CYBERBASED ANALYSIS, MODELING AND SIMULATION OF WIND LOAD EFFECTS IN VORTEX-WINDS

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1. Introduction

Wind-related catastrophes (e.g., hurricanes, tornadoes, thunderstorms/downbursts) inflict enormous devastation on the built environment and result in a staggering number of fatalities. To better manage the impact of extreme wind events, a new culture of resilience needs to be developed based on innovative design solutions. By harnessing new technologies, quality of life and economic strength can be improved. The concept of shared resources is at the center of any plan and includes the exchanging of databases, computational and experimental resources, and full-scale data, as well as participating in collaborative research. Current examples of networked facilities for hazard reduction are the Network for Earthquake Engineering Simulation (NEES) (Van Den Einde et al., 2007). These facilities have made high-end resources accessible to groups otherwise limited by their personal research tools allowing them to expand the scope of their research to address complex problems. A similar model in the area of wind effects that shares resources and includes global engagement with centers of research, education, and design would result in similar productive advances.

The interdisciplinary nature of wind effects on structures requires a knowledge base from a number of subject areas, including structural engineering, engineering mechanics, probabilistic methods, fluid dynamics, turbulence, structural dynamics, experimental methods and risk and reliability, to better quantify the load effects (e.g., Simiu and Scanlan, 1996; Kareem, 2005). Under this umbrella, reliance is on analytical (Chen and Kareem, 2003, 2005), computational (Kareem, 1987; Yu and Kareem, 1998; Fluent, 2006; Kareem, 2008; OpenFOAM, 2011), and experimental tools (Denoon et al., 2001; Bi and Smith, 2005; Burton et al., 2006; Sarkar et al., 2006; Butler and Kareem, 2007), full-scale measurements (Kareem, 1985, 1986; Main and Jones, 1999; Tamura et al., 2002; Masters et al., 2003; Jain and Smith, 2003; Satake et al., 2003; Campbell et al., 2004; Gurley et al., 2005; Smith et al., 2005; Kijewski-Correa et al., 2006a, 2006b; Kwon et al., 2010), codes and standards (SA/SNZ, 2002; AIJ, 2004; BSI, 2004; ASCE, 2005; NRC, 2005; Tamura et al., 2005; ISO, 2009), and databases (Simiu et al., 2003; Zhou et al., 2003; Cheng and Wang, 2004; Cheng et al., 2007; Kwon et al., 2005, 2008; NIST, 2006; TPU, 2011; FCMP, 2011; NIST, 2011). This presents a large set of subject areas and topics worthy of an Engineering Virtual Organization (EVO) to help assimilate information and resources into a publicly-accessible collaboratory. The resulting EVO would serve as an end-to-end system that integrates domestic and international community resources to facilitate an effective, transformative, and conveniently accessible venue for the acceleration of advances in research and development, as well as teaching and learning, in the area of wind effects.

Despite many advances in the area of wind effects on structures in recent decades, research has been conducted with limited resources scattered physically throughout universities, government, and private research laboratories as well as industry and trade organizations. With the trend toward increasingly complex designs such as free form architectures and the escalating potential for losses in coastal communities, the old paradigm is no longer optimal and requires the pooling of resources through a virtual organization reliant on cyberinfrastructure (CI). By centralizing tools and services within a flexible CI architecture to support research and education objectives in real-time, this synergistic, integrative approach offers efficacious tools that the community can use to minimize windstorm damage and meet the challenges posed by burgeoning emergence of wind sensitive structures in expanding urban and suburban locales.

Interestingly, other technology fields are fast recognizing the potential impact of virtual organizations, as evidenced by digital airports and, more recently, digital oil fields, which involve effective gathering, analyzing, and visualization of data in real-time during drilling to quickly react to problem spots as they are detected (Holland and Campbell, 2007). This is serving as a catalyst to gain competitive advantage over others in a business with astronomical stakes. Similarly, the structural engineering field is currently at the dawn of a new information technology (IT) known as Building Information Modeling (BIM), which promises to revolutionize the design and construction of buildings. Building Information Models are 3-D, smart, parametric e-models of buildings that are shared by a team of designers and builders to facilitate the exchange and interoperability of information in a digital format. While BIM addresses the visualization and information exchange associated with structural projects, it possesses limited if any advanced analytical resources requisite for the design process. Certainly, the enormous reported losses from wind-related events and the increased sensitivity of freeform and super tall buildings, long-span bridges, and deep water offshore platforms to wind make it an ideal hazard for an EVO providing these much needed design tools.

An engineering virtual organization (EVO) would enable such a paradigm shift by offering real-time shared access to geographically dispersed resources for more effective research and education to achieve improved understanding and modeling of wind effects on structures. This paper summarizes such a program recently launched by the authors to develop a prototype EVO, **V**irtual **O**rganization for **R**educing the **T**oll of **EX**treme **Winds** (**VORTEX-Winds**). The goals of this initiative are (i) to establish and sustain such a virtual community for wind hazard mitigation; (ii) to enhance this community's analysis and design capabilities to address next generation challenges posed by wind; and (iii) to facilitate education and training of the future workforce in the field. The steps toward the former goal have already been initiated through the collection of the field's leading universities, organizations, firms and government agencies to form this prototype collaboratory and their commitments to contribute their resources. The latter two goals will be accomplished through the formation of a virtual organization utilizing cyberinfrastructure technologies to stitch these geographically dispersed e-analysis and design modules encompassing Database-Assisted Design, Full-Scale Data, Stochastic Tools, Tele-Experimentation, Uncertainty Modeling, Damage Assessment, and Computational Platforms. The prototype EVO will allow access to the modules, while the fully functional EVO will also have the capability for automated, integrated analysis and design using multiple modules. In addition, both the prototype and full version of the EVO will offer an interactive knowledge base intended to aggregate and centralize the shared knowledge of the collaboratory, including a wind-wiki, damage database, help desk/FAQ, bulletin boards and curriculum tools to facilitate dissemination and education.

2. Overview of VORTEX-Winds

In order to mitigate escalating damage to property, loss of lives and disruption of local economies (AAWE, 2004; Burton et al., 2006; Prietula et al., 2007), a new research, teaching and design paradigm is proposed addressing wind effects on structures through the formation of a virtual organization utilizing an integrated cyberinfrastructure technologies, VORTEX-Winds (Figure 1). Wind hazards would particularly benefit from this paradigm given the reliance on experimental and empirical data in the design process.

Figure 1. Front page of VORTEX-Winds portal

Vision and goals

The basic vision of VORTEX-Winds is the development a comprehensive gateway for research and education to achieve improved understanding and modeling of wind effects on structures to counter the escalating loss of property and associated indirect losses and the increase in the sensitivity of emerging structural systems to winds. In response to this vision, the authors have established a virtual organization employing integrated cyberinfrastructure-based system that facilitates real-time, shared access to integrated design aids and services using geographically dispersed databases, specialized design/analysis tools, experimental facilities and full-scale monitoring networks, as well as providing a knowledge-base, with the following goals:

(i) To establish and sustain a community contributing to and employing the resources integrated by cyberinfrastructure technologies to facilitate the mitigation of escalating damage, loss of lives and disruption of local economies posed by wind;

(ii) To enhance analysis and design capabilities to address the challenges of innovative structural systems needed to realize, in a cost effective manner, buildings with ever increasing heights, bridges that span oceans, and offshore platforms tapping hydrocarbons in deeper waters exposed to weather extremes like hurricanes;

(iii) To facilitate education and training of the future workforce in the field so that the growing competition in the global market is met through a cadre of well trained professionals and educators.

