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Shear evaluation of tapered bridge girder panels with steel corrugated webs near the supports of continuous bridges

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ABSTRACT

Because of public construction budgets were cut over the last few years, new bridge girders with corrugated webs to reduce the construction costs have become more widely studied and used. In spite that tapered bridge girders with corrugated webs (BGCWs) are used in modern bridges, their shear strength and behaviour rarely exists in literature. Based on available literature, the web of the linearly tapered BGCWs may be divided into three typologies with different structural response to shear force. This paper presents a study into the shear strength and behaviour of the different web panels of the tapered BGCWs near the end and intermediate supports of continuous bridges using the dimensions of constructed bridges. Accordingly, parametric studies are conducted with variations in the aspect ratio of the web panel, different inclination angles of the tapered web panel and the flange slenderness ratio. After that, the paper checks the available design model under these additional parametric study models. The paper is extended to check corrugation dimensions for the use in conventional structures. It is noticed that as the corrugation angle (α) between longitudinal and inclined sub-panels decreases, the ultimate shear of the girders decreases because the rigidity of the web decreases. The available design model is compared to the FE results and it is found to yield suitable results for girders used in bridges as well as conventional structures. Overall, new conclusions on the shear strength and behaviour of tapered BGCWs are presented.

1. Introduction

In case of I-section plate girders (IPGs) with slender webs, the web panel buckles at a relatively low value of the applied load. Hence, to overcome the strength reduction associated with utilizing plate girders with slender webs in bridge construction, these flat webs are often reinforced with transversal stiffeners along their spans to increase their buckling strength. Recently, girders with steel corrugated webs (BGCWs) have been used as structural members in long span beams and bridges. Several examples representing the BGCWs may be found in literature with Maupré Bridge shown in Fig. 1(a) being one of them. This bridge was built by using trapezoidally corrugated steel web plate, which is the most commonly used corrugation type that compose of a series of longitudinal and inclined sub-panels. Because of their significant out-of-plane stiffness, corrugated web plates have much higher buckling strengths compared with flat web plates. Hence, the necessity of using stiffeners is eliminated and the required web thickness is reduced [1–5]. Additionally, the flexural strength of such girders is entirely provided by their flanges while the shear strength is provided by their webs due to the negligible axial stiffness of the corrugated webs in the longitudinal direction of the girders which is commonly known as the accordion effect [6–8]. It was proved [6–8] that the axial stiffness of the corrugated steel plates is negligible by nature of their unique geometric characteristics, while they own very high vertical stiffness to fully transmit vertical shear. Consequently, there is no interaction between shear and flexural behaviours of the BGCWs. Hence, BGCWs make the best use of the effective material properties of both flanges and webs. It was additionally found that the weight of the BGCWs can be 10% less than the weight of the original IPGs with the same static capacity [9,10]. However, it is worth pointing out that the corrugated webs under shear loading may buckle locally, globally or interactively. The first mode is controlled by deformations within a single sub-panel of the web. The second mode involves multiple sub-panels and the buckled shape extends diagonally over the depth of the web. However, experimental and finite element observed buckling often appears to have characteristics of both

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(a) Prismatic bridge girders (b) Tapered bridge girders

Fig. 1. Bridge girders with corrugated webs: (a) Maupré Bridge and (b) Dole Bridge.

local and global buckling modes. This was classified as an interactive buckling mode and Lindner and Aschinger [11], historically, were the first to provide its elastic buckling formula. Recently, tapered girders have been used in bridges based on their structural efficiency, providing at the same time aesthetical appearance. Fig. 1(b) shows an example of bridges that utilise tapered BGCWs: the Dole Bridge. The linearly tapered BGCW selected as the subject of this study is shown in Fig. 2. As can be seen, it is a continuous bridge composed of two spans. In spite that the advantages of corrugated webs were found to be greater in box girders, as those used in Maupré and Dole Bridges, than in plate girders [12], their main structural properties can be deduced from work on plate girders [1–10].

