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Database-Assisted Design: Performance-Based Approach for Dynamically Sensitive Steel Structures

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Abstract

This NIST Technical Note presents a User's Manual for the DAD_PBD software, a user-friendly tool designed for the advanced structural design of mid- and high-rise steel framed buildings. The software employs the Database-Assisted Design (DAD) procedure, a method developed at NIST that uses time-domain analysis, directional aerodynamic pressure data, and site-specific wind climatological data to design structures for wind loads.

The DAD approach has demonstrated superior performance in structural wind design for tall buildings compared to ASCE 7-based analytical methods. However, previous DAD programs lacked practicality for structural engineers, primarily due to their reliance on research-oriented in-house analysis software, high computational costs, and a MATLAB-based platform.

To address these limitations, the DAD_PBD software was developed. It integrates the widely used commercial structural analysis and design software, ETABS, thereby enhancing design reliability through the DAD method. Following industry recommendations, DAD_PBD has transitioned to a Python-based platform to enhance accessibility for practicing engineers and improve computational efficiency. An additional design parameter, the Deformation Damage Index (DDI), is included in DAD_PBD to evaluate drift demands and potential damage caused by shear strain in cladding and partition systems. These features empower structural engineering practitioners to execute advanced structural design of tall buildings, aligning with the novel concept of performance-based wind design.

This report also showcases a design example of a 45-story steel frame building, illustrating the practical application of the software.

Keywords

Climatological data; Database-Assisted Design (DAD); ETABS; High-rise buildings; Steel structures; Structural design; Structural dynamics; Wind effects.

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Acknowledgments

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Author Contributions

Daniel M. Rhee: Conceptualization, Methodology, Software, Visualization, Investigation, Validation, Writing- Original draft preparation; **DongHun Yeo**: Conceptualization, Methodology, Project administration, Supervision, Writing- Reviewing and Editing; **Steve Pingree**: Software, Visualization; **Sophie Sisson**: Investigation, Validation; **Eric Heumann**: Software. **Mehedy Mashnad**: Methodology, Supervision.

1. Introduction

As demand for tall buildings has continuously grown worldwide in urban habitats, the design of tall buildings for wind has also advanced. Instead of the ASCE 7 simplified and analytical methods that do not apply to dynamically sensitive buildings subjected to across-wind and dynamic effects or to buildings with unusual shapes or response characteristics [1], the time-domain analysis utilizing wind tunnel data has been employed to design tall buildings more reliably [2, 3]. The National Institute of Standards and Technology (NIST) has developed a Database-Assisted Design (DAD) procedure for the design of structural members subjected to direction-dependent wind loads [4-6]. The DAD procedure, based on the time-domain analysis, estimates the design wind effects using two datasets: (1) time series pressure coefficients from wind tunnel experiments or Computational Fluid Dynamics (CFD) simulations and (2) site-specific directional extreme wind speed datasets obtained from measurement or simulation.

Recently, a DAD_ETABS program that utilizes the DAD procedure and incorporates ETABS software (CSI 2020) was developed to facilitate the use of the DAD method in structural engineering practice [7]. The DAD_ETABS is a MATLAB-based software package enabling DAD's unique features to be part of general structural design practice for steel-framed buildings with rectangular shapes in plan. To test the practicality of the software, NIST collaborated with Walter P Moore (WPM) to assess the DAD_ETABS software from the point of view of their potential use in structural engineering design practice; the outcome of this phase of work was reported in NIST Technical Note 2236 [8]. One of WPM's primary concerns with the DAD_ETABS software was that MATLAB is not commonly used in structural engineering firms, and, therefore, its integral use may be a barrier to adoption, considering the cost of licensing. As a result, NIST adapted the DAD_ETABS software to be Python-based [9], which is freely available and more widely used by designers and software engineers. In transitioning to Python, many of the algorithms were restructured in matrix calculations, which allows a considerable reduction of computational time. Furthermore, the software, now renamed DAD_PBD, has taken the first step towards advancing the DAD concept in Performance-Based Wind Design (PBWD) for high-rise buildings. In recent years, there has been a paradigm shift in tall building design: from a design based on minimum requirements to a design based on expectations, such as specific performance objectives. ASCE/SEI has recently published a Prestandard for PBWD to provide guidelines for improving both structural integrity and economic efficiency [10]. The Prestandard acknowledges the inadequacy of the wind hazard curve based on the peak velocity and the necessity of the hazard curve based on the expected responses of the building up to the MRI of interest, which the DAD_PBD can provide.

In addition to transitioning to Python, DAD_PBD implements several other improvements over the previous DAD versions. The concept of a Deformation Damage Index (DDI) has been implemented as an additional design parameter to assess drift demands and potential damage in cladding and partition systems. For acceptance criteria of DDI, refer to the PBWD Prestandard [10] and the ATC design guide [11].

This report provides an overview of the new DAD_PBD procedure and software and presents the results of a structural design of a tall steel building using the DAD_PBD. For illustration purposes, a 45-story Commonwealth Advisory Aeronautical Research Council (CAARC) building [12] is used throughout the document.

2. User's Manual

2.1. Overview

The DAD_PBD software, developed in Python and compatible with the Windows operating system, allows for Performance-Based Design (PBD) of mid- and high-rise buildings. The current version focuses on steel-frame buildings with rectangular shapes in plan. Future updates, however, will expand its capabilities to include the design of reinforced concrete structures and buildings with irregular shapes.

The program requires the aerodynamic pressure data on a building of interest and the climatological data at a building site to perform the PBD. The pressure data can be obtained from wind tunnel testing or CFD simulations, and the climatological data can be from weather stations or simulations, which are described in more detail in Sec. 2.5 and Sec. 2.7, respectively.

The general procedure and flowchart of DAD_PBD are illustrated in Fig. 1. The processes within the orange dotted box comprise the main algorithm of the DAD_PBD written in Python, and the processes within the blue solid box are carried out in ETABS. The processes presented in the dashed boxes outside the red solid box (DAD_PBD) represent the input data provided by the wind engineer (yellow dashed box) and the structural engineer (blue dashed box). The following are the steps required to perform the DAD procedure using the DAD_PBD software:

1. The user defines acceptance criteria for all design parameters to be considered in the structural design.
2. Using the ASCE 7 gravity and wind loads [1], the user preliminarily determines the structural system and preliminary member sizes of the building, and creates an ETABS model of the building (Sec. 2.3).
3. Given the C_p data from the wind tunnel tests or CFD simulations, the software calculates the time-history wind loads at each floor and applies them to the ETABS model (Sec. 2.5). Note that this step is necessary once and is not repeated for iterative design.
4. The software commands ETABS to run dynamic analyses, producing the time-history of the structural responses (e.g., internal forces on members, joint displacements, and joint accelerations).
5. The response surfaces of the design parameters are constructed. Response surfaces, resulting from aerodynamic and mechanical properties, are the peak combined wind effects as a function of wind speed and direction. Design parameters include Demand-to-Capacity Index (DCI), inter-story drift ratio, floor acceleration, and Deformation Damage Index (DDI) (Sec. 2.6).
6. By projecting the climatological data (i.e., site-specific directional extreme wind speed data) onto the response surfaces obtained from Step 5, the design response curves are generated as a function of Mean Recurrence Interval (MRI) (see Sec. 2.7).
7. The design responses are compared with their corresponding acceptance criteria. If they do not comply with the design criteria (i.e., exceed the criteria requirement), the member sizes should be reselected and the processes from Steps 4 to 6 should be repeated until all the design criteria are met. Note that certain design criteria could be updated after the modal

analysis of the designed building. For example, the maximum acceptable peak acceleration can depend on the natural frequency of vibration of the structure.

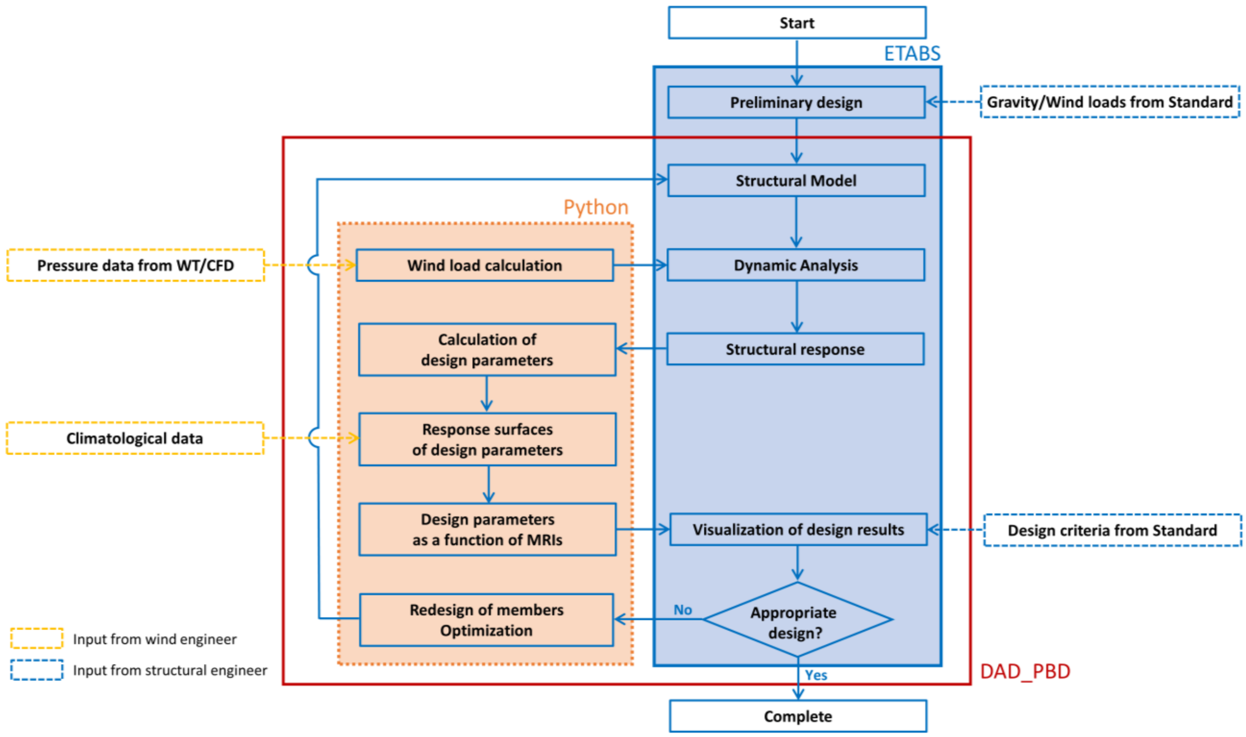


Fig. 1. Process diagram for DAD_PBD.

2.2. Required Software Packages

The DAD_PBD is compatible with ETABS version 18 and later [13]. However, for the design example presented in this document, ETABS version 20 was used. The user needs to confirm the existence of the "ETABSv1.dll" file in the ETABS program file folder. This library file contains the ETABS Application Programming Interface (API). For the detailed directory path of the dll file, refer to Sec. 2.4.1.

The DAD_PBD also requires the installation of the Python programming language. Python 3.8.11 served as the development language for DAD_PBD, but it should maintain compatibility with this version or any subsequent version. In addition, the following Python packages and libraries are required to run the software: NumPy, h5py, SciPy, Matplotlib, and Pythonnet [14-18].

2.3. Preliminary Design

Before launching the DAD_PBD software, an ETABS model of the preliminary design must be built, as shown in Fig. 1. For steel-framed buildings, the ETABS model consists of frame elements (beams, columns, braces, and truss members). The preliminary design is established based on the initial geometry of the structural members and the gravity and wind loads specified by the ASCE 7 standards [1].

Within the ETABS model, the user must ensure that the load type of all the gravity loads (e.g., dead load, live load) used for the preliminary design is correctly defined and that all loads are included in the load patterns. This can be achieved by navigating through the "**Define Load Patterns**" in ETABS. Figure 2 shows an example of load patterns for gravity loads defined in the design example ETABS model. Note that the names of the load patterns can be arbitrary. As long as the load types (e.g., Dead, Live) are correctly defined, the software can automatically detect and assign the loads to the corresponding load combinations (See Sec. 2.4.3 for load combinations).

Note that the current version of DAD_PBD does not include the feature of live load reduction, despite its allowance under ASCE 7-22, Section 4.7 [1]. While ETABS reduces the live loads of the members during the design phase, the DAD_PBD does not rely on the ETABS design procedure and determines the design capacity of each member independently. The live load reduction will be considered in future versions.

Before launching the DAD_PBD software, it is also recommended that any wind load patterns/cases used to establish the preliminary design of the building be removed. This step can help decrease the computational time by avoiding redundant calculations. Additionally, if the user intends to use the linear direct integration analysis for dynamic analysis, a dummy load case must be included in the list. Refer to Sec. 2.4.3 for more details.

The DAD_PBD provides three options to analyze a structure: 1) one frame element, 2) multiple frame elements, or 3) all members. For the second option, the user must assign "Groups" to frame elements in the ETABS model before starting the software. This step should be completed before generating multiple ETABS models via the DAD process to transfer the "Group" information. Refer to Sec. 2.6 for an example.

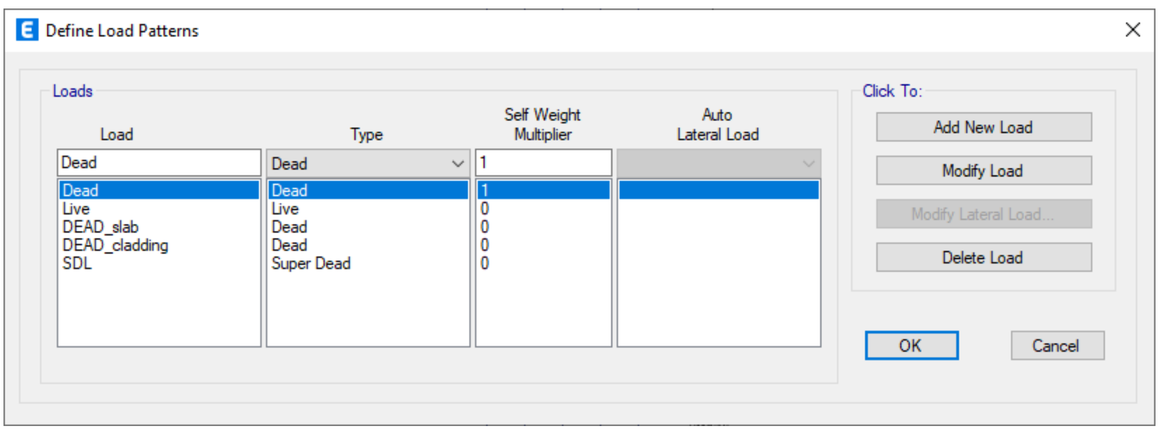


Fig. 2. Example definitions of load patterns of the preliminary design of the CAARC building.

2.4. Getting Started

2.4.1. Initialization

To start the DAD_PBD, the user executes the **DAD_PBD.exe** file, which can be downloaded from Section 3 Database Assisted Designs at www.nist.gov/wind. Once the software is initiated, the software will automatically locate and load the Python dll file (see Sec. 2.2 for Python installation). Typically, the Python dll file directory is in the format of 'C:\Users\Username\AppData\Local\Programs\Python\PythonXX\pythonXX.dll', where XX denotes the Python version. For example, the directory of the dll file for Python version 3.8 would appear as 'C:\Users\Username\AppData\Local\Programs\Python\Python38\python38.dll'. If Python is installed in a non-standard location and cannot be loaded automatically, a pop-up window will prompt the user to locate the Python directory manually.

To get started on the software, the user must locate and load the ETABS model of the preliminary design (file with extension .edb) and the API dll file (ETABSv1.dll) to the software using the "**Browse**" buttons in the "**Initialization**" tab (Fig. 3). The file path can be directly typed in if desired. For ease of reference, the ETABS model saved in this directory path will be referred to as the "base ETABS model" throughout this document. For standard installation of ETABS 20, the typical directory path to the API dll file is prescribed as: 'C:\Program Files\Computers and Structures\ETABS 20\ETABSv1.dll'. By clicking the "**Browse**" button under the "**Save Outputs In**" panel, the user must designate a folder path where all analysis outputs and figures will be stored. Note that modifying or deleting any files or paths within the folder could lead to errors, as the software relies on this directory path to save and retrieve the analysis results. DAD_PBD offers two unit systems: SI units and US customary units. SI units are displayed in kilo-Newton or Newton (kN or N) and meter (m), while US customary units are represented in 1000 pounds-force (kip) and feet (ft). For all data saved after the analysis, the units will be in Newton (N) and meter (m) for SI units and pounds-force (lb) and feet (ft) for US customary units. The CAARC building example used in this report employs SI units.

Some features are currently unavailable (indicated by being grayed out) in the present version, as depicted in Fig. 3. In the "**Type of Structure**" panel, only "Steel Structures" can be selected. Parallel computing options, also greyed out in the current software version, will be available in future versions to improve computational efficiency.

On the top right corner of each tab, there are two buttons for managing the input data: 1) "**Load Input**" and 2) "**Save Input**". By clicking the "**Save Input**" button, any input data entered by the user will be stored in a text file, which can be retrieved using the "**Load Input**" button. The user will be prompted to select a folder to save the input data file and provide a name for it. Each line in the text file corresponds to a specific input, allowing for direct modifications within the text file. Refer to Appendix C for the line correspondence. The two buttons across all tabs share the same functionality: saving the input on one tab effectively saves input for all tabs. This function is designed to assist the user in tracking inputs for the re-design process or any unexpected interruptions. If the software is disrupted at any stage during the analysis, the previously saved inputs can be retrieved using the "**Load Input**" function. It is recommended that an input data file be saved and created at each step or whenever modifications are made to the inputs. Note that the input data file (.txt) solely contains information entered into the software and does not include any analysis results.