Structure & Shared Resources

The EVO structure is conceptually defined in Figure 1 as having two branches: the e-analysis and design modules and the Knowledge Base. The e-analysis and design modules are harvested from the independent work of a number of universities (largely supported by federal funding) and NIST and will be classified into seven divisions. These seven divisions are *Database-Assisted Design, Full-Scale/Field Site Data Repository, Statistical/Stochastic Toolboxes, Tele-Experimentation Services, Uncertainty Modeling, Damage Assessment*, and *Computational Platforms.* Examples of the modules offered within each of the divisions are shown in Figure 2. As discussed later in this paper, the modules can be interrogated independently or automatically queried and input into an integrated analysis and design approach. This integrated approach mimics the traditional off-line analysis and design processes, pooling contributions from a number of different disciplines. The second branch of VORTEX-Winds is the knowledge base intended to aggregate and centralize the shared knowledge of the collaboratory. Services in this area include the virtual encyclopedia or *wind-wiki* encompassing basic terminology and concepts pertaining to wind-structure interaction, a *damage database* (curated archives of post-disaster reconnaissance, e.g., Kareem, 1985, 1986), a *help desk*, where users can submit a question to the collaboratory and where past responses are archived as FAQs, *bulletin boards* hosting open discussions, *email list servers* for rapidly circulating announcements and other information, and *curriculum tools* to provide educators a means to formally integrate EVO services into their teaching. The knowledge base material will be broadly classified into 4 major areas: *Engineering Micrometeorology; Aerodynamics and Aeroelasticity; Structural Dynamics; Experimental Methods; Performance Evaluation (*encompassing Risk/Reliability and Codes/Standards).

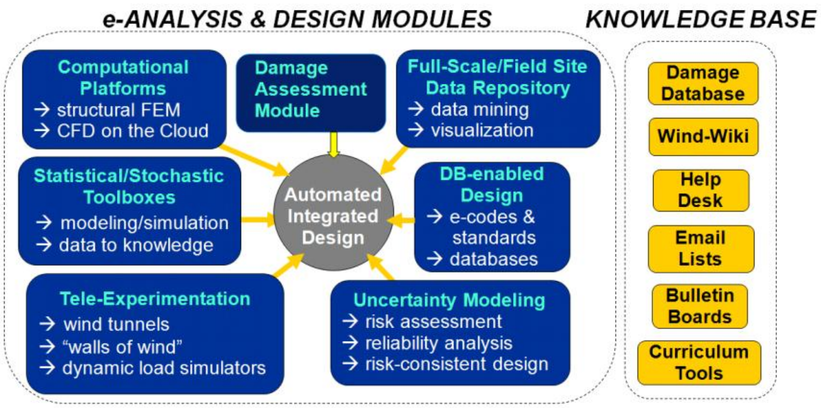

Figure 2. Schematic of VORTEX-Winds capabilities

Participants

Members: *Members* of the EVO will explicitly provide some shared resource in support of the stated mission. This diverse collection of resources includes aerodynamic and damping databases, wind load and response simulators and tunnels, computational fluid dynamics (CFD) platforms and real-time streaming meteorological (met) data. Most of these resources will come from leading universities in the area of wind effects on structures and generally have been the result of federal or state funding. A number of federal agencies are also poised to contribute to the EVO, including National Institute of Standards and Technology (NIST) and National Oceanic and Atmospheric Agency (NOAA). Members obtain this status after successfully contributing to the EVO. As a result, they will take a primary role in the governance of the organization.

An effective strategy for self-organization and governance is required to insure a collaboratory that is reputable, sustainable and technically reliable. This aspect of the EVO is particularly important due to the unique challenges that arise when pooling diverse resources that span institutional, cultural and professional boundaries. As such, VORTEX-Winds has adopted many of the proven organization and governing strategies that have already been accepted in professional circles around the world. The initial membership of the EVO has already been populated by many of the world's leading university research centers, laboratories and NIST specializing in wind effects on structures. These researchers agree to provide modules in support of the prototype, to contribute to the knowledge base, and serve as end users of the services in their educational endeavors.

End Users: While the collaboratory members plan on using the shared resources to further their own research and educational missions, a number of other end users have also been identified within the community. *End users* are defined as those accessing the various services offered by the EVO, but not directly contributing to them. This class of participants is primarily associated with designers of structures with particular sensitivity to wind effects, such as tall buildings; however, the EVO will also reach out to educators as another category of end users. Other private sector entities, such as wind tunnels and risk analysis firms, may also become end users of various modules within VORTEX-Winds. All persons accessing the EVO (as end users or members) will be required to register, which will not only streamline operations, but will also gather data important to the evaluation and assessment of the EVO's impacts.

A selective group of end users has also been identified and will help to drive the services and features of the EVO and beta test the prototype developed. These private sector end users are leading design firms: Skidmore Owings and Merrill LLP (Chicago, USA), Samsung Corporation (Seoul, Korea), LERA (New York, USA), Shimizu Corporation (Tokyo, Japan), McNamara-Salvia (Boston, USA) and Weidlinger (Los Angeles, USA).

Stakeholders: *Stakeholders* indirectly benefit from the EVO through the actions of members and end users using the VORTEX-Winds' services to improve wind-resistant design. These stakeholders represent all who benefit from safer civil infrastructure. Obvious examples of stakeholders include risk management firms like Aon, Institute of Business and Home Safety (IBHS) and Risk Management Services (RMS), the wider professional community representing end users, such as Council on Tall Buildings and Urban Habitat (CTBUH), American Association for Wind Engineering (AAWE), and American Society of Civil Engineers' (ASCE) committee on Tall Buildings and Technical Council on Wind Engineering, and organizations dealing with codes and standards, such as the International Code Council (ICC). However, all of society, as users of civil infrastructure, would benefit from more wind-resistant structures and thus also become indirect stakeholders.

Conceptual CI Design

VORTEX-Winds envisions to include all aspects of cyberinfrastructure support capabilities for the wind effects on structures research and engineering community, including: 1) communication tools to support collaboration, 2) high performance computational infrastructure, 3) data storage, data mining, visualizations, and data warehousing, and 4) access to remote sensors and tele-experimentation. As a result, VORTEX-Winds will ultimately offer three levels of functionality:

a) Level 1: Knowledge Base Queries – these would be handled within the Knowledge Base's resources such as the help desk, Wind-Wiki or bulletin boards.

b) Level 2: Module Stitching/Integration – utilization of specific e-analysis and design modules, e.g., retrieval of wind field data from the data repository for a specific region.

c) Level 3: Integrated Analysis and Design – integrated analysis and design using multiple modules, e.g., online execution of basic wind-resistant design with computation hosted by the EVO and automated queries to multiple modules as shown in Figure 3.

These services will be hosted on the front-side by a single gateway server, with computation and analysis conducted on backside parallel servers. With the organizational and governance structure of VORTEX-Winds already defined, the primary technical hurdle is in achieving the three levels of functionality introduced in the previous section. This will require significant effort and coordination, particularly with respect to the integrated design feature. As a result, the prototype deployment that will be pursued in this study will establish the basic components of the Knowledge Base and stitch together a number of geographically distributed resources representative of the seven module divisions identified in Figure 2. At this stage, VORTEX-Winds has been focused on the achievement of the Level 2 functionality. The next section will discuss more detailed information about a highlight of CI modules for analysis, modeling and simulation modules of wind load effects on structures.

