TENSILE FORCE MEASUREMENT OF CABLES IN A CABLE-STAYED BRIDGE USING LASER DOPPLER VIBROMETER

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ABSTRACT

In general, the tensile force of cables in a cable-stayed bridge is measured from vibrations by using a wired accelerometer. This measurement requires considerable effort when many cables need to be measured because the accelerometer needs to be attached to each cable. This has led to the utilization of the laser Doppler vibrometer (LDV), which is a non-contact vibration measurement device that uses laser light.

In this research, the vibrations of cables in a cable-stayed bridge were measured using a newly developed LDV. The laser light of the LDV is invisible because its wavelength is longer than that of infrared light. This LDV can also realize longer-distance measurements relative to a conventional LDV: according to specifications, up to 100 m.

The LDV was used to measure 24 cables in a bridge. The measurement was completed in about 1 h. We confirmed that there was little change in cable tension. We also conducted long-distance measurements exceeding the specifications. The results showed that natural frequencies in cables could be distinguished from ambient vibration up to distances of about 300 m. This result can lead to a reduction in maintenance work on bridges.

Keywords: Cable-stayed Bridge, Cable, Tensile Force, Vibration, Laser

1. INTRODUCTION

The Maizuru Crane Bridge is a three-span continuous steel cable-stayed bridge having a length of 672 m, central span length of 350 m, and total width of 11 m with a footway on one side. The bridge has 48 cables in total with a double-suspension structure (Fig. 1). The bridge was completed in 1999 as a construction road for a thermal power station and is currently under the management of Maizuru City as a city road.

The tensile forces in the bridge cables were measured in 1999 and 2005, but not since then. The local

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The government desires a feasible method for efficiently checking the condition of bridges; accordingly, we measured the vibrations of all the cables using a handheld laser Doppler vibrometer (LDV) in 2010 [1]. LDV is an optical instrument that measures the velocity of a vibrating object based on the Doppler effect [2]. Slight changes in the measurement values were observed in the tensile force of the cables over the last 10 years; however, the cause was found to be no more than natural influences such as snow and temperature.

The LDV used in [1] was a conventional type with a He–Ne laser as a light source. According to specifications, the LDV could measure distances of up to 30 m; therefore, the measurement was conducted by placing the measurement device set on a carriage and moving it to positions near the cables; a laser was then irradiated toward the cables. It took 3 h to measure a total of 48 cables.

In the present research, in order to further improve the efficiency of vibration measurement of cable-stayed bridges, we examined the applicability of a newly developed LDV that uses invisible laser light (Fig. 2). In contrast to a conventional LDV, this LDV features a laser light source with a longer wavelength than that of infrared light to realize long-distance measurement. The new LDV has a maximum measurement distance of 100 m, measurement range of 0.4–100 mm/s/V, and frequency band of DC to 25 kHz; it follows Class 1 laser safety standards and can be used for outdoor measurement. Even if a measurement object has a black surface, measurements can be carried out without any special surface treatment such as attaching reflective tape, unlike conventional LDV. The reason is that the reflectance has been increased because of an increased laser output, larger lens aperture, and longer laser wavelength. A computer is used to focus the laser based on a camera embedded in the head portion because the laser light is invisible to the naked eye (Fig. 3).
2. OUTLINE OF MEASUREMENT

We conducted measurements from 5:50 a.m. to 6:40 a.m. on September 9, 2010. The weather was clear. The measurement system set, including the LDV, was placed on a footway near the P1 main tower shown in Fig. 4, and a total of 24 cables were then measured from the side of the road or footway, as shown by C1–C12 in Fig. 4. Fig. 5 shows the measurement situation. The cables had a white surface without dimples or the like; no special treatment such as attachment of reflective tape was performed, and no special vibrations were induced. As measurement conditions, the LDV was set to have a measurement range of 10 mm/s/V and sample frequency of 200 Hz.

3. MEASUREMENT RESULTS

Fig. 6 shows an example of the measurement results. In the power spectrum, natural frequencies are integer multiples of the primary natural frequency, which is the fundamental frequency. In the low-frequency range of 0.5 Hz or less, a frequency component (0.33 Hz) was seen that could be attributed to the natural frequency of the bridge. Fig. 7 shows the identified natural frequencies with respect to each cable. The figure also shows natural frequencies obtained in 1999, 2005, and 2010. In the present measurement, although some natural frequencies were not identified depending on the state of vibrations of the cables, the identified components show good agreement with past measurement values. Fig. 8 shows tensile forces calculated from identified natural frequencies by the following equation.

\[ T = Af_4^2 - Bf_4 \]  

where \( T \) is the tensile force, \( A \) and \( B \) are coefficients determined from the initial measurement upon completion, and \( f_4 \) is the fourth natural frequency of the cable. Fig. 8 confirms that the calculated tensile forces were approximately ±10% of the design tensile forces induced by dead weight.
4. LONG-DISTANCE MEASUREMENT

Because an LDV can realize non-contact measurement by a laser, the measurement work is drastically reduced when long-distance measurement is also possible. We tried conducting long-distance measurements beyond the specifications of the LDV. The measurement system set was placed at the installation position shown in Fig. 9. The ambient vibration of several cables and a tower were measured from this position. Measurement distances are also shown in Fig. 9. The maximum measurement distance was approximately 500 m. The portion irradiated with a laser was the upper part of the main tower; no special treatment was given to the surface being measured.

Fig. 10 shows an example of the measurement results of a cable where the measurement distance was approximately 310 m. Although many noise components are included in the time history, outstanding peak components can clearly be recognized. These correspond to the integer multiples of the fundamental frequency of the cable. Fig. 11 shows the measurement results of a tower. Even though a typhoon was passing over Maizuru City on that day, with especially strong winds, the component of 0.33 Hz shown in Fig. 10(b), which is attributable to the natural frequency of the bridge, could be seen, although the signal level shown in the time history was small.

Table 1 summarizes the long-distance measurement. The results confirmed that super long-distance measurements beyond the specified range are possible. This can lead to the development of an effective maintenance method for cable-stayed bridges.
Figure 9 Measurement distance

**Figure 10** Long-distance measurement result at C13 (measurement distance: 310 m)

**Figure 11** Long-distance measurement result at T1R (measurement distance: 500 m)
In this research, we measured the vibration of cables of a cable-stayed bridge (Maizuru Crane Bridge) using a new LDV with invisible laser light in the hope that bridges under the management of the local government can be checked for current conditions more efficiently.

It took 1 h to measure a total of 24 cables. This is mainly because no special treatment was needed on the surface to be measured, because of the longer wavelength of the laser light and increased laser output compared with a conventional LDV, which made long-distance measurements feasible.

5. CONCLUSIONS

In this research, we measured the vibration of cables of a cable-stayed bridge (Maizuru Crane Bridge) using a newly developed LDV with invisible laser light in the hope that bridges under the management of the local government can be checked for current conditions more efficiently.

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