A building structural-performance monitoring system using RFID tag with sensors

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Keywords: structural-performance, monitoring, RFID, acceleration sensor, response displacement

Recently, changes to circulation-type production systems are strongly demanded from an environmental perspective in building construction fields. It is necessary to identify structural performance properly at each stage of a building’s life cycle to use structures for a long time. Based on identified results, appropriate structural repairs and anti-seismic retrofit methods can be planned. However, in Japan, structural performance monitoring systems have not been adopted in buildings. Aiming at ubiquitous and conventional structural performance monitoring systems, some application systems using wireless sensor networks have been applied to performance monitoring systems of buildings. Regarding other ubiquitous information systems, radio frequency identification (RFID) tags are used widely in various fields. Recently, RFID tags with sensors have come onto the market in Japan. However, these tags have no memory and the data collected by sensors are transmitted immediately to a controller. In order to reduce communication loads, built-in memory is considered indispensable because high-speed sampling is required to perform structural performance monitoring against earthquake and wind loadings. Regarding fundamental studies of active-type RFID tags with acceleration sensors, the authors performed shaking table tests using two-story and four-story specimens (Tani et al., 2007 a, b, 2008). In those studies, an alternative system (Microstrain, 2009) which has almost identical performance to RFID tags with sensors and built-in memory was used.

In this study, calculations of response displacements are performed using Fourier integration of response acceleration data observed in shaking table tests of two-story specimens. Calculation results are compared with response displacements measured by laser displacement meters. Based on those results, the applicability of RFID tags with acceleration sensors are verified and discussed along with accuracy of identification results related to structural characteristics (Ugaji et al., 2009).

In shaking table tests, absolute response acceleration and displacement data of the shaking table and each floor are measured using acceleration sensors (Sensor K) and laser displacement meters. Four earthquake wave data are used as earthquake inputs: El Centro NS (1940), Taft EW (1952), Hachinohe NS (1968), and JMA Kobe NS (1995). Measurements of sensors are started before the shaking table system is started, and are terminated after the shaking table system is terminated because the measurement system sensors can not be synchronized with the shaking table test system. Regarding the method of superpositioning, observed data, and origins of data collected by sensors are shifted horizontally to conform to clock times of maximal data obtained using the servo-type accelerometer and Sensor K on the shaking table. The sensors’ sampling interval is 0.03125 s (32 Hz). The sampling interval of the shaking table test system, measuring by servo-type accelerometers and laser displacement meters are 0.01 s. The duration is 20 s.

In this study, regarding an integration method of acceleration data, Fourier integration is performed in
the frequency domain. Generally, response displacements are calculable by the integration of measured acceleration data twice. However, integration results often become strange because the sensors’ dynamic characteristics affect the observed data. To modify these phenomena, filtering operations are used. In this study, the Butterworth filter is used as a high-pass filter. In accordance with procedures proposed in this study, the degree of the filter is fixed to 4, and the cut-off frequency $\omega_c$ is determined as 0.51 Hz. The round number 0.50 Hz is used as the Butterworth Filter cut-off frequency. Using the Fourier integration method and Butterworth filter ($\omega_c$=0.50 Hz, $N=4$), the absolute response acceleration data measured by sensors are integrated and the absolute response displacements are calculated.

Aiming at ubiquitous structural performance monitoring systems of buildings, the calculation method of response displacements using measured absolute acceleration data and Fourier integration method is proposed. Integrated results are verified in comparison with response displacements measured by laser displacement meters. The obtained results suggest the following conclusions.

1) Absolute response displacements can be calculated using acceleration data measured by sensors and Fourier integration methods with filtering operations. Regarding filtering operations, the Butterworth filter used in this study is also effective when appropriate parameters such as the cut-off frequency and the degree of the Butterworth filter are determined.

2) As for parameters of the Butterworth filter, the degree of the filter is fixed to 4. The cut-off frequency giving the minimal arithmetic average of calculation errors is determined as the optimal cut-off frequency. The proposed optimizing method of the cut-off frequency is proved to be effective, and errors of integration results are distributed from 0.528 to 10.7%.

3) As for the applicability to the structural performance monitoring system, changes of predominant periods can be detected by Fourier analysis using acceleration data measured by sensors. This method can detect the deterioration of the objective building totally. On the other hand, response displacements calculated by Fourier integration method can detect damages based on maximal response displacements and/or residual displacements. This method can detect damages in each floor and those of structural members such as columns, braces, shear walls and so on.

4) Based on results obtained in this study, RFID tags with acceleration sensors and built-in memory are considered to be applicable to structural performance monitoring systems of actual buildings based on measured response acceleration data and calculated response displacements. Furthermore, damage detection methods for buildings using response acceleration and displacement data must be developed to improve structural performance monitoring of buildings.

References