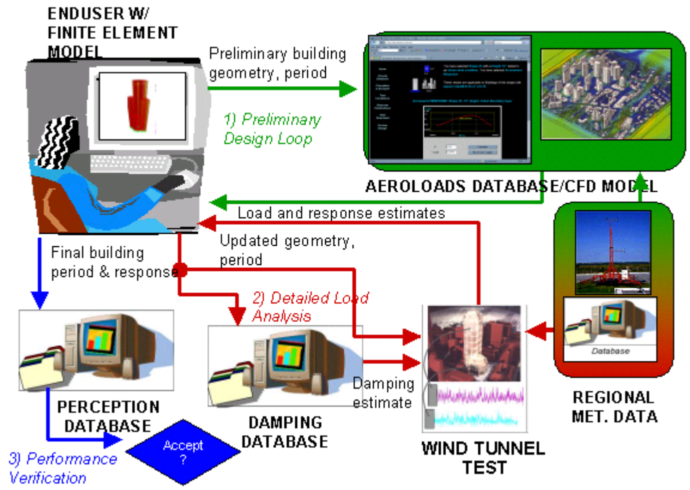

Figure 3. Schematic of integrated analysis and design concept

3. Cyberbased analysis, modeling and simulation modules of wind load effects in the VORTEX-Winds

Damage Database in the Knowledge Base

The Damage Database is a digital repository of reconnaissance documenting damage to structures during wind events such as hurricane/typhoon/cyclone, tornado, thunderstorm/downburst, extratropical winds etc. This has been established based on a typical database-query method and powered by Google Map/Earth API, which allows users to geographically view submissions of fellow VORTEX-Winds members, sorting by location, event classification and damage attributes (Figure 4). User can search damage archives either by pointing a spot in the Google map or by using query-criteria in the right side of the map. Each damage report is comprised of wind event on damage, maximum wind speed, damage location in either address or GPS coordinates, structural properties, damage photos etc. which registered members can upload their own damage reports to the database via a user interface (Figure 5). It is envisioned that the database will be enriched more with members' contributions.

Figure 4. User interface of Damage Database: damage archive in the Google map and query-based database search (left); damage information with photos (right).

NatHaz Aerodynamic Loads Database in the Database-Enabled Design

Most international wind codes and standards traditionally have relied on reductive formats and simplifications, which often lead to tables and plots that describe wind loads on structures. The level of accuracy inherent in codification information in this format and the uncertainty associated with interpolation or extrapolation of information may compromise the overall accuracy in code-specified load effects. This has led to database-enabled design procedures, which offer convenient meshing with existing analysis software. Primarily, such databases rely on wind tunnel-derived data, which may be couched in analysis portals to provide desired load effects.

Figure 5. User interface for uploading damage report in the Damage Database

The NatHaz Aerodynamic Loads Database (NALD) introduced in 2000 has served an important first step in establishing an on-line experimental archive of high frequency base balance (HFBB) data for use in the preliminary design of high-rise buildings subjected to wind loads. As a result, NALD was recently introduced in the Commentary of ASCE 7-05 (C6.5.8) as an alternative means of assessing the dynamic wind load effects on high-rise buildings. The NALD ver. 2.0 has integrated the latest advances in data management and mining for interactive queries of aerodynamic load data and an integrated on-line analysis framework for determining the resulting base moments and equivalent static wind loads (ESWL) for survivability and accelerations for serviceability (habitability). The key feature of NALD ver. 2.0 is the flexibility its analysis module offers: users may select not only the data from the on-line NatHaz aerodynamic loads database, but also may input desired power spectral density (PSD) expression or wind tunnel-derived PSD data set obtained from HFBB experiment for the evaluation of wind load effects on high-rise buildings. Thus it serves as a stand-alone analysis engine. The NALD ver. 2.0 provides a platform that can be readily expanded and supplemented to yield a comprehensive, simplified and efficient avenue for e-analysis of high-rise buildings. The architecture of NALD ver. 2.0 and the role of various web-based tools are summarized in Figure 6 and more detailed information can be found in Kwon et al. (2005, 2008).

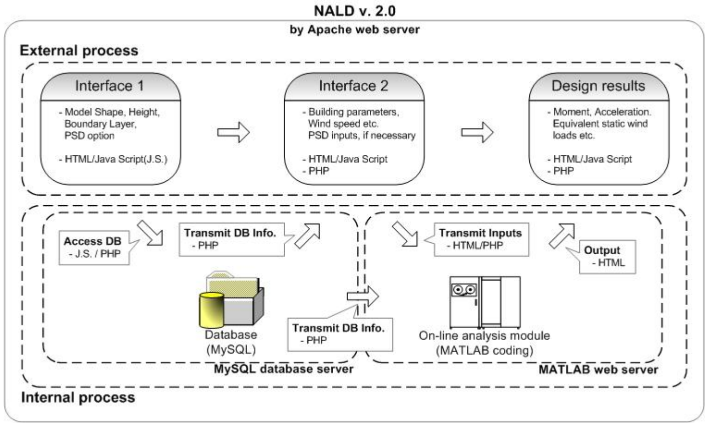

Figure 6. Diagram of NALD ver. 2.0 architecture

NatHaz Gust-front factor in the Database-Enabled Design

In comparison with atmospheric boundary layer winds, which are customarily treated as stationary, winds associated with gust-fronts originating from a thunderstorm/downburst exhibit rapid changes during a short time period which may be accompanied by changes in direction. This introduces nonstationarity both in the mean and the standard deviation of wind fluctuations. In order to realistically capture characteristics of gust-front winds and their attendant load effects, a new analysis framework is presented which is named here as the gust-front factor approach. This is akin to the gust loading factor format used in codes and standards world-wide for the treatment of conventional boundary layer winds. The gust-front factor expresses a generalized description of the genesis of the overall wind load effects on structures under both gust-front and boundary layer winds and it reduces simply to the gust loading factor for the case of conventional boundary layer winds. This approach encapsulates both the kinematic and dynamic features of gust-front induced wind effects on structures which distinguish themselves from those experienced in conventional boundary layer flows, i.e., variation in the kinematics of the velocity profile and its effects on the associated aerodynamics; dynamic effects induced by the sudden rise in wind speed; non-stationarity of turbulence in gust-front winds; transient aerodynamics (Figure 7).

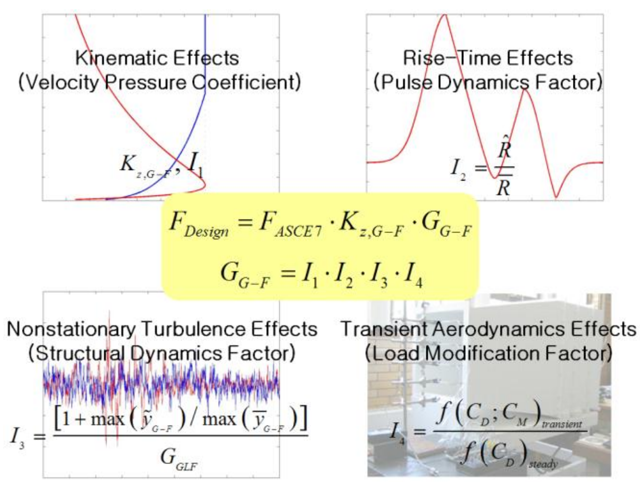

Figure 7. Schematic diagram of gust-front factor framework

To facilitate expeditious utilization of this framework in design practice and inclusion in codes and standards, the analysis framework and its workflow is introduced within a web-based portal. This eliminates the need for an in-depth understanding of the background within the framework and the need for associated computational effort. The portal has a user-friendly interface, permitting convenient analysis of several design scenarios with a host of potential loading conditions including the current ASCE 7-05 procedure in boundary layer winds for immediate comparison. More detailed information can be found in Kwon and Kareem (2007, 2009).

<u>NatHaz on-line wind simulator in the Statistical/Stochastic Toolboxes</u>

The NatHaz On-line Wind Simulator (NOWS) provides user with on-line simulation of stationary Gaussian multivariate wind fields for the longitudinal direction on-the-fly. With the help of rapid development of Internet/information technologies, the NOWS enables user to simulate stationary random wind fields at any time/space through network-enabled computer system and a general web browser such as Internet Explorer, Firefox etc. In addition, intuitive user-friendly interface and result interface makes user easy to input any terms and to check simulation results such as display of simulated wind histories. This web framework features supporting both Metric (SI) and English units as input/output with on-line unit converter, location inputs for vertical, horizontal or arbitrary 2-D coordinates, ASCE 7-based mean wind calculation in terms of terrain roughness to minimize user's input, offering to download simulation results providing user with further off-line analysis such as structural dynamic analysis under wind loads.

