



Influence of the width and thickness of the flange on the shear capacity of reinforced concrete T- beams.

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الملخص العربي :

تعتبر الكمرات ذات قطاع حرف T شائعة الاستخدام في العديد من المنشآت وخاصة في الكباري الخرسانية حيث تستخدم كدعامات للكمرات الثانوية سابقة الصب. وهذه الكمرات تختلف في سلوكها الإنشائي عن الكمرات بدون الشفة المحملة من أعلي حيث تعمل الشفة علي زيادة قدرة تحمل الكمرات . ويتضح من معظم الدراسات التجريبية والنظرية السابقة التي تم الإطلاع عليها بشأن هذا الموضوع على هذا النوع من الكمرات المسلحة المعرضة لقوي القص، أننا في حاجة الي بعض الدراسات والتجارب علي هذا النوع من الكمرات . ولذلك كان الهدف الرئيسي من هذا البحث هو عمل بعض التجارب العملية والنظرية لدراسة سلوك الكمرات المسلحة ذات القطاعات علي حرف T المعرضة الي قوي القص و التركيز على تأثير ابعاد الشفة على مساهمتها في مقاومة قوي القص. ولذلك لايجب أن نتجاهل مساهمة الشفة في مقاومة قوي القص كما هو الحالي في كثير من الأكواد التصميمية المختلفة وخاصة الكود المصري ECP-203 حيث أنه لا يضع أي مساهمة للشفة في مقاومة القص. وهنا تأتي أهمية عمل الدراسات المشار إليها حول هذا الموضوع والذي ينعكس بالفائدة الكبيرة علي المهندسين الانشائيين، وشركات البناء، والهيئات المعنية الأخرى.

Abstract:

This research presents the test results of experimental study on shear strength of reinforced concrete flanged beams. The test variables in this study were flange dimensions (thickness) and the reinforcement in flange. seven simply supported specimens, consisting of one of them with rectangular cross section and the remaining specimens with T section, subjected to two-point loads were tested until failure. During the test, the values of the diagonal cracks, crack width, strain and the maximum load were observed as well as the deformation of the beams. It was confirmed from the test that the shear capacity of T-beam was higher than for rectangular beams, with the values ranging from 166 to 312%, depending on the flange dimensions and longitudinal reinforcement in flange. In addition, based on the test results, a simple model for predicting the contribution of flange to shear capacity in T-beam was presented and comparison the results.

Keywords: Reinforced concrete beam, Flanged beam, shear cracks, Longitudinal reinforcements, Angle of diagonal crack.

1. Introduction

Reinforced concrete beams with T-cross sections are frequently used in construction especially in building floors, retaining walls, bridge decks, etc. More generally, such flanged beams are typical in all reinforced concrete construction projects, where an appropriate portion of the slab acts together with the web to resist the acting straining actions. A typical and important application of reinforced concrete (RC) flanged beams is their use as the main girders that support precast, secondary beams or slabs. Examples of such application include the popular structural systems for bridges and parking garages, which call for the use of T-shaped beams. Most previous experimental studies on the subject focused on reinforced concrete (RC) beams under flexure, shear, or torsion. The behavior T-beams with both web and flange closed stirrups are not fully explored. In this research, an innovative test setup capable of simulating the behavior of flanged beams under shear force will be developed and implemented.

Thamrin et al. [1] investigated the shear strength of RC T-beams without stirrups. Test results showed that the shear strength of T-beams is affected by both flange size and its longitudinal reinforcement in the beam web ratio. In particular, they found that the shear capacity of T-beams was 5% to 20% higher than that of rectangular beams with same web dimensions. It was also stated in the research that the angle of the diagonal crack was significantly influenced by the web longitudinal reinforcement ratio in the shear span. Generally, the angle of diagonal cracks decreased when the longitudinal reinforcement in the beam web increased for both rectangular and T-sections.

Antoni Cladera, Eva Oller and et al. [2] provided an analytical model for the ultimate shear capacity prediction of slender RC beams with rectangular section and T-section, the contribution of the compression flanges to the shear strength is relevant and cannot be neglected, When the neutral axis lies in the flanges, both the global inclination and the horizontal projection of the critical crack increase. As a result, the concrete contribution and the web transverse reinforcement have increased, resulting in higher ultimate shear capacity resistance.

