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DIGITAL SIMULATION OF WIND FIELD VELOCITY FOR EVALUATING PROPER STIFFNESS INDICATORS OF WINDOW MULLIONS

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Abstract

Mullions are important structural windows elements that provide their resistance to wind forces. These elements are of fundamental importance for the energy balance of the building since their structural behavior deeply affects its energy losses. A proper structural design of the windows mullions is therefore important for evaluating a suitable stiffness indicator of the mullions to avoid energy losses. In the present paper, a parametric study aiming to investigate the wind-induced displacements of the window mullions and their compatibility with their thermal barrier has been conducted. The proposed study aims to evaluate a proper moment of inertia of the aluminum profiles forming the mullions as a function of the windows exposition for different wind forces depending on the elevation of the building in which the window has been installed.

Keywords: wind induced effects, window mullions, stiffness indicators.

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1 INTRODUCTION

The This paper discusses the turbulent wind effects on the window mullions for different wind window expositions and different wind velocities. A proper design of the window mullions is of paramount importance for the energy balance of the building since their structural behavior deeply affects the energy losses of the building [1].

At present, it is always a big challenge for architects and planning engineers to design new buildings with different shapes with respect to the fact that the wind load is an important input parameter in the design of the windows. Wind forces acting on windows are strongly dependent on the building shape, on the environment and by the orographic in which the building has been built, such forces are usually determined by using Computational Fluid Dynamics (CFD) techniques or wind tunnel experiments [2].

In the present paper, a parametric study aimed to investigate the wind-induced displacements of the mullions and their compatibility with the energy losses of the building has been conducted, the study aims to assess a proper stiffness indicator of the mullions as a function of the window elevation.

2 DIGITAL SIMULATION OF WIND FIELD VELOCITY

Wind load simulation has been studied acting on the mullions through spatial discretization of the wind field using an idealized grid. At each node of the grid partially correlated wind turbulence time histories of the along-wind field (primary) load component are synthetically generated by the standard wave superposition method [2, 3]. The turbulent wind load, generated by assuming the validity of the quasi-steady formulation for pressures and equivalent forces (based on tributary areas), has been imposed for a duration equal to 600s, with a time step Δt = 0.01s and evaluated for elevation of the idealized grid (Fig.1).

The pressure coefficients of the surface window C_p have been obtained and adapted from the results by Hubova et al. [4] in the present case has been prudentially taken C_p=1. Mean wind velocity $\bar{U}(H)$ can be found through the following relation according to the reference wind speed $U_{ref,}$, and the constants k_T and z_0 provided by the Eurocode 1 [5]:

$$\bar{U}(H) = U_{ref} k_T \ln \frac{H}{z_0} \tag{1}$$

Accounting on the turbulent component of V_{turb} of the wind, the time varying wind speed at the altitude H can be expressed as:

$$V(t) = \bar{U}(H) + V_{turb}(t) \tag{2}$$

Figure 1 shows an example of the wind velocity simulated time history and its spectral compatibility.

