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WIND AND ITS EFFECTS ON HIGH-RISE BUILDINGS

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This paper examines the relation between high-rise buildings and wind, how wind flows, the action and interaction of the wind with structures, and the design factor which is considered a critical factor in the construction of skyscrapers.

Introduction. In the course "Building Physics", some engineering points of view are taken into consideration such as the temperature, acoustics, humidity, ventilation and light, and the way they act upon the building. Yet, air resistance isn't concerned that much, as well as the way air acts upon high rise buildings. For instance, we notice that some unmentioned domains in the region of building physics can relate to these high rise buildings, and they are studied under the name of " Building Aerodynamics" .When we talk about building aerodynamics, we take into consideration the wind factor, the way it acts on buildings, the way engineers solve problems concerning wind affecting skyscrapers, and the wind loads. In the field of wind, we relate to lateral loads leading to dynamic responses (resonance, acceleration, damping, oscillations) which are very severe and dangerous for people. Engineering is here for us to solve these problems.

Task formulation. The study of wind's interaction with high-rise buildings.

Basics of turbulent flow.

Wind is the flow of air characterized by its complicated dynamic displacement, and is studied in the field of "Fluid Mechanics". Flows of air can be laminar or turbulent. Laminar flow is a flow regime characterized by high momentum diffusion and low momentum convection, whereas the turbulent flow is a regime characterized by chaotic changes in pressure and flow velocity. Determining if a flow is laminar or turbulent depends on the viscous and inertial forces of the flow. The ratio of inertial to viscous forces is Reynolds number (Re). Building-Architectural aerodynamics is mostly related to the turbulent flow, where the velocity component and other factors (density, pressure, temperature) fluctuate in three dimensions, are time-dependent and rotational, which sets a very hard task even on developed methods for potential flow to calculate these fluctuations. The wind vector $\vec{\upsilon}$, at some stationary point in the flow may be regarded as the sum of mean wind vector $\vec{\upsilon}$ – static component and turbulent fluctuation vector υ' – dynamic component (fig. 1) [1].

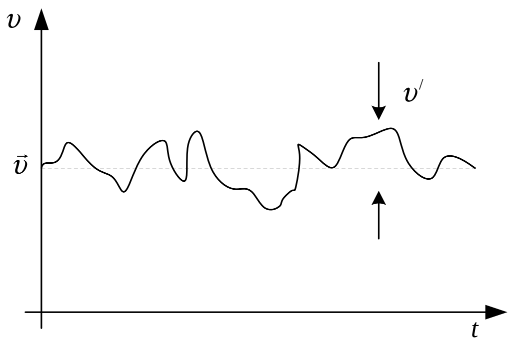

Fig. 1. Mean wind vector $\vec{\upsilon}$ and turbulent fluctuation υ' as a function of time t

The differential equations of mass, momentum and energy balance express fundamental physical laws for laminar and turbulent flows, since the mathematical models can't separately calculate the turbulent flow. For us to calculate these flows, we use "time-averaged" versions of these differential equations that are very effective in averaging out some fluctuation contributions. Before considering how the differential equations should be time-averaged, it is helpful to establish several rules. First of all, we define a time-averaged quantity a(t) as the average of the instantaneous quantity $a = \vec{a} + a'$ over a time period T, where T is much longer than any turbulence time scale, but much shorter than the time-scale for mean flow unsteadiness, e.g. wave fluctuation [2].

The period T has to be sufficiently long so that the fluctuations in the equation are averaged to zero

$$\vec{a}'(t) = \frac{1}{T}\int_{t-0,5T}^{t+0,5T} a'(t)dt = 0 .$$

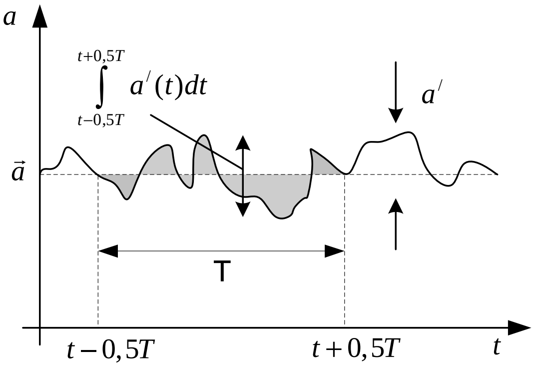

Fig. 2. Time-averaged velocity vectors as a function of time

Mentioning skyscrapers, different phenomena give rise in the dynamic response of structures on the wind, such as buffeting, fluttering, galloping, and vortex shedding. Engineers only take vortex shedding into consideration, since it has a big effect in the oscillation of the building. Wind comprises eddies of different sizes, where large eddies decompose into smaller ones by losing their mechanical energy. These eddies give the wind its gusty and turbulent character. We also set to notice that after air's collision with the surface of a building, air converts its kinetic energy into potential. This basic loss of energy is what is noticed in the phenomenon "Vortex shedding". Getting into more details, the eddies created by vortex shedding are related to the building's surrounding. For instance, if we have a building surrounded by other structures, we notice that the air turbulence differs from that which isn't surrounded by anything. This is clarified according to the gradient wind's alteration with the variation of height from the surface to the upper troposphere. There are several reasons to explain this tendency. First, especially in the middle latitudes, the pressure gradient increases with height. A second reason for the variation of wind gradient with height, especially near the ground, is due to surface friction. A third reason is due to air density which in turn decreases with height [3].

