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Structural evaluation of dynamic and semi-static displacements of the Juarez Bridge using GPS technology

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ABSTRACT

Global Positioning System (GPS) naturally produces position estimates representing a considerable advantage in comparison with others assessment instruments such as accelerometers, where double integration is required. Several investigations have demonstrated that GPS is an accurate and efficient tool for the evaluation of civil infrastructure. Therefore, an alternative bridge structural evaluation focused on in-service conditions of the Juarez Bridge located in Culiacan, Mexico by using GPS is addressed in this research. The Juarez Bridge connects two important zones of the city, it is a reinforced concrete structure constructed approximately 45 years ago, and it has a length closely to 200 m. The assessment process consisted in collecting continuous GPS data during one consecutive hour at three different periods of the day (rush hours) from Monday to Sunday under critical traffic loading. Since the response of a structure subjected to loads may result in different types of displacements, GPS time series were used for the proper calculation of dynamic and semi-static displacement at the center deck of the Juarez Bridge. However, GPS displacements obtained in terms of coordinates may not accurately reveal the behavior of the bridge without considering prior filtering of the data. Hence, two post-processing reliable filtering techniques: the moving average and Chebyshev filter were applied to improve the time series. It was observed that the vertical displacements were critical during the evaluation. Hence, vertical semi-static displacements were compared with respect to the AASHTO (American Association of State Highway and Transportation Officials) deflection limits, and probability of failure was properly calculated.

1. Introduction

The performance evaluation of bridges has been conducted over the last two decades, since around the world, several bridge structures are aging beyond their original design life period. These conditions require efficient, costly-effective, and reliable bridge-evaluation procedures. In order to characterize the response of bridges to stressing under use, the structural monitoring of bridges must be performed under real-time in-service conditions, Ashkenazi and Roberts [1]. According to Celebi [3], the structural evaluation of bridges might be sustained by accelerometers; however, their accuracy is questionable under real-time conditions, requiring double integration for the calculation of displacements and it is not possible to acquire the semi-static displacements [9]. As an alternative, several researchers have demonstrated the capability of high-rate ($\geq$1 Hz) Global Positioning System (GPS) for the structural health monitoring of bridges [1,5,22,23]. The advantage of GPS monitoring is to directly provide displacements without any further integration. GPS was essentially developed for continuous monitoring of slope stability for landslide hazards applications, precision differential surveying, or for seismological applications; however, its application has been expanded for civil infrastructures such as dams, high-rise buildings, and bridges. Hence, high-rate GPS techniques can be fully applied in lieu of conventional accelerometers to compute relative displacements in real-time and with sufficient accuracy to assess the behavior of bridge structures, Celebi [3]. In general, a suspension bridge experiences two types of deformations. The first type is considered as the long-term movement, which is a slow movement, unrecovered and

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caused by foundation settlement, bridge deck creep and loss of pre-stress. The second one is the short-term displacement produced by wind, tidal current, earthquake, or traffic, and it is a recoverable deformation, Meng [14]. Static, dynamic and a combination of both types of effects can be obtained by applying live loads to the civil infrastructure depending on the time of application. If the load is applied very slowly, the contribution of inertia forces (dynamic behavior) can be ignored and the load can be considered as semi-static. For instance, wind load produces both semi-static and dynamic displacements, Raziq [19]. GPS time series can be analyzed for semi-static and dynamic displacements. However, these time series are normally noise contaminated and cannot express a particular behavior without applying adequate filters. According to the AASHTO manual two vertical state limits of deflection should be considered for the evaluation of bridges. Since vertical displacements were found to be critical in this research, vertical semi-static displacements and AASHTO deflection limits were compared, and the corresponding probability of failure (p_f) was calculated. This task was accomplished by constructing the Probability Density Functions (PDFs) of the deformations of bridges under normal service loading conditions. Once PDFs were available, the p_f was computed as reported by Nowak and Collins [17].