Elgohary et al. [3] six of RC beams without stirrups, one with R-sec and five with T-sec, with variable flange width to web width ratio, studied the influence of flange dimensions on shear capacity of reinforced concrete T-beams. Test results showed that an increase in shear strength ranging from 10% to 30% occurred due to the flange contribution

Deifalla , A. Ghobarah [4] study the action of the T-shaped beams tested was influenced by the torque-to-shear ratio rating. Reducing the torque applied to the sum of shear force applied resulted in the following: (1) Significant decrease in the spacing between diagonal cracks, angle of strut for inclination, cracking and ultimate torque, flange and web stirrup strain ; (2) Significant increase in failure and cracking load, torsional rigidity after cracking, cracking and ultimate shear; and (3) The efficiency of the stirrups has been reduced and therefore beams

have failed due to concrete diagonal failure rather than the yield of stirrups, and The flange's presence revealed a section's shear strength increased by 29 %relative to the rectangular beam.

Emad Etman,[5] this research shown that strengthening RC beams in shear zone using carbon fibre-reinforced polymer (CFRP) to enhance the shear capacity of existing RC beams. The main objective was to obtain a good understanding and enhance the experimental database of shear behaviour of RC T-beams strengthened with externally bonded reinforcement (EBR) systems. The existence of the flange showed a 29 % increase in the shear capacity of the section compared with the rectangular section. The use of CFRP sheet shown higher specimen stiffnesses, compared with steel.

Most experimental studies on the subject focused on RC beams under shear strength. In this research, a test setup capable of simulating the behavior of flanged beams under shear force is developed and implemented. The studied variables are flange dimensions (thickness and width) and the existence of longitudinal reinforcement in flange.

2. Research Significance.

T- beams is used widely in bridge structures. In precast bridge structures, the flange thickness is relative to the web depth is much larger than in buildings. Thus, it does not seem wise to ignore the flange contribution in resisting shear as is currently done by various design codes [13-14]. For example, ACI 318-19: Building Code Requirements for Structural Concrete and the Egyptian Code of Practice ECP-203 do not utilize any contribution of the flange in resisting shear. Therefore, experimentally and theoretically studies on this subject shall be of great benefits to structural engineers, construction companies, and other involved bodies.

3. Experimental Work

3.1. Description of specimens

The test specimens consisted of nineteen simply supported beams with end columns to prevent bearing failure, one of them with rectangular section “control specimen”, and remaining specimens with flange (T-Section). All specimens with shear span to depth ratio equal 1.4. The total length of the tested specimen was 1300 mm with overall depth equal to 300 mm, web width 100 mm and an effective span of 1200 mm giving an l/h ratio (span-to-depth ratio) > 4 as shown in Fig.1. The beams were monotonically loaded until failure with two-point load using a 1000 kN capacity hydraulic jack and all specimens were designed in such a way to induce shear failure prior to any flexural distress, the typical details of tested specimens are shown in Fig. (1). Each specimen has a main bottom reinforcement consists of four Ø16 bars (diameter of 16 mm, area of 201 mm²) laid in two layers at the bottom that having yield strengths of 420 MPa and two Ø10 bars (diameter of 10 mm, area of 78.54 mm²) laid in one layer at the top. The bottom and top bars are anchored at the support with 90-degree hooks to prevent premature anchorage failure. The internal reinforcement in flange,

and the stirrups at supports and middle zone only “*all specimens without shear stirrups in the web within shear zone*” were 8 mm in diameter (area of 50 mm²), with yield strengths of 220 MPa.

The nomenclature of tested specimens given in Table-1 includes three parts. The first Part refers to reinforcement group in flange (*G1 without reinforcement G2 with longitudinal reinforcement in flange*). The second Part refers to flange thickness (*T1, T2 for 90mm, 120mm respectively*). The third Part refers to flange width (*0.3 refer-to B=300mm*).

