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Analytical Model of Coil Spring Damper Based on the Loading Test

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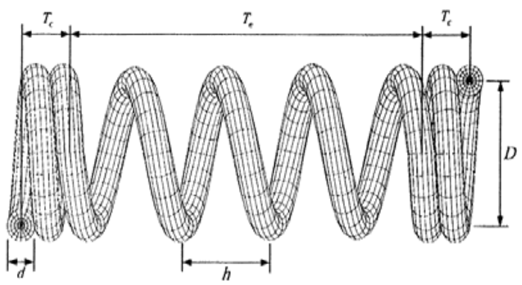
1. Introduction

There are some technical problems to reduce sufficiently the structural responses against strong winds and huge earthquakes with a long period and/or a long duration. The one way of solving such problems is to enhance and to develop an improved damping element used in base-isolation and response control system. A cost reduction of damper for a large scale structure is another important task to upgrade the total response control abilities in the near future. This study has examined a response control device using elasto-plastic hysteresis damping of metal material. The proposed damper is designed to be coil spring element shape for a uniform stress of metal and for a reduction of low cyclic fatigue in large deformation to upgrade a repetitive strength during the earthquake motions. By using the metal material of SS400 general structural rolled steel, the corresponding cost issues of the damping element will be effectively reduced. The analytical of elasto-plastic coil spring damper (CSD) is introduced, and basic mechanical properties evaluated experimentally and analytically.

2. Elasto-Plastic Coil Spring Damper



d : Wire diameter
D : Coil center diameter
L : Developed length
θ : Pitch angle
C : Coil index
h : Pitch
T_e : Effective deformation part
S : Effective deformation volume
T_c : Seat winding part

CSD has a highly stability because not only the stress of the coil is uniformly distributed without stress concentration but also the whole part of the coil spring can be used as a damping element to utilize hysteresis characteristics of metal material.

As the results, the fatigue characteristic has been largely improved and an economic life cycle becomes to be longer. The prediction formula for hysteresis dynamic behavior of elasto-plastic CSD is set up from parametric study as following.

Yield Displacement $$\delta_y = 1.91\frac{f_{sy}}{E_{s1}}\pi D N_e\left(\frac{D}{d}\right)$$

Yield Force $$F_y = 0.36 f_{sy}\frac{\pi d^2}{4}\left(\frac{D}{d}\right)^{-1}$$

Elastic Spring Const. $$k_e = 0.19\frac{\pi d^2}{4}\frac{1}{\pi D N_e}\left(\frac{D}{d}\right)^{-2}$$

Plastic Spring Const. $$k_p = 0.024\left[E_{s1}\frac{\pi d^2}{4}\frac{1}{\pi D N_e}\right]\left(\frac{D}{d}\right)^{-1.28}\left(\frac{h}{D}\right)^{0.22}\left(\frac{E_{s1}}{E_{s2}}\right)^{-0.75}$$

Besides, the parametric study is conducted using the analytical conditions shown in Table 1.

Table 1: Analytical conditions on Parametric Study

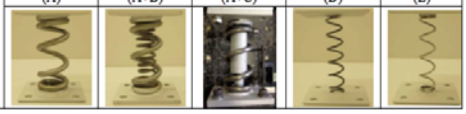
Condition	Analytical case	Number of times
Material model	SS400, SM570, low yield strength steel	3
Effective number of turns	3, 4, 5, 6, 7, 8, 9, 10	8
Wire diameter	20, 40, 60 mm	3
Coil index	3, 4, 5, 6, 7, 8, 9, 10	8
Pitch/Wire diameter	0.1-0.6	11
	Total	6336 ways

3. Loading Test for Evaluation of Mechanical Characteristics

3.1 Experimental Specimen

Five different specimens are designed and manufactured for the loading test. Table 1 shows the test specimens. Type (A) shows the basic type of CSD using SS400 as a wire rod. Type (A+B) is manufactured to investigate the restoring performance against residual displacement to install a coil spring into CSD. Type (A+C) is constructed by combination of CSD and viscoelastic damper. This type is examined how much is upgraded a damping ability as a response control damper in small deformation area under yield displacement of CSD. Type (D) and (E) are the dampers to compare a hysteresis damping in between SS400 and SWRM which has been commonly used as an elasto-plastic damping material.

