Condition-based decision using traffic-light concept applied to civil engineering buildings

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Abstract

Analyzing the integrity of a structure and implementing a process to estimate the level of damage in real time increase the safety of people and goods and reduce economic losses associated with the production interruption or operation of the structure. The appearance of damage to a building changes its dynamic response (frequency, damping and/or modal shape) and, therefore, one of the most effective methods for continuous assessment of integrity is based on the use of ambient vibrations. However, if the resonance frequency can be used as indicator of changes, a misinterpretation can be due to the fact that frequency is not only affected by the occurrence of damage, but also by certain operating conditions and especially certain atmospheric conditions. In this study, after analyzing the correlation of the resonance frequency values with temperature for one building, we used the data mining method called "association rule learning" (ARL) to predict the future frequency depending on the measured temperature. We then propose an interpretation strategy of anomalies using the method called "traffic-light".

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1. Introduction

The management of risks associated with potential hazardous activities in society remains a matter of profound public and technical interests. Among high-risk situations, deterioration of structures and infrastructures is critical. All the mechanical systems are inevitably subjected to deterioration [1]. Owners of civil engineering structures or infrastructures want to detect and track this deterioration at the earliest possible time [2] for safety reasons to users,

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but also for disruption of services [3], and finally for setting rational assets management policies, strategies and practices. We can distinguish two types of deterioration: due to aging effects (environmental erosion, operating loads, fatigue etc.) and after extreme events (e.g., fires, earthquakes, tornadoes). Keeping in mind that a structural failure could be catastrophic, not only from an economical and life-safety point of view, but also in terms of social and psychological impact, structural damage detection has become a worldwide research subject from early 2000 [4].

It has been proven that a maintenance program based on monitoring, when properly established and effectively implemented, can significantly reduce the operational and maintenance cost throughout the life-cycle of the system [5]. Moreover, we can increase the life-time, leading to a direct increase of income. The process of determining and tracking structural integrity and assessing the nature of damage in a structure or mechanical systems is often referred to as structural health monitoring [2,6,7,8,9,10]. This process involves the observation over time using periodically spaced measurements, the extraction of damage-sensitive features from these measurements and the statistical analysis of these features to determine the current state of the system. At the first level, the key issue that must be addressed is to determine whether damage has occurred or not in the entire structure. Damage can be defined as changes to the material and/or geometric properties of a system, including changes to the boundary conditions and system connectivity, which adversely affects its current or future performance. According to Worden and Manson [11], methods can be classified in two groups: (1) model-driven methods, where a model of the undamaged structure must be available beforehand, assumed to describe the normal condition and any deviation of the real parameters from the normal behavior indicates that damage is inferred; (2) data-driven methods, which establish statistical-based models using measured data only.

One of the most efficient methods for structural health monitoring, based on concept of pattern recognition and falling in the second group of algorithms, is vibration-based damage detection technique [1,9,12,13]. The premise of this technique is that damage in the structure cause changes in the measured modal parameters (frequency, damping and modal shape), and any modification of the stiffness, mass or energy dissipation characteristics of a system alter its dynamic response [1]. From all this parameters, the frequencies are certainly the most sensitive parameters to structural changes and are directly related to stiffness of the building [1]. However, for civil engineering structures (buildings and bridges), the most challenging problem we are facing is that the measure of the modal frequency, considered as the most cost-effective solution for SHM, is subjected to changes caused not only by damage, but also by environmental and operation condition (traffic, wind, humidity, solar radiation and most important, temperature). Salawu [14] indicated that significant frequency changes alone do not automatically imply the existence of damage, since variations exceeding 5% due to ambient conditions have been measured for both concrete and steel bridges within a single day. This natural wandering of dynamic parameters of real buildings was similarly observed by other authors and temperature seems to be the main parameter that induces changes in structures [15,16,17,18,19], but also wind or heavy rain can lead to considerable variations [15,16].

Therefore, we need to make sure that the natural variations are not misinterpreted as loss of integrity or vice-versa, i.e. the structural damage is not masked by changes due to weather parameters. The objective of this study is to integrate the temperature variation in the process of structural health monitoring in order to improve damage-detection. A real-time warning system based on deviation of the frequency from normal condition will be tested to check its reliability.

2. Data description

In this work, one building was tested (Fig. 1): the Ophite tower (OT) in France. OT is an 18-story dwelling structure built in 1972 and located in Lourdes. Shear walls of reinforced concrete provide the lateral resistance in the two horizontal directions. Its dimensions are 19-m wide, and 24-m long. This building is founded on a rocky site, and we therefore assume a shallow foundation system. This building has a permanent monitoring system, designed with 24 bits acquisition system and at least one accelerometric sensors located at the top of the building. The full description of the acquisition system is given in Mikael et al. [17]. Recordings are continuous, and the frequencies were measured hourly for 47 months, from 3 January 2011 until 3 December 2014 using the data at the building top. Mikael et al. [17] used the Random Decrement Technique [20] to assess the resonance frequency of the building, i.e. a method applied to extract an accurate value of resonance frequency each hour. The detail of this method applied to real data is given in Mikael et al. [17], Nasser et al. [21] and Roux et al. [22]. For temperature measurement, a sensor located at the top of Ophite Tower was used.
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