Comparison of the results between a rigid and an aeroelastic model of a tall building in wind tunnel

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SUMMARY
The present work analyses the results of tests performed at the Wind Tunnel of the Politecnico di Milano on a scaled model of a tall building. The model can be converted either into a rigid or an aeroelastic model, to compare these two standard approaches in the analysis of the effects of the incoming turbulent wind. Since the model wants to be a most general case of a tall building, it features complex structural dynamics (mass eccentricity) and complex aerodynamics (buffeting and vortex shedding). A Synchronous Multi-Pressure System (SMPS) was used to measure the pressure in several points of the model in both configurations. The tests were performed for different angles of attack of the wind and different wind velocities. Finally, the comparison of the results in terms of pressure and dynamic response of the models is shown. The modal numerical procedure differs from the direct measurement of the dynamic response of the structure because it does not consider the vortex-induced vibrations and the non-linear behaviour of the mechanical properties of the building.

Keywords: Rigid model, Aeroelastic model, modal approach, Wind tunnel.

1. INTRODUCTION
In recent years, the civil engineering field has been witnessing new challenges related to the use of new materials and technologies which allow building lightweight and flexible structures. Therefore, if up to now seismic events have dominated the design of structures, the wind load has now become important to address structural solutions. Not only repeated and continuous loading by wind can cause fatigue damage, but it can also induce vibrations in tall buildings affecting the comfort of people. Since international standards do not cover fully issues due to wind induced vibrations, tests performed in wind tunnels have got a foothold ever more. These experiments can be carried out in rigid models without any information in their mechanical behavior or in more detailed aeroelastic models which try to mirror their mechanical impedance.

This work compares the results obtained from tests conducted on a rigid and aeroelastic model of a tall building tested at the GVPM (Wind Tunnel of the Politecnico di Milano), to show the main differences and investigate the response of the structure. The well-known rigid model was already presented to the International Association for Wind Engineering in 2007 and the analysis of the results was performed by John D. Holmes and Tim K. T. Tse. The model represents a rectangular building, 30 m wide, 45 m long and 180 m high with a linear mass of 20000 kg/m. As for the dynamic properties, it is characterized by two flexural modes and a torsional one with frequencies between 0.1 Hz and 0.4 Hz.

2. METHODOLOGY

2.1. Models

The aeroelastic model is designed with an aluminum frame with the possibility of switching to the rigid model trough an additional internal constraint. The model is characterized by a length scale (λ_L) of 1:100, resulting in a model of 0.30 m wide, 0.45 m length and 1.80 m height. Secondly, for the aeroelastic model the velocity scale (λ_U) is set of 1:8. The list of similarities and scaling laws used is listed in Table 1.

Table 1. Similarities and scaling laws for aeroelastic tests

Description	Parameter	Value
Length	λ_L	0.01
Speed	λ_U	0.125
Frequency	λ_f	12.5
Mass	λ_M	10^{-6}
Acceleration	λ_a	1.56

The model is equipped by well distributed pressure taps (Synchronous Multi-Pressure System, density ranging from 0.4 taps/100m^2 near the floor and 3 taps/100m^2 near the top) and a set of accelerometers, placed at different locations, to directly measure the dynamic response.

2.2. Wind Tunnel tests

The tests were performed with different wind speeds (U_R) and different angles of attack (α) in order to investigate the dynamic behavior of the building in different conditions. An image of the model during the wind tunnel tests is shown in Figure 1. Furthermore, the signals were filtered through the equivalent moving average filter.

Figure 1. Model in the Wind Tunnel of the Politecnico di Milano

The study was approached with a dual strategy. On the one hand, tests were performed in the rigid model with high wind velocity U_M of 11.5 m/s for more effective response, and different angles of attack ($0° \leq \alpha \leq 90°$), while the structural response was numerically simulated. The calculation was based on the model approach of the first three modes of vibration [3].

