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Shear buckling strength and design of curved corrugated steel webs for bridges

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ABSTRACT

This paper presents the shear buckling strength and design of curved corrugated steel webs for bridges considering material inelasticity. The inelastic buckling strength is determined from buckling curves based on the proposed shear buckling parameter, which is a function of the elastic shear buckling strength of steel web and the material shear yielding strength. A finite element analysis is carried out to study the geometric parameters affecting the shear buckling strength of curved corrugated steel webs for bridges. Based on the numerical results, a shear buckling parameter formula is proposed with no need to calculate either local, global, or interactive buckling parameters. But it depends on the geometric properties of the curved corrugated web profile. Another formula is presented to maximize the shear buckling capacity of curved corrugated web. The proposed formulae agreed well with the published experimental data. The curved corrugated webs produce a tremendous increase in the shear buckling strength and considerable weight saving in regard to the corresponding trapezoidal corrugated webs. The corrugation angle has a considerable effect on the behavior of curved corrugated webs, where higher corrugation angles produce a tremendous increase in the shear buckling strength of curved corrugated webs. It was found that the proposed approach provides a good prediction for the shear buckling strength of curved corrugated steel webs of bridges.

1. Introduction

Trapezoidal corrugated steel webs, as shown in Fig. 1(a), eliminate the need for transverse stiffeners required for plate girder steel bridges. They provide enhanced buckling strength and weight savings. Pre-stressed concrete, PSC, box girder bridges with corrugated steel webs have been extensively constructed in France and Japan. The first PSC girder bridge constructed with corrugated steel webs has recently been constructed in South Korea [1]. In addition, applications of corrugated steel webs have been extended to extra-dosed and cable-stayed bridges [2], and, there have been several attempts to apply corrugated webs to plate girder bridges [3–5]. It is assumed that the web carries only shear forces due to the accordion effect [6]. Because of this characteristic, the corrugated steel webs fail due to shear buckling or yielding, while the flanges resist the moment. Fig. 1(b) shows the geometric notations of the corrugated steel webs used in this study. In Fig. 1(b), a is the flat panel width; b is the horizontal projection of the inclined panel width; c is the inclined panel width; d is the corrugation depth; t_w is the web thickness; and θ is the corrugation angle. Several researchers have conducted extensive studies on the shear buckling of corrugated webs [1–12]. Easley and McFarland [7] who initiated the buckling behavior of corrugated plates, proposed the global shear buckling equation of corrugated webs by treating the corrugated web as an orthotropic flat web. Elgaaly et al. [8] and Yamazaki [9] conducted experimental studies on the buckling characteristics and strength of corrugated webs. Recently, Yi et al. [1] studied the nature of the interactive shear buckling of corrugated webs, and concluded that the 1st order interactive shear buckling equation that does not consider material inelasticity and material yielding provides a good estimation of the shear strength of corrugated steel webs.

Driver et al. [10] suggested shear design criteria based on test results and finite element analyses for corrugated webs that is suitable for bridge design specifications. Eldib [11] proposed an interactive equation to calculate the shear buckling strength of trapezoidal corrugated webs depending on the linear buckling analysis. The method was verified with a published experimental data of forty specimens with corrugated steel webs which were carried out by Hamilton [6] indicating a very close prediction of shear buckling strength. Moon et al. [12] presented the shear strength and design of trapezoidal corrugated steel webs. First, global shear buckling equations were rearranged in order to derive the global shear buckling coefficient. The interactive shear buckling coefficient and the shear buckling parameter for trapezoidal corrugated steel webs were then proposed based on the 1st order interactive buckling equation. The inelastic buckling strength was determined from the buckling curves based on the proposed shear buckling parameter. A series of tests were conducted to verify the

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Notations

a	flat panel width;
b	horizontal projection of the inclined panel width;
b_f	width of flange;
c	inclined panel width;
d	corrugation depth;
E	Young's modulus;
f_y	yield stress;
h_w	web height;
k_G	global shear buckling coefficient;
k_I	interactive buckling coefficient;
k_L	local buckling coefficient;
t_w	web thickness;
t_f	flange thickness;
L	length of girder;
P_B	lower elastic buckling load;
P	applied load
R	radius of corrugation curve
w	maximum fold width;
β	global buckling factor that depends upon the boundary condition;
η	length reduction factor as $(a+b)/(a+c)$;
λ_L	local buckling slenderness;
λ_s	shear buckling parameter;
θ	corrugation angle;
τ_{cr}	critical shear buckling stress;
$\tau^e_{cr,B}$	critical elastic shear buckling stress from F.E. analysis;
$\tau^e_{cr,G}$	elastic global shear buckling stress;
$\tau^e_{cr,I}$	elastic interactive shear buckling stress;
$\tau^e_{cr,L}$	elastic local shear buckling stress;
τ_y	shear yield stress;
υ	Poisson's ratio

proposed design equations. From the test results of that study and those provided by previous researchers, it was found that the proposed shear strengths provide good predictions for the shear strength of the trapezoidal corrugated steel webs.

