NUMERICAL STUDY ON ENERGY DISSIPATION CAPACITY OF LOW-YIELD STEEL (LYS) DAMPERS

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1. INTRODUCTION

Metal dampers can increase energy dissipation of structures efficiently. The energy dissipation is provided by the plastic deformation of metals. Variety of dampers which utilize mild steel have been studied, e.g. cantilever bar, flexural plate dampers, ring shaped dampers and etc[1)]. Recently, low yield steel (LYS) dampers have received much attention. Comparing with mild steel, low yield steel has much higher ductility and energy dissipation capacity. Applicability of LYS shear panels has been studied by a number of experiments[2)]. In this way, performance of the damper is usually determined directly from loading test of real-scaled dampers.

The purpose of current study is to capture fundamental characteristics of LYS dampers by 3D finite element analysis, in order to provide useful information for more rational design to enhance energy dissipation capacity. Especially, the effects of shapes of dampers on energy dissipation capacity are studied in details by comparing several feasible realization of dampers.

2. CONSTITUTIVE MODEL OF LYS

A typical stress-strain ($\sigma-\varepsilon$) relationship for LYS under monotonic uniaxial loading is given by the solid line in Fig. 1. A combined isotropic/kinematic model[3),4)] was selected to simulate the nonlinear hardening behavior of LYS under cyclic loading. The model is the combination of a constant kinematic hardening, with initial isotropic hardening which eventually decays to zero as the equivalent plastic strain $\bar{\varepsilon}^p$ increases, as shown by the dotted line in Fig. 1.

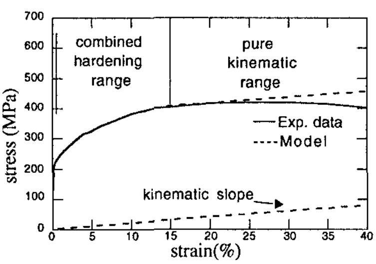

Fig. 1. Combined hardening model of LYS

Von Mises yield function $f=J2(\sigma_{ij}-\alpha_{ij})-1/3(\bar{A}(\bar{\varepsilon}^p))^2=0$ is employed to describe the yield condition, where $\bar{\varepsilon}^p$ is defined by $\bar{\varepsilon}^p=\int\dot{\bar{\varepsilon}}^p dt$, and $\bar{A}\dot{\bar{\varepsilon}}^p=(\sigma_{ij}-\alpha_{ij})\dot{\varepsilon}_{ij}{}^p$.(J2: second invariant of stress deviator tensor; σ_{ij}: stress tensor; ε_{ij}: strain tensor; $\bar{A}$: current size of yield about shifted origin; α_{ij}:current shift of yield surface center.).

3. PERFORMANCE OF VARIOUS TYPES OF LYS DAMPERS

1)Design of LYS dampers

Five typical and feasible shapes of dampers were chosen here (Fig. 2): simple cantilever bar, tapered cantilever bar, triangular cantilever plate, ring shaped damper, and shear panel. Height of all the dampers is fixed to 500 mm. The height-to-thickness ratio of shear panel was selected from experiment results of LYS panel[2)], while the height-to-thickness ratios of other dampers were selected according to previous research results of mild steel[1)].

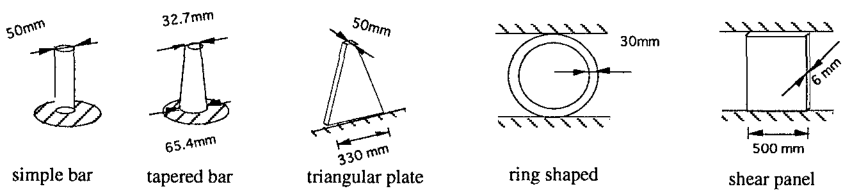

Fig. 2. Shapes of Dampers

The purpose of LYS dampers can be two-folded: the first is to provide rigidity against service loads at selected locations, the second is to yield and dissipate energy in seismic excitation. Hence, the yield displacement and force are important parameters for the design of steel dampers. These values are shown in table 1.

