NIST ADVANCES IN COMPUTER-AIDED AND COMPUTATIONAL METHODS IN WIND ENGINEERING

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ABSTRACT

The paper summarizes recent research and development of computer-aided and computational methods in wind engineering at the National Institute of Standards and Technology (NIST). Specific topics to be covered include:

1. Time-domain database-assisted design of tall, flexible structures excited by turbulent winds inducing dynamic structural responses.
2. Computational Fluid Dynamics (CFD) estimates of aerodynamic pressure on low-rise buildings with geometrical dimensions comparable to the across-wind integral turbulence length scale.
3. Development of synthetic directional wind speed databases covering on the order of 10,000 years, from measured wind speeds over periods of approximately 30 years.
4. Probability distributions of hurricane wind speeds, Gulf and Atlantic coasts.
5. Extreme wind speeds in non-hurricane prone conterminous United States.
6. Estimates of hurricane-borne missile speeds.
7. Disaster and Failure Events Repository – a new research tool for archival and analysis of post-disaster information and data.

INTRODUCTION

NIST has been active in wind engineering research and development for several decades. Recently developed computer-aided and computational methods include time-domain Database-Assisted Design methods for rigid gable frame buildings and for tall buildings, for which software (e.g., windPRESSURE, HR_DAD_RC) is available free of charge at http://www.nist.gov/wind. NIST has recently expanded its R&D efforts in wind engineering as part of the National

Windstorm Impact Reduction Program. This paper describes recently completed products and those currently under development, all of which will be available on the NIST web site when completed.

1. TIME-DOMAIN DATABASE-ASSISTED DESIGN OF TALL, FLEXIBLE STRUCTURES

Time-domain calculations are a revolutionary, highly effective approach to tall building design for wind, and have become possible only in recent years, owing to the development of improved pressure measurement technologies and the availability of powerful computational resources. An important advantage of the time-domain approach is that it automatically yields the requisite combinations of wind effects (e.g., wind effects associated with drift along the two principal axes of the building and with torsion; demand-to-capacity indexes for any individual member cross section), with no need for the guesswork required by current frequency domain methods on how those wind effects should be combined. Also, unlike for the High Frequency Force Balance method used in conjunction with the frequency-domain approach, the time-domain approach entails no limitations with respect to modal shape or number of modes of vibration.

Time-domain calculations require two wind engineering inputs. The first input consists, for each wind direction being considered (e.g., N, NNW,…, NNE), of time histories of the wind pressure coefficients measured simultaneously (or, in the future, computed) at a sufficiently large number of taps on the exterior surface of the building model. The second input consists of (a) a matrix **V** of directional wind speeds at the top of the building for n extreme windstorm events, where n is sufficiently large to allow the estimation of wind effects with sufficiently high mean recurrence intervals by using non-parametric statistics methods (e.g., Simiu, 2011), and (b) the mean rate of occurrence of windstorms at the building site. One reason for the use of non-parametric methods is dictated by the "wind effects space" structural reliability approach appropriate for structures for which wind directionality effects are significant, as explained subsequently. If the number of measured windstorm events is not sufficiently large, the matrix can be augmented as needed by using Monte Carlo simulation techniques based on extreme value statistics; software for this purpose was developed by NIST, as indicated later in this paper.

Once these two inputs are provided, the wind engineers have completed their tasks. The structural engineer is then in a position to determine the design wind effects and design the structure accordingly. The process is shown in Figure 1. First, the aerodynamic wind loads associated with each row of pressure taps are applied, at the elevation of that row, at the center of mass of the building. Next, for each wind speed in a set covering the range of speeds that may occur at the site (e.g., v = 10, 20,..., 80 m/s), and for each direction, dynamic calculations are performed that yield the time histories of the respective inertial loads.

The total lateral loads are sums of the aerodynamic and inertial loads. Using the total lateral loads and appropriate influence coefficients allows the rapid calculation, via simple linear summations, of the time history and peak value of any desired wind effect, e.g., inter-story drift, top floor acceleration, and demand-to-capacity index (DCI) for any member cross section (The DCI is the left-hand side of the interaction equation used for the design of members subjected, e.g., to bending and compression.) The result of the calculations consists of a set of matrices referred to as response databases – one matrix **W** for each peak wind effect of interest. Matrix elements, denoted by w_{ij}, represent the peak wind effect w produced by a wind speed v_{ij} belonging to wind event i (i = 1, 2, ...n) and blowing from direction j. The matrices **W** are properties of the structure and are independent of the wind climate. They provide a one-to-one correspondence between any wind speed blowing from any direction and the effect that the wind speed produces.

