Project and construction of a didactic wind tunnel for the vibration analysis of buildings experimental models

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Abstract. The usual practise in design of structures assumes that wind effects are represented by static loads. However, the wind presents a dynamic nature, and its effects on buildings can lead to problems associated with excessive vibrations. Therefore, it is important for Civil Engineering students to be able to investigate and understand the dynamic phenomena of structures. To facilitate the teaching of these concepts, this research work presents a practical methodology supported by the construction of a wind tunnel in order to simulate the dynamic actions of the wind on representative building models. These models are exposed to the wind and the dynamic response is filmed using a smartphone, and then analysed using appropriate computer programmes for image processing. Thus, it is possible to evaluate the dynamic structural response of the models (displacements and accelerations), in the time domain. It is worth noting that, despite the experimental tests showing larger total displacements in the wind direction, the floating part of the displacement is larger in the transverse direction, which is due to the occurrence of wind vortices. In conclusion, the authors believe that the development of this teaching methodology will support both, undergraduate and graduate Civil Engineering students, to better understand tall buildings dynamic behaviour when subject to wind actions.

Keywords: engineering education, dynamic analysis of buildings, wind tunnel.

1 Introduction

The usual practice in design of structures assumes that the wind actions are represented by static loads. However, this phenomenon presents a dynamic nature, and its effects on tall buildings can lead to relevant problems related to excessive vibrations. In such situations, it is important to carry out more accurate and refined checks, taking into account the dynamic properties of the structures, as well as the wind (Bastos [1]; Bastos [2]).

On that perspective, with the increasing tendency to build taller and slender structures, it is crucial that Civil Engineering students, even those who are still in the graduation phase, be able to study and better understand the dynamic phenomena of structures by acquiring the necessary physical and mathematical concepts, keeping in mind the importance of a perfect understanding of theoretical concepts.

In order to facilitate the concepts teaching related to structural analysis, this paper presents a practical methodology, developed within the Graduate Programme in Civil Engineering (PGECIV) at the Faculty of Engineering (FEN) at Rio de Janeiro State University (UERJ). The presented methodology envisages the construction of a small wind tunnel, for educational purposes, where the dynamic actions of the wind on reduced building models can be simulated. The proposed wind tunnel is inexpensive and easy to build.

This way, the investigated structural models made by the students in a reduced scale are exposed to the wind action in the tunnel, and the dynamic responses are filmed with a video camera or a smartphone, and then analysed with appropriate computer programs for image processing. Thus, it is possible to evaluate the types of vibrations, displacements and accelerations during the whole period to which the models are exposed (Ewins [4]). In particular, it can be clearly observed that, despite the experimental tests showing larger total displacements in the wind direction, the floating part of the displacement is larger in the transverse direction, which is due to the occurrence of wind vortices (Holmes [5]). It is expected that this teaching methodology can support both undergraduate and graduate Civil Engineering students to better understand the dynamic structural behaviour of tall buildings under wind actions.

2 Wind tunnel construction

A wind tunnel is a device whose function is to simulate, for purposes of study, the effects of air currents and their motions around solid objects located within it. Basically, it consists of a channel of appropriate diameter (tunnel) in which the air flows around the tested object (building model).

The wind tunnel proposed in this study (Figure 1) was built over an MDF base (Medium Density Fibreboard) with a thickness of 15 mm and side walls and a ceiling made of 5 mm thick transparent crystal acrylic. It has a constant cross-section with a width and height of 50 cm each and a length of 200 cm. At one end there is an exhaust fan with a diameter of 50 cm and a power of 750 W, which generates an air flow of 6800 l/minute, inducing winds in the tunnel with speed of up to 7.5 m/s². At the other end of the tunnel, a hive grille made of PVC pipes with a diameter of 40 mm is placed to standardize the airflow at the entrance (Figure 2). The proposed model, which can be easily made by the students themselves, was built on a flat surface using squares and a spirit level to ensure accuracy, and its parts were assembled using superglue and hot glue.

