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Study on shear strength of reinforced concrete T beams based on the size effect

Size effect has great influence on the shear strength of reinforced concrete T beams, flange width changes the shear mechanism of reinforced concrete T beams. In combination with shear database, comparing the calculation results of formula based on the effective flange width with other specifications formulas by means of Matlab, the flange width can increase the shear capacity of reinforced concrete T beams, and the recommended formula considering the effective flange width is reasonable.

Keywords: Reinforced concrete T beams; shear; size effect; Matlab.

1.0 Introduction

The concrete members under the action of shear force is a high degree of uncertainty system controlled by multiple variables, the obvious size effect is existed in shear strength. The follow-up studies continued to increase since 1967 Kani [1] put forward the size effect of the shear strength in concrete beams. There are a lot of factors which impact on the shear capacity of reinforced concrete beams, the influence of size effect on the shear capacity of concrete beams is more large. In the reinforced concrete T beams the size effect factors include height of the beam (span-depth ratio), web width, flange width and thickness, etc. That the shear stress of deep beams component is decreased with the increase of section size has been shown in research [2]. The effective height d_c of the critical section is considered in the ACI code, when the effective height of beams is more than 150 mm, the influence of size effect should be considered. On the basis of fracture mechanics of concrete, aiming at the brittleness characteristic of concrete fracture, Bazant put forward the size law of concrete structure [3]. But Collins believes that the modified compression field theory can fully explain the size effect of concrete shear based on the assumption of geometric similarity on crack width and crack height [4]. Zararis studied the influence of the size effect on the oblique shear failure [5]. The relationship between the average shear stress and the effective height of concrete beams was analysed and researched on detailed datas by Quzhe [6], there were obvious size effect in the beams with or without abdominal muscle. The influence coefficient of compressive flange α_3=1.1 is considered when calculating the shear bearing capacity for inclined section in "Code for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts structures" [7]. In this paper, the shear capacity of reinforced concrete T beams will be studied from studying the shear bearing capacity theory to collect shear datas of 62 reinforced concrete T beams, finally evaluating and analysising the shear strength based on the size effect.

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2.0 The shear strength of reinforced concrete T beams

Comparing to other rectangular beams with the same conditions, T beams are more favourable to transmit pressure of concrete compression area, the experiment results also show that the shear strength of T beams is higher than other rectangular beams[8]. The test results by Kani [9] show that the influence of size effect with the web width change of beams is very small. But in the comparison of ACI code formula with the test datas of rectangular section beams and T beams that ACI code formula is very safe to calculate with ACI code formula (1) in T beams, and the shear mechanism of beam without web reinforcement is changed by T beams flange in some degree.

$$V_u = 2b_w d\sqrt{f_c'} \quad \text{... (1)}$$

In American specification ACI 318-14 [10] the calculation formula on shear bearing capacity of reinforced concrete T beamas is:

$$V_u = \emptyset(V_c + V_s) \quad \text{... (2)}$$

$$V_c = (0.158\sqrt{f_c'} + 17.2\rho_w \frac{V_u d}{M_u})b_w d \le 0.291\sqrt{f_c'}b_w \quad \text{... (3)}$$

$$V_s = \frac{A_v f_{yt}}{S} d \le 0.665\sqrt{f_c'}b_w \quad \text{... (4)}$$

where: $\varnothing$ is the reduction factor of shear strength, the value is 0.75; f'_c is the compressive strength of concrete cylinder; ρ_w is the ratio of longitudinal steel reinforcement; b_w is the width of rectangular beam; d is the effective height of beam; M_u, V_u is respectively the bending moment and shear of calculation section, and $\frac{V_u d}{M_u} \le 1$; s is the stirrup spacing along the length direction of the components; A_v is cross section area of stirrup in spacing s; f_{yt} is stirrup yield strength.

Moreover, when the problem of size effect on the shear strength of T beams reduces to the problem of size effect on the splitting strength of concrete [11], a correction factor is introduced to account for the size effect in slender beams, as follows:

$$V_u = V_{cr} + (0.5 + 0.25\frac{a}{d})\rho_v f_{yv} b_w d \quad ...(5)$$

where $$V_{cr} = \left(1.2 - 0.2\frac{a}{d}d\right)\frac{c}{d} f_{ct} b_w \quad ...(6)$$

$$1.2 - 0.2\frac{a}{d}d \geq 0.65 \quad ...(7)$$

As it is commonly believed that $a = (a/d)d$ is taken into account, the size effect in T beams appears to depend not only on the size of the depth d, but also on a/d.

In the case of T-beams, it must be taken into account that the width of the compression area, therefor, the width of the area where the splitting of concrete occurs (forming the second branch of critical diagonal cracks) is not remaining constant, but it is changing from the width b_w of the web to the width b of the flange. It can be considered that the splitting of concrete in the compression area takes place in an area, the projection of which, on a cross section of the beam, is approximately defined from the shaded part of the section.in Fig.1. Defining as "effective width" of a T-beams in shear $b_{ef} = A/c$, where A equals the area of the shaded part of the cross section, and c equals the distance from extreme compression fiber to neutral axis (depth of compression zone), the following expression is derived [12]:

$$b_{ef} = b_w\left[1 + 0.5\frac{h_f}{d}\left(\frac{b}{b_w} - 1\right)/\frac{c}{d}\right] \quad ...(8)$$

where h_f is the flange thickness, d is The effective width b_{ef} can replace the width b_w in Eq. (1) for the shear strength of T-beams without shear reinforcement.