On the other hand, tests were carried out in the aeroelastic model with different wind velocities U_M (2.6 m/s, 3.9 m/s, 5.2 m/s and 6.4 m/s) and different angles of attack ($0° \leq \alpha \leq 90°$). The model was equipped with six accelerometers to directly measure the dynamic response of the structure. Furthermore, the smooth flow decay and vortex shedding phenomenon were analyzed.

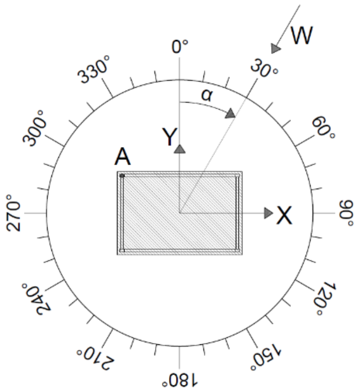

Figure 2. Modal orientation in the Wind Tunnel test section

3. RESULTS AND CONCLUSIONS

The aim of the present research is to investigate the differences in the results between the directly measurement obtained from an aeroelastic model and the modal simulation using results of tests on a rigid and aeroelastic model. The results are expressed in terms of pressure coefficients, base load coefficients and accelerations.

As regarding the pressure coefficients in terms of mean value and standard deviation, the differences between the two models are observed for low wind velocities, while as the test speed increases the response becomes more effective and these coefficients become similar. Figure 3 shows the values of the mean pressure coefficients and the standard deviations at 1.55 m and with a wind angle of attack of 85°.

