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An efficient modified flanges only method for plate girder bending resistance calculation

C.K. Lee *, S.P. Chiew

School of Civil and Environmental Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore

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ABSTRACT

The very popular "Flange Only" method suggested in the BS 5950 for calculation of bending resistance of plate girder with Class 4 slender web is studied and compared with the more complicated effective width method adopted by the EC3. It is shown that within all practical range of web depth to thickness ratio, the flanges only method is conservative but sometime may be inefficient. Based on the study of these two methods, a very simple modification factor, which can be obtained conveniently by hand calculation, is proposed to improve the efficiency of the flanges only method. It is shown that the proposed modified flanges only method, while still always remaining conservative, could be able to estimate the bending resistance of the girder more accurately than the original flanges only method. In most cases, the bending resistances predicted by the proposed method are within the range of 94% to 97% of those predicted by the more complicated effective width method.

1. Introduction

The introduction of the Eurocodes is undoubtedly the biggest change in design concept and practices in the European Union and many other countries [1]. With the Europe wide implementation of the Eurocodes since 2010, conflicting national standards are gradually withdrawn in the European Union and other countries which committed to adopt the Eurocodes such as Singapore [2]. Regarding design of steel structures, while both the Eurocode 3 (EC3) Part 1-1 [3] and the BS 5950 Part 1 [4] share the same origin and are both based on the limit states design concept [3–6], there are significantly changes in different aspects of the design practices, including notations, theoretical background, structural analysis requirements and calculation procedures [7]. Hence, many design aids were written to help practical engineers and engineering students to uptake the new design standard [8–12]. In general, when comparing with other national standards like the British Standard (BS) [4], the Eurocodes gives better harmonisation of treatment while more preferences and emphases are given to the use of appropriate (and sometime more complicated) mechanical models and comprehensive analysis procedure. Regarding the design of plate girder which is one of the most commonly encountered plated structures, unlike the BS [4], no explicit section is devoted in the corresponding EC3 Part 1–5 [13] to describe the detailed design requirements and procedures. Instead, in EC3 Part 1–5 [13] for plated structure design, only the main design principles and a set of rules for some common plated structures are presented and some design formulae are given in the accompanied informative annexes. Hence, practicing engineers often need referring to some design manuals such as reference [14] for design calculations and design examples. Toward this end, one example for such situation is the calculation of bending resistance of a plate girder without longitudinal stiffener when only the web of the girder is a Class 4 slender section. While both the BS [4] and the EC3 [13] are, in fact essentially based on the *same* design principle, in the BS it is stated explicitly (Clause 3.6.2.4 of Reference [4]) how the effective width could be calculated and a sub-section (Section 4.4 of Reference [4]) is devoted to describe the design requirement of plate girder structures. Furthermore, a very popular simplified "*Flanges only*" method [4,15] is also described to allow practicing engineers to quickly estimate a conservative bending resistance of the plate girder. However, in EC3 [13] (Section 4.3 of Reference [13]), only the essential design principles are described and they are supplemented by a footnote which indicates that in order to use the "*Effective width*" method (or sometimes called the "*Effective modulus*" method) suggested by EC3, an iterative procedure is required to obtain the effective cross section and then the bending resistance. In order to fully understand the theory behind the effective width method and the actual design and calculation steps needed, a practicing engineer who is new to the EC3 may need to refer to some detailed manuals such as reference [14] for the design rule (Section 2.4.2.2 of Reference [14]) and for calculation details (Example 2.4.2 of Reference [14]). For a structural engineer who is switching from the BS design to the EC3 design, it is interesting and important to note that while the BS allows the use of the more exact effective width method stated in EC3, EC3 does *not* state (nor in guidelines such as Reference [14]) that whether the well accepted

* Corresponding author. Tel./fax: +65 67905293.
E-mail address: ccklee@ntu.edu.sg (C.K. Lee).

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flanges only method mentioned in the BS is acceptable or not. Since when portioning the dimensions of a plate girder, estimating its bending resistance is often an essential initial step toward an efficient design, it would be much useful if a comparison between the bending resistances predicted by the flanges only method and that by the effective width method could be made. The main objective of this paper is to carry out such a study to compare the bending resistances predicted by these two methods for a plate girder with a Class 4 web without longitudinal stiffener. It will be shown that while in strict mathematical sense the flanges only method does not always give a conservative bending resistance when comparing with the effective width method, it is indeed conservative within virtually all practical aspect ratios covered in usual plate girder design. However, in some cases the flanges only method appears to be too conservative and is not efficient. As a result, another contribution of this paper is to suggest a simple but practical alternative procedure to increase the efficiency of the flanges only method.

In the next section, the calculation steps for predicting the bending resistance of a plate girder with a Class 4 web without longitudinal stiffener based on the BS's flanges only method and the more exact EC3's effective width method are described. They are then followed by a comprehensive analytical study on these two methods. Based on the study results, a simple modification factor will be suggested to improve the efficiency of the flanges only method while the resulting bending resistance is still be conservative when comparing with the more exact but tedious effective width method. A calculation example will be given to demonstrate the results obtained. Finally, conclusions of the works presented will be given.

