Thin-Walled Structures 94 (2015) 177–187

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Static resistance function of cold-formed steel stud walls

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ARTICLE INFO

Article history:
Received 21 February 2015
Accepted 9 April 2015
Available online 14 May 2015

Keywords:
Cold-formed steel studs
Static resistance
Analytical models
Numerical modeling

ABSTRACT

Previous research focused on the optimization of conventional stud-to-track wall systems for moderate blast threat level protection. It has been concluded that adding extra screws is a practical and an efficient solution for altering the failure mechanisms and increasing the blast resistant characteristics of these wall systems. This paper is focused on the evaluation of the static blast-resistance of conventional cold-formed steel stud wall systems. A general analytical model of the resistance, which is the first necessary step for performing dynamic response predictions under blast, is presented in this paper. A case study of sufficiently screwed stud-to-track connection is selected for further inspection and investigation. Particular emphasis is placed on the effect of including utility holes and sheathing on the static resistance of the wall system. For each experimental test, strain data were collected up to the failure point from a total of 11 longitudinal strain gauges installed on locations of interest. A finite element model was developed to include the sheathing effect and to add flexibility to the simulation of the conventional connection. Strain results provided insightful observations about the behavior of the stud and were used to validate the numerical simulations as well.

1. Introduction

Cold-formed steel (CFS) members are being used extensively in building construction, with the wall system generally consisting of CFS studs, braced laterally, and confined at the top and the bottom by track sections. CFS studs have been approved for their blast-resistance capability because of their inherent favorable strength and ductility. Adapting and developing wall systems to resist different levels of blast threats is one of the focus areas nowadays. A special concern is given to the conventional stud-to-track wall systems and how to customize their resistance against threats without significantly impacting the cost [1]. The stud-to-track connection details play an important role in affecting the overall behavior of the wall assembly. In 2007, LaBoube and Findlay [2] explored both the stud-to-track connection strength and the esthetic concerns associated with the stud-to-track gap in a typical CFS wall assembly. Recently, experimental research has been implemented on investigating the resistance of conventionally constructed CFS stud walls [3,4]. However, the resistance behavior has not yet been fully identified or characterized. Past research has identified three regions of the behavior for steel studs under uniform (blast) loading; bending phase (elastic and plastic bending), transition/softening phase, and tension-dominated behavior [1]. It has been also shown that the behavior of blast-loaded steel stud walls varies widely depending on the stud and track section and material properties, connection details, and sheathing characteristics [4,5]. A recent study that investigated the behavior of dissimilarly sheathed, load bearing, cold-formed steel studs under axial and lateral load demonstrated that sheathing has a definitive and positive impact on the stability and strength of the stud [6]. In this paper, the effect of the sheathing on the static resistance of CFS stud walls is investigated.

Since the early 2000s, blast-resistant design using cold-formed steel studs has been the focus of several investigations [7–12]. The static resistance function of the steel stud walls is incorporated in the single degree of freedom (SDOF) technique to predict the dynamic response under blast loads. To design blast-resistant steel stud walls, it is necessary to ensure that the wall has sufficient ductility to resist large deformations due to blast loads. Ductile performance requires that the walls yield, but continue to carry loads and absorb significant energy through the plastic response. Therefore, the potential premature failure modes, particularly at the connections, must be prevented. Recently, numerical models were developed to predict the static resistance of conventionally-connected steel stud wall systems [11,13]. Previous experimental/numerical research conducted to study the effect of screws configuration on the resistance showed that using at least 3 screws per connection would be sufficient to develop tension membrane behavior [5,14]. It has also been showed that a 4-screw

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http://dx.doi.org/10.1016/j.tws.2015.04.008
0263-8231/

stud-to-track connection provided sufficient strength that the stud developed enough tension membrane such that the failure occurred in the track-to-floor connection. This connection configuration (4 screws per connection) was selected as the case to study in the research presented in this paper so that the full behavior of the wall systems is thoroughly investigated.

It is worth noting that most of the previous experimental research were performed mainly to investigate the resistance (load–deflection relationship) of the stud without providing detailed information about the strains induced in the stud as it deformed. Measuring strains at points of interest in the stud would help to provide more insight into the behavior of the stud. Additionally, detailed experiments are required to verify developed finite element (FE) models. This leads to the main objective of the research study presented in this paper which is to investigate the stud behavior through well-documented experiments and to provide detailed information about strains induced in the stud which will be used to verify developed numerical model. The finite element model presented in this paper is considered to be an improvement to the numerical model previously developed by Bondok and Salim [13]. In this paper, the numerical model was enhanced by using a deformable screw behavior to add flexibility to the connection. In addition, the sheathing effect was also included in the numerical model presented in this paper.

