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Shear Strength of Reinforced Concrete T-Beams

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Abstract

This work aims at studying the behavior of concrete T-beams in shear, and comparing this work with existing codes.

Forty two T-beams, obtained from the literature, have been studied in this work-32 with stirrups and 10 without. All these beams, with their flanges and part of their stems in compression (i.e. acting truly as T-beams), failed in shear. Existing codes (1-4) do not give any additional strength estimation due to the presence of the flange.

Regression analysis led to a proposed design equation for T-beams. To examine the accuracy of the proposed method and the existing methods, statistical analysis [Standard Deviation (SD) and Coefficient of Variation (COV)] of shear failure strength to predicted design value are used. The proposed method gives lower SD and COV values which are 0.194 and 13.79% respectively comparing with the best values of BS method which are 0.358 and 20.58%.

Keywords: Longitudinal steel ratio ρ_w, reinforced concrete, T-beams, web reinforcement, shear design.

مقاومة القص للعتبات الخرسانية المسلحة على شكل حرف T

الخلاصة

يهدف البحث الحالي إلى دراسة تصرف القص للعتبات الخرسانية ذات مقطع على شكل حرف T ، تم دراسة سعة القص لهذه العتبات من خلال طرق تصميمية متوفرة في المدونات.

تمت دراسة 42 عتبة على شكل حرف T في هذا البحث أخذت معلوماتها من الأدبيات-32 عتبة منها مسلحة بالأطواق، والعشرة المتبقية بدون أطواق.فشلت كافة العتبات بالقص و كانت الشفة لكل منها في حالة أنضغاط. المدونات الحالية (1-4) لا تعطي تقديرا إضافيا لمقاومة القص في حالة وجود شفة للعتبة الخرسانية.

بالاعتماد على التحليل الارتدادي يقترح البحث طريقة لتصميم العتبات على شكل حرف T للقص. لفحص دقة الطريقة المقترحة ولمقارنتها بالطرق المتوفرة أستخدمت تحليلات أحصائية (الانحراف المعياري ومعامل التغاير) للمقاومة الفعلية والتصميمية للقص. كانت قيم النتائج الإحصائية للطريقة المقترحة هي 0.194 - 13.79% بالمائة لقيم الانحراف المعياري ومعامل التغاير على الترتيب مقارنة مع أفضل طريقة من الطرق المتوفرة وهي طريقة الكود البريطاني حيث كانت نتائجه 0.358 -20.58% بالمائة لقيم الانحراف المعياري ومعامل التغاير على الترتيب.

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Notation

a	Shear span, distance between concentrated load and face of support, *mm*
b_f	Flange width, *mm*
b_w	Web width, *mm*
COV	Coefficient of variation of (V_{test} / $V_{r\text{-}calc.}$)
d	Distance from extreme compression fiber to centroid of longitudinal tension reinforcement, *mm*
f'_c	Specified compression strength of concrete, MPa
f_y	Specified yield strength of reinforcement, MPa
M_u	Factored moment at section considered, *N.mm*
SD	Standard deviation
V_c	Nominal shear strength provided by concrete, *N*
V_n	Nominal shear strength , *N*
$V_{r\text{-}ACI}$	Shear resistance calculated by ACI-02 method (reference1),*N*
$V_{r\text{-}BS}$	Shear resistance calculated by BS-85 method (reference 2),*N*
$V_{r\text{-}NZ}$	Shear resistance calculated by NZ-82 method (reference 3), *N*
$V_{r\text{-}CAN}$	Shear resistance calculated by CAN-84 method(reference4),*N*
$V_{r\text{-}prop.}$	Shear resistance calculated by the proposed method, *N*
V_s	Nominal shear strength provided by stirrups, *N*
V_u	Factored shear force at section considered, *N*
$\bar{x}$	Mean value of (V_{test} / $V_{r\text{-}calc.}$)
ρ_v	Ratio of vertical shear rein- forcement
ρ_w	Ratio of tension reinforcement

Introduction

In practice there may exist beams that carry concentrated loads applied at distances far from their supports. With these beams there may be a situation where both shear and bending moment are high. When these beams are T-beams, a requirement is needed for design of these beams where both shear and bending are high.

