Journal of Constructional Steel Research 151 (2018) 94–107

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Shear behavior of corrugated web panels and sensitivity analysis

Moussa Leblouba *, Samer Barakat, Zaid Al-Saadon

Department of Civil & Environmental Engineering, College of Engineering, University of Sharjah, P.O. BOX 27272, University City, Sharjah, United Arab Emirates

ARTICLE INFO

Article history:
Received 19 February 2018
Received in revised form 25 August 2018
Accepted 12 September 2018
Available online xxxx

Keywords:
Corrugated web
Shear
Buckling
Residual strength
Sensitivity analysis

ABSTRACT

Steel beams and girders with corrugated webs have found many applications, especially in industrial structures and bridges. This choice is backed by the many features, this class of structural members can offer, such as the high load carrying capacity before failure due to the web geometry. The failure of a corrugated web may occur due to material yielding or due to geometrical buckling. Three modes of shear buckling are typical for corrugated webs: local, global, and interactive shear buckling. In this paper, the shear failure mechanisms of trapezoidal corrugated webs are investigated. Nine, shear-critical, corrugated web panels were tested until failure. The new test results confirmed a previous observation that all panels achieved a residual strength of about half of the buckling shear strength, regardless of their geometry and most of them reached yielding before buckling takes place. Since the shear strength of corrugated webs is a function of several material and geometric parameters, a comprehensive global, density-based, sensitivity analysis was performed to estimate the relative contribution of each parameter to the behavior of shear strength through a previously developed mathematical model. The analysis revealed that the length of the flat folds is the most influential parameter on the shear strength of corrugated webs, while the modulus of elasticity is the least influential. The study was extended to determine ranges on which each parameter is non-influential.

1. Introduction

Beams and girders with corrugated webs represent an intelligent solution to overcome the performance issues associated with traditional stiffened straight webs (Fig. 1(a)). The corrugation nature of the web improves significantly the shear bearing capacity of beams and girders, hence, eliminating the need for transverse stiffeners. The corrugations (i.e., web folds) may enhance the web's strength against shear buckling by 1.5–2 times the strength of conventional straight webs [1]. As a result, corrugated web girders are being currently used in many highway bridges, in both Europe and Japan [2]. Even though many types of web corrugations exist, the most commonly used ones are the trapezoidal, sinusoidal, and the triangular (Fig. 1(b, c)).

Previous studies [3,4] demonstrated that the required shear strength is provided by the corrugated web, while the flanges provide the flexural strength to counter the accordion effect. However, the contribution of the corrugated web in resisting bending moments is almost negligible [5–7]. Therefore, no interaction is seen between shear and flexural behaviors [7,8].

Failure of corrugated steel webs takes place due to either yielding of steel or due to shear buckling. In either case, the web is subjected to a state of pure shear stress as evidenced by laboratory tests [6] and nonlinear finite element analyses [5,7]. Shear buckling of a corrugated web is classified as local or global. However, there is a state in between, which is referred to as interactive, or zonal [9], shear buckling. Local shear buckling characterizes slender folds, whereas global shear buckling characterizes slender webs [10,11]. Local shear buckling occurs in the longitudinal folds and global shear buckling covers several folds and results in a diagonal crease. The interactive shear buckling involves several folds as well, however, it is localized in a part of the web, not its entire depth.

Elgaaly et al. [12] carried out experimental and theoretical studies on several trapezoidal corrugated beams and found that shear buckling of the web was the primary reason for the failure of beams. The authors observed the occurrence of local shear buckling in the coarse corrugated webs while in the beams with densely corrugated webs, global buckling was observed as the primary mode of failure.

At the onset of buckling, the shear stress is almost uniformly distributed throughout the web. Straight web panels loaded beyond the shear buckling stage (i.e., post-buckling stage) develop in their diagonal a tension field, which is known as the tension-field action [13–15], and the shear stress is non-uniformly distributed. At this stage, the bending stiffness of the longitudinal flanges affect the tension-field action (Fig. 2); the zone under tension yields and plastic hinges form in the flanges and the frame mechanism develops, leading, as a result, to the failure of the entire web [16].

The aims of this research are to investigate experimentally the shear failure mechanisms of trapezoidal corrugated web steel panels and to

* Corresponding author.
E-mail addresses: mleblouba@sharjah.ac.ae (M. Leblouba), sbarakat@sharjah.ac.ae (S. Barakat), zalsadoon@sharjah.ac.ae (Z. Al-Saadon).