2. Analytical model

In past research, steel stud walls subjected to blast loading exhibited a tendency to fail in shear at end connections. Thus, the energy absorption capacity of steel stud walls varied greatly with connection type and strength. The analytical model presented in this section is formulated to predict the response of steel stud walls assuming that out-of-plane distortion (lateral torsional buckling) and connection failure is prevented through properly designed lateral bracings and improved connection details [4,5,11]. The analytical model is developed to ascertain the resistance functions for dynamic analysis under blast loads. The resistance model is based on midspan deflection of the wall subjected to uniform loading. The analytical model developed in this section assumes that stud connections are strong enough to permit significant plastic tensile deformation in the studs. As sufficiently anchored steel studs deflect, they transition through four different resistance regions, which are shown in Fig. 1.

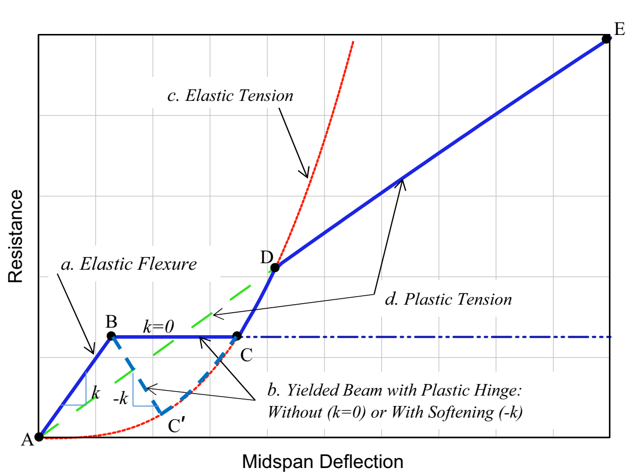

Fig. 1. Graphical depiction of the analytical resistance function for a steel stud wall with sufficient end anchorage: (a) elastic beam flexure; (b) yielding with plastic hinge formation; with or without softening depending on the connection detail; (c) elastic tension and (d) plastic tension.

An explanation of the four resistance regions is described below, including the equations required to produce the resistance function for a given steel stud; detailed derivations are provided by Dinan [1].

2.1. Elastic beam flexure

Initially, steel studs behave elastically and deflect as simply supported beams under uniform load according to classical beam theory. This elastic bending region is depicted as line A–B in Fig. 1. Therefore, stud resistance as a function of midpoint deflection in this elastic region is approximated by the following equation:

$$\Delta = \frac{5wL^4}{384EI} \tag{1}$$

where Δ = stud deflection at midspan, w = uniformly applied load per unit length, L = un-deformed steel stud length, E = Young's modulus and I = moment of inertia of stud cross-section.

The stud will respond according to Eq. (1) until its moment resistance capacity is exceeded and the stud yields (point B in Fig. 1). The load associated with this yield point is calculated by the following equation:

$$w = \frac{8M_n}{L^2} = \frac{8S_eF_y}{L^2} \tag{2}$$

where M_n = nominal flexural strength of the stud cross-section, S_e = effective section modulus at the initiation of yielding and F_y = maximum bending stress of the steel.

2.2. Beam yielding with plastic hinge

If a stud is loaded beyond its elastic moment capacity, it yields and forms a plastic hinge at midspan. In this region, a stud continues to strain without developing any additional resistance as depicted in line B–C in Fig. 1 for the case of rigid end anchor design. Depending on the end anchorage, rigid angles vs. soft tracks, this region could follow line B–C′, where a drop in resistance is predicted until the elastic tension region is reached. Thus, the slope of the analytical model in this region is assumed to be zero or $-k$, where k is the initial slope of the elastic beam flexure region, until the stud exhibits elastic tension behavior and again begins to increase in resistance.

2.3. Elastic tension membrane

Eventually, stud deflection reaches a point where it exhibits elastic tension cable behavior (shown as line C–D or C′–D in Fig. 1). The equation relating resistance to midpoint deflection is shown in Eq. (3); this equation is essentially the same as the classical equation for “Beams with Restrained Ends,” Case 6 in *Roark's Formulas for Stress and Strain* (Young, 1989).

$$w = \left(\frac{64AE}{3L^4}\right)\Delta^3 \tag{3}$$

where A = cross sectional area.

As loading increases, studs transition from elastic tension cable behavior to plastic tension cable behavior. This transition is marked by the point where Eqs. (3) and (4) yield the same deflection value (corresponding to point D in Fig. 1).

2.4. Plastic tension membrane

Each steel stud has a critical cross-section that controls the elastic tension capacity. Typically, such critical cross sections occur