



**NIST Grant/Contractor Report
NIST GCR 22-035**

Database-Assisted Design of High-Rise Steel Structures Using ETABS Software

User's manual, DAD_ETABS version 1.0

Dikshant S. Saini
Alice Alipour
Behrouz Shafei

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Abstract

This User's Manual is associated with the DAD_ETABS version 1.0 software based on the Database-Assisted Design (DAD) procedure for the design of high-rise steel buildings for wind, used in conjunction with the structural analysis and design program ETABS. For the design of structures for wind ETABS has so far been used in conjunction with static wind loads specified by building codes or wind engineering laboratories. The marriage of DAD with ETABS significantly enhances the capabilities of both programs. DAD allows the direct use of wind-tunnel measurements of time-varying pressure coefficients to determine the time-dependent wind loading induced by any directional wind speed. Structural and dynamic analyses performed by ETABS determine the dependence of any desired building response (i.e., member Demand-to-Capacity Indexes (DCI), inter-story drift ratios, floor accelerations) on wind speed and direction. Representations of this dependence, called *response surfaces*, are properties of the structure independent of wind climate. They are used to transform the matrix of the wind velocities at the building site into response matrices for as many responses as are required for structural design purposes. The elements of a response matrix are responses induced by their counterparts in the wind velocity matrix. For any response being considered, the vector whose components are the largest entry in each row of the response matrix is a data sample of the largest responses induced in the structure by the elements of the wind velocity matrix. The N-year response is obtained from that sample by using any appropriate extreme value estimation tool. The DAD_ETABS version 1.0 software was developed for the design of steel prismatic structures with rectangular shapes in plan. The User's Manual includes an example of the application of the software.

Keywords

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

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1 User's Manual

1.1 Overview

This user's manual pertains to the Database-Assisted Design (DAD) of buildings for wind used in conjunction with the structural analysis and design program ETABS, a highly automated commercial software for the analysis and design of buildings. For wind, ETABS typically uses static wind pressures specified by building codes or wind engineering laboratories.

However, the marriage of DAD with ETABS significantly enhances the capabilities of both programs. DAD allows the direct use of wind-tunnel measurements of time-varying pressure coefficients to determine the wind loading induced by any directional wind speed. Structural and dynamic analyses by ETABS make it possible to determine any desired building response (i.e., member Demand-to-Capacity Indexes (DCI), inter-story drift ratios, floor accelerations) as a function of wind speed and direction. ETABS constructs representations of this function for any desired responses. These representations, called *response surfaces*, are properties of the structure independent of wind climate, and are used by ETABS to construct *response matrices* for as many responses as are required for structural design purposes. The elements of a response matrix are responses induced by their counterparts in the matrix, supplied by the wind engineering laboratory, of the extreme directional wind velocities at the building site. For any response being considered, the set whose members are the largest entry in each row of the response matrix is a data sample of the largest responses induced in the structure by those extreme directional speeds. The N -year response being considered is obtained from that sample by using any appropriate extreme value estimation tool.

1.2 Software Needed

This program needs ETABS 18.1 and above. Since the application is developed in a MATLAB based environment, it also needs a MATLAB runtime version 9.5 (R2018b). This can be downloaded from the following link: <https://www.mathworks.com/products/compiler/matlab-runtime.html>.

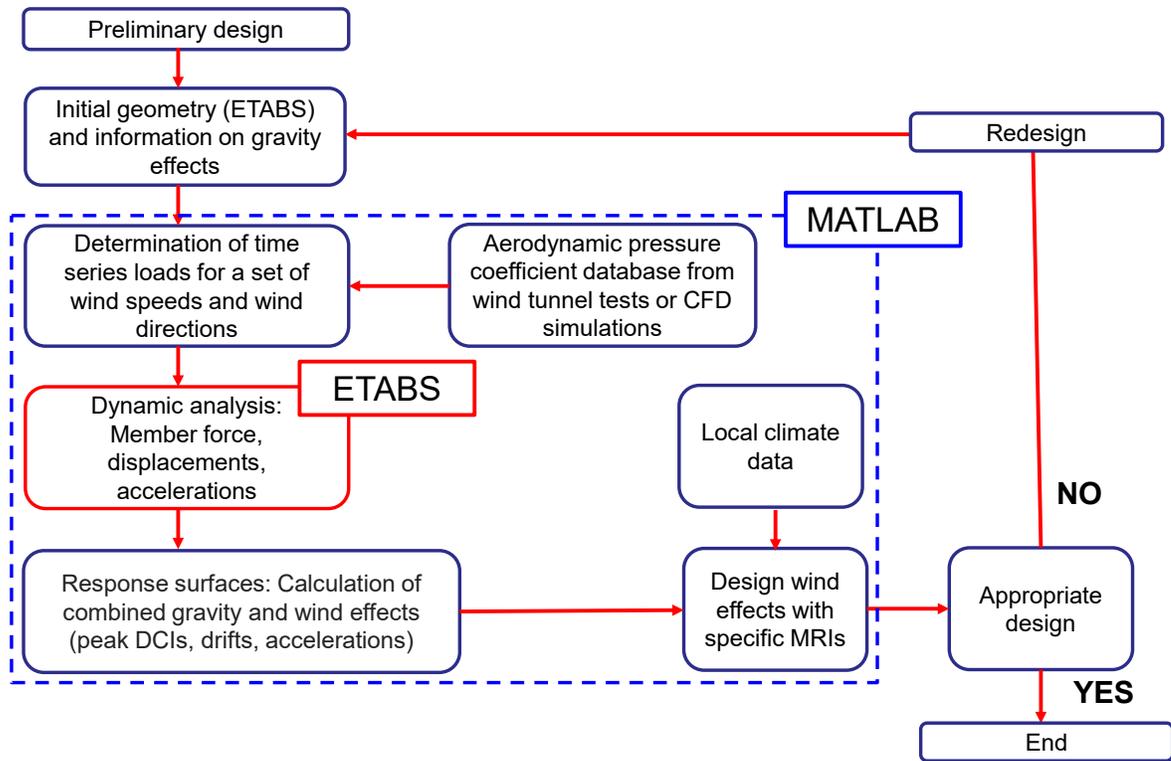


Figure 1.1. Computational framework of DAD ETABS

1.3 Getting Started

To run the software, the user needs to provide the ETABS model of the building along with the cross-sectional dimensions of the different structural members. The user also needs to provide the load details for various gravity loads in the ETABS model file. Since the program automatically runs the static analysis for these loads and performs the load combinations, it is recommended to use the standard name for the gravity load cases. For example, ‘DL’ or ‘DEAD Load’ can be used for defining the dead load case.

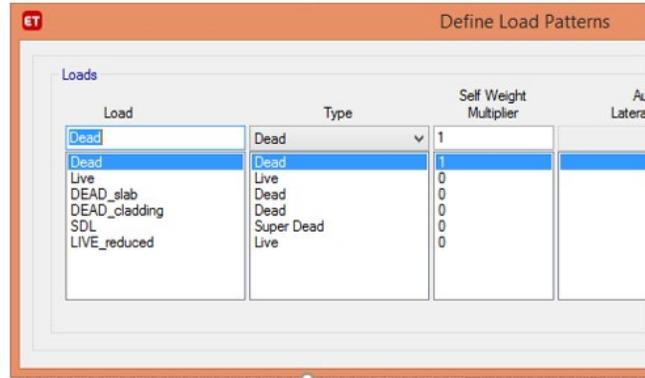


Figure 1.2. Definition of gravity load cases.

In the next sections, the various steps of the program are illustrated with the help of a 45 story CAARC building example. This is Project01 in the folder. A typical project folder consists of four folders which store data related to wind tunnel testing, building data, local climate data, and ETABS model files. To start the project, it is recommended that the user create a separate folder where the ETABS file on the initial geometry of the building can be placed. Along with it, it is recommended to keep the data for the aerodynamic database in that folder. A typical project folder should have the following folders:

1. Aerodynamics data: This folder contains the wind tunnel test data, i.e., pressure time histories and location of pressure taps.
2. Building data: This folder contains the member names for which DCIs are calculated, and nodes at which the accelerations and drifts are calculated.
3. Climate data: This folder consists of a MATLAB file containing local extreme directional wind climatological data over the last few decades.
4. ETABS model: This folder is dedicated to the ETABS model of the building.

After executing **DAD_ETABS.exe**, the user is asked by a series of pop-up windows to provide paths, via the Browse button, to various executable (e.g., ETABS 18) and data (e.g., Project01) files to perform the calculations. Typically, the user would have the executable modules and the model geometry in folders accessible via the Browse buttons in the pop-up windows. For a standard installation, the following paths are observed for the program path and API *dll* file path.

- ProgramPath = 'C:\Program Files\Computers and Structures\ETABS 18\ETABS.exe'
- APIDLLPath = 'C:\Program Files\Computers and Structures\ETABS 18\ETABSv1.dll'

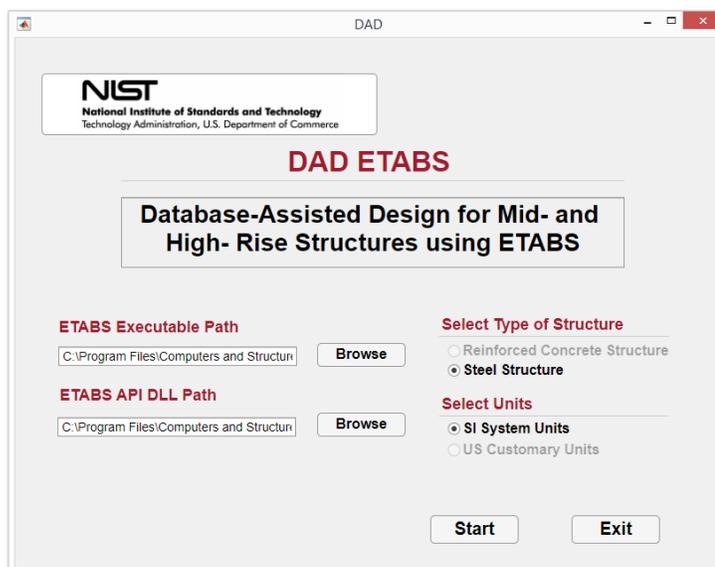


Figure 1.3. Graphical user interface of DAD ETABS

In the current version, only Steel Structures and SI units (N, m, and s) are available. Select those after using the Browse button to point to the appropriate folders for the paths requested. Press Start to continue. For steel frame buildings, the following data are expected:

- Frame sections: beam, columns, and bracings.
- Section types: W shape, and HSS sections.

For reinforced concrete buildings, the following data are expected:

- Frame sections: beams, and columns.
- Section types: rectangular and circular sections.

1.4 Building Information

The user needs to provide basic geometry details, as shown in Fig. 1.4. They include the building height, width and depth, and the number of stories. In ETABS, the dimensions along the x and y axis are the building width and depth, respectively. The wind direction is measured from the x direction. The user has two options. One option is to read the dimensions of the building from the ETABS model. This can be done by clicking the button Read from *ETABS Model*. The second option is to directly enter the building dimensions as shown below.

