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Deteriorating hysteresis model for cold-formed steel shear wall panel based on its physical and mechanical characteristics

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ABSTRACT

Shear wall panels (SWP) are the primary lateral load resisting elements in cold-formed steel (CFS) structures. In this paper, smooth hysteresis models that take into account strength and stiffness degradation, as well as pinching effect have been developed and implemented in OpenSees software, as user-defined uniaxial materials named CFSWSWP and CFSSSWP for wood and steel sheathed SWP, respectively. The proposed analytical models are validated using the experimental tests results obtained from the literature, where a good agreement has been achieved. In order to investigate the influence of the CFS SWP parameters variation on the hysteresis characteristics of the response, several non-linear quasi-static analyses have been carried out using different CFS SWP configurations. The key parameters which have most affected the cyclic response were identified and assessed.

1. Introduction

In recent decades, the cold-formed steel (CFS) sections are increasingly used in low to medium rise buildings as primary elements, even in seismic prone regions. In which, the shear wall panel (SWP) is the main lateral load resisting system. It is made of CFS C-shaped framing members (studs and tracks) attached to steel or wood sheathing using screw connections. Appropriately designed SWPs dissipate energy by the inelastic behaviour of its framing-to-sheathing connections. When subject to repeated cyclic loading, the formed hysteresis loops are characterised by severe strength and stiffness deteriorations as well as a pinching effect. These phenomenons which affect most the post-elastic behaviour must be taken into account in the dynamic nonlinear analyses. The basic requirement to perform such analyses is the availability of a constitutive model capable of simulating as accurately as possible the SWP response when subjected to a quasi-static or dynamic lateral loading.

In recent years, several experimental quasi-static test programs have been carried out by researchers Fulop and Dubina (2004) [1], Branston et al. (2006) [2], Yu (2010) [3], Balh (2010) [4], Pan and Chan (2011) [5], Nithyadharan and Kalyanaraman (2012) [6], Liu et al. (2014) [7], DaBreo et al. (2013) [8], and Shakibanasab et al. (2014) [9], as well as a dynamic test program performed by Shamim el al., 2013 [10]. The test outcomes underscored the impact of SWP physical and mechanical characteristics on its hysteresis behaviour. The main parameters which have been identified are: the fastener spacing, the sheathing thickness, the framing thickness, and the height-to-width aspect ratio of the panel. As far as the numerical aspect is concerned, many finite element models have been developed to simulate the hysteresis behaviour of the CFS SWP. Balh [4] used Stewart model [11] which accounts for the pinched behaviour and the stiffness degradation; however, the strength degradation has not been taken into account. Leng et al. [12] modeled CFS SWP using Pinching4 hysteresis model based on test results carried out on isolated SWP, then, two-storey CFS building was modeled for the assessment of its seismic performance employing the calibrated SWP model parameters. The Bouc–Wen–Baber–Noori (BWBN) [13] model was used by Nithyadharan and Kalyanaraman [14] to capture the deteriorating behaviour, in terms of the strength and stiffness degradation with severe pinching that has been observed in the screw connections between the CFS framing members and the sheathing under cyclic loading. Based on the dynamic tests results of two-storey SWP obtained by Shamim and Rogers [15], the pinching4 model has been calibrated. Other FE modeling techniques were used by Bourahla et al. [16], Fulop and Dubina [17] to assess the performance of CSF buildings under cyclic and earthquake loadings. All of the abovementioned hysteresis models CFS SWP have parameters which are depending on the conditions and results of the

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experimental tests and do not refer explicitly to the physical and mechanical characteristics of the CFS SWP.

In this paper, hysteresis models for wood and steel sheathed CFS SWP that take into account strength and stiffness degradation with pinching effect have been developed. The models parameters are related to the CFS SWP physical and mechanical characteristics, the latter have been implemented into OpenSees software, as user-defined uniaxial materials using Dynamic Link Libraries (DLL) named CFSWSWP and CFSSSWP for wood and steel sheathed CFS SWP, respectively. The accuracy of the proposed models is validated against the experimental test results obtained from literature and the sensitivity of each analytical parameter of the model has been parametrically examined.

2. Hysteresis models development

Smooth hysteresis models for wood and steel sheathed CFS SWP based on the model proposed by Lowes and Altoontash (2003) [18] that takes into account strength and stiffness degradation with pinching effect have been developed. The uniaxial hysteresis models of wood and steel sheathed CFS SWP consists of three parts: backbone curves of the hysteresis loops (states 1 and 2), hysteresis criteria (unloading–reloading path: states 3 and 4) and degradation criteria (Fig. 1). The following sections will respectively introduce the expressions of the three parts.

These models can represent characteristics observed in experiments such as the response at time/instance that depends not only on the instantaneous displacement, but also on its past history, such as the input and response at earlier times.