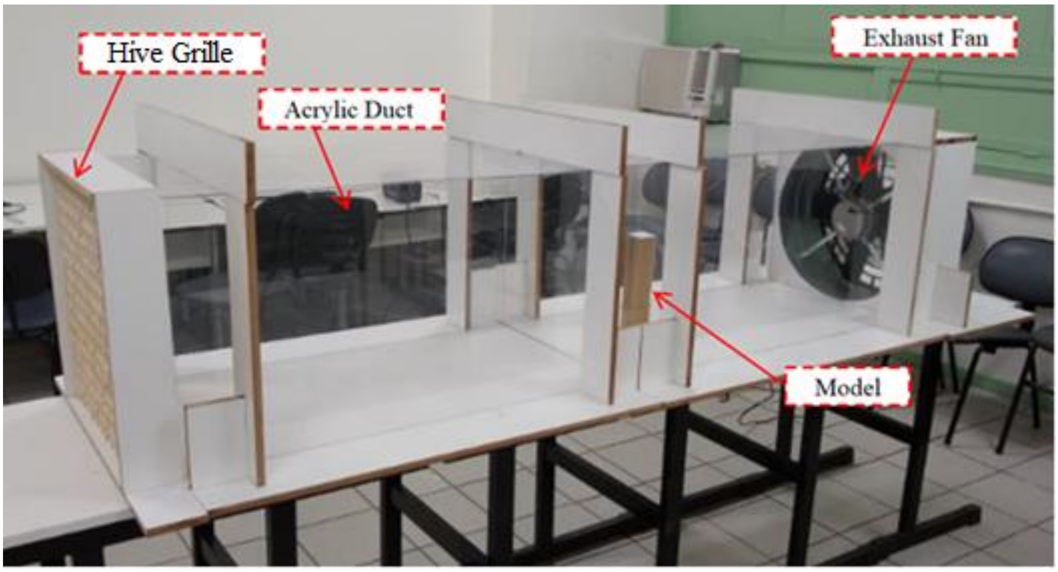
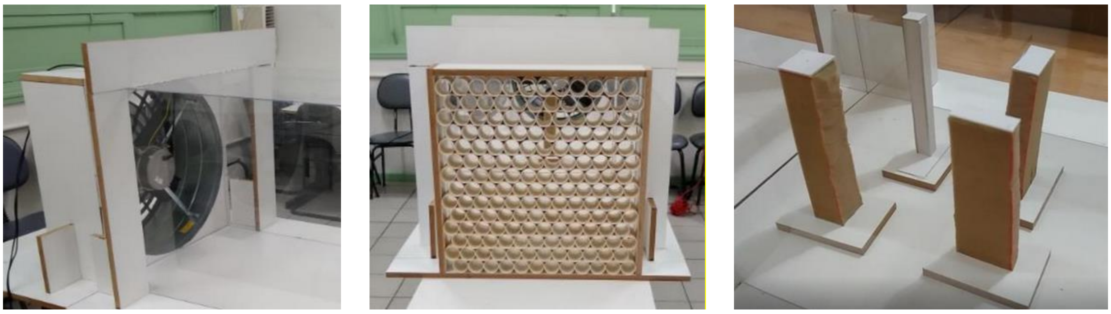