Figure 1.5 shows the plan of a 45-story building known by the name of CAARC, the axes x and y , and an isometric view of the building. The building has a height of 182.88 m, width of 45.72 m, and depth of 30.48 m. It has three types of columns and beams: core, external core, and internal core, and an outrigger and belt truss system located at the 14th, 15th, 30th, 31st, 44th and 45th stories. Bracings are divided into core and outrigger bracings. The dimensions of each type of structural member are kept the same for 15 successive floors. All the beams consist of rolled W-sections from AISC 360-10 (2010), whereas the columns and bracings are made of built-up hollow structural sections (HSS). The analytical model includes a rigid diaphragm which is provided by the floor slab at all floor levels. In addition to the self-weight, a live load and super-imposed dead loads of 2.4 kN/m² and 0.72 kN/m² are applied at each floor. The dead load from the cladding is applied only on the exterior beams. Table 1.1 provides the section details of the structural members used for the building. In addition, the user provides the orientation angle of the building from the North. The orientation angle of building is an important parameter used in the wind directionality analysis.

Table 1.1 Section properties for the structural members in the 45-story building

Member thickness Type	Section type	Depth (mm)	Width (mm)	Flange (mm)	Web (mm)
Corner Columns	Box/Tube	914.4	914.4	50.8	50.8
	Box/Tube	762.0	762.0	38.1	38.1
	Box/Tube	609.6	609.6	25.4	25.4
Core Columns	Box/Tube	1371.6	1371.6	76.2	76.2
	Box/Tube	1066.8	1066.8	50.8	50.8
	Box/Tube	914.4	914.4	38.1	38.1
Perimeter Columns	Box/Tube	609.6	609.6	38.1	38.1
	Box/Tube	457.2	457.2	31.8	31.8
	Box/Tube	304.8	304.8	25.4	25.4
Beam	I/Wide Flange	254.0	254.0	14.2	8.6

In Section 3 of Fig. 1.4 the program asks for the type of analysis. In the current version, only linear analysis is supported. The non-linear analysis will be added in the future. In Section 4

the user needs to provide the details of the load factors for different load types. At present, the program is capable of handling two load cases related to strength and serviceability designs. This can be done by performing the following steps. Specify load factors on the left side of the window, then press Add on the right side of the window for the appropriate design combination.

DAD ETABS
for mid- and high-rise structures

1. Model Path
D:\Etabs\Project01\Project1\Parentmodel\Parentmodel.EDB Browse

2. Building information

2.1 Building height	182.88
2.2 Building depth	30.48
2.3 Building width	45.72
2.4 No. of stories	45
2.5 Orientation angle (deg.)	270.00

Read from ETABS Model

3. Analysis type

Linear time history analysis
 Non linear time history analysis

4. Load combinations

4.1 Specify load factors

a) Dead load (DL)	1.40
b) Super-imposed dead load (SDL)	1.40
c) Live load (LL)	1.00
d) Wind load (WL)	1.00

4.2 For strength design

1.4 DL + 1.4 SDL + 1 LL + 1 WD Reset Add

4.3 For serviceability design

1 DL + 1 SDL + 1 LL + 1 WD Reset Add

Previous Next

Figure 1.4. Information related to building geometry and load combinations.

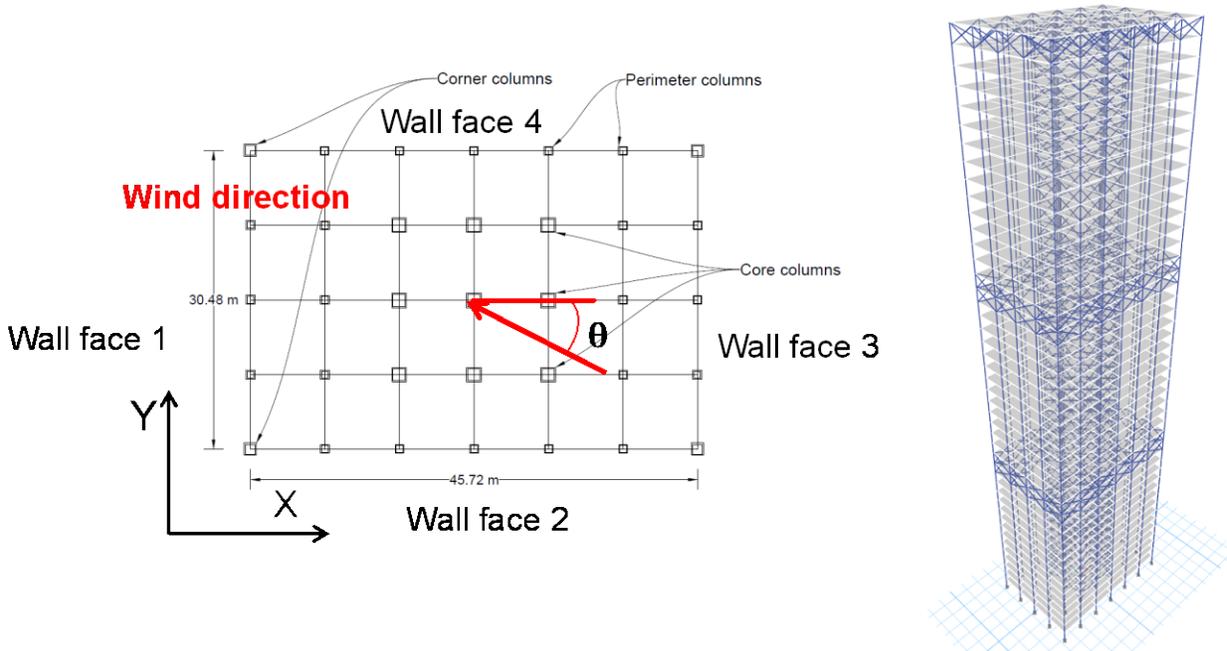


Figure 1.5. Plan and isometric view of the CAARC building.

1.5 Wind Load Calculation

Wind tunnel tests or computation fluid dynamics (CFD) simulations can be performed to calculate the aerodynamic loads acting on the building. Typically wind tunnel tests are performed to obtain the pressure time history data at multiple locations. The measured pressure data is used to calculate the aerodynamic loads acting on the structure. However, the wind tunnel testing may not use a sufficient number of pressure taps to allow the direct calculation of the floor loads. To calculate the wind loads on each floor of the building, the pressure data is processed using methods described in Park and Yeo (2018). Figure 1.6 illustrates the procedure used to calculate the floor loads. As shown in Figure 1.6, the physical taps are replaced by a set of “generated taps” whose pressures are equivalent to the pressures measured in the laboratory at the physical taps. The pressures at the generated taps are denoted by $p_{ijk}(t)$, where $k = 1, 2, 3, 4$ identifies the façade, j identifies the floor, and k identifies the individual generated tap being considered. The respective forces $p_{ijk} A_{ijk}(t)$ are acting at the center of each tap’s tributary area A_{ijk} . (In general k may differ from façade to façade and from floor to floor.) The sum $F_{ijk}(t) = \sum_k p_{ijk}(t) A_{ijk}$ is the resultant force acting at the CG_j of floor j due to the pressures $p_{ijk}(t)$.

In lieu of the forces $\sum_k p_{ijk}(t)A_{ijk}$ we consider a uniformly distributed lateral load $\frac{F_{ijk}(t)}{l_{ij}}$, where l_{ij} is the horizontal dimension of the façade i at the level of floor j . The resultant of this distributed load is $F_{ijk}(t)$. The torsional moment induced by this load at CG_j is zero. We now consider the torsional moments acting at CG_j due to the forces $p_{ijk}A_{ijk}$ acting at the centers of the tributary areas A_{ijk} . The resultant torsional moment induced by these forces at CG_j is $M_{ijk}(t) = \sum_k p_{ijk}(t)A_{ijk}w_{ijk}$, where w_{ijk} is the algebraic distance, normal to the direction of p_{ijk} , between CG_j and the force $p_{ijk}A_{ijk}$. The program then calculates the quantity $M_{ijk}(t)/l_{ij}$. Recall that, while the actual torsional moment about CG_j is $M_{ijk}(t)$, the torsional moment induced by the load $F_{ijk}(t)/l_{ij}$ is zero. Thus, the total torsional moment induced at CG_j by the distributed load $\frac{F_{ijk}(t)}{l_{ij}}$ and the distributed torsional moment $M_{ijk}(t)/l_{ij}$ is precisely $M_{ijk}(t)$. The notations used herein will also be helpful for the development of software applicable to buildings of arbitrary shape.

The pressure data on the structure's envelope are generally expressed as non-dimensional pressure coefficients C_p measured in wind tunnel tests and based on the mean hourly reference wind speed V_H :

$$C_p = \frac{p}{(1/2) \rho V_H^2}$$

where p is the net pressure relative to the atmospheric pressure and ρ is the air density (1.225 kg/m³ for 15°C air at sea level). The floor pressures calculated from the wind tunnel laboratory data are scaled up using the square of velocity scale (V_p/V_m). The time step in the prototype loading is modified by applying the calculated timescale, as follows:

$$\Delta t_p = \frac{L_p V_m}{L_m V_p} \Delta t_m \quad (1)$$

where (L_p/L_m) is the length scale and Δt_m is the time step of data time series in the model. Stochastic wind loads are calculated at each floor level for a range of mean wind speed and wind directions. The calculated aerodynamic loads are used to perform dynamic analyses.

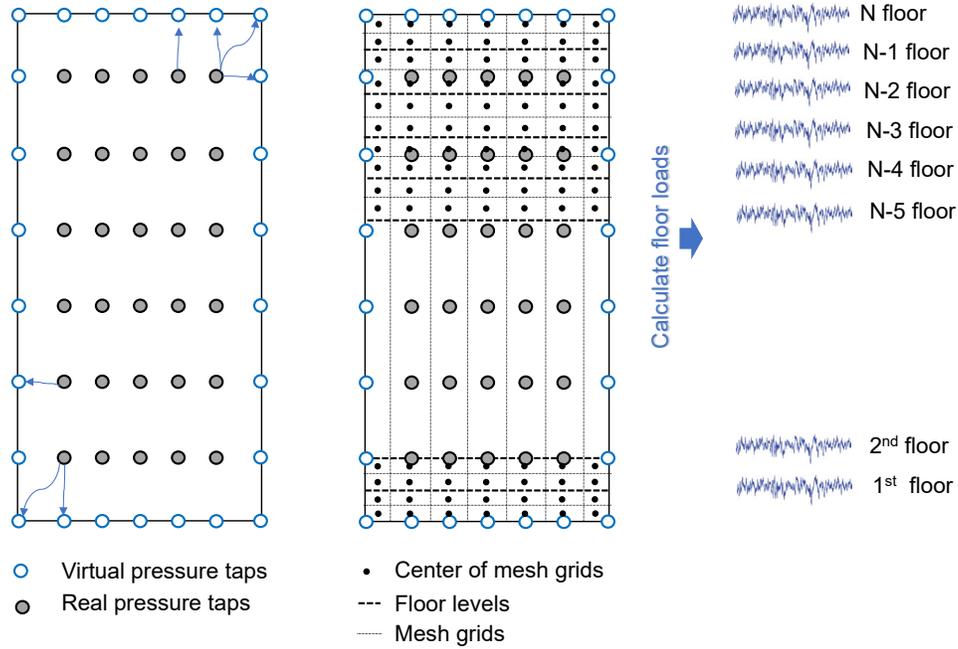


Figure 1.6. Schematic sketch illustrating the procedure to calculate the wind forces applied at the floor level.

