Design Procedure for Stiffening Panels of Slitted Steel Shear Wall

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Summary

Slitted steel shear wall stiffened by plywood panels is suggested as a new type of stud-type damper for the seismic retrofitting of buildings with many windows. Using experimental observations, finite element method analysis, and equations of plate lateral buckling, design procedures were proposed for estimating the required thickness of wood panels used to stiffen the slitted steel shear wall. Setting the ratio of modified buckling strength, which was obtained by assuming the effect of stiffening as an increase in bending stiffness relative to the yield strength, the design equations for the required stiffening panel thickness were derived. The design equations allowed the estimations of the effect of number of bolts and dimensions, and produced reasonable results in comparison with the experiments and numerical analyses.

Keywords: steel shear wall; stiffening; design procedure; FEM analysis; seismic retrofit

1. Introduction

This study proposes a hysteretic damper made of a thin steel plate with many vertical slits sandwiched between softwood plywood panels (Fig. 1). The steel plate segments between the slits behave as a series of flexural links, which dissipate the energy via yielding at both ends of the shear links. The strength and stiffness of the damper can be controlled fairly independently of one another by varying the slit arrangement. This study proposes sandwiching the steel plate between two wood panels in order to suppress the buckling of the slitted steel plate and to increase the energy dissipation in the shear wall. The proposed damper is significantly thinner than steel dampers with conventional stiffeners, light enough to carry by hand, easy to construct, and highly cost efficient. The damper can be installed in a limited area of beam spans as a stud-type damper and thus can be applied to existing buildings with many windows or door openings for seismic retrofitting.

In this study, design procedures were developed for estimating the required wood panel thickness and number of stiffening bolts to improve the damping performance of the shear wall using FEM analysis. Moreover, the validity of the procedures was examined by comparing with test results from previous studies.

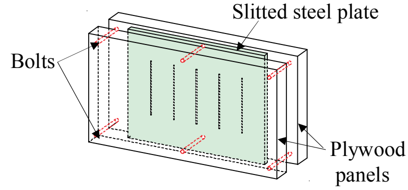

Fig. 1: Proposed damper

2. Design procedure for stiffening panels

2.1 Criteria for stiffening

Maximum strength ratio and slip strength ratio were selected as the design stiffening indices. The maximum strength ratio is the maximum strength divided by the design strength Q_{wtu} (in-plane strength).

$$Q_{wtu} = \frac{\sigma_y}{3} \cdot l \cdot \left(1 - \cos\frac{\sqrt{3}}{\alpha}\right) \cdot n \cdot t \quad (1)$$

where σ_y is the yield stress of the steel plate, t is its thickness, l is the length of the shear link, b is its width, α is aspect ratio of the shear link (=l/b) and n is the number of links.

The slip strength ratio is the slip strength, which is the strength at zero shear angle just after cyclic loading up to 0.03 rad, divided by the maximum strength. In this study, a maximum strength ratio of 0.8 and slip strength ratio of 0.5 were adopted as the stiffening criteria. The slip strength ratio of 0.5 corresponds to the equivalent damping ratio of 0.3.

2.2 Derivation of design thickness

Using FEM analysis and equations of plate lateral buckling, design procedures were proposed for estimating the required wood panel thickness for sufficient shear wall damping performance. The design equations were derived by setting the ratio of modified buckling strength, which was obtained by assuming the effect of stiffening as an increase in bending stiffness relative to the design strength. The modified lateral buckling strength (Q_{cr}*) was obtained with the following equation using coupling factor (k_1) and buckling-yielding ratio (k_2) was calculated from Q_{cr}* and $Q_{wtu.}$

$$Q_{cr}^{*} = n \cdot \frac{4.013}{\left(1 - \sqrt{\frac{EI_w}{GJ(l/2)^2}}\right)^2} \frac{\sqrt{(EI + k_1 E_r I_r) \cdot GJ}}{(l/2)^2} \quad (2)$$

$$Q_{cr}^{*} = k_2 Q_{wtu} \quad (3)$$

where EI is the bending stiffness of the steel plate, E_rI_r is the bending stiffness of the stiffening panel, which has the same width as the shear link of the steel plate, GJ is the torsional stiffness, EI_w is the warping stiffness of the shear link, and G is the shear modulus of the steel plate.

The design thickness of the stiffening panel was evaluated using Eqs. (1), (2) and (3) as follows. The design equations allowed estimations of the effect of number of bolts and the wall dimensions.

$$t_r = \left[\frac{1}{k_1}\left\{\frac{(1+\nu) \cdot k_2^2 \cdot \sigma_y^2 \cdot l^6}{32E \cdot E_r \cdot b^2 \cdot t}\left(1 - \sqrt{\frac{(1+\nu)}{6\alpha^2}}\right)^4 \cdot \left(1 - \cos\frac{\sqrt{3}}{\alpha}\right) - \frac{E}{E_r} \cdot t^3\right\}\right]^{\frac{1}{3}} \quad (4)$$

$$k_1 = 1.3\frac{l^4}{(d_{x1} d_{y1})^2}, \qquad k_2 = 2.5$$

where (d_{x1} d_{y1}) is the minimum area surrounded by 4 neighboring bolts in arbitrary slitted steel plate.

3. Comparison with test results and conclusions

The validity of design procedures for the panel stiffening was examined by comparing the stiffening criteria with test results. The ratio of the actual wood thickness to the design thickness (t_r) increased in direct proportion to slip strength ratio regardless of the stiffening panel thickness, number of bolts, or steel plate thickness as shown in Fig. 2. The design equations produced reasonable results in comparison with the experiments and numerical analysis.

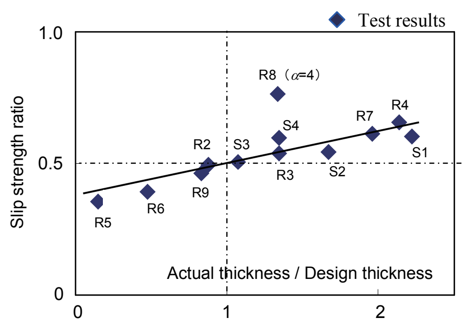

Fig. 2: Slip strength ratio vs the ratio of actual thickness to the design thickness