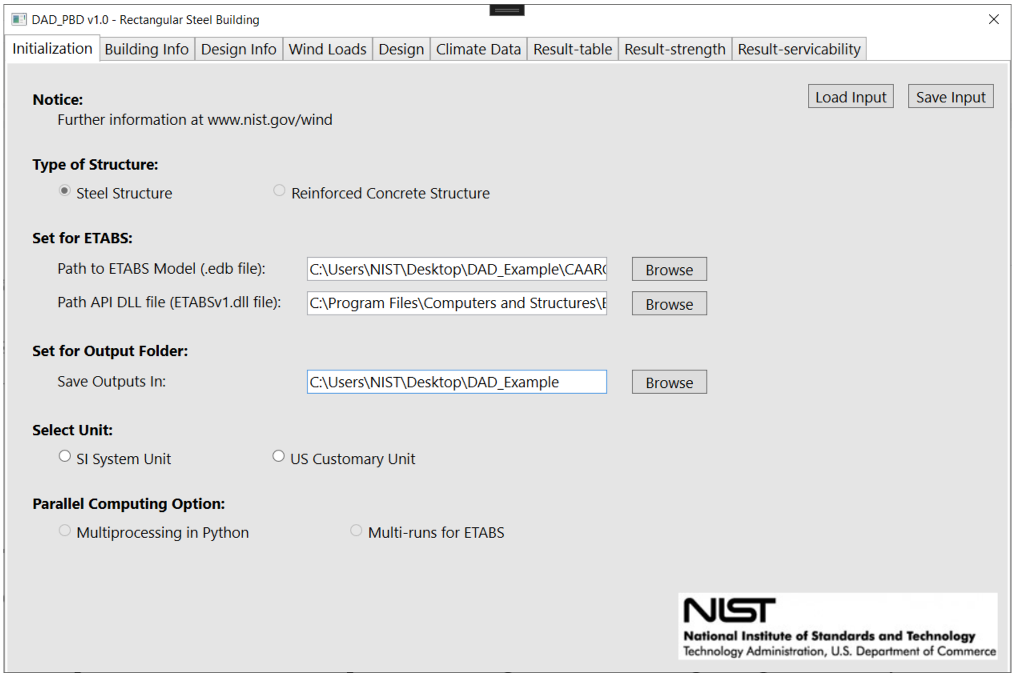


Fig. 3. Initialization step of the graphical user interface of DAD_PBD.

2.4.2. Building Information

Before beginning the wind load calculation, the basic geometry of the building must be entered in the "**Building Info**" tab. Building height, width, depth, number of stories, and the orientation angle are required. The width and depth are the horizontal length of the building along the *x*- and *y*-axis, respectively (Fig. 4). The basic dimensions can be either entered manually or imported directly from ETABS. By clicking the "**Read ETABS**" button, the ETABS model will be opened, and the information will be imported automatically. Building orientation (α_0) is defined as the clockwise angle from the true North to the positive *x*-direction of the building (Fig. 4). For example, if the positive *x*-axis (+) is directed toward the East, the building orientation would be 90 degrees. The orientation angle of the building is critical for wind directionality analysis. The wind direction (θ) is also defined as the angle of wind approaching the building measured from the *x*-axis and increasing clockwise, as shown in Fig. 4.

Note that the modal analysis module (e.g., number of modes, natural frequencies, damping ratio) is currently disabled, as shown in Fig. 5. This module will be available in future software versions and will provide users with information on structural dynamic properties.

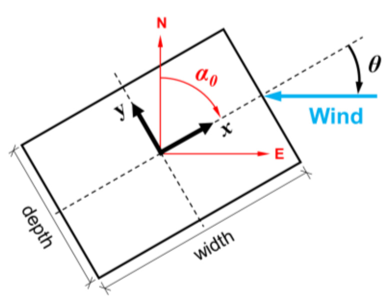


Fig. 4. Plan view of the building showing orientation angle and wind direction.

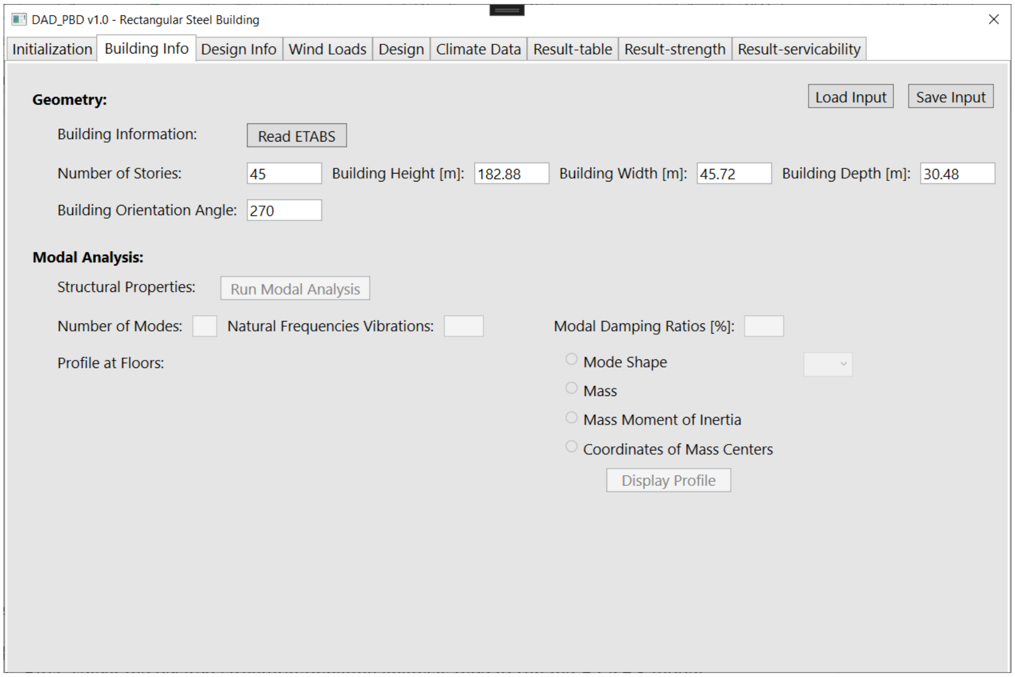


Fig. 5. DAD_PBD building information input window.

2.4.3. Design Information

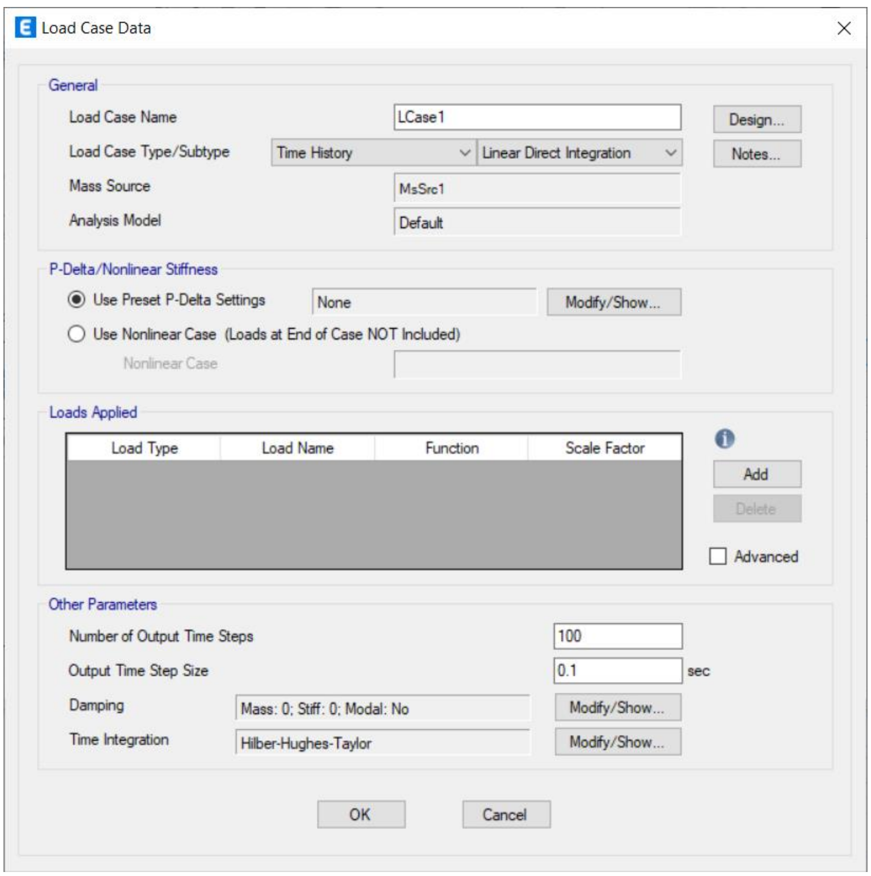
In the "**Design Info**" tab, the user must select the analysis type and enter the load combinations. First, select the desired structural/dynamic analysis type to perform the analysis of the ETABS model. Under the drop-down menu of "**Analysis Type**", the following six types of analysis are available:

1) *Linear Modal Time-History w/o P-Delta*
2) *Linear Modal Time-History w/ Pseudo P-Delta*: equivalent to Linear Modal Analysis with preset P-Delta in ETABS. The P-Delta effect is taken into account using the softened stiffness.
3) *Non-Linear Modal Time-History w/ Pseudo P-Delta*: equivalent to Nonlinear Modal Analysis (FNA) with consideration of P-Delta in ETABS. The P-Delta effect is included using the softened stiffness of a nonlinear static load case.
4) *Linear Direct Time-History w/ Pseudo P-Delta*: equivalent to Linear Direct Integration with preset P-Delta in ETABS. The P-Delta effect is taken into account using the softened stiffness.
5) *Non-Linear Direct Time-History w/ Pseudo P-Delta*: equivalent to Nonlinear Direct Integration using the initial condition of "Continue from State at End of Nonlinear Case" in ETABS. The P-Delta effect is included using the softened stiffness of a nonlinear static load case.
6) *Non-Linear Direct Time-History w/ Concurrent P-Delta*: equivalent to Nonlinear Direct Integration with zero initial conditions (start from the unstressed state) in ETABS. In this

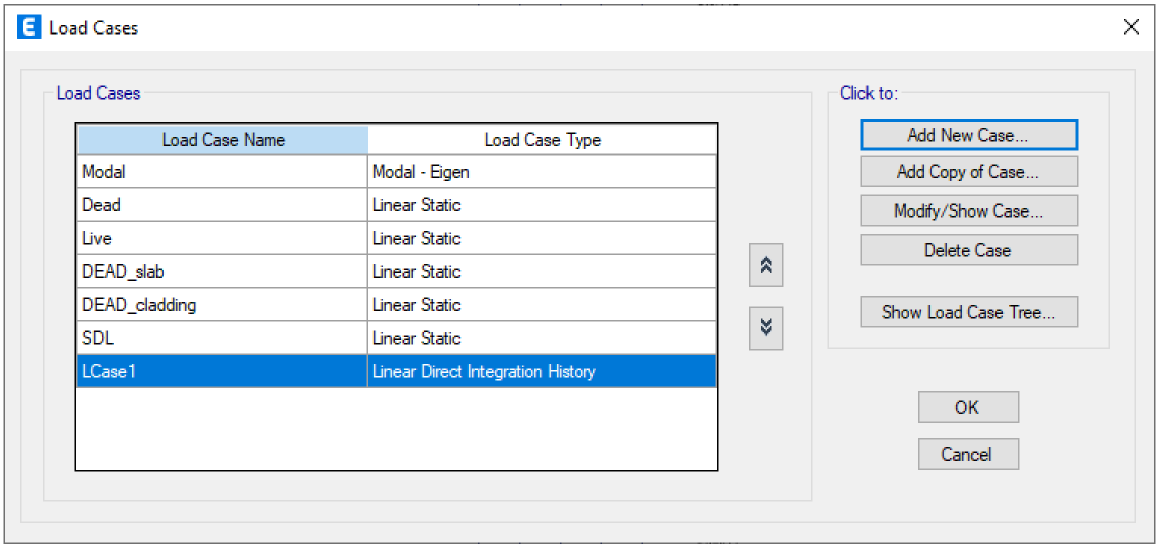
load case, the P-Delta effect is taken into account using the stiffness in the concurrent time step.

In the current version of the software, the available options are the linear modal time history analysis without P-Delta (Option 1 as stated above), the linear modal time history analysis with pseudo P-Delta (Option 2), and the linear direct integration time history analysis with pseudo P-Delta (Option 4). Additionally, the P-Delta preset is set to 1.2D + 1.0L. The remaining analysis types and freedom to manipulate the P-Delta preset setting will be added in the future DAD_PBD version.

Suppose the linear direct time-history analysis with pseudo P-Delta analysis is chosen. An extra step is required in that case: the user must add a “dummy” load case with Linear Direct Integration to the ETABS model. Due to a limitation in the ETABS API’s functionality, this step must populate a Time History Load Case Definition with Linear Direct Integration in the ETABS table. Once the load case has been populated, the API function can be used to manipulate the load case, and thus, no further modification of settings is necessary. After adding the load case, the user should be sure to click the “OK” button in the “Load Cases” window. A demonstration of adding a dummy load case is shown in Fig. 6. In this example, a load case named “Lcase1” is added as a dummy.



(a) ETABS Load Case Data window for adding the “dummy” Time History Linear Direct Integration load case



(b) ETABS Load Cases window after adding the "dummy" load case

Fig. 6. Demonstration of adding a "dummy" load case in ETABS for the Linear Direct Time-History w/ Pseudo P-Delta analysis.

In addition, the user should define the desired load combinations to run the structural/dynamic analysis. If load combinations are already defined in the ETABS, the ETABS load combinations can be imported by clicking the "**Import ETABS Load Combinations**" button. Otherwise, the user can manually add as many load combinations as needed by typing in the load factors and clicking the "**Add**" button. For example, the numbers for the load factors entered in Fig. 7 will generate load combinations for strength and serviceability designs as follows:

- Strength Design: $1.2D + 1.0L + 1.0W$
- Serviceability Design: $1.0D + 0.5L + 1.0W$

where D is the Dead Load, L is the Live Load, and W is the Wind Load. For no loads, 0 must be entered. For example, 0.9, 0, and 1 must be entered in 1) Dead Load, 2) Live Load, and 3) Wind Load, respectively, for a load case of $0.9D + 1.0W$. Note that the load factor for the wind load is typically set at 1.0 because the DAD employs the wind effects based on the mean recurrence interval. Nonetheless, different load factors may be used based on the engineer's judgment. Click the "**Clear**" button to remove all load combinations and the "**Delete**" button to remove a specific load combination.

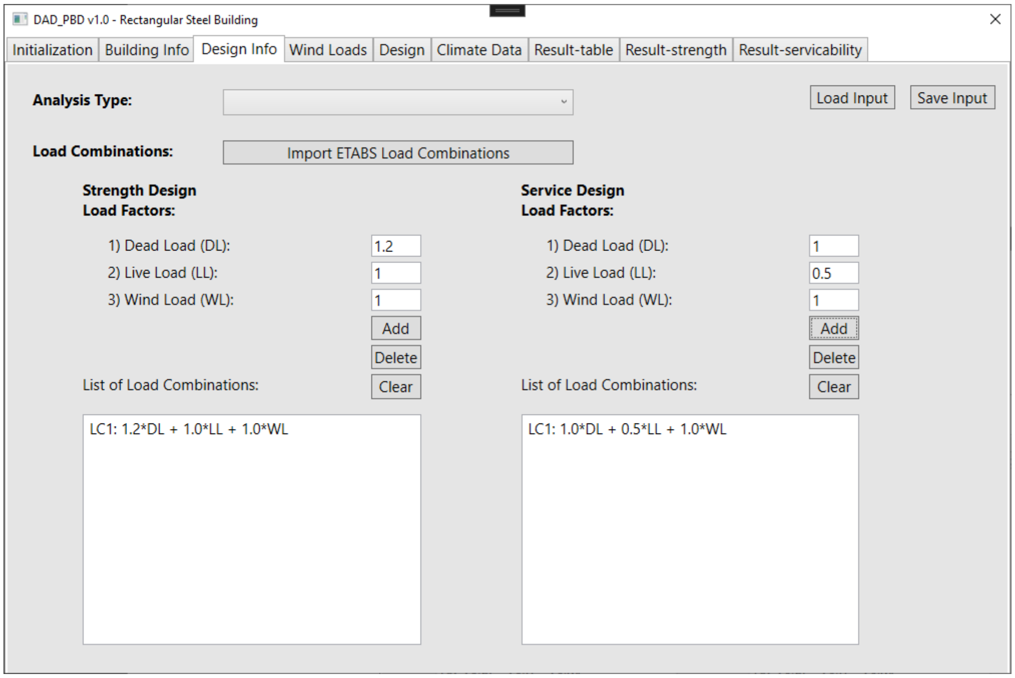


Fig. 7. DAD_PBD design information and load combinations input window.

2.5. Wind Load Calculation

For structural design for wind, the wind directionality is a critical factor because the wind-induced structural response can significantly depend on the wind direction [19]. In general, wind engineers perform wind tunnel tests to determine wind-induced aerodynamic loading on high-rise buildings. For measuring pressure time histories on a building, pressure taps are placed on the envelope of the scaled-down modeled building and a series of wind tunnel tests are performed at various wind directions (θ). In recent years, there has been an immense advancement in CFD techniques and computer technology [5]. Although the CFD method may not be able to replace the wind tunnel experiments entirely yet, the pressure data from the CFD simulations could be used for estimating the wind loads on a building *if the numerical method is verified and validated*, as stated in ASCE 7-22 Section 31.1 [1].

Typically, the pressures are described in the form of non-dimensional pressure coefficients, C_p, as follows:

$$C_p = \frac{p - p_{ref}}{\frac{1}{2}\rho V_m^2} \tag{1}$$

where p is the absolute pressure measured at a pressure tap, p_{ref} is the reference pressure measured away from the building, ρ is the air density, and V_m is the reference mean velocity at the roof height of the building.

With the C_p time histories given, the software determines the wind loads on each floor by the interpolation methods described in Ref. [20]. Three methods are available for the pressure interpolation: 1) nearest, 2) linear, and 3) cubic. Note that the computational cost increases for more complex interpolation methods. Figure 8 demonstrates the interpolation scheme where the outermost taps are first extrapolated to the edge of the building, and then “virtual taps” are created and interpolated using the extrapolated and the physical taps. The “virtual taps” are meshed at ΔB ($B/2n_B$) along the length and at ΔH ($H/2N$) along the height where B is the width, H is the height of the modeled building, and n_B is the number of pressure taps in each row. It implies that this approach performs best when the height of each story is consistent across all floors. This limitation will be addressed in future software versions to allow users to design buildings with different story heights.

