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Thin-Walled Structures 43 (2005) 291–332

THIN-WALLED STRUCTURES

www.elsevier.com/locate/tws

An analysis of the structural behaviour of axially loaded full-scale cold-formed thin-walled steel structural panels tested under fire conditions

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Received 29 September 2003; accepted 26 July 2004

Abstract

This paper presents a theoretical analysis to predict lateral deflections and failure times of six full-scale cold-formed thin-walled steel structural panels, tested under in-plane loads and exposed to fire attack on one side. The main objectives of this study are to investigate the effects of thermal bowing deflection and to check the relative merits of using either ENV 1993-1-2 or a modified version of ENV 1993-1-3 to perform design calculations for axially loaded steel studs under non-uniform temperature distributions. In general, the design of steel studs should also consider the effect of shift of neutral axes in both principal directions of the cross-section at elevated temperatures. However, such calculations can be rather time-consuming. Therefore, a secondary objective of this study is to assess how to effectively and accurately deal with this aspect in routine design calculations. It can be seen that thermal bowing deflections will have substantial effect on the fire resistance of steel structural panels exposed to fire on one side. However, for design calculations, it is not necessary to consider the effect of increasing thermal bowing deflections due to axial compression and reducing elastic modulus of steel at elevated temperatures. Both ENV 1993-1-2 and ENV 1993-1-3 may be used in design calculations of the ultimate load of this type of construction. It appears that ENV 1993-1-3 gives slightly better agreement with test results, but ENV 1993-1-2 is easier to implement because it does not require additional calculations of effective areas of thin-walled cross-sections at non-uniform elevated temperatures. The effect of shift of the minor axis is very small on the prediction of panel failure times and can be ignored to simplify routine design. Neutral axis shift of the major axis has some

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0263-8231/$ - see front matter
doi:10.1016/j.tws.2004.07.008

effect and may change the panel failure position from at the mid-height to the support. However, ignoring this neutral axis shift seems to give the best agreement to test results in term of panel failure location and panel failure times.

Keywords: Thermal bowing; Fire resistance; Effective width; Partial plasticity; First yield occurrence; Shift of neutral axis; Thin-wall steel; Structural panels

1. Introduction

Cold-formed thin-walled (CF-TW) steel lipped channels are the predominant sections used as load bearing wall studs in light-weight steel construction. Under fire conditions, because of their thinness, CF-TW steel sections heat up quickly resulting in fast reduction in their stiffness and strength. However, if gypsum boards are combined with thin-walled steel channels to form steel stud walls, the fire resistant performance of the steel structure will improve since the gypsum boards can protect the steel studs from fire exposure, thus delaying temperature rises in the steel studs. Achieving sufficient fire resistance to prevent or delay the spread of fire and to ensure building integrity so that occupants can safely evacuate and fire fighters perform their duties is a major issue when using CF-TW steel wall panels as load-bearing walls. At present, although some analytical studies have been performed to predict the structural performance of CF-TW steel panels subjected to the standard fire condition [2,3,6], the fire-resistance rating of load-bearing CF-TW steel wall panels are still assigned based on the results of standard full-scale furnace tests [3,4,5,7].

Among a few available analytical studies, Gerlich [3] presented a design model to determine the critical failure temperature of CF-TW steel studs. The model is based on the AISI design manual [1] and adopts the reduction factors for the yield strength and modulus of elasticity of steel given by Klippstein [4]. The purposed design checks are

$$\sigma = \frac{P}{A} - \frac{P[e(\Delta T) + e(M)]}{W} \leq F_{y,T} \text{ for the hot flange} \quad (1)$$

$$\sigma = \frac{P}{A} + \frac{P[e(\Delta T) + e(M)]}{W} \leq F_{y,T} \text{ for the cool flange} \quad (2)$$

where P is the applied compression force; A is the gross cross-sectional area of the steel stud; $e(\Delta T)$ is the mid-length deflection due to thermal effects; $e(M)$ is the mid-length deflection due to bending moment; W is the elastic modulus about the stronger axis of the cross-section and $F_{y,T}$ the yield stress of the steel stud at temperature T. This approach does not consider local buckling of CF-TW steel studs.

Alfawakhiri and Sultan [2] also presented a structural analysis model for CF-TW steel wall studs subject to non-uniform temperatures. In their model, they assumed that