International Wind Engineering Seminar 3: Modeling the Dynamics of Tall Buildings Under Winds: From Historical Perspective to Recent Advances and Beyond

Thursday December 3rd 12.00 UK time

Main Speaker

Prof Ahsan Kareem, NatHaz Modelling Laboratory, University of Notre Dame, USA

Panel Discussion

Professor Yukio Tamura, School of Civil Engineering, Chongqing University, China

Dr. Melissa Burton, Arup, Toronto, Canada

Dr. Tracy Kijewski-Correa, Keough School of Global Affairs and College of Engineering, University of Notre Dame, USA

Dr. John Kilpatrick, RWDI, Guelph, Canada

Abstract

The seminar will briefly summarize the history of wind engineering of tall buildings from the design of the World Trade Center Towers to the present-day skyscrapers and beyond. First of all, the equations of fluid motion are mathematically intractable, which has led to reliance on the physical modeling in wind tunnels. From earlier studies at the National Physical Laboratory in the UK involving the World Trade Center Towers, it was realized that it was essential to model the inflow that was reflective of the atmospheric boundary layer rather than a uniform flow in an aeronautical tunnel. At that juncture, the dynamic response was evaluated using base-pivoted aeroelastic models while a search for a more expeditious means of assessing wind loads was in progress, which led to the development of various force balances. In this context, a general overview of the basic techniques for the quantification of wind loads and their dynamic effects using analytical, experimental, computational fluid dynamics (CFD) and model-based and data-driven simulation schemes, database-enabled platforms, code and standards-based procedures and lessons from full-scale monitoring will be presented in a historical perspective. This will be followed by a synopsis of the emerging frontiers in computational approaches for shape and topological optimization, the vulnerability of glass cladding in extreme winds, the role of organic damping and damping devices for the mitigation of building motion. In closing, the concept of morphing tall buildings using sensing, computational intelligence and actuation of the dynamic façade for futuristic buildings will be presented.

Speaker and panel member biographies

Ahsan Kareem is the Robert M. Moran Professor of Engineering and the Director of the NatHaz Modeling Laboratory at the University of Notre Dame. His work focuses on probabilistic characterization and formulation of dynamic load effects due to wind, waves and earthquakes on tall buildings, long span bridges, offshore structures and other structures, via analytical and computational methods, fundamental experimental laboratory and full-scale measurements utilizing cyber and cyber-physical infrastructures, for their safety assessment and mitigation measure. He is elected President of the International Association for Wind Engineering (IAWE). He has been awarded numerous honors, including the Presidential Young Investigator Award from the White House Office of Science and Technology. A recipient of ASCE's: Theodore von Karman Medal, Masanobu Shinozuka Medal, James Croes Medal, Earnest Howard Medal, Robert H. Scanlan Medal and Jack E. Cermak Medal and State-of-the-Art Award, inducted to the Offshore Technology Conference Hall of Fame and Distinguished Member of ASCE; Alan G. Davenport Medal of IAWE; Distinguished Research Award of IASSAR (Int'l Assoc. for Structural. Safety and Reliability); the University of Notre Dame. He has served as a High-End Foreign Expert at Tongji University and delivered 2013 Scruton Lecturer at the Institute of Civil Engineers, London, UK. He has been appointed Honorary Professor at several universities overseas, serves on the Editorial Board of several international journals incuidng Guest Editor of Engineering, CAE Journal, and has recently co-authored two books. He is an elected Member of the US National Academy of Engineering and a foreign member of the Indian Academy of Engineering, Engineering Academy of Japan and Chinese Academy of Engineering.

Melissa Burton is a Principal at Arup. Her work focuses on the intersection of the built and natural environments. She started her career looking at how the wind climate affects the buildings we design, and how the consequential reaction of the buildings affects the people that occupy them. Her technical expertise extends to beyond code approaches using advanced analytical tools to quantify and reduce design risk from wind loading. She has most recently collaborated with the Charles Pankow Foundation to publish criteria and methodologies for designing tall buildings to be more resilient in wind events.

Tracy Kijewski-Correa is the Leo E. and Patti Ruth Linbeck Collegiate Chair and Associate Professor, Department of Civil and Environmental Engineering & Earth Sciences, and Associate Professor of Global Affairs at the University of Notre Dame Her research focuses on disaster risk reduction (DRR) and civil infrastructure challenges posed by increased urbanization and vulnerability. Her interdisciplinary scholarship links science and technology to vulnerable communities, delivering scalable paradigms to enhance the resilience and sustainability of civil infrastructure and inform the decisions of stakeholders such as homeowners, designers, planners, emergency managers and policymakers. She currently serves as the inaugural director of the Structural Extreme Event Reconnaissance (StEER) network, which organizes networks of engineers to assess damage after disasters globally and use this knowledge to drive recovery and future DRR practices.