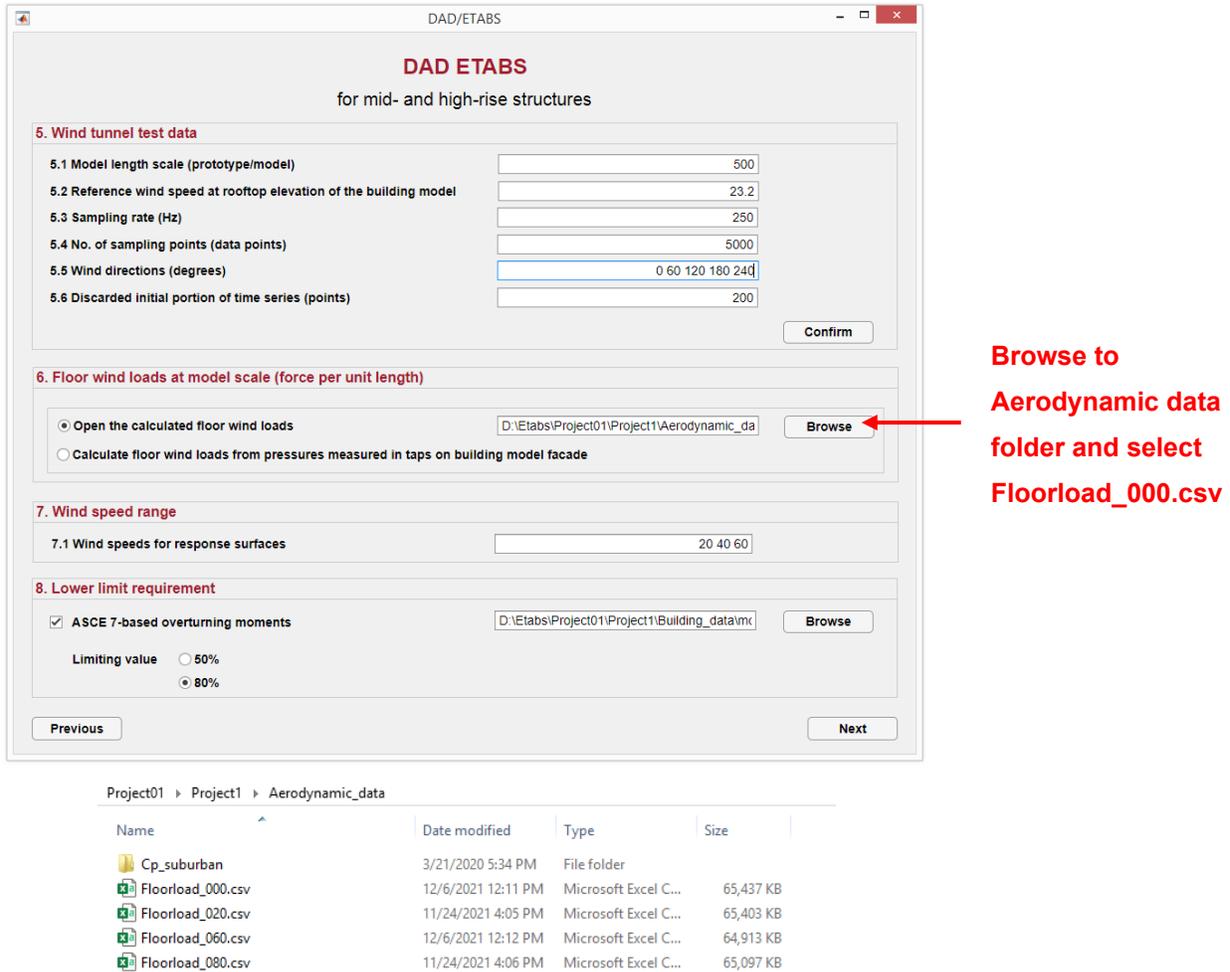
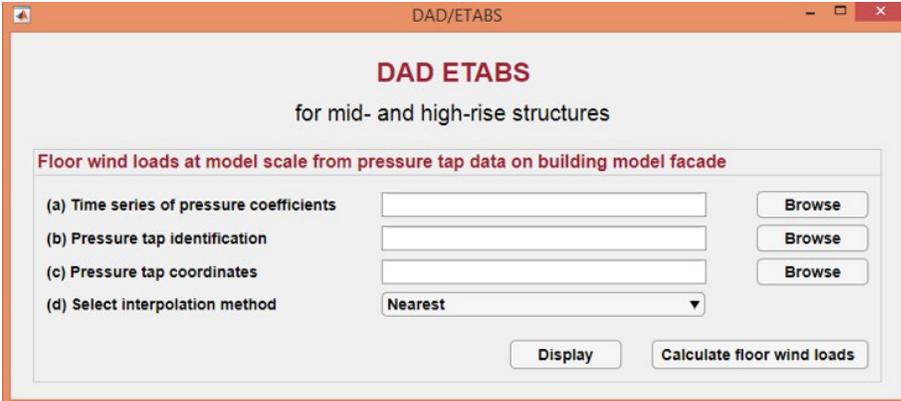


Figure 1.7. Details related to wind tunnel experiments and wind loads.

The user provides the details of the wind tunnel test in Section 5 of Figure 1.7. Those details include the length scale of the tested model, the reference wind speeds at the rooftop elevation, the sampling rate of measured pressure data, the number of data points in the samples, and the wind directions. For the floor load calculation, a new window will pop up (Fig. 1.8), which will ask for paths of the files consisting of data related to measured pressure coefficients, coordinates of pressure taps, and identification of pressure taps. This information is present in the aerodynamic data folder. All the required files are in MATLAB format i.e., *.mat. In the present version, the user can only use the rectangular grid in the wind tunnel tests. This will be extended in future to other grid patterns. The program calculates the wind loads as uniformly distributed forces and moments on all four faces of each floor i.e., a total of eight-time histories for each floor. These

loads are then saved in a Floorload_\$\$\$\$.csv files which will read by the ETABS using database tables operation. This is the only option available in current version of ETABS. More details about the wind loads application can be found in Section 3.



Browse to Aerodynamic data folder and select the files as shown below.

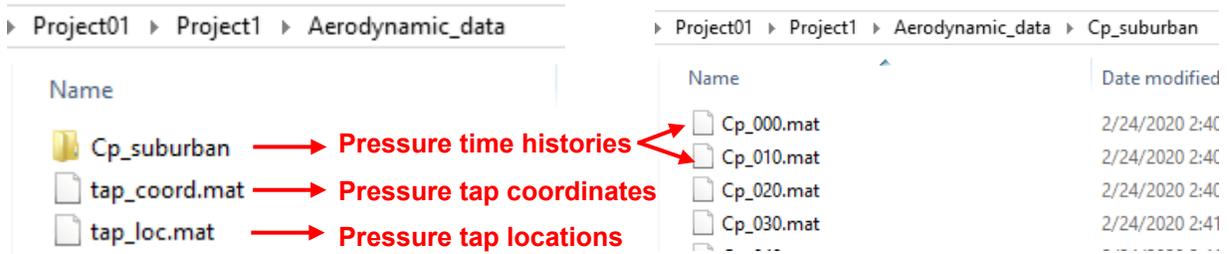


Figure 1.8. Details needed for wind load calculations.

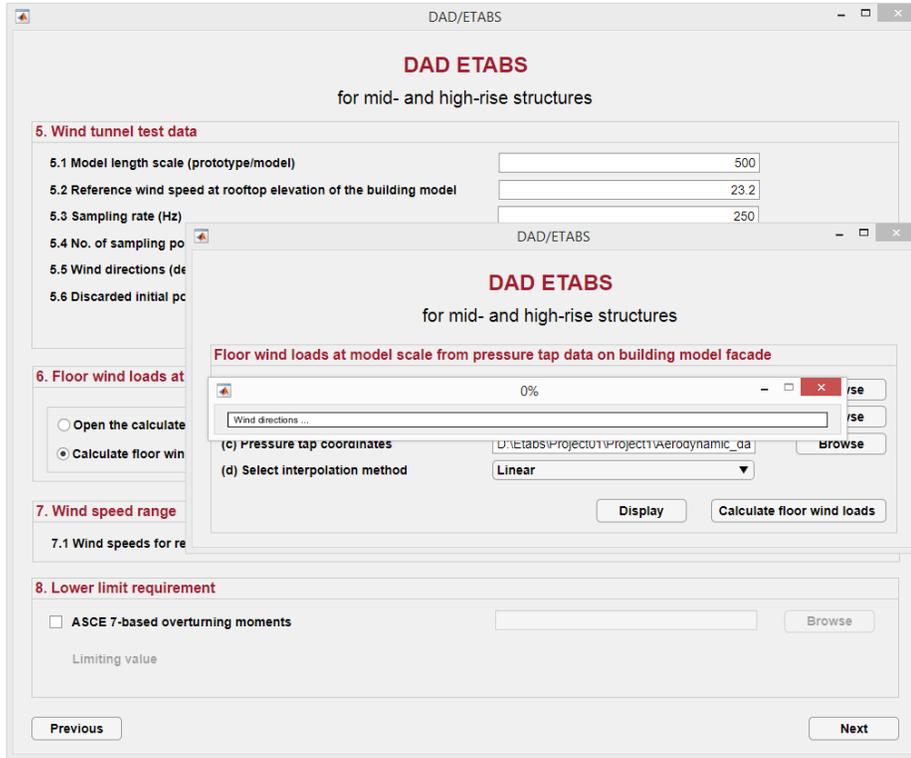
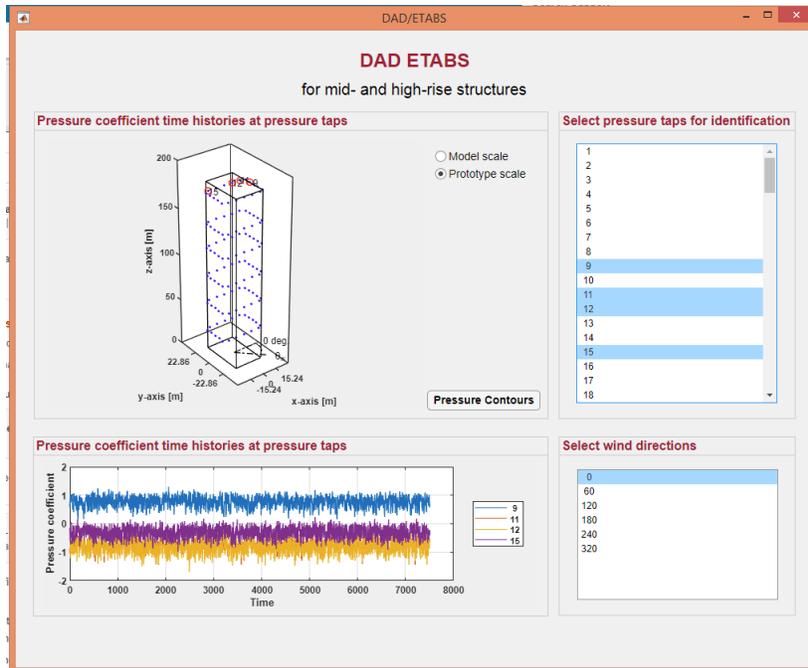
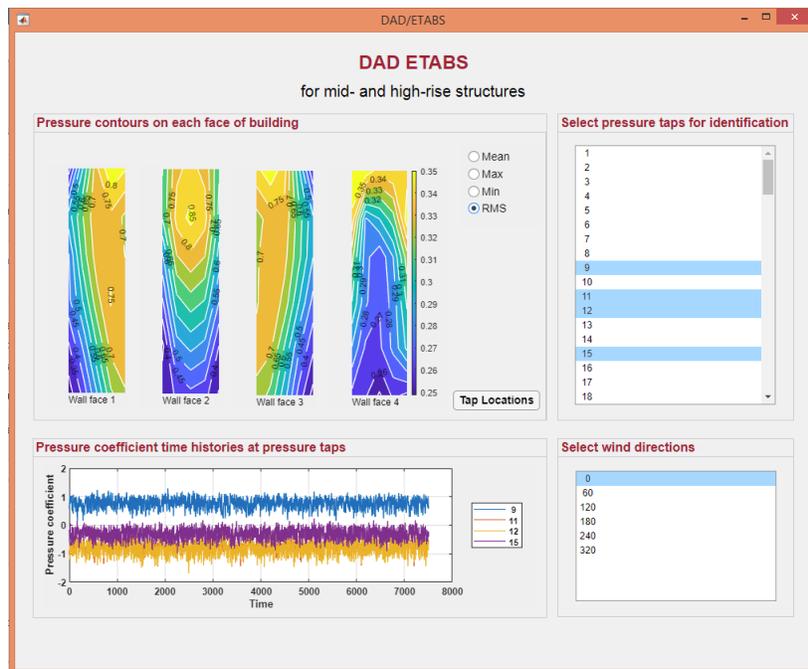


