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Evaluation of the transverse shear stiffness of a steel bi-directional corrugated-strip-core sandwich beam

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ABSTRACT

This paper presents a new concept in steel bi-directional corrugated-core sandwich structures. The focus is on the derivation of the transverse shear stiffness D_{Qy} of a sandwich beam using analytical methods. A braced frame analogy and its periodical unit cell, based on a force–distortion relationship concept, are used as the basis for deriving transverse shear stiffness relationships using the modified stiffness matrix approach. The transverse shear stiffness equation is consistent with a three-dimensional finite element solution. It is then used to assess the effect of geometrical parameters defining the corrugated sandwich beam. The performance of a steel bi-directional corrugated-strip-core sandwich beam compared with other corrugated-like core sandwich beams is then examined and discussed.

1. Introduction

The need for large structures with higher specific strength and stiffness is increasing. This is especially true in large building structures, where there is an interest in increasing the service load to structure weight ratios. To deliver such structures, engineers may arrange a structure into an advantageous topology such as a corrugated-core sandwich structure.

The core of a steel corrugated-core sandwich structure can be designed in various patterns. A conventional corrugated core sandwich plate, as shown in Fig. 1(a), is theoretically strong in the x-direction, but less strong in the y-direction [1]. To improve the stiffness in the weaker direction, the typical core may be arranged in both the x- and y-directions, as shown in Fig. 1(b) [2], or be constructed with a series of corrugated strip plates which are also arranged in a bi-directional format such as a bi-directionally corrugated core (Fig. 1(c)) [3] and a cross-corrugated core (Fig. 1(d)) [4].

It was presented by Ray [5] that the cross-corrugated core was more efficient in transverse shear stiffness than the conventional corrugated core sandwich plate (Fig. 1(a)); its shear stiffness was 173% higher. This may be because of the presence of a series of corrugated strip plates in both the x- and y-directions.

To derive the transverse shear stiffness of a corrugated-core sandwich beam, a simplified analytical approach based on the force–distortion relationship technique may be used. This technique relies on the estimation of the sandwich properties into an equivalent property. The stiffness of a sandwich structure can be found if the relationship between effort force and corresponding displacement are known.

The force–distortion relationship technique was used to derive the equivalent transverse shear stiffness of the corrugated-core sandwich structures of Libove and Hubka [6], Ko [7], Nordstrand et al. [8] and Ray [5]. This technique was also used to derive the equivalent transverse shear stiffness of C- and Z-cored sandwich panels by Fung et al. [9–12]. The equivalent transverse shear stiffness of an extruded truss-core sandwich panel was studied based on this technique by Lok et al. [13,14].

This paper aims to present a new alternative to steel corrugated-core sandwich construction, named a steel bi-directional corrugated-strip-core (Bi-CSC) sandwich construction, and to outline an analytical method based on the combination of the force–distortion relationship technique and the modified stiffness matrix method to model the transverse shear stiffness of this proposed sandwich type. Rather than using previous analytical techniques, e.g., those of Libove and Hubka [6] and Lok et al. [13,14], the modified stiffness matrix method is used here to overcome an indeterminate truss-core-like topology. The solutions will be validated with three-dimensional (3D) finite element (FE) solutions. The evaluation of performance of this proposed core compared with other similar cores will be presented.

2. Configuration of a bi-directional corrugated-strip-core sandwich beam

Fig. 2 shows a bi-directional corrugated-strip-core sandwich beam which is cut from the sandwich plate by two parallel planes. The configuration of the sandwich beam, face and core is clearly

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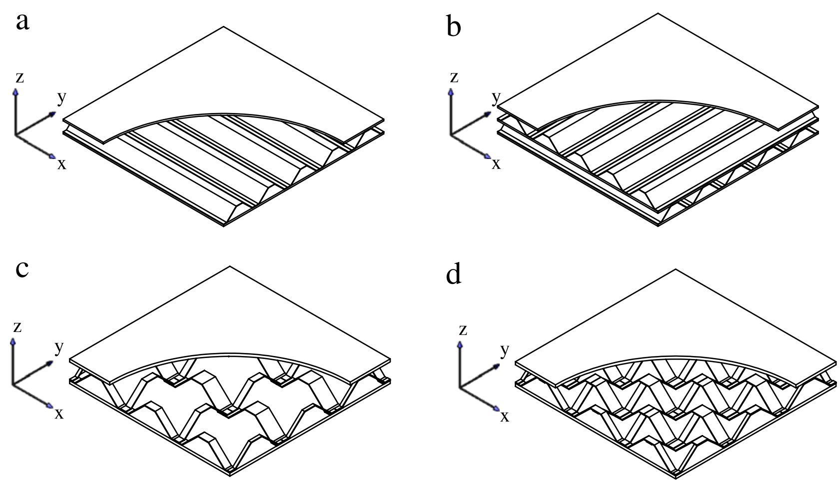

Fig. 1. Sketch of corrugated-core sandwich construction (a) one-way corrugated core, (b) two-way corrugated core, (c) bi-directional corrugated core [3] and (d) cross-corrugated core [4].