At present, no design code is available that takes into account the shear capacity of T-beams with high positive bending moments where the flange is in compression. This is evident from references (1-4).

Research Significance

The paper reviews the shear design based on 4-code methods: ACI-02[1], BS-85[2], NZ[3] and CAN[4], all of which show no strength contribution from the flange on the compression side.

The 42 tests of T-beams failing in shear are used to evaluate these 4 methods. A proposed simple design method, which is based on a regression analysis, is introduced.

Experimental Results

All available tests of shear failure of flanged beams obtained from the literature are used in this work. Table (1) gives the range of variables of these 42 flanged beams-32 of which are with stirrups. These variables are: compressive strength of concrete f_c', shear span to depth ratio a/d, width ratio b_f/b_w, ratio of tension reinforcement ρ_w and nominal stirrup strength $\rho_v f_y$. These beams are obtained from references (5-7).

Evaluation of Experimental Results Existing Shear Design Equations:

The following 4 existing methods considered in this work are applied to the experimental results of flanged beams failing in shear[1-4].

To compare between design methods, shear resistance $V_{r\text{-calc.}}$ will be used instead of the nominal $V_{n\text{-calc.}}$ throughout (e.g. per ACI318 code[1]: $V_{r\text{-calc.}} = 0.75\ V_{n\text{-calc.}}$).

1-ACI 318 M-02 Code Method[1]:

$$V_{r-ACI} = \phi\left\{\left[\left(\sqrt{f_c'} + 120\rho_w \frac{Vu \cdot d}{M_u}\right)\Big/7\right] b_w d + \rho_v f_y b_w d\right\} \quad ...(1)$$

where

$$V_c = \left[\left(\sqrt{f_c'} + 120\rho_w \frac{Vu \cdot d}{M_u}\right)\Big/7\right] b_w d \le 0.3\sqrt{f_c'}\, b_w\, d$$

$$V_s = \rho_v f_y b_w d \le \frac{2}{3}\sqrt{f_c'}\, b_w\, d$$

$$\frac{Vud}{Mu} \le 1.0$$

- ϕ Strength reduction factor equal to 0.75
- f_c' Specified compressive strength of concrete, MPa
- ρ_w Ratio of tension reinforcement
- b_w Web width, *mm*
- d Distance from extreme compression fiber to centroid of longitudinal tension reinforcement, mm
- V_u Factored shear force at section considered, N
- M_u Factored moment at section considered, N.mm
- ρ_v Ratio of vertical shear reinforcement
- f_y Specified yield strength of reinforcement, MPa
- V_c Nominal shear strength provided by concrete, N
- V_s Nominal shear strength provided by shear reinforcement, N

2-British Code Method[2]:

$$V_{r-BS} = 0.79\left(100\rho_w\right)^{1/3}\left(\frac{400}{d}\right)^{1/4}\left(\frac{f_c'}{20}\right)^{1/3} b_w d\phi_c + \rho_v f_y b_w d\phi_s \quad ...(2)$$

where

ϕ_c = Strength reduction factor for concrete equal to 0.8

ϕ_s = Strength reduction factor for reinforcement equal to 0.87

$0.03 \ge \rho_w \ge 0.0015$

$$\frac{400}{d} \geq 1$$

$$32\ \text{MPa} \geq f_c' \geq 20\ \text{MPa}$$

3-<u>New Zealand Code Method</u>[3]:

$$V_{r-NZ} = \phi\left[\left(0.07+10\rho_w\right)\sqrt{f_c'}\,b_w d + \rho_v f_y b_w d\right] \quad ...(3)$$

where

$\phi = 0.85$

$$V_c = \left(0.07+10\rho_w\right)\sqrt{f_c'}\,b_w d \leq 0.2\sqrt{f_c'}\,b_w d$$

4-<u>Canadian Code Method</u>[4]:

$$V_{r-CAN} = 0.2\sqrt{f_c'}\,b_w d\,\phi_C + \rho_v f_y b_w d\,\phi_S \quad ...(4)$$

where

$\phi_c = 0.6$

$\phi_s = 0.85$

$$V_c = 0.2\sqrt{f_c'}\,b_w d$$

Statistical evaluation of existing design methods:

Table (2) indicates the values of the results of the 42 tested beams, compared with predicted strength (V_{test} / $V_{r\text{-}calc.}$). These values show a range of 1.406-2.247 for the mean of this ratio. The Canadian code method is the most conservative with all 42 beams being on the safe side. This method has the highest mean value (2.247). The highest low ratio (1.298) and the highest high ratio (4.743) of all 5 methods of design are shown in Table (2).