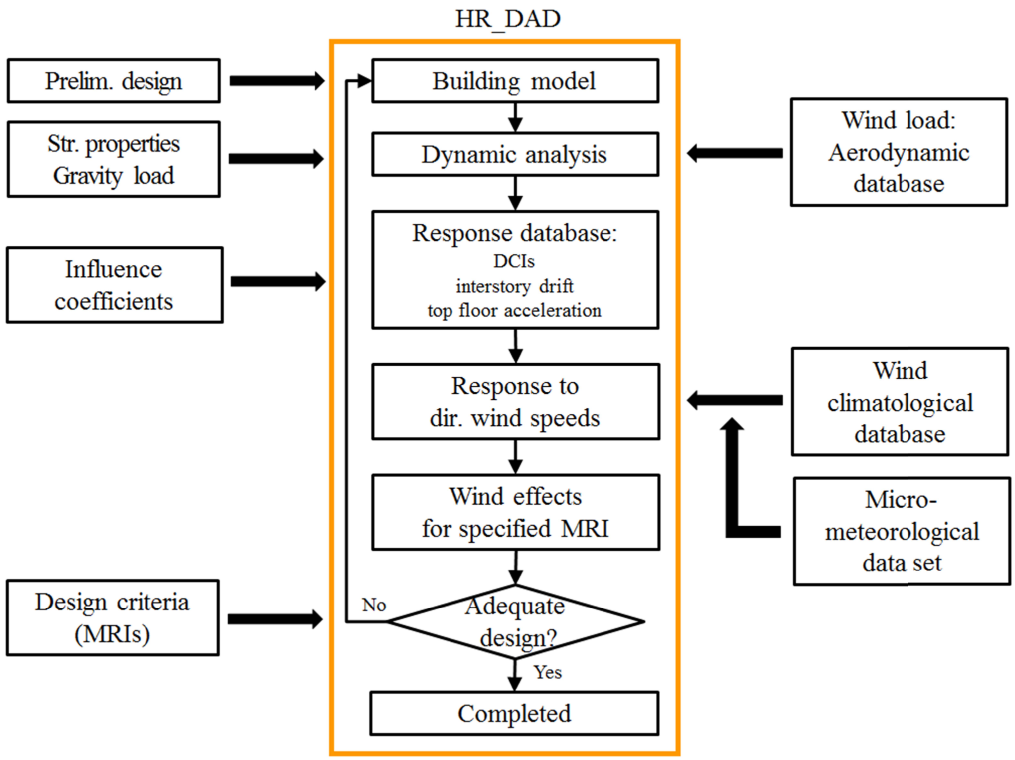

Figure 1. Basic algorithm for High Rise Database-Assisted Design (HR_DAD).

It is a simple operation to replace the elements of the extreme wind speeds matrix **V** by the corresponding wind effect extracted from **W**. A matrix $\mathbf{M_w}$ of the wind effects induced by the wind speeds contained in **W** is thus obtained. From a structural engineering point of view not all of the elements of $\mathbf{M_w}$ are of interest. For each row k, only the largest element – the largest of the wind effects produced by the directional wind speeds in that row – is of concern to the structural engineer. Thus, a vector of wind effects W is obtained. Wind effects with any mean recurrence interval lower than, say, $n/2$ or $n/3$ can be estimated from that vector if the mean rate of occurrence of windstorms at the site is known. If, following the preliminary design, the wind effects obtained by the procedure just outlined do not satisfy the design criteria, the structure is redesigned accordingly.

Software for the High Rise Database Assisted Design of both steel and reinforced concrete (RC) structures is available for download on the NIST web site (steel structures http://www.itl.nist.gov/div898/winds/HR_DAD_1.1/hr_dad_1.1.htm; RC http://www.itl.nist.gov/div898/winds/HR_DAD_RC_1.0/hr_dad_rc_1.0.htm). For details see Fritz, Gabbai and Simiu (2008), Spence (2009), Yeo (2010a) Yeo and Simiu (2010, 2011), and Simiu (2011).