Figure 1.9. Illustration of wind load calculations.

By clicking the display button, the user can check the location of the pressure taps and the corresponding time histories for a given wind direction. The first pressure tap is selected by default. The user can select multiple pressure taps but only one direction. Figure 1.10 shows the interface details illustrating the pressure time histories and the corresponding pressure tap location in the wind tunnel tests. In addition, the user can also investigate the pressure contours on the face of the building for a given wind direction. Next, the user is asked to enter the values of wind directions to be used for analysis.



(a)



(b)

Figure 1.10. Interface to check the pressure tap data and pressure contours measured in wind tunnel tests.

If compliance with ASCE 7-16 Section 31 is required, the user needs to provide the overturning moments along the two principal axes corresponding to the design Mean Recurrence Intervals (MRIs). Forces and pressures obtained from wind tunnel measurements may then not be

less than 80 %, or 50 % of ASCE 7-16 estimates based on the gust response factor method. For the current example, this information is included in the building data folder with a file name `moment_ovtn.mat`.

The screenshot shows the 'DAD ETABS' software window. The title bar reads 'DAD/ETABS'. The main window title is 'DAD ETABS for mid- and high-rise structures'. The interface is divided into several sections:

- 5. Wind tunnel test data**: Contains input fields for:
 - 5.1 Model length scale (prototype/model): 500
 - 5.2 Reference wind speed at rooftop elevation of the building model: 23.2
 - 5.3 Sampling rate (Hz): 250
 - 5.4 No. of sampling points (data points): 5000
 - 5.5 Wind directions (degrees): 0 60 120 180 240
 - 5.6 Discarded initial portion of time series (points): 200A 'Confirm' button is located at the bottom right of this section.
- 6. Floor wind loads at model scale (force per unit length)**: Contains two radio button options:
 - Open the calculated floor wind loads: D:\Etabs\Project01\Project1\Aerodynamic_da (with a 'Browse' button)
 - Calculate floor wind loads from pressures measured in taps on building model facade
- 7. Wind speed range**: Contains an input field for '7.1 Wind speeds for response surfaces' with the value '20 40 60'.
- 8. Lower limit requirement**: Contains a checked checkbox for 'ASCE 7-based overturning moments' and a 'Browse' button with the path 'D:\Etabs\Project01\Project1\Building_data\mc'. Below this, there are radio button options for 'Limiting value':
 - 50%
 - 80%

At the bottom of the window are 'Previous' and 'Next' buttons.

Browse to building data folder and select `moment_ovtn_ASCE.mat`

Figure 1.11. Illustration to define the ASCE 7-based overturning moments.

1.6 Structural Analysis

Given the wind tunnel test pressure data, a modal time history analysis is performed for a set of wind speeds and wind directions. The reference height for the mean hourly wind speed is assumed to be the height of the building. It is important to perform the analysis for a number of wind directions and wind speeds sufficient to adequately define the dependence of the response of interest upon wind speed and direction, i.e., the response surface for each response of interest.

For the peak response, two options are available. In the observed peak approach, the maxima for various quantities are calculated from the time histories and may correspond to

different times. In the multiple points in time approach, the maxima are calculated at the time of the n^{th} peaks of overturning moments (global demand).

The user is required to specify the structural members for which the DCIs are estimated, and to specify joints for which accelerations and drift calculations are performed. The response of members listed by the user in *.txt, *.csv, and *.mat files is provided. The drift and acceleration results are provided for any node along a column line specified by the user. These details can easily be obtained from the ETABS model. After entering the details, the user presses 'Perform Analysis'. This will execute the ETABS program, which will create a separate folder for one wind direction. Therefore, the program will create n folders for the given n directions.

- Specify members of interest: The user is asked to browse a file consisting of member IDs separated by a space. For the current example, the file is included in the building data folder having the name "Member_selected.txt"
- Specify column lines of interest for displacement/drift calculation: The user should browse a file consisting of node IDs separated by a space. For the current example, the file is present in the building data folder having the name "Joint_disp.txt".
- Specify column lines of interest for acceleration calculation: The user should browse a file consisting of node IDs separated by space. For the current example, the file is present in the building data folder having the name "Joint_acc.txt".

Browse to building data folder. Files consisting of unique IDs of members and nodes should be selected for DCI, drift, and acceleration calculation.

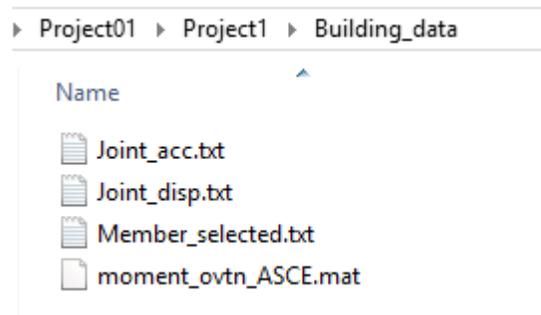


Figure 1.12. Interface to select the calculation methods and required input for the development of response surfaces.

1.6.1 DCI Calculations

For strength design, the performance of the building is evaluated by calculating the demand-to-capacity indexes for all the structural members of interest. The DCIs are calculated using the following equations:

$$DCI = \frac{P_r}{\phi_p P_n} + \frac{8}{9} \left(\frac{M_{rx}}{\phi_m M_{nx}} + \frac{M_{ry}}{\phi_m M_{ny}} \right) \quad \frac{P_r}{\phi_p P_n} \geq 0.2$$

$$DCI = \frac{P_r}{\phi_p P_n} + \left(\frac{M_{rx}}{\phi_m M_{nx}} + \frac{M_{ry}}{\phi_m M_{ny}} \right) \quad \frac{P_r}{\phi_p P_n} < 0.2$$

where P_r and P_n are the demand and available axial strength; M_{rx} and M_{nx} are the demand and available flexural strength about the major axis; M_{ry} and M_{ny} are the demand and available flexural strength about the minor axis; ϕ_p and ϕ_m are the resistance factors. The peak values of the DCIs, inter-story drift ratios, and accelerations are used to construct the respective response surface as functions of wind directions and wind speeds.

1.6.2 Results

Once all the analyses are performed, a new output folder is created in the directory for the displacements, accelerations, internal forces of members, and external forces.

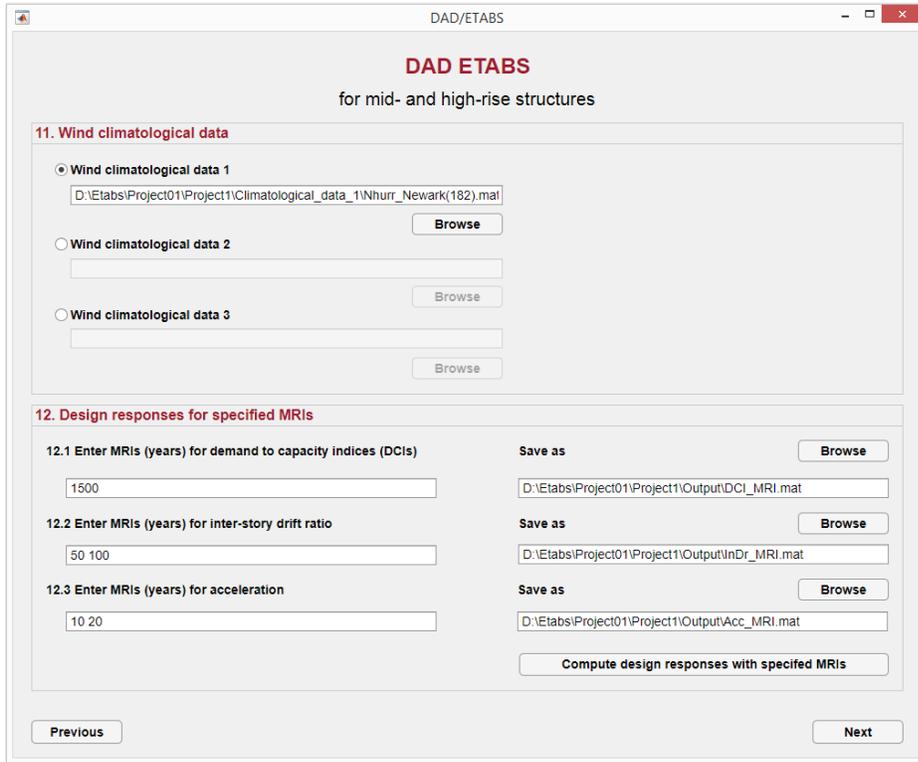
Name	Date modified	Type	Size
Acc_MRI_set_1.mat	7/23/2020 11:35 PM	MAT File	505 KB
Acc_MRI_set_2.mat	7/23/2020 11:36 PM	MAT File	505 KB
Acc_set_1.mat	7/25/2020 10:21 AM	MAT File	2 KB
Acc_set_2.mat	7/22/2020 10:27 AM	MAT File	252 KB
Acceleration.mat	7/22/2020 10:22 AM	MAT File	1,328,316 KB
DCI_LC_1.mat	7/25/2020 10:21 AM	MAT File	16 KB
DCI_MRI_LC_1.mat	7/23/2020 11:34 PM	MAT File	44 KB
Displacement.mat	7/22/2020 10:22 AM	MAT File	1,312,161 KB
Externalforces.mat	7/22/2020 10:22 AM	MAT File	72,278 KB
InDr_MRI_set_1.mat	7/23/2020 11:35 PM	MAT File	342 KB
InDr_MRI_set_2.mat	7/23/2020 11:35 PM	MAT File	342 KB
InDr_set_1.mat	7/25/2020 10:21 AM	MAT File	1 KB
InDr_set_2.mat	7/22/2020 10:25 AM	MAT File	168 KB
Internalforces.mat	7/22/2020 10:22 AM	MAT File	885,214 KB
mem_capacity.mat	7/19/2020 3:00 PM	MAT File	4 KB
mem_list.mat	7/19/2020 3:00 PM	MAT File	15 KB

