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Shear response of trapezoidal profiled webs in girders with concrete-filled RHS flanges

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ABSTRACT

The present paper deals with the shear buckling response of trapezoidal profiled webs in girders with concrete-filled rectangular hollow section (RHS) flanges. It outlines an experimental work of four girders with shear buckled trapezoidal profiled webs in interactive and global manners. Characteristic strain distributions on the trapezoidal profiled webs are reported. The analysis of load-deformation responses indicates that the trapezoidal profiled web buckled in the global manner suffered greater strength drops at early stage and less strength improvement contributed by the concrete-filled RHS flange in contrast to those buckled in interactive manner with partial local buckling. Finite element models explicitly allowing for isolated trapezoidal profiled webs with varied side boundaries and visual girder models with proposed design ratios are then presented for 572 cases. It is shown that the first eigenmode shape and critical stressing of the trapezoidal profiled webs are most likely influenced when the shear buckling in local manner takes place. Related geometric ratios involved with shear span, web slenderness, trapezoid altitude and subpanel height are examined through a parametric study. Afterwards, an analytical formula incorporating a proposed rigidity ratio as well as a correlated contribution coefficient is proposed for the determining shear buckling strength of trapezoidal profiled webs in the girders with concrete-filled RHS flanges. The proposed formula is verified in contrast to referred ones through a comparative study which can be deemed suitable for the design of trapezoidal profiled webs in girders with concrete-filled rectangular hollow section (RHS) flanges.

1. Introduction

The use of trapezoidal profiled (corrugated) webs in highway bridge girders has significantly increased in recently years. The growing popularity of their usage is due to high out-of-plane stiffness and so-called “accordion effect” which eases the introduction of prestress in prestressed concrete box girders [1–3]. However, the combined concentrated force, bending moment and shear force may lead to an interacting instability phenomenon of trapezoidal profiled web [4]. In such a case, the unbraced flange lengths and configurations of stiffening should be restricted for the design of girders to prevent local flange buckling. Therefore, the bridge girder with concrete-filled RHS flange has been introduced as a substitute in engineering since it has great capacity for local buckling, high stiffness for torsion and reduced web slenderness [5]. An exemplified application in China is the Maluan Mountain No.1 highway bridge which has been completed in the year of 2016, as shown in Fig. 1. The main girders in this bridge have continuous three-span with a total length of 135 m. The trapezoidal profiled webs have been welded to the concrete-filled steel tubes as girder flanges.

Several studies involved with an assessment of overall behaviour of girders with RHS flanges have been reported in recent years. Two typical girders can be referred as: (1) a trapezoidal profiled (corrugated) web girder with flanges located as upper concrete-filled rectangular hollow section (RHS) steel tube and lower flat steel plate (TFG) and (2) a trapezoidal profiled (corrugated) web girder in which the cross

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Fig. 1. Photograph of highway bridge girders with corrugated steel webs and concrete filled tubular flanges in construction (Maluan Mountain No.1 Bridge, Shengzhen, China, 2016).

section shape is similar to a dumbbell with RHS tubes (DTG), as shown in Fig. 2. In practice, such a configuration can be adopted for continuous girders since the bending moment always shifts from positive to negative between the interior support and within each span although the strength contribution of concrete-infill is negligible when the flange is in tension. Kim and Sause [6,7] showed that the flexural strength and stability of TFGs are much greater than that of counterpart girder with flat steel plate flanges. The corresponding design flexural strength formula was given for the capacity of the cross-section or lateral torsional buckling strength. In their later report [8], it was shown that the bending capacity related parameters, such as stiffness, yield moment, etc., of TFGs can be examined with the calculation of sectional transformation as well as strain compatibility approach. Its similar calculation has also been extended to the analysis of the flexural strength of DTG [9] and discussed with the design formula for flexural buckling with lateral torsion in codes. For its further application, Dong and Sause [10,11] showed that the structural efficiency of DTG lies in its greater primary bending resistant than corresponding I-girder which has greater warping and total stresses normally. Recently, Shao & Wang [12] tested a girder with concrete-filled rectangular hollow section (RHS) flange with point load at mid-span. In their reported test beam, 3 mm thick trapezoidal profiled web was connected with the flange consisted of 160 mm × 80 mm × 3 mm tube with C30 concrete infill. As the reported test beam deformed beyond the serviceability limit, the trapezoidal profiled web remained intact and the only buckling occurred at the top flange of the mid-span. Given the flexural yielding was governed and the trapezoidal profiled web was very strong in resisting shear buckling, the classic beam theory was suggested in the calculation of flexural strength.