2. COMPUTATIONAL FLUID DYNAMICS (CFD) ESTIMATES OF AERODYNAMIC PRESSURE ON LOW-RISE BUILDINGS

NIST is actively investigating methods for developing CFD estimates of aerodynamic pressures on low-rise buildings with geometrical dimensions comparable to the across-wind integral turbulence length scale (i.e., of the order of 25 m or less). For such buildings the effect of low-frequency turbulent fluctuations can be replaced in the calculations by an appropriate increase in the mean atmospheric flow velocity. This considerably reduces the volume of computations. The intent of this approach is to produce aerodynamic pressure plots that would replace current ASCE 7 Standard plots, shown in the literature to yield results that differ by as much as 30 % to 50 % from the results of tests conducted at the University of Western Ontario (St. Pierre et al. 2005, Coffman et al. 2010). Such differences are due in large measure to the fact that to-date no effective standard provisions have been developed for the wind tunnel testing of low-rise buildings, meaning that most wind tunnels differ from each other in their cross-sectional dimensions, fetch (distance from fan to model), roughness elements, and design of spires, hence, in the structure of their shear, turbulent flows. In our proposed approach the low-frequency flow fluctuations are suppressed, and their aerodynamic effect is replaced by the effect of a commensurate increase in the mean wind speed. Figure 2, where t denotes time, shows a time history of pressures on the windward wall induced by wind with mean speed normal to the wall. If the average effect of the imperfect spatial coherence of the low-frequency pressure fluctuations being suppressed is small, then, to within a small error, it is permissible to consider in the calculations the 3-min time history segment shown in Figure 2, instead of the entire time history over the typical duration of a storm. This is true for both large-scale storms and thunderstorms.

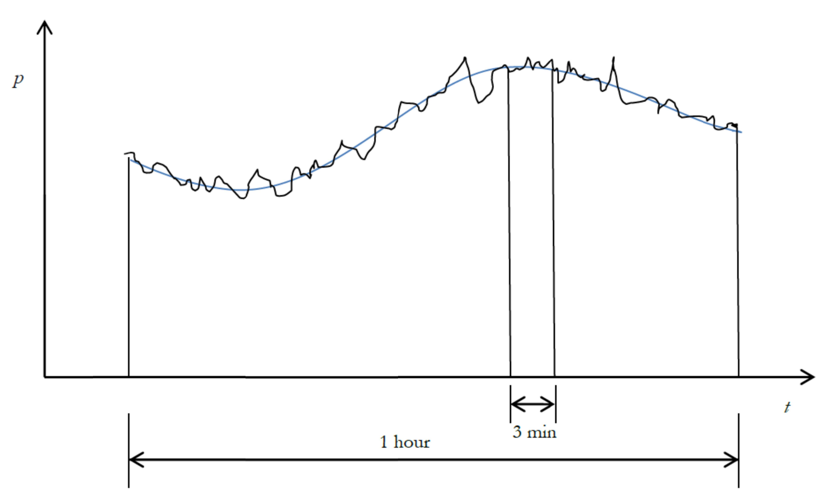

Figure 2. Time history of pressures *p*.

For buildings with dimensions larger than those of typical homes the spatial coherence of the pressures is on average smaller than unity, and a corrected augmented mean speed considered over the short (e.g., 3-min) time interval being considered can be used. The correction is based on simple calculations involving an integration of the pressures with imperfect coherence over the windward wall.

The question arises whether the proposed approach yields approximately correct results not only for the windward wall under wind with mean normal to the wall, but also for the roof and all walls under wind with any mean speed direction. Tests conducted at Florida International University (FIU) and reported in joint FIU-NIST papers indicated that, as expected, this is indeed the case, to within errors of typically 10 % to 15 %. In view of the typically larger errors inherent in conventional boundary layer wind tunnel testing, this result is deemed to provide a promising first validation of the proposed approach (Simiu et al., 2011; Fu et al., 2012). NIST development of CFD code consistent with the approach just described is in progress.