3.2. Material properties

Table-2 summarizes the average values of compressive strength of concrete the results obtained from 150 mm cubes and standard 150×300mm cylinders. The 28-days cylinder strength (*f_c*) and the 28-days cube strength (*f_{cu}*) results are calculated from the average values of three sample specimens each. The mixed concrete used to cast test specimens were ordinary Portland cement, irregular gravel of a maximum size of 1.5 mm and sand with a maximum size of 0.5 mm. The water–cement ratio by mass was 45% to the mass of cement was added. Both high and normal steel strength bars were tested in tension, for high tensile steel *f_y*= 420 MPa and normal *f_y*= 240 MPa.

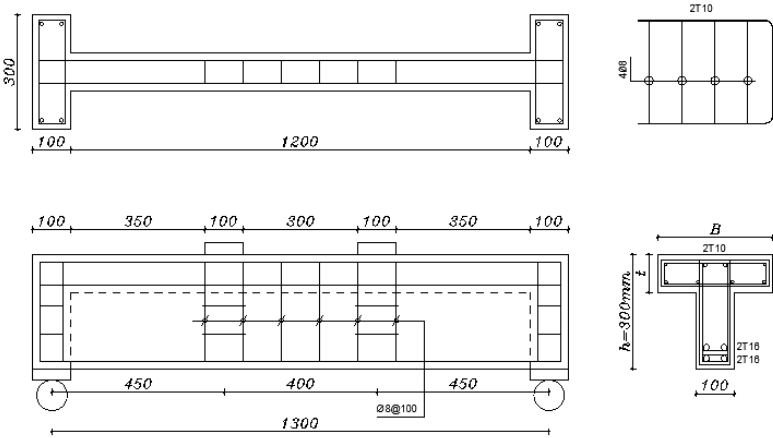


Fig. 1. Specimen details and arrangement of reinforcement (All dimensions in mm)

3. 3. Test set-up and instrumentation

The test set-up used in this study consisted of rigid steel frames supported by the laboratory rigid floor in Reinforced Concrete laboratory at faculty of engineering-Benha University. All beams were tested over a simple span of 1300 mm, and the load was applied through two symmetrical points of 400 mm apart. Schematic arrangement of loading for the tested beams refer to Fig. (2). The load was applied using a hydraulic jack of 1000 KN capacity and measured by using load cell connected to data logger. To monitor the deflection, fire Linear

Variable Differential Transformer (LVDT) were placed beneath the center of the specimen and under the two load points. The applied load was equally distributed on two concentrated points. The specimens were prepared for testing in a simply supported condition under two symmetrically placed concentrated loads and testing procedure for the all the specimen is same as mentioned above. Strain gauges were used to measure the strain in the longitudinal reinforcement in flange and in the concrete within shear zone.

The maximum shear load for each tested beam is listed in Table 2. It is shown that the maximum load for beams with T-sections is higher than that for rectangular section which depends on the flange

[Table-1] Experimental Program.

Total depth 300 mm, web width (b_w) 100 mm.

Specimen	Cross Sectional Area (cm ²)	Cross Sectional Area Increasing (%)	Flange Dim.			Stirrups in flange within shear zone (mm)	Longitudinal reinforcement in Flange		Longitudinal reinforcement in Flange [%]
			t_f (cm)	b_f (cm)	A_f (cm ²)		Bottom Steel	Top Steel	
C0	300	-----	-----	-----	-----	-----	-----	-----	
G1-T1-0.3						-----	-----	-----	
G2-T1-0.3	480	60%	0.3h=9		270	-----	4 Ø 8	3 Ø 6	1.055 %
G3-T1-0.3				30		Ø8@75			
G1-T2-0.3						-----	-----	-----	
G2-T2-0.3	540	80%	0.4h=12		360	-----	4 Ø 10	2 Ø 6	1.029%
G3-T2-0.3						Ø8@75			

G = Reinforcement group, "G1" without reinforcement, "G2" with longitudinal steel.

T = Flange thickness, "T1=0.3h" 90 mm, "T2=0.4h" 120mm. 0.3 refer to Flange width= 300 mm.

thickness and longitudinal reinforcement in flange. This fact confirms that the flange in T beams has beneficial effects on the shear stress distribution and propagation of the diagonal cracks in the web.

