Simple and Effective Seismic Semi-active Control for Cable-stayed Bridges

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1. Introduction

Semi-active control technologies have recently been widely investigated for seismic response reduction.

The main controller for the semi-active systems is mainly derived from active control algorithm, which is clipped to conform the limitation of the semi-active devices.

However, very rare papers discuss the hysteretic loops produced by the active control force under seismic excitation, although in earthquake engineering field, hysteretic loops have been the key in seismic response reduction.

This paper shows the importance of investigating the hysteretic loops produced by the active control force under seismic excitation, and proposes a method to reproduce the hysteretic loops with much simpler algorithm.

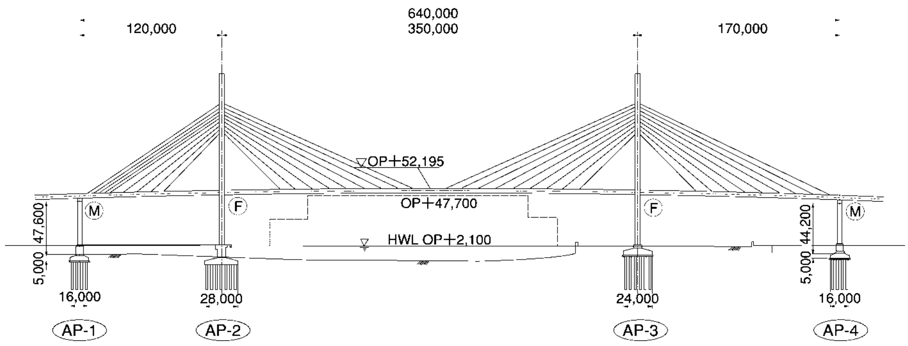

Fig. 1 Side View of the Tempozan Bridge

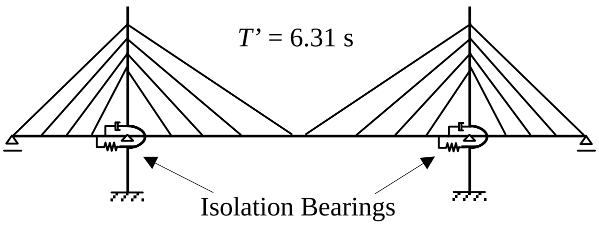

Fig. 2 Bridge Model for Control Study

2. Bridge Model

The bridge used as a model is the Tempozan Bridge [1], a three-span continuous steel cable-stayed bridge situated on the reclaimed land and crossing the mouth of the Aji River, Osaka, Japan (Figure 1). The bridge is relatively flexible with a predominant period of 3.7 seconds in the longitudinal direction. The existing structural system has fixed-hinge connections between the towers and the deck and rollers connection between the deck-ends and piers, so that the deck longitudinal movement is constrained by the towers.

However, for studying the effect of control devices put between the deck and the tower in the model herein, the fixed-hinge connections are replaced with isolation bearings (Figure 2). Information on how to determine the isolation bearing stiffness can be found in reference [2].

3. Active Control Force Hysteretic Loops

Active control herein uses the famous LQR control theory. The LQR weighting matrix herein is arranged to reduce the bridge's velocity responses. More information on weighting matrix of LQR control is available in the references [3, 4]. The input ground accelerations are Level II, Type 1-III-1, 1-III-2, and 1-III-3. They are artificial data used for bridge design in Japan [5]. The data was selected since they are suitable for the bridge site condition.

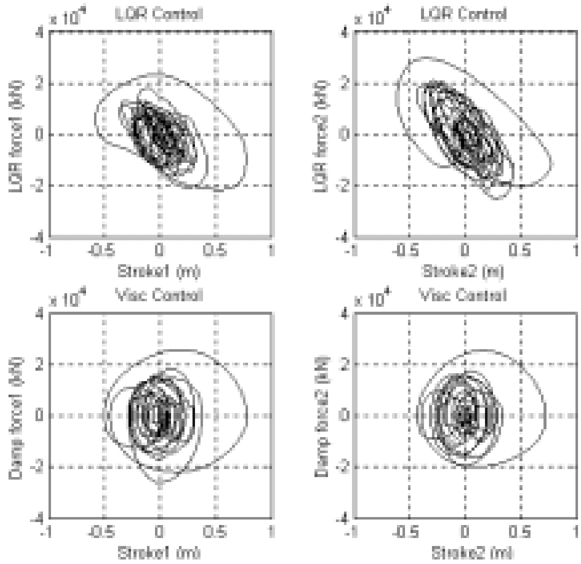

Fig. 3 LQR control (upper fig.) and Viscous control (lower fig.) hysteretic loops, at Tower AP2 (left) and AP3 (right)

The devices of the LQR control, which is assumed to be ideal, produces forces between the deck and the tower, parallel to the isolation bearings in the longitudinal direction. The bridge with LQR control is called herein "LQR control." For understanding on how passive control system works on the same model, viscous type damping is also employed. The viscous type damping is called herein "Viscous Control."

