HYSTERISIS CHARACTERISTIC OF LEAD PILLAR DAMPER

Shinji ARAMAKI[1], Kiyoshi UNO[2], Yoshito MAEDA[3] And Kathuhiko NOYORI[4]

SUMMARY

The existed damper usually has rectangular hysterisis when attenuation stiffness drops. It is used mainly for the stiffness hysterisis. However, it is not always useful for simple girder bridge for great horizontal displacement case. For example, the horizontal displacement induced by seismic wave specified by new Aseismatic Specifications for Highway Bridges, may be longer than the seat length. Therefore, it has to consider the aseismatic connector problem for bridge reinforcement. In turn, it is desired that a damper not only has attenuation but also has stiffness in order to confine the girder vibration. A new damper with large horizontal confinement and attenuation has been developed in order to satisfy these purposes. It has simple structure made of lead and steal bar. Cyclical horizontal loading experiments of the lead pillar are investigated, and the effect of the damper is confirmed. It is found that the function of the aseismatic connector is improved by increasing the horizontal resistance due to the damper, in which the two ends are fixed. The hysterisis attenuation of the new damper is lager than that of the lead one with same size. It means that the new damper can dissipate more vibration energy induced by earthquake.

INTRODUCTION

In 1995 a very intensive earthquake occurred in the south of Hyogo Prefecture in Japan. A lot of damages of bridges which are made before 1971, are suffered by, for example falling of bridge girder, cracking of bridge pier etc.. Recently, based on New Aseismatic Specifications for Highway Bridges revised, aseismatic design for bridges is required against severe seismic reinforce. Therefore, it is desired that new damper has not only with attenuation, stiffness, but also is cheap in order to decrease the repair cost.

This paper is emphasised that an improved damper with simple structure, in which large damp and steel bar are added to increase horizontal restraint stress for prevention of bridge. The hysteric characteristics of lead pillar damper are investigated by experiment, the effectiveness of the new damper is confirmed and design of method is proposed.

2. OUTLINE OF EXPERIMENT

The experimental setup is showed in Figure1. Hydraulic jack (displacement amplitude ±200mm/maximum load 73.5kN) is used to apply the horizontal direction load on the lead pillar damper through roller bearing. We measure load and displacement by the load cell and displacement gauge (displacement amplitude ±200mm). As the damper is elongation due to shear deformation, it is need to keep damper to return to original position. Load vertical is applied to prevent the uplift of damper. The capacity of vertical load of the experimental equipment is 294kN.

Test sketch is summarised in Table1. As shown in Figure2, the specimens used in this experiment are of three kind materials, that is, stainless steel (height 280mm), lead pillar damper (height 200mm), lead pillar damper inserted the stainless steel damper (height 200mm). Rates of loading of horizontal load are 0.01Hz in static test,

[1] *Department of Civil Engineering, Kyushu Kyoritsu University, Kitakyushu, Japan. Email : aramaki@kyukyo-u.ac.jp*
[2] *Department of Civil Engineering, Kyushu Kyoritsu University, Kitakyushu, Japan*
[3] *Department of Civil Engineering, Kyushu Kyoritsu University, Kitakyushu, Japan*
[4] *Toho Zinc Co.,Ltd, Japan*

