J. Wind Eng. Ind. Aerodyn. 104–106 (2012) 12–24

Contents lists available at SciVerse ScienceDirect

Journal of Wind Engineering and Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia

Alan G. Davenport's mark on wind engineering

Nicholas Isyumov *

The Boundary Layer Wind Tunnel Laboratory, The University of Western Ontario, London, Ontario, Canada N6A 5B9

ARTICLE INFO

Available online 12 May 2012

Keywords:
Davenport's contributions
Wind buffeting
Loads and responses
Wind tunnel testing
Development of the wind loading chain

ABSTRACT

This paper overviews the contributions to wind engineering made by the late Professor Alan G. Davenport. These include an engineering model of strong wind in the atmospheric boundary layer and its simulation in wind tunnels. His mean and turbulent wind profiles and his spectrum of longitudinal turbulence are known world-wide. He developed the theory of wind buffeting of line-like structures and introduced the gust factor method, which determines the magnitude of the peak wind-induced response, including the effects of wind-induced resonance. Also he has made key contributions to the development of statistical methods which are needed in the prediction of wind loads and wind-induced effects. These include the method of up-crossings, which predicts the probability of exceedance of particular extreme values. Foremost, he will be remembered for the wind tunnel model studies of many of the world's milestone buildings and structures.

Professor Davenport's approach to wind loading was to combine its key components in a chain of thought, analogous to a physical chain, whose strength is determined by its weakest link. In recognition of this and his many other achievements, the International Association of Wind Engineering has officially named his approach to wind loading as the "Alan G. Davenport Wind Loading Chain".

1. Introduction

The wind engineering community lost one of its most distinguished members, when Alan Garnett Davenport passed away on July 19, 2009. Accounts of Professor Alan Davenport's life and his contributions to wind engineering have since appeared in print. His obituary was published in the International Journal of Wind Engineering (Isyumov, 2009). A special edition of the Journal of Wind Engineering of Japan was published in Alan Davenport's memory. This included a paper which described his close collaboration with Japanese researchers (Isyumov et al., 2010). A special edition of the Canadian Journal of Civil Engineering (of which Professor Davenport was its Founding Editor) has also been published in 2011, in which several of his former students and colleagues have written papers on their areas of research which have been most influenced by Professor Davenport (Canadian Journal of Civil Engineering, 2011).

Alan Davenport first presented his ideas on the action of wind on buildings and structures in his doctoral thesis 50 years ago and has since left an indelible mark on wind engineering. His name is one of the most recognized in wind engineering, both for his many theoretical contributions, as well as for the many wind engineering studies of buildings and structures which he and his colleagues pioneered at the Boundary Layer Wind Tunnel Laboratory (BLWTL) at the University of Western Ontario. Alan founded the BLWTL in 1965 and was its director throughout its "heyday" years. This paper discusses Alan G. Davenport's many achievements and contributions, as I remember them. It is expected that the interested reader will turn to the technical literature for further details. Fortunately, Professor Alan Davenport has published widely and left a broad and long paper trail of his ideas and theories in papers, books and conference proceedings worldwide.

Whilst history is most likely to remember Alan Davenport for his pioneering work in wind engineering, he also made important contributions to the fields of meteorology, structural dynamics and earthquake engineering. Alan was committed to improve the safety of the built environment and found time and energy to become involved with the United Nations' declared International Decade for Natural Disaster Reduction. Among his many lifelong interests were the reliability and safety of structures. Towards this end, he contributed to building codes and standards of many countries and served on numerous national and international committees, charged with their improvement. Alan Davenport was instrumental in the establishment of the Centre for Studies in Construction and the Institute for Catastrophic Loss Reduction at the University of Western Ontario. These sister organizations added critical mass and complemented the activities of the BLWTL. He was a gifted and dedicated researcher and a much respected teacher and mentor to a countless number of students, both at the undergraduate and graduate levels. In recognition of

* Tel.: +1 519 661 3338; fax: +1 519 661 3339.
E-mail address: ni@blwtl.uwo.ca

0167-6105/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jweia.2012.02.007

his pre-eminence in both research and academia, Professor Davenport was awarded honourary degrees by 10 different universities and was appointed a Member of the Order of Canada for his lifetime achievements.

This paper expands the keynote address given at the ICWE-13 in Amsterdam in Professor Davenport's memory and honor. This is done with additional material which describes his approach for evaluating the action of wind on buildings and structures. In this process the action of wind is determined by a rational procedure which includes estimates of the local wind climate; the shaping of the site specific wind by the influence of local terrain and topography; project specific aerodynamic data; the recognition of dynamic effects, including wind-induced resonance and the establishment of criteria for evaluating acceptability. Alan's approach to wind loading has been named as the "Alan G. Davenport Wind Loading Chain". This wind engineering terminology has been formally announced by the International Association of Wind Engineering at ICWE-13, held at Amsterdam in July 2011. This was done in order to recognize Alan G. Davenport's many contributions to wind engineering and to honor his memory.