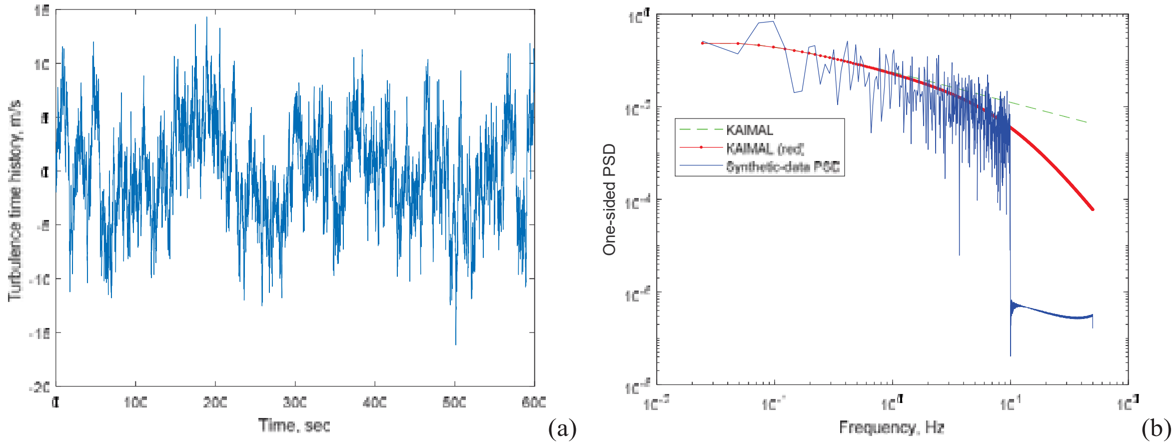

Figure 1. Wind speed simulation for elevation H=30m, U_{bar}=28m/s at H_{ref}= 10m; (a)Turbulent wind speed time history in one point of the idealized; (b) comparison between the employed synthetic data, Kaimal reduced and Kaimal power spectral density function.

According to the above formulated hypothesis, dynamic force $F_i(t)$ acting on the mullion can be written as:

$$F_i(t) = \frac{1}{2} C_p A_p V^2(t) \tag{3}$$

Wind force simulation has been performed through a concentrated load force acting on the center of the span of the elements accounting of an aerodynamic admittance function of rectangular plates, with “projected area” A_p (Fig. 2) orthogonal to the flow direction [6]. The loads have been evaluated for different “elevation” H and for a constant width B (mullion distance) of the idealized grid.

3 BACKGROUND MATHEMATICAL MODELS AND BENCHMARK SYSTEM

The present approach is based on the dynamic equilibrium equations of a discretized uncoupled Single Degree of Freedom (SDOF) lumped masse system [1] comparable to the one described by Giaccu in [7], in this treatment, structural interaction between mullion and glass has been conservatively neglected, it must be noted that this interaction is not often fully defined because of the uncertainties due to the assembly of the glass window. Geometrical properties of the glass window are described in Table 1.

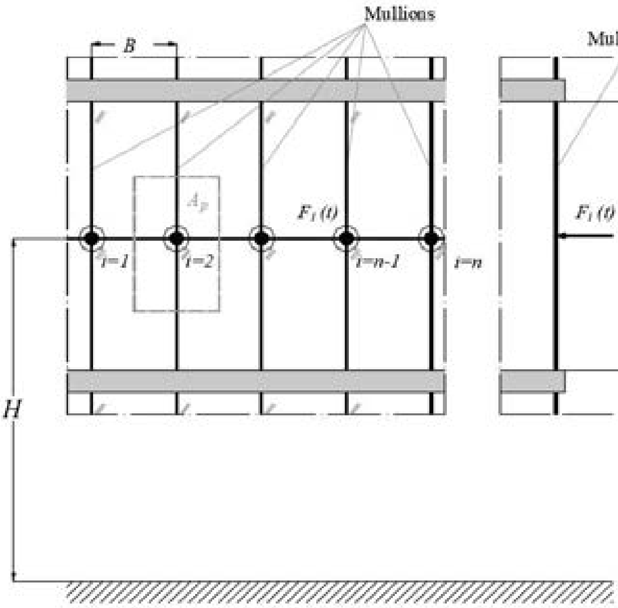

Figure 2. Benchmark model employed for the simulations of wind forces on facade.

Structural properties of the dynamic system have been calculated accounting of the geometrical features of the glass window illustrated in Fig.2 and in Table 1, which include the mass per unit area of the glass ρ_{glass}, the mullion span h, the modulus of elasticity of the aluminum E and its specific mass ρ_{al}, the a cross section area of the mullion A_{mul} and the mass of unit of length of the mullion ρ_{mul}.

h (m)	B (m)	A_p (m^2)	E (MPa)	A_{mul} (m^2)	ρ_{glass} (kg/ m^2)	ρ_{al} (kg/m^3)	ρ_{mul} (kg/m)	M (kg)	ζ_s (%)	E (MPa)
3.00	1.50	4.5	6.9×10^{10}	2.24×10^{-3}	20.00	2699	6.05	98.60	5.0	6.9×10^{10}

Table 1: Geometrical and Mechanical properties of the glass window and of the lumped mass model.

