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Dependency of wind excitation of tall timber buildings to structural damping

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SUMMARY:
Saving space in cities as well as reducing the carbon footprint of modern constructions advocate for the erection of more timber towers in the future. But such buildings are lighter than the usual concrete ones and their shear stiffness, to resist wind action is lower, what results in more concerns with the effect of strong wind on occupants' comfort. The horizontal acceleration of floors that people can feel is dependent on the structural damping of the bending and torsion modes, which is poorly known for timber structures. Some tall timber towers already built seem to pioneer building industry and engineering. An experimental campaign on two tall composite towers, with timber walls and floors and a concrete core, was achieved recently with the aim to characterize material properties and structural damping of the built structure. Assumptions made by the designers can be compared with real values measured on site, what it of great value to initiate design guidelines for this type of structures. Special precautions should be taken to carry out tests and process recorded data, as timber structures are lighter and less damped than other ones.

Keywords: Wind, timber, shaker, structural damping, shutdown test

1. INTRODUCTION TO IN-SITU TESTS

The verticalization of housing is one of the answers to the problem of the densification of cities with a view to saving materials and reducing carbon emissions. The use of timber materials for all or part of the structural elements is therefore a natural choice in this context, offering light structures. Beyond resistance criteria, service comfort criteria (limitation of deformations, vibrations, etc.) must be respected, which is a significant challenge for lightweight constructions intended for housing, since the criteria resulting from the structure's response to climatic constraints are more severe than for office use. Lighter means more excitable: the structural damping of building materials can make a difference but there are still many unknowns that complicate the task of designers.

As part of the European research project Dyna-TTB the dynamic behaviour of high-rise timber towers under the effect of wind has been studied. The objectives are as follows:

- To experimentally quantify the structural damping in as built high-rise timber buildings.
- To make FEM models more reliable (behaviour law of connections, effect of non-structural elements on stiff-ness, damping and the wind-induced dynamic response)
- To establish a guide of recommendations for in-situ tests and digital modelling of tall timber buildings.

Characterization of the dynamic behaviour of timber towers under imposed loads (heavy mechanical exciters) was carried out. In France, the Hyperion (16 floors, 56m high) and Treed It (11 floors, 36m high) towers were instrumented and tested at various stages of construction, before and after the installation of the inside partitions.

Figure 1. A view of Hyperion building at the time of testing and the shaker on top of the building, ready to operate

Shaking tests have been performed in 12/2019 and 07/2020 with a machine consisting of an electric motor with gears and flywheel, pushing and pulling its own mass of 550kg guided by casters and rails. The movement of the mass is close to sinusoidal, at a frequency given by the electronics driving the motor and with an amplitude that can be tuned to 150mm or 240mm. The sinusoidal force applied to the building by inertial effect depends on the mass, the stroke and the frequency squared and can reach 10 000N.

Horizontal acceleration of building’s floor was measured by very sensitive force balance accelerometers, located by groups of 3 at 3 different levels. They measure in two orthogonal horizontal directions corresponding to the main axis of the buildings. At each instrumented level of the building, two of these sensors are located at both ends of the storey in the same direction, to detect torsion modes. They are all wired to a central system recording at a frequency of 100Hz. First bending and torsion modes of both buildings are in the range 0-2Hz, which is compatible with the capacity of this heavy shaker. It was checked before achieving shaking that the applied force will not lead to local deformations larger than some micrometres and stays in the same range of magnitude as live loads. A finite element model was done for this purpose and this preliminary modelling was presented to each building owner to obtain his approval.

2. FOUR KINDS OF TESTS

Four different kinds of tests have been achieved, each having a particular purpose :

- The measurement of vibrations under **ambient excitation**, by turbulent wind, nearby traffic or works inside the building, gives way to long lasting records (10 to 60 minutes) with the aim to identify modal frequencies. This kind of record, with a low level random excitation, is well adapted to using classical spectral analysis, with summation of many FFT's giving way to a reduction of uncorrelated events, considered as noise. It provides a good insight of modal frequencies.

- An artificial excitation by a mass shaker delivering a horizontal sinusoidal force, with a continuous and slow variation of the frequency of which, called **swept sine** test. Because input force is controlled, the dynamic response of the building, i.e. accelerations measured at various locations, shows the frequencies of increased amplitude, pointing out the modal frequencies. Both spectral analysis and time domain analysis can be used, depending on the duration of records. With a heavy shaker input force is such that the amplitude of noise becomes negligible.
- An artificial excitation by a shaker delivering a continuous horizontal sinusoidal force at a fixed frequency. This **constant excitation** test must be brief to avoid beating, due to the unavoidable small difference between the frequency of the applied force and the modal frequency of the building which is excited. It was lasting 60s in this series of tests limiting data processing to time domain approach only, because the frequency step from FFT is only 0.017Hz, not accurate enough.
- An interrupted excitation by the shaker, called a **shutdown test**, is used to measure modal damping. The initial excitation frequency is the one of a selected mode, then amplitude decreasing after the excitation has been stopped gives a good approach of modal damping. Difficulties arise when there are two modes with close frequencies.

3. ADAPTED METHODS FOR THE MEASUREMENT OF STRUCTURAL DAMPING

Various methods are available for the measurement of structural damping, they have been evaluated with respect of the different kinds of records.

With the ambient excitation records, sub space identification methods can be used but they provide poor precision evaluation of the structural damping. Contrarily, with swept sine excitation the classical spectral analysis with the measurement of the "quality factor" gives good results.

