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DIRECTIONAL FLUID-STRUCTURE INTERACTIONS AND AUTOMATED DATABASE-ASSISTED DESIGN FOR WIND

Emil Simiu[1]*, DongHun Yeo[2]

[1] National Institute of Standards and Technology, 100 Bureau Dr., Gaithersburg, MD 20899, emil.simiu@nist.gov, http://www.nist.gov/el/nwirp/esimiu.cfm

[2] National Institute of Standards and Technology, 100 Bureau Dr., Gaithersburg, MD 20899, donghun.yeo@nist.gov, http://www.nist.gov/el/building_materials/dyeo.cfm

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Recent technological developments allow simultaneous, phase-preserving measurements of fluctuating aerodynamic pressures at hundreds of ports on the exterior surface of building models tested in aerodynamics testing facilities. The aerodynamic measurements capture the effect of the imperfect spatial pressure correlations due to turbulence associated with the oncoming atmospheric flow and flow-structure interaction. For this reason the measurements reflect in detail the actual loads experienced by the prototype in atmospheric flow with far greater accuracy than is possible for conventional code provisions. However, structural design technology as embodied in codes and standards has not kept pace with this remarkable advance. Rather, codified wind loads on buildings are still largely determined by using essentially slide-rule era methods, precluding in practice designs that are superior or optimal from the points of view of risk-consistency, cost, and CO_2 footprint.

Database-assisted design (DAD) is a set of tools based on aerodynamic and wind climatological information available in the public domain or obtained ad-hoc for specific projects with a view to calculating wind-induced internal forces and other wind effects. Directional aerodynamic databases created by Tokyo Polytechnic University and, to a lesser extent, by the University of Western Ontario, contain time histories for pressures at large numbers of ports for hundreds of building models covering a vast range of dimensions and features occurring in design practice. Influence coefficients allow the transformation of pressure time histories into time histories of wind effects induced by unit directional wind speeds. The requisite directional wind climatological data are obtained from measured data by Monte Carlo simulation techniques. A simple nonlinear transformation of the directional matrix of simulated extreme wind speeds allows the rigorous estimation based on non-parametric statistics of wind effects with any specified mean recurrence interval. Errors in the estimation of wind effects can also be obtained. DAD automatically calculates combined internal forces due to gravity loads, wind-induced shears along the principal axes, and wind-induced torsional moments about the building elastic center. DAD also calculates Demand-to-Capacity Indexes (DCIs), that is, the left-hand side of the interaction equations governing the design of structural members. The design of the members is acceptable if, in addition to satisfying serviceability criteria, the values of the DCIs are close to unity. Otherwise the structural members are strengthened or reduced until this criterion is satisfied. DAD can also be used in conjunction with push-over techniques that cause the structure to deform nonlinearly. Included in the paper are details on: data volume reduction for storage and computational purposes; adjusting aerodynamic databases for consistency with various requirements on record length; the rigorous estimation of directionality factors; the estimation by nonlinear transformations of peak statistics for individual non-Gaussian wind effects; the estimation of peak combined effects; and dynamic and aeroelastic effects.

DAD achieves a clear division of responsibilities between the wind and the structural engineer. The wind engineer is responsible for providing in electronic form, for the record, the requisite aerodynamic and wind climatological data. These data, and the requisite influence coefficients obtained by structural analysis, are then incorporated by the structural engineer in the DAD software to perform the structural design for wind. The design process is thus fully transparent and can be effectively scrutinized. Load combinations are inherent in the data and are therefore performed by DAD objectively, rather than, as is the case in current practice, "by eye." The effects of higher modes of vibration are accounted for naturally, whereas in conventional design procedures based on the High Frequency Force Balance approach they cannot be accounted for at all. The significance of these DAD features cannot be overemphasized. In their absence estimates of wind effects can differ substantially from laboratory to laboratory, as attested by differences in excess of 40 % between wind effects estimated for the World Trade Center towers by independent laboratories. In conclusion, it is argued that the switch from conventional design methods to DAD promises to have major beneficial effects on the construction industry by achieving a quantum jump in the quality and cost of structures subjected to wind loads.

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