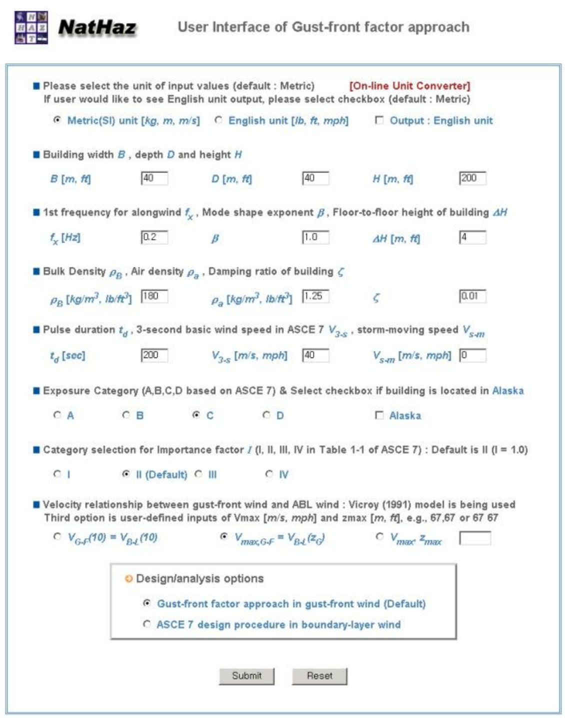

Figure 8. Web-based on-line gust-front factor framework : user interface

In particular, one unique feature of this on-line analysis module is the flexibility for user to choose one of four simulation schemes such as Discrete frequency function with FFT (Wittig and Sinha, 1975), Schur decomposition approach with autoregressive (Di Paola, 1998; Di Paola and Gullo, 2001), Ergodic spectral representation method (Deodatis, 1996; Ding et al., 2006) and Conventional spectral representation method (Shinozuka and Deodatis, 1991). Modified Kaimal spectrum is adopted for the PSD of longitudinal wind velocity fluctuations (Kaimal et al., 1972; Simiu, 1974), and Davenport coherence function (Davenport, 1967) is utilized to describe spatial correlation in the frequency domain. The user and results interfaces are given in Figure 9.

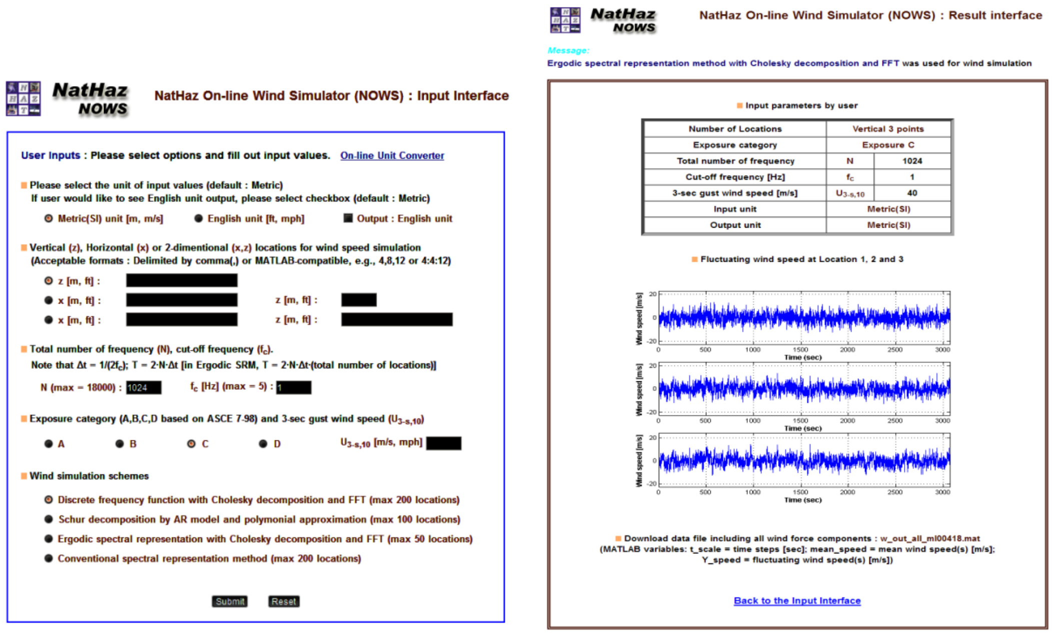

Figure 9. NatHaz on-line wind simulator (NOWS): user (left) and result (right) interfaces

VORTEX-Winds on-line wind simulator in the Statistical/Stochastic Toolboxes

The VORTEX-Winds on-line wind simulator (VOWS) offers wind simulations for three directions such as the longitudinal (*u*), lateral (*v*) or vertical (*w*) atmospheric turbulence components of winds. The wind profile is described by logarithmic law, which this framework accepts one of four different inputs such as friction velocity & roughness length, reference velocity at 10 m & roughness length, Eurocode (BSI, 2004) based inputs, and mean wind velocity & standard deviation/integral length scale of wind components. In addition, users can select one of three wind turbulence components (*u*, *v* or *w*) to be simulated (Carassale and Solari, 2006). Similar to NOWS, VOWS also offers to download simulation results as a file in the result interface, in addition to a comparison between target and simulated PSD for verification (Figure 10).

The VOWS is established in collaboration between Dr. Luigi Carassale, Univ. of Genoa (Italy) and NatHaz Modeling Laboratory, Univ. of Notre Dame (USA), which is the first international collaboratory to develop a cyberbased module in the VORTEX-Winds.

Damping database in the Data Repository

Despite the advancements that have been made in structural engineering in the last century, one critical parameter, damping, remains the complexity which is in part due to the diversity of sources contributing to the overall energy dissipation capability. The shortcomings of assuming viscous damping levels became apparent with the transition to light and flexible structures, as assumed levels of damping, on the order of 1% critical damping for steel structures and 2% for concrete, were often not realized in the constructed building. For this class of tall, wind-sensitive structures, the diminished levels of damping realized in practice led to a host of serviceability and especially habitability problems that were not anticipated in design. The resounding difficulty in engineering known levels of damping in design was partly responsible for the flurry of auxiliary damping devices in recent years, which were found to provide measurable and controllable levels of this critical parameter (Kareem et al., 1999).

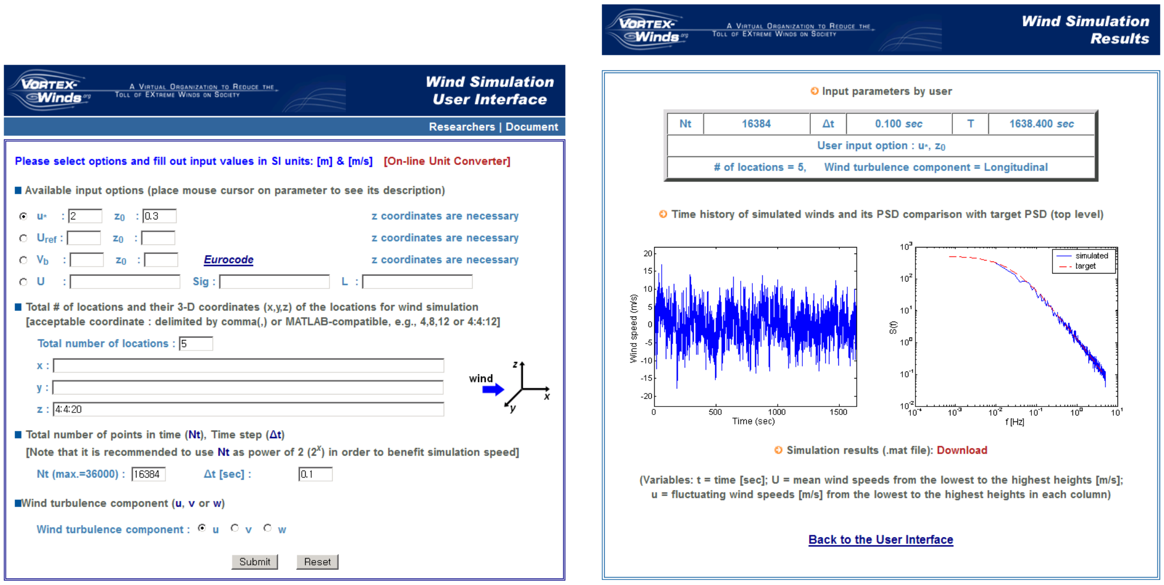

Figure 10. VORTEX-Winds on-line wind simulator (VOWS): user (left) and result (right) interfaces