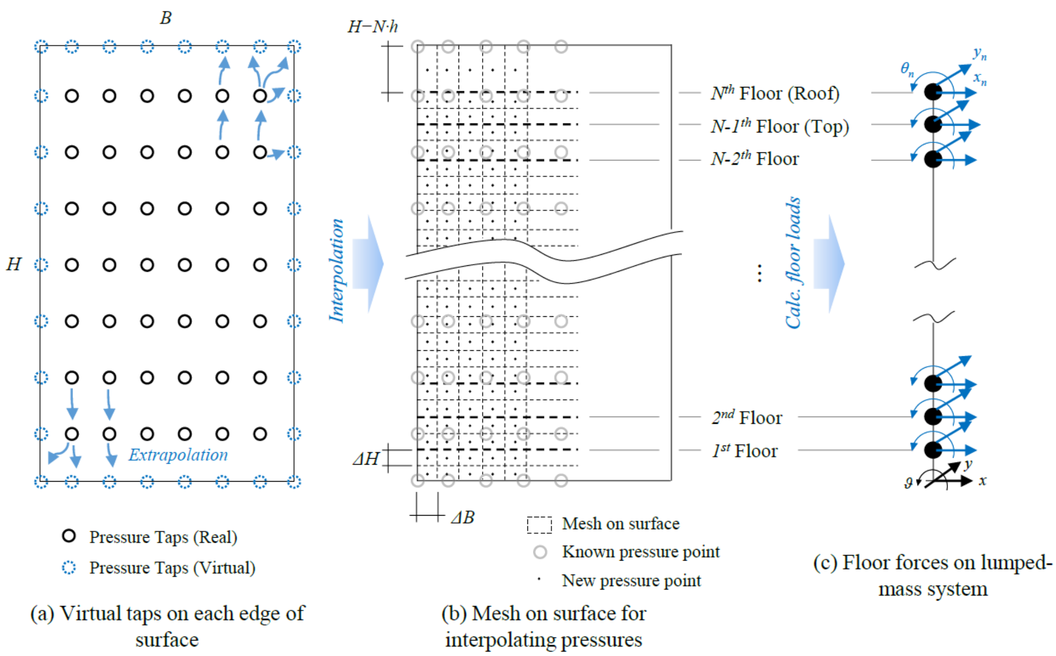


Fig. 8. Illustration of interpolation scheme and mesh on the model surface. Image taken from Ref. [20].

The wind loads are then determined using tributary areas, as shown in Fig. 9, and applied to the mass center of the floor slab on each floor. The time history wind loads acting on the floor mass centers consist of point loads along the principal axes of the structure (F_x, F_y) and the torsional moment about the center of mass (M_z). The mathematical expressions are shown in Eqs. (2-4):

$$F_x^n(t) = \frac{1}{2}\rho V_m^2 \sum_i \left(C_{p,i}^n(t) A_{T,i}^n \right) \tag{2}$$

$$F_y^n(t) = \frac{1}{2}\rho V_m^2 \sum_j \left(C_{p,j}^n(t) A_{T,j}^n \right) \tag{3}$$

$$M_z^n(t) = \frac{1}{2}\rho V_m^2 \left(\sum_i \left(C_{p,i}^n(t) A_{T,i}^n \right) d_i + \sum_j \left(C_{p,j}^n(t) A_{T,j}^n \right) d_j \right) \tag{4}$$

where A_T is the tributary area ($\Delta B \times \Delta H$); d is the moment arm (projected distance) from the tab to the floor mass center; the subscripts i and j denote the ith pressure point on the building surfaces perpendicular to the x-axis and jth pressure points perpendicular to the y-axis, respectively; and the superscript n denotes the n^{th} floor.

Additionally, DAD_PBD has newly introduced the ground floor load (GF_x, GF_y, GM_z) calculations, using the bottom-most tributary areas to assist structural engineers with foundation design.

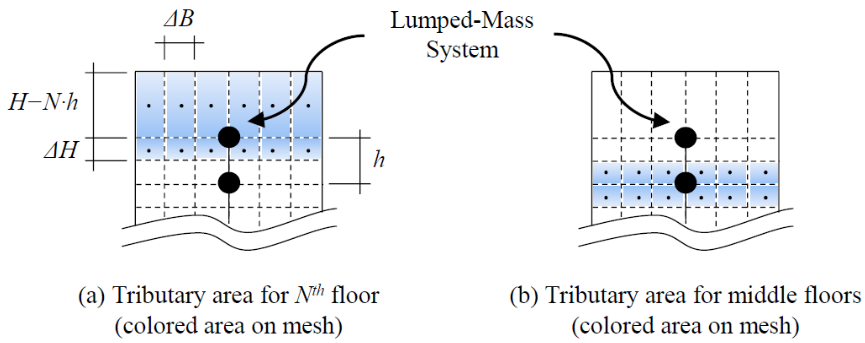


Fig. 9. Illustration of tributary area and floor loads calculation. Image taken from Ref. [20].

As wind tunnel testing requires similarities of the non-dimensional equations between full-scale and model scale, the time step and applied loads must be properly scaled. There are three scales associated with wind tunnel testing: 1) length scale (λ_L), 2) time scale (λ_T), and 3) velocity scale (λ_V), as expressed in Eqs. (5-7).

$$\lambda_L = \frac{D_m}{D_f} \tag{5}$$

$$\lambda_T = \frac{\Delta t_m}{\Delta t_f} \tag{6}$$

$$\lambda_V = \frac{V_m}{V_f} \tag{7}$$

where D is the reference length, Δt is the time step, V is the velocity, and the subscripts m and f represent the model-scale and full-scale tests, respectively. Using the law of dynamic similarity ($\lambda_V = \lambda_L / \lambda_T$) and Eqs. (5-7), the Δt_f can be expressed as Eq. (8), and the load scale factor (K_F) and moment scale factor (K_M) are determined by Eq. (9) and (10), respectively. Given the length scale, the reference wind speed, and the sampling frequency, the scale factors will be calculated and automatically assigned to the ETABS models for the dynamic analysis.

$$\Delta t_f = \frac{\lambda_V}{\lambda_L} \Delta t_m = \frac{D_f}{D_m} \frac{V_m}{V_f} \Delta t_m \tag{8}$$

$$K_F = \left(\frac{1}{\lambda_V}\right)^2 \left(\frac{1}{\lambda_L}\right)^2 = \left(\frac{V_r}{V_m}\right)^2 \left(\frac{D_r}{D_m}\right)^2 \tag{9}$$

$$K_M = \left(\frac{1}{\lambda_V}\right)^2 \left(\frac{1}{\lambda_L}\right)^3 = \left(\frac{V_r}{V_m}\right)^2 \left(\frac{D_r}{D_m}\right)^3 \tag{10}$$

In the "**Wind Loads**" tab, the user is prompted to input the specifics of the wind tunnel testing, which should be provided by the wind engineer, and other necessary input for calculating the wind loads (Fig. 10). The wind tunnel details include the length scale of the tested model (for the software input, the length scale is the reciprocal of λ_L), the reference mean wind speed at the roof height (V_m), the sampling rate of the C_p data, and the wind directions (θ) with respect to the building orientation (see Fig. 4). The wind directions can be entered by the lower bound (LB) and upper bound (UB) wind direction and the increment. For example, the input for wind direction of 0, 40, 80, … 280, 320, and 360 degrees is shown in Fig. 10. A comprehensive range of wind speeds, coupled with sufficient resolution of wind speed and direction, is crucial for accurately establishing a relationship between the response of interest and local wind climates. It is generally recommended that the increments for both wind speeds and directions should not exceed 10 m/s and 10 degrees, respectively. Note that all entries for wind direction (e.g., LB, UB, increment) must be integers.

To load the time history wind load data, two options are available: 1) loading the precalculated floor wind loads and 2) loading the C_p data only, allowing the software to calculate the floor loads. In some cases, the user might already have the floor load time histories, calculated by the wind engineer. In such cases, the user may choose to use them (as Option 1) instead of having the software perform calculations. If the second option is chosen, the user needs to upload into the software metadata regarding the pressure taps (i.e., tap identification and coordinates of taps). Also, the user must specify the folder directory where the calculated floor loads will be saved to define the number of data points. Once these steps are completed, the wind load calculation can be initiated by pressing the "**Calculate floor wind loads**" button. All necessary data files can be located and loaded using the "**Browse**" buttons. Refer to Appendix A for detailed descriptions of the data formats for the floor wind loads, the C_p data, and the pressure tap identification and coordinates.

Upon completion of the wind load calculation, a folder named "*Output*" will be created in the folder specified by the user in the "Save Outputs In" (Fig. 3). The folder will contain an HDF5 file, named "*forces.hdf5*", which contains all the wind forces and moments for each floor (including the ground floor) and the user-input parameters. Additionally, a subfolder named "*Floor_loads*" will be created within the "*Output*" folder. This subfolder will contain a series of folders with CSV files of floor loads. These files will be used to assign the wind loads to the ETABS model. The structure of the folders and files follow a specific format (see Fig. 11 as an example):

- Folder: The format of the folder name is *WD_XXX*, where *XXX* is the three-digit wind direction. For example, the folder containing the floor wind loads for 80-degree wind direction is *WD_080*.
- CVS Files: The format of the CVS file is *FYYY_XXX_Zz*, where *YYY* is the three-digit floor number, *XXX* is the three-digit wind direction, and *Zz* corresponds to the load type (e.g., F_x, F_y, M_z). For ground floor loads, *FYYY* is replaced with *GF*. For example, the CSV files corresponding to the floor loads in the *y*-direction on the 23rd floor for 240-degree wind direction and for ground floor moments acting in the *z*-direction for 60-degree wind direction are named *F023_240_Fy.csv* and *GF_060_Mz.csv*, respectively.

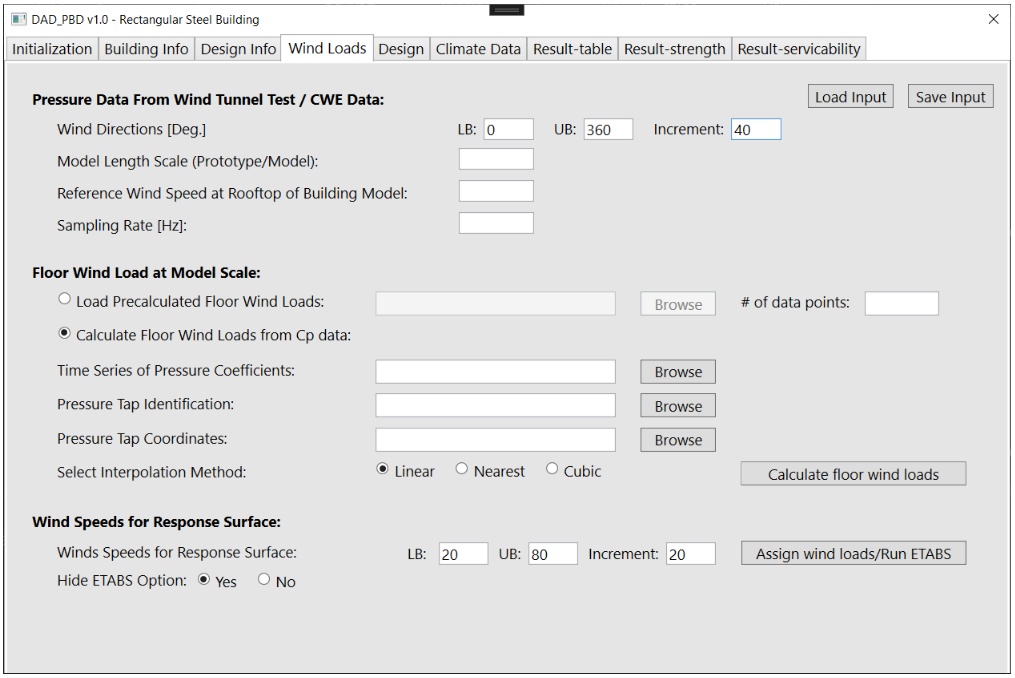


Fig. 10. DAD_PBD "Wind Loads" tab for loading files and input parameters.

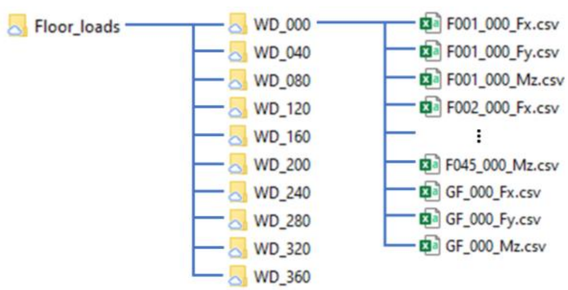


Fig. 11. Example list of folders and CSV files generated after wind load calculation.

Once the wind load calculation is completed, before proceeding to the "**Design**" tab, the user must specify the wind speed range and its increment for the response surfaces to be constructed. The range of wind speeds is inputted by providing the lower bound (LB) and upper bound (UB) wind speeds and the increment. For example, the input for wind speeds of 20 m/s, 40 m/s, 60 m/s, and 80 m/s are shown in Fig. 10. The user should consider the balance of accuracy and computational time when determining the range and increments of wind speeds. Although the wind speed range depends on the local wind climate of the building site, wind speeds from 20 to 80 m/s with an increment of 10 m/s are typically used for the DAD approach. Note that all entries for wind speed (e.g., LB, UB, increment) must also be integers.

The user has the option to run the ETABS analysis in the background by choosing "Yes" under the "Hide ETABS option." This option does not show the ETABS GUI to the user and is known to run the ETABS analysis slightly faster.

Upon the completion of all tasks mentioned above, the user can assign the wind floor loads and execute the time history analyses on ETABS by clicking the "**Assign wind loads/Run**

ETABS" button. At this stage, for each wind direction the software creates a duplicate of the base ETABS model (as shown in the "Path to ETABS model (.edb file)" in Fig. 3). For each selected wind speed (e.g., 20 m/s, 30 m/s,…, 80 m/s) at a given wind direction, the software calculates wind floor loads and assigns them to the floor mass centers of the ETABS model. It then performs the ETABS analysis with the chosen analysis option (Sec. 2.4.3). Once completed in each wind direction, a subfolder named in the format "WD_XXX" is generated under the "ETABS_Model" folder, where "XXX" represents the three-digit wind direction. The subfolder contains all ETABS files associated with that direction. Note that an ETABS model is not generated for a 360-degree wind direction since the analysis results are identical between 0 and 360 degrees. If the user inputs 0 degrees for LB and 360 degrees for UB, the software simply uses the responses from 0 degrees for those for 360 degrees to complete the response surface (Sec. 2.6).

2.6. Response Surface

After ETABS analyses are completed, the peak responses are determined for each selected wind speed and direction. These responses are then used to construct response surfaces (i.e., 3D contour maps) as a function of wind speed and direction. The design parameters include Demand-to-Capacity Index (DCI)[1], inter-story drift ratio, floor acceleration, and Deformation Damage Index (DDI), which are further described in the following subsections.

Within the "**Design**" tab, the user can select design parameters in the "Design Parameters" panel (Fig. 12). The user is allowed to select multiple design parameters for analysis. Then, the user is required to specify the following details:

1) If "**DCI**" is chosen, select "**Individual**", "**Group**", or "**All**". Enter the individual unique name (i.e., Unique Name in ETABS) or the group name (i.e., Selected Group in ETABS) of the frame elements for DCI calculation. For the "**Individual**" option the DCI of one selected member is calculated. For the "**Group**" option the DCIs of multiple frame elements are determined. The software utilizes the "Group Definitions" feature in ETABS, which groups frame elements. The group must be defined in the base ETABS model before running the ETABS model to transfer the group information to the duplicated ETABS model with the assigned wind load. Refer to the ETABS manual for defining and assigning members to a specific group. The user should ensure to include only frame elements (i.e., column, brace, beam) to prevent errors. Figure 13 shows an example of group definition in the base ETABS model, where the user enters "Group1" (without quotation marks) to calculate the DCIs of all frame elements in "Group1".

   If "**All**" is selected, the software will determine the DCI of all frame elements. Note that this requires substantial computational resources and storage.

2) If "**Inter-Story Drift**" is chosen, enter the column line index (see Fig. 14) for which the inter-story drift ratios are determined.
3) If "**Resultant Acceleration**" is chosen, enter the column line index (see Fig. 14) for which the accelerations are determined.
4) If "**DDI**" is chosen, enter the panel index (see Fig. 14) for which the DDIs are determined.

[1] Note that DCI is different from the conventional Demand-to-Capacity Ratio (DCR). Refer to Sec. 2.6.1 for more details on the DCI.

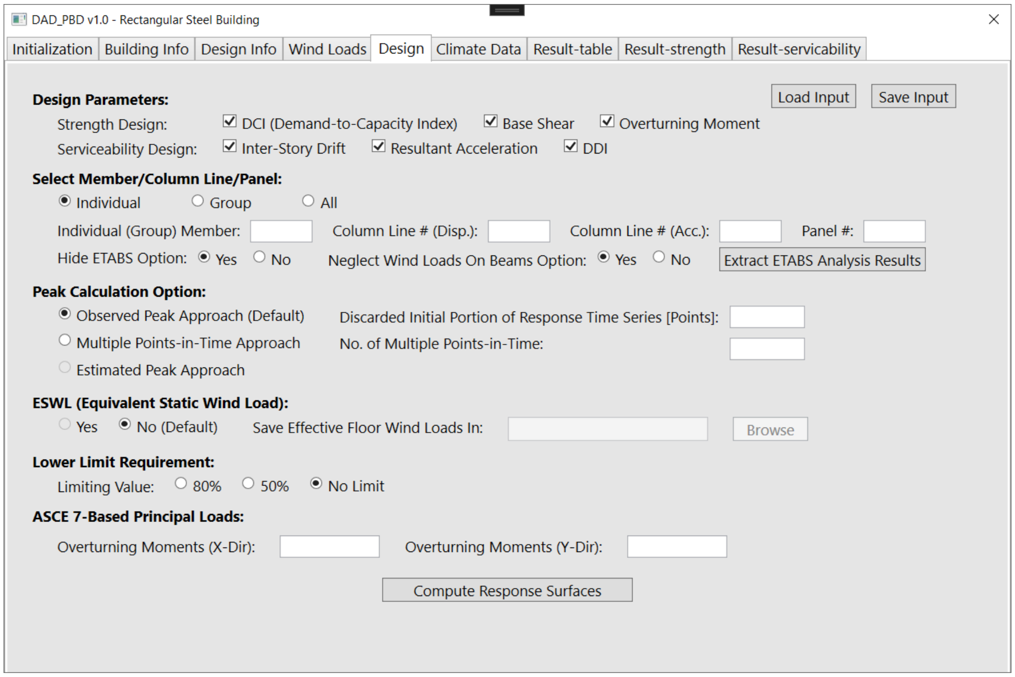


Fig. 12. DAD_PBD “Design” tab and necessary inputs for constructing response surfaces.