4. Results and Discussion

Additional reinforcement to prevent the flexural failure, for both types of specimen cross sections "rectangular and flanged cross sections", thus, when the concrete reached its tensile strength, the all cracks and collapse were in the shear region. The test results will be interpreted in terms of: a) the load at rupture and the gain in capacity due to the flange dimensions and reinforcement within flange; b) the load versus deflection relationship and the gain in stiffness; and c) the cracking pattern and the failure modes observed; d) the strain data gathered will be used to study the longitudinal steel in flange and concrete responses.

for beams with T sections is higher than that for rectangular section, that depending on the flange thickness and longitudinal reinforcement in flange. This fact confirms that the flange in T beams has beneficial effects the shear stress distribution and propagation of the diagonal cracks in the web.

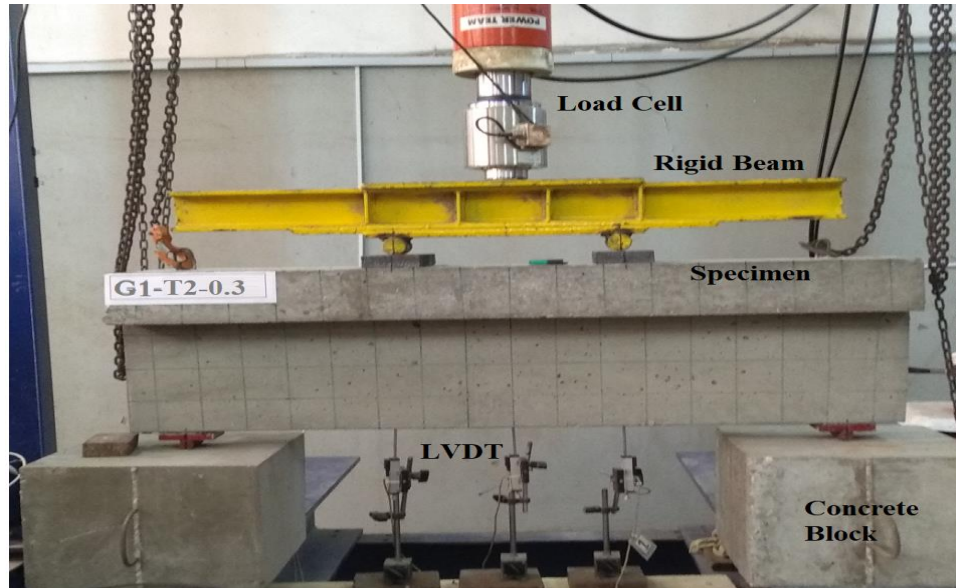


Fig. 2. Preparation of Test set-up Specimens

4.1 Ultimate Load.

The ultimate load is defined as the maximum load depicted for each specimen; it was investigated for 7 specimens that are given in Table 2 and shows a comparison between ultimate load for all Specimens ($B = 0.3$) & control. It is clear that flange dimensions give very good results especially with longitudinal reinforcement in flange, where improved the shear strength capacity and ductility.

As observed from results the ultimate load P_u for first group G1-T1-0.3, G1-T2-0.3&G1-T3-0.3 that haven't any reinforcement within shear zone, the load at ultimate failure attained 281.9,362&430 kN respectively, compared to the control specimen "C0" that collapsed at 106 kN that is a gain of 166, 240& 300% respectively. As for the influence of the longitudinal steel in flange on the gain in shear strength, that is for second group, G2-T1-0.3, G2-T2-0.3&G2-T3-0.3 the loads at ultimate failure were 326 ,377.4& 438.6 kN respectively, shows a gain of 207, 255& 312%respectively on loads over control specimen C0.

On the other hand, when you compared the flanged specimens with each other, you can observe the width ratio effect (ρ_b) on increasing the shear strength by 6, 8 &0.4 % for T1, T2& T3, respectively with first group "G1". while with the second group" G2" the shear strength gains 4.8,1.6& 1.8%, for T1, T2& T3 respectively.

