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Mitigation Effect of Vortex-Induced Vibration of Suspension Bridge Hangers with Stockbridge Dampers

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ABSTRACT

This study investigates a mitigation effect of stockbridge damper (SD) on vortex-induced vibration (VIV) of hanger rope of suspension bridge. One of the hangers of the suspension bridge was selected as the target hanger and frequency range of the hanger was determined with wind data obtained from anemometer on the bridge. Dynamic parameters of SD, which was modeled as 2-DOF system, were extracted by excitation experiment with shaking table. Effectiveness of applying SD to hanger is evaluated by calculating amplitude of VIV with Energy Balance Method (EBM) with obtained dynamic parameters. SD reduced the amplitude effectively in the vicinity of its natural frequencies. Based on this concept, asymmetric SD was designed to have several natural frequencies which are located within the target frequency range. As a result of applying the designed asymmetric SD to the target hanger, it mitigated the vibration more efficiently than symmetric SD.

1. INTRODUCTION

When cable vibration occurs, various vibration modes of the cable appear depending on wind velocity. The vibration of suspension bridge hanger causes damages to the cables and serviceability problems of the bridge.

Stockbridge damper (SD) is an appropriate control device for cable vibration whose frequencies are widely distributed, because it has mitigation effect on wide frequency range of the vibration through changing combination of two masses or stiffness of messenger cable. However, it has been only adopted to transmission lines which are much lighter than cables in bridges.

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In this paper, SD was applied to vortex-induced vibration of the hanger and its mitigation effect was evaluated with Energy Balance Method (EBM). In order to improve efficiency of SD on reducing vibration of specific hanger, asymmetric SD, which has different masses at each side, was designed. Mitigation effect of designed one was also evaluated.

2. APPLYING SD TO SUSPENSION BIRDGE HANGER

2.1 Target hanger

Recently, a vortex-induced vibration was observed at a number of hangers of completed suspension bridge. Among them, the longest hanger (124.17m) was selected as target hanger in this study. The wind velocity ranged from 3m/s to 12m/s based on the measured data. Consequently, the corresponding vibration frequency of the hanger, which ranged from 5Hz to 20Hz, was calculated.

2.2 Extracting dynamic parameters of SD

Three different ready-made SDs were selected to reduce the vibration of the target hanger. All of dampers have same masses at each side and their masses were 8, 12 and 16 pounds respectively. In order to evaluate mitigation effect of SDs on the vibration, two of dynamic parameter should be required: 1) impedance of dampers, 2) phase lag between velocity of the hanger and force applied to the hanger by dampers. These dynamic parameters were extracted through excitation tests using the shaking table with assuming that masses at both ends of SD have 2-DOF which are translation and rotation (Wagner 1973). With the excitation test, the phase lag and impedance of SD can be calculated by following equations (Hagedorn 1982).

$$F(t) = Z\dot{y}_0 \sin(\omega t + \alpha) \quad (1)$$

$$\dot{y}(t) = \dot{y}_0 \sin \omega t \quad (2)$$

where F is force measured by load cell on the shaking table, $\dot{y}$ is velocity of shaking table, $\dot{y}_0$ is maximum velocity of that, Z represents the impedance and α represents the phase lag.

2.3 Evaluation of mitigation effect of SD

In order to validate the effect of applying SD on the hanger, amplitudes of the hanger was calculated with Energy Balance Method (EBM) using dynamic parameters of dampers and specifications of the hanger (Wolf 2008). EBM is formulated with

$$P_W(A) = P_H(A) + P_D(A) \quad (4)$$

where $P_W(A)$ is energy transmitted to the hanger by the wind, $P_H(A)$ is energy dissipated by the hanger with its self-damping and $P_D(A)$ is energy dissipated by the damper attached to the hanger. Since there was no specific criterion for allowable amplitude of the hanger, the allowable amplitude of the hanger was assumed as $D/10$

(Bang 2016), where D is diameter of the hanger. Fig. 1 presents that amplitudes of the vibration of the hanger calculated by EBM.

