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Numerical investigation on the nonlinear shear behaviour of high-strength steel tapered corrugated web bridge girders

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ABSTRACT

Recently, there have been many attempts all over the world to reduce the own weight of the superstructure of the bridges, as well as reducing the work and cost involved in construction. One attempt is to utilise the tapered (i.e. non-prismatic with varying depth) steel plate girders with corrugated webs (TPGCWs). The corrugated steel plates are widely used as structural elements in many structural applications because of their numerous favourable properties compared with traditional flat plates. Moreover, they have been used due to their aesthetical appearance, especially in the case of TPGCWs. On the other hand, the use of high strength steels (HSSs) has gained greater commercial interest over the last decades. The capabilities of these HSSs allow obtaining smaller structural parts and slender sections and less weight without compromising security. Hence, the present paper combines the advantages of the tapered corrugated webs and the HSSs by investigating the strength and behaviour of the TPGCWs built with HSSs. The corrugated webs considered in this finite element (FE) analyses have practical dimensions similar to those used in available bridges with corrugated webs. Accordingly, a nonlinear modelling, using the ABAQUS programme, was conducted on TPGCWs after validating the FE models through comparisons with the experimental results available in literature. Parametric study was, then, performed on TPGCWs to study their behaviour under shear loading using HSSs. Finally a new equation was proposed for calculating the ultimate shear strength of TPGCWs. Overall, this investigation expands the available engineering knowledge and assists in utilising the HSS, currently used in a wide range of applications, with the TPGCWs with their favourable aesthetical and structural characteristics.

1. Introduction

1.1. Corrugated web girders

Although girders made of structural steels have been used for a long time, new type of corrugated web girders is generated thanks to the developments in both fabrication technologies and structural design. Corrugated web girders have been widely used in long span beams and bridges all over the world [1–3]. Typically, these girders are built-up flexural members, with each girder consisting of a corrugated web that is welded to two flange plates. Generally, sinusoidal and trapezoidal corrugations are used in buildings and bridges, respectively. Opposite to I-plate girders with conventional flat webs, the webs of the corrugated web girders do not contribute in transferring the longitudinal bending stresses. Hence, in case of laterally restrained girders with corrugated webs, the ultimate moment capacity may be predicted based on the yielding or local buckling capacity of the flanges depending on their class. This is a direct result of their profiling or what is so called the accordion effect [4,5]. Hence, the corrugated web girder and the lattice girder are alike [6,7] in their load carrying mechanism. In both girders, the flanges only transfer the bending moments and normal forces, whereas the web members alone (the webs in the corrugated web members and the diagonals and verticals in the lattice girder) transfer the transverse forces. On the other hand, the corrugated web, which increases the girder's web shear buckling stability, results in an economical girder by the elimination of transverse stiffeners essential for flat webs. The significant out-of-plane stiffness of the corrugated webs reduces the web thickness as well relative to conventional flat webs [1–5]. In a recent study, Zevallos et al. [8] suggested to use two corrugated web plates with small thicknesses (similar to that suggested by Kim et al. [9]) instead of a single web plate of a large thickness to increase the strength-to-weight ratio of the girder. Additionally, this may facil-

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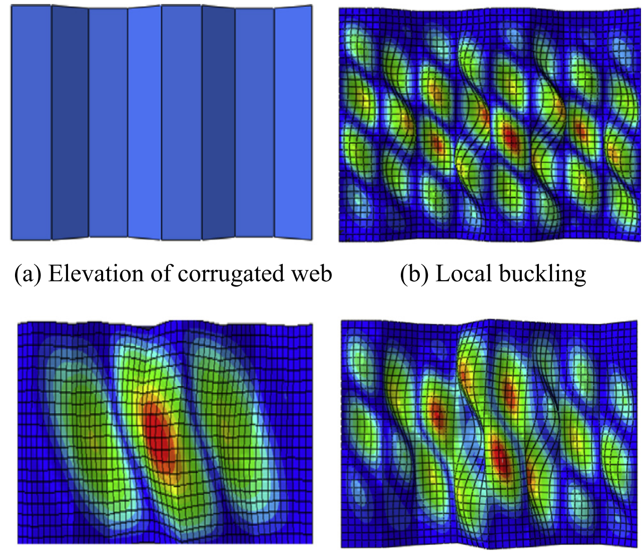
itates and accelerates the production of these girders by benefiting from the recent enhancements in the automatic fabrication technology of the corrugated webs which became possible up to 6 mm thickness [8]. Based on above mentioned advantages, plate girders with corrugated webs have been used in practical, as can be seen in Fig. 1(a) which presents the Maupré Bridge in France [10].