The coefficient of variation (COV) gives a good indication as a measure of the relevance of the method for prediction of the ratio (V_{test} / $V_{r\text{-}calc.}$). From Table (2),it can be seen that the Canadian code method has the highest COV (at 37.51). The best COV of all 4 existing methods is in the BS code method (at 20.58).

Regression analysis of test results:

By using the regression analysis, the 42 test results were analyzed by a personal computer. The aim is to obtain a simple and conservative design method for shear that gives the lowest possible COV values of the ratio (V_{test} / $V_{r\text{-}calc.}$). This has led to the following prediction equation for $V_{r\text{-}prop.}$:

$$V_{r-prop} = \left(0.084+11\rho_w\right)\left(f_c'\right)^{0.3} b_w d + 0.315\left(b_f - b_w\right)t_f + \rho_v f_y b_w d \quad ...(5)$$

where

b_f = flange width, *mm*

t_f = flange thickness, *mm*

The proposed equation has lesser values of statistical results than other methods with safer predictions. Table (2) shows a summary of statistical evaluation of the proposed design method.

To illustrate the relevance of the proposed design method the ratio of (V_{test} / $V_{r\text{-}calc.}$) has been compared by this method with that of the latest available design code procedure-Eqn.(1) by ACI 318 M-02. These are shown in Figs. (1,2 and 3).

The comparison in Fig.(1) between the ACI-02 method and the proposed method shows, as expected from Table (2), a large scatter in the ACI-02 method, as compared to the proposed Eqn.(5). Proposed equation gives the more accurate representation with the safety consideration.

Fig.(2 and 3) show that the ACI-02 method leads to excessively conservative predictions at higher ratio of tension by reinforcement (ρ_w) and stirrup stress values ($\rho_v f_y$) in marked contrast to design by Eqn. (5).

Conclusions

Based on this work, the following conclusions are made:

1. Most results of ACI-02 indicate conservative prediction of strength with high arithmetic mean of (V_{test} / $V_{r\text{-}calc.}$). While the proposed method led to improve results compared to ACI-02. The proposed method gives conservative strength values with low arithmetic mean of (V_{test} / $V_{r\text{-}calc}$).
2. Table (2) shows that the COV of the ratio (V_{test} / $V_{r\text{-}calc.}$) was in descending order 37.51, 30.23, 27.19 and 20.58 respectively using CAN-84, ACI-02, NZ-82 and BS-85 methods.
3. In the comparison between the latest available code method of design (ACI-02) and the proposed method, the following conclusions are obtained:

   i- Fig.(1) shows that the safety of prediction by the proposed method is essentially unchanged within the range of f_c'. This contrasts with ACI-02, a slight drop of safety with increasing f_c' can be noticed indicating that this method has lesser margin of safety with increasing f_c', i.e. a negative slope is obtained from results of (V_{test} / $V_{r\text{-}calc.}$) versus f_c'.

   ii- Similarly the longitudinal steel ratio Fig.(2) has little influence on the safety of prediction by the proposed method, in contrast with ACI-02 method.

   iii- Similar conclusion is drawn from Fig.(3), where changes in ($\rho_v f_y$) has little influence on the safety of prediction by the proposed method- contrasting with ACI-02 method.

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Future Research

The following items are recommended for future studies

1. Shear capacity of high strength concrete flanged beams.
2. Modifying the equations, which are used in present study for predicting the shear strength for beams having I and L sections .

References

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Table (1): Range of variables for 42 tested beams.

