Estimation of Bridge Displacement from Measured Acceleration Records

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Abstract

There is agreement among researchers that bridge deflection is an important component of bridge design and assessment that needs to be accurately measured. Under vehicular loading, the bridge will vibrate as it deflects. Monitoring of this vibration is important because it represents an amplified load and raises concern about fatigue and pedestrian perception. Deflection tolerance has historically been controlled through a quasi-empirical deflection limit which has now been made optional since the introduction of the new AASHTO LRFD Bridge Design Specifications Code in 1994.

Bridge deflections may be obtained directly or indirectly through measurements of girder rotation, velocity, and acceleration. While direct methods provide measurements with the lowest error, the instrumentation systems are more elaborate and require more time for field assembly. Conversely, indirect measurement systems are easier to handle but contain more errors due to sensor drift, unknown initial bridge conditions, and noise. This study focuses on methods of minimizing such errors for the purpose of obtaining deflections indirectly, specifically from acceleration records.

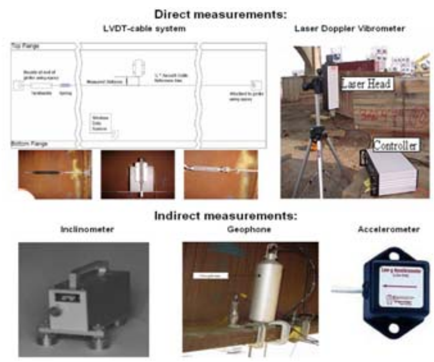

Figure 1: Deflection-measurement systems

Bridge Dynamics

Datasets recorded from field tests consist of three main segments: Initial vibration, Forced vibration and Free vibration. The forced vibration portion (i.e. when the truck is present on the bridge) may be represented by two superimposed responses; the low frequency pseudo-static response and the high frequency dynamic response. In estimating the displacement profile from measured acceleration records, it is the low frequency response that is difficult to replicate. This is because low frequency errors, which become increasingly large through successive integrations, also occur in the same frequency range. As a result, correction methods are needed to remove such distortions.

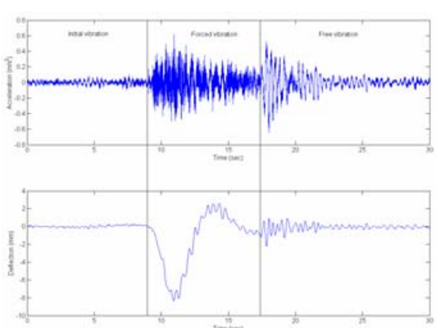

Figure 2: Typical dynamic bridge response to truck load traffic

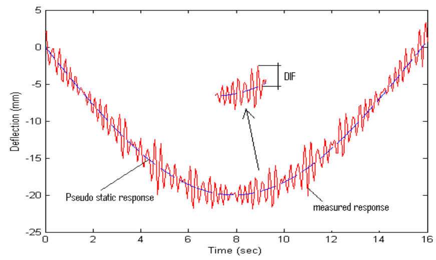

Figure 3: Pseudo-static and dynamic components of forced vibration

Field Test

The Doremus Avenue Bridge, serving the port area of Newark, New Jersey, is instrumented and tested as part of a research program conducted by Rutgers University. The 9-span composite steel girder bridge is constructed as three 3-span continuous units. The instrumentation scheme includes three accelerometer types of varying frequency response ranges, and a laser Doppler vibrometer (LDV). The LDV is capable of directly measuring both girder velocity and displacement.

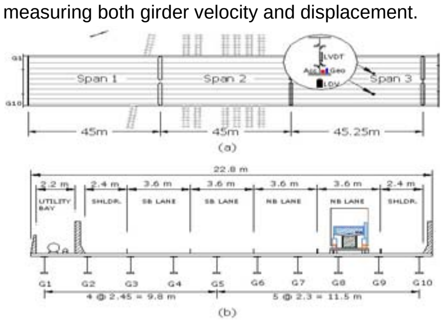

Figure 4: Instrumentation unit of Doremus Avenue Bridge

Several controlled live load tests are performed using two 5-axle trucks with known axle weights and configurations. Various loading cases are considered including single, following, side-by-side, and staggered. The results from one test case is shown in Figure 5.

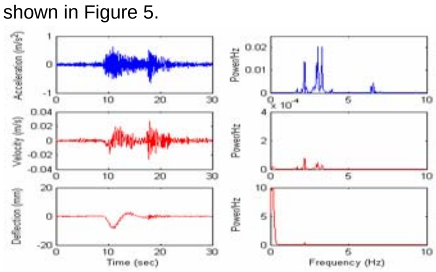

Figure 5: Time and frequency domain response for measured acceleration, velocity, and displacement

Correction Methods

Ideally, displacement can be calculated from acceleration through double integration.

$$x_{(t)} = \int\int a_{(t)} dt$$

However, small errors present in the measured acceleration signal greatly distort the integrated displacements. Direct integration of the acceleration record shown in Figure 5 results in a 63% error for maximum deflection. Results are improved if only the forced vibration is considered (19% error). Predictions are further improved by integrating acceleration record segments between zero points of displacement. However, knowing such points a priori is impractical.

Many correction techniques exist for different applications. For bridge acceleration records this study considers two methods, namely the velocity estimation method (VEM) and a linear baseline correction of the acceleration signal. VEM is an iterative procedure intended to estimate the initial bridge velocity.

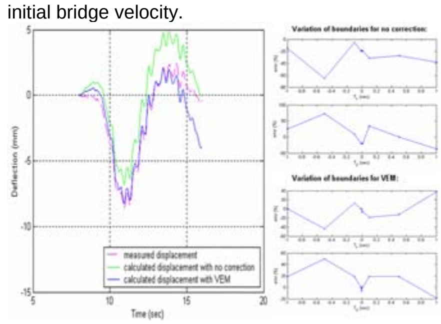

Figure 6: Comparison of Velocity Estimation Method with direct integration of isolated forced vibration

A DC offset in the measured acceleration record will appear as a line in the integrated velocity. A linear baseline correction method (BCM) removes this linear drift before integrating to displacement.

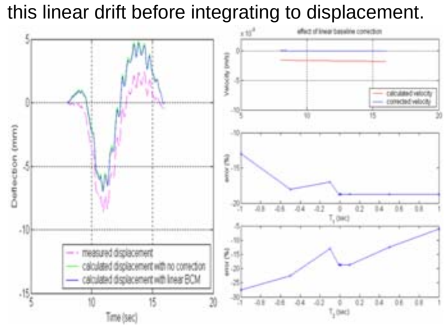

Figure 7: Comparison of linear baseline correction with direct integration of isolated forced vibration

However, both correction methods have been found to be sensitive to the choice of integration boundaries. While the maximum deflection error for the VEM varies from -45% to +50% with a 1-second shift of the forced vibration boundary, this error only varies from -28% to -6% for the linear BCM.

Conclusions

Various correction methods of integrated displacements are considered. Bridge acceleration and displacement are independently measured from two systems under various truck loading scenarios. It is found that while VEM and BCM provide reasonable estimates for some records, none are consistent or repeatable. Both methods are sensitive to the choice of integration boundary conditions.

Acknowledgments

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