John Kilpatrick, Ph.D., P.Eng., C.Eng., F.ICE, is the Wind Engineering Practice Leader at RWDI and a Principal of the firm. John is a former Chair of the UK Wind Engineering Society, and is a contributing author to the ASCE/SEI Prestandard for Performance-Based Wind Design and ASCE 49 Standard for Wind Tunnel Testing for Buildings and Other Structures.

Yukio Tamura is a Professor of the School of Civil Engineering, Chongqing University, China, and the Honorary Director of the Wind Engineering Research Center, Tokyo Polytechnic University, Japan. He served as the President of the International Association for Wind Engineering for eight years from 2007 to 2015. He is currently serving as an Adjunct/Guest/Honorary Professor of 19 universities in China, Korea, Malaysia, Poland, and USA. Professor Yukio Tamura is a member of the Engineering Academy of Japan, a Foreign Fellow of the Indian National Academy of Engineering, and a Foreign Member of Chinese Academy of Engineering.

Questions to the panel

Questions from Albert Hansel to Prof. Kareem:

1. Does the philosophy of earthquake design such as the formation of plastic hinge in the beams also applied to wind loading?

2. In light of design processes especially for tall buildings, should the earthquake loading separated with wind loading, or we can combined them together at the same time?

3. How much approximate damping ratio that we usually use in wind loading for design? for example in earthquake we usually use 5% of damping ratio

AK: (1) It could but at this time it is being explored under the performance-based design approach. (2) There are some combination rules in special cases, but as such concurrent occurrence of earthquakes and a severe wind events are not considered. There a a few studies that are exploring based on risk the combination of the two loads. However, there is a very limited data to build upon. (3) Each standard or a building code has its own specification, for wind typically it is 1% though several of the tall towers even of concrete exhibit values lower than this number for low wind speeds, i.e., for serviceability/human comfort. ASCE & addresses this in detail.

Question from Karim Mostafa to Dr. Kareem, Thank you Dr. Kareem for your presentation, my question is Could it be possible to depend mainly on CFD models instead of wind tunnels models in the near future or wind tunnels are always and will remain a necessary tool for verification of CFD models?

AK: I am hopeful that computational resources large enough become available so that CFD can be conducted reliably and accurately. This may happen soon but will be limited to select groups. I think in the near future we will have to rely on the wind tunnel and slowly we may start to see CFD competing on a limited basis. Also one needs to explore a combination of machine learning to enhance the CFD based schemes, which may help to usher CFD on the table sooner.

Question from Simon Leefe to Dr. Kareem: where can I obtain further details of the synthetic influx boundary condition of CFD?

AK: You may find it on the web site of NHERI SimCenter web site at https://simcenter.designsafe-ci.org/research-tools/tinf/. The tool name is TinF.

From Chris Geurts to Everyone: Dear all, thanks Ahsan, and Tracey for your comments on the importance of full scale measurements. I hope that we are able to get this done in practice. My experience so far with full scale measurements is that it needs a driving question for a party to invest in such activities. Usually a client is happy to have the building built, sometimes then sells it to another party and no one has, or feels, the interest to start (and pay for) monitoring. Currently we are starting a monitoring programme in the Netherlands. Maybe not so high, but we typically have very soft soils, so the effect of deep foundations are of our particular interest. Any tips and tricks for us on how to 'sell' these activities to customers are very welcome!

YT: At the dawn of tall buildings, e.g. the late 1960s to the early 1970s in Japan, some owners could understand the meaning and significance of the full-scale monitoring for the following two purposes: confirmation of the assumptions at the design stage; and purely scientific fact-findings. Recently, the full-scale monitoring is commonly made for buildings which install some special damping devices to confirm their performance. Some big real-estate companies are interested in monitoring behaviors of a group of own buildings to immediately capture the situations of their buildings in case of disasters. They also understand the merit of the full-scale monitoring with "Invest Today, Save Tomorrow" policy.

TKC: The sell is always more challenging after a building is commissioned, so I do believe it is going to be better going forward that we build this into the contract when the building is designed and constructed. This was how the door was opened for Burj Khalifa (via Samsung as part of their contract to build the tower). For post-construction instrumentation, the no-cost sell for us was easier, in that we argued much like personal health, it is helpful to verify from time to time that the vitals are as expected and affirm the structure is operating as intended. This also ensures that their structure can have a well-calibrated Digital Twin to engage in evaluating future modifications to the building (or assessments after some shock as Yukio also suggested). So these were cases where a grant paid for the hardware and we just needed the permission to get into the building. Cases of at-cost post-construction instrumentation have been isolated for us but in all cases stemmed from the owner having a concern (so it was for either "sick" buildings or buildings undergoing some design revision or retrofit where they needed to calibrate a reliable FEM for an older building), so as you suggest, they really need to have a pressing need or question to be willing to make that investment, since benefits for day-to-day operations are too little to justify the cost.

