Seismic Response of a Cable-stayed Bridge by using Semi-active Control

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1. Introduction

Seismic responses of a simplified model of a cable-stayed bridge with dynamic response control devices in the means of isolation bearings and variable dampers are examined through numerical simulations. The variable dampers use algorithm that performs pseudo negative stiffness for better energy absorption. Analytical results show that damping ratio of the structure is significantly large.

2. Background of Research

In order to study the effectiveness of semi-active control on a cable-stayed bridge, numerical analyses on a simplified model of a cable-stayed bridge is carried out. An existing cable-stayed bridge which has fixed-hinge connections between deck and towers is modeled and its connections are replaced by elastic bearings and variable dampers. The objective is to increase the damping ratio of the bridge by using semi-active control technologies. Calculation of damping ratio is possible as the semi-active control produces a certain hysteretic loop under harmonic motion.

3. Simplified Model

The simplified model consists of a set of massless bar elements and one vibrating concentrated mass (**Figure 1(b)**) (Branco et al., 2000). This mass corresponds to the mass associated with the first longitudinal vibration mode of the bridge (in fact, it is close to the total mass of the deck). The lower vertical element (depicted in bold) simulates the stiffness of the bridge for a horizontal displacement of the towers at the deck level. The contribution of the cables and of the towers above the deck level to the overall longitudinal stiffness of the bridge is simulated by other vertical elements.

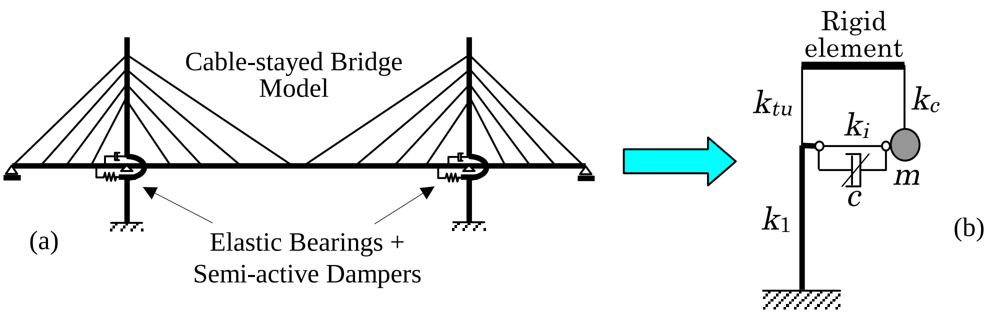

Figure 1. Simplified model for the cable-stayed bridge

4. Semi-active Control Algorithm

The variable dampers use algorithm that produces pseudo negative stiffness so that sum of damper force and bearing force produce hysteresis loop that is as close as to that of rigid–perfectly plastic force–deformation characteristics (**Figure 2(a)**). However, no residual displacement is expected at the bearings after an earthquake attack because the hysteresis loop is frequency dependent. **Figure 2** shows ideal and realistic force–deformation characteristics of bearings and dampers if pseudo negative stiffness algorithm is used. One algorithm that can approach the hysteretic loop in **Figure 2(b)** requires variable damper force $F_{d,t}$ as that in **Equation (1)**. K_d is connecting stiffness (negative value) and C_d is certain damping coefficient (positive value). u_t and $\dot{u}_t$ are relative displacement and velocity at the variable damper. The algorithm is practical because displacement and velocity sensors are placed in the dampers. The variable damper is superior to linear damper. Because, maximum variable damper plus bearing force can be set to be equal to the maximum bearing force. When the contribution of cable and upper tower stiffness is large, bearing stiffness becomes the connecting stiffness between the deck and towers.

$$F_{d,t} = K_d u_t + C_d \dot{u}_t \tag{1}$$

Figure 3 shows typical results for the simplified model of the bridge that incorporates variable damper under type I-III-1 earthquake motion. **Figure 3(c)** shows apparent negative stiffness hysteresis loop produced by the variable damper. **Figure 3(b)** shows hysteresis loop of variable damper plus isolation bearings and elements above the deck level that has large energy absorption. This loop corresponds to 53.4 % elemental damping ratio. **Figure 3(a)** shows structural hysteresis loop that is