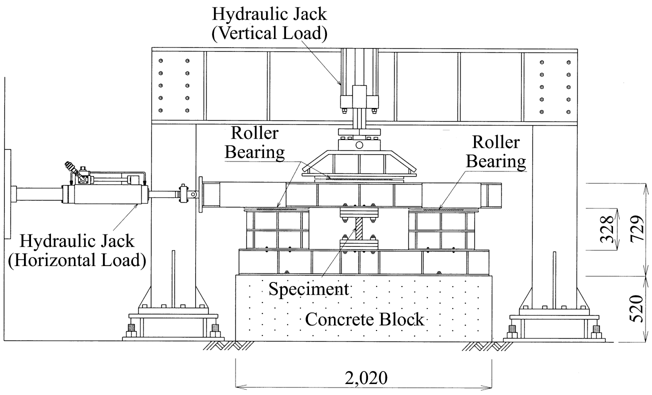

Figure1 Experimental setup

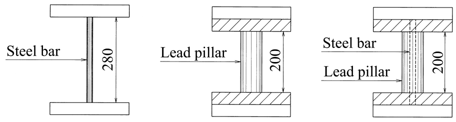

Figure2 Specimens used this experiment

Table1 Test sketch

CASE	Diameter of Lead Pillar(mm)	Diameter of Steel bar(mm)	Static loading test	Dynamic loading test
1	————	ϕ13	SS13	SD13
2		ϕ19	SS19	SD19
3	ϕ50	————	————	CD50
4	ϕ70		CS70	CD70
5	ϕ50	ϕ13	AS53,BS53	AD53,BD53
6	ϕ70	ϕ13	————	AD73
7		ϕ19	AS79,BS79	AD79,BD79
			CS79,DS79	CD79,DD79

and 1.0 Hz in dynamic test. Melting method is used to unite lead pillar and set point, which are produced by separately, and the mould method is used by running melting lead into the whole mould.

3. RESULTS OF EXPERIMENT

The results of CASE2 of static loading test are shown in Figure3. Horizontal displacement is increasing rapidly with the increasing of loads. Collapse displacement is about 80㎜ in static test, and is about 50㎜ in dynamic test.

Figure4 shows the results of CASE4 of static loading test. With the increasing of horizontal displacement, load increases gradually. Load –displacement hysteresis curve is almost at rectangular shape. Collapse displacement is about 140㎜ at the static test, and the collapse displacement is about 90 ㎜ at the dynamic test.

Figure5 and 6 show the results of loading test of CASE7. As the larger horizontal displacement grows, the larger horizontal load grows immediately. This is an effect of the deformation of the steel bar in the lead pillar. At static test the lead pillar and steel bar collapse at the same time when deformation of the lead pillar is of about 80㎜. In dynamic test the only steel bar break when deformation of lead pillar is of about 70㎜, then, it shows same load-displacement relation with that of the lead pillar damper, the lead pillar breaks at about 90㎜.