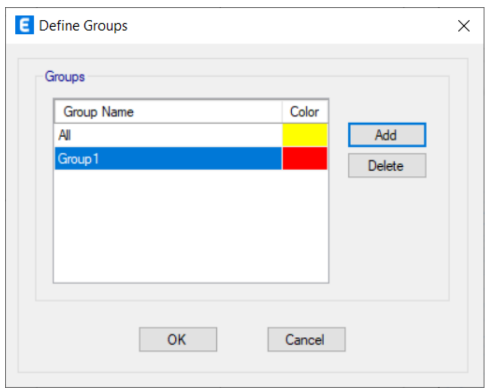


Fig. 13. Example group definition window in ETABS.

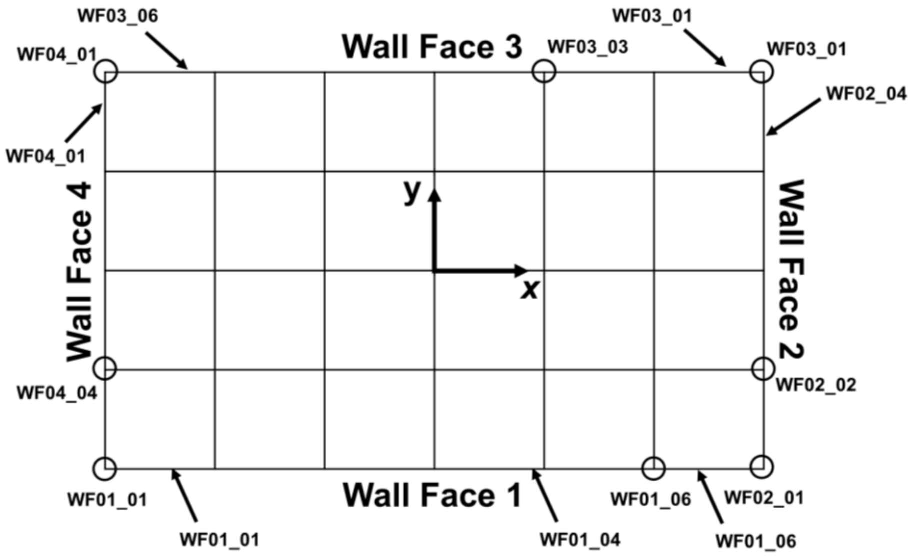


Fig. 14. Column line and panel number indexing.

The indexing of column lines and panels is outlined in Fig. 14. The indexing follows the "*WFXX_YY*" format, where *XX* represents the two-digit wall-face-number and *YY* signifies the column- or panel-number, increasing in a counter-clockwise direction. For instance, the index for the column line at the top left corner (i.e., columns joining wall faces 3 and 4) is denoted as "*WF04_01*". Refer to Fig. 14 for additional examples. Wall Face 1 is defined as the bottom face (negative in *y*-direction), with the numbering increasing counter-clockwise (Wall Face 2 is the face in the positive *x*-direction). Note that each corner marks the start of a column line. For example, the index of the top right corner is "*WF03_01*", not "*WF02_05*". It is also noted that the user must eliminate any unnecessary joints that may have been used during the construction of the ETABS model. This is crucial to avoid potential misclassification of column lines and panel numbers.

Once the design parameters are chosen, the user can begin the data extraction process for the ETABS analysis results by clicking the "**Extract ETABS Analysis Results**" button. This action triggers the ETABS application to post-process the ETABS analysis results, generating the responses, such as joint displacements and internal forces. Note that the data extraction process can be time-consuming. For example, extracting the ETABS results of 27 elements for 7 wind speeds and 36 wind directions selected in the design could take approximately 38 hours on a single desktop PC with eight cores and 64GB RAM. Note that the number of timestep of the time history was 7504. Future versions of the software will incorporate parallel computing features to expedite not only the ETABS analyses but also the data extraction process.

Again, the user has the option to run the ETAB GUI in the background during the data extraction process by choosing "Yes" under the "Hide ETABS Option". Another decision the user needs to make is whether to neglect the effects of wind load on the beams. The effects of wind load on the beams may be negligible, depending on their location and connection. Choosing the "Neglect Wind Loads on Beams Option" to "Yes" will make the DCI of the beams independent of time (see Eq. (14) in Sec. 2.6.1 for details), potentially leading to a significant reduction in the computational runtime for the DCI calculation. If the beams are designed to be part of the lateral force-resisting system, the beams will contribute to resisting the wind loads, and the wind load effects should not be considered negligible.

The option to run Equivalent Static Wind load (ESWL), presented in Ref. [20], will be added in future versions. The details on the "**Peak Calculation Option**", "**Lower Limit Requirements**" and "**ASCE 7-Based Principal Loads**" are discussed in the following subsections.

In the "**Discarded Initial Portion of Response Time Series [Points]**" box, the user should input the number of initial data points (an integer greater than zero) to be excluded from the time histories of the structural responses (e.g., internal forces, displacements, accelerations). It is recommended to discard a portion of initial data points due to the transient response caused by the sudden application of wind load to the model at the beginning of the simulation.

Once the ETABS data extraction is completed and all the inputs are entered, the user can press the "**Compute Response Surfaces**" button, which will execute the following tasks:

1. Construct the response surfaces for the design parameters using the extracted data. Figure 15 shows an example of a response surface.
2. Save the response surfaces of the design parameters for the selected members and column lines and panels in an HDF5 file named "*ResponseSurfaces.hdf5*."

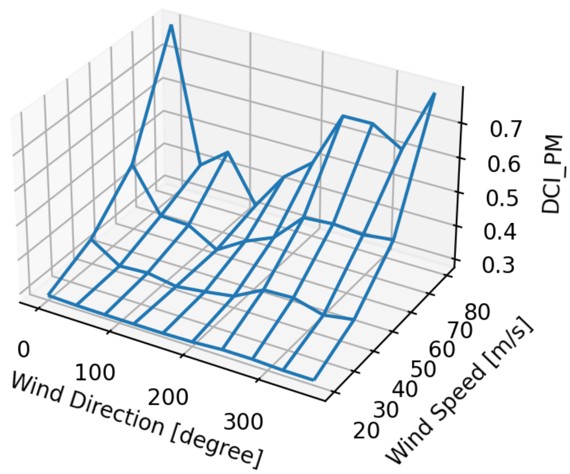


Fig. 15. Example of a response surface for DCI_{PM}.

2.6.1. Demand-to-Capacity Index

The performance of the steel frame member under the combined effect of lateral loads (e.g., wind) and gravity loads is evaluated using the Demand-to-Capacity Index (DCI) in DAD_PBD. For each frame member, the DCI time-history is calculated at various cross sections of the frame element (e.g., both ends for columns and bracings; both ends and the mid-span for beams) using the internal forces extracted from the ETABS time history dynamic analysis and the design strengths of the member. The peak values of the DCI time-histories are determined by the methods described in Sec. 2.6.5, and a response surface is constructed for each critical section of the member. Note that an in-house Python code was developed to determine the capacity (i.e., design strength) of the steel members, and only the capacity of the W- and HSS-sections can be determined for the current DAD_PBD version. For future editions, commercialized software will possibly be added, allowing analysis of various types of steel members.

For the DCI of steel members subjected to simultaneous flexural and axial forces (DCI_{PM}), the interaction equations (Eqs. (H1-1a) and (H1-1b)) in ANSI/AISC 360-22 [21] (Eqs. (11a) and (11b)) were adopted and modified.

$$If\ \frac{P_r(t)}{\phi_p P_n} \geq 0.2, \quad DCI_{PM}(t) = \frac{P_r(t)}{\phi_p P_n} + \frac{8}{9}\left(\frac{M_{rx}(t)}{\phi_m M_{nx}} + \frac{M_{ry}(t)}{\phi_m M_{ny}}\right) \tag{11a}$$

$$If\ \frac{P_r(t)}{\phi_p P_n} < 0.2, \quad DCI_{PM}(t) = \frac{P_r(t)}{2\phi_p P_n} + \left(\frac{M_{rx}(t)}{\phi_m M_{nx}} + \frac{M_{ry}(t)}{\phi_m M_{ny}}\right) \tag{11b}$$

In Eqs. (11a) and (11b), P_r(t) is the internal axial force (tensile or compressive) of the member; P_n is the axial design strength (tensile or compressive according to the internal force); $M_{rx}(t)$ and $M_{ry}(t)$ are the internal flexural forces of the member in the major and minor axis, respectively; $M_{nx}(t)$ and $M_{ny}(t)$ are the flexural design strengths of the member in the major and minor axis, respectively; ϕ_p and ϕ_m are strength reduction factors for axial and flexural strength of the member, respectively.

Due to the discontinuity in Eqs. (11a) and (11b), an abruptly large increase in DCI occurs if the $P_r(t)$ becomes greater than 20 %, especially when the contribution from the moment is minimal. Figure 16 illustrates an example case of an abrupt increase in DCI, where Figs. 16(a) and 16(b) display the time histories of the axial force and DCI_{PM}, respectively, of a column member subjected to wind loads scaled to a wind speed of 60 m/s. The lines in Fig. 16(a) indicate 20 % of the $\phi_p P_n$, with the solid green line representing the tensile strength and the orange dashed line representing the compressive strength of a column. When $P_r(t)$ intersects the 20 % lines, the DCI nearly doubles the adjacent DCIs, despite the axial force increment being relatively small.

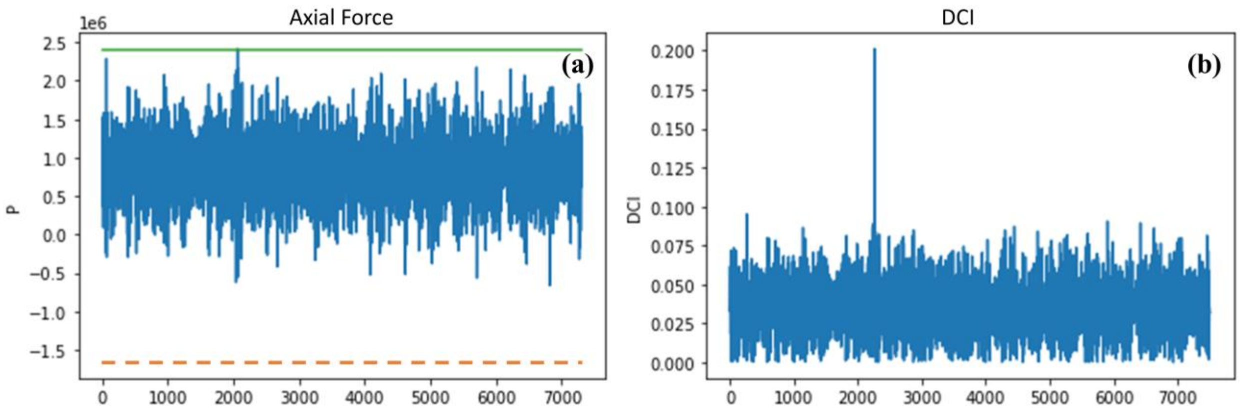


Fig. 16. Illustration of a large increase in DCI with time history of (a) axial force and (b) DCI.

Thus, the authors have proposed a new method for calculating DCIs that eliminates the discontinuity. This method, similar to the DCI calculation of reinforced concrete column members, uses the ratio of the distance of the demand point to the distance to the failure envelope. Figure 17 shows the schematic drawing of the proposed method where *A* represents the distance from the origin to the demand point ($M_u/\phi M_n$, $P_u/\phi P_n$), and *B* denotes the distance from the origin to a specific pint referred to as the capacity point. This capacity point is located on the capacity line (solid line), which intercepts with another line (dashed line) that starts from the origin, passes through the demand point, and concludes at the capacity point. The capacity line is constructed with Eqs. (11a) and (11b) at DCI equal to unity. The newly proposed DCI_{PM} is defined as A/B. As shown in Fig. 17, the contour plot demonstrates a gradual and smooth transition in the DCI values across the ($M_u/\phi M_n$, $P_u/\phi P_n$) domain.

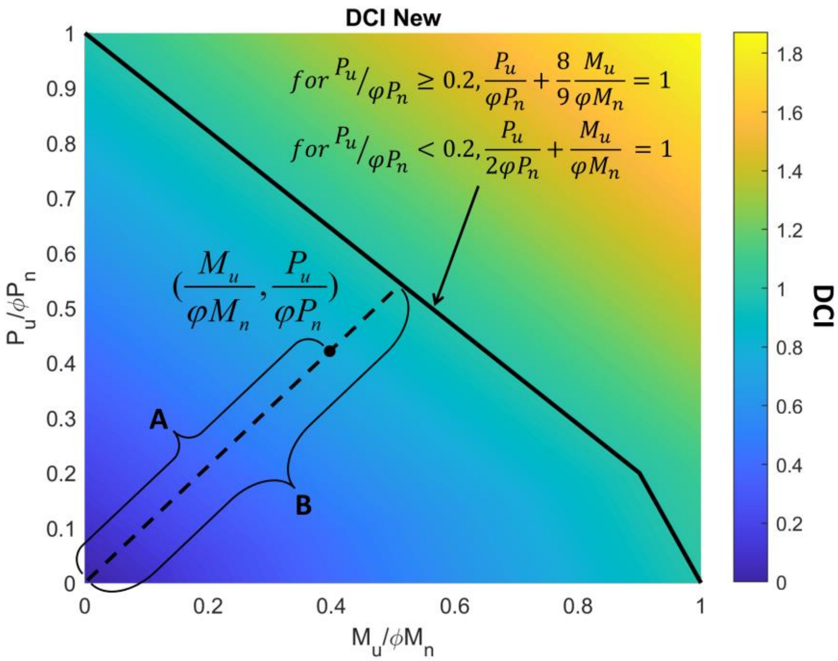


Fig. 17. Schematic drawing of the proposed DCI method.

For steel members subjected to shear forces, the DCI time-history for shear (DCI_{VT}) is calculated using Eq. (12), and the maximum DCI is determined as the larger value between the two global maxima of the $DCI_{VT}(t)$'s in the principal axes.

$$DCI_{VT}(t) = \frac{V_r(t)}{\phi_v V_n} \tag{12}$$

where V denotes the shear force; the subscripts r and n denote the internal force and the design capacity strength of the member, respectively; and the ϕ_v denotes the strength reduction factor for shear strength.

For a Hollow Structural Section (HSS), the DCI_{PM} and DCI_{VT} can be combined into one expression shown in Eq. (13) (see Eq. H3-6 of [21]). However, if the internal torsional force is less than or equal to 20 % of the torsional design capacity, the torsional effect is ignored. The newly proposed DCI_{PM} and Eq. (12) shall be used for the DCIs.

$$If\ \frac{T_r(t)}{\phi_t T_n} > 0.2, \quad DCI_{PMVT} = \left(\frac{P_r(t)}{\phi_p P_n} + \frac{M_{rx}(t)}{\phi_m M_{nx}} + \frac{M_{ry}(t)}{\phi_m M_{ny}}\right) + \left(\frac{V_r(t)}{\phi_v V_n} + \frac{T_r(t)}{\phi_t T_n}\right)^2 \tag{13}$$

where T denotes the torsional force and the subscripts r and n denote the internal force and the design capacity strength of the member, respectively. The ϕ_t denotes the strength reduction factor for torsional strength. $V_r(t)/\phi_v V_n$ in Eq. (13) is taken as the larger value for the two principal axes of the member.

For beam members, if the lateral forces affecting the beams and the internal axial forces can be assumed to be negligible, the $DCI_{PM}(t)$ reduces to Eq. (14) with flexural moments only generated by the static gravity loads and no longer becomes a function of time.

$$DCI_{PM} = \left(\frac{M_{rx}}{\phi_m M_{nx}} + \frac{M_{ry}}{\phi_m M_{ny}} \right) \tag{14}$$

If the DCI value for any member exceeds the required value (typically unity), it indicates that the design of the member is inadequate. Therefore, it is recommended that the member be resized during the re-design process.

2.6.2. Inter-story Drift Ratio

The time-histories of the inter-story drift ratio at the n^{th} story in the x- and y-axis directions, $d_{n,X}(t)$ and $d_{n,Y}(t)$, are shown in Eqs. (15) and (16), respectively:

$$d_{n,X}(t) = \frac{\left| X_n(t) - X_{n-1}(t) \right|}{h_n} \tag{15}$$

$$d_{n,Y}(t) = \frac{\left| Y_n(t) - Y_{n-1}(t) \right|}{h_n} \tag{16}$$

where $X_n(t)$ and $Y_n(t)$ are the displacements from ETABS analysis, respectively, along the x-axis and y-axis (global) at the column line on the n^{th} story; h_n is the story height between the n^{th} and n-1^{th} floor.

2.6.3. Resultant Floor Acceleration

The time history of the resultant floor acceleration at the n^{th} story, $a_n(t)$, is shown in Eq. (17):

$$a_n(t) = \sqrt{\ddot{X}_n^2(t) + \ddot{Y}_n^2(t)} \tag{17}$$

where $\ddot{X}_n(t)$ and $\ddot{Y}_n(t)$ are the absolute accelerations from ETABS analysis, respectively, along the x-axis and y-axis (global) at the column line on the n^{th} story.

2.6.4. Deformation Damage Index

The Deformation Damage Index (DDI) is a newly added design parameter in the DAD procedure that can assess the potential damage caused by shear strain on the architectural components of the building [10]. In cases of buildings where large or unusual displacements are expected, in addition to the inter-story drift, DDI can also be used to assess the elastic displacement-based serviceability design level acceptance criteria [11]. The DDI equation is shown in Eq. (18), with the location of each panel joint shown in Fig. 18.

$$DDI_n(t) = 0.5 \left| \frac{x_{n,A}(t) - x_{n,C}(t)}{h_n} + \frac{x_{n,B}(t) - x_{n,D}(t)}{h_n} + \frac{y_{n,D}(t) - y_{n,C}(t)}{l_n} + \frac{y_{n,B}(t) - y_{n,A}(t)}{l_n} \right| \tag{18}$$

where l_n is the length of the panel on the n^{th} floor, and the subscripts A, B, C, and D denote the location of the panel joints. Note that $x_n(t)$ and $y_n(t)$ are different from $X_n(t)$ and $Y_n(t)$ in Eqs. (15) and (16). DDI limits for the serviceability design of the building are provided in Table 1.