The Damping database is an initiative project to provide users with on-line damping information for various building structures in terms of query-based module. The query parameters include not only building information such as cross-sectional shapes, widths, depths and heights but also test excitations, damping estimation methods, ranges of damping ratios etc. (Figure 11). This database is currently established with the Japanese damping data sets (AIJ, 2000; Satake et al., 2003), however, it is expected that the contents will be expanded with other damping data in the future.

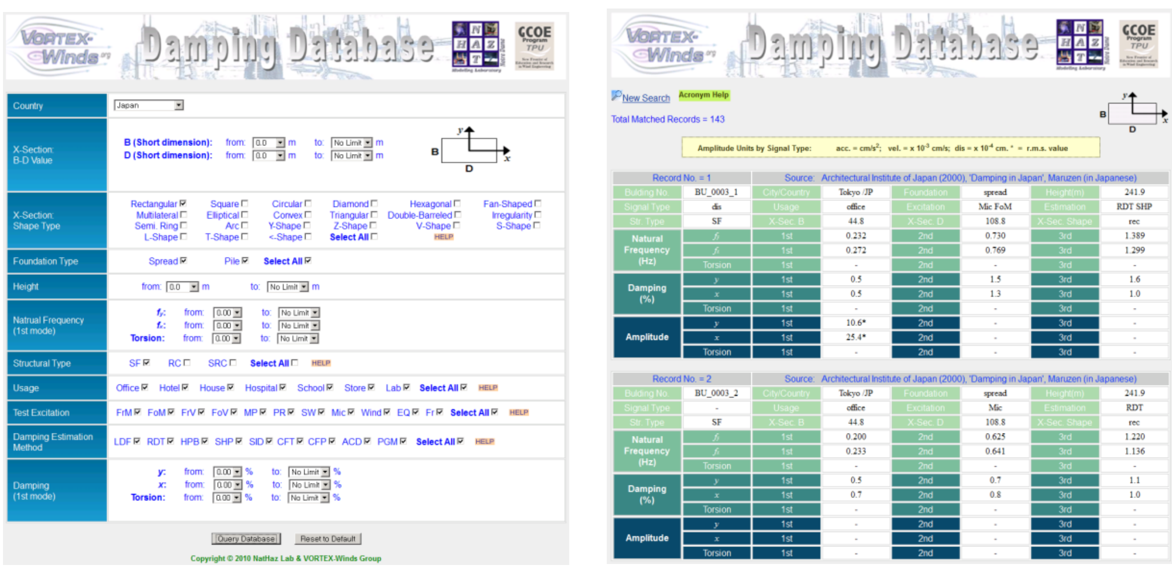

Figure 11. Damping Database: database-query (left) and result (right) interfaces

Database-enabled design module – high-rise in the Database-Enabled Design

The Database-enabled design module – high-rise (DEDM-HR) provides a web-based on-line tool for the preliminary design of high-rise buildings subjected to wind loads utilizing experimental archives of HFBB results, similar to NALD ver. 2.0 described earlier. It offers building response estimates, i.e., base moments, maximum displacements & accelerations, and equivalent static wind loads (ESWL) etc. (Fig.

10). This e-module offers a unique feature, accommodating multiple data sets in collaboration with other research groups to overcome a limitation of database-enabled design procedure being a lack of data sets. Note that the DEDM-HR utilizes an advanced approach, distributed databases, which a central server communicates with multiple databases in terms of advanced IT solutions. This is more efficient way not to modify pre-existing web servers located in other regional/international groups, especially in view of disparate web server environments each other. Currently, the DEDM-HR is associated with two databases: one is NatHaz database from NatHaz modeling laboratory, University of Notre Dame, USA, which is the same with the one used in the NALD (Zhou et al., 2003; Kwon et al., 2005, 2008), and the other is Tamkang database from Wind Engineering Research Center (WERC), Tamkang University, Taiwan (Cheng and Wang, 2004; Cheng et al., 2007). Accordingly, the DEDM-HR offers data that pools information from both sources, thus expanding the range of building configurations and exposures. The examples of user and result interfaces are shown in Figures 12 and 13.

A bank of database involving synchronously measured pressure field around building surface is being developed to supplement the HFBB DEDM-HR. A schematic diagram is shown in Figure 14.

<u>Database-enabled design module – low-rise in the Database-Enabled Design</u>

The Database-enabled design module – low-rise (DEDM-LR) provides a web-based on-line tool for the preliminary design of low-rise buildings subjected to wind loads utilizing experimental archives of synchronous wind pressure measurements for a variety of models (Figure 15). The wind load associated with each of the pressure taps is distributed to the primary structural system at a number of discrete locations, i.e., the wind loads are distributed to the structural frames at the attachment points of girts and purlins which support the cladding panels. Time series of structural loads are obtained from the measured time series of wind pressures for each wind direction. Then, these pressure time series are utilized to compute peak wind effects of the structural frames corresponding to winds with various speeds and directions.