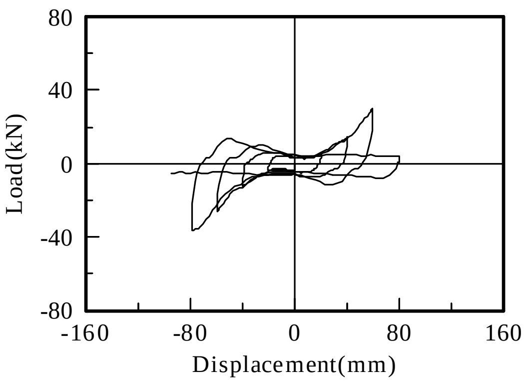

Figure3 Results of CASE2 in static loading test

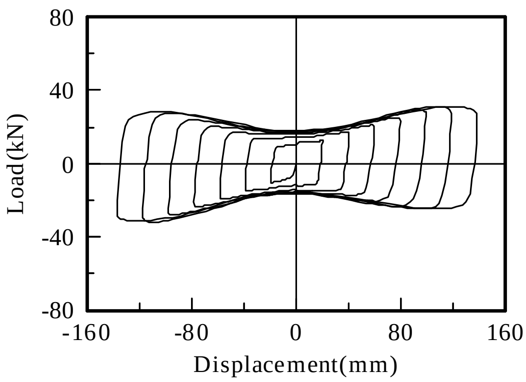

Figure4 Results of CASE4 in static loading test

The reason why break displacement of CASE7 is

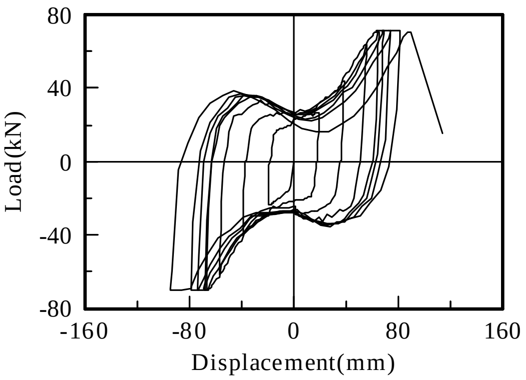

Figure5 Results of CASE7 in static loading test

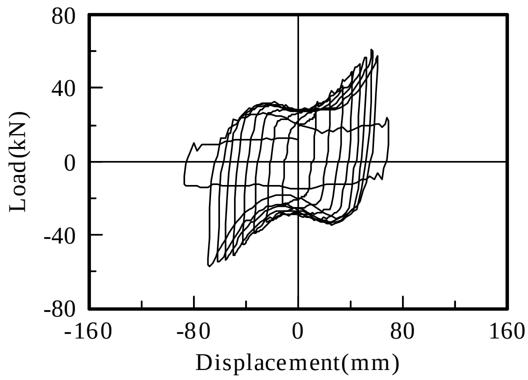

Figure6 Results of CASE7 in dynamic loading test

smaller than that of CASE4, is considered that when large deformation occurs, the steel bar moves in lead pillar, and fault occurs in the lead pillar. Compared with Figure4, the hysteretic area is large, energy absorption is great by inserting steel bar.

4. HYSTERTIC CHARACTERISTICS AND ESTIMATING FORMULA

In practice, diameter and height of lead pillar damper of damper in real bridges, are different according to bridge forms. It is hoped that it is able to design arbitrary shape of damper. Furthermore, it is hoped that steel bar does not break at maximum horizontal displacement for a seismic motion of Type Ⅱ. The seismic motion of Type Ⅱ assumes an inland direct strike type earthquake. Therefore, it is worth to investigate the lead pillar damper design method based on the results of load test.

From hysteresis curve of load test as shown in Figure7, equivalent damping ratio *he* and hysteretic energy Wd, which are characteristic values of damper, are calculated by

$$he = \frac{Wd}{4 \cdot \pi \cdot Ws} \qquad (1)$$

$$Ws = \frac{1}{2} \cdot P \cdot \delta \qquad (2)$$

Where *he* is equivalent damping ratio, Wd is hysteretic energy of damper (displacement-hysteresis curve area of load), Ws is strain energy of damper(triangular area showed in Figure7), P is horizontal restraint stress(= $\tau \cdot A$), δ is horizontal displacement(= $\gamma \cdot L$).

τ and γ are shear stress and strain, A and L are section area and height of the damper.

Because hysteresis curve of load test is in irregular shape, it is difficult to calculated hysteretic area. We calculate this area by planimeter which is usually used in surveying.

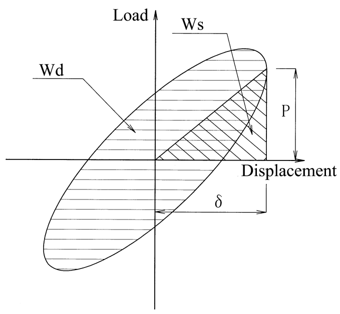

Figure7 Hystertic characteristic

4.1 Steel bar

Figure8 shows hysteretic energy in unit area Wds /As and shear strain of steel bar γs in CASE1 and CASE2. Because Wds /As are proportional to γs, hysteretic energy of steel bar Wds can be written by

$$Wds = 64.4 \cdot \gamma s^{1.6} \cdot As \qquad (3)$$

As showed in Figure8, it is found that the value of Wds /As predicted by equation (3) agrees with the result of test. And a correlation between shear stress τs and shear strain γs showed in Figure9 can be expressed by