Based on previous researches [13,14], the web of the tapered girder may be classified into three typologies. This classification is based on (1) the inclination of the flange and whether the flange is under tension or compression and (2) the direction of the developed tension field, which may appear on the short or on the long web diagonal [13]. However, the check of shear of the girder (Fig. 2) should be preceded by an elastic analysis for bending and shear. The purpose of such analysis is to determine the bending moment and shear force distributions throughout the girder, so that (1) the girder can be divided into different typologies and (2) the maximum shear forces can be found and compared with the shear capacities of each typology. Fig. 3 provides the bending moment and shear force diagrams, where the points of zero moment and zero shear divide the web into three typologies; I, II and III, with the boundary cross-sections of each typology (defined by digits in Fig. 3(c)) should be checked in design. It should be noted that Refs. [13,14] provide the general behaviour of the different typologies of the linearly tapered girders with flat and corrugated webs, respectively. Owing to the lack of research papers related to tapered BGCWs, this paper, which is a part from the Master thesis of the first author [15], provides the behaviour of Cases I and II web panels existing in linearly tapered BGCWs which lay near the supports of continuous bridges, with the contribution of this paper can be summarised as:

1. More realistic corrugation dimensions using those of Maupré and Dole bridges were used. This increases the data points available in literature which has concentrated on Shinkai and Matsnoki bridges [14].

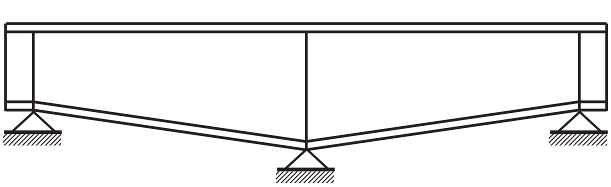

Fig. 2. Considered linearly tapered continuous two-span BGCW.

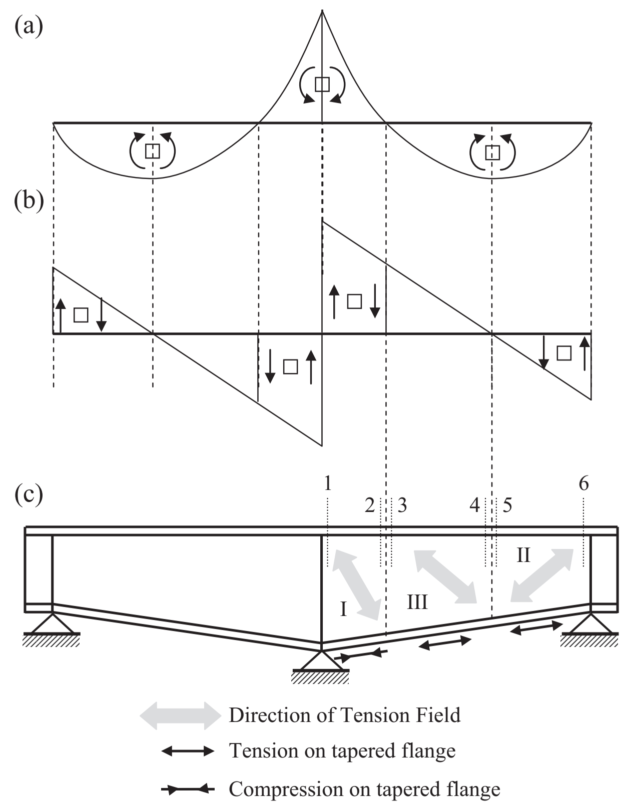

Fig. 3. Classification of the web into different typologies; (a) bending moment diagram, (b) shear force diagram and (c) web typology.

2. Initial imperfections were linked in this paper to the height of the girders with values of $h_{w1}/200$ following the Eurocode, instead of the value used by Hassanein and Kharoob [14] which was taken equal to the web thickness.
3. The failure mode of the BGCWs which differs from the case of tapered bridge girders with flat flanges was monitored and deeply analysed.
4. BGCWs with different web plate aspect ratios (a/h_{w1}) were considered to get the relationship between them and their ultimate shear capacities.
5. The relationship between the increase in strength and the increase in weight associated with the increase of the web thickness was investigated. A new corrugation configuration using two web plates are then suggested.
6. The effect of the inclination angle (γ) on the load-deformation response of the BGCWs was checked with general results provided.