AK: I concur with YT and TKC. Sometimes even if it is at no cost to the owner and the owner realizing some value to monitoring, their legal office advises them against permitting because if we find anything it may be detrimental to the rental space market for the building. In one case I asked what could we find that could impact, the answer was if we find asbestos. So this was the technical level with which the legal office was placing their opinion!

From Giuseppe Piccardo to Everyone: Question from Giuseppe Piccardo to Prof. Kareem and Dr. Burton: thank you very much for the presentation and for the heartfelt memory of our dear Giovanni, thank you! The higher oscillation modes can be of actual technical interest even for tall buildings or just for special cases of super tall buildings ? (but I remember a seminar where they didn't seem particularly important even for NY 432 Park Avenue). Then Dr Melissa Burton added that she often found results highly influenced by higher modes in terms of building serviceability. Is there an influence of VIV on the higher modes? Thanks again.

YT: I presume Melissa will answer, but the following is just for your reference. As the human perception threshold suggests that people are more sensitive to vibration in the frequency region 1Hz – 2Hz, even if the higher-mode acceleration amplitude is lower than the fundamental mode, people can be more sensitive to the higher mode vibration with a higher frequency in the case of tall and super-tall buildings as shown here. In this case, the effect of VIV is not significant for the higher modes.

TKC: My experiences in monitoring have affirmed that higher modes are not an issue for the vast majority of tall buildings UNLESS the fundamental mode is very low-frequency, e.g., 0.1 Hz or lower. The most flexible building I have worked on, Burj Khalifa, did have notable higher frequency mode participation in its responses. This produced a "tail wagging the dog effect" where the spire could actually excite the main tower via a second sway mode that kicked out at lower elevations (akin to what Melissa noted). Most buildings at best have only the fundamental mode in the "sweet spot" where the wind field's energy is highest, but in the case of Burj Khalifa it had up to 6 modes that could be easily excited by wind. The emphasizes the importance of considering these higher mode effects, particularly for occupant comfort, as the affected floors will not be the top floors for these modes, but lower floors of the building. (See Dr. Tamura's comment above)

AK: I concur with observations made by YT and TKC. When in my lecture I mentioned the higher modes I was referring to super tall buildings where higher modes could be closer to the VIV type wake excitation. The other point I was making was about the spatial geometry of the mode shape and the distribution of the fluctuations in loading. After all the net effect is the weighted loading concerning the mode shape. If they negate each other it would not matter even if the frequency alone is in the range of excitation. When one talks about VIV what comes to mind is a resonant type behavior with more of a sinusoidal type excitation. Most of the acrosswind loading on buildings shows spiky spectra but not like those of a sinusoidal loading. So when you heard about 432 PA they may have preferred to call it to wake excited rather than a VIV type. However, if we have motion-induced loads or negative damping come into play it can further complicate the situation. We may have VIV with lock-in features if we keep building needle-like structures which would require fortifying them with damping devices. That is where your models may come into play. Actually, there are energy-harvesting structures that exhibit VIV and that energy is captured.

Question from Yufen Zhou to all panelists: Regarding occupational comfort, for buildings that are in the design stage without the full scale monitoring data available, how can we ensure that the acceleration response from the analysis predicts the full scale performance in a conservative way? In other words, can the common approach from HFFB wind tunnel tests or CFD capture effectively the possible discomfort level of tall buildings in the future under wind?

YK: In general, HFFB can be useful, but considering the higher-mode problems, the pressure integration technique using the simultaneous multi-channel pressure measuring system (SMPMS) might be better.

TKC: Echoing Prof. Tamura's point, the first issue is understanding the dynamics sufficiently to appreciate if HFFB is sufficient (with higher modes, you need to use other approaches to determine the wind load). Even with a well executed FEM, you still will need to guess a damping value. This is our biggest uncertainty in the process. We have continued to work to document the effect of high efficiency tall buildings with strong cantilever overturning behaviors and the fact that they have very little energy dissipation (far less than systems dissipating through frame racking). So the biggest threat to occupant comfort prediction mistakes is picking damping too high. It is very common for us to see damping below 1% critical in service conditions for tall buildings with high efficiency systems, even if they are made of concrete. Our model helps to predict damping values for such systems but the key takeaway is only through monitoring will we be able to continue to update/refine that model and our FEM and wind tunnel methodologies so they can be helpful in predicting the responses of future designs — its a critical feedback loop!

AK: Both YT and TKC have made good points. We cannot overemphasize the importance of damping. I have been involved in several buildings in which a minor increase in damping would qualify the building to be OK from human comfort consideration. Therefore, as we have done in ASCE 7 damping in wind is chosen to be on the lower side to give you the conservative results you were referring to.