WIND ENGINEERING FOR RESILIENT, SMART AND SUSTAINABLE STRUCTURES

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Wind engineering analyzes the effects of wind on the natural and the built environment and studies the possible damage, inconvenience or benefits which may result from wind. Wind engineering as a discipline grew out of the activities of a number of research establishments around the world in the 1950's and 1960's, including the National Physical Laboratory in Teddington and the Building Research Establishment in Watford. Wind engineering draws upon meteorology, fluid dynamics, mechanics, geographic information systems and a number of specialist engineering disciplines including aerodynamics, and structural dynamics. This talk will address special topics in wind engineering of civil engineering structures, including: atmospheric boundary layer simulation for the built environment, vibration mitigation in flexible structures for improved resilience and performance under wind loads, and aerodynamic optimization by retrofitting buildings with solar panels for improved sustainability with resilience benefits.

Atmospheric boundary layer simulation in a new open-jet facility at LSU

Although hurricanes occur at large scales, the reproduction of the atmospheric wind characteristics within the lower part of the boundary-layer is very important as the interaction between the wind and the structures occurs in this part of the atmosphere. Atmospheric boundary-layer (ABL) involves wind which can be moderate, strong or destructive. ABL simulation at a relatively high resolution (for wind-structure interaction) is very important for wind/structural engineering disciplines. The available tools include atmospheric models, wind tunnels, and computational fluid dynamics (CFD) models. The purpose of this study is to generate hurricane wind with proper flow characteristics at a new open-jet facility at Louisiana State University (LSU). Numerical investigations via Computational Fluid Dynamics (CFD) were carried out to reduce the effort required for experimentally simulating hurricane wind flows. The purpose of the CFD simulations was to help select among different flow management schemes proposed to create a wind profile with characteristics that mimic certain terrain category. Two basic models are used to do the numerical analysis: 2D and 3D computational domains. The velocities of wind at several locations were taken from the CFD results to provide guidance on the choice of the most appropriate flow management scheme. In parallel to the CFD study, experimental investigations were carried out in order to validate the computational results. Future research will focus on the generation of hurricane winds with wave. This concept of wind and wave (WAW) simulation is being under development at LSU. The WAW research is thought to push the boundaries of science towards the understanding of the complex hurricane-induced wind and wave loading and their impact on the built environment, with the objective to build the more resilient coastal communities.

Vibration Mitigation for Traffic Lightening Structures: Traffic signs and signals are extensively used as vital elements in highways and urban roads for making communications with drivers, in order to convey the rules, guidance, warnings, and other highway agency information. On this basis, it is crucial to have reliable and well maintained traffic signs and signals to ascertain that the desired massages are properly conveyed to the drivers on the streets in various environmental conditions; as a result, a safe drive can be achieved. Among the support structures, long mast arm cantilever structures are widely used on the highways all over the world. Cantilevered traffic signal support structures are slender, lightly damped structures, and since they may have a span as long as 20 m, they are very flexible structures, and highly sensitive to wind-induced vibrations, and their fatigue life is an important issue in the design process. Another important concern about traffic signal structures is their vulnerability in critical weather conditions, such as during hurricanes. The serviceability of these structures during hurricanes is extremely important due to their critical role in directing traffic, specifically for evacuation and rescue operation during an event. These concerns highlight the importance of vibration control in cantilever traffic signals. Consequently, the current paper presents a methodology to suppress wind-induced vibrations in a mast arm cantilever traffic signal with a circular cylinder section, by using CFD simulations to create wind load time series and a dynamic model for structural control. For wind load simulations, a time-dependent approach by implementing the Large Eddy Simulation (LES) has been used. Monitoring points are defined on the mast arm to capture pressure coefficients, and then calculating distributed lift and drag forces at different sections. The simulated time histories of drag and lift forces are then used for the control purpose, after experimental validation. In order to mitigate the vibrations, distributed tuned mass dampers are investigated, making use of the available weights of the lighting boxes. The structural response with and without the dampers are simulated by a dynamic model. The dynamic analysis shows that the dampers can effectively control the vibrations of the structure and can reduce the displacements of the free end of the mast arm. In addition, the results show that damping enhancement in traffic lighting structures can significantly reduce vibration-induced stress, with promises to improve the safety to the traveling public, extend the life of existing traffic structures, increase traffic efficiency, and reduce the cost of new structures. Moreover, the generated wind load time histories with the dynamic model are being used for different vibration control schemes, including passive and semi-active control devices with drift magnification connections, with the objective of building a database useful for creating guidelines and recommendations on the proper use of damping enhancement devices, for future implementation in the AASHTO standard.