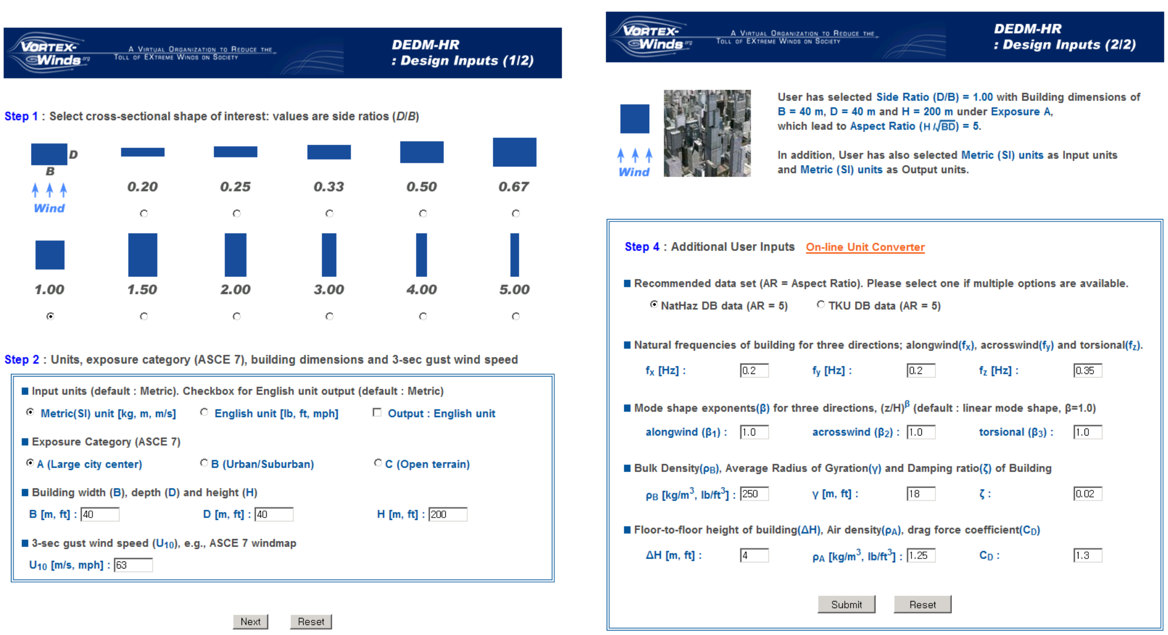

Figure 12. User interfaces of the DEDM-HR

The analysis codes are similar to WindPRESSURE software, which is an off-line codes provided by NIST (Main and Fritz 2006). The wind pressure data sets used in this DEDM-LR are TPU (Tokyo Polytechnic University, Japan) aerodynamic database which is available at http://wind.arch.t-kougei.ac.jp/system/eng/contents/code/tpu (TPU 2011). The TPU database contains numerous results of low-rise models for three roof types such as Gable, Hip and Flat and each model was tested in various wind directions. This project is in the progress of a beta testing and it is expected to be finalized in the near future. The user interface is shown in Figure 16.

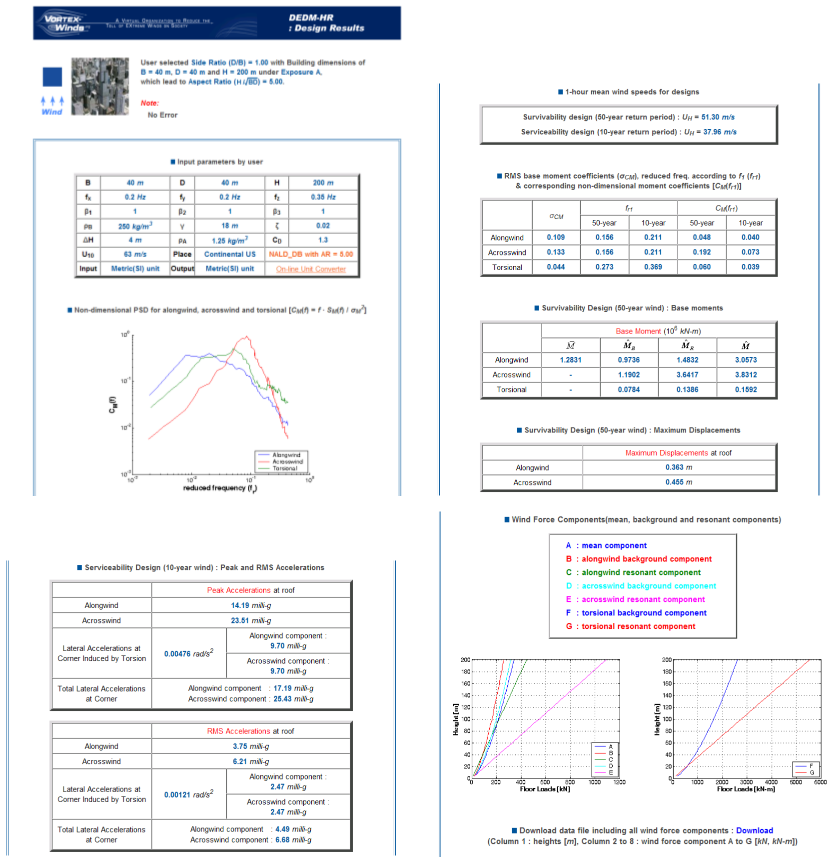

Figure 13. Result interface of the DEDM-HR

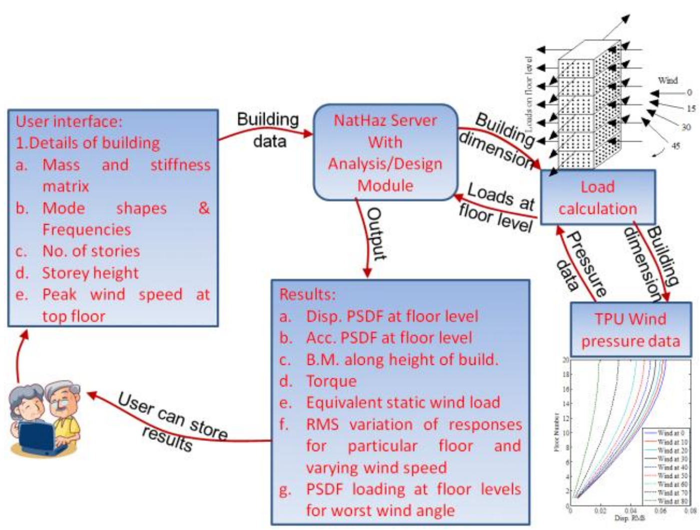

Figure 14. A schematic diagram of analysis of high-rise building using synchronous pressure data

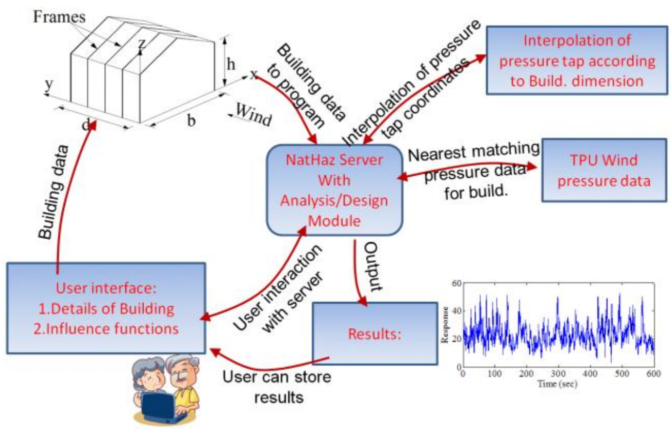

Figure 15. A schematic diagram of DEDM-LR

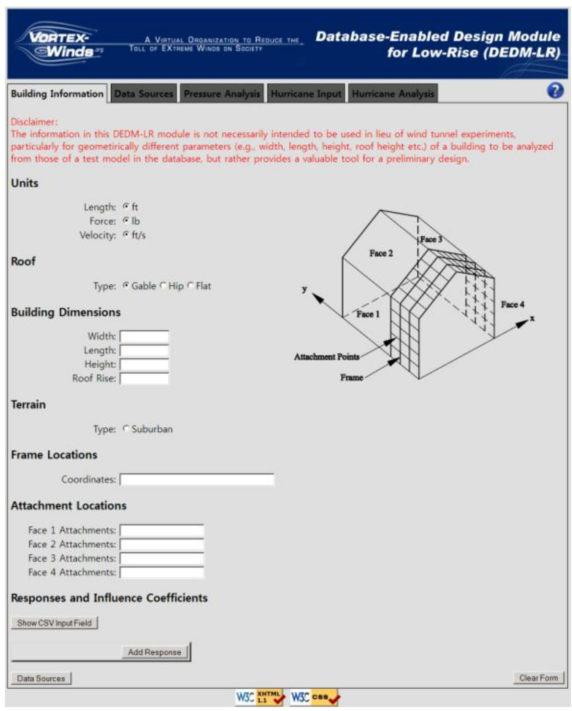

Figure 16. User interface of the DEDM-LR

CloudCFD in the Computational Platform

Computational Fluid Dynamics (CFD) has been extensively developed over the last three decades and widely used in many fields in both academic research and industrial applications. From the basic discretization scheme, mesh generation and treatment, turbulence modeling, matrix solver, to parallel computing, all have advanced over the last thirty years. But what has not improved is the steep learning curve needed for using CFD despite availability of numerous CFD documentations and textbooks in the market. A beginner may easily get lost while deciding which turbulence model to choose, or what parameters to set and how to control the solver, not even mentioning mesh generation and complex post-processing. From the programming point of view, when a code is written to solve a practical problem, the complexity of Navier-Stokes equation will soon make any good code unwieldy, and the final software is usually so difficult to handle (definitely needs a team to maintain) that even some basic verification and validation would require months to finish. Another fact is that CFD by nature needs more powerful computational resources than most other disciplines. For medium to large simulation cases, even if the code is tailored to perform effectively in a parallel mode, Infiniband support is still crucial to get a good scalability. And beginners usually have no understanding of these details.

