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Predicting the shear–flexural strength of slender reinforced concrete T and I shaped beams

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ABSTRACT

A mechanical model previously developed by the authors for the prediction of the shear–flexural strength of slender reinforced concrete beams with rectangular cross-section with or without stirrups has been extended to beams with T and I cross-sections. The effects of the section shape on each shear transfer action have been identified and incorporated into the corresponding equations. General expressions for strength verification and transverse reinforcement design have been derived. The contribution of the flanges to the shear strength is accounted for by means of an effective shear width, which depends on the section geometry and on the longitudinal reinforcement ratio. The effect of the vertical confinement stresses introduced by the shear reinforcement on the concrete web is also considered. The expressions derived are valid, as particular cases, for beams with inverted T or rectangular cross sections. The proposed equations have been checked with experimental results available in the literature, obtaining very good results. The simplicity, straightforwardness of application and the accuracy of the method make it suitable for daily engineering practice.

1. Introduction

T-shaped sections are widely used in RC beams and slabs because of their high flexural efficiency. The compression force generated by the bending moment is distributed along the effective width of the compression flange, b, which is higher than the web width, b_w, generating a lower compression block depth and a higher lever arm z, compared to that in a rectangular section of width $b = b_w$. In addition, the weight of the section is reduced with respect to a rectangular beam of the same top width.

Current codes usually separate the flexural and the shear resistant mechanisms: while bending is taken by the pair of forces C (compression at the concrete chord) and T (tension at the longitudinal reinforcement), shear is assumed to be taken by the web, by means of a truss mechanism, see Fig. 1. Therefore, they do not consider any contribution of the flanges to the shear strength.

Such simplification does not represent with fidelity the behavior of slender RC members with T-shaped sections at ultimate load levels. Even in the case of rectangular sections, the truss analogy must be corrected to take into account that part of the shear is taken not only by the web, but also by the compressed concrete chord, by the longitudinal reinforcement (dowel action), by frictional forces along the crack length and by residual tensile stresses in the closest part of the cracks. All these aspects are included in a term called “concrete contribution to shear strength”, V_c, which in case of slender beams does not include the “arch effect”.

In slender beams subjected to shear and bending, flexural cracks initiate at the tensile face, and subsequently develop inclined through the web. As the load increases, damage concentrates around the so-called critical shear crack [1], whose first branch arrives to the neighborhood of the flexural neutral axis. Under incremental loading, a second branch of the critical shear crack develops inside the concrete chord, which eventually connects the first branch of the crack and the point where the load is applied, producing failure, see Fig. 2. This way of dividing the critical shear crack in two branches was also observed by Zararis and Papadakis [2].

As the load increases, the inclined cracks open and the contributions to shear strength of the frictional forces along the crack length and that of the residual tensile stresses diminish. The shear stresses along the critical crack decrease and they concentrate in the closest top part of the cracks and in the compression chord of the beam, especially after stirrups yield. In addition, as the load increases, the compression force C and the normal stresses due to bending at the uncracked concrete chord increase, thus increasing

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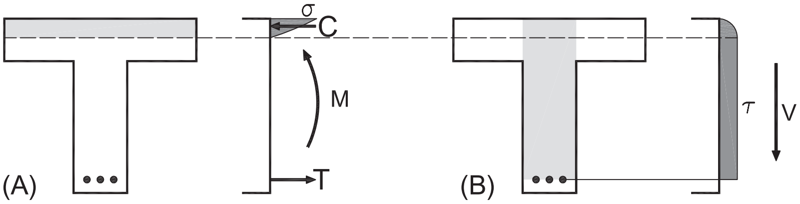

Fig. 1. Uncoupled resistant mechanisms: (A) Flexure. (B) Shear.

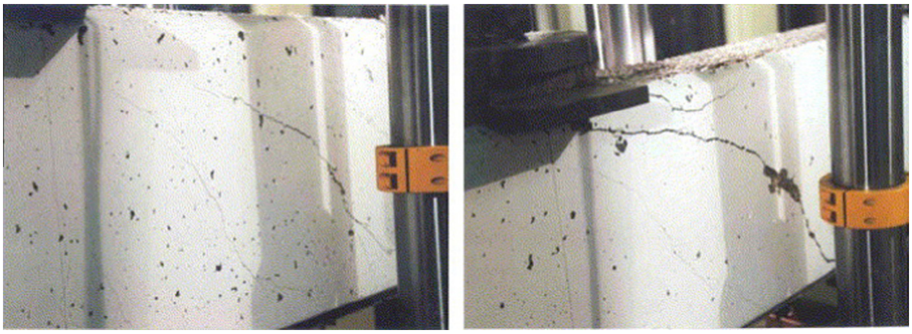

Fig. 2. Cracking prior to failure and at failure in a rectangular beam with web reinforcement (photographs from the authors) [3].

the capacity of the concrete compression chord to resist shear stresses. Therefore, near the ultimate limit state, the shear resisted by the concrete compression chord becomes very relevant.