To show the thickness effect on the shear strength, take the specimen of the minimum thickness "T1" from every group as a reference value, for the first group, the ultimate load increased by 28.7, 52.7% for T2&T3 respectively. For second group **Table.2 Experimental Results of Specimens** provided 15.8% and 34.5% for T2&T3 respectively, increase in maximum load of G2-T1-0.3. finally, the third group Submitted 7.2%

From the previous discussion we noted that the declined of increasing percentage for T3 with the

Specimen	f_{cu} (Mpa)	ρ_b	ζ	Cracking Load "P _{cr} " (kN)	Ultimate Load "P _u " (kN)	Max. Recorded Deflection (mm)	Mode of Failure
C0	36.4	---	---	95	106.35	2.33	Shear
G1-T1-0.3	36.4	3	---	100	281.90	4.74	Shear
G1-T2-0.3	36.4		---	105	362.72	5.97	Shear
G1-T3-0.3	36.4		---	110	430.58	5.98	Shear
G2-T1-0.3	34.2		1.055	90	325.98	5.80	Shear
G2-T2-0.3	34.2		1.029	105	377.45	5.87	Shear
G2-T3-0.3	34.2		1.047	115	438.56	4.43	Shear

ζ : Longitudinal reinforcement ratio, ρ_b : width ratio (b_f / b_w)

increase of the width and thickness of flange, this due to inter of neutral axis from the flange.

4. 2. Load Deflection relationship.

After the first diagonal crack appeared a larger deflection was observed with increasing of load especially for specimens that without longitudinal reinforcement in flange. There is a very good control on mid-span deflection when adding longitudinal reinforcement in flange, where a large reduction in the deflection at the same load. Specimens with different flange dimensions and without reinforcement provided for the study of the effect of the flange dimensions during a comparison between them and another rectangular one” control specimen”. At 25% Pu of control specimen, the deflection of specimens with longitudinal reinforcement decreased by 30% - 80% with respect to the deflection of control specimen. Fig. 3 show load-deflection curves of the tested specimens.

It is shown from these figures that beam capacity increases as the thickness and width of flange increases, also the shear capacity improves with the existing of longitudinal reinforcement within the flange. In addition, it is confirmed from Fig. 3 that beam G3-T2-0.5 and G3-T3-0.5 failed in shear after longitudinal reinforcement yielded. This is indicated by the flat region in the end part of load-deflection curve “improvement the ductility”. However, the reinforcement in beams G3-T1-0.3 and G3-T1-0.3 did not reach the yield strength up to the occurrence of shear failure. Comparison between load-deflection curves for individual group with rectangular and T sections are shown in Fig. 3. Due to the contribution of flange in the compression zone of the section, it is revealed that the capacity and stiffness of beams with T sections are higher than that of beams with rectangular sections and lead to improvement the shear strength significantly.

4.3. Cracking Pattern and Modes of Failure

The cracking pattern and modes of failure of all specimens with flange are as shown in Fig.4. For the rectangular specimen, the diagonal cracks were initiated at the shear zone about 89% of maximum load, and these are followed by diagonal cracks at both sides. With load increasing more inclined cracks appeared in the compression path joining the load and support points, while for flanged specimens the diagonal shear cracks at a load of 19:30% of maximum load, in addition, the failure modes are listed in table2.

The cracks started at the center of both shear zone. As the load increases, the crack widened and propagates towards the support and loading points. For the flanged specimens leading to diagonal shear cracks at a load of 104 kN and a horizontal crack appeared at the flange but late, depending on the thickness, width of the flange, and the presence of reinforcement in it. The inclined cracks followed a much shallower path (approximately 15-25°) in the flange according to the flange thickness and longitudinal reinforcement in flange.

Visual inspection of Control specimen C0 at failure revealed that it had a wider main inclined crack compared with the corresponding cracks in flanged specimens. For group (G1, B = 0.3 m), the onset of cracking was observed at the bottom of the web at a total load value of 95-110 kN. Afterwards, more diagonal cracks were initiated within both the web and the flange, which were spiral and uniformly distributed, as shown in Fig.4. Before failure, significant concrete cover spalling from the flange, and additional longitudinal cracks in the flexure compression zone side were observed as shown in specimen (G2-T3-0.3). It was also noticed that with the increase in thickness and width of flange, there was great control over the width of the cracks.

