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Finite element modeling of steel-plate concrete composite wall piers

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ABSTRACT

A finite element model is developed in LS-DYNA to simulate the nonlinear cyclic response of flexure-critical steel-plate concrete (SC) composite shear walls. The developed finite element model is validated using data from tests of four large-scale SC wall piers with an aspect ratio (height-to-length) of 1.0. Each SC wall was constructed with steel faceplates, infill concrete, steel studs and tie rods, and a steel baseplate that was post-tensioned to a reinforced concrete foundation. Steel studs tied the faceplates to the infill concrete and the infill concrete to the baseplate. Damage to the SC walls included cracking and crushing of the infill concrete and yielding, outward buckling and tearing of the steel faceplates. The finite element predictions include global force–displacement responses, equivalent viscous damping ratio, damage to the steel faceplates and infill concrete, strain and stress distributions in the steel faceplates, and estimates of the contribution of the steel faceplates and infill concrete to the lateral resistance of the walls. The DYNA-predicted responses are in good agreement with the measured responses. The impacts of interface friction between the steel faceplates and the infill concrete, and of the distribution of shear studs on the baseplate, to the global response of the SC walls are investigated using the validated DYNA model.

1. Introduction

Steel-plate concrete (SC) composite walls, consisting of steel faceplates, infill concrete, headed steel studs anchoring the faceplates to the infill, and tie rods connecting the two faceplates through the infill (see Fig. 1), have potential advantages over conventional reinforced concrete and steel plate shear walls in terms of constructability and seismic performance. However, these SC walls have not been used for earthquake-resistant *building* construction, in part because there are little data on their seismic performance at deformation levels expected in maximum considered earthquake shaking, aside from the experiments of Zhao and Astaneh-Asl [48], Eom et al. [12], and Nie et al. [25].

The seismic response of an SC wall is influenced by the nonlinear cyclic responses of the steel faceplates, the infill concrete, bond between the steel faceplates and the infill concrete, and the connectors (studs and tie rods). Analysis that assumes perfect bond between the steel faceplates and infill concrete, and ignores the effects of friction between the steel and concrete and connector spacing will generally not accurately simulate the behavior of SC walls (e.g., [46]). The connections of an SC wall to adjacent elements, SC and/or reinforced concrete (RC), or to a foundation, must be considered in the development of a finite element model because they provide sources of flexibility that could substantially influence global response.

This paper describes the nonlinear finite element modeling of SC wall piers using the general-purpose finite element code LS-DYNA [23,24]. The models are validated using data from tests of four large-scale SC walls. The effects of steel material model, friction between steel and concrete, studs and tie rods embedded in the infill concrete, concrete cracking and crushing, buckling and tearing of the steel faceplates, and foundation flexibility are considered.

2. Literature review

Ozaki et al. [29] conducted an analytical and experimental study on steel-plate reinforced concrete panels subjected to cyclic in-plane shear loading. The experimental study investigated the effect of steel faceplate thickness, axial load, partitioning webs, and penetrations on global response. Finite element models were developed to predict the pre-peak response of the SC panels, including those with openings. Vecchio and McQuade [42] applied the Distributed Stress Field Model (DSFM) to SC walls subjected to axial load, in-plane shear, and the reversed cyclic lateral

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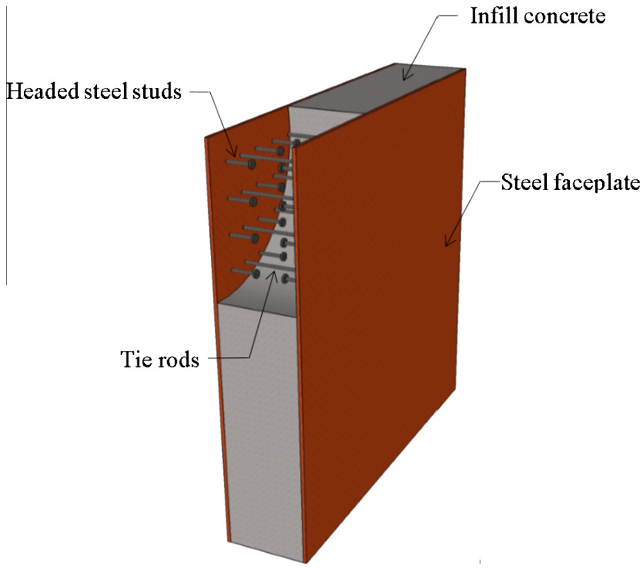

Fig. 1. SC wall panel.

displacement, using the two-dimensional nonlinear finite element analysis program, VecTor2 [38,39,43]. The strains in the steel faceplates were calculated assuming perfect bond between the steel faceplates and infill concrete. Buckling of steel faceplate element was assumed to occur when the principal compressive stress exceeded the critical buckling stress [35]. The adequacy of the model was investigated by simulating the monotonic and cyclic responses of SC walls tested by Sasaki et al. [32], Usami et al. [35], and Ozaki et al. [28,29]. The DFSM predicted the reported shearing strengths to within 5% but the stiffness at displacements less than those associated with peak strength were significantly overestimated [42]. The influence of the axial force and steel faceplate thickness on the global response of double skin steel–concrete composite shear walls was investigated by Xiaowei et al. [45] using a finite element package. The pre-peak-strength hysteretic behavior of SC walls was parsed into three regions, namely (1) elastic, (2) elastic–plastic, and (3) hardening. Cracking of the infill concrete and yielding of the steel faceplates were assumed to occur in stage 2, and the faceplates were assumed to buckle in stage 3. Post-peak-strength response, where pinching and stiffness and strength deteriorations are expected, was not considered.