2.1. Backbone curve

Maximum lateral shear strength and the associated displacement are assessed using two analytical methods for wood and steel sheathed CFS SWP proposed by, respectively, Xu L and Martinez J [19], and Yanagi N and Yu C [20] which take into account a wide range of factors that affect the behaviour and strength of a CFS SWP, namely: material properties, thickness and geometry of sheathing and framing, spacing of studs, construction details such as size and spacing of sheathing-to-framing connections.

Equivalent energy elastic–plastic (EEEP) multi-linear model, as shown in Fig. 2, is used to determine the key points' coordinates through which the envelop curve passes. This model assumes an envelope curve that is capable of dissipating an equivalent amount of energy as the real shear wall does when it is tested experimentally (area $A_1 = A_2$).

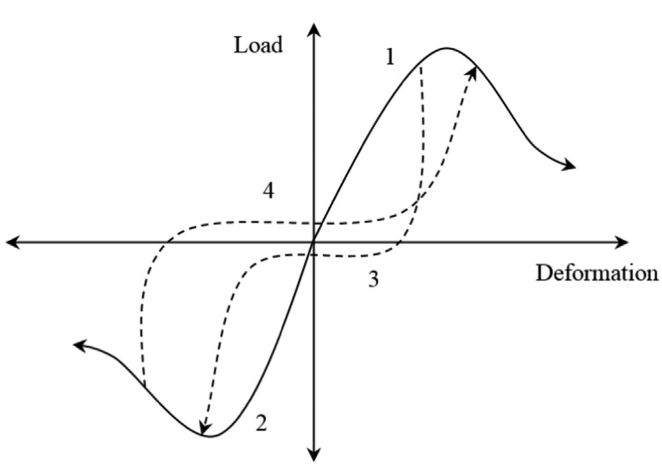

Fig. 1. Uniaxial hysteresis model states.

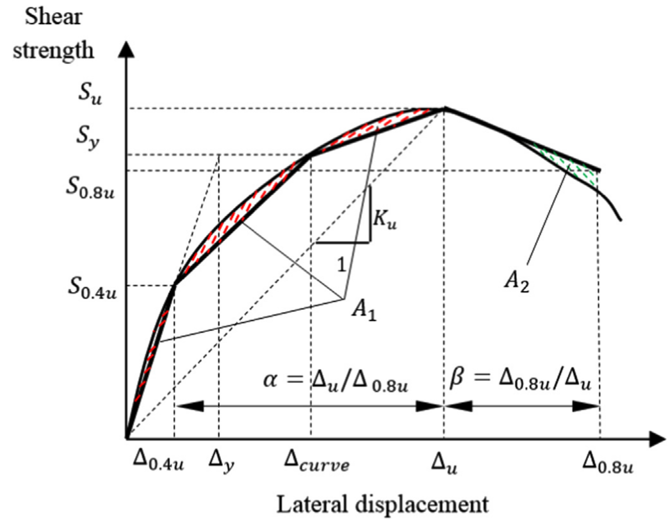

Fig. 2. Multi-linear envelope curve.

where

1. S_u : ultimate shear strength;
2. Δ_u : displacement corresponding to S_u;
3. $S_{0.4\,u}$: Strength corresponding to 40% of the ultimate shear strength value;
4. $\Delta_{0.4\,u}$: displacement corresponding to $S_{0.4u}$;
5. $S_{0.8\,u}$: Strength corresponding to 80% of the ultimate shear strength value;
6. $\Delta_{0.8\,u}$: displacement corresponding to $S_{0.8u}$;
7. S_y : yield strength limit idealized as 85% of the ultimate shear strength value;
8. Δ_y : displacement corresponding to S_y;
9. $k_e = \frac{S_{0.4\,u}}{\Delta_{0.4\,u}}$: elastic stiffness;
10. Δ_{curve} : displacement adjusted so that the area (A_{multi}) limited by the x-axis and the multi-linear curve till the failure point is equal to that limited by the experimental curve.

$$\Delta_{curve} = \frac{S_y.\,(\Delta_u + \Delta_y - 2.\,\Delta_{0.8\,u} - \Delta_{0.4\,u}) + S_u.\,\Delta_{0.8\,u} + S_{0.8\,u}.\,(\Delta_{0.8\,u} - \Delta_u)}{0.6.\,S_u} \quad (1)$$

According to the experimental results of tests conducted by Serrette et al. [21] on shear wall panels with wood sheathing attached by pins, the displacement ratio α of the ultimate displacement Δ_u to the elastic displacement $\Delta_{0.4u}$ value varies from 8.61 to 10.29, with an average value of 9.25. The ratio β of the failure displacement limit $\Delta_{0.8u}$ to ultimate displacement Δ_u varies from 1.0 to 1.63 with an average value of 1.40. Given the similarity between pins and screws nonlinear behaviour, for the simplicity, the authors applied the abovementioned factors in CFS SWP with screw connections.

Given the key points shown in Fig. 2, a curved envelope is adjusted by applying the B-Spline algorithm; this achieves the curvature for the states 1 and 2 of the hysteresis model. As can be seen in Fig. 3, a good agreement between the envelope curves of a SWP developed analytically and the one derived from experimental monotonic tests [2,4].