What we see here are two road blocks; one is the lack of a user-friendly access platform that can encourage "trial and error", another is the availability of computational resources. The CloudCFD project is designed to remove these barriers; it aims to provide a platform for a broader user's community with various levels of skill, including amateurs, beginners, intermediate and even advanced CFD users. It also aims to be user-friendly and easily accessed and operated from a remote interface as well as offers resources needed to run the CFD solver with dynamic allocation (including server, cloud and computing nodes). Our philosophy in this endeavor is: to provide easy to use hands on experiences to beginners so that they are more enthused by the capabilities of CFD so that they start developing their own codes and on the other hand offer a versatile robust platform to those who are interested in application only. To accomplish this we need to design a task management system in such a way that it can dynamically allocate resources to the end-users, so that the end-users can focus more on their applications and not be distracted by the hardware issues. And just as in new field, our platform is not without guidelines; it is created with many useful "templates", so that users can start from a template most fitting to their needs. Additionally, the default numerical settings for categories such as boundary conditions, discretization schemes, and turbulence modeling are preset, so that users can input minimal parameters and their simulations do not blow-up.

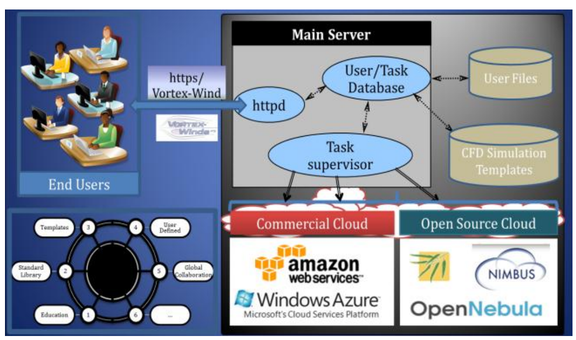

Figure 17. Architecture of CloudCFD

Figure 17 shows the vision and architecture of CloudCFD platform. It will have the following features (many of which have been completed.): (i) basically, it is a Software as a Service (SaaS) platform and is developed from dozens of open-source codes; (ii) it moves the CFD operation from a desktop-based to a web-based system. By doing this, it easily allows geographically dispersed users to access the platform; (iii) the computational resources burden is moved from the local desktop to a remote server and handled by a newly designed task management system so that the server, cloud, computing nodes or even a user defined IP node, can be dynamically allocated; (iv) the central pillar of the scheme is based on a well trusted CFD code (OpenFOAM); (v) by virtue of the back-end and front-end, modules and templates, it allows independent development and contribution.

Currently, the CloudCFD platform has been tested on two different groups of people and the results are promising (Figure 18). The back-end task management is stable. Four templates have been implemented (One 3D channel flow, three 2D cylinder external flows). Monitoring of the Courant number as well as visualization of mesh, scalar and vector fields and basic post processing tools have been provided. In the next stage, besides adding more templates, we will also: (i) give more flexibility to the users to perform advanced tasks; (ii) allow users to operate on the template directly; (iii) generate mesh for arbitrary 2D shapes automatically; (iv) enhance the post-processing utility and visualization tools; (v) provide an even more user-friendly interface.

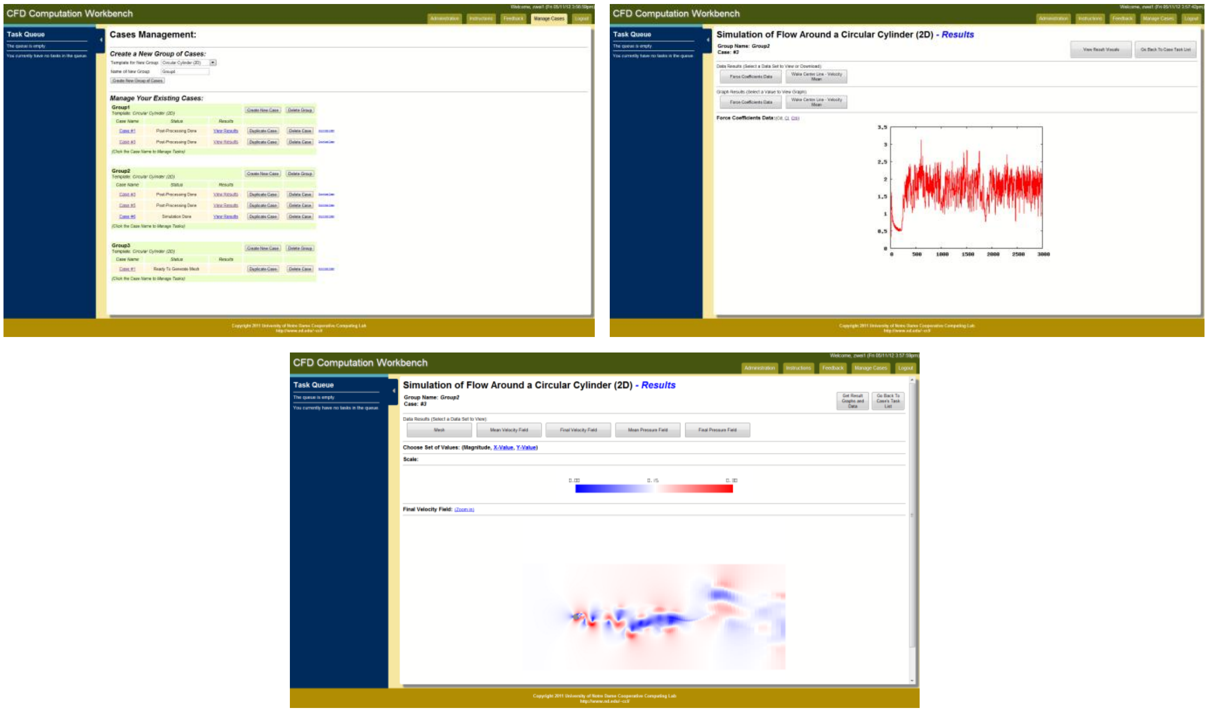

Figure 18. User and result interfaces of CloudCFD

NatHaz Interactive Wind Tunnel (NH-GUST) in the Tele-Experimentation Services

Given the interconnectedness of research, and the lack of available experimental hardware at every research location, developing a system that can bring the greatest amount of technology to as many people as possible is certainly warranted. To that end, a prototype system for an interactive wind tunnel, *NH-GUST*, has been developed. This system, conceptualized in Figure 19, consists of various components arranged within a local network. The end user does not interact will all of the local network components, only with the front end system displayed on a webpage or other similar form. A dedicated web interface connects to the networked components. The prototype interface was originally designed to be controlled from a series of LabView (National Instruments) based control panels, however this is highly cumbersome and does not work with many operating systems.

Creating a cross-platform simulation framework, similar to that of the Network for Earthquake Engineering Simulation (NEES), for severe wind experiments can be a method for improving both the range and quantity of experimental data and for enhancing the wind engineering field as a whole. Instead of only a few schools sharing a limited number of wind tunnel facilities, a customizable (although limited) wind tunnel framework can be developed for anyone to input a wind field scenario to see how it will impact a physical model, either through the measurement of surface pressures or through a high frequency force balance (HFFB). Modification of existing wind tunnels and the development of research portals can have the effect of quickly building the body of knowledge for the effect of severe storm events, matching the body of knowledge that has been produced over several decades regarding the effects of boundary layer flows on prismatic structures.