Figure 1. Wind tunnel built for the experimental tests

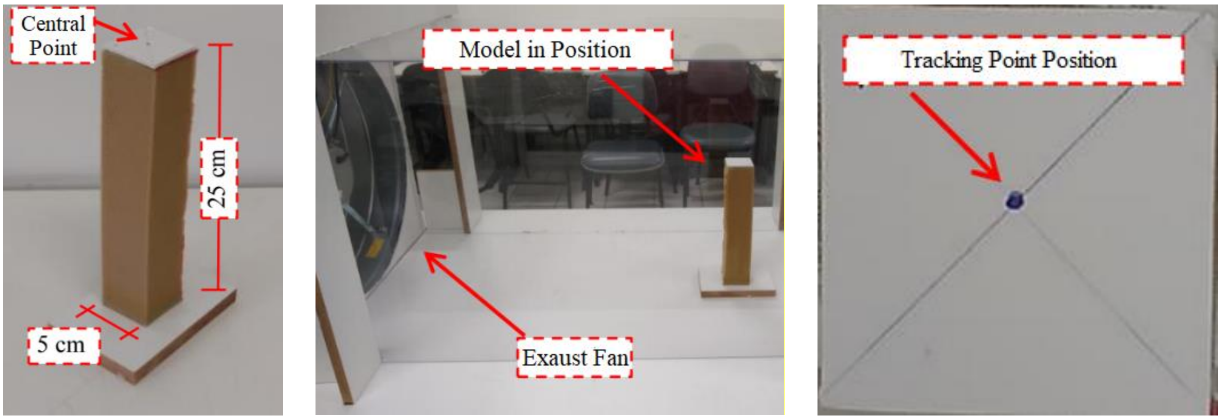


a) Exhaust Fan b) Hive Grille c) Building Models

Figure 2. Wind tunnel details

3 Experimental monitoring

The models can be built from a variety of materials, the most common being: Styrofoam, wood, MDF, and others. This paper presents the results obtained by experimental monitoring of a reduced building model made of High Density Foam (Figure 3). The model under study has a square cross-section with a side length of 5cm and a height of 25 cm, i.e. it has a ratio of 1:1:5 (width x depth x height). A PVC plate is placed on the top of the model and a small point is marked in the middle with a pen, so that the camera can record the movements of the model during the video.



a) Model 1:1:5 b) Model placed inside the tunnel c) Tracking point

Figure 3. Representative building models made with high density foam

After placing the model in a convenient location in the centre of the tunnel, the experiment begins by turning on the exhaust fan, which creates the wind that flows toward the structure. A video camera mounted on the tunnel ceiling just above the model, focuses on the previously marked point. In this particular experiment, a smartphone camera was used, filming at a rate of 60 frames per second.

The model is left to swing freely in the wind for a period of 90 seconds. The video file is recorded in digital format and transferred to a computer. The image processing is done with the software TRACKER (Brown [3]), which produces tables and graphs of the displacement of the point during the period of the experiment.

The software TRACKER (Brown [3]) is a free video analysis tool developed using the Java Open Source Physics (OSP) framework. It is intended for use in physics education. Among its capabilities, the rapid generation of graphs from data obtained by video tracking of the object under study stands out.

Before starting the analysis, a scale calibration is required to define the origin of the Cartesian axis. The tracking of the model's position throughout the video is automatically performed by the software TRACKER (Brown [3]) (Figure 4), which searches the position frame by frame and records its coordinates in a table.

At the end of the tracking, a table of Cartesian coordinates (x and y), frame by frame, is generated and provided to the user. Since in this test the images were taken at a rate of 60 frames per second, the interval between measurements is 0.016 seconds, which provides a high degree of accuracy. The data table is then exported to the software EXCEL for further data processing of the results.

One way to measure the wind speed inside the tunnel is by using a hot wire anemometer. In this work we used the Thermal Anemometer model 405i, manufactured by Testo. It has a resolution of 0.1 m/s and detects velocities up to 30 m/s (Figure 5). Its antenna can be adjusted in length to allow measurement at different heights. The wind speed is recorded and transmitted directly to a smartphone application via Bluetooth and the signal obtained can be exported to the computer.