Table 1. Fundamental data of dampers

shape	yield disp. (mm)	yield force (kN)	volume (mm^3)
simple cantilever bar	2.5	3.431	9.812×10^5
tapered cantilever bar	2.7	6.599	9.797×10^5
triangular cantilever plate	3.3	41.929	4.75×10^6
ring shaped damper	3.5	4.768	1.413×10^6
shear panel	0.8	209.95	1.5×10^6

Keywords: low-yield steel, energy dissipation, finite element analysis.
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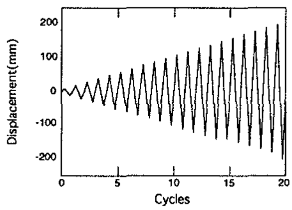

Fig. 3 . Displacement history

2) Loading History

The dampers were cyclically loaded according to the path shown in Fig. 3, in which the ordinate indicates the horizontal displacement at the top of dampers. The displacement amplitude increases gradually to 200 mm in twenty cycles.

3) Hysteretic Capacity and Energy Dissipation Behavior

The shapes of the hysteretic loops and estimated forces of FEM analysis are found to be close to previous experimental results[2]. The numerical hysteric loops of the simple bar are shown in Fig. 4, as an example. Energy dissipation behavior is the most important when evaluating the performance of steel dampers as energy dissipaters. Dissipated energy is equal to the area of hysteric loops. Fig. 5 shows the cumulative dissipated energy ΣE_i in terms of cumulative plastic displacement $\Sigma \Delta_{pi}$. Here, the cumulative dissipated energy is normalized by the volume v of each damper, and the cumulative plastic displacement is normalized by yield displacement Δ_y. Fig. 5 clearly shows that the shear panel have the largest energy dissipation capacity , followed by triangular plate, tapered cantilever bar, ring and simple bar.

One tip of designing steel dampers is trying to produce uniform curvature throughout the damper and induce almost uniform plasticization over the volume. Comparing the simple bar (SB) with the tapered bar (TB) of the same volume, the tapered bar could absorb about 50% more energy than simple bar (Fig. 5) and have more uniform strain distribution even after large displacement (Fig. 6).

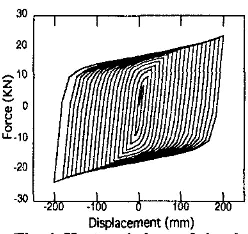

Fig. 4. Hysteretic loop of simple bar

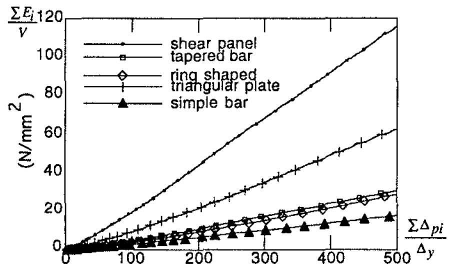

Fig. 5. Comparison of energy dissipation

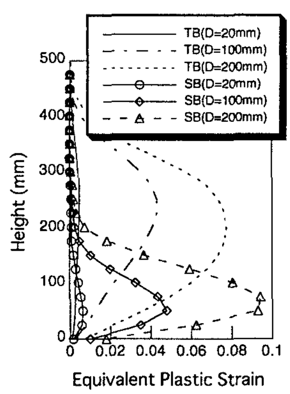

Fig. 6. Strain distribution

4)Equivalent Plastic Strain

The equivalent plastic strain of these dampers at every displacement stage is shown in Fig. 7. Much larger strain is observed for shear panel even at small displacement stage. For other kind of dampers, the largest equivalent strain is below 10% when the displacement amplitude is 200 mm. Although large strain generally yields large energy dissipation, it shortens fatigue life. The fatigue life of LYS dampers which is not considered in the present study, needs to be included to find appropriate strain level for LYS dampers.

4. CONCLUSION

A nonlinear plastic model for LYS and 3D FEM technique are applied to analyze the performance of various kinds of LYS dampers under cyclic loading. Large energy dissipation in unit volume is observed for dampers which allow uniform plasticization over the volume. Larger strain resulted in large energy dissipation capacity in this study because the effect of fatigue is neglected. To evaluate the energy dissipation capacity more precisely, the analysis method presented here will be extended to include the effect of fatigue in the future study.

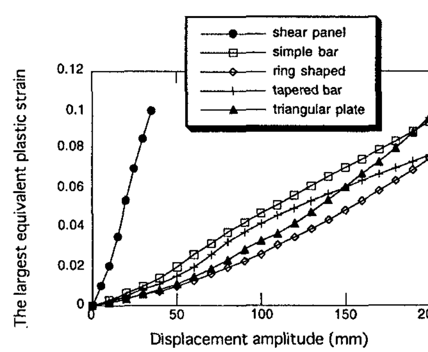

Fig. 7. Equivalent plastic strain

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