# GPS for Monitoring the Dynamic Response of Tall Buildings: Experimental Verification and Full-Scale Application

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## Introduction

Previously, the global dynamic displacements of large Civil Engineering structures could only be ascertained using the integration of measured accelerometer data; however, this does not permit the recovery of static displacements, especially of interest for structures under the action of wind. As the sampling rates of Global Positioning Systems (GPS) have reached levels of 10 Hz, they are now suitable for monitoring longer period structures to within millimeters. The current effort is dedicated toward long-term monitoring of a host of tall buildings in Chicago as part of a larger NSF study (Abdelrazaq et al. 2000). In developing the GPS for this project, a series of static and dynamic calibration tests on the Leica MC-500 differential GPS system were conducted, utilizing a small shake table, to quantify the system performance. The objectives included quantifying the significance of geometric dilution of precision (GDOP) and validating the kinematic performance of the system for signals of varying amplitude, frequency and complexity. This paper will present the findings of these calibration tests and discuss the performance of the full-scale application.

## Dynamic Field Calibration Studies

The calibration of the GPS system (see Figure 1) was conducted prior to its full-scale installation to verify its performance during motions of various amplitudes and frequencies. There were 4 types of dynamic signals that were tracked by GPS mounted on a shaking table in this stage of the study: (i) 23 different sine waves with amplitudes from ± 0.5 cm to ± 3 cm and frequencies from 0.1 to 2 Hz, (ii) sinusoidal chirp with frequencies sweeping 0.1 to 2 Hz over 1 minute and amplitudes of ±1 cm, (iii) Random white noise with an amplitude range of ±2 cm and frequency content from 0-2.5 Hz and (iv) simulated MDOF response of a tall building under random excitation with frequencies at 0.1297, 0.3527 and 0.5300 Hz and assumed 1% damping in each mode.

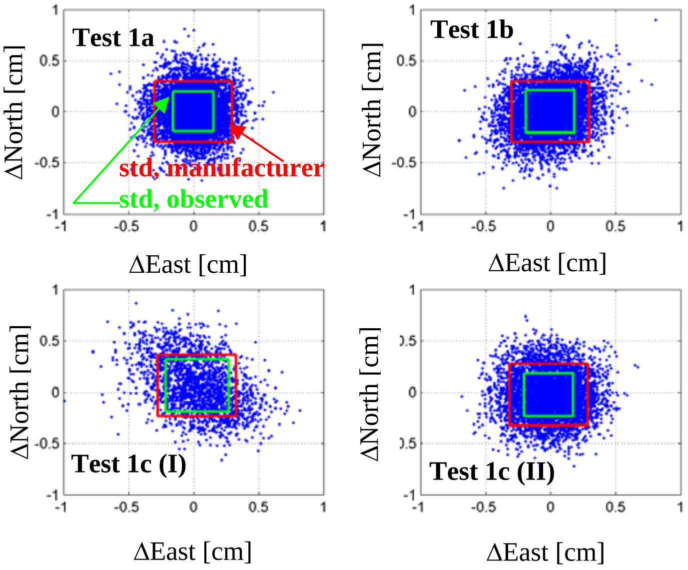

Figure 1. Results from static tests and comparisons between observed standard deviation (inner box) and manufacturer's prediction (outer box).

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Table 1. Relative displacements recorded by GPS during static testing

| Test | Time | East Displacements [cm] | | | | North Displacements [cm] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | min | max | mean | std | min | max | mean | std |
| 1a | 9:22-9:33 | -.638 | .612 | ~0 | 0.156 | -.672 | .808 | ~0 | .193 |
| 1b | 12:57-13:07 | -.700 | .810 | ~0 | .186 | -.745 | .895 | ~0 | .208 |
| 1c (I) | 15:29-15:32 | -.991 | .819 | .029 | .242 | -.660 | .870 | .065 | .256 |
| 1c (II) | 15:32-15:41 | -.681 | .669 | -0.01 | .190 | -.720 | .740 | -.026 | .211 |

## Static Field Calibration Studies

As discussed in Kijewski and Kareem (2002), both the availability and position of satellites will limit the accuracy of GPS results. Typically, in order to resolve the ambiguities, up to seven satellites may be required, depending on their positions. When this condition is achievable, the manufacturer's predicted GPS static accuracy is 3 mm (RMS) over short baselines.

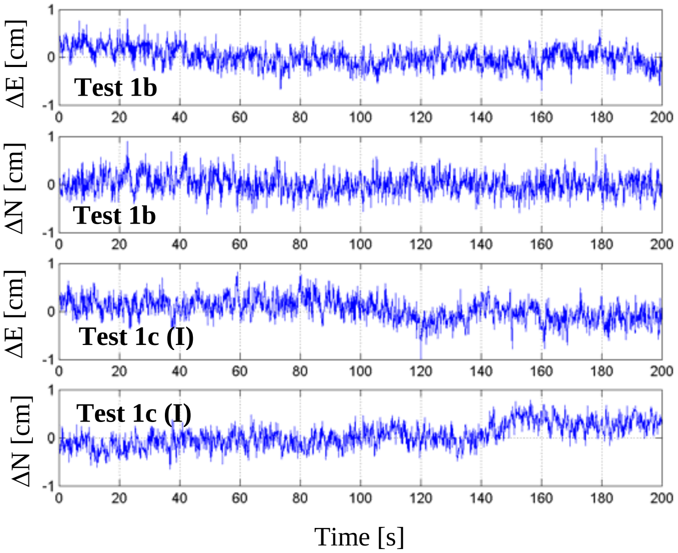

Figure 2. Portion of time history of GPS relative displacement for static tests.

To demonstrate underlying accuracy of the GPS system, static test data collected at three different times of day are presented in Table 1. In the case of Test 1c, part way through the test, one of the satellites moved out of view, reducing the available number of satellites. When the system is stationary, mean displacements in Test 1a and Test 1b are essentially zero, with standard deviations on the order of 1 to 2 mm, actually reflecting performance better than the manufacturer's specifications. However, notice that in Test 1c, a mean offset is detected, though being less than 1 mm. As shown in Figure 1, Test 1b and Test 1c (I) demonstrate a deviation from the classical circular shape, indicating some static offset or bias. Looking more closely at the time histories of displacements for these cases in Figure 2, a slight bias toward the positive East in the first 30 seconds, explains this subtle trend. This is more marked in the case of Test 1c (I) where the GPS data manifests a positive eastern bias through the first 100 seconds, a sudden negative bias and then some stabilization. Similarly, there is a marked positive northern bias later in the signal, explaining the shape in Figure 1. This emphasizes the need be aware of the potential for such low frequency trends in GPS data, noting that any static or pseudo static relative displacements of under ±0.5 cm may not be physically meaningful.

## References

Abdelrazaq, A., Baker, W., Isyumov, N., Kareem, A., Kijewski, T., and Sinn, R., "Studies to Correlate Actual and Expected Behavior of Tall Buildings Under Wind Action", *Proceedings of Structures Congress*, ASCE, 8-10 May 2000, Philadelphia.

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