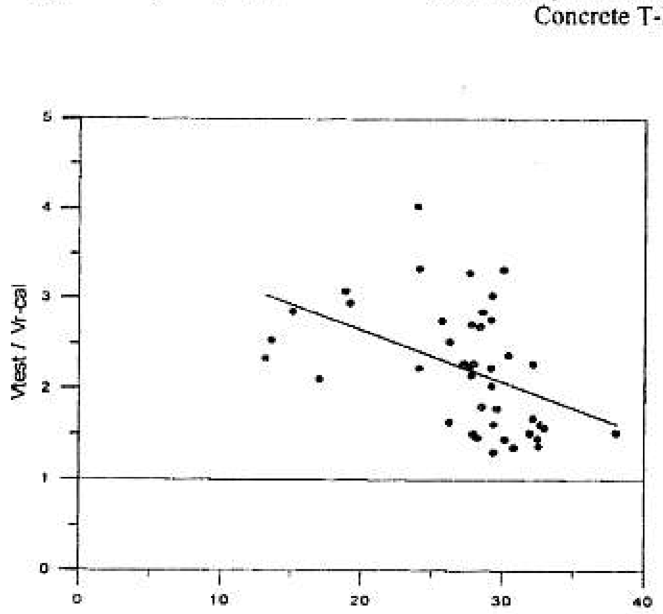
Detail	f_c', MPa	Depth ratio a/d	ratio Width b_f/b_w	ρ_w, percent	$\rho_v f_y$, MPa
Low	13.22	2.5	2.49	0.49	0.22*
High	38.07	6	4.28	4.75	2.71

*10 specimens without stirrups are not included where $\rho_v f_y=0$

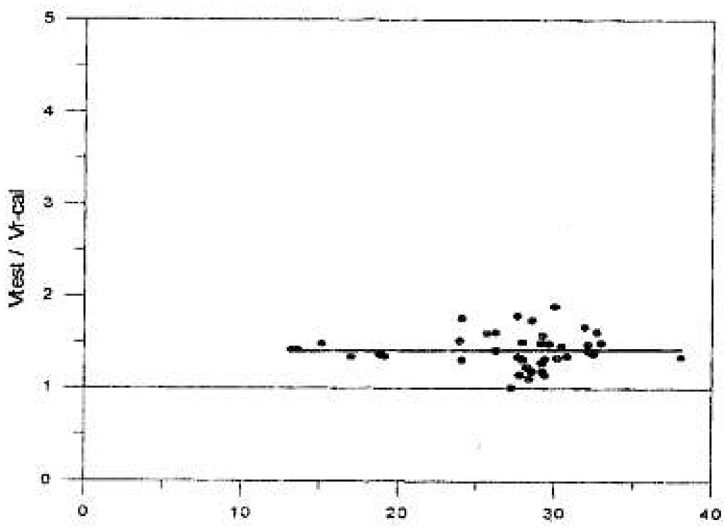
Table (2): statistical analysis of the ratio ($v_{test}/v_{r\text{-}calc}$) for 42 specimens.**

Detail	ACI-02	BS-85	NZ-82	CAN-84	Proposed equation
$\bar{x}$	2.23	1.740	1.917	2.247	1.406
SD	0.674	0.358	0.521	0.843	0.194
COV%	30.23	20.58	27.19	37.51	13.79
Low	1.298	1.123	1.05	1.22	1
High	4.018	2.599	3.348	4.743	1.88
No.<1.0	0	0	0	0	0