5-Strain analysis

This part of the study investigates the behavior of the longitudinal steel, and the concrete element, extensive instrumentation for strain monitoring was carefully engineered to provide the information and data much needed for the understanding of the shear resistance mechanisms of flanged reinforced concrete beams.

5.1 Longitudinal steel reinforcement strain

Figure 5 presents for flanged specimens, respectively, the curves for the applied shear force versus the strains in the longitudinal steel within the flange. These curves indicate that the behavior of the longitudinal steel went through three phases during loading. In the first initial phase, no noticeable contribution of the steel to the resistance was observed. In the second phase, the first diagonal cracks initiated and the longitudinal steel started to strain. In the flanged specimens, for instance, this phase started at an average applied shear force of approximately 95-125kN for G2 specimens. The longitudinal steel strain continued to increase with increasing load until either the steel yielded or steel that yielded is easily identified by the failure occurred by flexure in flange. Given the applied load, the strain in the longitudinal steel

was substantially greater in specimens with T3. It must be noted, however, that yielding of longitudinal steel wasn't achieved in most cases, this is due to small of flange thickness.

5.2 Concrete strain

The results representing the shear force versus the concrete strain measured on the concrete, for all specimens, indicate that in the initial phase of loading, the compression concrete struts are practically not strained. This holds true up to an applied shear force of approximately 85 kN for specimens with no flange and 105 kN for specimens retrofitted with flange. In other words, contributions of both the concrete struts and the flange engage only after the diagonal cracks have developed. Consequently, the truss mechanism becomes effective only after the formation of the diagonal cracks. From then, it is observed that the strut strain increased almost linearly with increasing loads until it reached approximately 800 micro-strains, on average. Beyond that point, the curves featured a somewhat plastic response. Physically, this corresponds to the propagation of cracks towards the compression zone. The strut strain at failure attained 1000 to 1800 micro-strains on average.

