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Comparison of laser Doppler vibrometer with contact sensors for monitoring bridge deflection and vibration

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Abstract

This paper compares results from dynamic live load tests using the non-contact laser Doppler vibrometer (LDV) system with those from two types of contact sensors. Bridge girder deflections and vibrations are simultaneously measured using a linear variable differential transducer (LVDT)-cable system (deflection) and geophone sensors (velocity), both attached to the girders, and the LDV, equipped with displacement and velocity signal decoders. Live load tests are performed on a 3-span continuous unit of the 9-span Doremus Avenue Bridge Replacement Project using 5-axle trucks of known weight and configuration. The Doremus Avenue Bridge is a composite steel slab-on-girder construction. Bridge response is compared for two of the 10 girders. Overall, the LDV measurements of deflection and velocity compare very well with those recorded by the contact sensors and may be used as an alternative to the two systems. Other advantages and disadvantages are also highlighted.

Keywords: Laser Doppler vibrometer (LDV); Bridge vibration; Deflection; Non-destructive technique (NDT); Bridge health monitoring; Bridge dynamic testing

1. Introduction

The calculation of deflection is an important element in the design process of girder bridges. The flexibility of the superstructure (mainly girder stiffness) is essential in the cracking behavior of the concrete deck. Moreover, the actual deflection in girder bridges depends on the system behavior of the superstructure, including slab thickness, girder stiffness, and span length. Currently, the American Association of State Highway and Transportation Officials (AASHTO) load and resistance factor design (LRFD) bridge design specifications [1] specifies the prediction of deflection based on a one-dimensional beam model representing an isolated girder. The girder is considered composite or non-composite. For composite bridges, the girder stiffness includes the contribution of the deck slab as well as the type of material used. Moreover, the applied load is taken as the LRFD design truck (HL-93) which is applied to one lane. However, the loading on a bridge system is more complex and is considered to be site-specific. Thus, there is a need to accurately determine the bridge deflection due to actual truck traffic.

The study of the dynamic response of bridges under normal traffic conditions using experimental data has become increasingly useful for many reasons. The effect of increased load on existing bridges, whether due to truck induced vibration or fatigue, can be studied and compared to the effect of design loads. This will lead to a better understanding of bridge structures and a formulation of bridge design codes that more accurately reflect actual bridge behavior. Also, analytical and experimental

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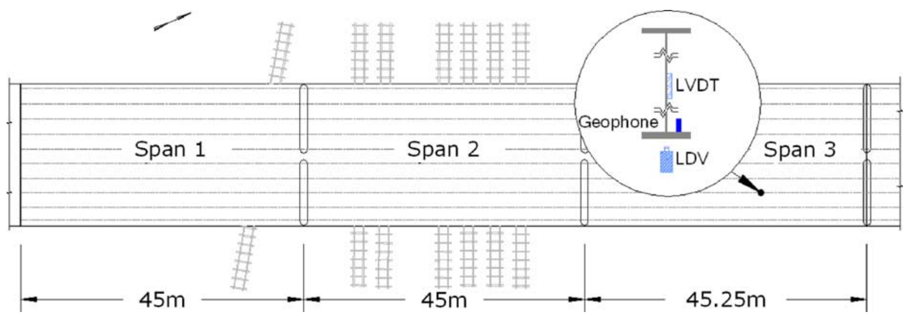


Fig. 1. Instrumentation unit of the Doremus Avenue Bridge (a) Elevation (b) Plan.

models can be developed and verified for the use of damage detection on bridges via changes of the dynamic response.

2. Doremus avenue bridge

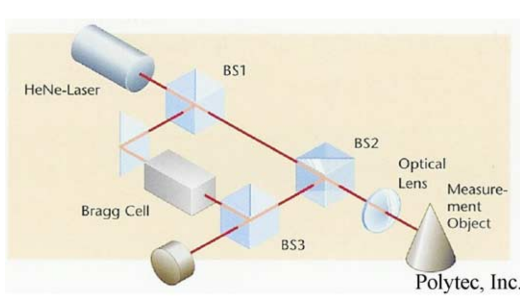
The Doremus Avenue Bridge structure is New Jersey's initial LRFD design. The construction project involves replacement of an existing deficient bridge structure that primarily carries truck traffic into the state's sea port area. It is a vital link in the Portway intermodal corridor providing access to Newark City's air and sea ports. It is part of an integrated roadway infrastructure system that will carry heavy weight truck traffic [2]. The bridge is four lanes wide (3.6 m) with shoulders (2.4 m) in both traveling directions. It has nine spans in total consisting of three 3-span continuous units with a total span length of 401 m, spanning over 33 active rail tracks. Construction is divided into two stages; Stage I consists of constructing a five-girder bridge alongside the existing structure and Stage II involves replacing the existing bridge with another five-girder structure. Span 3 of unit I is chosen for instrumentation because of its accessibility to the underneath part of the bridge structure. The instrumentation unit is shown in Fig. 1.

3. Instrumentation systems

The LDV system, provided by Polytec PI, Inc., is a non-contact portable system that measures surface vibrations based on laser interferometry and provides both velocity and displacement readings. The vibrometer consists of a modular controller (OFV-3001) and a helium neon (Class II) laser sensor head (OFV-353), which is rated for distances ranging from 450 mm to 250 m when used with reflective tape. The controller provides signals and power to the sensor head and processes the vibration signals. The signals are electronically converted by decoders within the controller to velocity and displacement in either analog or digital form.

The LDV is based on the detection of the Doppler shift of laser light. The Doppler shift refers to the frequency shift of the light that is reflected back from the vibrating object to the source. An object moving away from the sensor head will reflect light that has a longer wavelength (lower frequency) than it had when it was emitted. Similarly, an object moving towards the sensor head will reflect light that has a shorter wavelength (higher frequency) than it had when it was emitted. The measured frequency shift of the wave is given by $f_D = 2v/\lambda$, where v is the velocity of the object and λ is the wavelength of the emitted wave.

An optical interferometer is used to mix the scattered light with a reference beam, with a known frequency f_0



(a)

(b)

Fig. 2. Laser Doppler vibrometer (a) Optical configuration (b) Field setup.