Experimental investigations of a walnut tree multimodal dynamics

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Abstract

Experimental data on the frequencies of a walnut tree are presented. These are derived from several kinds of tests using protocols that are commonly used in vibration analysis: pull and release test, hammer impact tests and wind excitation test. The results from these experiments are then used to validate an analytical approach based on the allometry of the tree. This is made possible by a detailed digitization of the tree geometry.

1. Introduction

Over the last decades, time-dependent dynamic effects have been found to play a major part in wind deformations of trees and windbreaks. However, the dynamic interactions between wind and trees are complex issues (Niklas, 1992). Wind velocity has a large spectrum of eddy size and frequency, as well as mean vertical profiles (de Langre, 2008). Most trees also have a branched architecture with different modes of branching (monopodial vs. sympodial) depending on species, up to 11 orders of axes, and reiterated patterns of various sizes and positions (Barthelemy and Caraglio, 2007). A first approach is to tackle this complexity is to focus first on the oscillatory elastic behaviour of the structure (for examples in trees, see Sellier et al., 2006; Moore and Maguire, 2008). A few authors have used modal analysis on trees (e.g., Fournier et al., 1993; Sellier et al., 2006; Moore and Maguire, 2008). All have concluded that modes involving significant branch deformation could rank in-between modes deforming mainly the trunk (Fournier et al., 1993; Sellier et al., 2006). Experiments from Moore and Maguire (2005) and Sellier and Fourcaud (2005) confirmed the excitation of several modes in a conifer trees under wind load, with again some of the modes having their deformation mainly located on branches. Although not using modal analysis, James et al. (2006) also showed that the measured frequency spectra of the responses under wind excitation of four trees with different architectures, including conifers, two eucalyptus and a palm tree, were also significantly dependent on the branching system. Moreover, James et al. (2006) and Spatz et al. (2007) argued that such multimodal dynamics including branch deformation could be beneficial to the tree by enhancing aerodynamic dissipation through a mechanism called multiple resonance damping or multiple mass damping.

In a recent paper, Rodriguez et al. (2008) showed that there exist a relation between the architecture of a tree and its modal organization. More specifically, the ratio between frequencies of flexural modes was directly related to the length/diameter allometry and to the ratio between diameters below and above branching. In their paper, this was validated on frequencies computed from the digitized geometry. Here, we aim at comparing with measured frequencies.

2. Experiments

An experimental investigation of a walnut tree (Juglans regia L.) dynamics has been conducted. The investigated walnut tree is an isolated tree. It is 4.2m high and has a 7.7cm diameter at 1.3m high. It also has up to eight orders of branching. Preliminarily to the experiment on the tree dynamics, the geometry of the tree (positions, orientations, diameters of the stem segments, and the topology of branching points) was recorded in great details through 3D magnetic digitizing. During the experiment, an electromagnetic system (3Space Fastrak; Polhemus Inc., Colchester,VT, USA) has been used to record the tree dynamics. It consists in creating a magnetic field, around the tree, in which the 3D positions of magnetic sensors can be tracked. Four sensors were positioned on four successive segments of branches of the tree, starting from the trunk. During experiments, sensors were tracked at 30Hz with 1mm spatial resolution. A sonic anemometer was also installed a few meters from the tree to record the wind velocity. For wind excitation, the spectra from both wind velocity and sensors' signals were computed.

Fig. 1: Walnut tree. Left : general features. Right : digitized geometry. The dots show the position of displacement sensors.

Two types of excitation protocols were applied to experimentally investigate the dynamical characteristics of the walnut tree: i) localized controlled excitations and ii) distributed and wide spectrum excitation through natural wind. Localized excitations were obtained through impacts with pull-release tests with a rope and hammer impact. They were applied to four positions corresponding to each segment bearing a sensor, in two orthogonal directions. Spectral analysis was applied to analyze the response of the walnut to these excitations. Fig 2, 3 and 4 shows typical responses that were measured. The spectra show that frequencies of modes could be well defined.