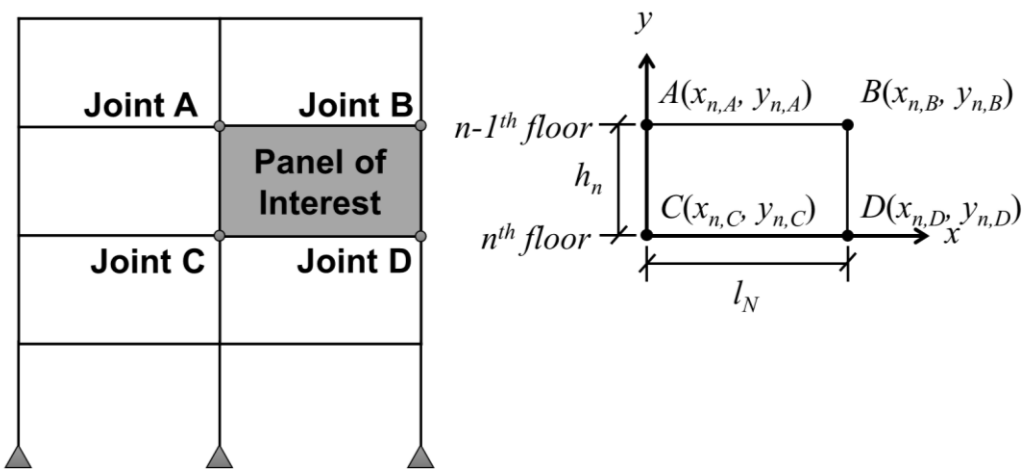


Fig. 18. Terminology for computation of deformation damage index.

Table 1. Recommended DDI limits for serviceability design from ATC Design Guide 3 [11].

Architectural Component		DDI Limit
Exterior Cladding	Brick veneer on metal studs	0.0025[1]
	Brick veneer on unreinforced masonry	0.0025[1,2]
	Plaster or stucco	0.0025[3]
	Architectural precast	0.0025[4]
	Stone clad precast	0.0025[4]
	Architectural metal panel	0.0100[5]
	Curtain wall, window wall	0.0025[6]
Interior Partitions	Gypsum drywall, plaster	0.0025[7]
	Concrete unreinforced masonry	0.0015[8]
	Tile, hollow clay brick	0.0005[9]
Elevators	Drywall enclosure	0.0025[10]

[1]Steel relief angles supporting the brick are provided at each floor with 3/8 in. soft joints and 3/8 in. control joints are provided in the brick at each column bay.
[2]Control joints are provided in masonry walls and/or isolation joints (3/8 in. soft joints) are provided between CMU and structural frame.
[3]Panelized wall with 3/8 in. control joints used at each floor line and between each column bay.
[4]Assumes flexible and deformation-controlled connections of panels to floors or columns with ¾ in. joints between panels. Panel connections to floors or frames are simply supported or determinant.
[5]Metal panels are designed with this limit or as defined by manufacturer. Other building elements generally demand stricter limits.
[6]Applicable to most off-the-shelf systems. The manufacturer shall be consulted, and the limit defined in specifications. American Architectural Manufacturers Association (AAMA) wall testing recommended for most projects unless similar test results exist.
[7]Soft joints recommended between floors as defined in ASTM C754 to allow for LL deflection and racking.
[8]Applies if CMU is constructed hard against floors and structural frame. Soft joints recommended between floors between structural frame to accommodate building sway and to eliminate stiffness contribution to lateral load resisting system.
[9]Assumes wall system constructed hard against floors and structural frame. Soft joints recommended between floors and to structural frame to accommodate building sway.
[10]Proper performance of elevator system requires a knowledge of building mode shapes, frequencies, deflections, and accelerations under design wind loads. Information shall be placed in contract documents for elevator manufacturer design.

2.6.5. Multiple Points-In-Time Option

For the peak calculation, two options are available: 1) the Observed Peak approach and 2) the Multiple-Points-In-Time (MPIT) approach. The default observed peak approach utilizes the full time-histories of individual wind effects, in which their extrema can occur at different times, and finds the global maximum of the combined wind effects. On the other hand, the MPIT approach determines the peak combined wind effect only at the instances corresponding to the highest *n* peaks of the individual wind effects. The user may choose to use the MPIT approach for the benefit of a significant reduction of computation time. To use the MPTI approach, the "Multiple Points-In-Time" button must be selected, and the *n* points must be entered in the "**No. of Multiple Points-in-Time**" box in Fig. 12. At least 30 points are recommended to use the MPIT approach. For details on the methodology and significance of the MPIT approach, refer to Ref. [22].

2.6.6. Lower Limit Requirement

According to Section 31.4.4. of the ASCE 7-22 [1], the loads for the Main Wind Force Resisting System (MWFRS) determined by wind tunnel testing should be, "… limited such that the overall principal loads in the *x* and *y* directions are not less than 80 % of those that would be obtained from Chapter 27 … The overall principal load for buildings shall be based on the overturning moment for flexible buildings and the base shear for other buildings. … The limiting values of 80 % may be reduced to 50 % for the MWFRS … if either of the following conditions applies:

1. There were no specific influential buildings or objects within the detailed proximity model.

2. Loads and pressures from supplemental tests for all significant wind directions in which specific influential buildings or objects are replaced by the roughness representative of the adjacent roughness condition, but not rougher than Exposure B, are included in the test results."

DAD_PBD offers the user an option to adjust the DCI value if the overturning moment (M_o) estimated by the DAD procedure is less than 80 % or 50 % of the M_o estimated from the ASCE 7-based wind loads. An adjustment factor γ is applied to the DCI where γ is expressed as the following:

$$\gamma = \frac{0.8 \text{ or } 0.5}{M_o^{DAD} \big/ M_o^{ASCE7}} \tag{14}$$

where the superscripts *DAD* and *ASCE 7* indicate the estimation method using DAD and ASCE 7, respectively. The numerator on the right-hand side of Eq. (14) shall be 0.5 if one of the above two conditions is satisfied.

In applying the DCI adjustment factor, the user must select the limit value (i.e., 80 % or 50 %) and provide the ASCE 7 principal loads (i.e., overturning moments) in the "**Overturning Moments (X-Dir)**" and "**Overturning Moments (Y-Dir)**" text boxes as shown in Fig. 12. These values represent the overturning moments at the base in the *x*-direction and *y*-direction, respectively, and are calculated using the procedure in Chapter 27 of the ASCE 7-22. Typically, these ASCE 7 principal loads can be determined by using the ETABS "ASCE 7 Wind Load" during the preliminary design process.

2.7. MRI Design Curve

The DAD_PBS software constructs the design curves for various design parameters as a function of MRI using the wind climatological data and the response surfaces (Sec. 2.6). A crucial component of the DAD_PBS procedure is the determination of design wind effects at local climates. This aspect of the procedure allows for an accurate consideration of wind directionality effects.

The design parameters associated with the specified MRI are determined by examining their respective design curves at the given MRI.

The climatological data requires peak directional wind speeds with long MRIs. Given that the MRI of the climatological data is typically advised to be at least three times larger than the MRI used for design of a building, these datasets are commonly generated in the basis of measurements or by simulations [23]. Publicly available wind climatological data can be obtained from www.nist.gov/wind. The site-specific wind climatological data should be provided by the wind engineer. Refer to Appendix B for the required data format compatible with the software.

The following steps outline the process for constructing the MRI design curve using the climatological data and the response surface for a design parameter:

1) The values of design parameter (e.g., DCI, inter-story drift, floor acceleration, DDI) corresponding to specific wind speeds and directions of each storm are determined by projecting the storm's directional wind speeds onto the response surface for the design parameter.
2) The peak design value for the design parameter within each storm is identified.
3) The peak design parameters for all storms are ranked in order and their MRIs are estimated using nonparametric statistics (Eq. (15)). The MRI of the k^{th} highest ranking is:

$$\bar{N}_k = \left[1 - exp\left(-\frac{\lambda k}{n+1}\right)\right]^{-1} \quad (15)$$

where n is the total number of storms and λ is the mean annual rate of storm arrival.

In the **"Climate Data"** tab, the user is required to upload the wind climatological data specific to the building site (Fig. 19). The current version of DAD_PBD is capable of utilizing two types of wind climatological data. For example, the hurricane data and synoptic wind data can be employed for wind climatological data 1 and 2, respectively. In this case, it is necessary to select both checkboxes. By considering multiple storm types, DAD_PBD can analyze design wind effects under mixed wind climates. For a more detailed methodology, refer to [20, 24].

The user is also required to input both the performance requirement value and its corresponding MRI for each design parameter. These specific MRIs should be determined based on their performance objectives (see e.g., [10]). After all inputs are provided, the user can proceed to construct the MRI design curves by clicking the "**Compute MRI design curves with specific MRIs**" button. Figure 20 shows examples of MRI design curves for DCI_{PM} and DCI_{VT} and inter-story drift ratios, respectively. For inter-story drift, acceleration, and DDI, the profile along the height of the building can also be displayed (see Sec. 3.6.2). Note that DCI, Inter-story Drift, and DDI are dimensionless quantities, while the unit for acceleration is milli-g (g/1000), where g denotes the gravity acceleration (= 9.81 m/s^2).

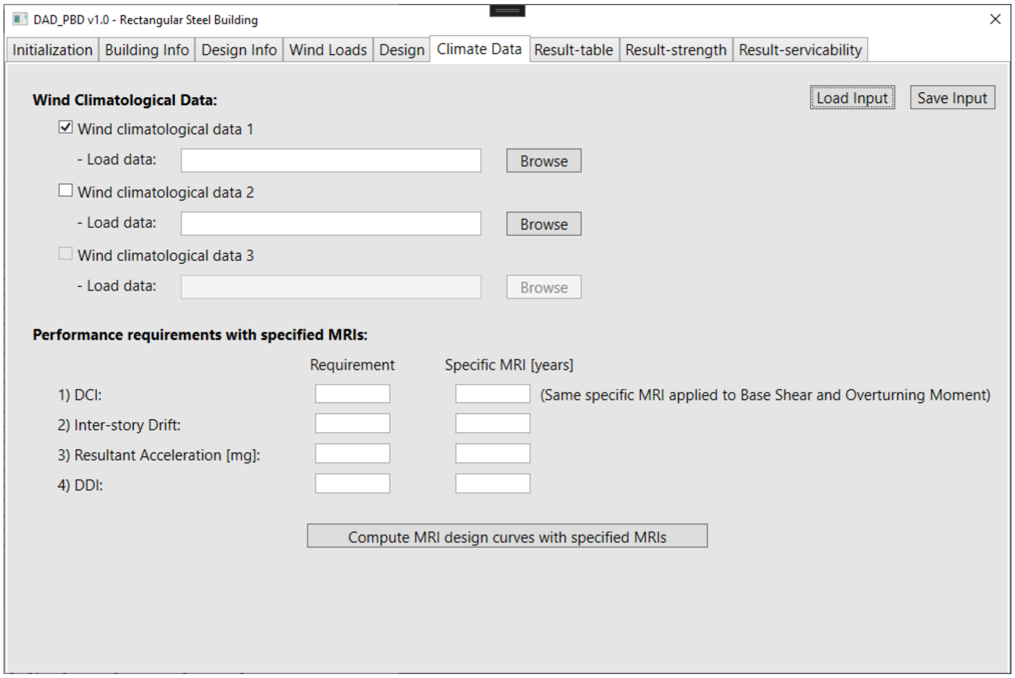


Fig. 19. DAD_PBD "Climate Data" tab for inputs for MRI design curve.

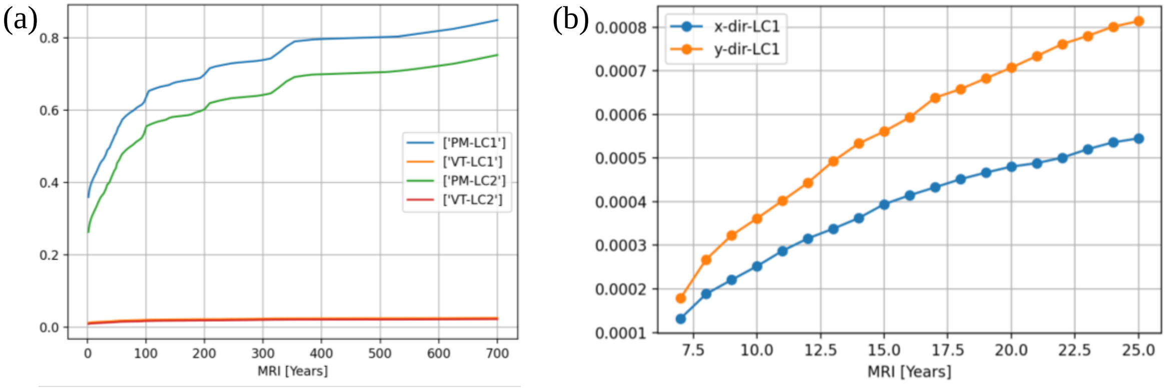
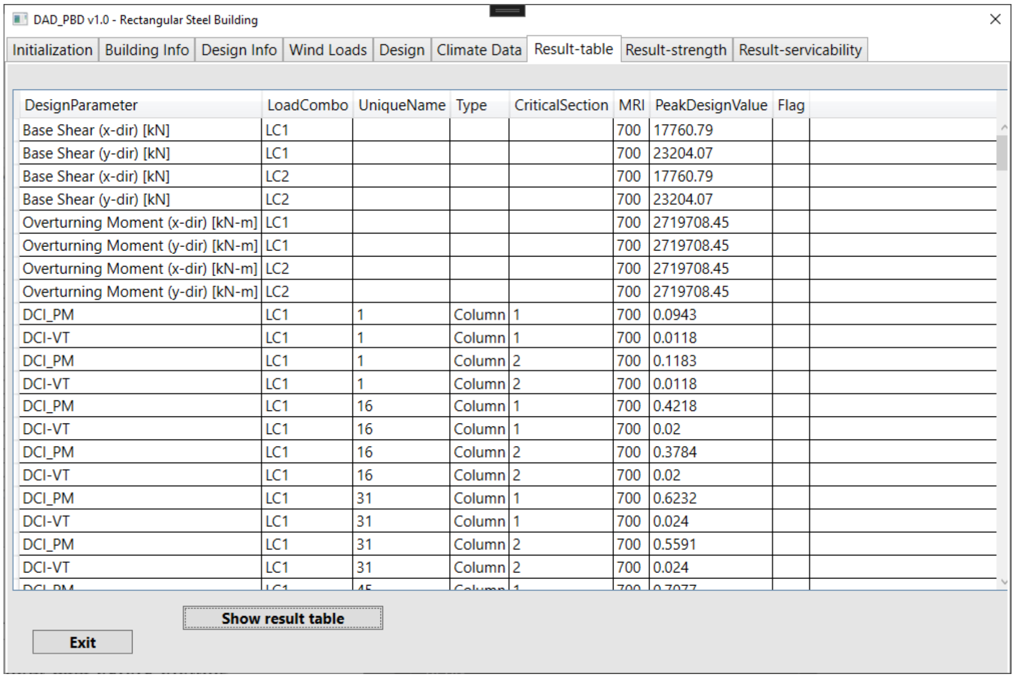


Fig. 20. Examples of MRI design curves for (a) DCI_{PM} and DCI_{VT} and for (b) inter-story drift ratio.

2.8. Results

This section describes how the analysis results are visualized in the software. There are three tabs for displaying results: 1) Result-table, 2) Result-strength, and 3) Result-serviceability. The "**Result-table**" tab provides a summary of all results in a tabular format for the selected design parameters, as shown in Fig. 21. For the serviceability design parameters, only the maximum values across all floors are displayed. If the design value of the design parameter exceeds the design requirements specified in Sec. 2.7, the "flag" column, which is the last column of the table, will be marked with an "X". This indicates that a re-design is necessary. During the re-design process, the user must update the necessary members in the ETABS building model and repeat Steps 4 through 7 from Sec. 2.1 with the updated ETABS model. Note that the file path should also be updated to match the revised ETABS model before initiating the analysis in Step 4.



DesignParameter	LoadCombo	UniqueName	Type	CriticalSection	MRI	PeakDesignValue	Flag
Base Shear (x-dir) [kN]	LC1				700	17760.79	
Base Shear (y-dir) [kN]	LC1				700	23204.07	
Base Shear (x-dir) [kN]	LC2				700	17760.79	
Base Shear (y-dir) [kN]	LC2				700	23204.07	
Overturning Moment (x-dir) [kN-m]	LC1				700	2719708.45	
Overturning Moment (y-dir) [kN-m]	LC1				700	2719708.45	
Overturning Moment (x-dir) [kN-m]	LC2				700	2719708.45	
Overturning Moment (y-dir) [kN-m]	LC2				700	2719708.45	
DCI_PM	LC1	1	Column	1	700	0.0943	
DCI-VT	LC1	1	Column	1	700	0.0118	
DCI_PM	LC1	1	Column	2	700	0.1183	
DCI-VT	LC1	1	Column	2	700	0.0118	
DCI_PM	LC1	16	Column	1	700	0.4218	
DCI-VT	LC1	16	Column	1	700	0.02	
DCI_PM	LC1	16	Column	2	700	0.3784	
DCI-VT	LC1	16	Column	2	700	0.02	
DCI_PM	LC1	31	Column	1	700	0.6232	
DCI-VT	LC1	31	Column	1	700	0.024	
DCI_PM	LC1	31	Column	2	700	0.5591	
DCI-VT	LC1	31	Column	2	700	0.024	

Fig. 21. Example result summary table.

The "**Result-strength**" and "**Result-serviceability**" tabs provide a summary and visualization of the results for strength and serviceability design parameters, respectively (see Fig. 22 and 23). The user must click the "**Load Information**" button at the top to load the input data before plotting any figures or displaying results. After the input data is loaded, the load combination dropdown menu will be populated, and the MRI box will be filled in accordingly.

To display the peak design results in numbers, choose the desired design parameter (i.e., Base shear, Overturning Moment, or DCI), load combination, and additionally either the member and critical section number ("CS#") for DCI or the floor level for serviceability design. Then, click the "**Show results**" button. This will display the peak design values in the text box. Choosing "Max" in the load combination will display the maximum value across all load combinations. The user may also modify the value in the "For MRI" box. However, note that MRI must be an integer, and only an MRI year less than what was specified in the "**Climate Data**" tab can be entered. If the user wishes to see the design parameter value with a higher MRI, the MRI design curve analysis must be re-run in the "**Climate Data**" tab as the result data is only available up to the specified MRI.

To display the result plots, choose the desired design parameter, load combination, and additionally either the member and critical section number ("CS#") for DCI or the floor level for serviceability design. Then, click the "**Plot response surface**" button or "**Plot MRI design curve**" button to plot the respective plots. Any figures displayed will be saved in the "*Display*" folder. Figure 22 and 23 show examples of the response surface plot of a strength design parameter and the MRI design curve of a serviceability design parameter, respectively. When generating figures, several factors need to be taken into account:

1) For DCI, there are two critical sections defined for columns and braces, and three for beams. Thus, if the user chooses 3 for CS#, it will not be applicable for columns and braces and a warning message will appear.

