Recent research and applications of GPS-based monitoring technology for high-rise structures

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SUMMARY

Monitoring the response of structures, especially tall buildings, under severe loading conditions is an important requirement for the validation of their design and construction, as well as being a maintenance concern. This paper presents a review of current research and development activities (since 1995) in the field of high-rise structure health monitoring using the Global Positioning System (GPS). The GPS monitoring technology and its accurate assessment method are firstly briefly described. Then, the progresses on monitoring the displacement of the high-rise structure caused by the ambient effects including wind, thermal variation, and earthquake-induced responses are discussed in details. Following that, the states of the art of augmenting the GPS monitoring technology are reviewed. Finally, existing problems and promising research efforts in the GPS-based health monitoring are given.

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1. INTRODUCTION

Today there are many more large and/or tall engineering structures than in the past. These structures are being designed to be more flexible and to resist extensive damage from changes in temperature, severe wind gusts, and earthquake tremors. The finite element model (FEM) analysis, shaking table, and wind tunnel tests of scaled models are often carried out to assist structural design (e.g., Li and Huo [1]). However, loading conditions in the real environment are always much more complicated than what engineers consider. On the other hand, during the service time, it is inevitable that these slender structures suffer from environmental corrosion, material aging, fatigue, and coupling effects with long-term load and extreme load. The induced damage accumulation and performance degeneration due to the aforementioned factors would reduce the resisting capacity of the structures against disaster, even resulting in collapse due to structural failure under extreme loads [2,3].

Therefore, there is significant interest in securing the investment with two fronts: first, the safe operation and maintenance of the project to ensure a long service life and, second, insuring safety and efficiency of modern design practice. Both of these intentions may benefit from instrumentation and monitoring of the structures. Structural monitoring serves several purposes. For example, it can provide structural response data allowed for the built performance to be checked against design criteria, which will be an increasingly useful exercise given for the movement towards ‘performance based design’ of structures. Over a long period, the monitoring can also provide the opportunity to identify ‘anomalies’ that may signal unusual loading conditions or modified structural behavior, which can, in the extreme case, include damage of failure. The final use is to provide data for calibrating design codes [4,5].

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5.3. GPS multi-antenna system

Although an effective tool for the deformation monitoring of large structures, one of the major drawbacks of continuous GPS is the high capital cost of the GPS equipment required at each site [59]. Each installation will include a receiver, antenna, communications hardware and software, power supply, and security fixtures. Thus, it is desirable to moderate this expense, which may be achieved using the episodic GPS in the form of a switched multi-antenna array. In this case, the multiple GPS antennae are connected to a receiver, which records data continuously while switching between antennae periodically [60]. This will, of course, reduce the overall capital cost of the whole monitoring process significantly because of the reduction in the number of receivers used compared with the continuous GPS. Although the number of GPS antennae is unchanged, these have significantly lower unit costs. Each antenna is mounted at the required test location, and the signal from each antenna is multiplexed to the receiver through a switch mechanism, which consists of multiple input channels and a single output channel, as shown in Figure 20. This allows the receiver to sample sequentially the signals from each antenna for a certain time interval, producing periodic GPS data for the network of fixed monitoring stations.

The concept of a multiple-antenna array has been discussed previously in several investigations with different perspectives. One of the earliest was by Santerre and Beutler [61], who linked the multiple antennae to a GPS receiver with the aim of improving height determination for baselines of few kilometers in length. Ding et al. [62] tested a GPS multi-antenna system (GMS), which was near to the typical accuracy achieved using the conventional GPS surveying systems, to monitor deformations such as landslides or unstable slopes. Forward et al. [63] developed a GPS-switched antenna array system comprising four switched antennae, in addition to two continuously operating reference stations recording at 1 Hz. Three-dimensional deformations of 2 mm/week were detected. He et al. [64] developed a prototype of GMS with eight channels, called GMAS (GMS), as shown in Figure 21. The average precision of baselines over the whole observation period may reach around 1–2 mm.

Figure 20. Schematic diagram of antenna array connections [60].

Figure 21. GPS multiple-antenna switching device [64].