Table 2: Combination of Experimental Specimens used for the loading Test

	CSD (A)	CSD (A+B)	CSD (A+C)	CSD (D)	CSD (E)
Type					

3.2 Experimental Method

The loading test is conducted to investigate a displacement and frequency dependency on mechanical characteristics. Loading frequency range set from 0.05Hz to 0.5Hz from the maximum velocity performance of loading apparatus. Besides, the fundamental loading frequency in the test is 0.3 Hz. Displacement amplitude of loading is from 2mm to 80mm. Figure 1 shows the loading test condition set to hydraulic servo actuator. The displacement transducer and load cell installed in the hydraulic servo actuator are used to measure the displacement and the force. The sampling frequency set to 50 Hz and 100 Hz. Besides, the temperature on the surface of the damper specimen is measured before and after loading test by using a contact typed thermometer.

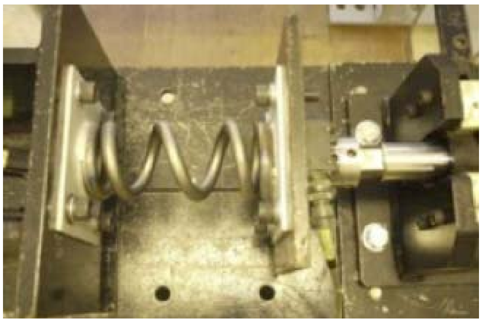
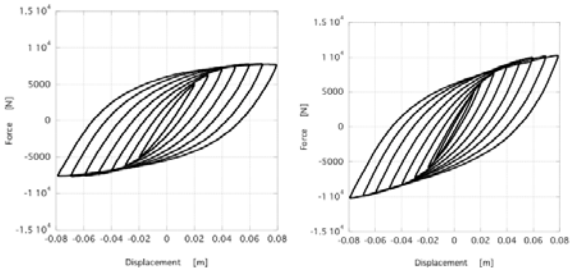


Fig. 1. Experimental set-up of loading test

3.3 Experimental Results

Figure 2 shows the comparison with damping performance in large deformation area in CSD type A and A+B. The damper type A+B increases spring constant by adding an elastic coil spring into damper type A. However, it is confirmed that both damping performances have stable elasto-plastic damping characteristic even in large deformation region.



(a) CSD (A) (b) CSD(A+B)

Fig. 2. Comparison of Damping Performance in Large Deformation Area using CSD (A) and CSD (A+B)

4. Examination of Analytical Model

Based on the results obtained from loading test, the analytical model is examined to evaluate the damping performance in time history analysis. In this time, Rate Model is selected to express the damping force characteristic. The formulation of Rate Model shows from formula. Figure 3 indicates the comparison of analytical and experimental hysteresis loops in case of CSD type A. The experimental condition is 0.3Hz of loading frequency and 80mm of loading displacement. It is confirmed that the both damping characteristics have a good coincident.

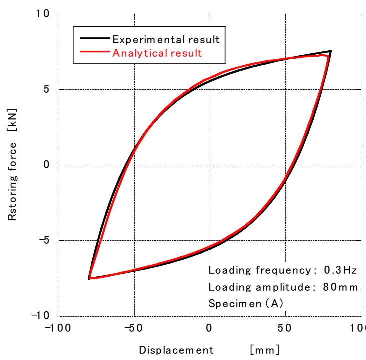


Fig. 3. Comparison of Analytical and Experiment by Hysteresis loops

5. Conclusions

This study has been examined the response control damper using elasto-plastic hysteresis characteristics of metal material. The paper described the design method of elasto-plastic coil spring damper, basic mechanical properties evaluated from loading test, and analytical model of damper are summarized. It was confirmed that the damping force and mechanical characteristics of elasto-plastic coil spring damper are almost satisfied the design specifications.

REFERENCES

[1] Ishigaki, H., Ishimaru, H, Hata, H. and Yoshida, A.: A Retrofit Method of a Traditional Wooden Structure by two Damper Systems, AIJ J. of Technol. Des., pp. 91-96 (in Japanese).