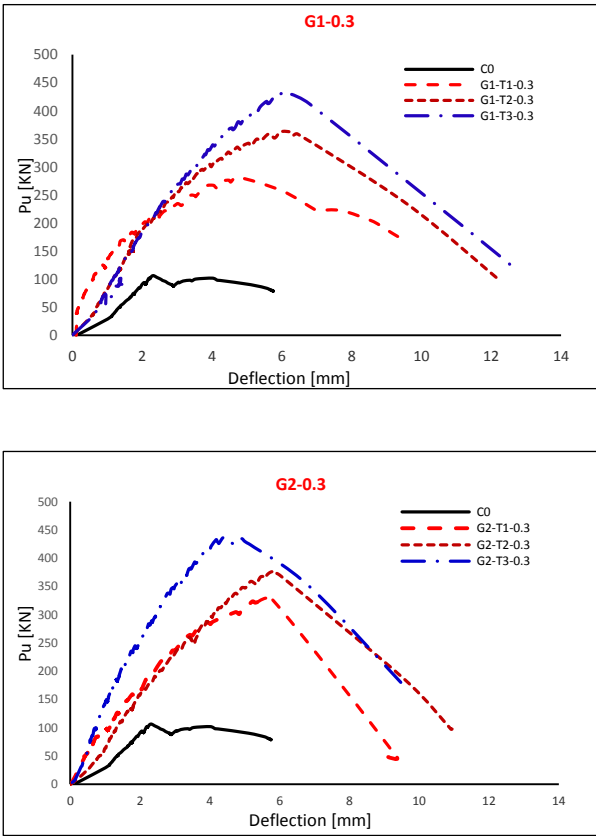


Fig. (3) Load deflection relationship

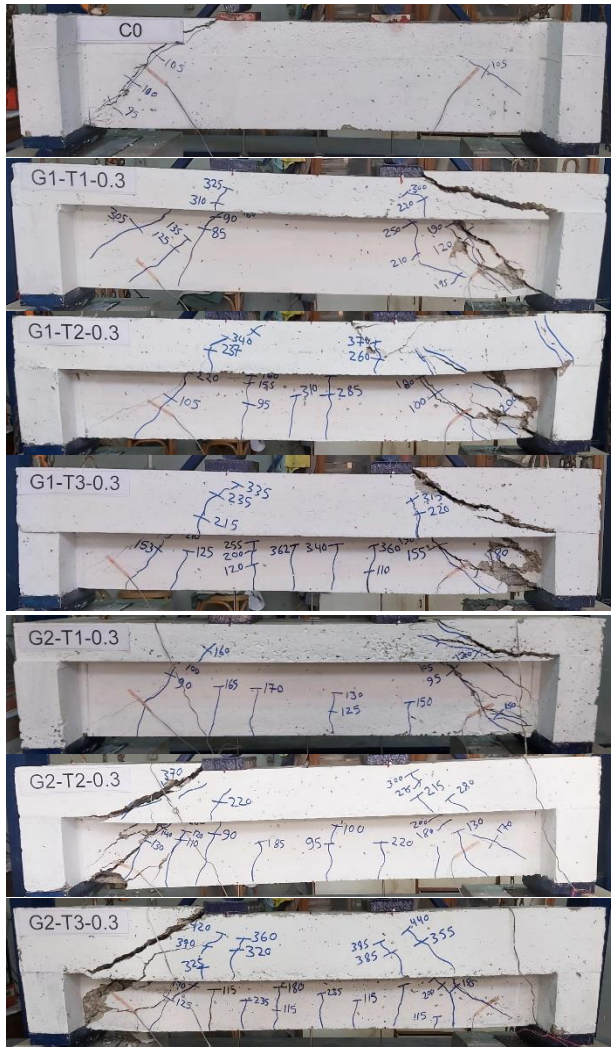


Fig. (4) Experimental Crack Pattern

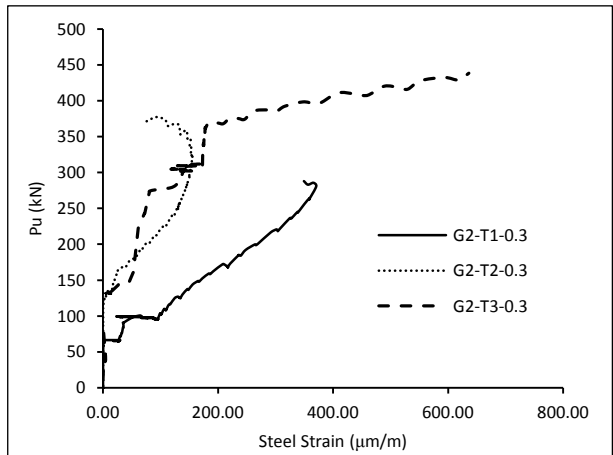


Fig. (5) Steel Strain ($\mu\text{m/m}$)

6. Brief overview for shear capacity of the rectangular beam models.

The total shear resistance (V) is as generally known, Eq. [1], the addition of the shear resisted by concrete and the transverse reinforcement is called (V_s). However, the shear-resistant concrete contribution in this model is split specifically into the following components Fig. 9, The term of uncracked compression chord defied shear as (V_c), transferring shear through across web cracks (V_w) and the participation of the longitudinal reinforcement (V_l).

$$V = V_c \cdot V_w \cdot V_l \cdot V_s = f_c \cdot b \cdot d (v_c + v_w + v_l + v_s) \quad [1]$$

where v_c , v_w , v_l and v_s are the dimensionless values of the shear transfer actions, whose relative contribution to the shear strength varies along the different load stages. As the load increases, the strains at the web, and consequently the crack width, increase and the aggregate interlock decreases; therefore, due to equilibrium, the decrease on aggregate interlock must be balanced by an increase in the shear transferred by the compression concrete chord. The magnitude of each dimensionless contributing component at the imminent failure can be estimated as presented in Table 3. A brief summary of the derivation of each equation presented in Table 1 will be presented later on this paper. It must be highlighted that, in Eq. 1, the individual components have been normalized with respect to the section tensile capacity $f_{ct} \cdot b \cdot d$ but, as will be seen later on this paper, the model assumes that failure is given for a combination of biaxial stresses and, therefore, the proposed formulation could be derived as a function of the tensile concrete strength or the compression concrete strength, without affecting the final result.