2) For all design parameters for strength design, if the user selects the "All" radio button and clicks the "**Plot MRI design curve**" button, the MRI design curves for both *x*- and *y*-directions (or all DCIs for DCI) in all load combinations will be displayed. However, this is only applicable for displaying MRI design curve figures. If the user clicks the "**Plot response surface**" button, a warning message will appear.
3) For all design parameters for serviceability design, if the user selects the "All" for the floor level and clicks the "**Plot MRI design curve**" button, the vertical profile (values at all floor levels) of the design parameters will be displayed.

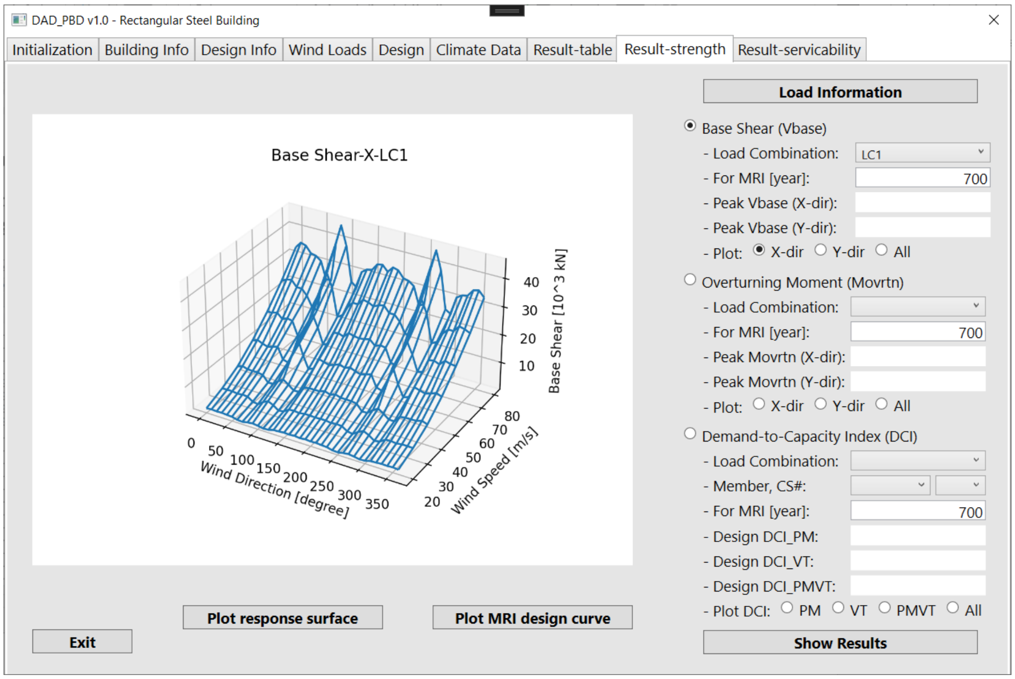


Fig. 22. Example of "Result-strength" tab with Base Shear (*x*-dir) response surface plot.

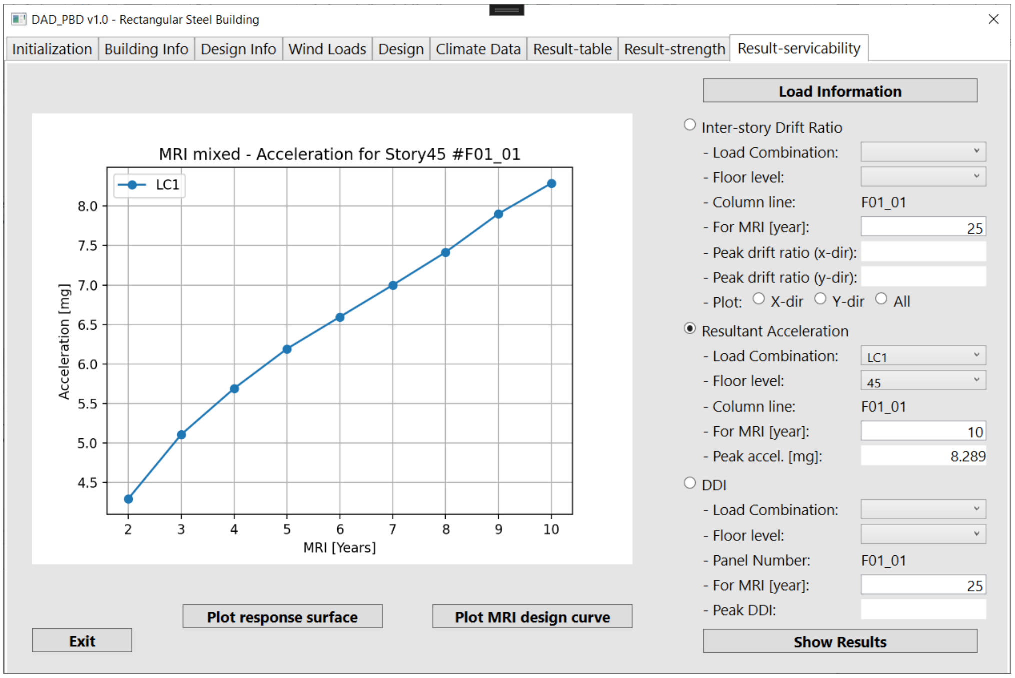


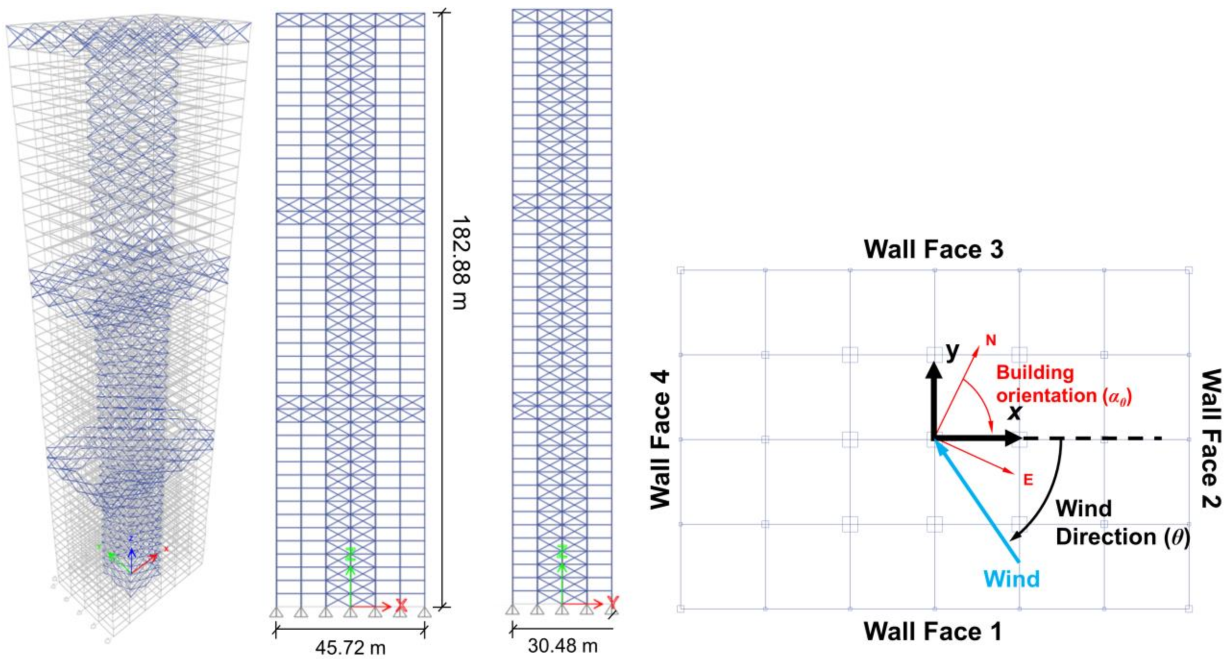
Fig. 23. Example of “Result-serviceability” tab with resultant acceleration MRI design curve plot.

3. Design Example

3.1. Building Information

For this example, the CAARC building was assumed to be an office building located in Newark, New Jersey, in terrain with Exposure C, and was designed for a 700-yr Mean Recurrence Interval of the strength limit state. This corresponds to building Risk Category II. The building dimensions are 182.88 m in height, 45.72 m in width, and 30.48 m in depth with 6 × 4 bays (7.62 m × 7.62 m in each bay), and the floors were assumed to be rigid diaphragms. Figure 24 shows schematic views of the 45-story CAARC building with an outrigger and belt truss system on the 15th, 16th, 30th, 31st, and 45th stories.

The wind direction (θ) is determined by measuring clockwise from the *x*-axis. Wall Face 1 is defined as the bottom broad face of the building with the number increasing in a counterclockwise direction (Fig. 24; also refer to Fig. 14 for a detailed definition of the wall faces).



(a) 3D view (b) Front view (c) Side view (d) Plan view of 45th floor

Fig. 24. Schematic views of the CAARC building.

3.2. Preliminary Design Loads

A uniform live load of 50 psf (2.394 kPa) for office occupancy was applied on all floors. As mentioned in Sec. 2.3, no live load reduction was taken. Superimposed dead loads of 20 psf (0.958 kPa) were applied for allowance for ceiling and mechanical on all floors, and cladding superimposed dead loads of 25 psf (1.197 kPa) were used on the vertical surface for the window system.

3.3. Load Combinations

The DAD procedure typically implements two load combinations for strength design and one combination for serviceability design [4], and the same load combinations were used in this example. In the combinations below, *D*, *L*, and *W* denote dead, live, and wind loads, respectively.

- Strength Design:

  Load Combination 1 (LC_1) = 1.2D + 1.0L + 1.0W

  Load Combination 2 (LC_2) = 0.9D + 1.0W

- Serviceability Design (see Eq. CC.2-3 in ASCE 7-22 [1]):

  LC_{srv} = 1.0D + 0.5L + 1.0W

3.4. Aerodynamic Pressure Coefficient Data

The CAARC building is assumed to be located in open terrain exposure, as mentioned before. The pressure coefficients were measured with wind directions in 10 ° increments (0 °, 10 °, …, 350 °) in the wind tunnel at the Prato (Italy) Inter-University Research Centre on Building Aerodynamics and Wind Engineering (CRIAC IV-DIC) Boundary Layer Wind Tunnel with Exposure C terrain condition, a length scale of 1:500, sampling frequency of 250 Hz, and 7504 data points for each pressure tap [25]. The reference mean wind speed at the top of the building model is 23.2 m/s. The time series of the wind floor loads on each floor were calculated from pressure coefficient data in ETABS, and the first 200 points of the time histories of structural response were discarded after the analysis.

3.5. Design Example Inputs

Table 2 comprehensively summarizes all the inputs used for this design example, including the wind load inputs and the specific design criteria (e.g., *h*/400 for 25-year MRI for the inter-story drift ratio). Figure 25 shows the maximum acceptable peak acceleration for office buildings, plotted as a function of the natural frequency of vibration, across various MRIs. Thus, this design limit was determined after the modal analysis (see Sec. 3.6.1).

Table 1, derived from Table 5-4 of ATC Design Guide 3 [11], shows recommended DDI limits for serviceability design for various architectural components, such as exterior cladding, interior partitions, and elevators. For the exterior window systems, the DDI limit was set to 0.0025, which corresponds to a 25-year MRI. Table 6-1 in ATC Design Guide 3 [11] presents potential design objectives, taking into account MRI, DDI, and the desired level of quality and durability. The DDI limit of 0.0025 is considered appropriate for structures exhibiting a typical or moderate level of quality and durability.

In this design example, a single column element (Unique Name: 976; one of the core columns located on the 15th floor) was selected for DCI. Additionally, the column line "WF01_01" and panel "WF01_01" were chosen for drift/acceleration and DDI, respectively.

Figures 26-29 show the windows that contain required inputs for the "**Wind Loads**", "**Design**", and "**Climate Data**" tabs, respectively.

Table 2. Design example input summary.

Tab Name	Input Item	Input Value
Design Info	Analysis Type	Linear Modal Time History w/ Pseudo P-Delta
	Strength Design Load Factors	LC1: 1.2DL+1.0LL+1.0WL LC2: 0.9DL+1.0WL
	Serviceability Design Load Factors	LC1: 1.0DL+0.5LL+1.0WL
Wind Loads	Wind Direction LB [Deg.]	0
	Wind Direction UB [Deg.]	360
	Wind Direction Increment [Deg.]	10
	Model Scale	500
	Reference Wind Speed at Rooftop [m/s]	23.2
	Sampling Rate [Hz]	250
	Interpolation Method	Cubic
	Wind Speed LB [m/s]	20
	Wind Speed UB [m/s]	80
	Wind Speed Increment [m/s]	10
Design	Peak Calculation Option	MPIT Approach
	Number of Discarded Initial Points	200
	Number of Points for MPIT	30
	Individual (Group) Member	976
	Column Line # (Disp.)	WF01_01
	Column Line # (Acc.)	WF01_01
	Panel #	WF01_01
	Limiting Value	80 %
	ASCE 7 Overturning Moments (X-Dir) [kN-m]	2022469.8917
	ASCE 7 Overturning Moments (Y-Dir) [kN-m]	1238141.7689
Climate Data	DCI Requirement	1.0
	DCI Specific MRI [years]	700
	Inter-story Drift Requirement	0.0025
	Inter-story Drift Specific MRI [years]	25
	Acceleration Requirement [mg]	25
	Acceleration Specific MRI [years]	10
	DDI Requirement	0.0025
	DDI Specific MRI [years]	25

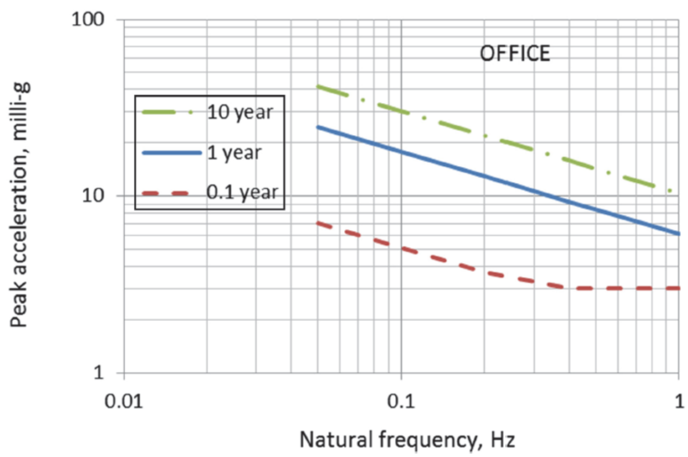


Fig. 25. Maximum acceptable peak acceleration versus natural frequency for office buildings, for 10-year, 1-year, and 0.1-year return periods. (ATC Design Guide 3 Figure 4-1 [11]; used with permission).

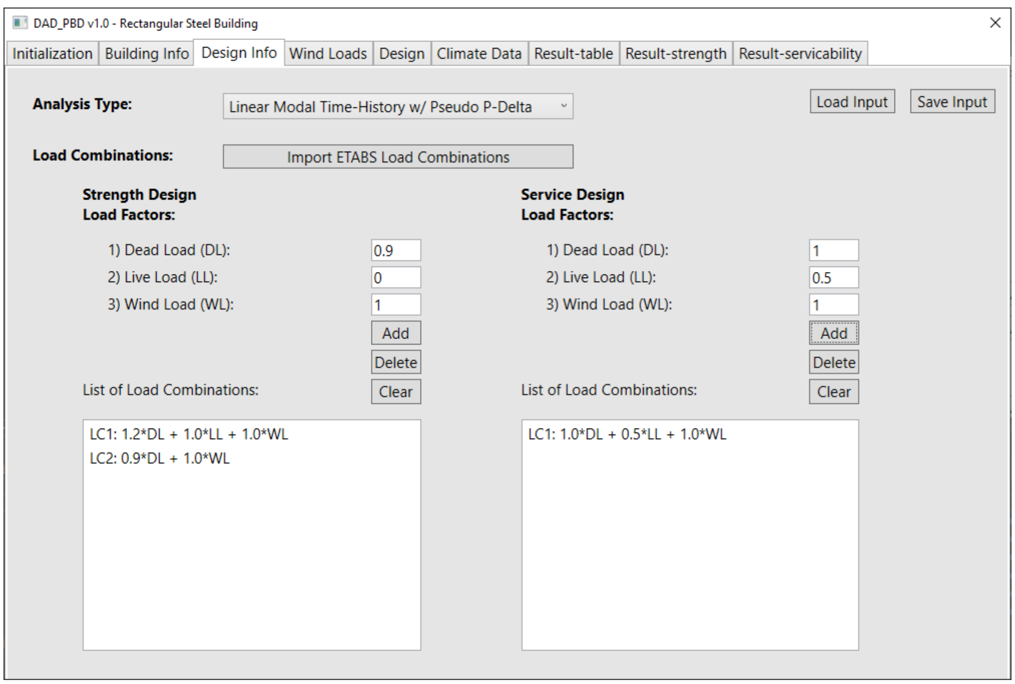


Fig. 26. Design example inputs for “Design Info” tab.

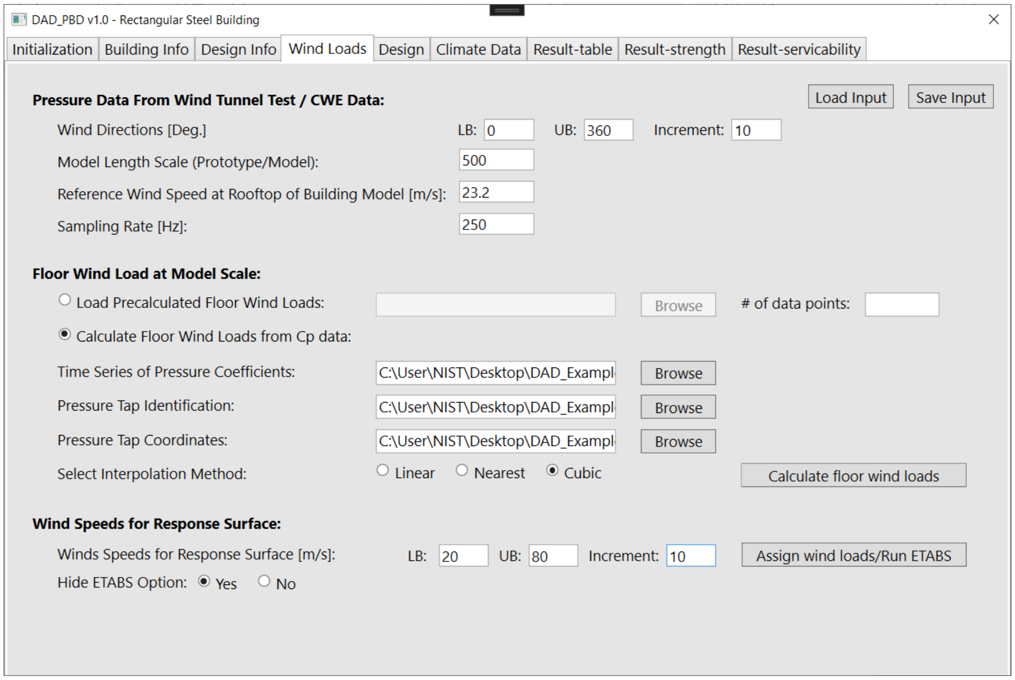


Fig. 27. Design example inputs for “Wind Loads” tab.