Eldib [13] carried an extensive study on the behavior of curved corrugated profile steel webs. The interactive critical shear strength due to buckling and yielding of curved and semi-circled corrugated steel webs was studied with corrugation angles of 45° and 90° respectively. A tremendous increase on the shear buckling strength occurred due to the use of curved corrugated webs.

This paper presents the shear buckling strength and design criteria of curved corrugated steel webs considering the material inelasticity. A numerical analysis is carried out using the software program ANSYS-10 [14] to study the behavior of the actual constructed bridges shown in Table 1 when its trapezoidal corrugated webs are replaced by curved corrugated webs. For simplicity and design purposes, the yielding strength, and inelastic and elastic shear buckling strengths of curved corrugated steel web are not predicted by carrying out a direct inelastic buckling analysis but by carrying out a linear elastic buckling analysis to calculate the shear buckling parameter λ_s of the steel web which is a function of elastic shear buckling strength of the web and the material yielding shear strength. A buckling curve from the design manual for PC bridges with steel corrugated webs [15], which considers the material inelasticity depending on the shear buckling parameter λ_s to define the yield strength, and inelastic and elastic strengths of steel webs. Therefore, the linear elastic buckling analysis is conducted to calculate the elastic shear buckling strength of the steel web using a finite element models. The proposed approach calculates the yielding, and inelastic shear strengths by indirect method. Many parameters are considered such as the ratio of web thickness to web height t_w/h_w, the radius R of the curved profile web, and the corrugation angle θ. The analysis results are also used to proposed formula which predicts the shear buckling parameters of the curved corrugated webs. Then, the inelastic buckling strength was determined from the buckling curve based on the predicted shear buckling parameter. Also, other formula is presented to maximize the shear buckling capacity of curved corrugated web

The proposed approach is verified by experimental data from the literature. For practical design purposes, the lower bound of shear buckling strength is the target in this study from the design safety point of view. Where, the lower elastic shear buckling strength produces a higher buckling parameter λ_s, which in turn produces conservative inelastic shear strength according to the design curve [15]. It is recommended for practical design purposes that the corrugated webs are designed within either yield or inelastic behavior. Therefore, it is not of interest in this paper to consider the post buckling shear strength.

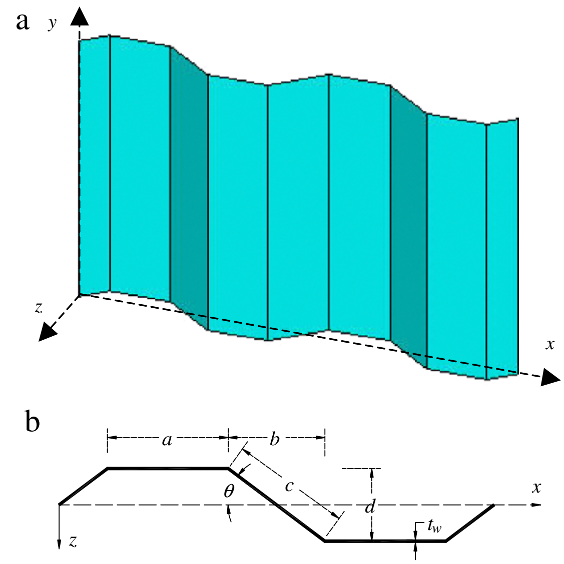

Fig. 1. (a) Profiles of trapezoidal corrugated steel webs; (b) Geometric notations.

2. Shear buckling behavior of trapezoidal corrugated webs

2.1. Local shear buckling

Local buckling occurs when a flat sub-plate between vertical edges has a large width to thickness ratio as shown in Fig. 2. The buckling strength equation is taken from the classical plate buckling theory [16] as follows;

$$\tau^e_{cr,L} = k_L \frac{\pi^2 E}{12(1-\upsilon^2)} \left(\frac{t_w}{w}\right)^2 \quad (1)$$

where E is Young's modulus of elasticity; υ is Poisson's ratio; w is the maximum fold width (maximum of flat panel width a, and inclined panel width c); and t_w is the web thickness. k_L is the local shear buckling coefficient. Assuming that the panel has simply supported edges, k_L is given by

$$k_L = 5.34 + 4\left(\frac{w}{h_w}\right)^2 \quad (2)$$

in which, h_w is the web height.

Table 1 represents trapezoidal profiles of existing bridges in France and Japan that have corrugated webs. It is found that the