Figure 1.13 Output folder consisting of response data from the time history analysis.

1.7 *Local Wind Climate Data*

In the next step, a wind directionality analysis is performed using the wind climatological data. The extreme wind climatological data consist of the extreme Velocities (i.e., directional wind speeds) at the building site available in the record provided by the wind engineering laboratory. Estimates of hurricane data for various locations are available at the following NIST website <https://www.itl.nist.gov/div898/winds/hurricane.htm>. More recent estimates of hurricane wind speeds and directions are available from commercial laboratories. The NIST website for non-hurricane winds, https://www.itl.nist.gov/div898/winds/NIST_TN/nist_tn.htm, does not have directional data and is not part of the DAD-ETABS interface at this time.

The detailed description of this method can be obtained in Simiu and Yeo (Chapters 8 and 13, 2019). For each response of interest, the wind velocity matrix (i.e., the matrix of recorded wind directions and speeds at the site) is replaced by a response matrix, with the same number of rows and columns as the wind velocity matrix, each element of which is the peak response induced by its counterpart in the velocity matrix. That peak response is taken from the response surface for the response of interest. Next, the maximum value of the peak response is selected for each windstorm event. Finally, non-parametric statistics are used with the mean annual rate of storm arrival λ to obtain the design results for the MRI specified by the user. For calculating design responses, the user can input the desired MRI values.



Browse to climatological data folder and select the MATLAB file consisting of climate data i.e., Nhurr_Newark(182).mat

Figure 1.14 Interface details for performing wind directionality analysis.

1.8 Design Results

The final page consists of design values and plots for different response measures such as overturning moment, DCIs, IDR (Inter-story Drift) ratios, and accelerations. Figure 1.15 presents an example of the results page. The desired response can be obtained by clicking the bubble button. The design and response plots for any selected member can be opened by clicking the corresponding plot button. Figure 1.16-1.18 shows the response and design curves for the DCI, acceleration, and drift calculations.

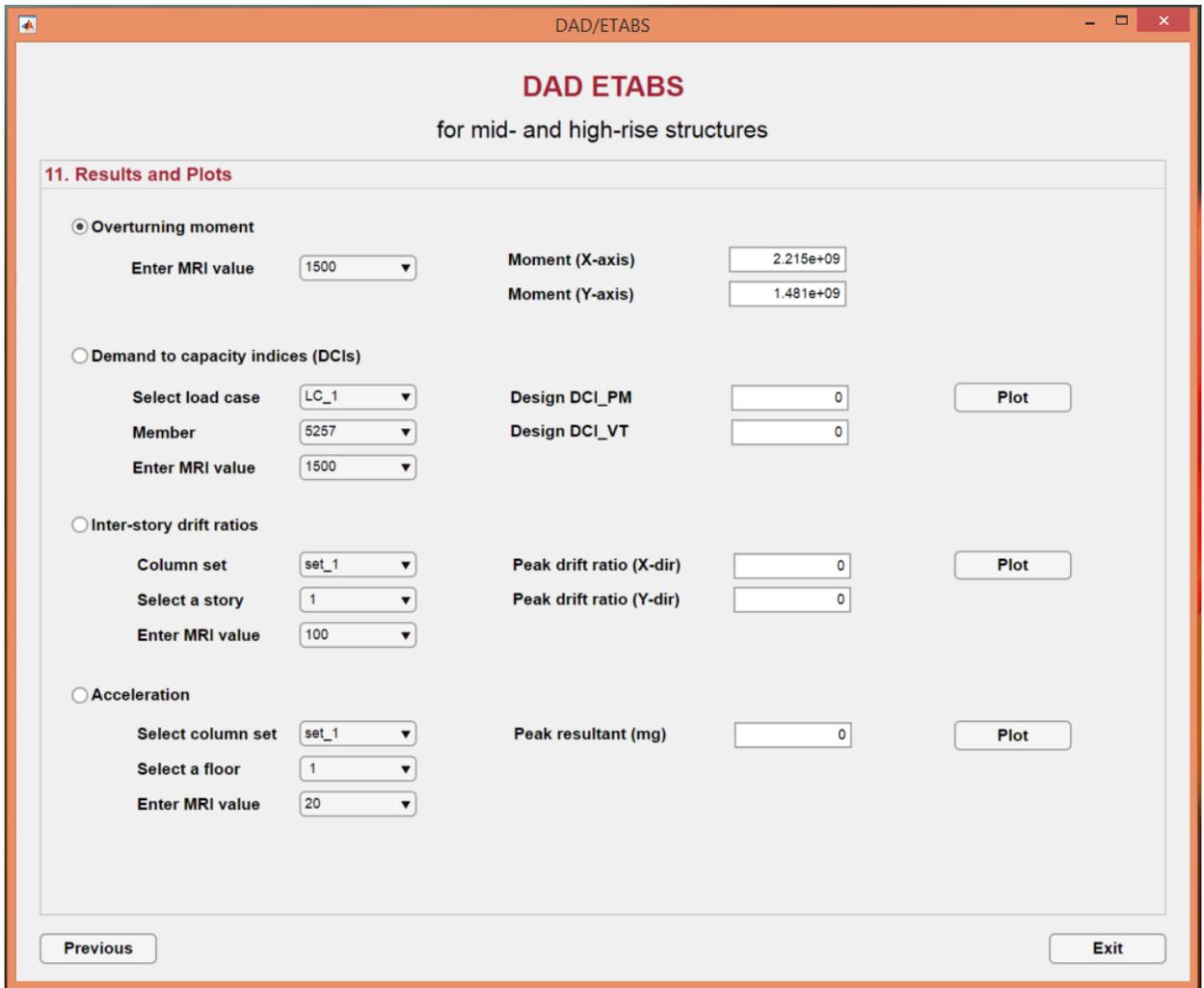
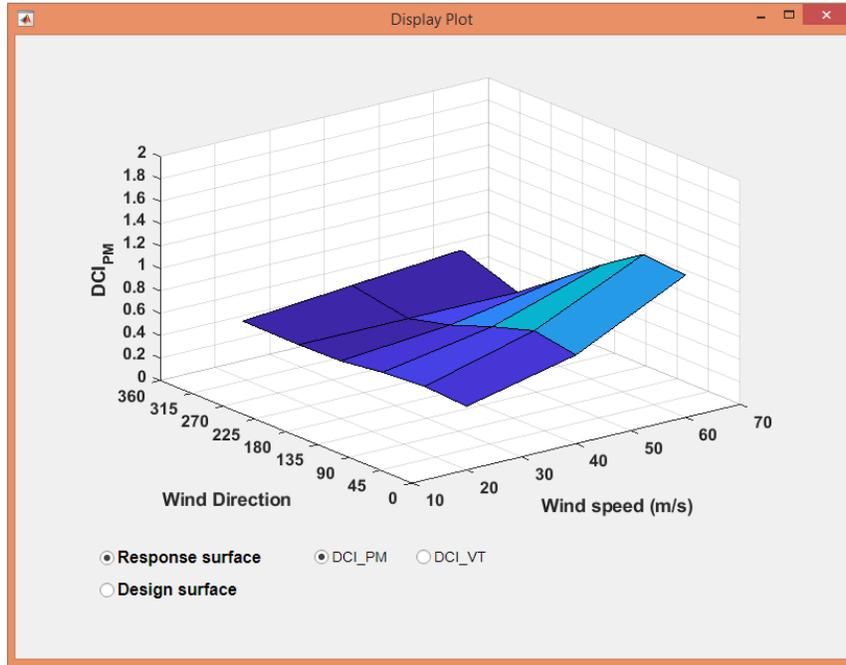
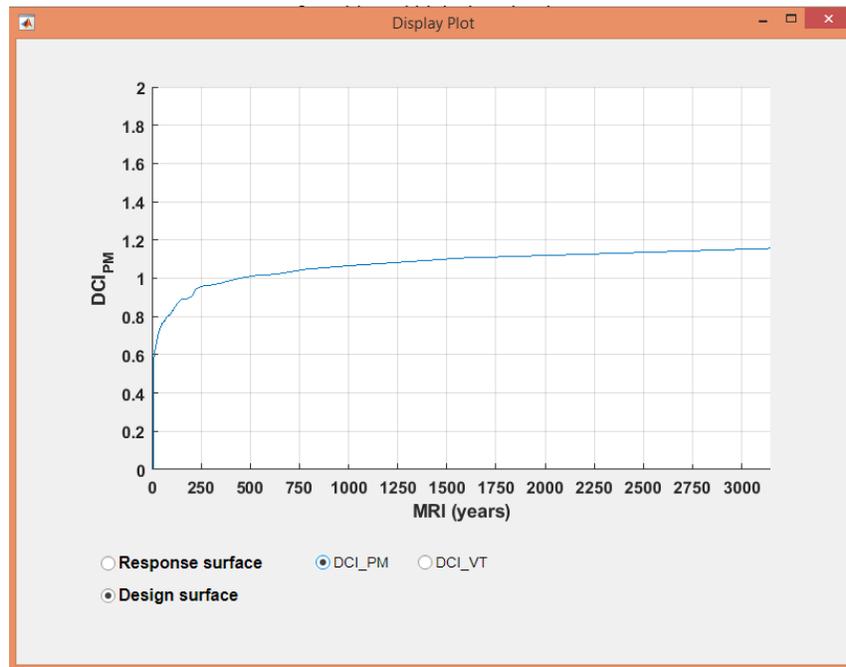


Figure 1.15. Details of the results page in the program.

