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Energy dissipation characteristics of steel coupling beams with corrugated webs

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ABSTRACT

Steel coupling beams are considered as an efficient alternative to reinforced concrete coupling beams in coupled shear wall systems. The application of corrugated webs as an alternative to flat webs with stiffeners in steel coupling beams has been lately proposed and its effective role in improving the ultimate rotation capacity of such beams has been demonstrated in published studies. However, the energy absorption characteristics of corrugated-web steel coupling beams have not been investigated. In this paper, the energy dissipation characteristics as well as cyclic performance of steel coupling beams with flat and corrugated webs are investigated through detailed numerical simulations. To this end and following the validation of the numerical simulation, numerous finite element models have been developed based on several key parameters including the flat, trapezoidal, curved, and zigzag web-plate corrugation forms, web thickness, number of corrugation half-waves, and corrugation angle. In addition to the advantages of application of corrugated webs in eliminating the web stiffeners and improving the ultimate rotation capacity in steel coupling beams, results and findings of this study demonstrate that corrugated-web steel coupling beams possess appropriate energy absorption characteristics and are capable of dissipating the input energy in a quite desirable and efficient manner. Moreover, it is shown that the energy dissipation capabilities of such coupling beams can be effectively improved via efficient design and proper adjustment of corrugation parameters.

1. Introduction

Coupled shear walls are considered as high-performing, economical, and architecturally-practical lateral force-resisting systems in design of tall buildings. Such structural systems, in general, consist of two or more in-plane shear walls interconnected with coupling beams, which exhibit considerable lateral stiffness and strength against wind and earthquake loads. Structural performance of such systems highly depends on the design and behavior of the coupling beams which have an effective role in the energy dissipation of the system.

Steel coupling beams are deemed as viable alternatives to reinforced concrete coupling beams which may improve the ductility and seismic performance of the coupled shear wall systems [1,2]. Steel coupling beams are advantageous, particularly where height restrictions do not permit the use of deep reinforced concrete or composite coupling beams, or where the required capacity and stiffness can not be developed economically using a conventionally-reinforced concrete coupling beam [3].

In a recent study reported by Shahmohammadi et al. [4], the application of corrugated webs as an alternative to flat webs with stiffeners in steel coupling beams has been proposed and its effective role in improving the ultimate rotation capacity of such beams has been demonstrated. Considering the various structural and seismic characteristics of coupling beams required for desirable behavior of the coupled wall systems including sufficient strength, stiffness, and ductility, favorable yielding behavior, i.e. yielding before the wall piers, and significant energy-absorbing characteristics [5], the cyclic performance and energy dissipation characteristics of steel coupling beams with flat and corrugated webs are investigated in this paper through detailed numerical simulations, as a sequel to Shahmohammadi et al.'s [4] study. To this end, 36 steel coupling beam models with flat and corrugated webs of trapezoidal, curved, and zigzag forms are developed on the basis of several key parameters such as corrugation type and angle, number of corrugation half-waves, and web thickness, and their cyclic performance is studied via nonlinear finite element analysis.

2. Specifications of beam models

The geometrical properties of the finite element models in this study are similar to those of the steel coupling beam in specimen HCWS-SCF,

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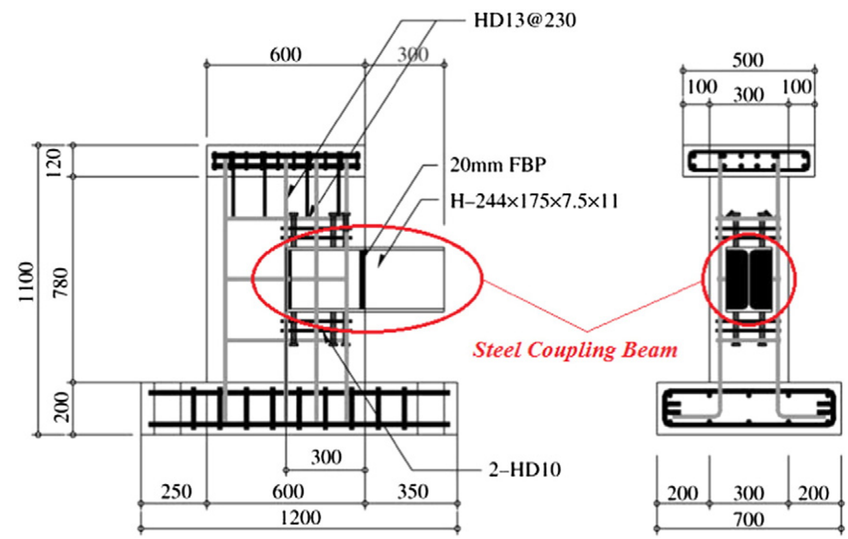

Fig. 1. Details of specimen HCWS-SCF tested by Park and Yun (2005). *(All dimensions are in millimeters.)*

which was tested by Park and Yun [3]. The details and dimensions of the steel coupling beam as well as the reinforced concrete shear wall system, in the aforementioned specimen, are shown in Fig. 1.