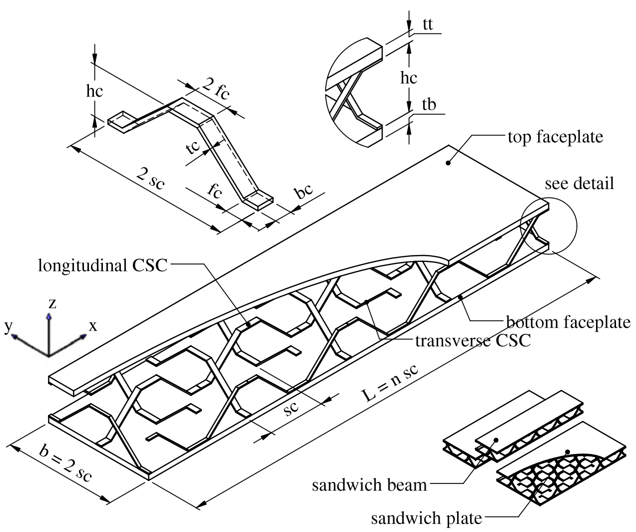

Fig. 2. Configuration of a bi-directional corrugated-strip-core sandwich beam.

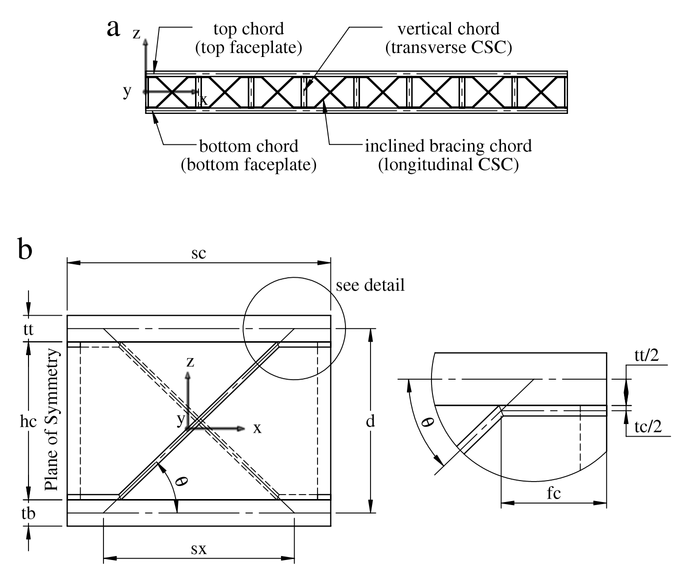

Fig. 3. Configuration of (a) a two-dimensional plane frame structure and (b) the periodical unit cell.

defined by the parameters as shown in the figure. The corrugated strip plates are linearly arranged in equal spacing, s_c, in both the x-direction and/or the y-direction. The length of the beam is n times s_c.

A two-dimensional (2D) plane frame structure (PFS), as shown in Fig. 3(a), is used to represent the 3D corrugated-strip-core sandwich beam. Any part of sandwich beam is represented by a single straight line which passes through the neutral axis of such part. The PFS consists of four basic elements: top chord, bottom chord, inclined bracing chord, and vertical chord. They are compatible in material properties and geometrical dimensions with the top faceplate, bottom faceplate, longitudinal corrugated strip core, and transverse corrugated strip core, respectively, as shown in Table 1. The connections between the face and the core are assumed to be fully bonded so that there is no relative displacement. The PFS is modeled using rigid-link elements which are stiffer than the previously mentioned four basic elements.

A unit cell, as shown in Fig. 3(b), is used to represent the periodical substructure of the bi-directional corrugated-strip-core sandwich beam. The angle of the inclined part, θ, can be expressed in terms of t_c, s_c, f_c, and h_c, or in terms of d and s_x, as $\theta = \arctan\left(\frac{h_c - t_c}{s_c - 2f_c}\right) = \arctan\left(\frac{d}{s_x}\right)$, where s_x is the effective horizontal length of inclined part of the unit cell. Therefore, this paper will use s_x/d to present the angle of the corrugated-strip-core (CSC).

Table 1
Structural model and mechanical properties of element of the braced frame model.

Sandwich beam	Braced frame model		
	Element	Structural model	Mechanical property
Top faceplate	Top chord	Beam	$E_t = E_t$ $A_t = bt_t$ $I_t = \frac{1}{12}bt_t^3$
Bottom faceplate	Bottom chord	Beam	$E_b = E_b$ $A_b = bt_b$ $I_b = \frac{1}{12}bt_b^3$
Longitudinal CSC	Inclined chord	Beam	$E_c = E_c$ $A_c = b_c t_c$ $I_c = \frac{1}{12}b_c t_c^3$
Transverse CSC	Vertical chord	Beam	$E_{tc} = E_c$ $A_{tc} = b_c \frac{t_c}{\sin\phi}$ $I_{tc} = \frac{1}{12}b_c^3 t_c$