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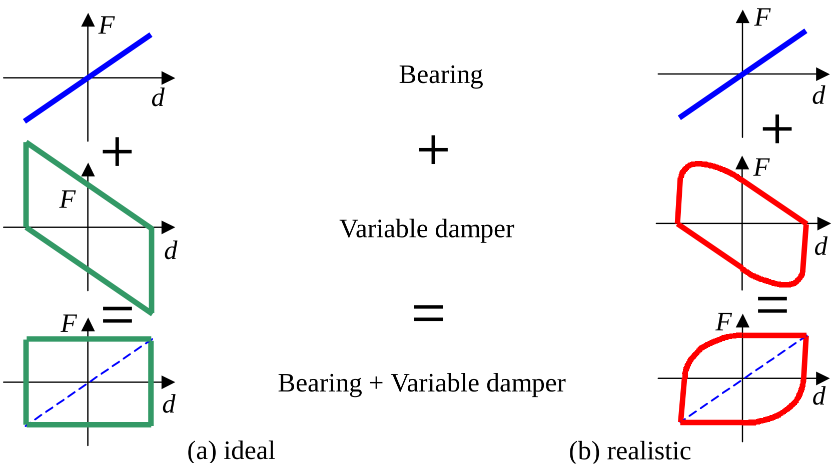

Figure 2. Ideal and realistic hysteretic loops produced by pseudo negative stiffness damper

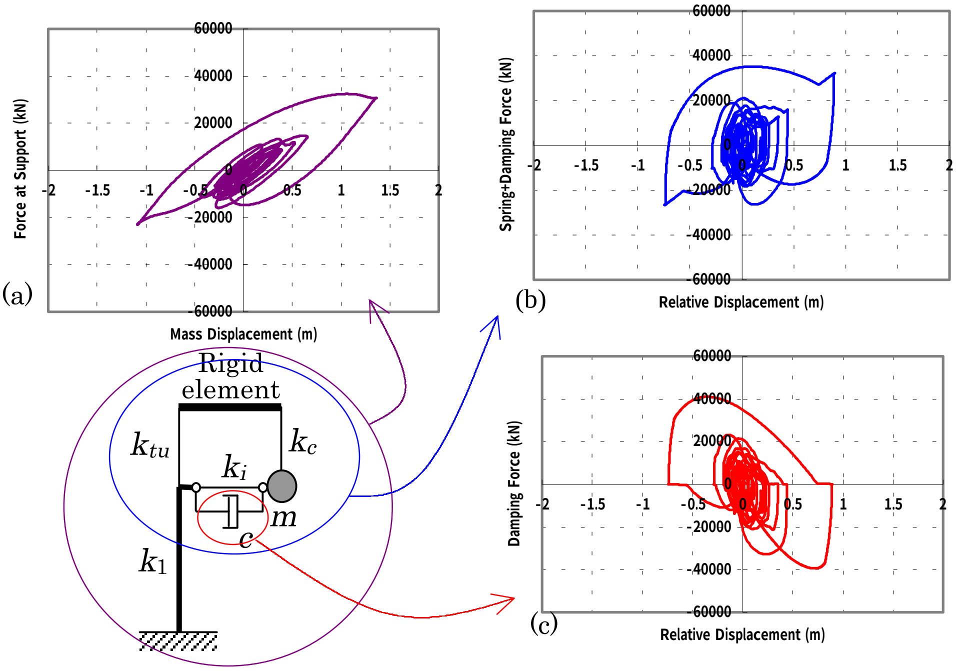

Figure 3. Typical result for a semi-active control for the bridge simplified model

apparently lower in structural damping ratio, 35.6 %. The reduction of this damping ratio is because of tower flexibility k_1 (in this case $k = 0.5k_1$; k is the total stiffness of k_{tu} (towers above the deck level), k_i (elastic bearing), and k_c (cables)). The elemental damping ratio of 53.4 % was calculated by considering only the strain energy of the stiffness k. However, for the structural damping ratio, strain energy because of stiffness k_1 is also included. This will make the structural damping ratio lower than elemental damping ratio. Therefore, if the variable damper was put between the deck and some stiff supports on the ground, then structural damping ratio would not have been reduced as much.

5. Conclusions

- Elemental damping ratio of the variable damper plus isolation bearings and elements above the deck level is 53.4 %.
- Structural damping ratio of the cable-stayed bridge simplified model is 35.6 %.
- If the variable damper is put between the deck and some stiff supports on the ground, then structural damping ratio will not be reduced as much.

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