Tributary area of the window can be therefore found as $A_p = Bh/2$, mechanical properties of the lumped mass model can be obtained, accounting of the halved mass of the mullion, as $M = \rho_{wind} A_p + \rho_{al} h/2$ and the stiffness of the spring which can be obtained as $k_s=48EI/h^3$.

The moment of inertia of the profile can be written, accounting of the the radius of gyration of the mullion r_G, as $I = A_{mul} r^2_G$ and damping constant can be written as $c=2\zeta_s(kM)^{0.5}$, considering a conventional structural damping ζ_s =5%.

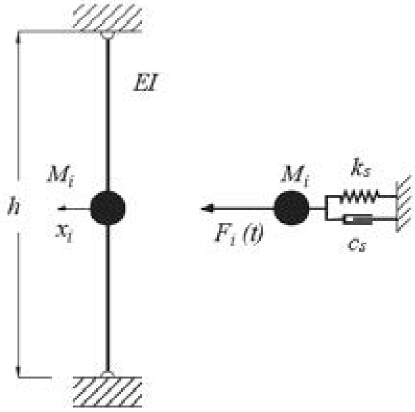

Figure 3. Schematic representation of the mathematical model employed for the simulations.

4 PARAMETRIC STUDY

The parametric study has been conducted according to Eq. 1 for the mean wind speed U_{ref}=28m/s at reference altitude H_{ref}= 10m, with k_T=0.17 and for a roughness length z_0=0.03 (m). The maximum displacement for different elevation *H* of the glass window has been detect.

For simplicity, the considered moments of inertia correspond to the same cross section A_{mul} for different slenderness λ of the mullion. Moment of inertia *I* of the mullion, can be therefore obtained as function of the slenderness λ through the following relation:

$$I = A_{mul}\left(\frac{h}{\lambda}\right)^2 \tag{4}$$

Deflections of the aluminum profiles have been compared with the conventional limit deflection indicator discussed in [1] (1/200 of the span *h*) which indicates the threshold beyond which the thermal barrier rigidity is necessary. The number of mullions considered in the idealized grid is *n*=6.

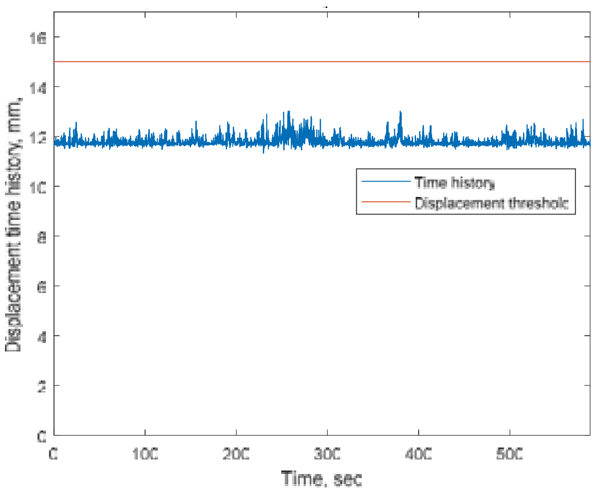

Figure 4. Displacement time history for *H*=40m, U_{ref}=28m/s at H_{ref}= 10m and λ=45 in comparison with the displacement threshold *h*/200.

Results have been illustrated in Fig.5 as function of the elevation H of the window for different slenderness λ. Three different slenderness have been considered for the proposed simulation λ=*45, 50* and *55*.