For details see Fritz et al. (2009), Coffman et al. (2010), and Yeo (2010b).

3. DEVELOPMENT OF SYNTHETIC DIRECTIONAL WIND SPEED DATABASES

This project concerns the development of synthetic directional wind speed databases covering on the order of 10,000 years, from measured wind speeds over periods of approximately 30 years. Synthetic data are developed to allow:

(i) Estimates of structural responses with mean recurrence intervals of up to thousands of years, for buildings and other structures sensitive to wind directional effects (see part 1 of this paper), and
(ii) Estimates of sampling errors inherent in the estimates of the structural responses. Such estimates are useful for structural reliability calculations.

The methodology employed to perform the estimates relies on the peaks over the threshold approach to estimating extreme values used in conjunction with Monte Carlo simulations. One difficulty encountered in estimating extreme speeds is that, for some directions, the sample size of the directional data is small, so that the estimates of the probability distributions required for the Monte Carlo simulations are not sufficiently reliable. In such cases sufficiently large data samples are developed by consolidating data samples from adjacent individual directional sectors. A report on this research is currently in preparation.

4. PROBABILITY DISTRIBUTIONS OF EXTREME WIND SPEEDS AT COASTAL AND INLAND LOCATIONS, GULF AND ATLANTIC COASTS.

Estimates of hurricane wind speeds, regardless of their direction, are available for any location on or near the Gulf and Atlantic coasts, for mean recurrence intervals of 300, 700, and 1700 years in the ASCE 7-10 Standard, and for 10^6 and 10^7 years in a United States Nuclear Regulatory Commission report (Vickery, Wadhera and Twisdale (2011). The estimates were obtained by using a Monte Carlo methodology developed in the 1970s and subsequently refined by several authors. The estimates corresponding to these five mean recurrence intervals can be used to estimate the parameters of the extreme value distributions describing the probabilistic behavior of hurricane wind speeds and, therefore, to produce estimates of hurricane wind speeds with any desired mean recurrence interval. The latter are needed to obtain estimates of the probabilities of exceedance of limit states other than those currently considered in design; in particular, such estimates are needed for limit states associated with performance-based design. The procedure for estimating the probability distribution parameters is based on fitting the data to an Extreme Value distribution, for example by using a least squares approach, and was developed by NIST engineers and statisticians; it is currently being prepared for publication, and will be posted online on http://www.itl.nist.gov/div898/winds/publications.htm when completed. The procedure accounts, where necessary, for the mixed character of the extreme value distributions by making allowance for the contribution of non-hurricane winds to the extreme values of interest. The procedure will be illustrated by numerical examples for several coastal and inland locations, and can readily be applied to any location. Calculations performed so far confirm an earlier finding that hurricane wind speeds are best modeled by the reverse Weibull distribution (Heckert, Simiu and Whalen, 1998).

Hurricane wind rosettes cannot be obtained by the procedure described above. However, rough estimates of directional hurricane wind speed rosettes can be obtained from sets of 999 simulated directional hurricane wind speed data for the entire Gulf and Atlantic coasts (though not for inland locations) at http://www.itl.nist.gov/div898/winds/hurricane.htm.

5. EXTREME WIND SPEEDS IN THE NON-HURRICANE PRONE CONTERMINOUS UNITED STATES.

The current formulation of the wind speed map used for design in ASCE 7-10 was developed with data from meteorological stations having low spatial resolution as well as relatively short record lengths (~500 US stations having15 to 25 years of data each) with assumed open exposure (Peterka and Shahid, 1998). The low spatial resolution led to a spatial averaging procedure which grouped stations together to reduce sampling errors, but may have washed out some characteristics of the extreme wind climate (Lombardo, 2012). In addition, the open exposure assumption was shown to be questionable in cases, sometimes leading to differences in the estimated wind speeds of up to 40% (Masters et al., 2010). A single statistical distribution (Gumbel) was used to describe the extreme wind climate throughout the entire country, and the data contained no information on type of wind (i.e., thunderstorm or synoptic). Storm types have been shown to have different probability distributions (Gomes and Vickery, 1977) and considering the probability distribution of each storm type within a mixed distribution model (Simiu, 2011) has been shown to be a better way to estimate extreme wind speeds (Lombardo et al., 2009).