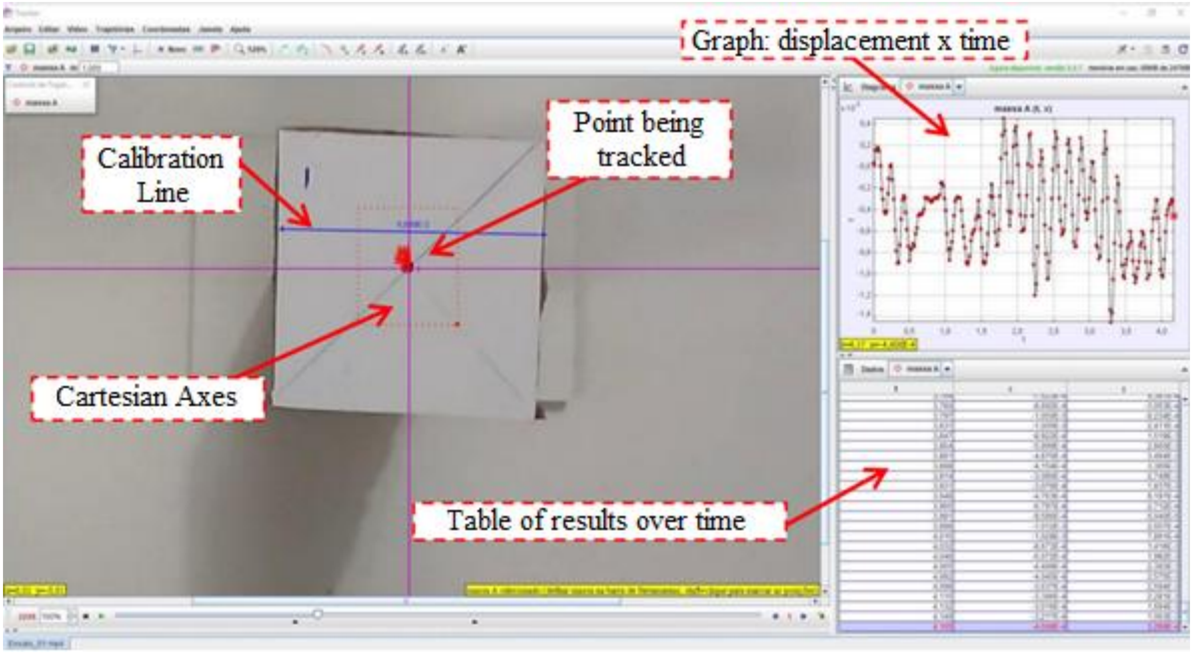
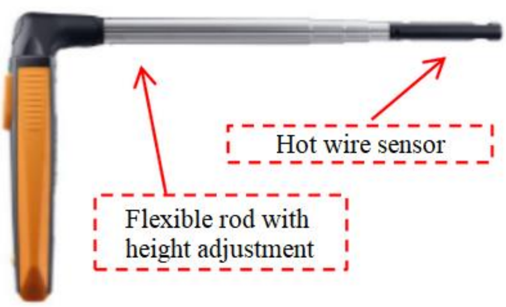


Figure 4. TRACKER software performing the tracking of the selected section for further analysis



a) Testo 405i thermal anemometer

b) Anemometer placed on the wind tunnel

Figure 5. Hot wire anemometer used in the experiment

4 Results

The experimental test provides displacement and acceleration results in the time domain at the top of the studied model. Figure 6 shows the displacement signal in the longitudinal direction (parallel to the wind flow), considering 90 seconds of the test. From the graph it is possible to observe that the model is at rest at the beginning and after the exhaust fan is turned on, the vibrations of the model caused by the wind start to manifest. It is interesting to note that the model has a permanent displacement of about 7.5 mm in the wind direction. This result is a consequence of the static part of the wind, and around this average displacement there are oscillatory movements caused by the floating part of the wind.

The oscillatory motions in the direction transverse to the wind flow are shown in Figure 7. In this case it is interesting to see that there is no static part of the wind, but only a floating part around the origin. To compare the motions in the two directions, Figure 8 shows the displacements obtained in a 60-second section of the test, so that the students can observe the difference in the behaviour of the model face of the wind action. Although the average displacement is larger in the longitudinal direction, the amplitudes (floating component) are larger in the transverse direction. The magnitude of this difference can be understood by calculating the standard deviation of both signals. In the longitudinal direction, the standard deviation is 0.42 mm, while in the transverse direction it reaches 1.83 mm. Therefore, the standard deviation in the transverse direction is 3.36 times larger than that in the longitudinal direction. This phenomenon can be explained by the occurrence of wind vortices on the sides of the model. Such structural behaviour is relevant and should be emphasized for the students, as it shows that the oscillatory character of the structure is much larger in the transverse direction of the wind flow.