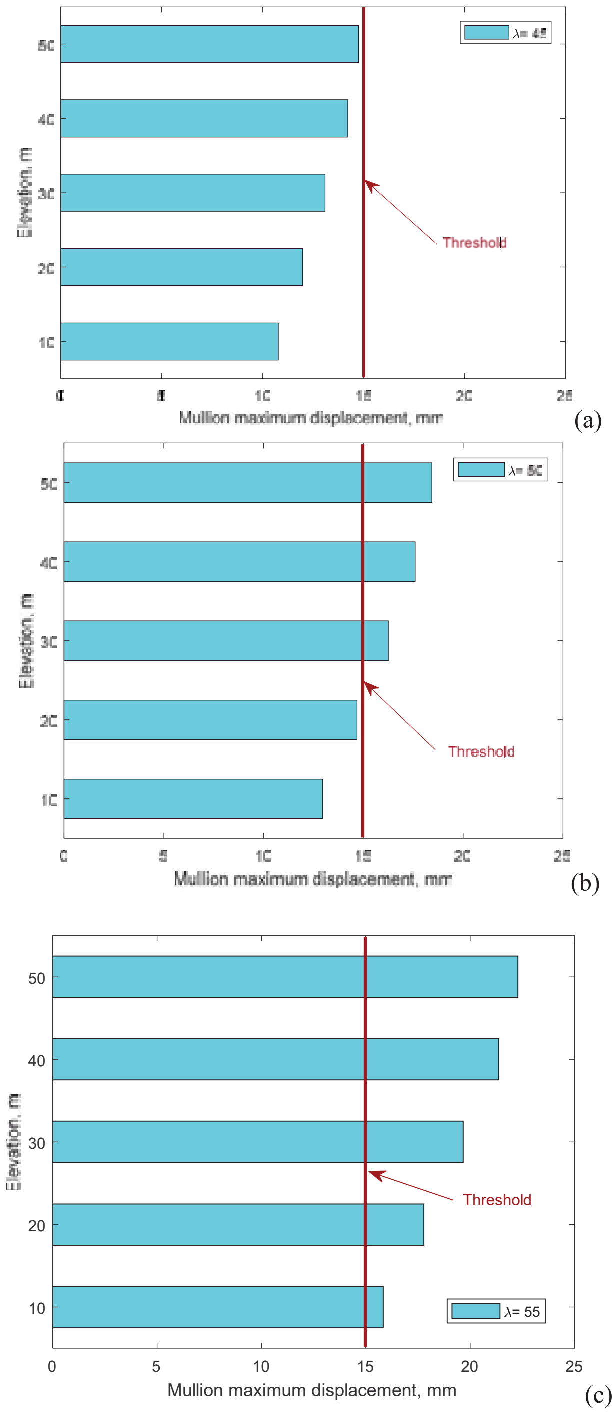

Figure 5. Maximum displacement of the mullion in case of U_{bar}=28m/s at H_{ref}= 10m for different elevation H, in comparison with the displacement threshold $h/200$ for different slenderness λ of the mullion cross section: (a) λ=45, (b) λ=50 and (c) λ=55.

From an examination of the results illustrated in Fig.5, it can be inferred that, slenderness of the mullion plays an important role in the wind induced deflections, in particular, for the considered case, a slenderness of the aluminum profile λ>55 leads to crossing the threshold limit (1/200 of the span *h*) for all the considered altitudes, whereas profile with slenderness λ=50 can be utilized used up to heights of 30 m, finally the slenderness λ=45 can be utilized up to heights of 50 m without crossing the threshold.

5 CONCLUSIONS

The comparison of the data obtained during the performed simulations allowed to study different cases of buildings accounting of different expositions and different wind loading, a parametric study has been conducted for the considered cases assessing proper stiffness indicators of the mullions for different window properties and for different window expositions. A parametric study aimed to investigate the wind-induced displacements and of their compatibility with the windows' thermal barrier has been conducted. Results indicate that slenderness of the mullions plays an important role in limiting the wind-induced displacements in the mullion of the window since displacements are in turn directly related to the energy losses of the building. Suitable stiffness indicators of the mullions were indicated for all considered cases.

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