In the case of members with T-shaped sections this phenomenon is even more apparent because of two reasons. Firstly, the neutral axis depth of a T-shaped section is closer to the top compressed fiber. Therefore, for a given ratio $M/M_{cr} > 1$, where M is the applied moment and M_{cr} is the cracking moment, and for the same reinforcement area and effective depth, the crack opening is higher in a T-shaped section beam than in a rectangular beam of the same web width, so the aggregate interlock is lower, see Fig. 3. Secondly, the concrete flange of a T-shaped section produces that, once the shear stresses concentrate on it, the contribution to the shear strength of the concrete chord is higher than in a rectangular section of $b = b_w$, turning out in higher total shear strength, as can be seen in Fig. 4.

Experimental studies [4–9] show that a considerable increase in the shear strength of slender RC beams and slabs with T-shaped section takes place with respect to beams with equal height, web width and reinforcements amounts. Fig. 4 shows that beams with 30 cm or wider flanges had about 25% greater ultimate strength than the rectangular beams [10]. This fact indicates that there exists some contribution of the compression flange which is being ignored in the current codes shear provisions.

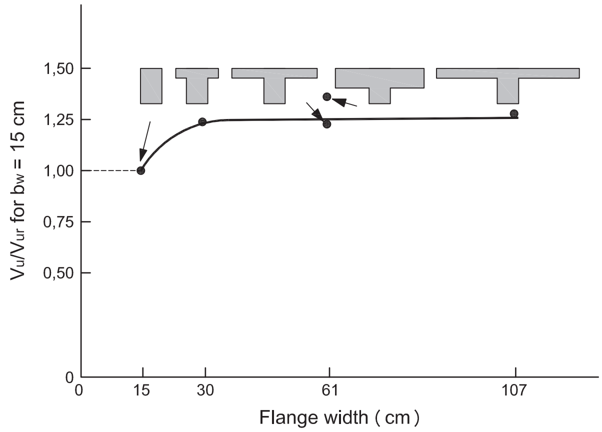

Fig. 4. Effect of flange width, adapted from [10], based on an experimental campaign published in [7].

In addition, rigorous theoretical and numerical studies carried out [11–13] confirm such concentration of stresses toward the neighborhood of the crack tip and toward the concrete compression chord. Fig. 5 shows the concrete shear stresses in a rectangular section at service and at ultimate load levels. In the case of T

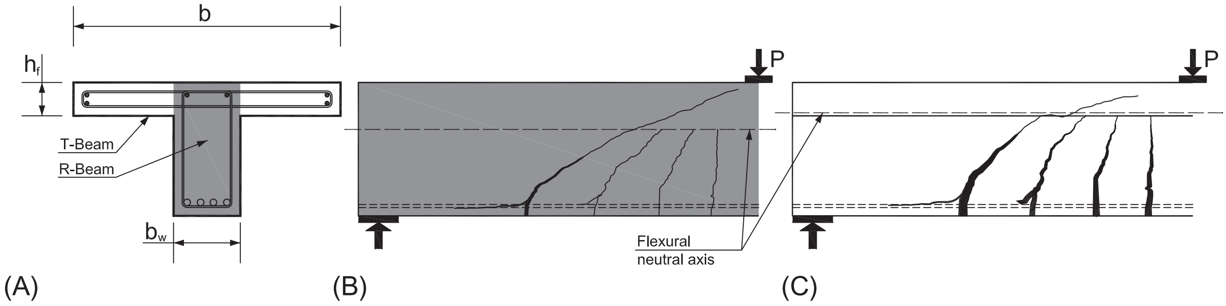

Fig. 3. Comparison between T-shaped section beam and rectangular beam. (A) Sections. (B) Crack pattern scheme of a rectangular beam. (C) Crack pattern scheme of a T beam.