Wind loads and their effects on high-rise buildings. Wind exerts dynamic and static loads on a building, that lead to major types of deformation into shear, bending, twisting and deflection (curvature). Depending on the shape of the building, different loads will have different degrees of effect on the building. Static (dead) wind load is the horizontal pressure that tries to push the structure sideways, which creates elastic bending, deflection and twisting of the building , while dynamic (live) wind load creates vertical fluctuating forces all over the structure that creates motions, most commonly oscillations (thus dynamic). Taller, slender structures are impacted more significantly affected by dynamic wind loads. The taller the building, the stronger the force as wind is affected less by friction with the earth and surrounding topography, thus making wind load a greater challenge for high-rises.

Air's collision with a building's surface, changes its momentum, spawning the phenomenon of vortex shedding which basically leads to large wind pressure fluctuations, tending to vibrate the building's façade in the rectilinear and torsional modes. Under the action of wind, tall buildings are simultaneously loaded in the along-wind, cross-wind and torsional directions [4].

Along-wind causes windward and leeward pressures, denoted by pressure and suction respectively. Wind pressure is exerted uniformly on all the faces of the building, just as conventional pressure, with exception for the wind-ward side which is affected differently based on the height. These pressures are subjected to be "Shearing wind forces" and "Bending moments" that tend to pull the building on two countering directions on two parallel horizontal axis and curl the building at two ends on two parallel horizontal axis at both ends respectively.

The torsional wind twists the building's axis in the direction of the torsional moments created. The cross-wind mainly created by vortex shedding, generates an oscillatory motion derived by the resonance of the building. Tall buildings are bluff (as opposed to streamlined) bodies that cause the flow to separate from the surface of the structure, rather than follow the body contour. For a particular structure, the shed vortices have a dominant periodicity that is defined by the Strouhal number. Hence, the structure is subjected to a periodic cross pressure loading, which results in an alternating crosswind force. If the natural frequency of the structure coincides with the shedding frequency of the vortices, large amplitude displacement response may occur and this is often referred to as the critical velocity effect. The asymmetric pressure distribution, created by the vortices around the cross section, results in an alternating transverse force as these vortices are shed. If the structure is flexible, oscillation will occur transverse to the wind and the conditions for resonance would exist if the vortex shedding frequency coincides with the natural frequency of the structure. This situation can give rise to very large oscillations and possibly failure [5].

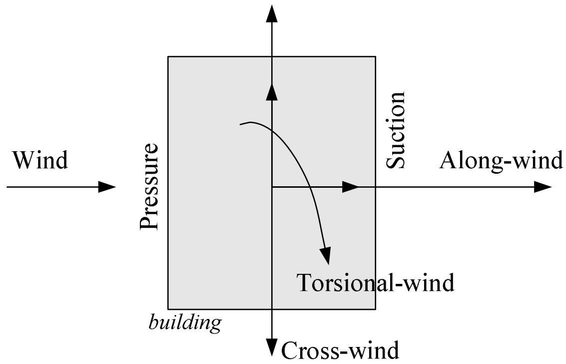

Fig. 3. Action of lateral wind on the facade of a building

Design criteria. In terms of designing a structure for lateral wind loads, the following basic design criteria need to be satisfied.

– **Stability** of the building against overturning (falling down), uplift and/or sliding of the structure as a whole.

– **Strength** of the structural components of the building is required to withstand imposed loading without failure during the life of the building.

– **Serviceability** where overall deflection is expected to remain within acceptable limits. Control of curvature and deflection is essential for high-rise buildings with the aim of limiting damage and cracking of non-structural members (ceiling, internal partitions, etc.). An additional criterion that requires careful consideration in high-rises is control of sway acceleration and damping when subjected to wind loads. This criterion is based on human tolerance to vibration discomfort in the upper levels of the buildings.

Wind response is relatively sensitive to both mass and stiffness, where response accelerations can be reduced by increasing either or both of these parameters.

In the process of designing high-rise buildings, some criteria should also be preserved by the structure itself.

– High-rise buildings should have a positive relationship with relevant topographical features and other high-rise buildings.

– The high-rise building must conserve, or not damage or detract from:

1. World heritage and local historical sites and their settings,
2. Registered ancient monuments, their settings, and registered buildings,
3. Conservation areas and their settings,
4. Other open spaces, including rivers, waterways, the Straits, their settings and views from them,
5. Other important views, prospects and panoramas.

The architectural quality of the building including its scale, form, massing, proportion and silhouette, facing materials and relationship to other structures. The design of the top of a high-rise building is also important when considering the effect on the skyline [6].

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