Moreover, because the failure is due to splitting of concrete in the compression area when it also occurs in the rectangular beams, there is a similar size effect and the same correction factor to account for it. According to the aforementioned, the shear force at the formation of the second branch of the critical diagonal cracks, that the shear strength of T-beams without shear reinforcement is:

$$V_{cr} = \left(1.2 - 0.2\frac{a}{d}d\right)\frac{c}{d} f_{ct} b_{ef} d \quad ...(9)$$

According to the aforementioned, the ultimate shear strength of the T-beams is given as follows[13]:

$$V_u = \left[\left(1.2 - 0.2\frac{a}{d}d\right)\frac{b_{ef}}{b_w} \times \frac{c}{d} f_{ct} + (0.5 + 0.25\frac{a}{d})\rho_v f_{yv}\right] b_w d \quad ...(10)$$

3.0 Datas evaluation based on analysis of size effect

In order to evaluate the influence of the flange of T beams, the ratios of required to computed shear areas (A_{req}/A_{comp}) versus flange-to-web width (b_f/b_w) for the rectangular and T-beams combined databases were plotted in Fig.2. Required shear areas A_{req} were calculated by dividing the reported shear at a distance d away from the supports with the uniform shear stress assumed to be carried in that section at failure ($5\sqrt{f'_c}$). Computed shear areas A_{comp} were based on the concrete compression area that was calculated using an elastic cracked section analysis considering the entire flange width. Because there is a discontinuity in the shear stress diagram for beams whose neutral axis lies below the flanges, these beams were considered to not provide an accurate indication of the effect of the flange. Therefore, only T-beams with neutral axis depths, calculated using a linear elastic cracked section analysis, remaining within the flange thickness were included in Fig.2.

From the ACI code formula, "Code for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts structures" [7] (Bridge code), "Code for design of concrete structures" [15] (Concrete code), Formula (10) and the results of experiment that is found the shear of T beams is higher than the rectangular beams with the same size (the web width), at the same time almost all the test datas are

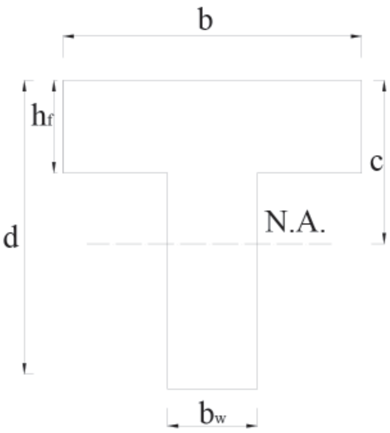

Fig.1: Cross section of T-beam with effective in shear area of concrete

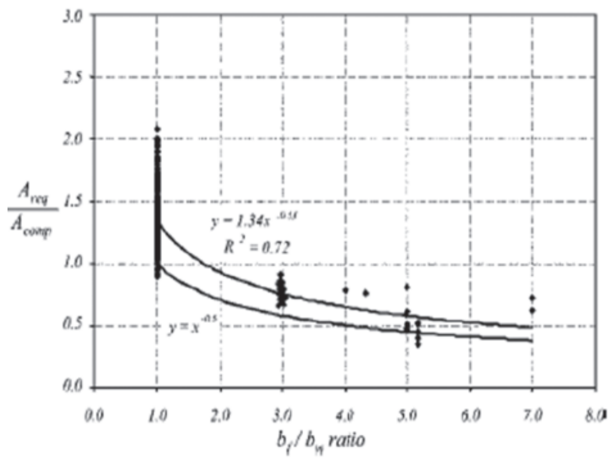

Fig.2: Effect of b_f/b_w ratio on effective shear area [14].

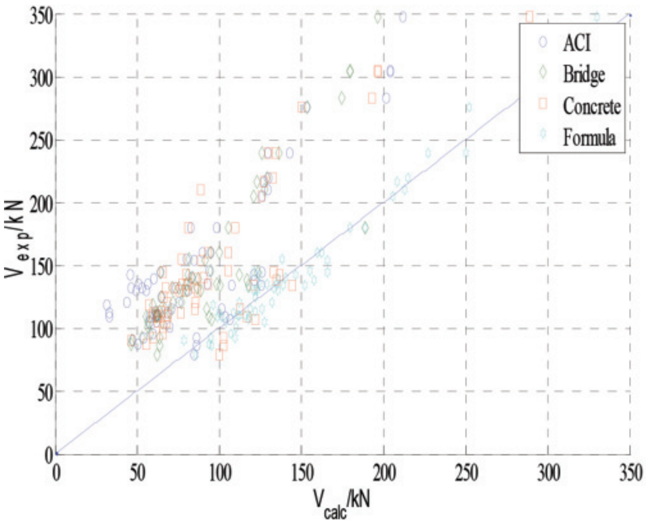

Fig.3: The comparison of experiment value with the theoretical value

bigger than the datas of standard formula, in Fig.3 that almost all of the experimental values of shear versus the theoretical values is above 45 degrees line, it suggests that the standard calculation formula of T beams is more safe.

At the same time in the experiment b/b_w is 1~6, that is to say in a way the flange changes the shear mechanism of T beams. The shear bearing capacity of T beams and rectangular beams is different with the change rule of reinforcement ratio, concrete compressive strength, ratio of shear span to effective depth and effective depth of section etc.. From the databases V_{exp}/V_{calc}>1 that computed by ACI, "Bridge code", "Concrete code", but the average V_{exp}/V_{calc} calculated by formula (10) is alomost 1, the standard deviation is smaller than the above three results. It suggests that formula (10) is in line with the experiment, the values are close to each other, formula (10) can be used to calculate the shear strength of reinforced concrete T beams.

4.0 Conclusion

Size effect has great influence on the shear strength of reinforced concrete beams, flange width obviously increases the shear strength of reinforced concrete T beams, and changes the shear mechanism. Comparing the calculation results of formula based on the effective flange width with other specifications formula on the basis of collected shear datas, it showes that the recommended formula is feasibility.

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