A methodology currently exists to improve upon the aforementioned limitations of the current map. These improvements are bolstered by the use of datasets from the Integrated Surface Hourly (ISH) database as provided by NOAA (ftp://ftp.ncdc.noaa.gov/pub/data/noaa/). This database contains approximately 1200 stations across the US with 5+ years of data, including approximately 1000 having 10+ years of data and approximately 400 stations with 25 to 40 years of data. The ISH data also contains information on storm type, which has been used in a NIST developed extraction program, ASOS-WX (http://www.itl.nist.gov/div898/winds/asos-wx/asos-wx.htm). ASOS-WX also includes an algorithm to reduce the correlation between wind speed data for use in extreme value analysis. In addition to extraction of winds and separation by storm type, an updated version of ASOS-WX soon to be publicly available can also standardize wind speed data by using available information on anemometer location, type and elevation changes as well as averaging time and roughness information. The updated version will also utilize NOAA databases to eliminate tropical storm and hurricane wind speeds as they may affect extreme wind climatological analyses.

Quality controlled databases produced from ASOS-WX for approximately 1200 stations will be available on the NIST website (http://www.nist.gov/wind). Information described above (e.g., anemometer elevation histories) used to produce the wind speed databases will also be available. Directional event databases consisting of directional histories for each independent windstorm are also available and will be used in conjunction with other ongoing NIST projects (Yeo, 2011).

Preliminary results with data generated using the methodology described above have shown significant distributional differences in storm types (i.e. different slopes of distributions represented on probability paper) as well as large variability amongst the same storm type, as illustrated in Figure 3. Areas where a certain storm type dominates the extreme wind climatology, and areas where mixed distributions are of importance, have also been identified, as shown in Figure 4a as regions with contributions of annual maximum wind speeds generated by thunderstorms. Also, significant station-to-station variability of extreme wind occurrences has been noted, suggesting spatial averaging is still necessary. Even after accounting for station-to-station variability, a distinct regionality of the extreme wind climate is evident. This regionality is illustrated in Figure 4b by two bold lines bracketing an area of higher wind speeds in the Central US at a 50 year mean recurrence interval. The preliminary map of Figure 4b, which represents estimates of 3-s wind speeds at 10 m above ground, was obtained using annual maxima only. It is not yet corrected for exposure and storm type (although tropical storm and hurricane wind speeds were removed from the records being analyzed). Heavy lines drawn on Figure 4b define a region with typically stronger winds than in the rest of the conterminous United States. Future work on developing the maps will include further characterization of the regionality of the extreme wind climate by techniques that leverage both spatial statistics and extreme value theory, developed in the NIST Statistical Engineering Division (Pintar and Lombardo, in review). Prior to employing such techniques, roughness estimates from both statistical formulations (Masters et al., 2010) and aerial photos will be provided for approximately 1200 stations to make additional, needed corrections to wind speed data. Additional manual quality control measures will also be taken, especially on the highest wind speed values, to ensure that the raw ISH wind reports are not in error due to anemometer malfunctions (e.g., birds landing on sensor). The NIST website will be populated with updated databases as available.

The NIST website will also have the capability for the user to specify mean recurrence intervals at any location specified by its longitude/latitude coordinates for both directional and non-directional databases. Such estimates can serve for the estimation of probabilities of exceedance of limit states other than those specified for design purposes.