2. Description of the Juarez Bridge

In the city of Culiacan, Mexico exist several civil constructions that are standing beyond its original design life period. This issue represents a problem that clearly exposes the safety of people because of the possible collapse. The presented case of study is the Juarez Bridge, which was built 45 years ago to streamline the congested traffic between northern and southern parts of the city. It is a reinforced concrete structure with an approximate length of 200 m and is one of the most important civil infrastructures because allows access for thousands of pedestrians, vehicles and bicycles that cross it every day. Recently, its traffic circulation was changed to four lanes plus one additional lane for bicycles, beyond its design tolerances loads, even a non-adequate performance of the Juarez Bridge is detected day-to-day by users. Fig. 1 shows a current picture of the bridge from different angles. Fig. 1 (b) illustrates a protuberance on the pavement, which may cause high dynamic fluctuations in displacements. Fig. 1(d), illustrates how the bridge just has a "L" joint between the mid-span and the support pilot, which may be one of the main reasons of high vertical deflections, detected during the structural evaluation, this will be commented later in this research.

3. GPS bridge deformation evaluation and data processing technique

The use of GPS in bridge deformation evaluation has been previously addressed in the literature; Roberts et al. [20] evaluated a bridge located in England with an approximate length of 1400 m. They monitored the bridge by means of GPS measurements in real-time obtaining very accurate results. Additionally, Wieser and Brunner [23] analyzed a suspended bridge located in Austria with a length of approximately 400 m by performing GPS measurements in real-time. These research works demonstrated the utility of GPS for structural bridge monitoring. Considering precise GPS data, time series can be generated to extract the response of bridge structures under service conditions. In this paper, the data was obtained in a succession of observations collected in a regular and homogeneous way over time allowing for the statistical characterization of the response of the bridge. In addition, GPS seems to be more efficient in comparison with seismic instruments that record acceleration. Essentially, the data obtained from accelerometers require double integration to obtain displacements, subject to drift errors that contaminate the lower frequency content of the displacement time series, adding certain degree of difficulty to the structural evaluation process. The deformation evaluation of the Juarez Bridge was developed by using six geodetic-grade GPS receivers: two Topcon Hyper V, denoted as TOP1 and TOP2; two Zenith Geomax, denoted as ZEN1 and ZEN2; and two Leica SR530, denoted as LEI1 and LEI2. It should be point out, that these type of sensors are normally calibrated by the manufacturer under laboratory conditions (e.g. zero baseline test); furthermore, the manufacturer also provides information regarding how accurate (millimeter to centimeter level) and reliable could be the results of the measurements by using these instruments in static or dynamic conditions. The receivers were properly mount-leveled and fully fixed to the bridge; Fig. 2 illustrates the location and fixing conditions of the GPS receivers. Furthermore, two very stable sites with previously precise determined coordinates denoted as

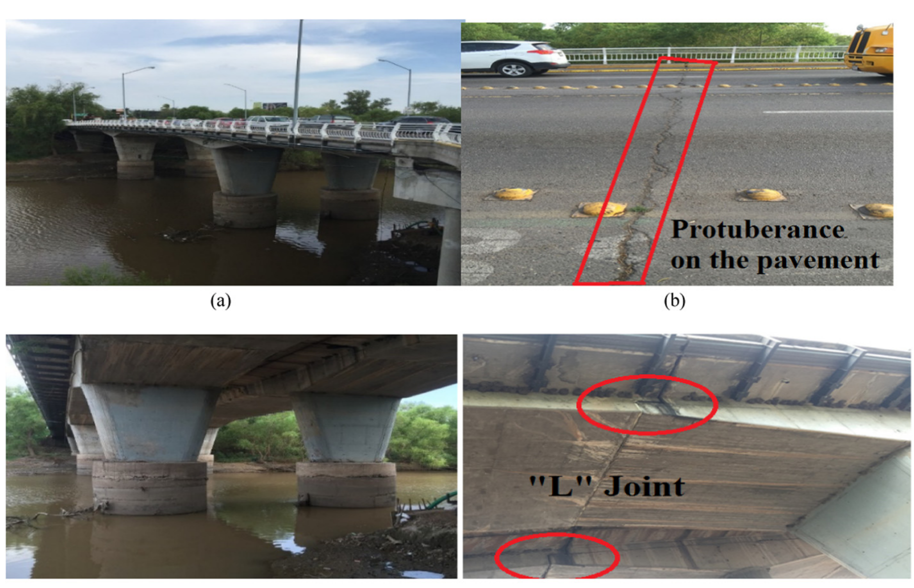

Fig. 1. Dimension and condition of the Juarez Bridge. (a) – longitudinal view; (b) – top view (protuberance on pavement); (c) – piers condition; (d) – joint of mid span.