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Local shear buckling and bearing strength in web core sandwich panels: Model and experimental validation

Casey R. Briscoe [a], Susan C. Mantell [a,*], Taichiro Okazaki [b], Jane H. Davidson [a]

[a] Department of Mechanical Engineering, University of Minnesota, 111 Church St. SE, Minneapolis, MN 55455, USA
[b] Faculty and Graduate School of Engineering, Hokkaido University, Kita 13-Nishi 8, Kita-ku, Sapporo, Hokkaido 060-8628, Japan

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ABSTRACT

A model and experimental validation of shear buckling and local bearing failure of web core sandwich panels are presented. Of particular interest are steel-faced panels with stiffening metal webs and a polymer core. The metal webs provide the required panel stiffness and the foam core serves the dual purposes of preventing local buckling and providing thermal insulation. In applications, such as the building sector, in which thermal performance is crucial, the webs are thin and widely spaced to reduce conduction between the face sheets. The models of shear buckling and bearing failure account for the influence of the core material on web strength and provide closed-form solutions. The models are validated by symmetric four-point bending tests to evaluate shear buckling and asymmetric three-point bending for bearing failure. The shear buckling model predicted buckling strength to within 4% of the test results. The bearing failure model overpredicted the observed strength by 11% on average, similar to test results reported in the literature for the bearing strength of webs with no foam support.

1. Introduction

Web core sandwich panels, Fig. 1, are foam-filled sandwich panels with stiffening webs between the face sheets. They were recently studied as a structural option for the design of residential roofs [1,2]. Roof panels must provide structural performance under long-term loading in addition to thermal insulating performance. In web core panels, the webs provide stiffness and strength and are needed to prevent excessive deformations over time due to creep of the core material. The webs also provide a thermal conduction path between the face sheets, and this effect is minimized by using thin, widely spaced webs [1]. The use of thin webs leads to the possibility for several failure modes, including local buckling and stress failure in the webs and core [2,3].

For web core roof panels, the two failure modes of particular importance for panel design are shear buckling and bearing failure. Shear buckling, illustrated in Fig. 2, is an elastic instability phenomenon resulting from the role of the webs in resisting the transverse shearing stresses in panels under transverse load. If the loading is uniformly distributed, buckling will be localized to regions near the supports, where the shearing stresses are greatest.

At the supports, stress failure is possible due to the resulting concentrated load. This failure mode, referred to as bearing failure in the present work, is illustrated in Fig. 3. It is a combination of plastic failure in the webs (web crippling) and crushing of the core material. Web failure occurs via the formation of yield lines which meet at a plastic hinge in the face sheet.

Detailed models for shear buckling and bearing failure strength are developed in Refs. [2,3] and summarized here. The models are unique in that they account for the influence of the core material on web strength and provide closed-form solutions that can be used for panel design. The models were validated using a combination of finite element analysis and prototype testing. This work summarizes the models and presents the results of the testing. It is shown that the core can provide significant strength to the webs and should be considered an important part of the structural panel design.

2. Failure mode models

The strength of the webs in foam-filled panels may be increased significantly by the core material. For elastic buckling failure modes (e.g. shear buckling), the core acts as an elastic foundation to increase buckling strength. For inelastic failure modes (bearing failure), the core contributes directly via its crushing strength. These impacts must be considered in modeling the panel behavior. The appropriate modeling approaches are illustrated in this section using the models for shear buckling and bearing strength.

The web core panel geometry considered in this work is shown in Fig. 1. The face sheet and web thicknesses are t_f and t_w, respectively. The core depth and web spacing are h_c and p, and the panel

* Corresponding author. Tel.: +1 612 625 1324; fax: +1 612 625 6069.
E-mail address: smantell@me.umn.edu (S.C. Mantell).

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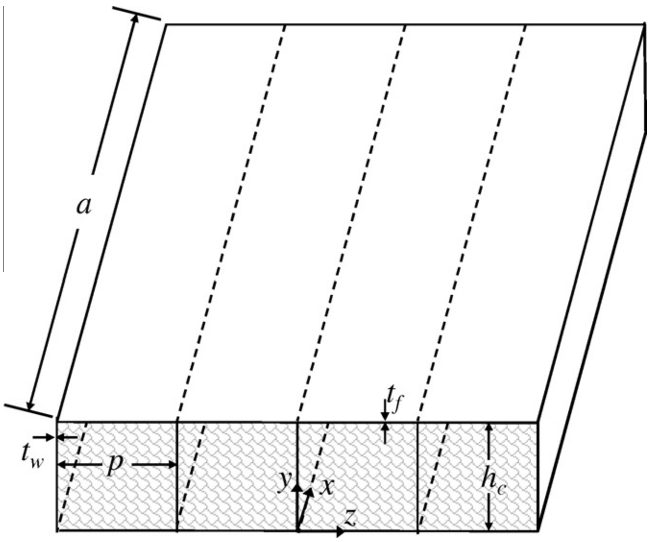

Fig. 1. Web core sandwich panel geometry and coordinate system.