The same evaluation by the quality factor at -3dB issued from power spectrum of the measured acceleration was tested with various techniques on the 60s records of shutdown tests.

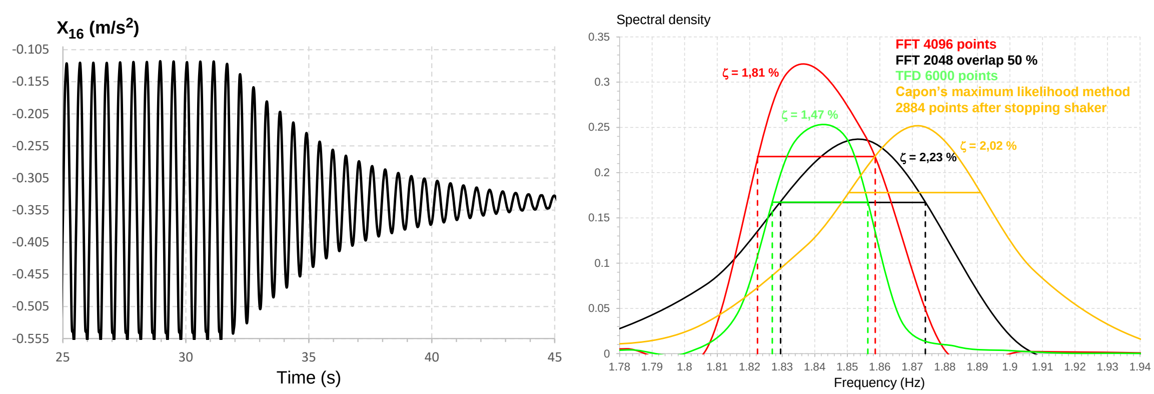

Figure 2. Example of shutdown test record for mode 3 and the evaluations of damping.

In this case the simple FFT without overlapping gave the best results. Because these shutdown tests records are short, a time-count method of successive maximum values of the oscillation has been tested and gave very stable results when tests have been repeated several times.

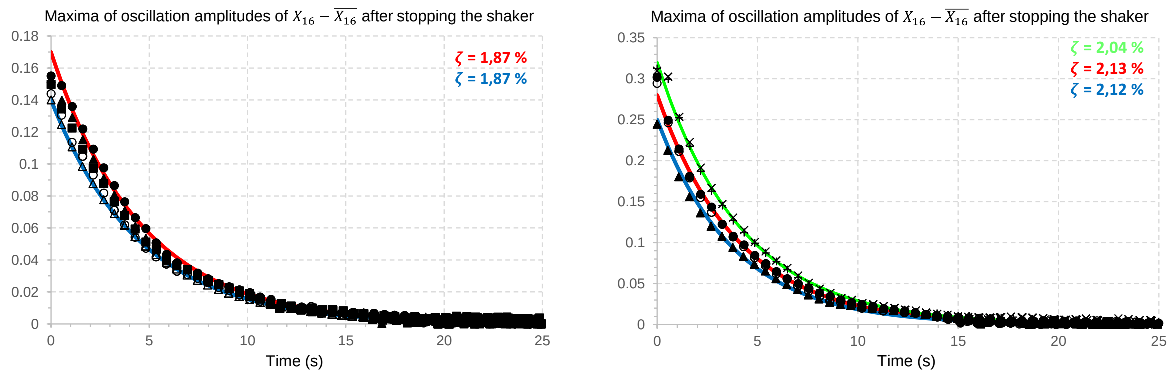

Figure 3. Examples of damping evaluation from repeated shutdown test records for mode 3 with shaker located in the south corner of the building and with small amplitude (left) and on the east side with large amplitude (right)

Analysing the variation of structural damping and modal frequency with amplitude showed an increase of damping with amplitude on bending modes, but for the torsion mode (mode 2) on the Hyperion tower the behaviour is different with a structural damping constant above a threshold. But below this threshold structural damping is very low, indicating a stick-slip mechanism.

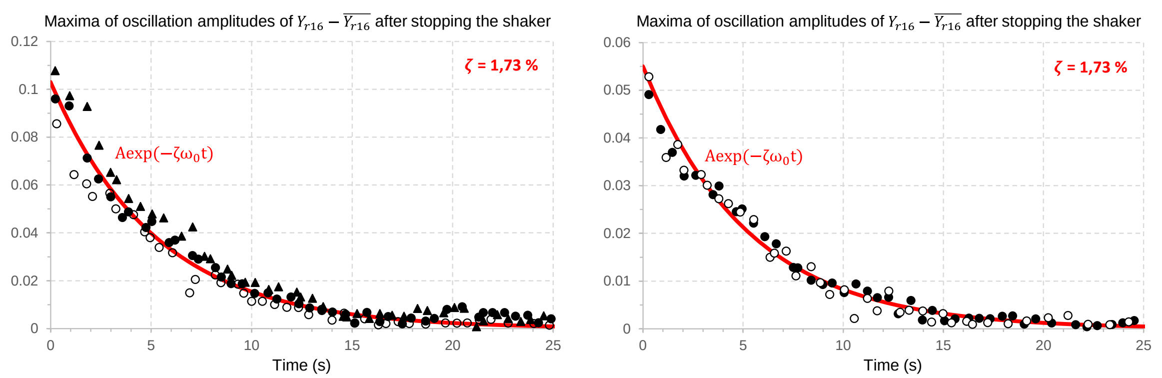

Figure 4. Examples of damping evaluation from repeated shutdown test records for mode 2 with shaker located in the south-east corner of the building and with small amplitude (left) and large amplitude (right)

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