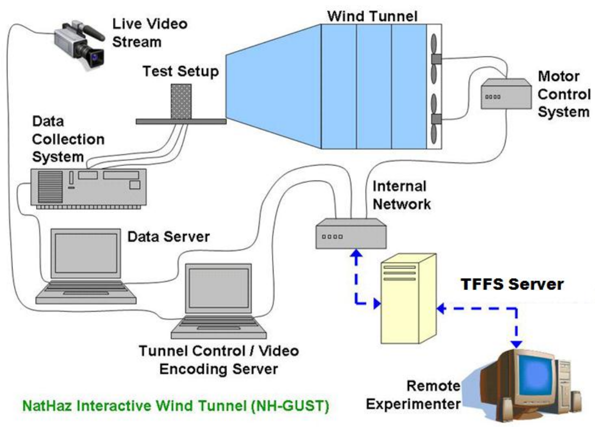

Figure 19. Prototype system for an interactive wind tunnel capable of generating gust-like events for remote experimentation

<u>*Damage Assessment from Remote Sensing Imagery in the Damage Assessment*</u>

This module is focused on automating damage assessment scheme based on before-and-after storm satellite/aerial imagery. The module aims at providing an accurate per-building assessment of damage. The framework for damage estimation consists of three steps. First, objects of interests such as buildings are detected automatically from pre-storm images. Next, correction of photometric and geometric differences between before and after image-pairs is done. Third, change detection is performed and the damage is classified based on quantitative measures of change.

In registering before and after images, the interest point detector finds the points which are repeated in both the images irrespective of variations due to damage, lighting conditions or camera viewpoint. For feature extraction we adopted a scale- and rotation-invariant interest point detector and descriptor termed SURF (Speeded Up Robust Feature). The choice of SURF features for this application is inspired by the fact that they are more robust and faster than other state-of-the-art detectors and descriptors while maintaining high accuracy in matching. An approximate k-Nearest Neighbor algorithm is used for feature matching. A speed-up of 10x was achieved without compromising robustness through randomized kd-trees and a constrained RANSAC algorithm.

Automatic color balancing approaches for different applications have been studied by different research communities in the past decade. However, in our work we addressed color balancing for the purpose of change detection. For multitemporal images, an ideal color correction approach should be effective at transferring the color palette of the source image to the target image for the unchanged areas while being able to transfer the global color characteristics for the changed area without creating visual artifacts. Towards this goal, we proposed a new local color balancing approach that uses adaptive windowing. We evaluated the proposed method against other state-of-the-art ones using a database consisting of aerial image pairs. The test image pairs were taken at different times, under different lighting conditions, and with different scene geometries and camera positions. On this database, our proposed approach outperformed other state-of-the-art algorithms.

A segmentation-based scheme that uses a maximum likelihood classifier along with k-means clustering was adopted for building detection. We use MEPS features (Measure of Estimated and Predicted Shadows) along with shape-based features to combine segments together. We proposed a fusion of color and edge based features to classify rooftops into damage states. The evaluation was performed on a database of post-hurricane rooftops images that is larger than the ones used in previous studies. The classifier was found to perform with 80% accuracy for a 3-scale damage metric and 72% accuracy for a fine grained 4-scale damage metric. To validate results of building segmentation and damage classification, preparation of ground truth datasets is being done and is hoped to be made publicly available for research communities.

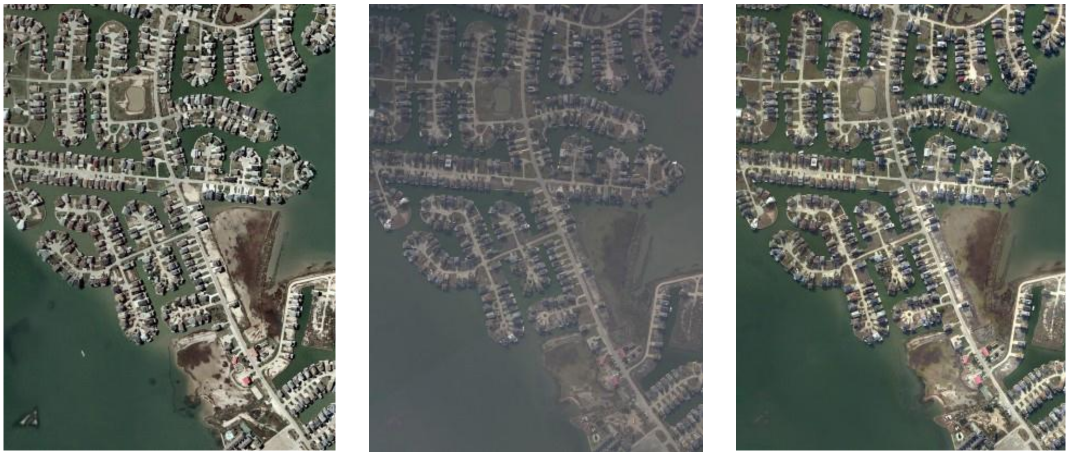

Figure 20. Source images (left), Target images (middle) that have been corrected geometrically. New target image transformed using the proposed local color transfer technique (right)

Figure 21. Example of a satellite image (left) and extracted buildings in white (right)

The first row in Figure 22 shows a collapsed building and the corresponding false color images for edge density, V Histogram (edge based features) and H means (color based feature). Notice that the edge density values are significantly higher in this case. The second row corresponds to a partially damaged building with a cavity in the rooftop. V histogram indicates a significant change in the cavity area and H means shows a minor damage on the roof.

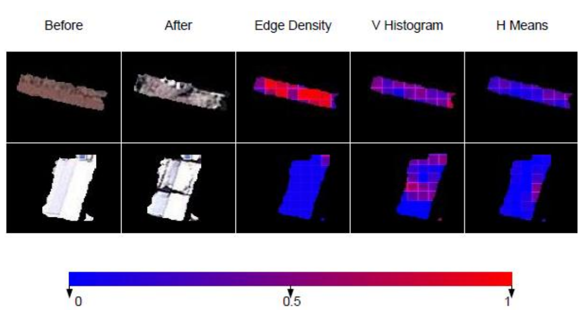

Figure 22. Damage assessment: extracted features for a collapsed building (top) and a partially damaged building (bottom)

This automated damage assessment scheme based on satellite imagery is being transported to a web-based portal for inclusion in VORTEX-Winds.

4. Concluding Remarks

Despite many advances in the area of wind effects on structures in recent decades, research has been conducted with limited resources scattered physically throughout universities, government, and private research laboratories as well as industry and trade organizations. This has not permitted the community to fully benefit from the collective physical, computational and intellectual resources dedicated to this topic. The enormous reported losses from wind-related events and the increased sensitivity of freeform and super tall buildings, long-span bridges, and deep water offshore platforms to wind make it an ideal hazard for a virtual organization and associated cyberbased modules providing these much needed design tools. Through a collection of tools and services networked with a flexible architecture and interfaces to support research and education objectives in real-time, these cyberbased analysis, modelling and simulation tools in the VORTEX-Winds EVO promise to enhance the capability of each individual beyond one's current resources through a synergistic, integrative approach to understanding and modeling the complex wind-structure interactions. The result will be a community as a whole better positioned to address the next frontiers in the field. Accordingly, VORTEX-Winds and associated cyberbased modules would serve as an end-to-end system that integrates domestic and international community resources related to wind effects on structures. It would facilitate an effective, transformative, and conveniently accessible venue for the acceleration of advances in research and development, as well as teaching and learning, in this area and would have a revolutionary impact on this field due to its unprecedented dissemination of knowledge and resources.

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