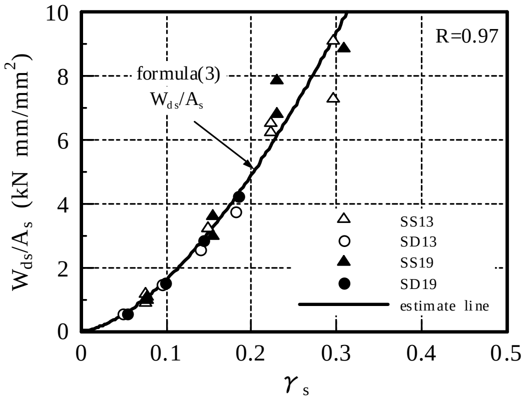

Figure8 Hysteretic energy unit area in CASE1,2

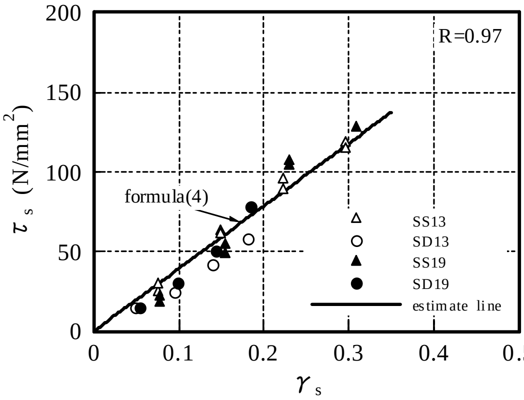

Figure9 Shear stress in CASE1,2

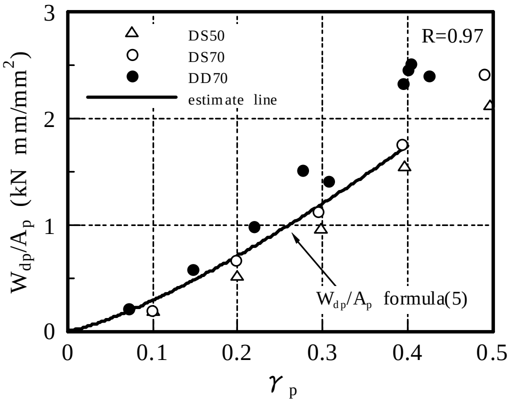

Figure10 Hysteretic energy unit area in CASE3,4

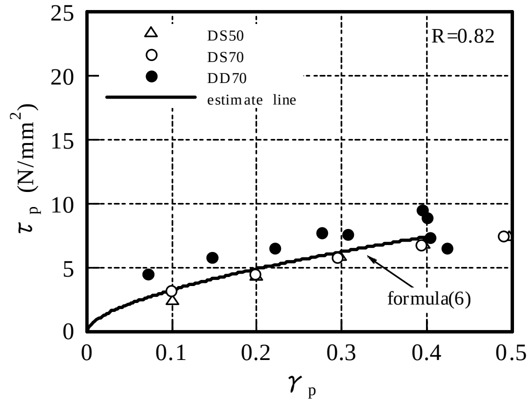

Figure11 Shear stress in CASE3,4

$$\tau s = 392.5 \cdot \gamma s \tag{4}$$

4.2 Lead pillar damper

Figure10 shows hysteretic energy in unit area Wdp /Ap and shear strain of steel bar γp in CASE3 and CASE4. Although there is some scatter of test values, hysteretic energy Wdp can be written as

$$Wdp = 5.74 \cdot \gamma p^{1.3} \cdot Ap \tag{5}$$

Figure10 shows the curve estimated by Equation (5), the correlation coefficient is R=0.97.
Next, a correlation between shear stress of lead τp and shear strain γp as shown in Figure11,is given by