https://doi.org/10.1016/j.jcsr.2018.09.010
0143-974X/

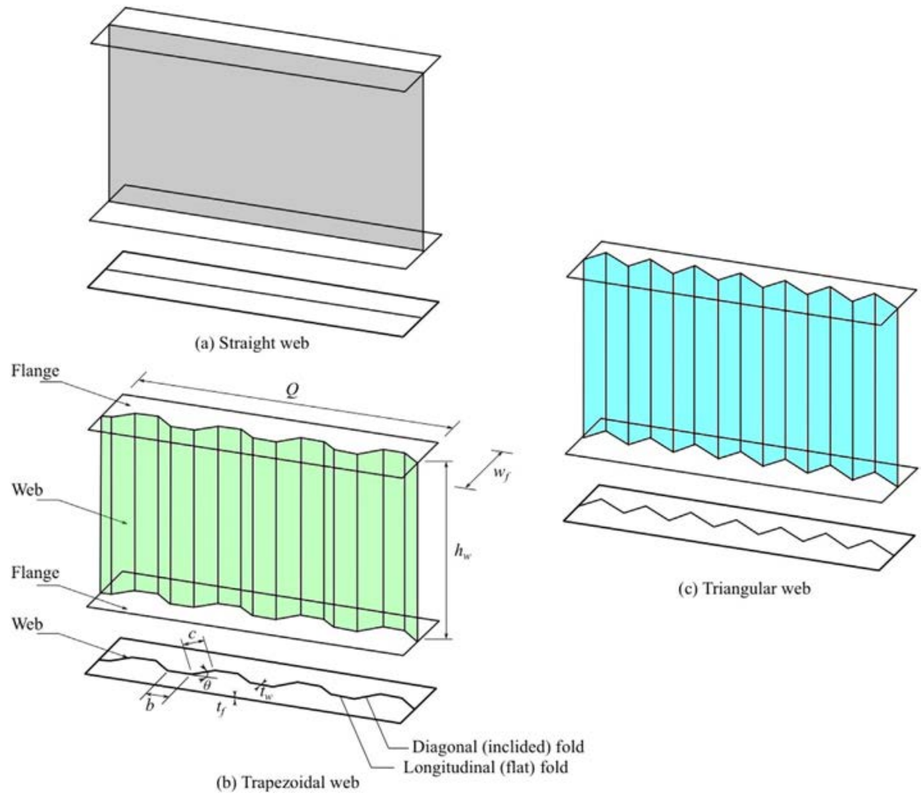

Fig. 1. Wireframe representation of (a) straight, (b) trapezoidal, and (c) triangular webs.

estimate their residual strength. In addition, a sensitivity analysis is conducted to investigate the relative contribution of material and geometric parameters in the uncertainty of the shear strength of corrugated web panels.

2. Problem statement and research objectives

Laboratory tests on corrugated web beams are very limited in number. Sause and Braxtan [11] gathered 102 test results, in a database, for the purpose of verifying their model for the estimation of shear strength of trapezoidal corrugated webs. Moreover, the same authors noticed the lack of tests on stocky corrugated webs (i.e., webs with slenderness ratios below 0.7) except the two tests conducted by Peil [17], which were excluded from the model verification since the geometry of the specimens was not consistent with the theory behind most of the shear strength analytical models. Consequently, Sause and Braxtan model assumes the shear strength of stocky corrugated webs to not reach the yield shear strength of the material. This was supported later by the results of finite element simulations conducted by Hassanein and Kharoob [18]. In contrast, other researchers [4,10,19,20] proposed different shear strength models, however, all of them consider stocky corrugated webs to reach yield shear strength.

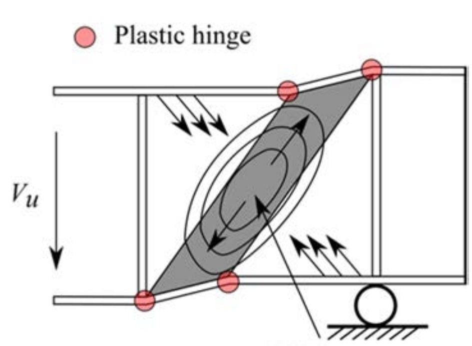

Fig. 2. Formation of plastic hinges and yielding of the diagonal zone under tension-field action [7].

Previous experimental studies [7,9,12,21–23] demonstrated that trapezoidal corrugated webs exhibit a residual strength after buckling. For instance, Leblouba et al. [7] tested six corrugated web steel beams and reported that the residual strength is not significantly influenced by the mode of shear buckling and estimated it to be around 50% of the ultimate load carrying capacity of the tested beams. Since, an accurate estimation of the residual strength may prevent catastrophic failures, it is worthwhile conducting more tests to verify/validate previous observations.

In addition, the current body of work lacks sensitivity analysis to evaluate the effect of various material and geometric parameters on the uncertainty of shear strength of corrugated webs.

This study attempts to address the above shortcomings in a systematic and coherent way through the following research objectives:

1- To test nine shear-critical corrugated web panels, with different web configurations until failure and enrich the literature body with more test data;
2- To investigate the various shear failure mechanisms from the onset of buckling until the post-buckling stage. This investigation will be reinforced by several sequential and realistic sketches of the behavior of each test specimen as it goes from one loading stage to the next one, until failure;
3- To estimate the residual strength exhibited by the trapezoidal corrugated web beams and verify previous observation reported by Leblouba et al. [7];
4- To conduct a comprehensive sensitivity analysis and evaluate the influence of material and geometric parameters on the shear strength of trapezoidal corrugated webs.