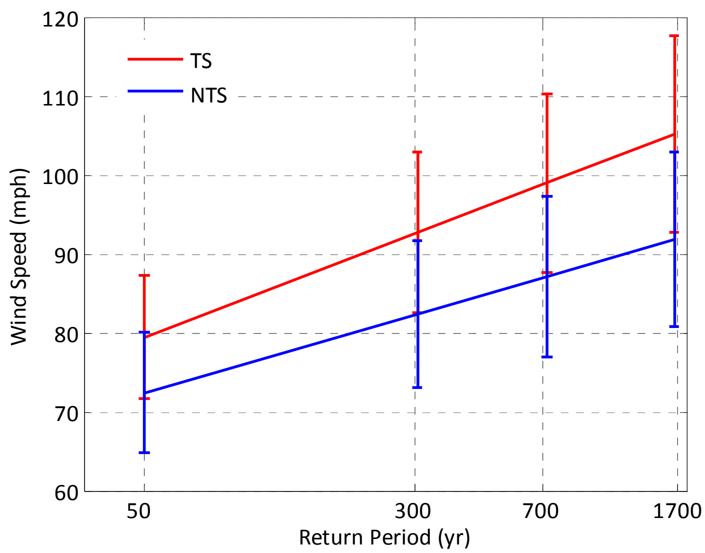

Figure 3. Mean and standard deviation of wind speeds at 50, 300, 700 and 1700 years using Gumbel distribution for 400 ISH stations that have 25+ years of both thunderstorm (TS) and non-thunderstorm (NTS) annual maximum data.

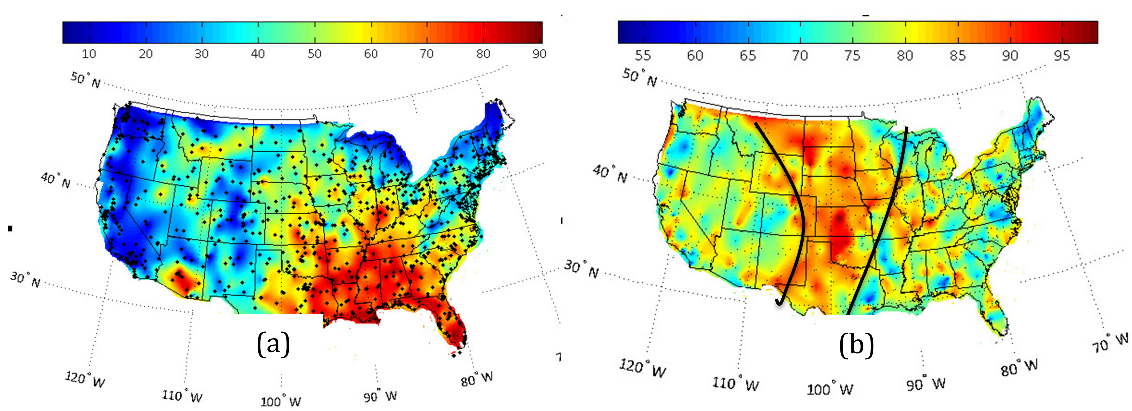

Figure 4. (a) Percent of annual maximum wind speeds generated by thunderstorms. (b) Preliminary estimates of 50-year wind speeds in mph; (1 mph = 0.447 m/s).

6. ESTIMATES OF HURRICANE-BORNE MISSILE SPEEDS

NIST developed a report (Simiu and Potra, 2011) intended to provide the technical basis for a potential new regulatory guide that would provide licensees and applicants with guidance that the staff of the U.S. Nuclear Regulatory Commission (NRC) considers acceptable for use in selecting the design-basis hurricane-borne missile speeds for the design of nuclear power plants. The design must prevent undue risk to the health and safety of the public in accordance with General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena," and General Design Criterion 4, "Environmental and Dynamic Effects Design Bases," of Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10, Part 50, of the *Code of Federal Regulations*, "Domestic Licensing of Production and Utilization Facilities."

The report documents the approach to and results of the calculation of hurricane-borne missile (i.e., wind-borne debris) speeds that may be considered in the design of nuclear power plants. The missile spectrum, the assumptions on which the analyses are based -- which are similar to assumptions used for the development of Revision 1 to Regulatory Guide 1.76, "Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants,"-- and the range of wind speeds being considered, were based on consultations between the authors and NRC staff. In addition, calculated missile speeds based on assumptions on the initial missile height above ground that differ from the assumption used in Revision 1 to Regulatory Guide 1.76 are included in Appendixes. The staff initiated this study because Revision 1 to Regulatory Guide 1.76 was based on the new Enhanced Fujita scale, in which tornado design-basis wind speeds are lower than in the earlier Fujita scale. The design-basis tornado wind speeds presented in Regulatory Guide 1.76 correspond to an exceedance probability of 10^{-7} per year. This report covers missile speeds that, under several hypotheses, could occur in hurricanes with 10^{-7} per year probability of exceedance wind speeds. Software for estimating speeds and trajectories for different types of hurricane-borne missiles is available at http://www.itl.nist.gov/div898/winds/mathematica/nrc.htm.