This specimen is in 1/2 scale and only one half of the coupled shear wall system was tested due to symmetry in geometry and loading, as shown in Fig. 1. Hence, the steel coupling beam in this test specimen was considered to behave as a cantilever beam subjected to tip load on the cantilever end with considerable fixity at its end support. The geometrical properties of the steel coupling beam considered in the finite element simulations of the current study are illustrated in Fig. 2.

By replacing the stiffened flat web of the steel coupling beam, shown in Fig. 2, with corrugated web-plates of various geometrical properties, a series of corrugated-web steel coupling beams are generated for the purpose of this study. The geometrical properties of the considered corrugated web-plates are presented in Fig. 3, in which a = flat (or horizontal) sub-panels width, b = horizontal projection of inclined sub-panels width, c = inclined sub-panel width, d = corrugation depth, t_w = web thickness, w = maximum fold width, R = radius of corrugation curve, θ = corrugation angle, and x,z = coordinate axes.

The numbers and specifications of the finite element models are summarized in Table 1, in which N is the number of corrugation half-waves for the selected type of corrugation. It is noted that all considered steel coupling beams, i.e. the 36 finite element models, are 300 mm long. In addition, the considered steel coupling beams are labeled such that the web-plate form and geometrical as well as corrugation properties of each model can be identified from the label. For example, the label "F-3" indicates that the model has a flat web with a thickness of 3 mm; also the label "T-45-2-5" indicates that the model has a corrugated web of trapezoidal form with a corrugation angle of 45°, 2 corrugation half-waves, and a thickness of 5 mm. It should be noted that the flat-web beam models in this study are similar to the original steel coupling beam as shown in Fig. 2, and hence are all strengthened by stiffeners.

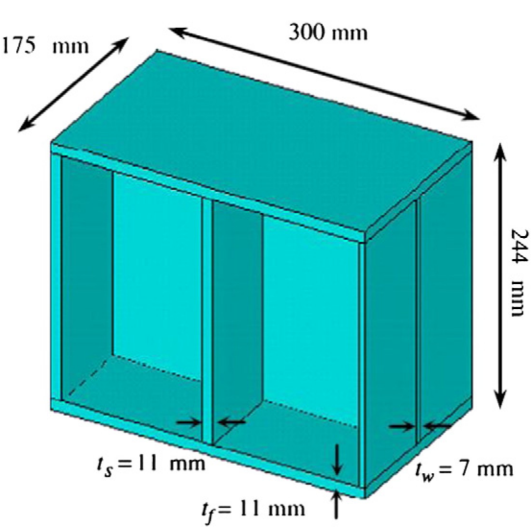

Fig. 2. Geometrical properties of the steel coupling beam models.

As it is seen in Table 1, corrugation angle (θ), number of corrugation half-waves (N), and web thickness (t_w) are considered as the effective geometrical and corrugation parameters in evaluation of energy dissipation characteristics as well as cyclic performance of the steel coupling beams with flat, trapezoidal, curved, and zigzag web-plate forms in this study. These parameters are selected in a manner which allows the comparison of performances of the models with different web-plate corrugation forms and details.

In the models with trapezoidal web (Fig. 3(a)), the flat/horizontal (a) and inclined (c) sub-panel widths are considered to be equal, i.e. $a = c = w$. Moreover, in the models with zigzag web (Fig. 3(c)), θ is considered to be 45° which results in $b = d$. Lastly, it should be noted that since the numerical models are in 1/2 scale, all dimensions and number of half-waves in real steel coupling beams are twice as large as those in the finite element models.

3. Finite element modeling and verification

The steel coupling beams have been modeled and analyzed using ANSYS [6] finite element software. The 8-noded shell element, i.e. SHELL63, is used to model the steel beams, which has six degrees of freedom at each node including translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. This element also has plasticity, stress stiffening, large deflection, and large strain capabilities, and is well-suited for modeling the buckling of steel plates. Concrete shear walls, on the other hand, are modeled using SOLID65 element, which is an 8-noded solid brick element and has three translational degrees of freedom per node in x, y, and z directions. Moreover, this element has crushing (compressive) and cracking (tensile) capabilities, and is capable of plastic deformation and creep. LINK8 element is also used to model the longitudinal and transverse steel reinforcement of the shear walls which is capable of plastic deformation. This element has two nodes and each node has three-degrees of freedom including translations in the nodal x, y, and z directions.