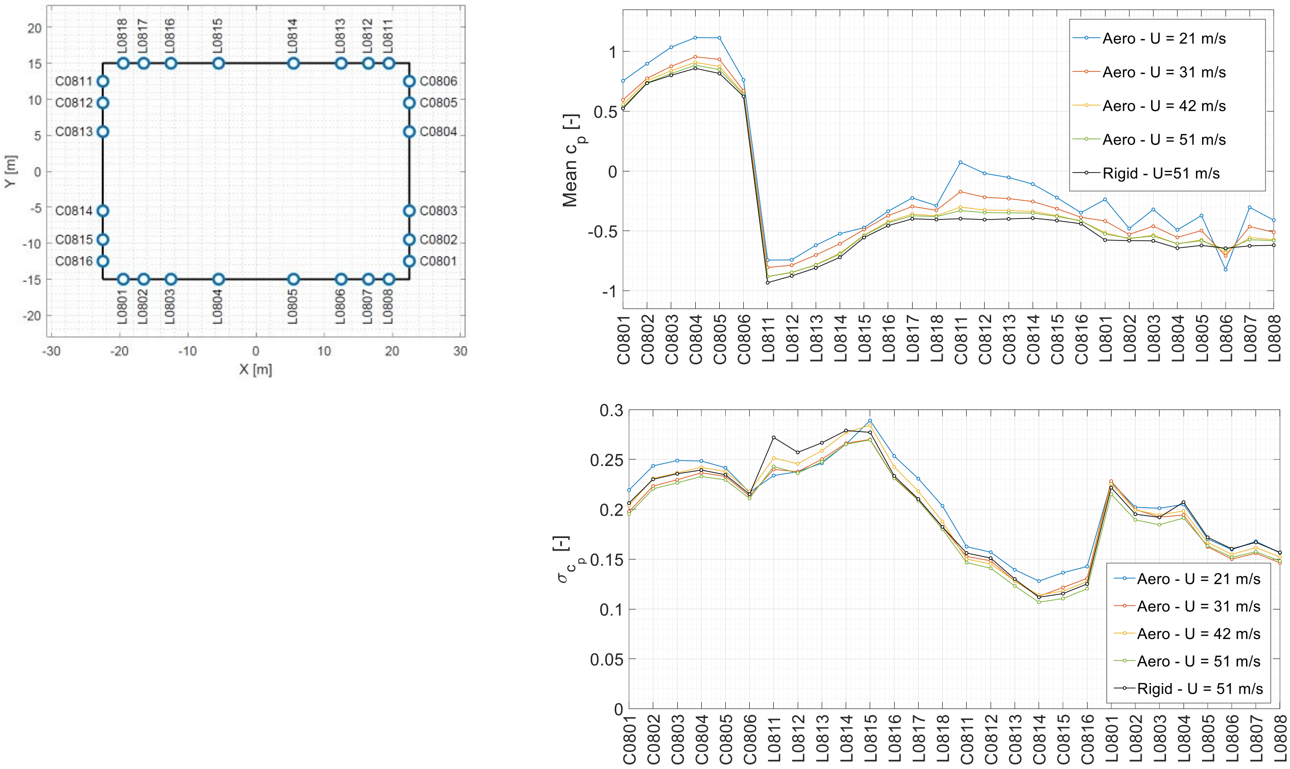

Figure 3. Comparison between rigid and aeroelastic model in terms of mean pressure coefficients and Standard deviations at 1.55 m and α=85°

Regarding the dynamic response of the structure, some differences can be observed in the two models due to the different approach. In the rigid model, the structural dynamic response is performed by a modal simulation with the assumption of constant damping ratio regardless of the amplitude of the vibrations. While the accelerations in the aeroelastic model are obtained by direct measurement with accelerometers. Furthermore, the numerical simulation does not take into account the vortex-induced vibrations which, in the y direction, occurs for wind speed in the test range. Figure 4 shows the differences between the direct measurements of the accelerations and the modal approach using the pressures coming from both models. The line charts show some differences in the standard deviation of the accelerations for angles of attack close to 90 ° and medium-high wind velocities corresponding to the vortex-induced vibrations.

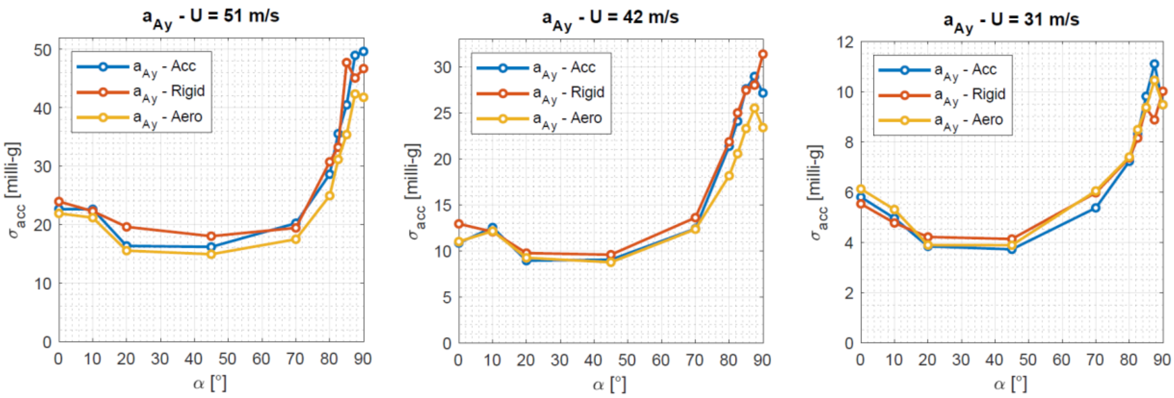

Figure 4. Standard deviation of the accelerations in the corner of the second quadrant at 1.50 m: direct measure of accelerations (Acc), numerical simulation based on rigid model (Rigid), numerical simulation based on aeroelastic model (Aero)

The results reported show that, in terms of mean and standard deviations of the pressure coefficient, the two models give similar results while some differences can be found in terms of dynamic response. These differences will be analysed considering more sophisticated models in order to take into account the non-linear effects of the mechanical properties and the vortex-induced vibrations.

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