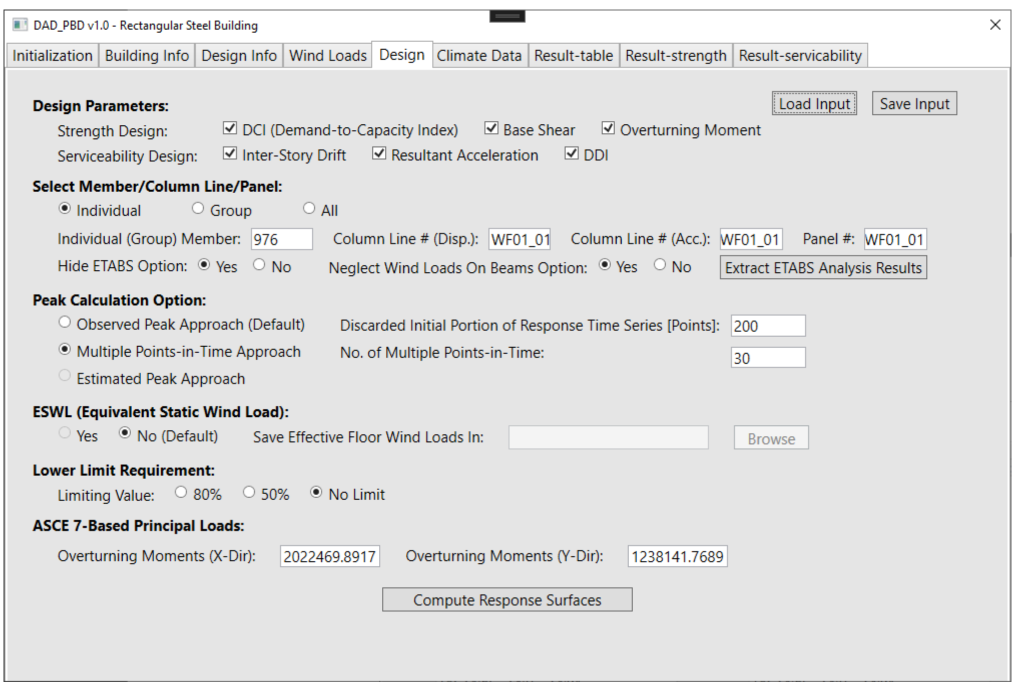


Fig. 28. Design example inputs for “Design” tab.

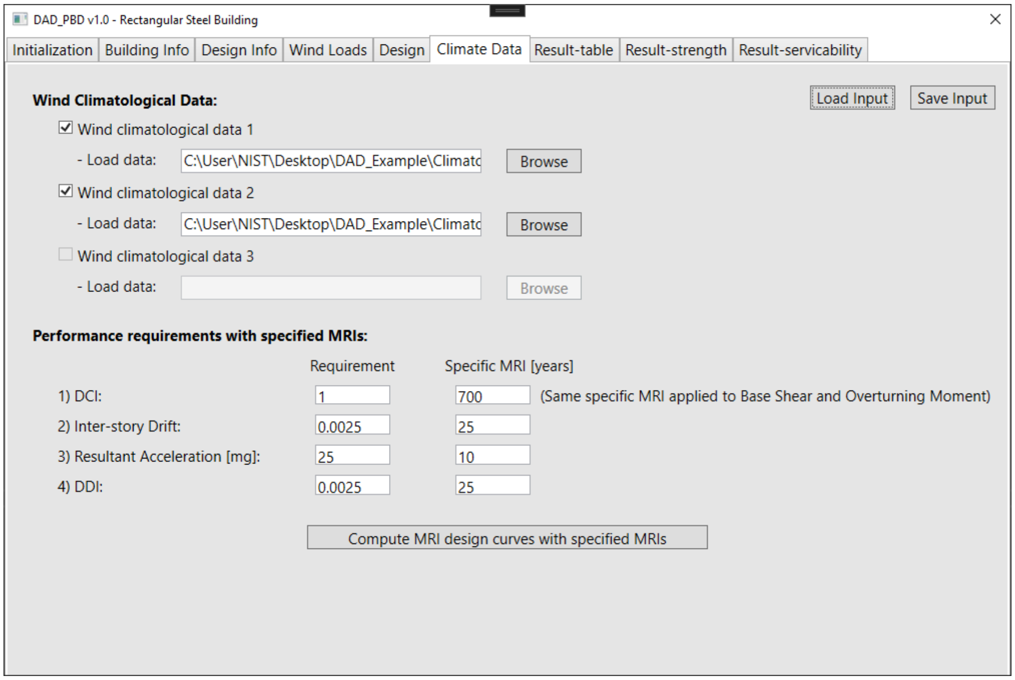


Fig. 29. Design example inputs for “Climate Data” tab.

3.6. Design Scenario Results

3.6.1. Dynamic Structural Properties

The dynamic modal analysis resulted in the highest natural period of 5.77 sec (corresponding to the lowest natural frequency of $f_n = 0.173$ Hz). The first two modes are translational in the principal *x*- and *y*-directions and the third is torsional. The modal periods and frequencies are reported in Table 3, and the mode shapes are shown in Fig. 30. In this example, 25 milli-g was used as the maximum acceptable acceleration for a 10-year MRI, based on the building’s fundamental natural frequency as recommended by the ATC Design Guide [11] (Fig. 25).

Table 3. Dynamic structural properties.

Mode Number	Periods (sec)	Frequency (Hz)
1	5.777	0.173
2	5.134	0.195
3	4.368	0.229

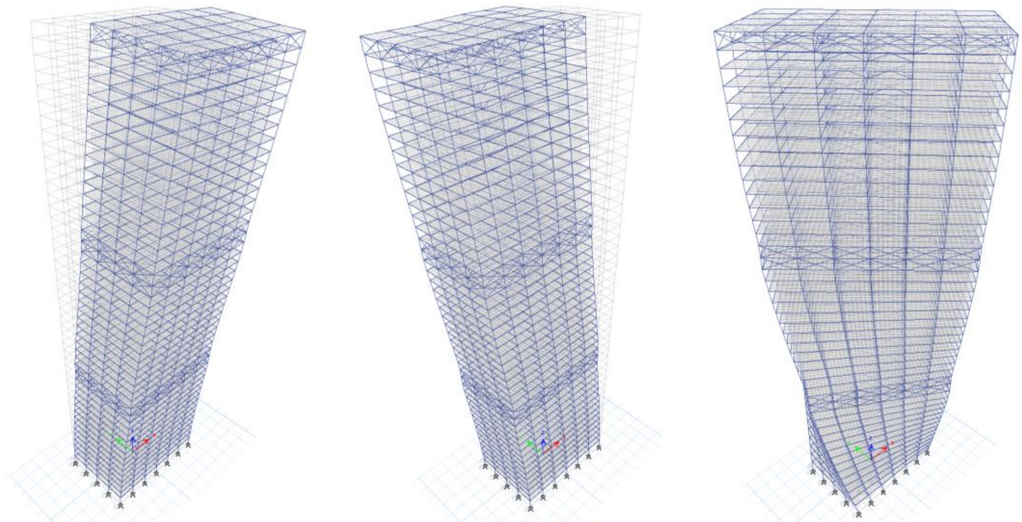


Fig. 30. The first three mode shapes of the CAARC building.

3.6.2. DAD Design Results

The results of the DAD design example are shown in this section. The desired results can be obtained by selecting the desired ratio button and then clicking the "**Plot response surface**" or the "**Plot MRI design curve**" button. Figures 31-36 display the response surfaces and MRI design curves for various design parameters: the base shear, overturning moment, DCI, inter-story drift ratio, acceleration, and DDI, respectively. Figure 37 illustrates the vertical profiles of the inter-story drift ratio, acceleration, and DDI, demonstrating the variation of the design parameter along the height of the building.

While there is significant potential for optimizing the size of building members for strength, as well as some potential for optimizing inter-story drift and acceleration, such optimization could quickly result in the Deformation Damage Index (DDI) exceeding desirable values. For illustration purposes, the example frame member (Column #976) was not iterated or optimized although the users are able to do so by repeating Steps 3-7 in Sec. 2.1.

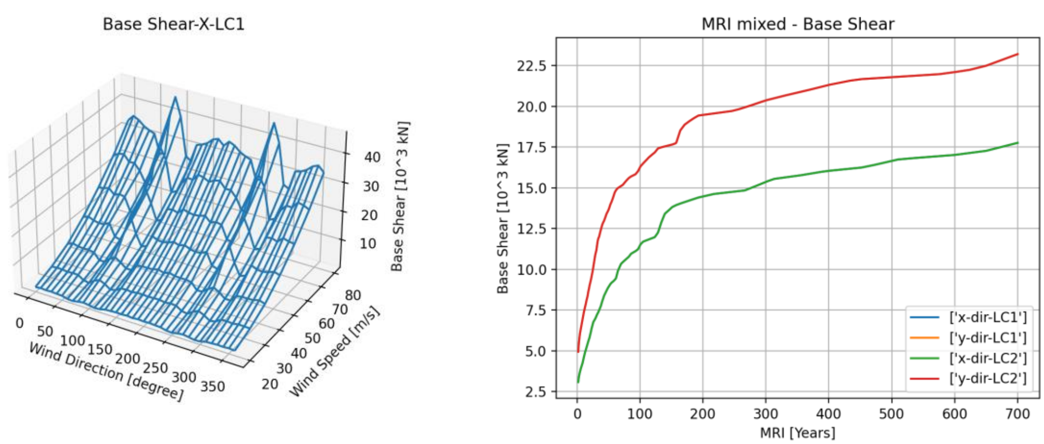


Fig. 31. Base shear response surface (*x*-dir) LC1 (left) and MRI design curve (right).

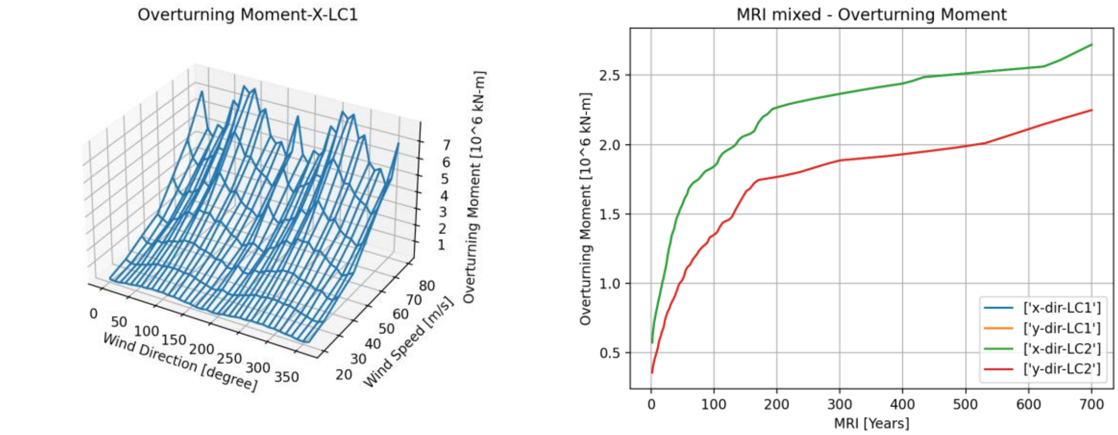


Fig. 32. Overturning moment response surface (*x*-dir) LC1 (left) and MRI design curve (right).

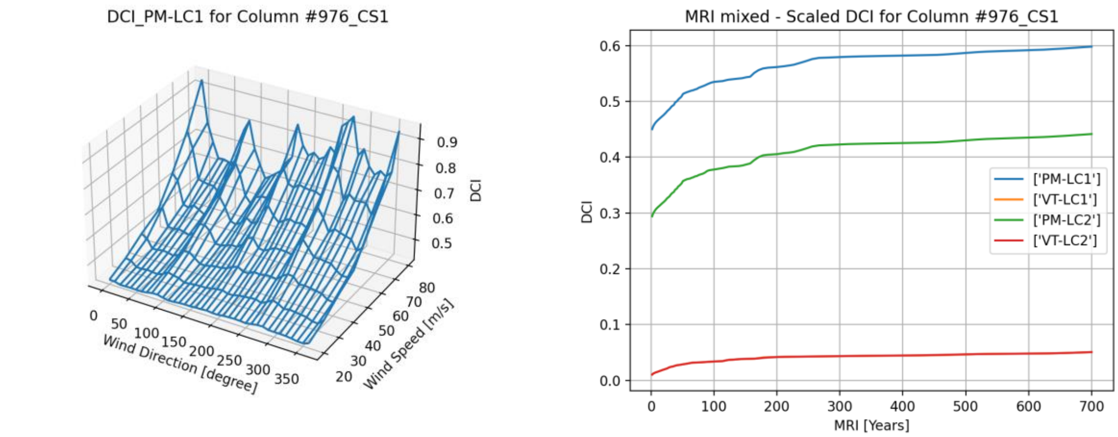


Fig. 33. DCI_{PM} response surface LC1 (left) and MRI design curve (right) for Column #976 CS1.

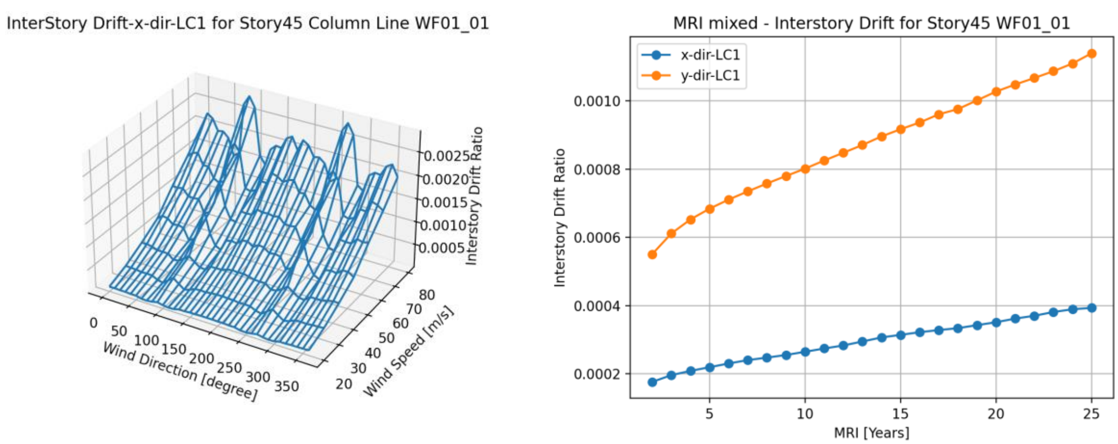


Fig. 34. Inter-story drift ratio response surface (*x*-dir) LC1 (left) and MRI design curve (right) for Column line WF01_01 on the 45th floor.

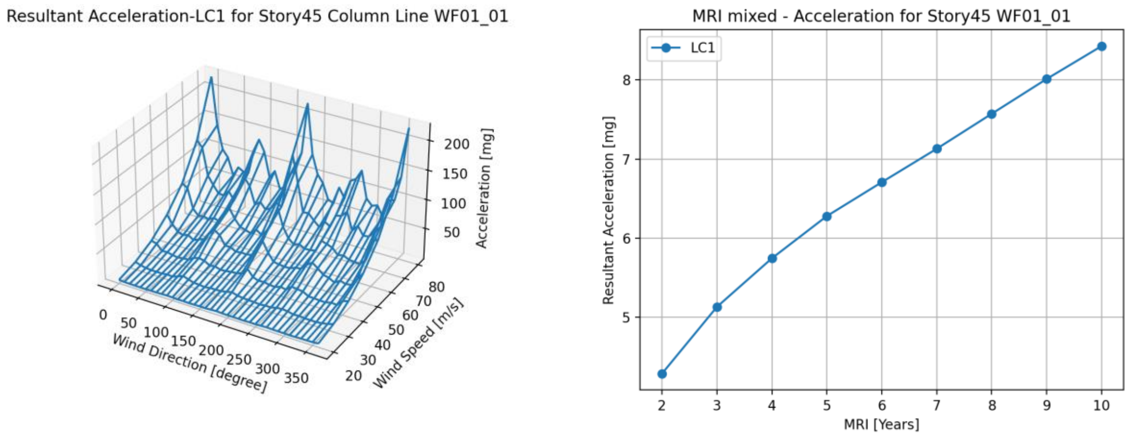


Fig. 35. Acceleration response surface LC1 (left) and MRI design curve (right) for Column line WF01_01 on the 45th floor.

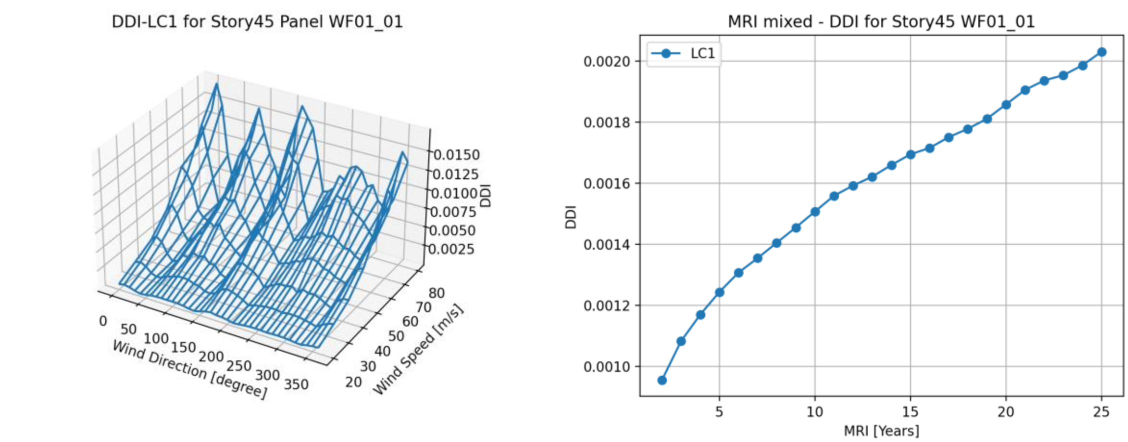


Fig. 36. DDI response surface LC1 (left) and MRI design curve (right) for panel WF01_01 on the 45th floor.