Rafiei et al. [31] simulated the behavior of SC shear walls constructed with corrugated steel faceplates using ABAQUS/CAE [1]. The design parameters considered in the investigation were (a) configuration of the intermediate fasteners along the height and length of the wall, (b) yield strength of the steel plate, and (c) compressive strength of the infill concrete. Ali et al. [2] conducted a set of nonlinear finite element analyses with ABAQUS/CAE to investigate the cyclic behavior of four I-shaped SC walls (i.e., walls with flanges) with different steel faceplate thicknesses in the web and flanges. The ABAQUS predictions showed reasonable agreement with experimental results prior to peak strength. Post-peak-strength response was not addressed.

Varma et al. [36,37] studied the in-plane behavior of shear-critical SC walls with boundary walls or boundary flanges. They proposed a mechanics-based model (MBM) to predict the in-plane response of SC wall panels subjected to shearing forces. The model was based on numerical and experimental test data available at that time. The MBM model included the effects of concrete cracking, post-cracking orthotropic behavior, and yielding of the steel faceplates. A layered composite shell finite element model was developed in ABAQUS to extend the simplified model and to simulate the pre-peak-strength behavior of SC walls under monotonic loading. Analytical and numerical models were used to generate in-plane force, and in-plane force and out-of-plane moment interaction curves.

Kurt et al. [22] used LS-DYNA to analyze rectangular and flanged SC walls under monotonic in-plane shear loading and to perform a parametric study to investigate the effect of wall thickness and aspect ratio on the behavior of SC walls. Zhang et al. [47] evaluated the effect of connector spacing on composite action and local buckling of steel faceplates in SC walls using ABAQUS/CAE. The products of their analysis related to connector spacing have been implemented in AISC N690s1 [3].

Most of the prior studies focused on the pre-peak response of SC walls. Many of the available 2D and 3D models assumed perfect bond between the steel faceplates and the infill concrete and did not address the effects of steel faceplate buckling and connector spacing on in-plane response.

This paper builds on prior studies on numerical modeling of SC walls. A robust finite element model is developed to simulate both pre- and post-peak responses of flexure-critical SC walls up to drift ratios of 3%. Alternate steel material models are investigated. Damage to SC walls, including the cracking and crushing of concrete at the ends of a wall, and the outward buckling and tearing of steel faceplates are accounted for. The effect of the base connection on response is investigated. The contributions of the steel faceplates and infill concrete to the total strength and stiffness are presented. The impacts of the assumptions on contact and constraints, and the connection of the infill concrete to the baseplate are presented.

3. Experimental program: data to validate numerical models

Four large-scale SC wall specimens (SC1 through SC4) were built and tested under displacement-controlled cyclic loading at the University at Buffalo, with support from Purdue University. The aspect ratio (height-to-length, H/L) of all walls was 1.0. All four walls were flexure-critical, namely, the shearing resistance of the walls were limited by the flexural strengths at the base of the walls [13,19]. Flange plates (boundary elements) were not provided at the ends of the walls. A photograph of one specimen, SC1, is presented in Fig. 2. Data from the testing of these walls are used to validate the numerical model. Data in the literature on SC shear wall piers cannot be used because the detailed descriptions of forces,

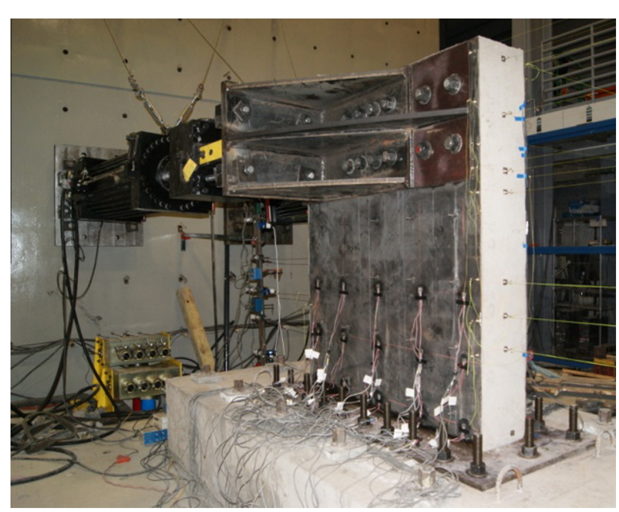

Fig. 2. Specimen SC1 in the laboratory at UB.