Figure 3 shows the LQR force and the viscous damping force between the deck and Tower AP-2 and Tower AP-3, for the "LQR control" case and "Viscous control" case. It is clear from the figure the LQR control adds negative stiffness hysteretic loops to the bridge system, to increase the damping ratio of the structure.

Keywords　simple algorithm, semi-active control, hysteretic loops, cable-stayed bridge, active control

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4. Proposed Simple and Effective Algorithm

Looking at the fact that LQR control for the model above shows hysteretic loops which are combination of damping plus negative stiffness forces, a simple control force F_d is proposed in Equation (1).

The simple algorithm is called “pseudo negative stiffness control algorithm” or simply “PNS algorithm,” where K_d is a selected negative stiffness value, C_d is a selected damping coefficient, and u is piston displacement (stroke).

The parameter K_d and C_d are adjusted to follow the hysteretic loops produced by LQR control theory to obtain the lowest seismic responses. However, as the PNS control force will be realized by variable-orifice oil damper, then it is interesting to apply the PNS force to a real-damper model. The real-damper model is derived from the work by Iemura and coworkers [6].

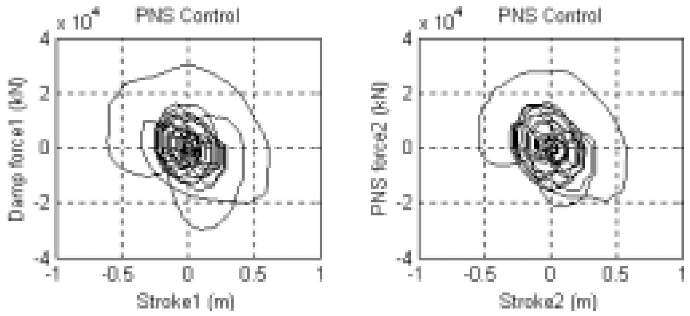

Fig. 4 PNS Control hysteretic loops at Tower AP2 (left) and AP3 (right)

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

The hysteretic loops of the PNS controlled variable damper in the bridge under Type 1-III-1 earthquake is shown in Figure 4. It is clear that the PNS control algorithm can be realized by variable orifice oil damper. These hysteretic loops are almost similar to those in Figure 3 for LQR control (upper figure).

The seismic response of the cable-stayed bridge model using this PNS controlled variable damper is shown in Figure 5, together with results of LQR and viscous control. It is clear from the figure that PNS control system can further reduce displacement (even smaller than the LQR control case) with base shear smaller than that of viscous control system. The coefficient K_d is minus 1.25 times the isolation bearing stiffness and the coefficient C_d is the same with damping coefficient of viscous control case. The coefficients can further be altered for desirable responses. It shows that the PNS control algorithm is effective for this type of cable-stayed bridge.

Furthermore, since the PNS control only needs information of relative displacement and velocity between the deck and the tower, then it reduces significantly the needs for sensors used commonly by LQR control. The LQR control used herein needs information of displacement and velocity on other members.

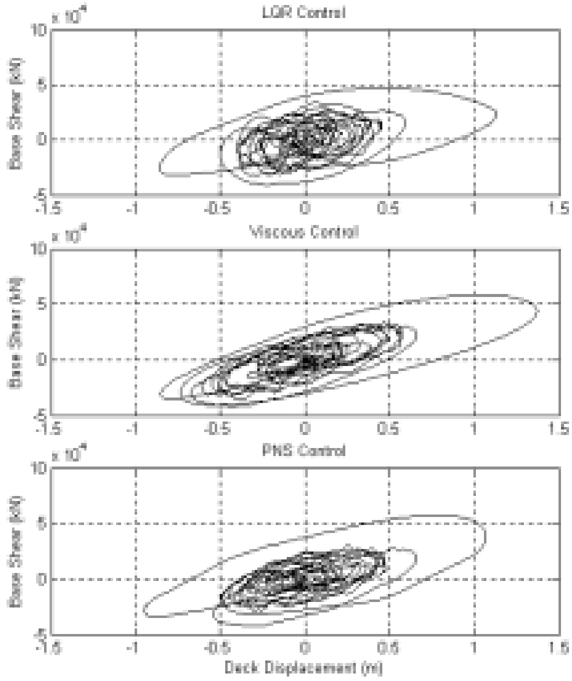

Fig. 5 Base shear vs deck displacement for LQR, Viscous, and PNS control systems

5. Conclusions

A simple algorithm is proposed for seismic response control of cable-stayed bridge. The algorithm is based on the fact that ideal active controller used herein produces hysteretic loops that are combination of damping and negative stiffness forces. Variable dampers controlled with this algorithm produces pseudo negative stiffness hysteretic loops.

Combination of these loops with those of elastic bearings will produce artificially rigid-perfectly plastic force-deformation characteristics.

The results shows that the responses of PNS controlled bridge are better than those of viscous controlled bridge, and comparable to those of actively controlled bridge.

For a close relation with practical problem, the PNS control force is applied to variable orifice oil dampers, where the damper’s model was derived from experiments. The sensors needed for this variable damper to work under PNS control algorithm are significantly less than those for the active control.

6. References

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