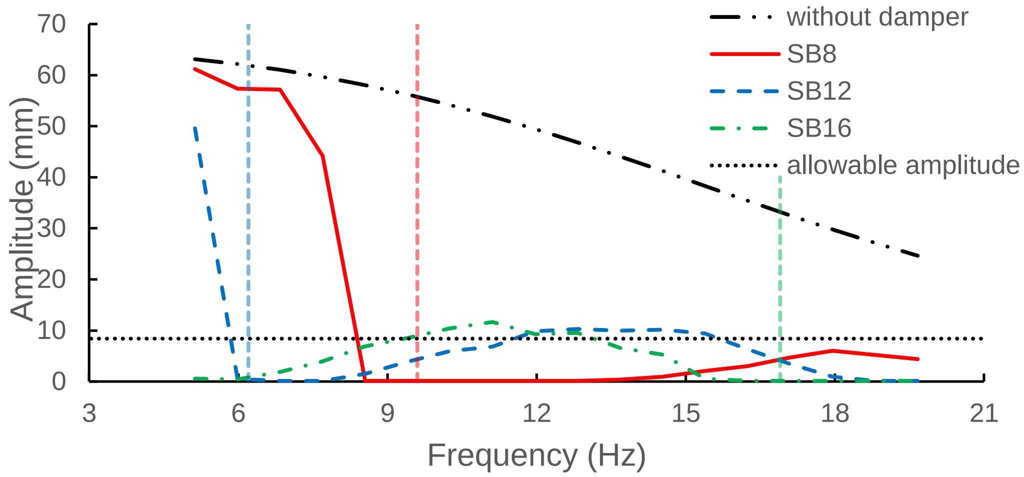

Fig. 1 Amplitude of the hanger vibration

Although amplitudes were dramatically decreased after SDs were installed especially, near the natural frequencies of each damper, they exceeded the allowable amplitude.

3. DESIGN OF ASYMMETRIC SD

3.1 Design procedure for asymmetric SD

Since ready-made SDs couldn't reduce the hanger vibration below the allowable amplitude, asymmetric SD was proposed which have several natural frequencies within the frequency range of the target hanger. Design procedure for asymmetric SD based on trial-and-error is as follows.

Initially, material properties such as masses and stiffness of dampers are determined to allocate natural frequencies of SD within the target frequency ranges of the hanger. Next, Impedance and phase lag (i.e. dynamic parameters) of SD are extracted with its material properties using 2-DOF model. Finally, after all of the properties of SD are determined, the mitigation effect of that is evaluated by EBM. If amplitudes are not reduced below the allowable level, return to first step to modify the material properties and repeat following steps.

3.2 Evaluation of mitigation effect of designed SD

Asymmetric SD was designed with aforementioned procedure. Masses of each end were respectively 7.5kg and 4.5kg, diameter of messenger cable was 15mm. Dynamic parameters of designed one were extracted, then amplitudes of the vibration of the target hanger, on which designed SD was applied, were evaluated as shown in Fig. 2. After the designed asymmetric SD was applied, the amplitudes were reduced effectively below the allowable amplitude on the whole frequency range.

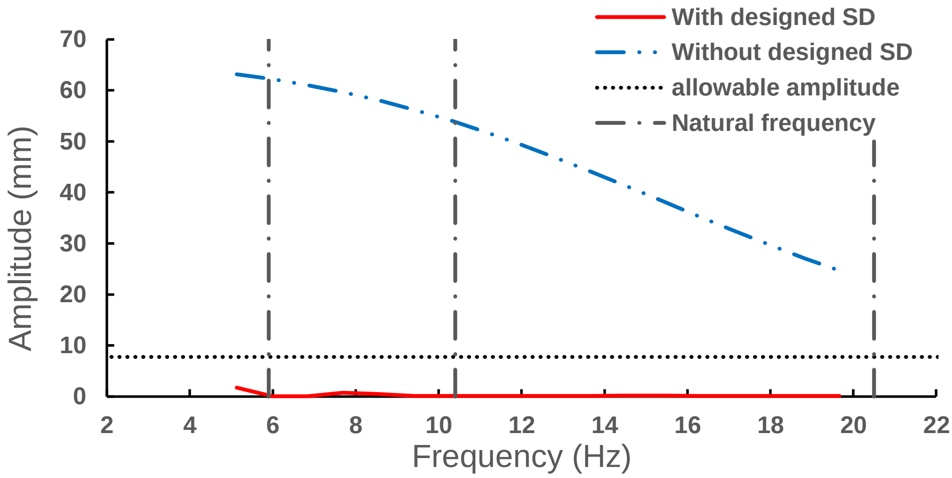

Fig. 2 Amplitudes of the hanger vibration with designed SD

4. CONCLUSION

SD was applied to VIV on hanger of suspension bridge to mitigate the vibration. Although ready-made SDs could reduce the vibration of suspension bridge hanger effectively near their natural frequencies, they couldn't decrease the amplitude below the allowable amplitude on the whole frequency range. In order to improve damping effect of SD, design procedure of asymmetric SD was presented. The natural frequencies of designed SD were intended to allocate within the target frequency range. Asymmetric SD for the target vibration of the hanger was designed under the procedure, then, the mitigation effect of designed one was evaluated with EBM. Designed asymmetric SD could reduce the vibration of the hanger efficiently and decrease the amplitudes below the allowable level on the whole frequency range.

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