2. Analytical methods

2.1. Wind loading chain concept

Alan Davenport's doctoral research (Davenport, 1961a) laid the foundation of today's wind engineering. His approach was based on the chain of thought which recognized that the wind loading experienced by a particular building or structure is determined by the combined effects of the local wind climate, which must be described in statistical terms; the local wind exposure, which is influenced by terrain roughness and topography; the aerodynamic characteristics of the building shape and the potential for load increases due to possible wind-induced resonant vibrations. He also recognized that clear criteria must be in place for judging the importance of the consequences of the predicted wind action. This included the effects of wind on the integrity of the structure and the exterior envelope and various serviceability considerations, such as the control of the wind-induced drift, the effects of building motions on occupants and the usability of outdoor areas at and near particular buildings and structures. In his papers Alan Davenport referred to this process of evaluating the effects of wind action as the "wind loading chain". This was in recognition that the evaluation of the wind loading and its effects relies on several interconnected considerations, each of which requires scrutiny and systematic assessment. With analogy to a physical chain, the weakest link or component in this process determines the final outcome. Little is gained by embellishing strong links but much is lost by not paying attention to the weak ones.

This symbolic chain of thought is shown in Fig. 1. Alan used this "chain" analogy throughout his practice, lectures and publications. Not only does the wind loading chain provide a firm basis for the evaluation of wind loads it also forms the basis for the chain of thought needed to define and solve other wind engineering problems. The format of Alan's wind loading chain has been adopted in the specification of wind loads in most building codes and standards worldwide.

The chain approach permits systematic estimates of the statistical variability of the predicted wind action. The link with the largest uncertainty dominates the reliability of the entire process. Alan's papers detailed this approach and demonstrated the improvement in reliability that can be made by strengthening weak links in the wind loading process. He clearly showed the benefits which result from improvements in the description of the local wind climate and how the use of aerodynamic data from a wind tunnel model simulation instead of information from building codes improves reliability. As part of his wind loading chain, Alan also suggested criteria for evaluating the effects of wind induced accelerations on the comfort of occupants in tall buildings (Davenport, 1972) and the effects of wind speeds on the comfort and safety of pedestrians in outdoor areas (Davenport, 1975).

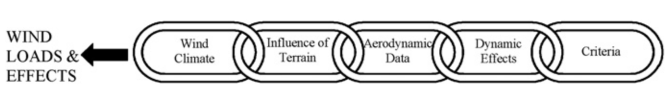

Fig. 1. Alan G. Davenport's wind loading chain.

2.2. New direction

A major change in the technology of buildings and structures occurred in the post World War II years. This was most evident from the building boom experienced in North America. These new or "modern" buildings and structures were becoming taller and/or of greater span, more daring in shape and concept and more slender in proportions. In addition, more powerful structural computation methods, the emergence of new materials and fastening methods with welding replacing the traditional use of rivets in steel construction, collectively contributed to the emergence of lighter weight and more flexible elastic structures with less inherent energy dissipation or damping. However, while more economic than traditional construction, buildings and structures of this new generation were more susceptible to the dynamic wind action. Building codes of those days described wind loads as static and did not address possible wind-induced resonant vibrations which can increase the effective loads. Alan Davenport's innovative approach recognized the stochastic characteristics of natural boundary layer wind in both the time and space domains and the importance of allowing for both its static and dynamic actions. This required an improved understanding of the nature of the wind itself, a better description of the aerodynamics of buildings and structures and the use of structural vibration theory to determine their wind-induced responses. Alan's ideas first presented in his Ph.D. Thesis and shored up by a burst of key papers in internationally available journals and in conference proceedings, were very much needed in order to support these rapid changes in the technology of the built environment.

Alan's approach to wind loading was able to correctly evaluate the dynamic action of wind on buildings and structures and to determine their oscillatory behavior in the presence of wind-induced resonant vibrations. This set a new direction in wind engineering. Also, it made Alan Davenport an internationally recognized authority on the action of wind on buildings and structures and a much sought-after consultant on the characteristics of boundary layer winds and their effects on wind sensitive tall structures, such as skyscrapers, towers and long span bridges. His ideas and methods were put into practice in the design of such landmark projects as the World Trade Center in New York, the Sears Tower in Chicago (now Willis Tower) and the CN Tower in Toronto. Many others projects followed and the skylines of many of the world's major cities are graced with buildings and/or structures, whose designs were influenced by Alan's ideas and the efforts of the Laboratory which he founded.

2.3. Engineering model of natural wind

The cornerstone of Alan Davenport's approach was a rational and computationally manageable framework for describing the spatial and temporal characteristics of wind. This is essential for