FRF-based modal testing of sway modes using OCXO synchronised accelerometers for simultaneous force and response measurements

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ABSTRACT

High-rise buildings dominate skylines of many cities in the world which decided to go 'up' rather than 'out' to cope with transportation and other challenges facing their growing population. Vibration serviceability due to wind-induced lateral sway has become de-facto governing design criterion for high-rise buildings above 50m dictating the size, shape and therefore cost of such structures. Damping ratios and natural frequencies of key modes of vibration that can be excited by wind are key modal parameters which are used in design to size the structre and predict wind-induced sway vibrations of tall buildings in service.

However, recent practice is showing that damping and natural frequencies of tall buildings are also quite unreliable parameters to assume in design. Underestimation of the fundamental natural frequency of up to 50% by the finite element model (FEM) relative to its experimental counterpart is comon. The situation with damping ratios is simlar or worse due to uncertainties in the values of modal damping ratios measured in as-built buildings. Natural frequencies and damping ratios in as-built tall building structures are fundamentally non-linear and amplitude-dependent. Therefore, output-only ambient vibration testing (AVT) or ambient vibration survey (AVS) methods for their estimation based only on measured responses to unmeasured ambient excitation which vary with time are naturally producing estimates of modal parameters which vary from one block of data to another.

An input-output modal testing (MT) or experimental modal analysis (EMA) where both the excitation force and the correspodning dynamic response are measured with the aim of experimentally estimating structure's frequency response function (FRF) is a much more powerful tool to deal with structural non-linearities and unceratin modal parameters such as the natural frequency and damping. For many decades EMA has traditionally dominated aerospace and automotive sectors whereas AVT has been very much used in experimental dynamic testing of large civil engineering structures. This despite the fact that AVT has in principle inferior performance as to its quality of modal parameters relative to EMA.

The key reason for this situation are practical difficulties in exciting a tall building with a measurable force causing measurable response without damaging the building at the point of excitation. If this problem is overcome the next logistical complication is measuring such responses *simultanously* throughout the building needed to estimate experimentally mode shapes to complete the set of four modal properties: natural frequencies, modal damping ratios, modal masses and mode shapes. Hence, MT based on FRFs in tall buildings practically do not exist in literature.

This paper describes novel FRF-based MT of sway modes of a large 15-tonne laboratory structure using a set of synchronised electrodynamic shakers and OCXO high-precision synchronised wireless accelerometers for simultaneous force and response measurements. This MT system makes no use of cables or radio-waves to connect response accelerometers simultanously with the multi-channel data acuistion system and provides perfect synchronous measurement of practically unlimited number of force and response channels. The system will be used to estimate sway modes via FRF-based MT of as-built tall timber buildings in 2020.