7. DISASTER AND FAILURE EVENTS REPOSITORY

NIST is creating a new research tool for archival and analysis of post-disaster data and information. The Disaster and Failure Events Data Repository will host a national archival database of significant hazard events, real-world performance of the built environment during those events, associated emergency response and evacuation procedures where appropriate, and the technical, social, and economic factors that affect pre-disaster mitigation activities and post-disaster response efforts. The repository will be accessible via the NIST Engineering Laboratory's Disaster and Failure Studies website (http://www.nist.gov/el/disasterstudies/). A comprehensive archival repository of disaster and failure data does not currently exist. Data that are gathered during and after an event may be lost or inaccessible relatively soon after. The repository will help ensure that this valuable information is organized and maintained to enable study, analysis, and comparison with subsequent disaster events that may not occur for many years. The data repository is being established in three phases:

- Phase 1 was deployed in the summer of 2011 and includes the publicly releasable data for the World Trade Center investigation conducted by NIST – see http://www.nist.gov/el/disasterstudies/repository_home.cfm. The website facilitates viewing and downloading the World Trade Center dataset which includes over 90000 photos, videos and other documents collected during the investigation.

- Phase 2 is a pilot repository of data collected from the 2010 Chile earthquake. This is scheduled to be completed in late 2012, and will be available at the same website. The Chilean data repository pilot is being developed for NIST based on the HUBzero technology developed at Purdue University. HUBzero is an innovative platform used to create dynamic web sites for scientific research and educational activities (http://hubzero.org/). HUBzero is also employed by the NSF-funded Network for Earthquake Engineering Simulation (http://www.nees.org).

- Phase 3 will include a larger repository of hazard events (earthquakes, hurricanes, tornadoes, windstorms, community-scale fires in the wildland-urban interface, structural fires, storm surges, floods, and tsunamis) and man-made hazards (accidental, criminal, or terrorist). It will also include (1) developing a cost estimate to implement and maintain a production version of the repository, (2) selection of the operating platform, (3) finalizing user requirements including processes for data input, organization, tagging and release to the public, (4) building the production repository to meet system architecture requirements including those for input of data and IT security requirements commensurate with risk levels and data sensitivity, (5) finalization of the minimum data and quality requirements, and (6) populating the repository with selected high-impact historical and future events. It is envisioned that data from future events would also come from agencies and organizations outside of NIST.

The envisioned Phase 3 plan initially focuses on recent and future disaster and failure events, especially those in which NIST has a role in the study. As the first implementation of Phase 3, NIST is creating a repository of the publically-releasable data used in its current NIST study of the May 22, 2011 Joplin Tornado. The Joplin Tornado repository will likely include data and information such as geolocated still and video imagery of building and community damage (including ground and aerial imagery), damage data, wind data, modeled tornado wind field, tornado climatology of the region, and other data as available. The Joplin Tornado repository will be available at the Joplin tornado study webpage after the completion of the project (http://www.nist.gov/el/disasterstudies/weather/joplin_tornado_2011.cfm).

Future plans for the Repository call for archival of data from selected significant events from the past few decades. This data repository effort will also support the development of standards and new technologies for efficient and effective collection of data on disaster and failure events.

REFERENCES

American Society of Civil Engineers (ASCE) (2010). *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-10, 2006, Reston, VA.

Coffman, B.F., Main, J.A., Duthinh, D., and Simiu, E. (2010). “Wind Effects on Low-Rise Metal Buildings: Database-Assisted Design versus ASCE 7-05 Standard Estimates,” *J. Struct. Eng*., 744.

Fritz, W.P., Bienkiewicz, B., Cui, B., Flamand, O., Ho, T.C.E., Kikitsu, H., Letchford, C.W., and Simiu, E. (2008), “International Comparison of Wind Tunnel Estimates of Wind Effects on Low-Rise Buildings: Test-Related Uncertainties,” *J. Struct. Eng*. 1887.

Fu, T.-C., Aly, A.M., Gan Chowdhury, A., Bitsuamlak, G., Yeo, D., and Simiu, E. (2012). “A proposed technique for determining aerodynamic pressures on residential homes,” *Wind and Structures*, 27.

