Analytical Study on Large Deformation in Shear Panel Hysteresis Damper Using low Yield Point Steel

2013 NZSEE Conference

D.Y.Abebe & J.S.Jeong

Graduate School of Architectural Engineering, University of Chosun, Gwangju, Korea.

J.W. Kim

Senior Researcher at Smart Green Construction and Development Technology, University of Chosun, Gwangju, Korea.

J.H. Choi

Associate Professor at School of Architectural Engineering, University of Chosun, Gwangju, Korea.

ABSTRACT: The objective of this study is to simulate and investigate the inelastic response behavior of shear panel hysteresis damper using low yield point steel (SLY120). Energy dissipating members play an important role to mitigate the damages caused by earthquakes. Shear panel hysteresis damper is among these seismic energy dissipating members which dissipates seismic energy by metallic deformation of the panel and fatigue resistance around the connection part. The disadvantage of such dampers is that they absorb seismic energy only when they go through inelastic deformation. To overcome this restriction of hysteretic dampers, low yield strength steel is used as the material for hysteretic damper because it has excellent ductility performance. Nonlinear finite element analysis was carried out to predict the large deformation and hysteretic behavior of low yield point steel (SLY120). The analysis was carried out by considering nonlinear inelastic material properties with combined hardening model. The developed nonlinear shear panel damper (SPD) model is verified with loading test results. Failure mode and hysteresis loops as well as cumulative energy absorption capacity were compared and satisfactory result was obtained.

1 INTRODUCTION

Damage control design method for civil engineering structures have been widespread to mitigate hazards caused by earthquake since 1995, Kobe, Japan earthquake disaster. At the same time energy dissipating devices have been developed and their dissipating capacity as well as behaviour has also been evaluated through experiment and numerical model considering different parameters such as aspect ratio and limiting the plate slenderness ratio at which buckling controls.

The shear panel hysteresis damper is an energy dissipating device through inelastic deformation (using material hysteresis of steel panel) and fatigue resistance around the connection part. Since SPD dissipate energy through hysteresis of material, the steel material characteristics used as a dissipating device is critical. So that the low yield point steel is good material to be used because of its excellent ductility performance and also its adaptability to steel structures. Shear panel dampers using low yield strength steel has been used in steel building and recently high-rise reinforced concrete apartment buildings to improve the seismic performance.

In this paper, nonlinear finite element analysis was carried out in order to evaluate the performance such as: maximum shear strength, reliable energy dissipating capacity (allowable deformation) and hysteretic behaviour of shear panel damper using commercially available FE software, ANSYS LS-Dyna version 12.0. The finite element simulation conducted was verified by loading test.

2 NONLINEAR FE ANALYSIS MODEL

2.1 Material Model

The analysis model under consideration has components consisting of a web (panel) modelled by SLY120; flanges modelled with the conventional mild steel SS400 and rigid body (loading plate) with dimensions shown in the fig. 3. It is tried to conduct the analysis with reasonable accuracy as much as possible using low yield point steel. The analysis material is modelled as a shell element considering the following two conditions: First, we consider large deformation kinematics to simulate the residual displacement. Of course, without large deformation kinematics, the deformation behaviour cannot be predicted in the analysis model. Second, the inelastic material behaviour, including the cyclic characteristics, is considered in other words the inelastic kinematic material properties are used during modelling. In order to consider strain hardening characteristics steel material, which is important parameter to be considered in modelling steel structure, combined kinematic and isotropic hardening model was implemented. Combined hardening model allows both translation and expansion of initial yield surface so it is considered as a best hardening model in simulating shear panel damper.

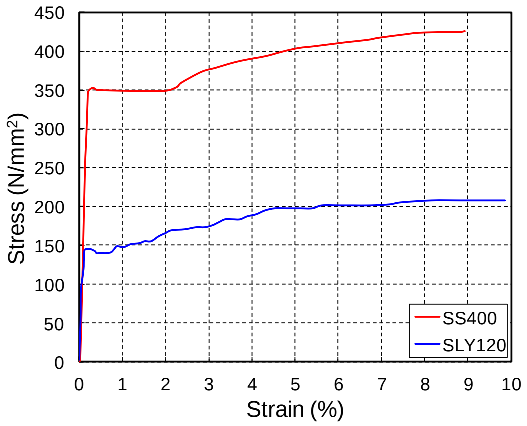

Fig. 1. Stress-strain relationships

The other hardening model such as kinematic hardening model allows only translation of initial yield surface whereas isotropic hardening model is an expansion of initial yield surface. Strain rate is accounted for using the Cowper-Symonds model which scales the yield stress by the stain rate dependent factor as shown below:

$$\sigma_y=\left[1+\left(\frac{\dot{\varepsilon}}{C}\right)^{\frac{1}{P}}\right]\left(\sigma_o+\beta E_p \varepsilon_p{}^{eff}\right) \tag{1}$$

where: σ_o is the initial yield stress, $\dot{\varepsilon}$ is the strain rate, C and P are the Cowper-Symonds strain rate parameters, ε_p^{eff} is the effective plastic strain, and $E_p$is the plastic hardening modulus which is given by:

$$E_p=\frac{E_{tan}E}{E-E_{tan}} \tag{2}$$

where E: young's modulus, and E_{tan}: tangent modulus

Isotropic, kinematic or the combination of isotropic and kinematic hardening models is adjusted by the hardening parameter β. The value of β varies between 0 and 1; β = 0 is kinematic hardening and 1 is isotropic hardening, and between 0 and 1 is the combined effect. Material nonlinearity was included in the finite element model by specifying a stress–strain curve in terms of the true stress and plastic strain. The engineering stress and strain obtained from the coupon test were converted into true stress and strain for this purpose. Fig.1. shows the stress-strain relationships. Table 1 presents the summary of inelastic kinematic material properties used during analysis.

Table 1. Summary of analysis model material properties.

Property	Panel (Web)	Flange	Upper &Lower rigid body
Young’s Modulus(GPa)	205	205	205
Poison’s ratio	0.3	0.3	0.3
Density (kg/m^3)	7800	7865	7700
Yield Strength (MPa)	126.7	245	
Tangent Modulus (MPa)	556	756	
Hardening Parameter	0.5	0.5	
Strain rate [C](s^{-1})	50	40	
Strain rate [P]	5.0	5.0	
Failure Strain	0.25	0.75	

2.2 Boundary and Load Condition

The boundary condition was modelled to have a shear effect on the panel. The lower rigid body is constrained both translation and rotation in all direction. The upper rigid body is modelled to have translation in X-direction and the other axis, Y and Z - axes constraint translation and rotation is constraint in all direction. Fig. 2 shows meshed 3-D shells of analysis model with axis.

The load is applied on the upper rigid body in X-direction. Basically there are two ways of applying loads: the constant stress loading and the constant strain loading. In this study, the constant strain loading is used; that the loading is applied by controlling the displacement. The specimen deforms up to prescribed displacement. Fig. 5 shows the displacement protocol used for both analysis and experiment.

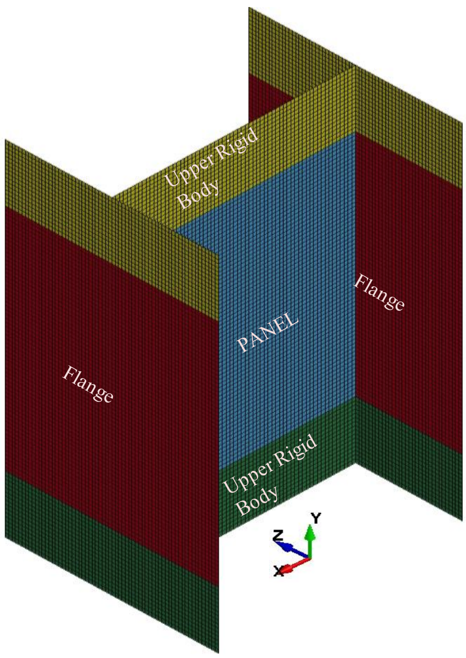

Fig. 2. Meshed 3-D Analysis Model

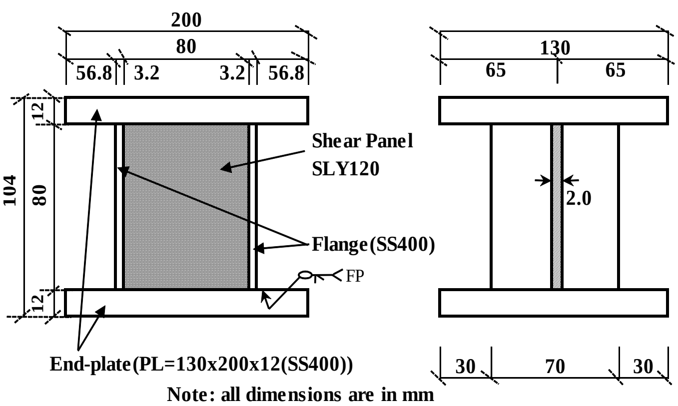

Fig.3. Specimen Detail

3 VERIFICATION OF ANALYSIS MODEL

To verify the feasibility and reliability of the proposed nonlinear finite element analysis, experiment was undertaken on the low yield steel panel. After conducting the loading test, the inelastic deformation, the hysteresis loop and cumulative energy dissipated by specimen was compared. The mechanical properties of the material and the dimensions used in the test are same with that of the analysis model. The detail of experimental specimen is shown in the fig. 3.