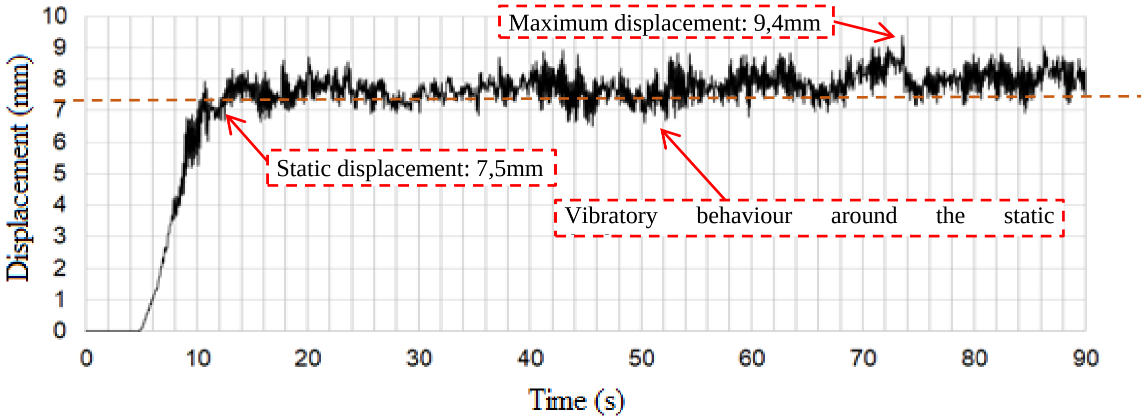


Figure 6. Horizontal translational displacement at the top of the model in the wind direction

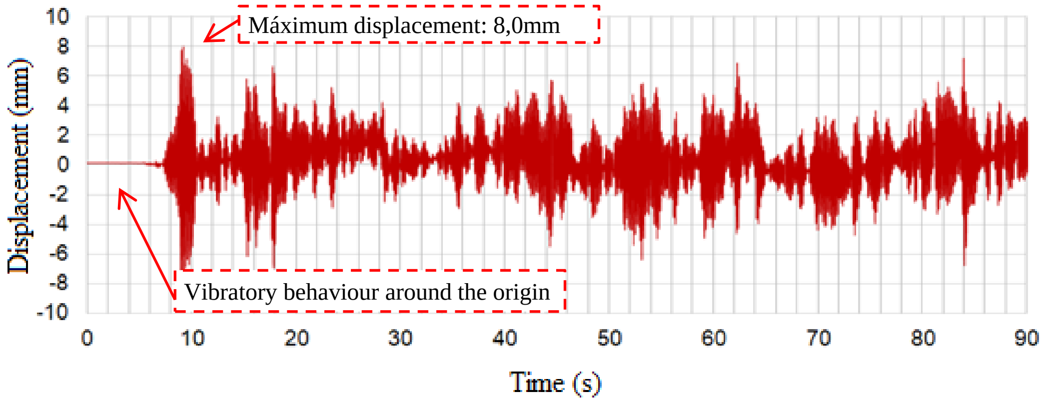


Figure 7. Horizontal translational displacements at the top of the model in the perpendicular direction

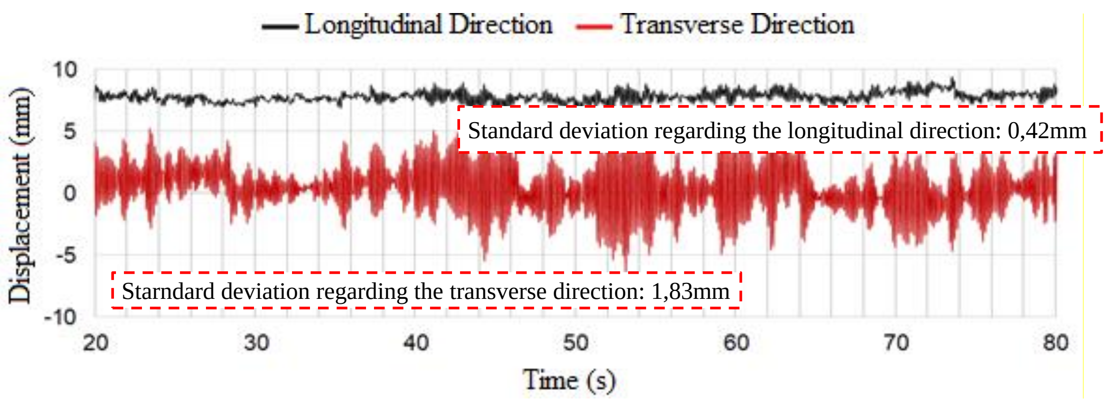


Figure 8. Horizontal translational displacements at the top of the modal in the two directions

To introduce students to the concept of human comfort in tall buildings exposed to wind actions, it is possible to determine the accelerations at the top of the models using displacements data. Figure 9 shows the results of acceleration in both directions. It can be seen that the vibrations in the transverse direction clearly produce the strongest accelerations. The accelerations in the longitudinal direction have a standard deviation of 0.47 m/s², while this value is 2.65 m/s² in the transverse direction, i.e. 5.61 times larger.