The shear limit state in the bare steel corrugated web girders is, however, an important limit in design because of their relatively small web thicknesses. Also, in case of prestressed concrete hybrid bridges [11], steel corrugated webs without steel flanges may be used with the webs directly embedded in the concrete slabs, as can be seen in Fig. 2, which is the most cost-effective connection between the steel webs and the concrete slabs of the box girders [12,13]. Hence, their latter application shows that they are mainly used to bear the shear loading, of course besides maintaining the relative distance between the concrete flanges. As the shear behaviour and design of corrugated web girders has been realised, several investigations (see for example Refs. [1–4,14]) have been done to raise the engineering knowledge and design experiences, with the main benefit is to provide design equations to replace the half-scale experiments usually tested in the design stage of the constructed bridges [11]. The results of these investigations showed that corrugated webs, unlike flat webs, buckle with three different modes (i.e. local, global and interactive buckling modes) as shown in Fig. 3. The interactive shear buckling stress, which considers the interaction between the local and global shear buckling stresses, was recommended to be used in design [1–4,14]. Lindner and Aschinger [15] were the first to propose a generalised formula for the interactive buckling stress ($\tau_{cr,I}$) as given by Eq. (1);



(a) Elevation of corrugated web (b) Local buckling

(c) Global buckling (d) Interactive buckling

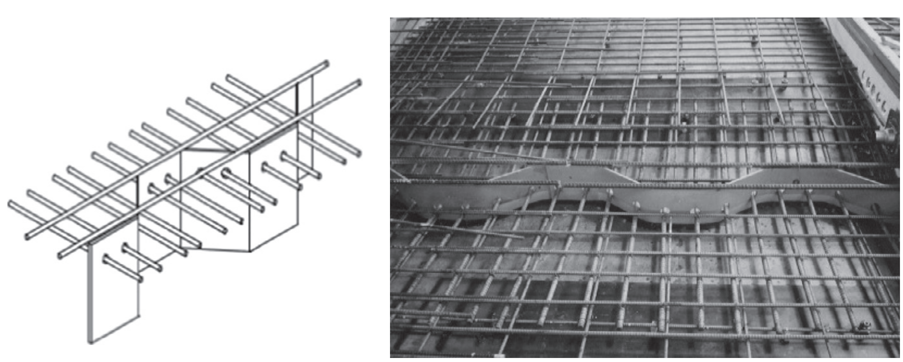
Fig. 3. Different buckling shapes in prismatic corrugated webs: (a) elevation of the corrugated web, (b) local buckling, (c) global buckling and (d) interactive buckling.

where $\tau_{cr,L}$ is the local buckling stress and $\tau_{cr,G}$ is the global buckling stress.

$$\frac{1}{(\tau_{cr,I})^n} = \frac{1}{(\tau_{cr,L})^n} + \frac{1}{(\tau_{cr,G})^n} \tag{1}$$

(a) Maupré Bridge (b) Dole Bridge

Fig. 1. Plate girders with corrugated webs: (a) prismatic and (b) tapered plate girders [10].



(a) Typical connection (b) Application in Hondani Bridge

Fig. 2. Embedded connection in prestressed concrete bridges [11].