3.1 Test set-up and Process

Fig. 4 presents the loading test equipment system. As loading experiment equipment system, Pantograph was installed so that rotation angle does not occur at the top part of experiment specimen while load was applied horizontally at experiment specimen of low yield point shear panel damper. By installing Counter Weight using the principle of a pair of scale, it was arranged that axial force is not applied to experiment specimen.
Displacement meters for measuring displacement of low yield point shear panel dampers was installed at the top end plate and the bottom end plate of the experiment specimen. Average value of the right and left side displacement devices was evaluated as displacement value of the experiment specimen. In addition, horizontal force on the experiment specimen was measured by installing load cell adding actuator.

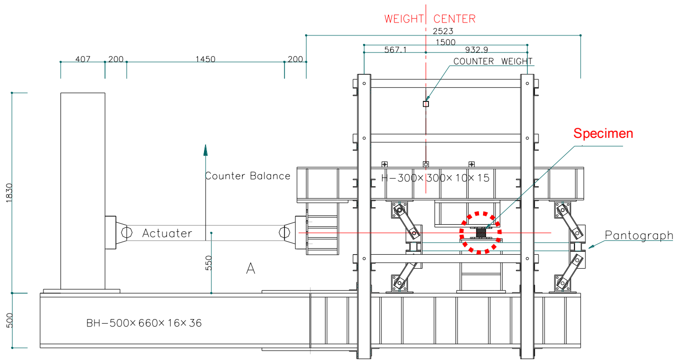

Fig.4. Schematic illustration of SPD testing set up

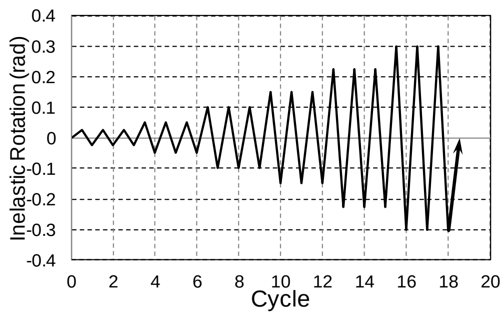

Fig. 5. Loading protocol

4 RESULT AND DISCUSSION

4.1 Failure Mode

The failure mode of loading test result and deformation mode of analysis result with von Mises's stress distribution is presented in Fig. 6.

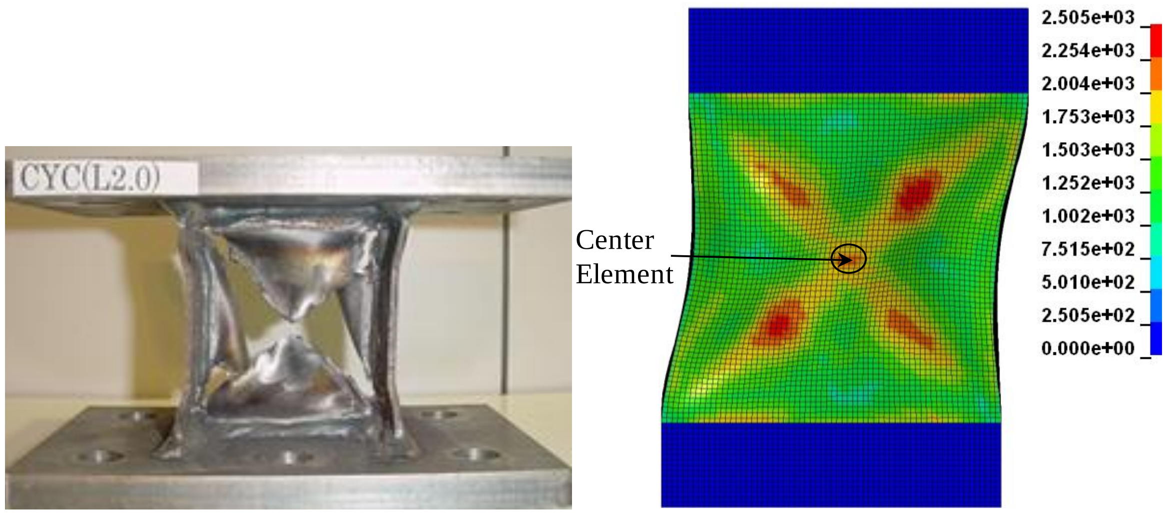

Fig. 6. (a) Failure mode of test result and (b) von Mises stress distribution of analysis result

The stress developed on the panel in the analysis model especially concentrated at the centre part propagates from the centre to each corner with an X-shape. Before final fracture the panel buckles out-of-plane in both analysis and loading test result. Local buckling of flange is also observed on both results.