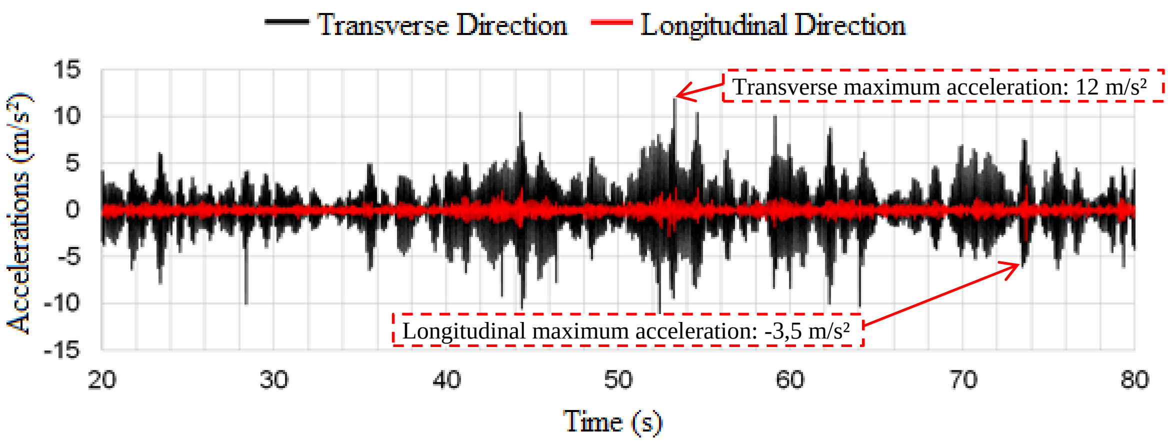


Figure 9. Accelerations at the top of the model in the two directions

5 Conclusions

The teaching methodology developed in this research work aims to facilitate the understanding of tall buildings dynamic analysis, having in mind that the undergraduate and graduate Civil Engineering students could investigate and understand the effects of wind on buildings through experimental tests in wind tunnel.

This way, the investigation of the dynamic structural behaviour of a reduced building model with a ratio of 1:1:5 was presented, which was built by the students themselves in the laboratory from high density foam and subjected to wind effects in the wind tunnel. The study was based on dynamic experimental monitoring through video images using the software TRACKER.

The results show the vibratory character recorded as a function of the wind action. It can be observed that the longitudinal response has lower values compared to the transverse response of the studied model, which shows the complexity of the dynamic behaviour of the system. Thus, engineering students will be able to understand important concepts associated with vibration analysis by obtaining displacements and accelerations in the time domain.

The authors believe that the engineering teaching methodology developed in this study will stimulate the learning of undergraduate and graduate Civil Engineering students with respect to the study of concepts related to the dynamic analysis of structures by combining theoretical knowledge with practical experiments. Considering that the reduced models have similar characteristics and behaviours as real buildings, it is possible to obtain similar qualitative results that will help students to better understand the structural analyses that are relevant to the design of buildings. As a result, future civil engineers will be better able to develop more rational and economical structural projects for society.

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References

[1] L. S. Bastos. Study of structural behavior and human comfort analysis of concrete buildings. MSc dissertation, Rio de Janeiro State University, 2015.
[2] L. S. Bastos. Study of the non-deterministic structural dynamic behavior of buildings subjected to wind action and considering the effect of soil-structure interaction. DSc Thesis, Rio de Janeiro State University, 2019.
[3] D. Brown. *Innovative uses of video analysis.* The Physics Teacher Vol. 47 (145). Doi. 10.1119/1.3081296, 2009.
[4] D. J. Ewins. *Modal Testing: Theory and Practice*. Research Study Press LTD., 1984.
[5] J. D. Holmes. *Wind Loading Of Structures*. Taylor & Francis Group, New York, 2004.