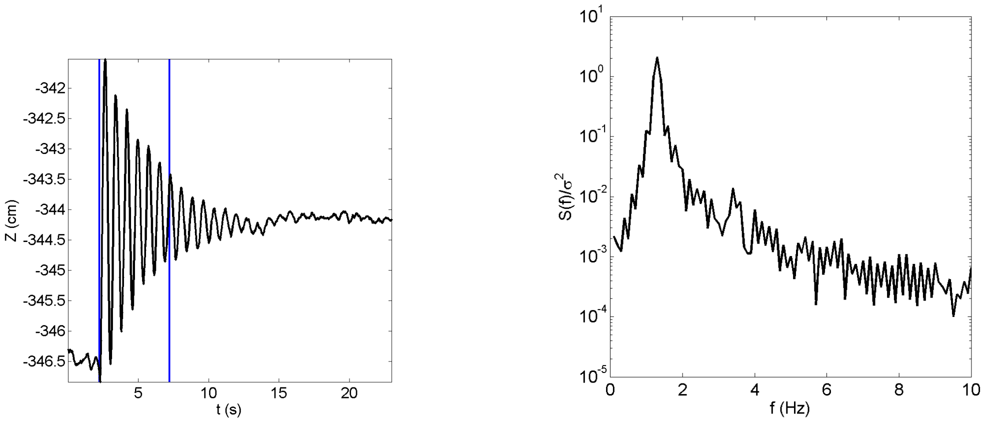

Fig. 2: Pull and release test. Typical results. Left : displacement as a function of time. Right : corresponding spectrum.

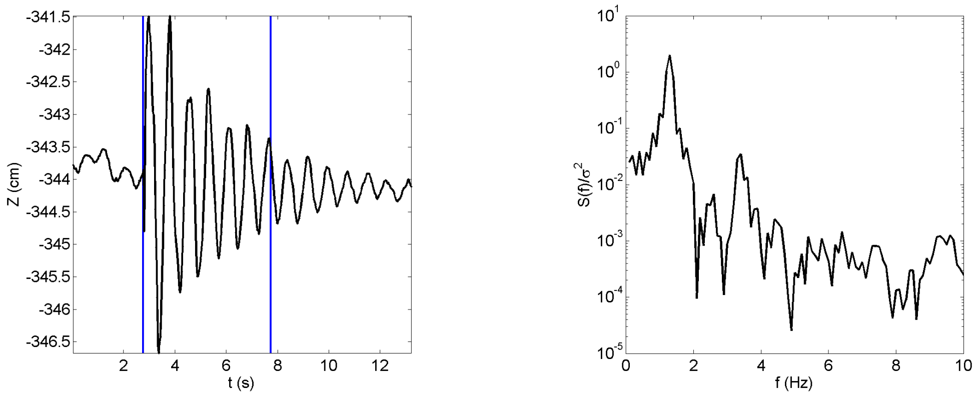

Fig. 3: Hammer impact test. Typical results. Left : displacement as a function of time. Right : corresponding spectrum.

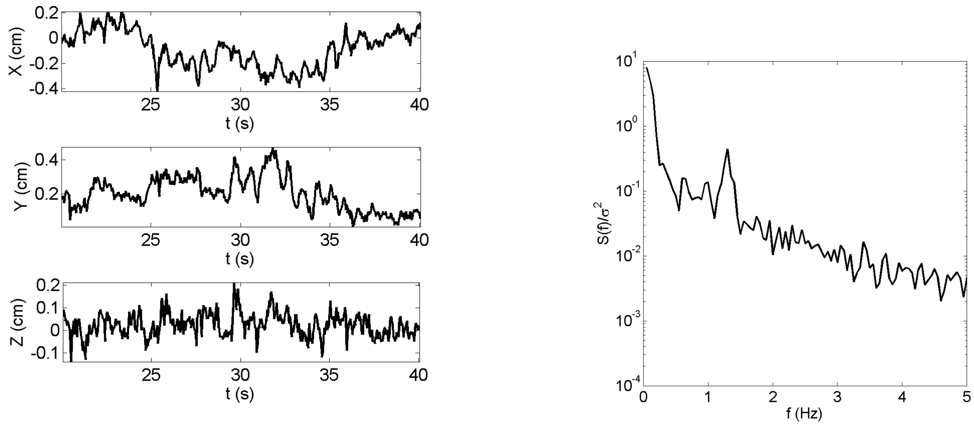

Fig. 4: Response under wind excitation. Left: displacements as a function of time. Right: corresponding spectrum.

