第 I 部門

Seismic Response Control of Cable-stayed Bridges with the Pseudo Negative Stiffness Damper

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1 Introduction

Dynamic responses of cable-stayed bridges under earthquake excitations were studied by numerical simulation to study the efficacy of pseudo negative stiffness control in reducing the seismic responses. The bridge used for the model is the Tempozan Bridge in Osaka.

2 Background of Research

Many active control systems for civil engineering applications operate primarily to modify structural damping. Moreover, semi-active control in seismically excited structures is mainly to dissipate energy from the structure. Therefore, it is thought to be significantly beneficial if the device itself is controlled. This will simplify the control algorithm and reduce the amount of sensors. The focus of the research is then to study the pseudo negative stiffness control algorithm in improving the hysteretic loop produced by a variable damper.

3 Pseudo Negative Stiffness (PNS) Control

By using a variable damper, hysteretic loop in **Figure 1a** can be approached using the following formula **[1]**,

$$F_d = K_d u + C_d \dot{u} \qquad (1)$$

$$f_D \begin{cases} F_d & \text{if } F_d \dot{u} > 0 \\ 0 & \text{if } F_d \dot{u} \le 0 \end{cases} \qquad (2)$$

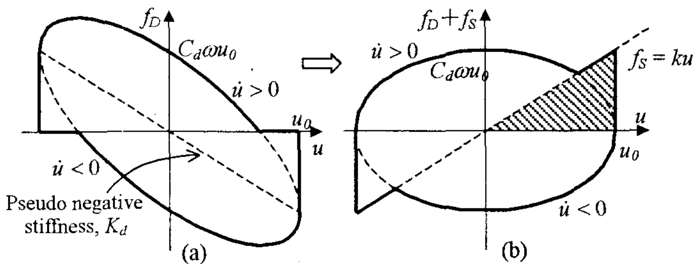

Figure 1. Hysteretic loop for (a) variable damper (b) spring and variable damper in parallel

where u and $\dot{u}$ are piston displacement and velocity, respectively. f_D is the demand force to the variable damper. By choosing appropriate K_d and C_d, hysteretic loop in **Figure 1** can be achieved under harmonic excitation whose frequency is the same with natural frequency of the structure ω.

4 Experimental Results of PNS-controlled Variable-Orifice Oil Damper

Experimental test has been performed by Iemura and coworkers **[2]**. The relationship among damping force f_D, orifice opening ratio h, and piston velocity $\dot{u}$ is shown in **Equation (3)**.

$$f_D = \text{sgn}(\dot{u})\left[\left(\frac{159.23}{h^2} + 307.2\right)\dot{u}^2 + 0.6\right](\text{kN}) \qquad (3)$$

By changing the opening ratio of the oil flow control (based on signal from PC), quantity of flow through orifice can be adjusted and oil pressure is varied. This series of mechanism enables variable damper to generate the demanded force (F_d or 0) as close as possible in real time. The result is in **Figure 2**.

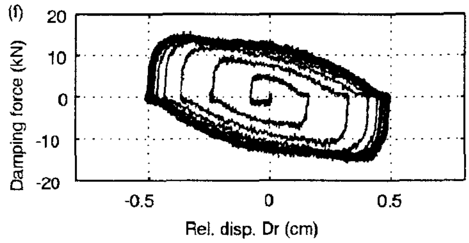

Figure 2. PNS controlled variable damper subjected to sinusoidal input (1.8 Hz, max 10 gal)

Hirokazu IEMURA and Mulyo Harris Pradono

5 Seismic Response of the Tempozan Bridge

PNS dampers and elastic bearings are put between the deck and the towers (**Figure 3**). Inputs are Type I-III-1, I-III-2, and I-III-3 earthquakes (artificial data used for bridge design in Japan). **Figure 4** shows damping force at Tower AP3, for Type I-III-1 earthquake. The figure shows negative stiffness hysteretic loop produced by the PNS damper.

Figure 5 shows damping plus bearing force. PNS-controlled damper results in lower restoring force and bearing displacement than those of linear damping.