4.2 **Load-displacement relationship**

The inelastic rotation versus shear force relationship or the hysteresis loops is presented in Fig. 7.below. As shown in the fig. 7, after attaining the maximum resisting capacity, the strength starts to decline at initial displacement. A sag or a decrease in resistance force is formed at initial displacement is due to out-of-plane buckling of the panel and as the load continuous the panel starts to fracture. The reduction of resistance force due to out-of plane buckling for loading test result starts at 7th cycle and continues up to 11th cycle. For the analysis curve it start from 9th cycle to 14th cycle then after the overall strength degradation was noticed before final failure.

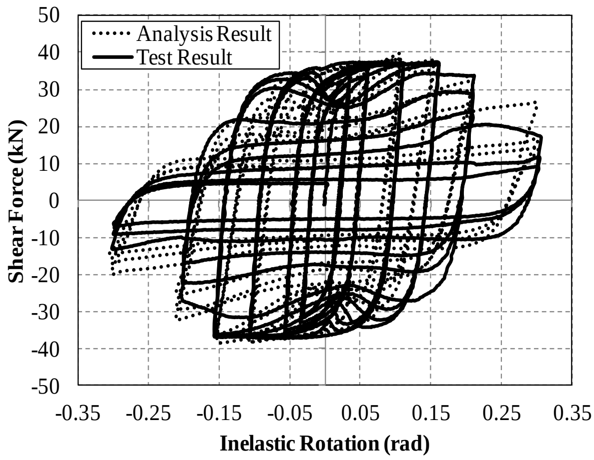

Fig. 7. Shear force versus inelastic rotation

During cyclic loading processes and analysis the specimen, a phenomenon of increase resistance force by hardening of deformation of shear panel hysteresis damper was observed for the first 6 and 8cycle respectively. The lateral deformation 0.15rad, failure at the center part of the panel occurred and afterward, according to the progress of cyclic loading, the panel was failed with an X-shape and reduction of resistance force was also occurred.

The failure of the SPD is predicted by the failure index defined by the triaxiality of the stress field and the accumulated plastic strain in tension and compression. The objective function is the dissipated energy before failure of the damper. The ductility capacity of the damper is defined using failure index as follows. The variables, which are functions of pseudo-time, such as stresses and strains are evaluated at integrated maximum possible point. Let $\varepsilon_p(t)$ denote the equivalent plastic strain defined as:

$$\varepsilon_p(t)=\int_0^t \sqrt{\dot{\varepsilon}_{ij}^p(\tau)\dot{\varepsilon}_{ij}^p(\tau)d\tau} \tag{3}$$

where $\varepsilon_{ij}^p(t)$ is the plastic strain tensor, $(\dot{})$ is the derivative with respect to time, and the summation convention is used. The equivalent plastic strain represents amount of plastic deformation in material level, and is evaluated at each integration point. Many fracture criteria have been presented using $\varepsilon_p(t)$. In the following, the argument t is omitted for brevity. We use an extended version of the SMCS criterion that was developed for simulating ductile fracture of metals due to void growth. The critical plastic strain ε^{cr} is first defined as:

$$\varepsilon^{cr}=\alpha \exp\text{-}1.5\frac{\sigma_m}{\sigma_e} \tag{4}$$

where σ_m is the mean stress, and σ_e is the von Mises equivalent stress given by eqs. (5 and 6) respectively. The parameter α is dependent on material. Eq. (7) indicates that the critical plastic strain for ductile fracture depends on the stress triaxiality σ_m/σ_e. Then the failure index for monotonic loading is defined as in eq. (11).

$$\sigma_m=\frac{\sigma_1+\sigma_2+\sigma_3}{3} \tag{5}$$

$$\sigma_e=\sqrt{\frac{1}{2}\left\{(\sigma_1-\sigma_2)^2+(\sigma_1-\sigma_3)^2+(\sigma_3-\sigma_2)^2\right\}} \tag{6}$$

$$I_f=\frac{\varepsilon_p}{\varepsilon^{cr}} \tag{7}$$

The material is assumed to fracture when I_f reaches 1.0. Fig. 8 shows failure index versus cycle relationship of analysis result. From the fig. the specimen was fractured at about the 16^{th} cycle.