Vibration Mitigation in Wind Turbines: The increased energy demand has led to explorations in nontraditional sources, particularly in renewable energies. Wind energy is one of the cleanest sources and plays significant role in augmenting sustainability. Wind turbines, as wind energy power convertors, are tall and slender structures, and depending on their location, which can be inland or offshore, can be exposed to high wind and/or strong wave loads. These loads can cause unwanted vibrations with detrimental effects on energy production. A dissipative analysis study was carried out to permit the understanding of whether these types of structures require damping enhancement or rigidity modifications to reduce the vibrations. Following the dissipative analysis study the results suggest that wind turbines are lightly damped structures and damping enhancement is a potential solution for vibration suppression. Accordingly, the paper reviews different approaches to suppress the vibrations and investigates the influence of using different techniques to suppress the motion of a wind turbine tower, via an application numerical case study. In this study, the capability of tuned mass dampers, tuned liquid column and sloshing water dampers and viscous dampers to decrease the tower's vibration are evaluated. Finally, a comparison among these devices in terms of robustness and effectiveness is made. Based on the results presented, viscous dampers can reduce both displacement and acceleration response of the tower better than other types of dampers, for the same control effort (total control force). Nevertheless, the use of viscous dampers may require space considerations, compared to tuned mass dampers. In addition, tuned mass dampers proved to be efficient, compared to tuned liquid dampers and sloshing water dampers. However, sloshing water dampers may be recommended for offshore floating wind turbines, when the space allows for that, as they can suppress vibrations at different frequencies and in different directions.

Retrofitting Building Roofs with Aerodynamic Features and Solar Panels to Reduce Hurricane Damage and Enhance Eco-Friendly Energy Production: Negative pressures on roofs of low-rise buildings are a major source of losses and community disruption during various types of windstorms. Vortex suppression technologies play a role as a means to reduce wind loads on buildings. The challenge, however, is on exploring mitigation features that can reduce wind loads on roofs and at the same time has minimal loads on the feature itself. Aerodynamic features with relatively high lift and drag forces can become wind prone debris or introduce excessive loads to the main structure, which is not a feasible solution. In the current paper, several roof aerodynamic mitigation features are proposed and tested by computational fluid dynamics (CFD) simulations, in a comparative study. Different aerodynamic mitigation features, including barriers, circular edges, inclined edges and airfoil edges are investigated. The results show that a slope-in feature, which can be replaced by solar panels, for green energy production, is relatively effective in reducing roof induced suctions. Such feature, among other devices, can potentially protect roofs under windstorms, creating economic and green buildings. In addition, compared with all mitigation features presented, the airfoil brings the lowest uplift loads to the whole structure (building with feature), which provides promises to proceeding research in this area. Also, since an ideal mitigation feature should be attractive to building owners, to permit a wide-spread usage and applicability, the study investigates the wind impact on a gable roof building with solar panels at different configuration, from an overall wind-induced loads perspective. CFD simulations were carried out using a high resolution 3-D, Reynold's Stress Models (RSM) and Large Eddy Simulation (LES) turbulence closures. Laboratory experiments were carried out at a new small-scale open-jet testing facility at Louisiana State University (LSU). Pressure coefficients on the roof and solar panels of each model from both CFD and laboratory experiments are compared. The trialing results of several solar panel arrangements show that the proper arrangement can help reduce wind uplift loads on the building. Current research is focusing on buildings with different roof shapes and patterns of panels, to better understand the flow mechanism, and to estimate the potential load reduction benefits of retrofitting roofs with solar panels, with an objective to reduce wind-induced damage to low-rise buildings, and to enhance eco-friendly energy production.