Figure 6 shows the base shear – deck displacement relationship of the bridge. It is clear from the figure that the bridge model with PNS-controlled damper results in lower base shear and deck displacement than those of linear damper.

Application of PNS-controlled dampers to another cable-stayed bridge also shows these advantages **[3]**.

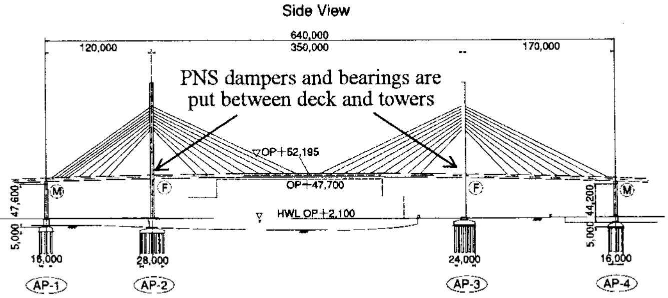

Figure 3. Drawing of the Tempozan Bridge

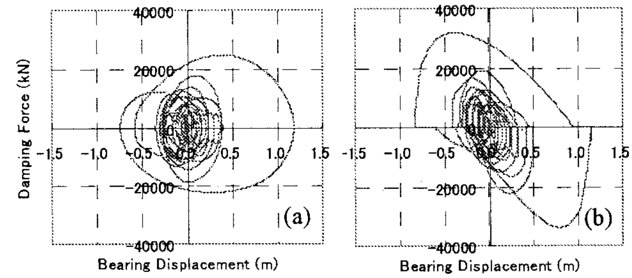

Figure 4. Damping force – device stroke relationship (a) linear damper (b) PNS control

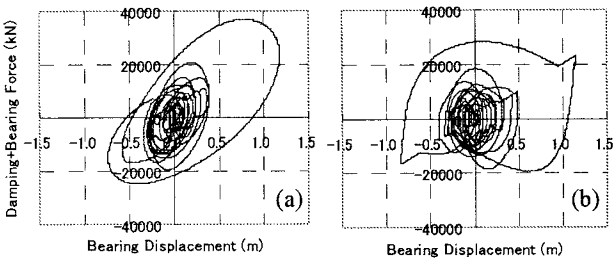

Figure 5. Restoring force – device stroke relationship (a) linear damper (b) PNS control

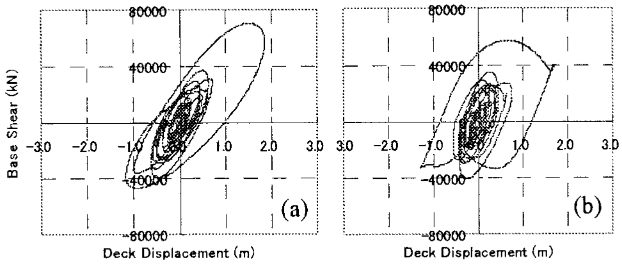

Figure 6. Base shear – deck displacement relationship (a) linear damper (b) PNS control

6 Conclusions

Pseudo negative stiffness control is effective for seismic response reduction of cable-stayed bridges. Base shear and deck displacement can be reduced significantly better than those of linear damper. Moreover, the control algorithm is simple, and unlike commonly semi-active control, the sensors are put only at the dampers.

7 References

[1] Iemura, H. and Pradono, M. H. (2002) Passive and Semi-active Seismic Response Control of a Cable-stayed Bridge, *Journal of Structural Control*, Vol. 9, pp. 189-204, December.

[2] Iemura, H., Igarashi, A., and Nakata, N. (2001) Semi-active Control of Full-scale Structures using Variable Joint Damper System. *The 14th KKNN Symposium on Civil Engineering*, Kyoto, Japan, November 5-7.

[3] Iemura, H. and Pradono, M. H. (2003) Application of Pseudo Negative Stiffness Control to the Benchmark Cable-stayed Bridge, *Journal of Structural Control*, (To be published).