From the hysteresis loops it is possible to calculate the cumulative energy dissipated, fig. 9 presents the comparison of the loading test and analysis result of cumulative energy. From the analysis result the part total energy can be computed and presented in Fig. 10. As presented in figure 10 the resisting capacity of flange is small compared with panel.

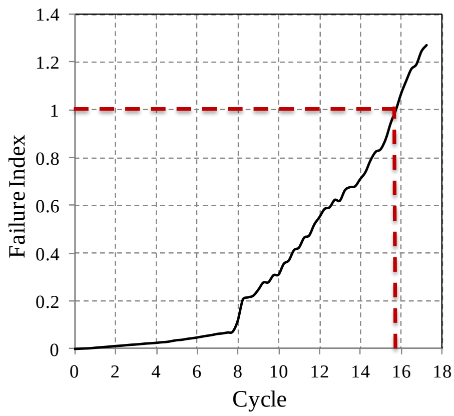

Fig. 8. Failure index of FE analysis model

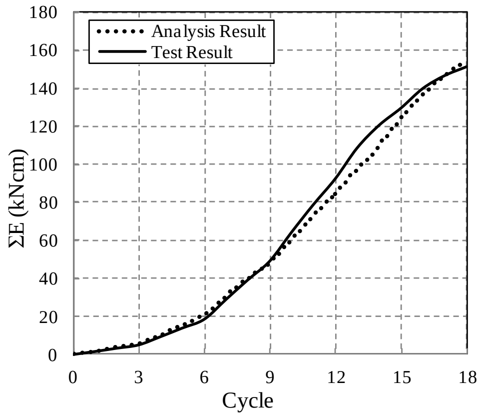

Fig. 9. Comparison of Cumulative Energy

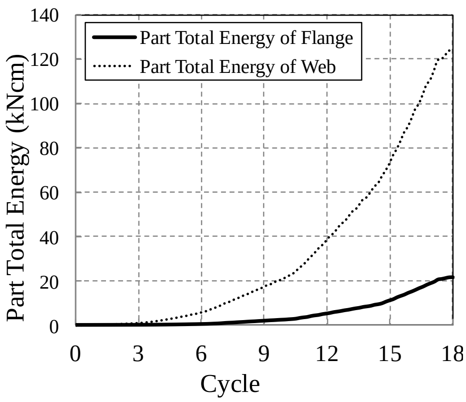

Fig. 10. Part Total Energy of analysis result.

5 CONCLUSION

The following conclusion was obtained from the analysis and loading test results of low yield point shear panel hysteresis damper.

The hysteresis behaviour of shear panel damper was evaluated both numerically and in loading test and the stress−strain relationship was obtained. The comparison of the simulation results with experimental solutions showed that approximately fit able, in terms of the stress–strain curves, final deformation or failure mode and cumulative energy dissipated under cyclic loading. The experiment conducted to verify the finite element analysis and extend its application. Thus, the finite element analysis can evaluate the performance of shear panel hysteresis damper.

Acknowledgment

This work was financially supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (No.2012-0008837, No.2012-0004069)

References

Abebe, D.Y. In, J.H & Choi, J.H 2012. Study on Structural Performance Evaluation of Shear Panel Hysteresis Damper, *Proc. of 2nd Int. Conference on Computational Design in Engineering, 13-16 November 2012,* Jeju, Korea

Soong, T.T & Spencer, B.F Jr, (2002), Supplemental energy dissipation: state-of-the-art and state-of-the-practice, *Engineering Structures, Vol. 24*, 243-259

Ricky W.K Albermani, F. & Williams, M.S., (2007), Hysteretic Damping of Shear Panel Energy Dissipater, *pro. of 5th Australasian Congress on Applied Mechanics, 10-12 December 2007*, Brisbane, Australia.

Chan, Z. Dai, Z. Huang, Y. & Bian, G. (2013), Numerical simulation of large deformation in shear panel dampers using smoothed particle hydrodynamics, *Engineering Structure, Vol. 48*, 245-254

User Manual of ANSYS LS-Dyna Version 12.0

Ohta, Y. & Nakane (2004), Study on Shear panel Damper Using Low yield Strength Steel Applied to Reinforced Concrete Building, *Proceeding of 13th WCEE, 1-6 August,* Vancouver, B.C., Canada

Tanaka, K. & Sasaki, Y. (2000), Hysteresis Performance of Shear Panel Damper of Ultra Low-strength Steel for Seismic Response Control of Building, *Proc. of 12th WCEE, 30 Janiuary-4 February*, Auckland, New Zealand