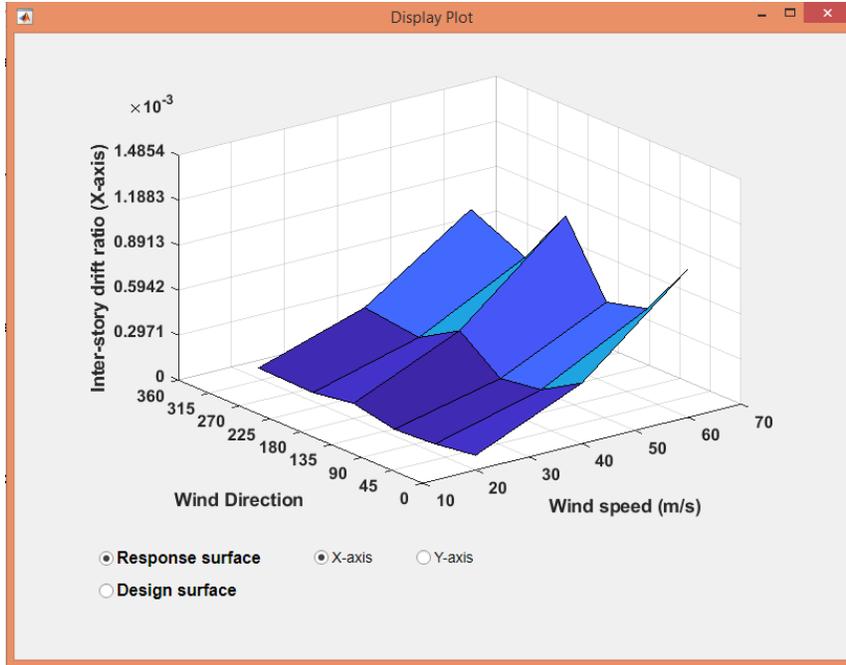


(a)

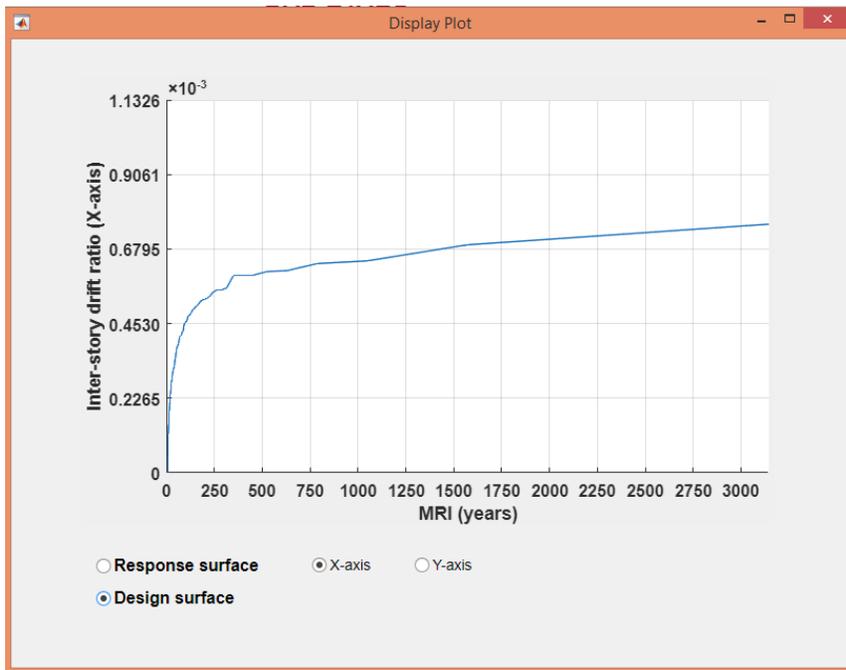


(b)

Figure 1.16. DCI results: (a) response surface, and (b) design curve.

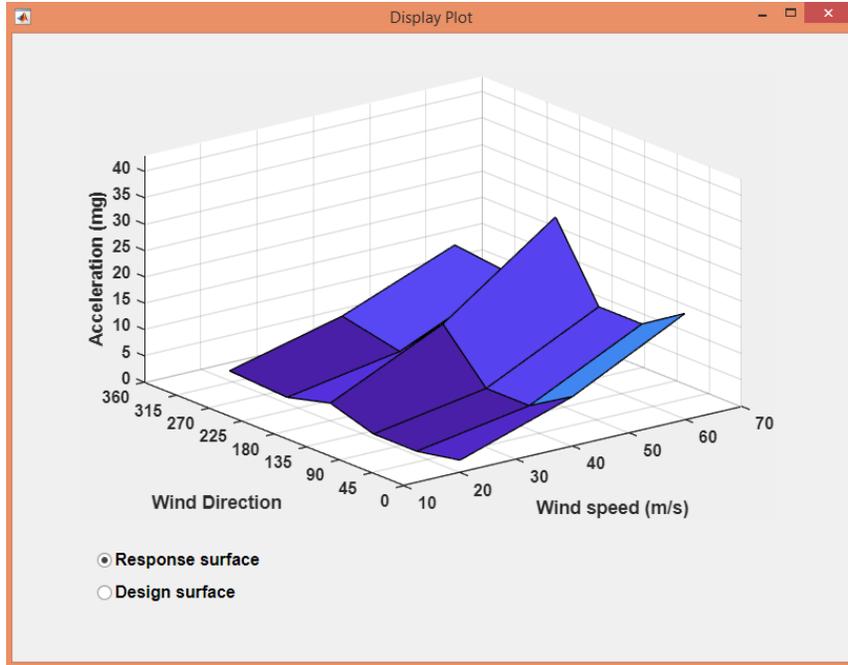


(a)

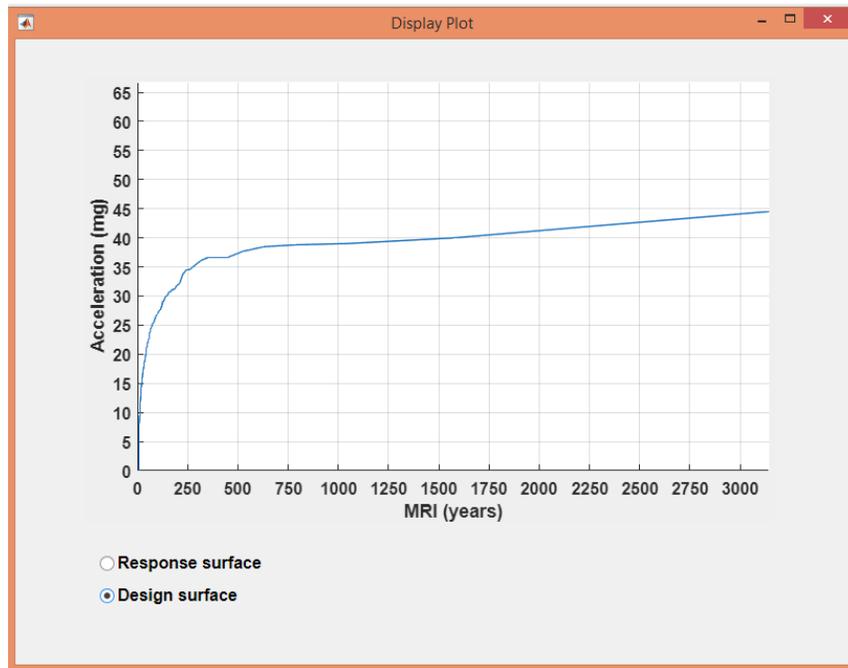


(b)

Figure 1.17 Inter-story drift results: (a) response surface, and (b) design curve.



(a)



(b)

Figure 1.18 Acceleration results: (a) response surface, and (b) design curve.

1.9 Conclusion

The computer interface described herein will allow structural designers familiar with ETABS to take advantage of Database-Assisted Design for wind. DAD allows the direct use of wind-tunnel time-dependent pressure measurements, takes explicit account of wind directions, and provides design results for various mean recurrence intervals (MRI) of the wind responses of interest.

A few words of caution: Data transfer to and from ETABS consumes significant time. Depending on wind time histories, building type, and computer speed, a complete analysis can take hours or more than one day to complete. Furthermore, for reinforced concrete buildings ETABS has Application Programming Interface (API) commands only for rectangular and circular sections.

2 Program Information

To run the program, the user needs to have CSI ETABS and MATLAB Runtime installed on the computer along with the DAD_ETABS.exe file. There is no need to have MATLAB program to be installed on the computer. In the current form, the program is only supported in Microsoft Windows platform.

2.1 *MATLAB Runtime*

Verify that version 9.10 (R2021a) of the MATLAB Runtime is installed. If not, you can run the MATLAB Runtime installer.

1. MATLAB is installed on computer: To find its location, enter “mcrinstaller” at the MATLAB prompt. You will need administrator rights to run the MATLAB Runtime installer.
2. Download from MATLAB webpage: Alternatively, download and install the Windows version of the MATLAB Runtime for R2021a from the following link on the MathWorks website:

<http://www.mathworks.com/products/compiler/mcr/index.html>

For more information about the MATLAB Runtime and the MATLAB Runtime installer, see "Distribute Applications" in the MATLAB Compiler documentation in the MathWorks Documentation Center.

2.2 *Files to Deploy and Package (for developers)*

Files to Package for Standalone:

1. DAD_ETABS.exe
2. MCRInstaller.exe

If end users are unable to download the MATLAB Runtime using the instructions in the previous section, they can include it when building their components by clicking the "Runtime included in package" link in the Deployment Tool.

2.3 Definitions

For information on deployment terminology, go to <http://www.mathworks.com/help> and select **MATLAB Compiler >Getting Started > About Application Deployment >Deployment Product Terms** in the MathWorks Documentation Center.

2.4 ETABS API

In this program, API commands are used to control interactions between the MATLAB and ETABS. To learn more about the API commands and their usage, please check CSi API ETABS v1.chm file in the root directory of ETABS software.

3 Wind loads in DAD-ETABS

This section explains the procedure concerning the transfer of wind loads to the ETABS program. In the first step, the wind loads are calculated as uniformly distributed lateral forces and moments on four faces of each floor. Each Floorload_\$\$\$\$.csv file consist of two main variables i.e., WL_{m_n}, and WM_{m_n}. Here, WL represents the uniformly distributed lateral loads, and WM represents uniformly distributed moments. The variables *m*, and *n* indicates the floor number and the face of the buildings as indicated in Figure 1.5. Figure 3.1 gives one such example of the Floorload_\$\$\$\$.csv file showing the three columns. The first column indicates the name of the time history, second column shows the time, and third columns shows the magnitude of either lateral force or moment.