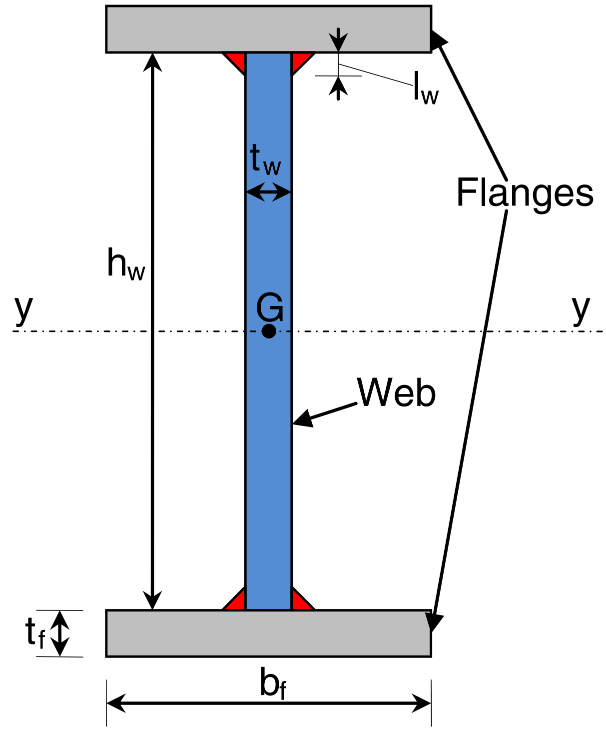

Fig. 1. A symmetrical plate girder with Class 4 web and with no longitudinal stiffener.

2. The BS's “Flanges only” method and the EC3's “Effective width” method

2.1. Notations and assumptions

Since in this paper, both the design methods based on the BS [4] and the EC3 [3,13] are referred, in order to avoid ambiguity, all the symbols used (except those newly defined in this paper) will be based on the EC3 notations. In addition, in order to simplify the discussion, it is assumed that the plate girder under concern is symmetrical about its major axis and subjected to pure bending only. The flanges of the girder are not in Class 4 according to EC3 classification. Furthermore, the yield strength of the flanges and web are the same (i.e. no hybrid cross section is allowed) and no longitudinal stiffener is applied.

2.2. The BS's “Flanges only” method [Clause 4.4.4.2(b) of Reference [4]]

In the BS's flanges only method, it is assumed that the web is designed for shear only and all the bending resistance of the plate girder (Fig. 1) is provided by the flanges only. Note that since it is assumed that the whole web contribution is ignored, the centroid of the section G remains at the middle of the web. By ignoring the contribution from the weld between the web and the flanges (since the leg length of the welding $l_w \ll b_f$ and h_w), the bending resistance based on the flanges only method, $M_{f,Rd}$, can be expressed as

$$M_{f,Rd} = 2b_f t_f \left(h_w/2 + t_f/2\right) f_y = b_f t_f \left(h_w + t_f\right) f_y = A_f \left(h_w + t_f\right) f_y \quad (1a)$$

where in Eq. (1a), f_y is the yield strength of the section and $A_f = b_f t_f$ is the area of the single flange. Eq. (1a) can be rewritten in the form of

$$M_{f,Rd} = A_f h_w \left(1+t_f/h_w\right) f_y = A_f h_w (1+\xi) f_y = W_{pl,fl} \cdot f_y \quad (1b)$$

$$W_{pl,fl} = A_f h_w (1+\xi) \quad (1c)$$

where $W_{pl,fl}$ is the section plastic modulus contributed by the flanges only. Since usually $t_f < h_w$, the dimensionless parameter $\xi = t_f/h_w$ should be within the range $0 < \xi \le 0.2$. The BS [4] allows to take $M_{f,Rd}$ as a conservative estimate of the section bending resistance $M_{c,Rd}$. Obviously, Eqs. (1a) to (1c) are very simple and $M_{f,Rd}$ could be conveniently obtained by hand calculation. It can be seen that one important assumption of the flanges only method is that despite the web which is Class 4 slender, both the compression and tension flanges are assumed to be yielded to provide the bending resistance at the ultimate limit state (ULS).

2.3. The EC3's “Effective width” method [Section 4.3 of Reference [13]]

In the EC3's effective width method, it is assumed that since the web is Class 4 slender, part of the compressive web is subjected to local buckling and could no longer able to contribute to the effective section of the plate girder (Fig. 2). In this case, only the remaining effective section will act like an equivalent Class 3 section to provide the bending resistance at the ULS. As part of the compressive web is ineffective, under the action of a sagging moment, the centroid of the effective area will shift down from G to its new position G' (Fig. 2). Hence, at the ULS the top extreme fibre will be yielded while the bottom extreme fibre will remain elastic. From Reference [14], in the effective width method, the following assumptions are made in order to compute the bending resistance of the equivalent Class 3 section:

(1) A linear strain distribution is assumed for the web.
(2) The ULS is reached when f_y is reached at the centroid of the compressive flange while stress at the centroid of the tension flange will be less than f_y.

In order to compute the corresponding effective section properties, EC3 requires the following iterative calculations steps [3,13,14].