Dynamic characteristics and model updating of damaged slab from ambient vibration measurements

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Ambient vibration testing (AVT) is an output-only dynamic test where the structure is excited by natural or environmental excitations such as traffics and winds. These excitation forces are not measured, thus an experimental modal analysis procedure for AVT will need to base itself on output only response measurement data. The modal analysis involving output-only measurements present a challenge that requires the use of special modal identification technique, which can deal with very small amplitudes of ambient vibration that are usually contaminated by noise. The AVT is also known as Natural Input Modal Analysis (NIMA), Operational Modal Analysis (OMA) or Output-Only Modal Analysis. In civil engineering applications the excitation force is often assumed to be stochastic in nature, such as excitations by wind, traffic, earthquakes, waves or human movements [1]. The ambient vibration tests describe the linear behavior of structure, since the amplitudes of vibration is small. They can be used to describe the linear behavior of damaged structures and of their components, and can help on developing time and amplitude dependent structural models and analysis algorithms, to be used in structural health monitoring and in structural control studies [2]. Therefore the development of experimental methods for in situ measurement of full-scale partially damaged structure is of considerable interest. An advantage of the ambient vibration over the forced vibration surveys is that usually only light equipment and smaller number of operators are required. The sources of excitation are wind, micro tremors, microseisms, and various local random and periodic sources. Ivanovic et al. [2] stated that the dynamic testing method of full scale structure was first reported regularly around the 1970s and has become more prolific in recent years. Various civil engineering structures were tested and studied using ambient vibration testing such as buildings [3,4], dams [1] and bridges [5]. A complete process on the dynamic testing on a bridge revealed by Zivanovic et al. [6] stated four important key phases in the updating process of a civil engineering structure; initial FE modelling, modal testing, manual model tuning and automatic updating conducted using dedicated software.

The objective of this investigation is to verify the feasibility of using operational modal analysis to acquire the modal parameters of a damage structural element in a building for purpose of condition assessment. By comparing the modal parameters from the undamaged and damaged structural elements, the percentage of severity can be calculated. In the past, there have been very few studies on the use of modal analysis for condition and damage assessment on full scale civil engineering structures and the outcome of this investigation will further enhance the awareness and understanding of this non-conventional approach in non-destructive structural testing. Several comparative studies were made on the results from experimental works. The results from this study is anticipated to further investigation of other types of civil structures that is exposed to natural disaster mainly for the interest of professionals and researchers involved with design of civil engineering structures.

Test structure

The structure considered in this investigation comprised of a three storey reinforced concrete frame building which housed the administrative offices and library of one of the faculties in the main campus of University of Malaya. The building was built in 1999 and located at the toe of a hill. Due to abnormal heavy rainfall in October 2008, a slip failure of the soil on the slope occurred triggering a landslide and burying some parts of the ground and first floor at the rear of the building. Fig. 1 shows the landslide area while clearing works was in progress. The impact on the structural frame resulting from the movement of soil during the landslide caused severe damage on the perimeter beams. In addition the massive amount of soil into the building resulted in excessive loading on the first floor causing some parts of the floor slab to crack. However, the main columns, beams and slab of the second floor remain unaffected and intact. The total amount of soil removed from the site during the clearing work amounted to about 16,000 m^3. Consequently the building was vacated and rendered unsafe to occupy until full structural investigation was carried out and repair work on the building completed. Fig. 2 illustrates the condition of the perimeter beams and slab of the affected floor while Fig. 3 shows the overall extent of damage to the affected building.

The severely damaged zone was confined to two bays of the first floor slab measuring approximately 7.6 m by 15.4 m. The slabs with a thickness of 150 mm were supported on three internal primary beams and four perimeter beams measuring 460 mm by 300 mm deep and 150 mm by 600 mm deep respectively. In addition two secondary beams having cross sectional dimensions of 300 mm by 300 mm deep, spanning between the internal primary beams and perimeter beams were provided. The structural configuration and detailing for the undamaged slab on the second floor were identical. The load was transferred to the foundation via six main columns measuring 600 mm by 600 mm as shown in Fig. 4. The external walls were unreinforced masonry while dry board panels made up the internal partitioning.

Ambient vibration testing

The ambient vibration test (AVT) was conducted upon completion of the clearing works, visual inspection and in situ testing to ascertain the structural integrity of the building. The damage zone at each floor level was subdivided into 5 by 12 rectangular grids and the response measurements obtained from 78 test points as shown in Fig. 5. The time signals were recorded using a 24 bit PCbased data acquisition system on recorder mode with 40 kHz bandwidth and maximum sampling frequency of 102.4 kS/s. It is equipped with 24 dynamic input channels with 4 DSP’s for gap free recording. Single axis force feedback accelerometer capable of measuring static acceleration or low-level, low-frequency vibration were used in this investigation. The accelerometer has a frequency response of 0–500 Hz, sensitivity of 1200 mV/g and measuring range of ±3 g with 1.3 lg resolution. The data recorder and accelerometer are shown in Fig. 6.

Time signal records for all the 78 test points were acquired using seven accelerometers. In order to cover all the test points, 19 measurement setups were configured with the data acquisition parameters as shown in Table 1.

Fig. 1. Landslide area and clearing works in progress.

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