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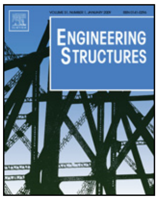

Measurement of the dynamic displacements and of the modal frequencies of a short-span pedestrian bridge using GPS and an accelerometer

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ABSTRACT

Signal analysis techniques (supervised-type learning filter in combination with a Chebyshev filter) constrained and tested by independent accelerometer data were used to process noisy GPS measurements of oscillations of 40 m long steel footbridge excited by coordinated jumps of a group of people. This approach permitted to de-noise the geodetic displacement record and reconstruct a minimum bias waveform for the dynamic displacement of this stiff bridge (4.3 Hz modal frequency, ∼6 mm oscillation amplitude). This result indicates that properly processed high-frequency satellite geodetic data may be used to measure dynamic displacements not only of high-rise buildings, cable-stayed bridges and other flexible structures, but of stiff civil engineering structures as well and may be useful for the Structural Health Monitoring, analysis and design of a large range of engineering structures. It was also found that although currently used 10 Hz sampling rate GPS receivers may underestimate certain high-frequency peak displacements, this will not be a problem for the recently introduced 50–100 Hz receivers.

1. Introduction

The understanding of the response of major structures to dynamic effects such as earthquakes, wind and traffic load, and especially the measurement of their displacements and dynamic parameters are issues of major importance for structural engineering for four reasons. First, in order to identify whether the real (‘‘as built’’) and the design dynamic characteristics of a certain structure are similar [1,2]. Second, to understand the response of major structures to wind and earthquake loads [3,4] and detect the effects of the soil–structure interaction (SSI) [5]. Third, because the post-seismic recovery of a certain structure [6] sometimes requires an assessment of its structural integrity and the identification of possible seismic damage reflected in changes of its dynamic characteristics, i.e. the monitoring of its structural health [7]. And fourth, because of new trends for displacement or deformation-based design of earthquake-resistant structures [8,9].

Traditionally, measurements of dynamic parameters of structures are based on accelerometers, and rarely on strain gauges, displacement transducers and more recently fiber optic sensors [10–12]. The basic problem of these methods is the limitation in the measurement of displacements. Accelerometer-derived displacements are contaminated by serious errors (‘‘drift’’) induced by double numerical integration [13–15], while non-geodetic sensors can only measure *relative* displacements/deformations and not the displacements of a structure relative to a fixed reference frame, independent of the structure (i.e. absolute displacement measurements).

Although the first absolute measurements of displacements of structures were made in the 19th century in the Eiffel Tower in Paris and in the 1940s in certain high-rise buildings in Chicago [16], a real step towards the solution of the problem of the measurement of the absolute, dynamic displacements of major structures was made 10–15 years ago, with the advent of the Global Positioning System (GPS) [17–19] and more recently with the advent of the Robotic Theodolites [20,21] and other modern instruments like Laser scanners [22] and microwave sensors [23,24].

In the last years, a large number of measurements of displacements of structures using GPS has been published (for a review, see [25]), and most probably these data open a new era for Structural Health Monitoring. Still, these measurements were practically confined to flexible structures, high rise buildings and cable-stayed bridges, i.e. structures with modal period > 1 s and displacements > 10–20 mm ([2,26,27] for a summary see [25]). The basic reason is that GPS records of displacement of more stiff structures are very noisy and the displacement signal remains covered by ambient noise, despite the available advanced filtering (de-noising) techniques [4,28–33].

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