Structural Member Monitoring of High-rise Buildings Using a 2D Laser Scanner

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Abstract

Numerous research projects have sought to monitor the usability and safety of buildings with various measuring devices. Particularly with high-rise buildings, it is important to assess the structural response to the lateral loads such as wind load. Accordingly, the standard for the top-floor displacement as a result of a wind load is limited to 1/400-600. In this research, a 2D laser scanner was used to measure the top floor displacement and inter-story drift. The data thus obtained are used in an interpretive program to draw a back analysis, leading to the development of a monitoring method for structural members. The accuracy of the displacement measurement of each floor and the degrees of strain of the structural members were estimated in an effort to judge the possibility of applying the method in a multi-degree-of-freedom structure.

Keywords: Structural Health Monitoring, 2D Laser Scanner, High-rise Building

1. Introduction
High-rise buildings, due to their particular shape, are prone to be affected by lateral loads such as seismic and wind loads, unlike low-rise building. The top floors of these structures are typically designed and constructed with a horizontal displacement range of around 1/400 – 1/600 of the height of the building. In this regard, an increased amount of research attention is being directed toward both devices that measure the maximum displacement and those that record the displacement history and conduct overall monitoring of these shallow and long structures. High-rise building monitoring is typically done in one of two methods: unit-member step monitoring which measures and estimates the structural response of structural members and joints, and structural-level monitoring which measures the entire high-rise building and assesses the safety and usability of the structure. The former monitors the safety of structural members in comparison with the design strength or the allowable stress calculated by the strain and the stress, as estimated with an electrical resistive sensor or a fiber optic sensor. The latter monitors the safety and usability of the entire structure by estimating the static and dynamic displacement and acceleration level which enables an assessment of the rigidity of the structure via GPS and an accelerometer.

Monitoring at the structural level leads to relatively accurate acceleration level assessments of the usability of a structure. However, there can be some degree of numerical integration error and difficulties in estimating the static element when measuring the displacement of a structure. Moreover, the accelerometer requires wiring which can cause noise signal disturbances. When using GPS, via the triangulation principle using an artificial satellite, estimation and monitoring only of the horizontal displacement of the top floor of the structure with GPS on it are provided. Thus, it cannot provide a measurement of the overall deformed shape of the structure, including the inter-story drift.

In this thesis, a measurement method using a 2D laser scanner and its degree of applicability are verified through an experiment that focuses on measuring not only the displacement of the top floor but also the horizontal displacement of each floor of the structure. The 2D laser scanner has two main strengths: it is used in industrial monitoring and with GIS applications and is mainly unaffected by environmental conditions. It enables both spot monitoring and overall monitoring of the subject.

2. Back Analysis Principle

There is an allowable range according to the NBCC standard and the Lawrence theory for the horizontal displacement of the top floor and the inter-story drift of a high-rise building. However, it is challenging work to quantify the influence of the allowable range of a specific member while monitoring structural members. Therefore, the back analysis method was introduced to tackle this issue.

Back analysis starts by measuring the displacement of the top floor and the inter-story drift of the structure with a 2D laser scanner and produces random displacements through the model displacement using an interpretive program based on a simulation of the actual structural design. Finally, the stress of the member level can be assessed. Sensors currently being used are only able to assess the structural response of a section of a structure; however, the use of a 2D laser scanner enables monitoring over the entire structure.

3. Experiment

In the experiment, the possibility of monitoring a structural member through back analysis was evaluated while focusing on the main advantages of the 2D laser scanner for an estimation of the inter-story drift of a high-rise building. For this experiment, we created a specimen of a multi-degree-of-freedom structure which is similar to an actual high-rise building and carried out a free vibration test to obtain the data.

As shown in Figure 1, an experiment was conducted to assess the stress level at the member level in which free vibration was introduced into the specimen after creating a degree of random displacement on the top floor. Here, the specimen was a three-story multi-degree-of-freedom structure. This structure was also used in a free vibration test to measure the displacement. The initial peak value during the generation of free vibration contains two types of information at the same time: the displacement of the laser displacement meter and the strain value of the electrical resistive sensor. The two outputs were recorded and compared. The value of the stress should be obtained from the end of each column, where most of the stress arises. As shown in Figure 2, a total of 12 strain gauges were attached onto the end of each of the four corners on every floor, and the data was obtained during the free vibration of the specimen. The values of the strain at each floor obtained during the free vibration test were sorted by grouping them per floor and obtaining an average value after the conversion of each individual value into its absolute value. It should be noted that the
values of the stress from each floor were identical in each case apart from the theoretical differences in the tension and compression between them. A relatively precise laser displacement meter was used to obtain data to compare it with that from the 2D laser scanner after the meter was installed at each floor in the same way as the 2D laser scanner during the measurement of the displacement. This comparison was done before the back analysis of the data obtained from the actual 2D laser scanner. The laser displacement meter has more accuracy than a millimeter unit; however, it cannot be applied to a high-rise building due to the measuring distance. The measuring efficiency levels of the values from the laser displacement meter and the 2D laser scanner during the experiment with the multi-degree-of-freedom specimen are shown in Table 1 given the relatively precise laser displacement meter. The initial result ranged from about 4 to 20%, but these figures were changed by the standard of 5cm of maximum displacement of the top floor. A lower degree of Table 1. Measuring Efficiency of the Maximum Displacement of the 2D Scanner (%)
measuring efficiency is expected in the case of an actual high-rise building with 50~100 cm of maximum displacement at the top floor. The structure was modeled after an actual specimen with the measurement data from Table 1 with the MIDAS structural analysis program. In addition, the stress value for each floor was estimated after applying the measured data from the 2D laser scanner. The results showed that the stress values at each floor were less than 10%, thus showing a nearly equal value to the stress value obtained from the actual electrical resistive sensor.

4. Conclusion

In this research the value of the stress of a member level under displacement load was assessed using an interpreted model by comparing the displacement values from a 2D laser scanner and a relatively precise laser meter in a free vibration test of a multi-degree-of-freedom structure for an assessment of the feasibility of the back analysis method.

Useful results were obtained when the values of the stress obtained from the strain gauge were compared to those from the 2D laser scanner and the laser displacement meter by back analysis. The values after the back analysis with the 2D laser scanner were found to be less accurate than those of the laser displacement meter. The cause for this was possibly the mechanical accuracy of the 2D laser scanner, which prevents it from obtaining a more accurate displacement value of each floor compared to the laser displacement meter. However, the 2D laser scanner provides the displacement value for each floor with time progression, and it generally enables structural member monitoring through back analysis.

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6. References