High-rise structural responses data analysis base on the long-term structural health monitoring system

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Abstract: With the development of the construction technology, the high-rise and long-span structure emerges rapidly in the world and how to evaluate and assess the structural performance and health status during the construction and in-service is essential. Structural health monitoring system makes it impossible using the long-term recorded data and protect the structure. This presentation is divided in the two sections. Section I present the responses analysis, the damage identification and finite element model updating of Canton Tower using the field measurement data. Section II describe the structural health monitoring system implemented on the wind turbine tower, and some preliminary analysis results obtained using the recorded data. Finally, some impossible study points on the wind turbine are given.

Key words: Structural health monitoring, high-rise structure, wind turbine tower.

BRITISH COLUMBIA SMART INFRASTRUCTURE MONITORING SYSTEM (BCSIMS)

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Keywords: Seismic structural Health Monitoring; Strong motion Network; Earthquake Notification; Real-time Data Processing

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Southwest coast of British Columbia (BC), including Vancouver and the densely populated Lower Mainland, is located over an active subduction zone, which results in one of the most seismically active regions of Canada. This zone, called the Cascadia subduction zone, is capable of producing large, up to magnitude 9.0, earthquakes. The last mega quake in this region was approximately 300 years ago and evidence suggests that strain has been accumulating in the subduction boundary, off the west coast of Vancouver Island. Analysis of contemporary crustal deformation proves the same strain accumulation in the subduction boundary. Even though Vancouver has not yet experienced a large damaging earthquake, the paleo seismic evidence on the Fraser delta, south of Vancouver, confirms that large earthquakes have occurred in prehistoric time. Ongoing occurrence of earthquakes, which are large enough to cause damage to structures, is a reminder of the fact that the southwest coast of BC is still a seismically active area. Other smaller but still potentially damaging earthquakes may also occur in the overlapping crust and in the subduction slab. Such seismic activity, as a result, presents hazard to the area and risk to the civil engineering structures built in those areas.

To help mitigate this seismic risk, the Geologic Survey of Canada (GSC) through the Pacific Geoscience Centre (PGC) has maintained an urban strong motion network (SMN) in BC since 2003. As part of this network, the GSC developed a strong motion Internet accelerograph (IA) network, which is permanently connected to the Internet and records ground vibration data continuously. The instrument continuously computes a set of strong motion (SM) parameters, which characterize the intensity of shaking, and actively reports those values to the GSC's and the University of British Columbia's (UBC) data centres via four relays whenever ground shaking exceeds predefined threshold levels. Over the last several years, the British Columbia Ministry of Transportation and Infrastructure (MoT) has been working with the PGC to expand the range of the network outside of urban centres and increase the number of stations in the network to the current 162 strong motion stations.

The MoT is responsible for 400 km of provincial disaster response routes in BC. The loss of any portion of these routes after an earthquake could significantly impact emergency response efforts and negatively affect public well-being. The MoT, moreover, maintains over 2500 bridges in the highest seismic zones, many of which are vulnerable to extensive damage in even a moderate quake and potential collapse in a major earthquake. The loss of the use of several structures would not only have immediate impact on public well-being and the ability of emergency vehicles to respond effectively, but would also cripple the economic recovery of the region. The better the information on these areas where structures and facilities are most vulnerable, the better is the planning and the preparation that can be done. By identifying those structures and facilities most susceptible to seismic forces through automatically generated shakemaps, decision-makers can do effective risk management. Fast and accurate field intelligence immediately following an earthquake can ensure the most effective deployment of vital services and mitigate damage to the built environment.

In a parallel effort, the MoT has also been instrumenting bridges and tunnels in collaboration with the Earthquake Engineering Research Facility (EERF) at the UBC since the late 1990s. The primary purpose of these legacy systems was to capture the ground motion input and its effect on structures in the event of an earthquake. Building on these collaborations, the MoT and the UBC recently embarked on a program called the British Columbia Smart

Infrastructure Monitoring System (BCSIMS), which integrates data from the instrumented structures (currently 16 in total) and the SMN. The system organizes and processes real-time data in an efficient manner and delivers results and related reports to predefined recipients such as bridge inspectors at the MoT. This instrumentation program provides immediate notification after an event and incorporates remote Structural Health Monitoring (SHM) system. The goals of the system are: (1) to provide a real-time seismic structural response system to enable rapid deployment and prioritized inspections of the MoT's structures; (2) to develop and implement a structural health monitoring program to address the need for safe and cost-effective operation of structures in BC; and (3) to provide a real-time working platform (www.bcsims.ca) that can integrate many aspects of seismicity in BC.