$$\tau p = 12.8 \cdot \gamma p^{0.6} \tag{6}$$

4.3 Lead pillar damper inserted steel bar

Figure12 shows the relationship between hysteresis energy Wdsp and shear strain γp for the results of the static test and dynamic test. Both of static test and dynamic test values Wdsp for $\gamma p<0.3$ are almost the same values. But in case of $\gamma p>0.3$, Wdsp increases as γp increasing in static test, and Wdsp decreases as γp increasing in dynamic test. This reason is thought that in dynamic test steel bar in the lead pillar is broken when shear strain is about 0.3, and fault is formed by the moving of steel bar in the lead damper.
From Figure8～11, it is understood that the shear stress of steel bar or the lead pillar only and hysteric energy in unit area are able to calculate by shear strain as a parameter. By combining both results and equivalent damping ratio C from Equation (9), it is able to predict hysteretic energy Wdsp and shear stress τsp of lead pillar damper inserted steel bar. Therefore, it is possible to predict arbitrary shape of lead pillar damper inserted steel bar for practice design.

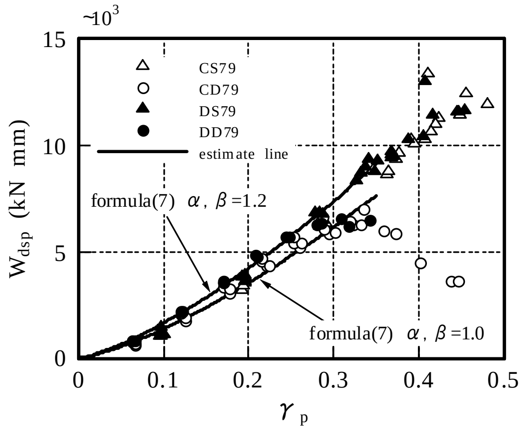

Figure12 Hysteretic energy in CASE7

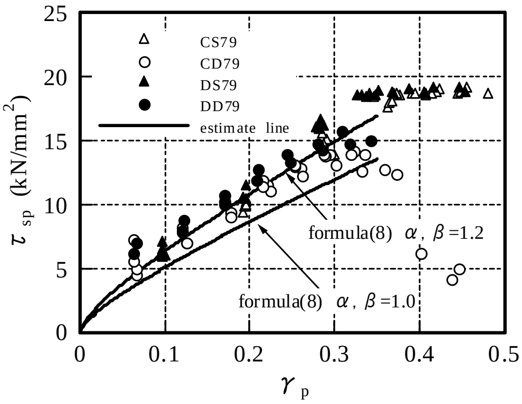

Figure13 Shear stress in CASE7

Assume Wdsp and τ sp of lead pillar damper inserted steel bar be calculated by the sum of section area of steel bar and lead pillar damper, we can obtain a estimating formula. Figure12 shows the results predicted by the estimating formula, where $\alpha, \beta=1$. As the figure shown, it is lower than test values. This is because that additional energy occurs due to the effect of steel bar moving.

Considering the area ratio of steel bar and lead pillar, and additional energy of steel bar and lead pillar, hysteretic energy, Wdsp, shear stress τ sp and equivalent viscous damping cofficient C can be calculated by follows formula. However, because the heights of the lead pillar and steel bar are different, shear strains for the same horizontal displacement are different. Here, we assume steel bar shear strain as a variable of lead pillar shear strain.

$$Wdsp=\alpha \cdot Wds+\beta \cdot Wdp=\alpha \cdot 64.4 \cdot \gamma s^{1.6} \cdot As+\beta \cdot 5.74 \cdot \gamma p^{1.3} \cdot Ap \tag{7}$$

$$\tau sp=\frac{\alpha \cdot \tau s \cdot As+\beta \cdot \tau p \cdot Ap}{As+Ap}=\frac{\alpha \cdot 392.5 \cdot \gamma s \cdot As+\beta \cdot 12.8 \cdot \gamma p^{0.6} \cdot Ap}{As+Ap} \tag{8}$$

$$C=\frac{Wdsp}{\pi \cdot (\gamma p \cdot Lp)^2 \cdot \omega} \tag{9}$$

$$\gamma s=\gamma p \cdot Lp/Ls \tag{10}$$

Where α and β are additional energy ratio to steel bar and lead pillar, Lp and Ls are the heights of steel bar and lead pillar. ω is natural frequency.