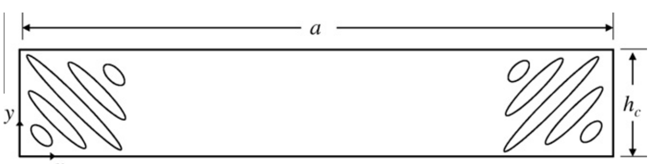

Fig. 2. Web shear buckling mode: view of a buckled web in a panel under uniformly distributed loading.

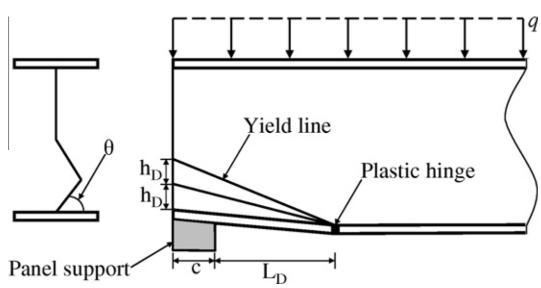

Fig. 3. End bearing failure mechanism in the webs.

length is a. The panels are supported on rectangular bearings of width c (Fig. 3). The panels are loaded by a uniformly distributed load q on the exterior surface.

2.1. Shear buckling

A detailed model for shear buckling strength developed in Ref. [3] accounts for the influence of the core material as an elastic foundation and is applicable for web core panels with widely-spaced webs. The model is summarized here, and validation through prototype testing is provided.

The web shear buckling is modeled by treating the webs as plates on an elastic foundation. Each web is modeled as a simply-supported plate of length a and width h_c, subjected to the uniform shear stress τ on all four edges, per Fig. 4. The maximum shearing force $qpa/2$ occurs at the panel supports ($x = 0$ and $x = a$). The average shear stress at the supports is given by

$$\tau = \frac{qpa}{2t_w h_c}. \tag{1}$$

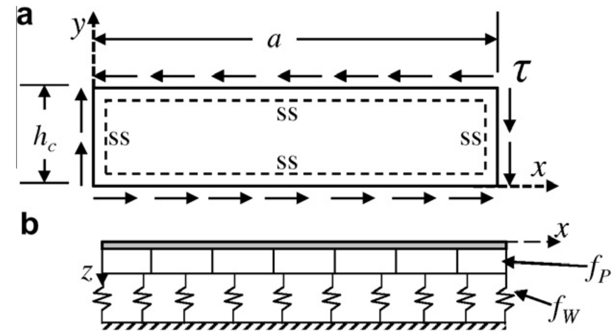

Fig. 4. Model used for the shear buckling analysis: (a) simply supported plate loaded by uniform in-plane shear, and (b) Pasternak foundation model characterized by foundation parameters f_W and f_P.

The critical buckling stress $\overline{\tau}$ is [4]

$$\overline{\tau} = \chi \frac{\pi^2 D}{h_c^2 t_w}, \tag{2}$$

where D is the plate stiffness of the web,

$$D = \frac{E_w t_w^3}{12(1-\nu_w^2)}, \tag{3}$$

and E_w and ν_w are the elastic modulus and Poisson's ratio of the plate material. Following an energy method approach as detailed in Ref. [3], the buckling coefficient χ is approximated by

$$\chi = 2.006\sqrt{0.690 + f_W + 1.020 f_P} + f_P + 3.749, \tag{4}$$

and the non-dimensional foundation parameters f_W and f_P are

$$f_W = \frac{12(1-\nu_w^2)\sqrt[3]{6}}{2\pi^4}\left(\frac{h_c}{t_w}\right)^4 \sqrt[3]{\frac{G_c^2 E_c^2}{E_w^4}}, \tag{5}$$

$$f_P = \frac{12(1-\nu_w^2)}{2\pi^2\sqrt[3]{6}}\left(\frac{h_c}{t_w}\right)^2 \sqrt[3]{\frac{G_c E_c}{E_w^2}}. \tag{6}$$

In Eqs. (5) and (6), E_c and G_c are the compressive and shear modulus, respectively, of the core material.

The foundation model is applicable for deep foundations or foundations with high shear stiffness. In particular, for a foundation depth H, the model is applicable for [3]

$$\frac{H}{t_w}\sqrt[3]{\frac{6G_c^2}{E_c E_w}} \geqslant 2. \tag{7}$$

In web core panels with web spacing p, this requirement is restated as:

$$\frac{t_w}{p} \lesssim 0.454\sqrt[3]{\frac{G_c^2}{E_c E_w}}. \tag{8}$$

Eq. (8) is satisfied for most web core panel designs. For example, in panels with a rigid polyurethane core and webs approximately 1 mm thick, the requirement is satisfied if the web spacing is greater than 250 mm. Due to the thermal insulating requirement for roof panels, web spacing is typically greater than 600 mm in practice [2].

2.2. Bearing failure

Roberts and Newark [5] developed a mechanism solution for the bearing strength of webs with no foam support based on the plastic hinge failure mechanism observed in web crippling tests