**No. of specimens = 42 (10 without stirrups + 32 with stirrups)

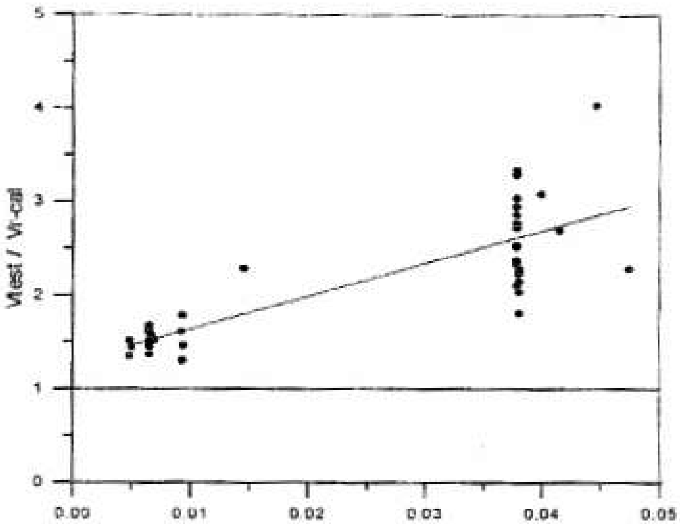


Compressive strength of concrete f_c', MPa
a- ACI-02 method

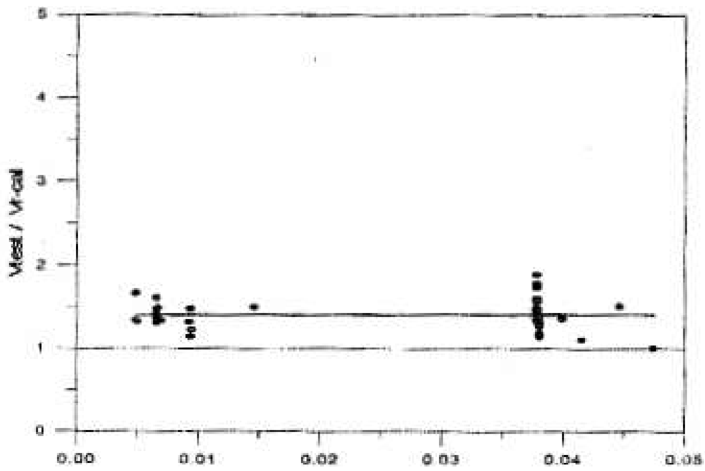


Compressive strength of concrete f_c', MPa
b- Proposed method

Figure (1): Influence of compressive strength of concrete f_c' on test results.

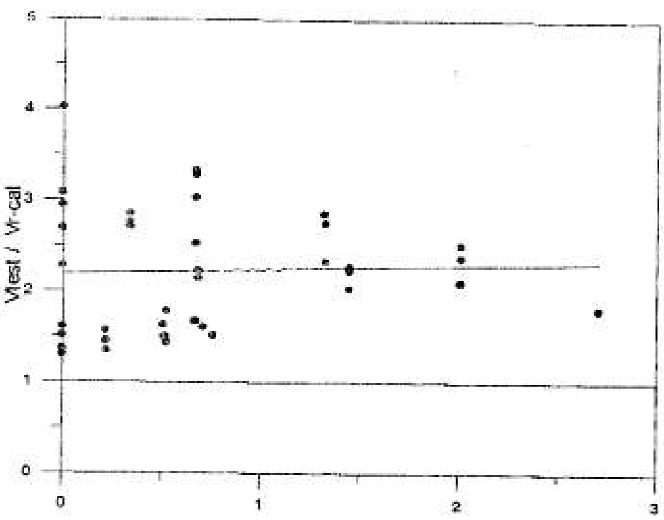


Ratio of tension reinforcement ρ_w
a- ACI-02 method

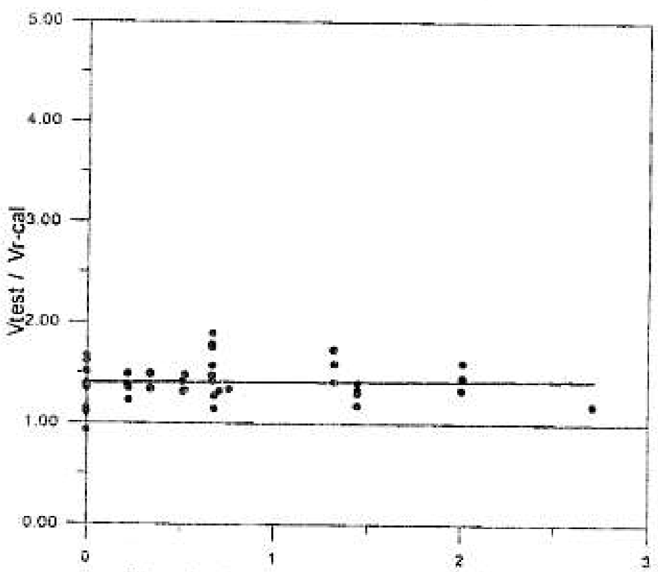


Ratio of tension reinforcement ρ_w
b- Proposed method

Figure (2): Influence of Ratio of tension reinforcement ρ_w on test results.



Nominal stirrup strength $\rho_v f_y$, MPa
a- ACI-02



Nominal stirrups strength $\rho_v f_y$, MPa
b- Proposed method

Figure (3): Influence of Nominal stirrup strength $\rho_v f_y$ on test results.