1	Name	Time	Value
2	WL_1_1	0.004	0.831706
3	WL_1_1	0.008	0.69173
4	WL_1_1	0.012	1.0218
5	WL_1_1	0.016	0.806671
6	WL_1_1	0.02	0.963719
7	WL_1_1	0.024	0.639224
8	WL_1_1	0.028	0.933683
9	WL_1_1	0.032	0.892837
10	WL_1_1	0.036	1.030606

Figure 3.1 Floorload file description.

For each wind direction, a Floorload_\$\$\$\$.csv file is generated. If the analysis must be performed for sixteen wind direction, there should sixteen Floorload_\$\$\$\$.csv files in the Aerodynamic data folder.

Once the first step is finished, the calculated wind loads need to transfer to the ETABS program. This is done by performing Database Tables operation. It should be noted that any formatting error in the Floorload_\$\$\$\$.csv file will result in undesirable results. The following two lines as mentioned in the MATLAB code are used to add the wind loads in the ETABS program.

1. `ret=DatabaseTables.SetTableForEditingCSVFile('Functions - Time History - User Defined',TableVersion,Floorload,',');`

2. *ret=DatabaseTables.ApplyEditedTables(FillImportlog, NumFatalErrors, NumErrorMsgs, NumWarnMsgs, NumInfoMsgs, ImportLog);*

The first statement opens the time history tables for editing and adds the Floorload file for a particular wind direction. The second statement saves the time histories in the ETABS program. It should be noted that the loads calculated and stored in the Floorload_\$\$\$.csv files are at model scale. The time scale and length scale of the measured forces are applied when the load patterns are created using the API commands. To apply calculated wind loads in the building model, load patterns are created for each floor i.e., eight load patterns. This can be done using the following statement.

3. *ret = LoadPatterns.Add([LoadName], ETABSV1.eLoadPatternType.Other, 0, true());*

This step only creates the load patterns which are independent of each other. To perform a wind time history analysis, all these load patterns are combined by creating load cases wind speeds and corresponding wind directions. The following command creates the load cases and add the corresponding time histories.

LoadType{k,1}='Load';

LoadName{k,1}={Load pattern name}

MyFunc{k,1}={Time history name}

SF(k)={Scale factor for loads}

TF(k)={Scale factor for time}

AT(k)=0

MyCSys{k,1}='Global';

Ang(k)=0

ret=ModHistLinear.SetLoads(Load case name, number of load patterns, LoadType, LoadName, MyFunc, SF', TF', AT', MyCSys, Ang');

The applied wind loads in the ETABS building model can be visualized using the ETABS interface.

4 Inclusion of P- Δ effects

The current version of the software performs modal time history analyses to determine the response of buildings under time-varying wind loads. For the modal time history analysis, ETABS has the option of including P- Δ effects from an initial P- Δ analysis, which requires definition of the gravity load cases and their load factors. The iterative (rather than the non-iterative method) is used, as it considers P- Δ effects on a member-by-member basis. This is specified by the user in the initial geometry defined for the DAD analysis.

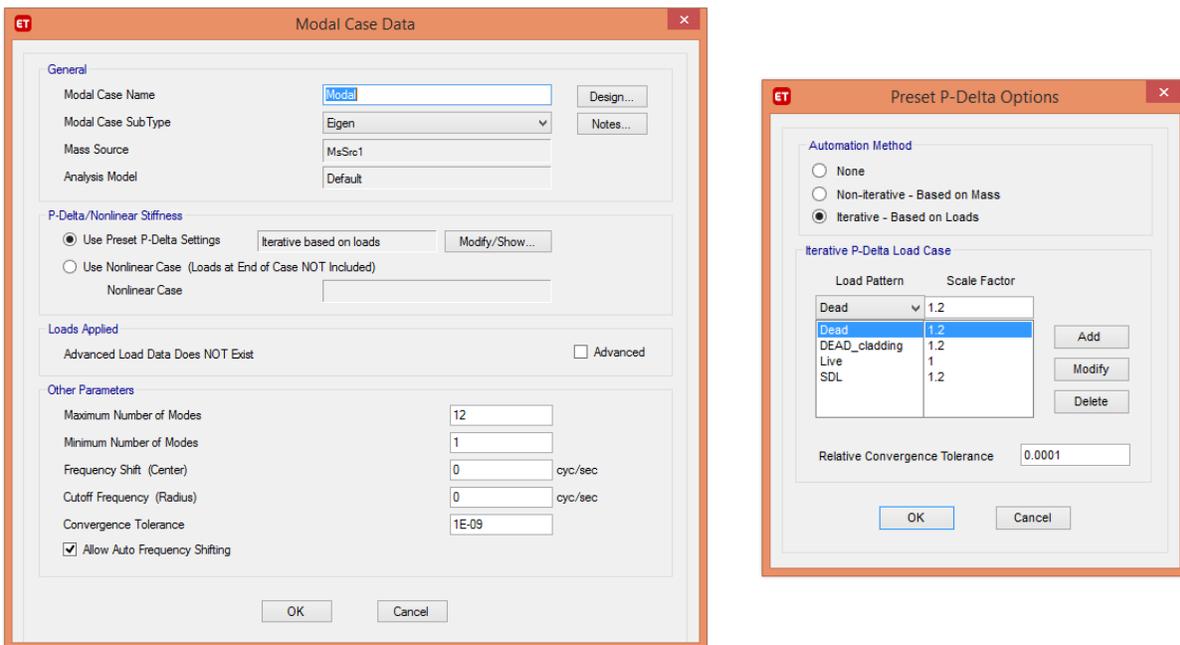


Figure 4.4.1 Inclusion of the P- Δ effects in the ETABS model.

The influence of P- Δ effect is first investigated by performing modal analysis. The modal analysis of the building as shown in Figure 1.1 is conducted. Table 3.1 illustrates the first six natural frequencies of the building with and without second order effects. The first mode of vibration corresponds to the drift in the Y direction. The second and third modes corresponds to drift along the X axis and torsion about the Z-axis. A slightly lower value of the natural frequencies is obtained with the inclusion of P- Δ effects.

Table 4.1 Modal analysis results of the building in case study

Mode No.	Frequency (Hz)		Mode type
	Without P- Δ effects	With P- Δ effects	
1.	0.221	0.212	Translation
2.	0.247	0.238	Translation
3.	0.303	0.294	Torsion
4.	0.733	0.717	Translation
5.	0.745	0.726	Translation

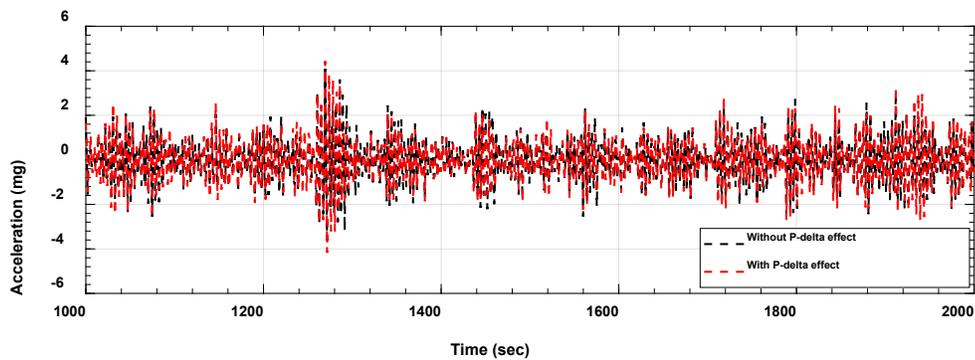


Figure 4.4.2. Effect of p-delta effect on top floor acceleration of the building.

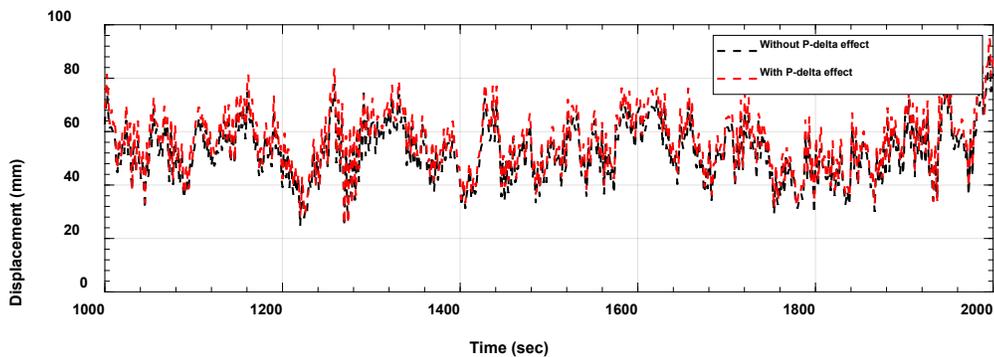
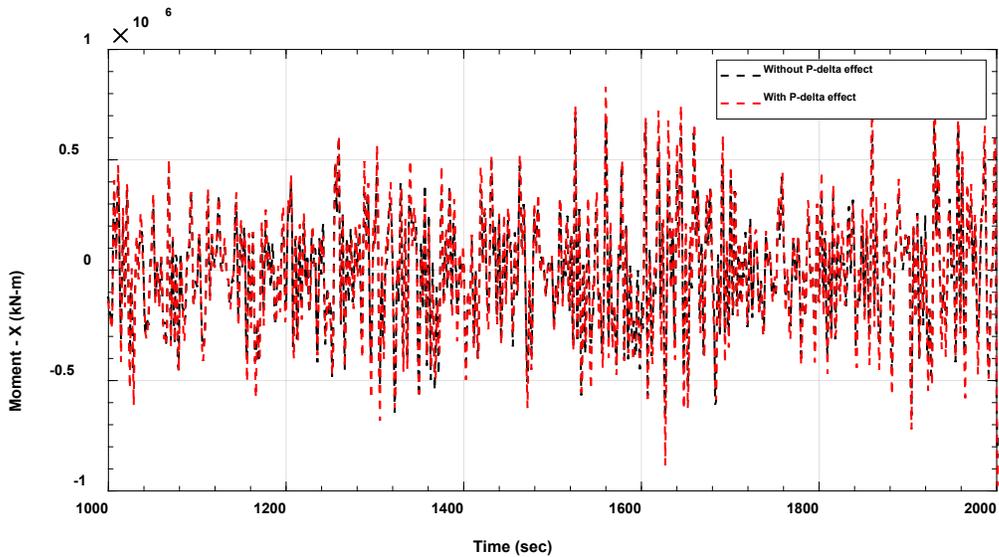


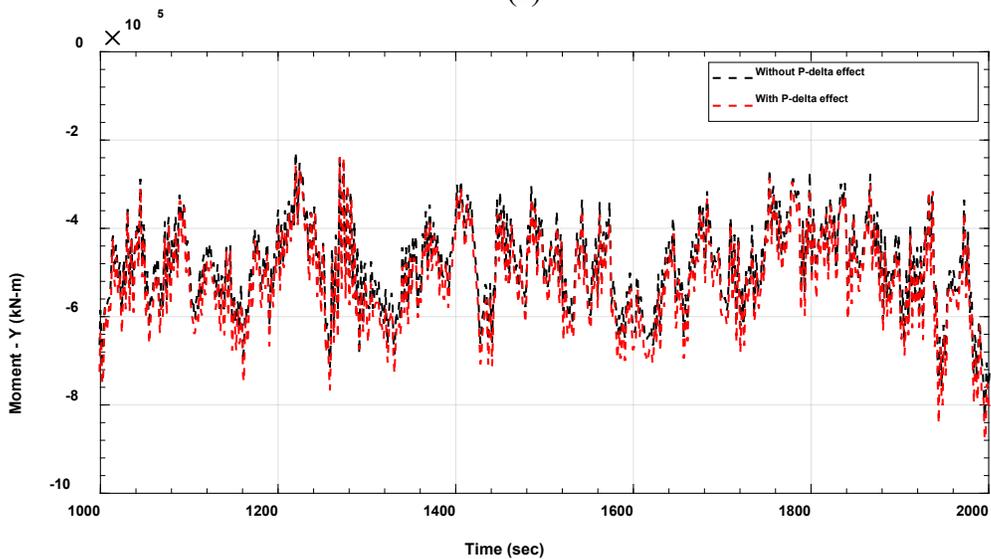
Figure 4.4.3. Comparison of Effect of P- Δ effect on top floor acceleration of the building.