3. Comparison with scaling laws

Using data from digitization the relation between length and diameters of segments could be analyzed. Fig 5 shows that a relation $D \approx L^{\beta}$ with $\beta \approx 0.8$ could be inferred.

Similarly the parameter that relates diameters before and after branching is deduced from digitized data, giving $\lambda \approx 0.3$. These two parameters allow deriving the ratio between frequencies, following the results given in Rodriguez et al. (2008). This is also shown in Fig. 5, in comparison with measured frequencies.

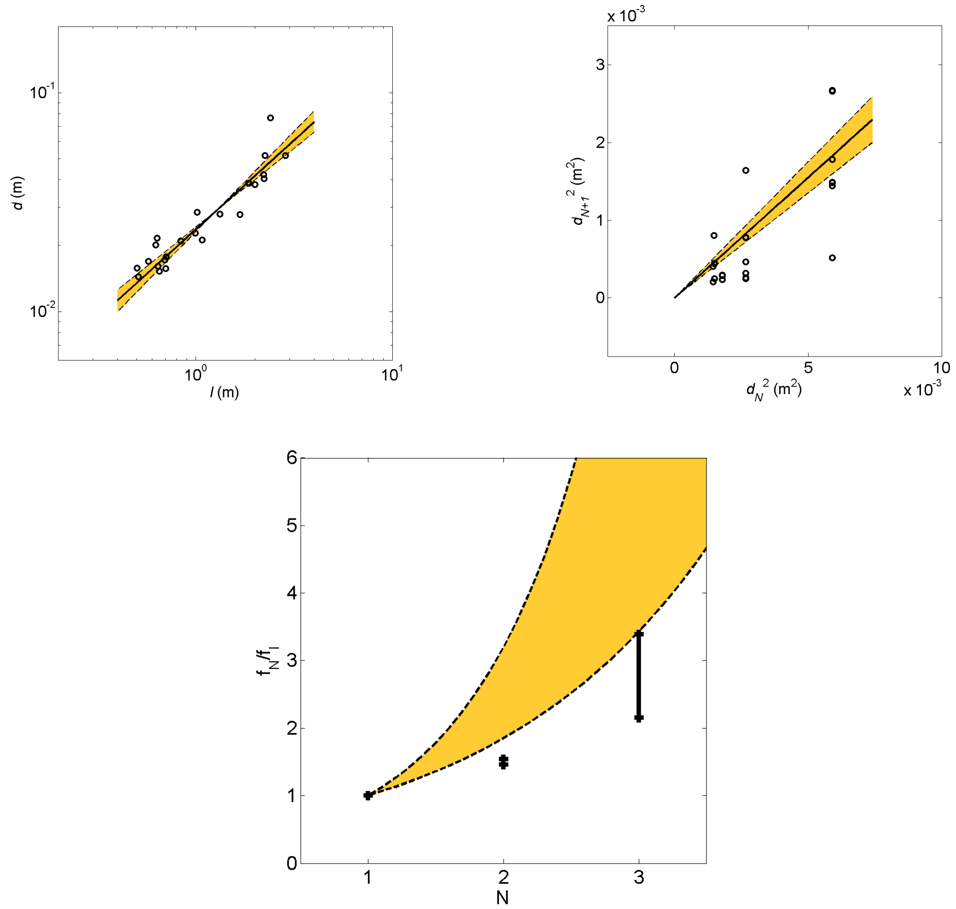

Fig. 5: Comparison between measured frequencies and prediction derived from the allometry of the tree. Top left: Length/diameter allometry. Top right: relation between diameters of successive segments. Bottom: measured frequencies and the range predicted from the data above. The shaded zone shows the 90% confidence intervals .

5. Conclusions

All these results show that it is possible to infer the organization of modes in a given tree from data derived statistically from its geometry. Other results (not presented here for the sake of brevity) show that frequencies computed by finite elements, lead to very similar values. Moreover, detailed results show that the simultaneous use of pull and release tests, hammer impact tests and wind motion test give consistent results.

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