The implementation of BCSIMS transforms the current practice of inspecting and evaluating all structures after an earthquake to a more rational and effective one that makes effective use of state-of-the-art sensing technology with fast and efficient techniques for data analysis and interpretation; therefore, the inspections can then be focused and prioritized to maximize the effective use of the scarce resources

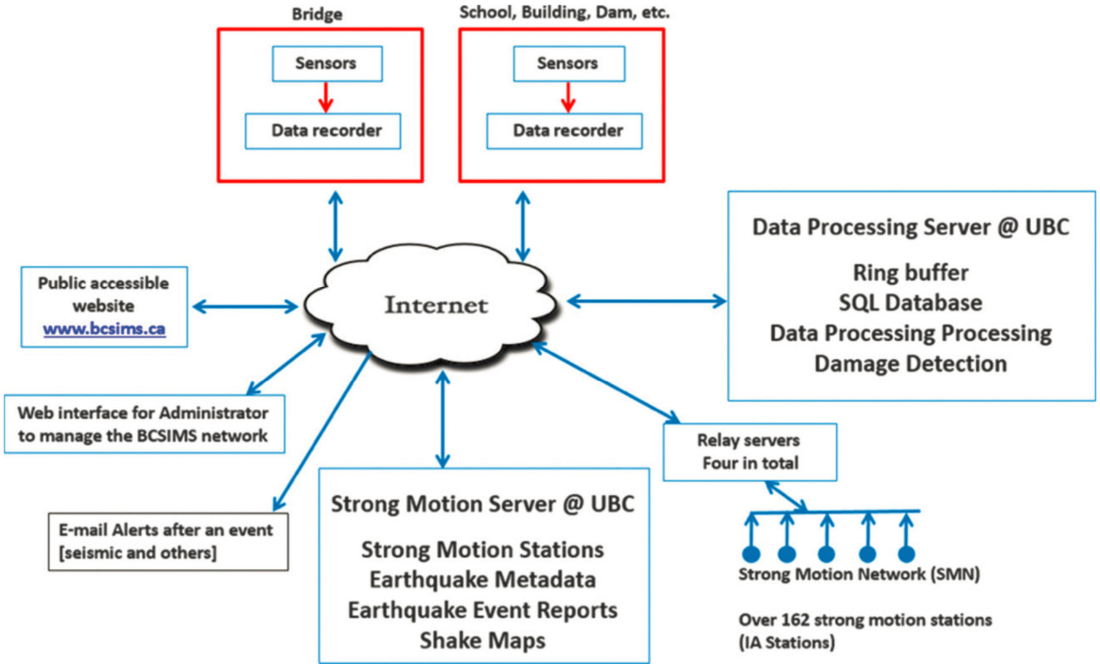

Figure 1: The architecture of the BCSIMS that consists of several servers, hardware and software, data acquisition system, data storage and processing tools, and network communications. All of them are connected to central servers located at UBC via Internet.

SIMULTANEOUS IDENTIFICATION OF STIFFNESS, MASS AND DAMPING USING AN ON-LINE MODEL UPDATING APPROACH

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Keywords: on-line model updating; Kalman filter; energy equilibrium theory; damage identification; structural health monitoring.

Objectives

One challenge of structural health monitoring is having the ability to rapidly and accurately locate and quantify damage in complex structures. The development of damage identification methods that enable rapid implementation holds great promise for assessing structural integrity to avoid further damage or catastrophic failure. Here an on-line model updating approach is proposed to rapidly and simultaneously identify the mass, stiffness and damping properties of a structural model. The proposed approach facilitates identification of these unknown parameters using two steps: first, energy equilibrium equations are used to establish a relationship between structural energy and unknown parameters; second, the Kalman filter is adopted to obtain the unknown parameters in a short period of time.

A verification is conducted on a 158 degrees-of-freedom (DOFs) truss model with 324 unknown parameters based on a the real-world structure, which is one segment of a sign support truss, formerly placed at Interstate I-29 near Sioux City in Iowa, USA, as shown in Figure 1

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Figure 1 The sign support structure over Interstate I-29 when it was in service, and in Bowen Lab, Purdue Unversity

Relevant Results

To identify the mass, stiffness and damping of a structure, a mathematical relationship between these unknown parameters and the structural energy is established. The core equations of the proposed model updating approach are as follows:

The time update equations:

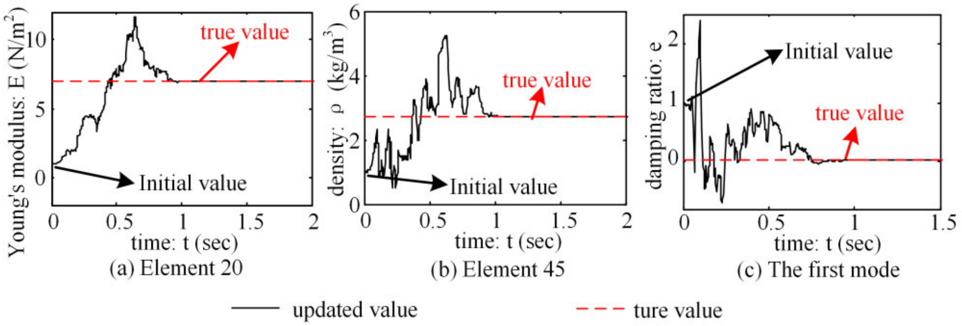
$$\begin{aligned} \hat{\mathbf{Y}}_k^- &= \mathbf{I}\hat{\mathbf{Y}}_{k-1} \\ \mathbf{P}_k^- &= \mathbf{I}\mathbf{P}_{k-1}\mathbf{I}^T + Q \end{aligned} \qquad (1)$$

The measurement update equations:

$$\begin{aligned}\mathbf{K}_k &= \mathbf{P}_k^- \bar{\mathbf{W}} \left(\bar{\mathbf{W}} \mathbf{P}_k^- \bar{\mathbf{W}}^T + R \right)^{-1} \\ \hat{\mathbf{Y}}_k &= \hat{\mathbf{Y}}_k^- + \mathbf{K}_k \left(W_f^{\Delta t} - \bar{\mathbf{W}} \hat{\mathbf{Y}}_k^- \right) \\ \mathbf{P}_k &= \left(\mathbf{I} - \mathbf{K}_k \bar{\mathbf{W}} \right) \mathbf{P}_k^- \end{aligned} \tag{2}$$

where $\hat{Y}_k^-$ is the *a priori* unknown vector estimated at time step k-1, and $\hat{Y}_k$ is the *a posteriori* unknown parameters estimated at time step k; $\mathbf{P}_k^-$ is the *a priori* estimation error covariance of the unknown vector at time step k, $\mathbf{P}_k$ is the *a posteriori* estimation error covariance at time step k, $\mathbf{K}_k$is the Kalman gain at time step k; $W_f^{\Delta t}$ is the change in the input energy of the true structure, $\bar{\mathbf{W}}$ is the energy of the initial structure.

Verification of the method is performed on the structure, and results indicated that the modal updating method do always converge to the true stiffness, mass and damping with arbitrary initial values, as shown in Figure 2.



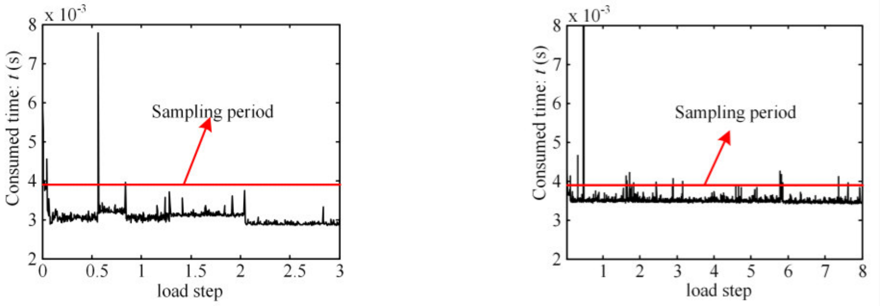
(a) Element 20

(b) Element 45

(c) The first mode

Figure 2 Procedure of updating the Young's modulus, density and damping ratio of the undamaged structure

Compared to traditional structural model updating and health monitoring methods, the approach has the advantage to update the finite element model on-line. The results demonstrate that the required time for most load steps is smaller than sampling period, which means that the method is fast enough for on-line updating of the model and detection of damage, as shown in Figure 3.



(a) Time consumed evaluation of undamaged truss

(b) Time consumed evaluation of damaged truss

Figure 3 Comparison between the time consumed at every load step and sampling period

Conclusions

(1). The proposed approach can effectively identify the structural mass, stiffness and damping.

(2). The unknown parameter readily converges to the true value by adopting this approach, which provides an efficient computational (recursive) algorithm to estimate unknown parameters.

(3). The proposed on-line model updating approach is also found to be effective for use in a noisy environment. In this study, with reasonable noise included, no error in calculating the stiffness and mass is greater than 7.5% of the true value.