Wind Engineering Joint Usage/Research Center
FY2024 Research Result Report

Research Field: Wind Hazard Mitigation/Wind Resistant design
Research Year: FY2024
Research Number: 24242005
Research Theme: Aeroelastic effects on idealized super-slender tall buildings characterized by square sections

Representative Researchers: Luisa Pagnini, Giuseppe Piccardo

Budget [FY2024]: 380,000 Yen

*There is no limitation of the number of pages of this report.
*Figures can be included to the report and they can also be colored.
*Submitted reports will be uploaded to the JURC Homepage.

1. Research Aim

This research aims to address a gap in the existing literature on finite-length square cylinders by conducting comprehensive full aeroelastic tests. The objective is to investigate the dynamic response of idealized super-slender tall buildings, with a particular focus on the potential influence of second-order vibration modes on vortex-induced vibrations (VIVs). Additionally, the study aims to compare the three-dimensional full-aeroelastic dynamic response of these structural typologies with results obtained from both three-dimensional and two-dimensional dynamic rigid models, with particular attention to the possible occurrence of VIV-galloping oscillations under different flow conditions (smooth and turbulent).

2. Research Method

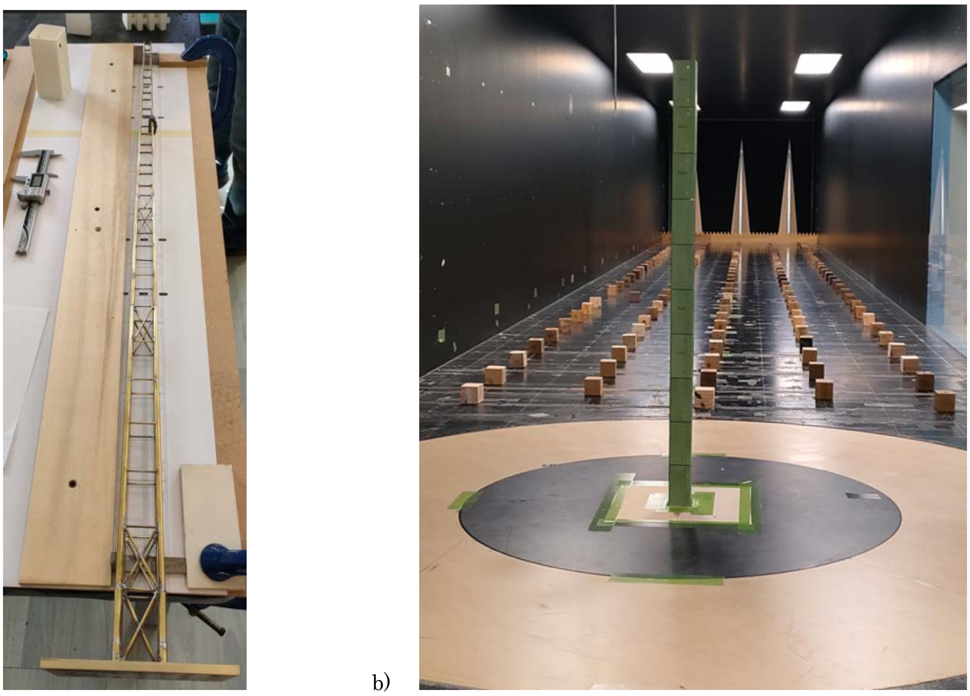
The research methodology involves an experimental test campaign on a 1:400 scale model of a super-slender tall building, characterized by an aspect ratio of 20:1. In full scale, the idealized structure stands 400 meters tall, with a square cross-section measuring 20 meters by 20 meters and a building density of approximately 250 kg/m^3. The model's stiffness is provided by an internally tapered brass lattice spine, carefully crafted to replicate the balance between flexural and shear deformations typical of full-scale structures (Figure 1a). An approximate frequency ratio of 3 between the first and second vibration modes is anticipated.

The model's outer cladding consists of 10 shell sections with 1 mm air gaps between them, each point-connected to the internal spine (Figure 1b). These sections are 3D printed using rapid prototyping techniques, specifically Selective Laser Sintering (SLS). Accelerometers are positioned inside the model, both at the top and at the antinode of the second vibration mode.

A distinctive feature of the experimental setup is the integration of 20 pressure taps distributed along the model. The design strategy prioritizes a greater number of measurement rings over a higher density of taps per ring, aiming to capture a detailed profile of VIV behavior along the building's height, while at the same time avoiding a significant increase in the model's damping capacity.

Two cross-sectional shapes are being investigated during the TPU campaign: a rounded-corner square section (curvature radius r/b = 1/15 relative to the side b) and a sharp-edge square section. Preliminary tests carried out on a similar model in the Giovanni Solari Wind Tunnel at the University of Genoa have shown promising results regarding second-order VIV excitation in the rounded-corner configuration.