Table-3: simplified expressions for rectangular or T beams of dimensionless shear contributing components. Adapted from Ref. [15]

Contributing component	Final simplified dimensionless expressions
Cracked concrete web	$v_w = 167 \frac{f_{ct}}{E_c} \left(1 + \frac{2E_c G_f}{f_{ct}^2 d} \right) \frac{b_w}{b} \quad [23]$
Longitudinal reinforcement	if $v_s > 0 \rightarrow v_l = 0.23 \frac{v_c \rho}{1 - \chi/d} \quad [24.a]$
	if $v_s = 0 \rightarrow v_l = 0 \quad [24.b]$
Transversal reinforcement	$v_s = 0.85 K_\theta \rho_w \frac{f_{yw}}{f_{ct}} \quad [25]$
Compression chord	$v_c = \zeta \left[\left(0.70 + 0.18 K_T + \left(0.20 + 0.50 \frac{b}{b_w} \right) v_s \right) \frac{\chi}{d} + 0.02 K_T \right] \frac{b_{v,eff}}{b} \quad [26]$

The model presented is applied for the prediction of the ultimate shear strength of reinforced concrete T-beams. Table 4 shows comparisons of the theoretical results according to the proposed model with 7 test results of T-beams. The experimental and the theoretical model results are in good agreement for all tests with a mean deviation less than 1.22 and a standard deviation of 0.17.

Table-4: Verification of experimental results for rectangular and T specimens.

Specimen	$P_u(\text{exp.})$	$P_u(\text{cal.})$	$P_u(\text{exp./cal.})$
C0	106.35	105.80	1.01
G1-T1-0.3	281.9	261.40	1.08
G1-T2-0.3	362.72	288.38	1.26
G1-T3-0.3	430.58	294.15	1.46
G2-T1-0.3	325.98	271.67	1.20
G2-T2-0.3	377.45	297.55	1.27
G2-T3-0.3	438.56	303.09	1.45
mean			1.22
Stdev.			0.17

Conclusions

Based on the analysis of test results presented above, the following conclusions are drawn:

1. Presence of flange in the compression zone of T-shaped beams enhances the section shear strength at both cracking and failure. This enhancement increases with the increase in flange dimensions. Nevertheless, the increase in flange width is more effective in increasing section shear strength than the increase in flange thickness. Results also depend on whether the flange is unreinforced (type G1); reinforced with longitudinal bars only (type G2).
2. Test results showed that increasing the flange-width to web-width ratio (b_f/b_w) from 3 to 5 increased the shear strength of T-beams by up to 6%, 8% & 0.4% for unreinforced flanges (type G1) with flange-thickness to beam-depth ratios (t_f/t) of 0.3, 0.4 & 0.5, respectively. These values increased to 4.8%, 1.6% & 1.8%, respectively, for flanges reinforced with longitudinal bars only (type G2); and to 19.8%.
3. The thickness effect on the shear power, take the minimum thickness "T1" of each group as the reference value, for the first group, the final load increased by 28.7, 52.7 per cent for T2&T3, respectively. For the second group the cumulative load of G2-T1-0.3 was increased by 15.8 per cent and 34.5 per cent respectively for T2&T3. Finally, the third group Submitted 7.2%, 26.7% respectively for T2&T3
4. The amount of longitudinal reinforcement in flange affects the percentage of shear force carried by the flanges. The longitudinal reinforcement ratio, lead to enhancement its shear transfer capacity in the web and increasing the shear resisted by the flanges.
5. The rate of propagation of crack decreases as the T-shaped specimens reach the flange, especially in specimens that include longitudinal reinforcement in flange.
6. The approaching of neutral axis to the flange leads to a decrease in shear strength, with the specimens without longitudinal reinforcement.

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