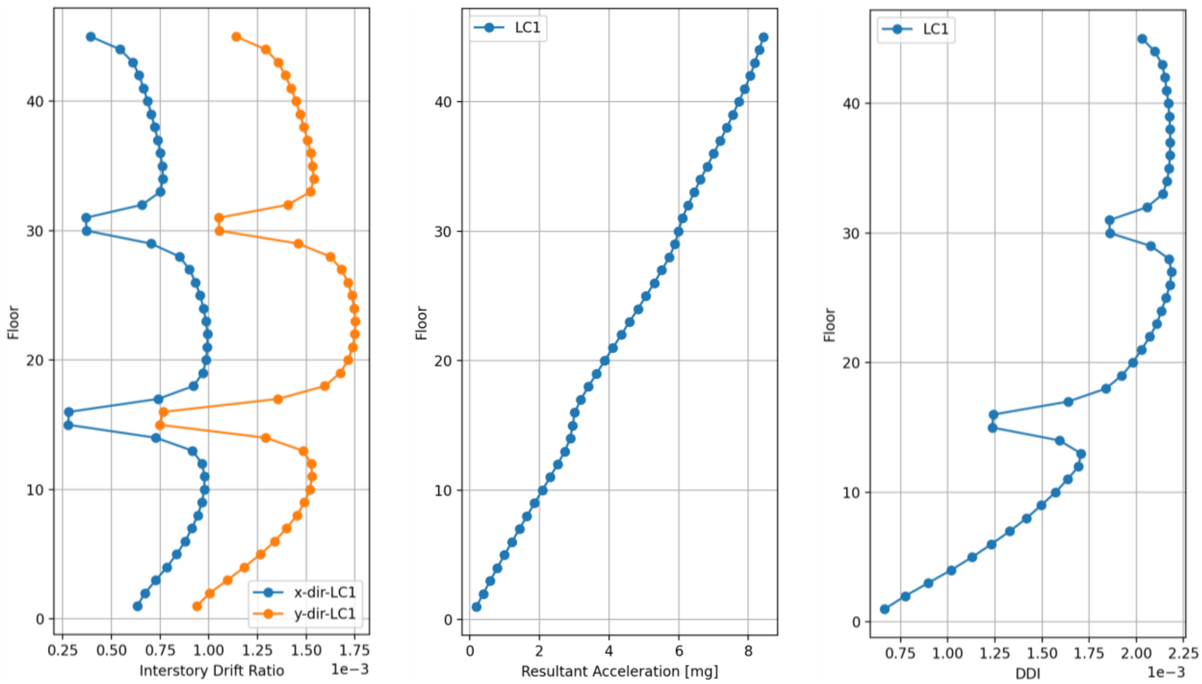


Fig. 37. Inter-story Drift (left), acceleration (center), DDI (right) profile for column line WF01_01 and panel WF01_01.

4. Summary

This report provides an overview of the newly developed DAD_PBD software aiming for the practical use of Database-Assisted Design in structural engineering design practice under the concept of performance-based wind design of tall buildings. The DAD_PBD software offers several improvements over its predecessor, DAD_ETABS, including (1) a transition from MATLAB-based to Python-based software, making it more easily accessible to structural engineers; (2) a reduction in computation time; and (3) the addition of Deformation Damage Index (DDI), as a new design parameter for use in serviceability design.

Unlike the simplified ASCE approach, the DAD approach employs time series of aerodynamic pressure data for conducting the structural dynamic analysis of a building. This analysis is performed by ETABS, a widely used commercial software for structural analysis. The DAD_PBD software utilizes the wind climatological data to account for the site-specific wind directionality. These features empower structural engineers to execute an advanced structural design of tall buildings, aligning with the novel concept of the performance-based wind design.

The software provides users with the following design parameters: (1) demand-to-capacity indices (DCIs) for axial force and moments and for shear force and torsion, (2) inter-story drift ratios, (3) resultant floor accelerations, and (4) Deformation Damage Indices (DDIs). By precisely estimating the peak design values for these parameters using DAD_PBD, structural engineers can fulfill their specific MRI-based performance objectives of the building. This report also showcases a design example of a 45-story steel frame CAARC building, illustrating the practical application of the software.

The first version of the DAD_PDB software presented in this report is developed explicitly for steel-framed rectangular-shaped buildings. However, further improvements are planned to enhance its capabilities. These include expanding the DAD_PBD's applicability to irregular-shaped reinforced concrete buildings, introducing a user-friendly GUI for reviewing design results, and integrating non-linear analysis into wind design. The DAD_PBD will also be designed to work seamlessly with widely used structural member design software, ensuring reliable and efficient analysis of structural members. Furthermore, a parallel computing procedure will be implemented to significantly reduce the computational cost, especially for non-linear analyses.

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Appendix A. Format of Data Required for Wind Load Calculation

A.1. Pressure Coefficient (Cp) Data

Pressure coefficient data must be in a MATLAB file (.mat) or HDF5 file (.hdf5) containing the time histories of the pressure coefficients measured at all the taps of a building model. The variable for the C_p time histories must be named "Cp_n". The file name should adhere to the naming scheme "Cp_XXX", where the suffix XXX represents the direction of wind WD in degrees. For example, "Cp_000.mat" refers to a file that contains the Cp time histories for the wind direction of 0 degrees, while "Cp_180.mat" pertains to the file with the C_p time histories for the wind direction of 180 degrees. The following shows the data structure of the variable "Cp_n":

Cp_n [No. of data points (n) x No. of pressure taps (m)] =

$$\begin{bmatrix} \mathrm{Cp}_{\text{timestep 1, tap \# 1}} & \mathrm{Cp}_{\text{timestep 1, tap \# 2}} & \mathrm{Cp}_{\text{timestep 1, tap \# 3}} & \cdots & \mathrm{Cp}_{\text{timestep 1, tap \# m}} \\ \mathrm{Cp}_{\text{timestep 2, tap \# 1}} & \mathrm{Cp}_{\text{timestep 2, tap \# 2}} & \mathrm{Cp}_{\text{timestep 2, tap \# 3}} & \cdots & \mathrm{Cp}_{\text{timestep 2, tap \# m}} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \mathrm{Cp}_{\text{timestep n, tap \# 1}} & \mathrm{Cp}_{\text{timestep n, tap \# 2}} & \mathrm{Cp}_{\text{timestep n, tap \# 3}} & \cdots & \mathrm{Cp}_{\text{timestep n, tap \# m}} \end{bmatrix}$$

For example, if pressure coefficient time histories consist of 7504 timesteps for each of 120 pressure taps, the corresponding variable, named "Cp_n", would be represented by a 7504 × 120 matrix.

A.2. Floor Wind Load Data

Floor wind load data should be stored in CSV files (.csv). These files contain the time histories of the floor loads of the building model determined from the wind tunnel or CFD simulations. The files must follow the same format as the CSV files generated using the C_p data. With each file containing one array of corresponding data, the folders and files follow the following format (see Fig. 11):

- Folder: The format of the folder name should be *WD_XXX*, where *XXX* represents the three-digit wind direction. For example, the folder containing the floor wind loads for the 80-degree wind direction should be *WD_080*.
- CVS Files: The format of the CVS file should be *FYYY_XXX_Zz*, where *YYY* is the three-digit floor number, *XXX* is the three-digit wind direction, and *Zz* corresponds to the load type (e.g., F_x, F_y, M_z). For ground floor loads, *FYYY* is replaced with *GF*. For example, the CSV file for floor loads acting in the *y*-direction on the 23rd floor for the 240-degree wind direction and for ground floor moments acting in the *z*-direction for the 60-degree wind direction should be named *F023_240_Fy.csv* and *GF_060_Mz.csv*, respectively.

A.3. Pressure Tap Identification

The pressure tap identification file must be located in a MATLAB file (.mat) or HDF5 file (.hdf5) containing the tap number information of the building model. For each wall face, four variables must be saved, named "WF_1", "WF_2", "WF_3", and "WF_4". The tap ID file can be saved under any chosen name. The suffixes 1 to 4 represent the building's face numbers, arranged in the order of south (-y), east (+x), north (+y), and west (-x) sides of the building (refer to Fig. 14). These variables are matrices composed of rows representing the number of taps along the height of the building model (z-direction), and columns representing the number of taps along the width or depth of the building model (x- or y-direction). Each component of this variable represents the tap number. See the example below for illustration.

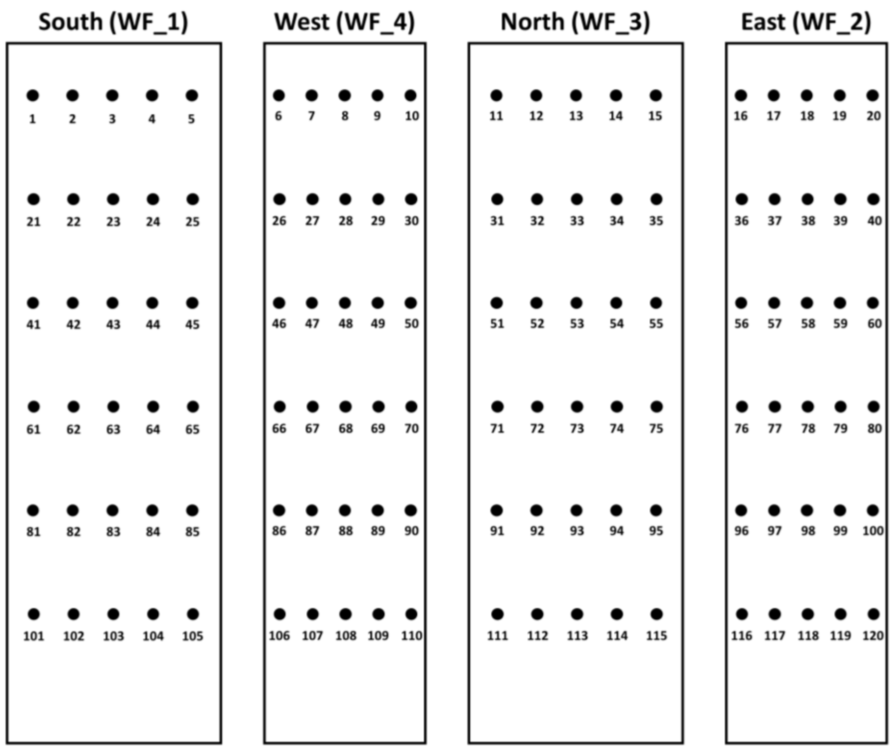

Fig. A-1. Pressure tap locations of the CAARC building model.

WF_3 [No. of taps along height x No. taps along width or depth] =

$$\begin{bmatrix} 11 & 12 & 13 & 14 & 15 \\ 31 & 32 & 33 & 34 & 35 \\ 51 & 52 & 53 & 54 & 55 \\ 71 & 72 & 73 & 74 & 75 \\ 91 & 92 & 93 & 94 & 95 \\ 111 & 112 & 113 & 114 & 115 \end{bmatrix}$$

WF_4 [No. of taps along height x No. taps along width or depth] =

$$\begin{bmatrix} 6 & 7 & 8 & 9 & 10 \\ 26 & 27 & 28 & 29 & 30 \\ 46 & 47 & 48 & 49 & 50 \\ 66 & 67 & 68 & 69 & 70 \\ 86 & 87 & 88 & 89 & 90 \\ 106 & 107 & 108 & 109 & 110 \end{bmatrix}$$

A.4. Pressure Tap Coordinates

The pressure tap coordinate file must be in a MATLAB file (.mat) or HDF5 file (.hdf5) containing the coordinates (*x*, *y*, *z*) of each tap in the model scale. The variable must be named "tap_coord", but the filename can be saved with an arbitrary name. The variable must be structured as a matrix composed of rows representing the number of taps and four columns corresponding to the sequential number of the tap, its *x*-, *y*-, and *z*-coordinates, respectively.

tap_coord [No. of pressure taps (m) x 4] =

$$\begin{bmatrix} 1 & x_{tap\,\#\,1} & y_{tap\,\#\,1} & z_{tap\,\#\,1} \\ 2 & x_{tap\,\#\,2} & y_{tap\,\#\,2} & z_{tap\,\#\,2} \\ 3 & x_{tap\,\#\,3} & y_{tap\,\#\,3} & z_{tap\,\#\,3} \\ \vdots & \vdots & \vdots & \vdots \\ tap\#\,m & x_{tap\,\#\,m} & y_{tap\,\#\,m} & z_{tap\,\#\,m} \end{bmatrix}$$

Appendix B. Format Required for Climatological Data

The Climatological data file must be stored in a MATLAB file (.mat) or HDF5 file (.hdf5), in which the filename can be saved with an arbitrary name. The following variables and properties of the extreme directional wind speed data must be contained:

Variable Name	Data Content	Data Type	Data size
lambda_wind	Annual probability of storm occurrence	Float [double]	1 [1,1]
N_wind	Number of storm events	Integer	1 [1,1]
dir_wind	Wind directions of storm events	Array of float [double array]	(No. of directions,) [1, No. of directions]
w_speed	Wind speed matrix	Array of float [double matrix]	(N_wind, No. of directions) [N_wind, No. of directions]
Ratios_Vs	Micro-meteorological data	Array of float [double array]	(4,) [1,4]
terrain	Directional terrain exposures surrounding the building of interest	List of string [Cell array]	37 [1,37]

Note: Data type and size are in Python format; the formats in brackets are in MATLAB.

- Micro-meteorological data (Ratio_Vs)

  The variable “Ratio_Vs” is a row vector containing the ratios between wind speeds at the weather station (e.g., at 10 m above ground in open terrain exposure) and the mean hourly wind speeds at the building height for the requisite terrain exposures. The extreme wind speed analyses must use micro-meteorologically homogeneous data, meaning that all the wind speed data in a set correspond to (1) the same height above ground, (2) with the same terrain exposure (e.g., open or suburban), and (3) the same averaging time (e.g., 3-s, 1-min, 10-min, or 1-hour). If the wind speed data do not satisfy the micrometeorological homogeneity requirements, they should be transformed to satisfy the requirements. To convert them to the mean hourly wind speeds at the building height in the requisite terrain exposure, the wind speed ratios, i.e., the variable “Ratio_Vs”, should be used for each terrain exposure. The variable must consist of four columns with respect to the terrain exposures, as shown below.

$$\mathbf{Ratio\_V_s} = \left[\underset{\text{Urban}}{\frac{V_A^H}{V_C^{10m}}} \quad \underset{\text{Suburban}}{\frac{V_A^H}{V_C^{10m}}} \quad \underset{\text{Open}}{\frac{V_A^H}{V_C^{10m}}} \quad \underset{\text{Water surface}}{\frac{V_A^H}{V_C^{10m}}} \right]$$

For details refer to the 'Micro-meteorological data' section in 'NIST Hurricane wind speed data' at www.nist.gov/wind. Note that if the extreme directional wind speed data already meets the micro-meteorological conditions, all values of the "Ratio_Vs" should be set to 1.

- Directional terrain exposures surrounding the building (terrain)

  The variable terrain can be a row vector containing terrain roughness in 37 directions clockwise from 0° to 360° with 10° increments from the North. The terrain exposure is categorized as A, B, C, and D for urban, suburban, open, and unobstructed terrains (water), respectively. The terrain exposure can be different according to directions, which enables DAD_PBD to account for the directionality effects of the terrain exposure. This variable should be made by a cell array for the .mat file or a string list for the .hdf5 file, which has the characters like 'A', 'B', 'C', and 'D'. Note that if the extreme directional wind speed data already satisfy the micro-meteorological conditions, all values of the terrain should be set to 'C'. Also, note that the directional terrain exposures surrounding the building should be identical to those used in wind tunnel tests for measurements of the aerodynamic pressure data described in Sec. 2.5.

Appendix C. Input Data Format

The input data file must be saved in a ".txt" file. For any checkbox, the inputs should be either 1 or 0, where 0 and 1 represent "unchecked" and "checked", respectively. For radio buttons, the inputs should be arranged in order, starting from top to bottom and left to right.

Line #	Content	Line #	Content	Line #	Content
1	Path to ETABS .dll file	**21**	Path to Cp data	**41**	Overturning moment checkbox
2	Path to EABS model	**22**	Path to tap ID	**42**	Inter-story drift checkbox
3	Path to "Save Output"	**23**	Path to tap coordinates	**43**	DDI checkbox
4	Unit	**24**	Interpolation method	**44**	Acceleration checkbox
5	# of floors	**25**	Wind speed LB	**45**	ASCE limit radio
6	Height of the building	**26**	Wind speed UB	**46**	ASCE 7 Principal loads Movtn X-dir
7	Width of the building	**27**	Wind speed increment	**47**	ASCE 7 Principal loads Movtn Y-dir
8	Depth of the building	**28**	Hide ETABS option radio (Wind load assign)	**48**	Climatological data1 checkbox
9	Orientation	**29**	Peak calculation option	**49**	Climatological data2 checkbox
10	Analysis type	**30**	# of points discarded	**50**	DCI requirement
11	Strength load combo	**31**	# of points for MPIT	**51**	Inter-story drift requirement
12	Serviceability load combo	**32**	Selected member radio	**52**	Acceleration requirement
13	Wind direction LB	**33**	Unique Name or Group Name	**53**	DDI requirement
14	Wind direction UB	**34**	Column line (Acc.)	**54**	MRI DCI
15	Wind direction increment	**35**	Column line (Disp.)	**55**	MRI Inter-story drift
16	Model scale	**36**	Panel (DDI)	**56**	MRI Acceleration
17	Reference wind speed	**37**	Hide ETABS option radio (Data extraction)	**57**	MRI DDI
18	Sampling rate	**38**	Beam wind effect neglect ratio		
19	Floor wind load radio	**39**	DCI checkbox		
20	Number of data points	**40**	Base shear checkbox		