Figure12～13 illustrate results estimated by Equation (7)～(8) and tested. Because they comparatively agree with each other, it can be said the proposed estimating formula is effective.

It is found that the hysteric energy of lead pillar damper inserted steel bar is of about 1.2 times the sum of steel bar and lead pillar. Similarly, shear stress of lead pillar damper inserted steel bar is also 1.2 times of total shear stress of steel bar and lead pillar.

Figure14 shows the product of equivalent viscous damping coefficient of lead pillar damper inserted steel bar C and ω against shear strain γ p calculated by Equation (9) based on the test values. The curves shown in the figure are estimated values of lead pillar damper and lead pillar damper inserted steel bar. For shear strain <0.25, Cω value of lead pillar damper inserted steel bar is around 1.5 times the one of lead pillar damper. For shear strain >0.25, the difference decreases with increasing of the shear strain. This reason is that the insertion effect of steel bar decreases by forming fault of the lead pillar with the large displacement.

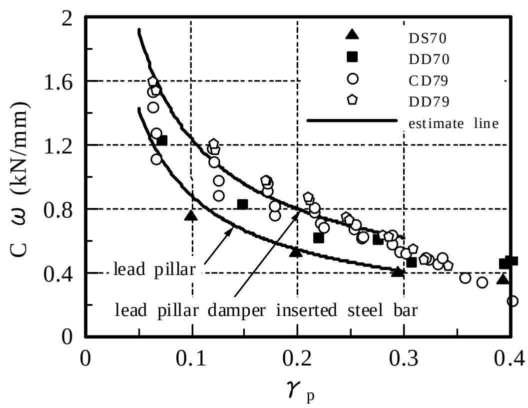

Figure14 The product of C and ω against shear strain γ p

Lead pillar dampers, which were produced by of melting method (D) and mould method(C) as shown Figure 12～14, have almost same dynamics characteristics. Therefore, it is inferred that the mould method is good to produce arbitrary shape of lead pillar damper, because mould method does not need whole metal shape.

From the above tests, it can be confirmed that the proposed damper has function of prevention for falling bridge. And when shear strain is less than $\gamma = 0.3$, the hysteretic energy of lead pillar damper inserted steel bar become larger than that of the lead pillar of the same size. When shear strain is $\gamma < 0.25$, the equivalent viscous damping coefficient of lead pillar damper inserted steel bar is around 1.5 times that of lead pillar damper. Considering the area ratio of steel bar and lead pillar damper, and the additional energy, we are able to predict the damper's hysteretic characteristic with enough accurate.

5.CONCLUSION

It is evident that hysteretic damping of the lead pillar damper by inserting steel bar is larger than that of lead pillar damper with same size, and can greatly absorb vibration energy of bridge pier in earthquake. Estimating formula of hysteretic characteristics of lead pillar damper inserted steel bar are proposed here. The proposed method can consider the area ratio of steel bar and lead pillar and additional energy, and has high prediction accurate that makes us able to design arbitrary shape of damper.

6.REFERENCES

1 Japan Road Association (1996)" Design specifications of highway bridges Part Ⅴ seismic design"

2 R.Ivan Skinner, William H.Robinson and Graeme H. McVerry(1993)"An Introduction to Seismic Isolation"

3 MORITA,K., TAKAYAMA,M.,(1996),"A Study on Ultimate Capacity of Lead Damper by the Scale Model Experiments",Bulletin of Fukuoka University,Vol.56,(in Japanese)

4 MORITA,K., TAKAYAMA,M.,(1996),"The Dynamic Tests of the U180 Type Lead Damper", Bulletin of Fukuoka University,Vol.56,(in Japanese)