Tests are conducted under both smooth flow and turbulent atmospheric boundary layer conditions, replicating an urban environment (Category IV, AIJ), across different angles of attack ranging from 0° to 9°. Additionally, a motion detection test was carried out under smooth flow conditions, with 1/15-rounded corners and 0° angle of attack.



a) b)

Figure 1. Inner core (a) and building model with external cladding (b)

3. Research Result

Up to now, the data measured during the TPU campaign have only been partially analyzed. The research primarily aimed to investigate the influence of corner geometry on the vortex-shedding second vibration mode, ranging from sharp edges to increasingly rounded corners. In smooth flow conditions, all tested angles of attack (up to 9°) exhibited only vortex-induced vibration behavior while, under turbulent flow conditions, vortex-induced vibrations were found to be coupled with galloping, at least for the two geometries tested to date. These results partially align with the literature. Kwok & Melbourne (1980, https://doi.org/10.1061/JMCEA3.0002584) observed no evidence of galloping in uniform smooth flow using a rigid model pivoted at the base, with a height-to-breadth ratio of 18:1, until the angle of incidence of the mean wind was about 9° from normal to one face. Similarly, Cammelli and Nguyen Sinh (2016, Conf. Proc. IN-VENTO 2016) did not report galloping when using a slightly larger corner curvature (r/b = 1/10 compared to the r/b = 1/15 adopted in this study), even under turbulent flow conditions for zero incident angle. Recently, Shan et al. (2024, https://doi.org/10.1063/5.0194289) observed strong across-wind oscillations in turbulent flow conditions, indicative of galloping or interaction between VIV and galloping, using a pivot-mounted model of a square cross-section tower with large aspect ratios (16 and 20).

Overall, the findings suggest that classical galloping of sharp-edged square sections in smooth flow is essentially a phenomenon restricted to strictly two-dimensional conditions and does not manifest in the three-dimensional scenarios explored in this study.

As evident, the work is still in an early phase of data processing, with the large amount of measured data only partially analyzed. Among the most urgent tasks, it is essential to investigate the feasibility of using a reduced velocity, assess the peak factors, try to estimate total damping and aerodynamic contributions, and conduct an in-depth analysis of the pressure measurements to assess resistance coefficients, crossflow coefficients, and crossflow RMS coefficients.

4. Published Paper

[Presentations at academic societies]

1. Luisa Pagnini, Stefano Cammelli, Edoardo Ruffini, Stefano Torre, Akihito Yoshida,

Giuseppe Piccardo (2025). Experimental Analysis of Vortex-Induced Second-Order Vibration Modes in Highly Slender Aeroelastic Models. Extended abstract accepted for oral presentation at the 9th EACWE, Trondheim (Norway), June 16-19, 2025.

5. Research Group

1. Representative Researchers
   Luisa Pagnini, DICCA, University of Genoa (Italy)
   Giuseppe Piccardo, DICCA, University of Genoa (Italy)

2. Collaborate Researchers
   1. Yukio Tamura, School of Civil Engineering, Chongqing University (China)
   2. Akihito Yoshida, Dept. of Architecture, Tokyo Polytechnic University (Japan)
   3. Stefano Cammelli, WSP, London (UK)
   4. Edoardo Ruffini, NOVA Fluid Mechanics Ltd (UK)
   5. Stefano Torre, DICCA, University of Genoa (Italy) – NOVA Fluid Mechanics Ltd (UK)

6. Abstract

Research Theme: Aeroelastic effects on idealized super-slender tall buildings characterized by square sections

Representative Researchers: Luisa Pagnini, DICCA, University of Genoa (Italy)
Giuseppe Piccardo, DICCA, University of Genoa (Italy)

This research investigates the aeroelastic behaviour of a square cylinder representative of a super tall building with an aspect ratio of 20:1. The model is made by a internally tapered brass lattice spine, designed to provide the target stiffness and deformation, and an outer cladding consisting of 10 shell sections point-connected to the internal spine. Two different cross-sectional shapes have been investigated: one with rounded corners (corner radius equal to 1/15 of the side) and one with sharp edges. The model is instrumented with 20 pressure taps, distributed over the building envelope, and two accelerometers, placed at the top and at an intermediate height. It exhibits a transverse natural frequency of approximately 11 Hz for the first vibration mode and 31 Hz for the second vibration mode, corresponding to about 0.055 Hz and 0.155 Hz at full scale. The damping ratios are approximately 0.45 % and 1% for the first and the second vibration mode, respectively. Wind tunnel tests have been carried out exploring wind speeds up to approximately 16 m/s, in both smooth flow and urban environment, and across different angles of attack ranging from 0° to 9°. In smooth flow, resonant vibrations due to vortex shedding were observed in both the first- and second-order vibration modes, at critical wind speeds around 5.7 m/s and 13.4 m/s, respectively. Under turbulent flow conditions, vortex-induced vibrations were found to be coupled with galloping behaviour. Pressure measurements distributed across five rings along the model's height enhance the 3D characterization of its aeroelastic response, enabling a more detailed description of vortex-shedding behavior along the building's height.