Gomes, L. and Vickery, B.J. (1977). “Extreme wind speeds in mixed climates”, *J. Ind. Aerodyn.*, **2**, 331.

Heckert, N.A., Simiu, E., and Whalen, T.A. (1998). "Estimates of Hurricane Wind Speeds by the 'Peaks Over Threshold' Approach," *J. Struct. Eng.,* **124,** 445.

Lombardo, F.T., Main, J.A., and Simiu, E. (2009). “Automated extraction and classification of thunderstorm and non-thunderstorm wind data for extreme value analysis”, *J. Wind Eng. Ind. Aerodyn.*, 97, 120.

Lombardo, F.T. (2012). “Improved wind speed estimation for wind engineering applications”, *J. Wind Eng. Ind. Aerodyn.*, available online.

Masters, F., Vickery, P., Bacon, P., and Rappaport, E. (2010). “Towards objective, standardized intensity estimates from surface wind speed observations”, *Bull. Amer. Met. Soc.*, **12**, 1665.

Peterka, J.A. and Shahid, S. (1998). “Design Gust Wind Speeds in the United States”, *J. Struct. Eng.*, **124**, 207.

Pintar, A. and Lombardo, F.T. (in review). “Mapping return values of extreme wind speeds”, *Risk Assessment and Evaluation of Predictions*.

Simiu E. (2011). *Design of Buildings for Wind*, 2nd Ed., Hoboken: Wiley.

Simiu, E., Gabbai, R. D., and Fritz, W. P. (2008). “Wind-induced tall building response: A time-domain approach,” *Wind and Struct*., 427.

Simiu, E., Bitsuamlak, G., Gan Chowdhury, A., Li, R., Tecle, E., and Yeo, D. (2011). “Testing of Residential Homes Under Wind Loads,” *ASCE Nat. Haz. Rev*., 166.

Simiu, E., and Potra, F.A. (2011). *Technical Basis for Regulatory Guidance on Design-Basis Hurricane-Borne Missile Speeds for Nuclear Power Plants* (NUREG/CR-7004), U.S. Nuclear Regulatory Commission, Rockville, MD. http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr7004/

Spence, S.M.J. (2009). *High-Rise Database-Assisted Design 1.1 (HR_DAD_1.1): Concepts, Software, and Examples, NIST Building Science Series 181.* http://www.itl.nist.gov/div898/winds/pdf_files/BSS181.pdf

St. Pierre, L. M., Kopp, G. A., Surry, D., and Ho, T. C. E. (2005). "The UWO contribution to the NIST aerodynamic database for wind loads on low buildings: Part 2. Comparison of data with wind load provisions." *Journal of Wind Engineering and Industrial Aerodynamics*, 93(1), 31-59.

Vickery, P.J., D. Wadhera, D., and Twisdale, L.A., (2011). *Technical Basis for Regulatory Guidance on Design-Basis Hurricane Wind Speeds for Nuclear Power Plants* (NUREG/CR-7005), U.S. Nuclear Regulatory Commission, Rockville, MD. http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr7005/

Yeo, D. (2010a). *Database-Assisted Design of high-rise reinforced concrete structures for wind: Concepts, software, and application*. *NIST TN 1665.* http://www.itl.nist.gov/div898/winds/pdf_files/NIST_TN_1665_HR_DAD_RC.pdf

Yeo, D. (2010b). *Numerical simulation of along-wind loading on small structures using a simplified wind flow model. NIST TN 1683*. http://www.itl.nist.gov/div898/winds/pdf_files/NIST_TN_1683_Yeo1.pdf

Yeo, D. (2011). "Database assisted design for high-rise structures in mixed extreme wind climates", *Proc., 13th Intl. Conf. on Wind Engineering*, Amsterdam.

Yeo, D., and Simiu, E. (2010). *Effects of veering wind and structure orientation on a high-rise structure*. *NIST TN 1672.* http://www.itl.nist.gov/div898/winds/pdf_files/NIST_TN_1672_Yeo_Simiu.pdf

Yeo, D., and Simiu, E., (2011). "High-rise reinforced concrete structures: Database-Assisted Design for wind," *J. Struct. Eng*., **137**, 11, 1340.