Apart from a research focus mentioned above; however, it can be expected that the girders may not be able to flexibly deflect until serviceability limit if the trapezoidal profiled web is relatively weak and buckled due to shear force. As a basic issue, isolated trapezoidal profiled webs in shear buckling have been investigated extensively and summarized in the literature. Three shear buckling manners of trapezoidal profiled webs in local, global and interactive modes can be categorized depending on the web geometry which has been concerned by contemporary researchers. Initially, the isotropic and orthotropic plates based elastic buckling stress formulae were proposed by Easley [13] and Elgaaly et al. [14] in the prediction of the buckling in local and global manners, although slightly varied shear buckling coefficient are involved. It appears that these early studies together with related design rule discussions, e.g. Johansson et al. [15], form a good basis for further consideration into design. Eurocode 3 [16] seems to be the only design code available presenting design formulae for shear capacity of trapezoidal profiled webs by multiplying the web shear yield load by the lesser of two reduction factors for the buckling in local and global manners. Recently, Leblouba et al. [17] showed that all beams in their tests had residual strength that is about half of their ultimate load carrying capacity regardless of shear buckling manner. The design formulae suggested by Eurocode 3 [16] was observed to give an accurate and conservative estimation for shear strength of test data.

Notwithstanding this, former experimental observations also indicate that the trapezoidal profiled web may exhibit buckling in local

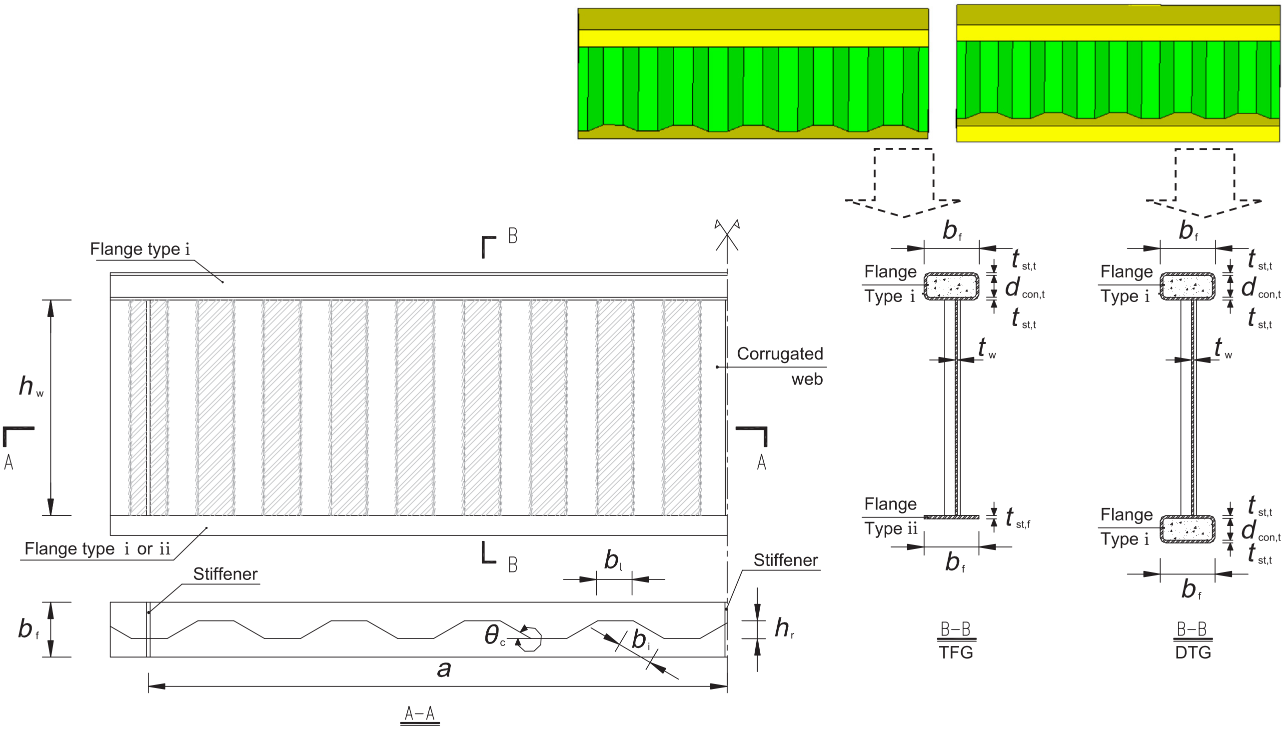

Fig. 2. Illustration of geometric parameters.