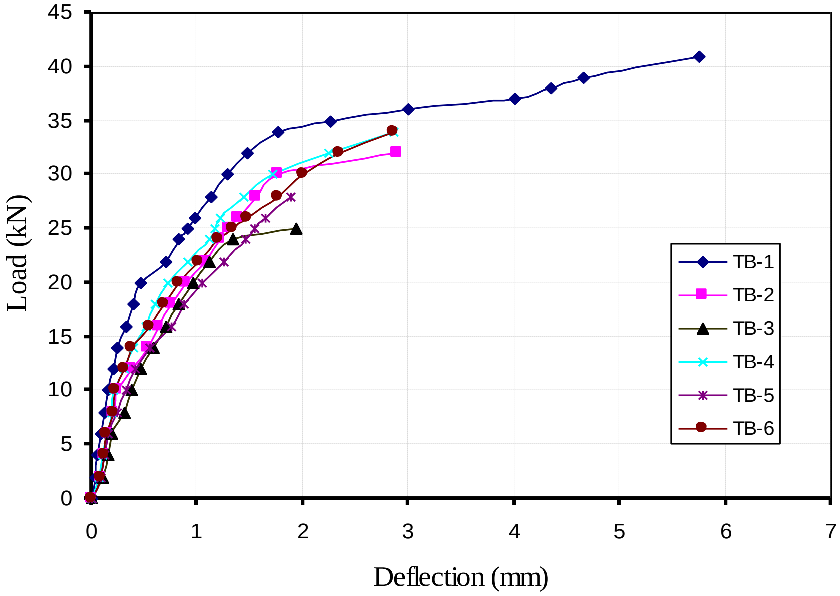

Fig. (6) Load-Deflection Relationship of tested Beams containing Openings

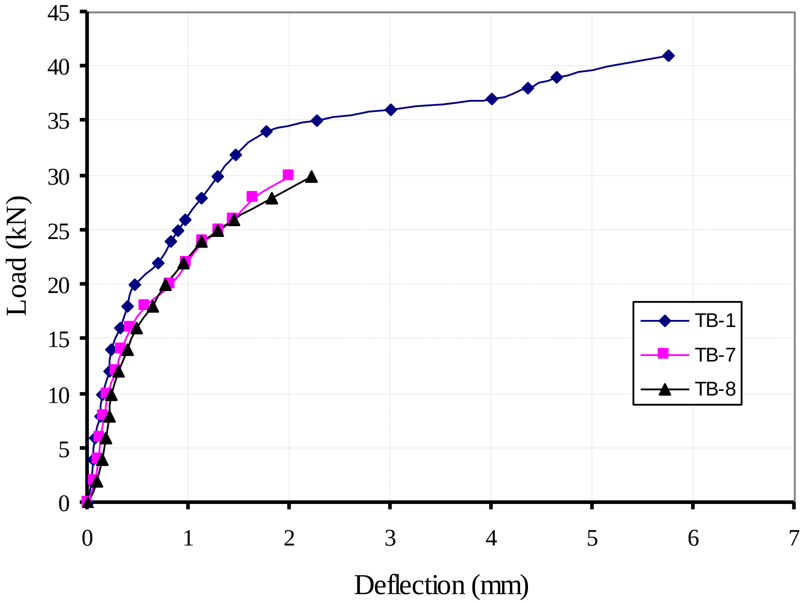

Fig. (7) Load-Deflection Relationship of tested Beams containing cold joints

CONCLUSIONS

Based on the results obtained by the experimental work, the following conclusions are presented:-

- For tested beams with one opening in flange, the ultimate strengths were decreased (22%) and (32%) for beams containing one opening at distance (L/3) and (L/2) from edges respectively. Also, the change in openings locations from edge toward the center lead to decrease the carrying capacity for about (10%). Presence of openings lead to concentrated of stress around their hollow and caused decreasing in the load carrying capacity. This evidence shows the contribution of flanges to increase the ultimate shear capacity of T-Beams in comparison with rectangular sections.

- For tested beams which have two openings in flange, the ultimate shear strengths were decreased (17%) and (39%). This marginal difference in ultimate strengths (in comparison with tested beams with one opening in flange) may be due to subjected of compression flange degree of stress concentration.

- Experimental results shows that the decreasing in ultimate load was (27%) for both (TB-7) and (TB-8), which have one and two cold joints respectively. This means that the location of cold joint not affected on the ultimate capacity of tested beams.

- 4-In all tested beams, the crack path forced to passing through the weak locations (locations of openings or cold joints). Therefore, in design, special details most be added at these locations.

REFERENCES

- ACI Committee 318, “***Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary (ACI 318R-08)”***, American Concrete Institute, Farmington Hills, MI, 2008, pp.465.

- ASTM, "***Test Method for Compressive Strength of Cylindrical Concrete Specimens***", (ASTM C39-96), American Society for Testing and Materials, 1996.

- ASTM, "***Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*** ", (ASTM C496-79), American Society for Testing and Materials, 1979.

- ASTM, "***Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)***", (ASTM C78-75), American Society for Testing and Materials, 1975.

- Dainel H.R., and McMullen A.E., "***Torsion in Concrete Beams Containing an Opening*****”,** Journal of the Structural Division, ASCE, Vol.103, No.ST3, March 1977, PP. 607-617.

- Giaccio, C., Al-Mahaidi, R. and Taplin, G., “***Flange Effectiveness in Shear Strength of RC T-Beams***”, Department of Civil Engineering, Monash University, Wellington Road Clayton, Vic. Australia, 2003,10 pp.

- McCormac, J. C. and Nelson, J. K., “***Design of Reinforced Concrete***”, 7th Edition, John Wiley & Sons, Inc., USA, 2006, 721 pp.

- Mansur, M.A., **"*Design of Reinforced Concrete Beams with Web Openings*",** Faculty of Civil Engineering, Universiti Teknologi, 81310 UTM Skudai, Malaysia, (Proceeding of the 6th Asia-Pacific Structural Engineering and Construction Conference, Kuala Lumpor, Malaysia ,5-6 September, 2006).

- Nawy, E. G. , “***Reinforced Concrete –A Fundamental Approach***”, 6th Edition, Pearson Education International, New Jersey, USA, 2009, 933 pp.

- Wang. C. K. and Salmon, C. G. , “***Reinforced Concrete Design***”, 4th Edition, Harper International Edition, New York, USA, 1985, 947 pp.

NOTATION

a = Shear Span;

b_f = Flange width;

d = Effective depth of T-Beam;

$f_c^{'}$ = Cylinder compressive strength of concrete;

f_{ct} = Indirect tensile strength (splitting tensile strength);

f_r = Flexural tensile strength of concrete (modulus of rupture);

f_y = Yield strength of steel;

h = Total depth of T-Beam;

L = Effective Span

P_u = Ultimate load;

t_f = Flange thickness;

t_w= Web thickness;

V_u= Ultimate Shear Force;

$(V_u)_i$= Ultimate Shear Force of a certain beam;

ϕ = Reinforced bar diameter;