In the next step, the influence of the P- Δ effect is investigated by performing the dynamic analysis. The example building was subjected to wind loads at a wind speed of 40.0 m/s. For a thorough comparison, the displacement and acceleration at the top of the building, and base moments are investigated. Figures 3.2 and 3.3 show the effect of P-delta effect on top floor

acceleration, and displacement of the building, respectively. On comparing the time-histories with and without P-delta effects, it is seen that a response of the building increase slightly with the inclusion of P-delta effects. Further, the base moments about the two principal axes are compared. Similar to accelerations and displacements, base moments are also observed with the inclusion of P-delta effects.



(a)



(b)

Figure 4.4.4 Comparison of base moments along the two-principal axis with and without P- Δ effects: (a) moment about X axis, and (b) moment about Y axis.

5 Design example: 60 Story Steel Building

5.1 Description of building

The example building is a 60-story standard CAARC building located in Miami, Florida. This is Project02 in the folder. The building has a height of 182.88 m, width of 45.72 m, and depth of 30.48 m. The building consists of three types of columns i.e., core, external core, and internal core columns. The building has an outrigger and belt truss system located at 20th, 21st, 40th, 41st, and 60th story. Figure 4.1 shows the schematic views of the 60-story steel building. Bracings are also divided into core and outrigger bracings. The dimensions of each type of structural member are kept the same for 10 successive floors. All the beams consist of rolled W-sections from AISC 360-10 (2010), whereas the columns and bracings are made up of built-up hollow structural sections (HSS). The analytical model includes a rigid diaphragm provided by the floor slab at each floor level. In addition to the self-weight, a live load and super-imposed dead load of 2.4 kN/m² and 0.72 kN/m² is applied at each floor. A detailed description of the section properties is given in Table 4.1. The building is assumed to have an orientation of 270° from the north. This implies that the façade of the building faces east. The steel building is assumed to be located near Miami, Florida.

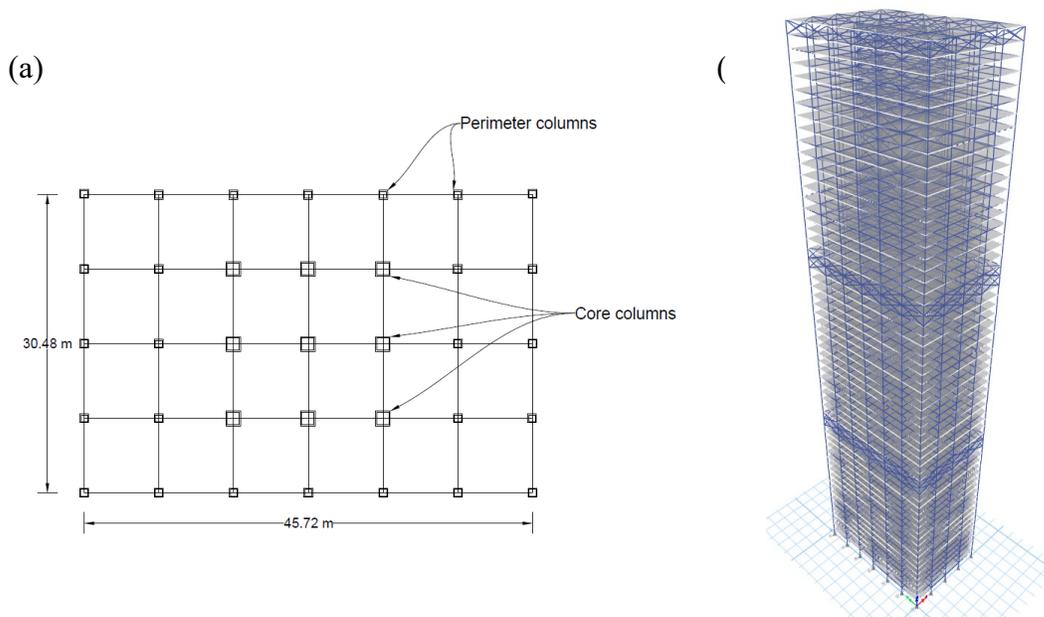


Figure 5.1 60 story steel building: (a) plan, and (b) isometric view.

Table 5.1 Section members in the 45-story properties for the structural building

Member type	Section type	Depth (mm)	Width (mm)	Flange thickness (mm)	Web thickness (mm)
Columns	Box/Tube	700	700	50	50
	Box/Tube	600	600	50	50
	Box/Tube	600	600	40	40
	Box/Tube	600	600	30	30
	Box/Tube	500	500	20	20
	Box/Tube	400	400	15	15
	Box/Tube	1400	1400	50	50
	Box/Tube	1200	1200	50	50
	Box/Tube	1000	1000	50	50
	Box/Tube	800	800	40	40
	Box/Tube	600	600	30	30
	Box/Tube	400	400	20	20
Beam	I/Wide Flange	254.0	254.0	14.2	8.6
Bracing	Box/Tube	500	500	15	15
	Box/Tube	400	400	15	15
	Box/Tube	300	250	12	12

Table 5.2 Modal analysis results of the building in case study

Mode No.	Frequency (Hz)	Mode type
1.	6.849	Translation
2.	6.516	Translation
3.	5.427	Torsion

4.	2.082	Translation
5.	2.041	Translation

5.2 Aerodynamic loads

For this example, the wind tunnel data is obtained from a DAD database available at NIST. The test data is obtained from wind tunnel tests on a rigid model. Therefore, the aeroelastic effects are assumed to be negligible. The wind tunnel test was performed for 36 wind directions between 0° and 350° using a model with a length scale of 1:500. For each wind direction, the data in terms of pressure coefficients (C_p) was collected for 30 s at a mean hourly wind speed (V_H) of 23.2 m/s (suburban terrain exposure) at the rooftop elevation (H) of the building model. It is assumed that the measured pressure coefficients which are not affected by the violation of the Reynolds number, a not unreasonable assumption in view of the building geometry.. The aerodynamic data were obtained from 30 pressure taps placed on each face of building model, i.e., from a total of 120 pressure taps. The pressure taps were placed in a rectangular pattern on each face of building model. The procedure described earlier in this manual was used to calculate the distributed frame loads at each floor of the building.

5.3 Step by step tutorial for DAD-ETABS

In this section, steps are provided to analyze the example building subjected to wind loads. The complete analysis of the building is performed in the following steps:

Initialize the program using the ETABS model: after running the program, enter the details for the program path, and API file path. Next, select the steel structure and press the start button.

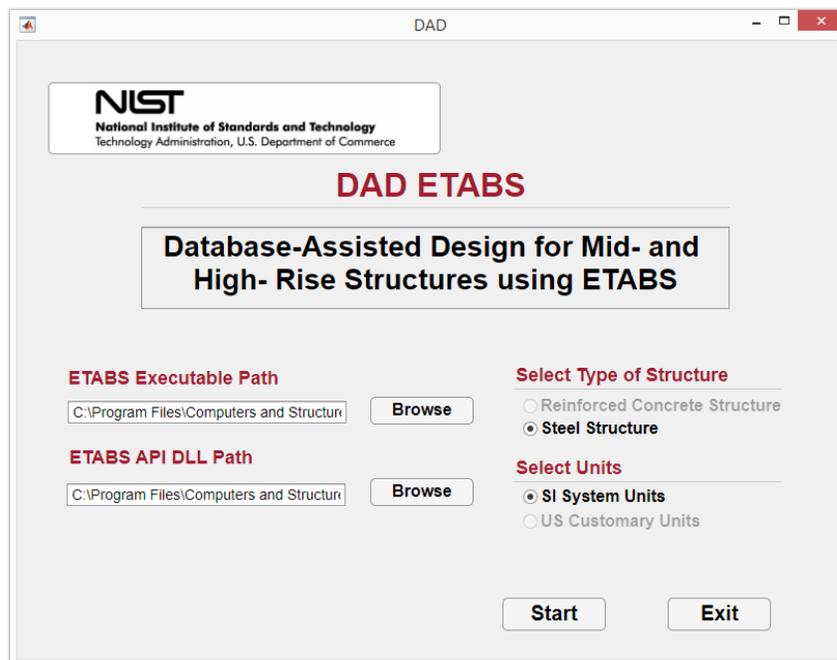


Figure 5.2 First page of the user interface.

1. Enter the path for the ETABS model in section 1. If any progress has been saved for the model, the user will be prompted to load the previously saved data.
2. Building information: The user has two options. One option is to read the dimensions of the building from the ETABS model. This can be done by clicking the button *Read from ETABS Model*. The second option is to directly enter the building dimensions as shown below.
 - 2.1.1. Set the number of stories to 60.
 - 2.1.2. Set the building height to 182.88 m.
 - 2.1.3. Set the building depth to 45.72 m.
 - 2.1.4. Set the building width to 30.48 m.
 - 2.1.5. Set the orientation angle to 270°.
3. Analysis type
 - 3.1.1. Linear time history analysis.
4. Load combinations:
 - 4.1. Enter 1.1 for dead load, 1.1 for super-imposed dead load, and 1.0 for live load. After that, press the add button on the strength design panel.

- 4.2. For the serviceability design, enter 1.0 for dead load, 1.0 for super-imposed dead load, and 1.0 for live load. After that, pressure the add button on the serviceability design panel.

The screenshot shows the 'DAD ETABS' software interface. The title bar reads 'DAD/ETABS'. The main window title is 'DAD ETABS for mid- and high-rise structures'. The interface is organized into four numbered sections:

- 1. Model Path:** A text box contains 'D:\Etabs\Project01\Project2\Model\60story.EDB' and a 'Browse' button.
- 2. Building information:** Five input fields with values: 2.1 Building height (182.88), 2.2 Building depth (45.72), 2.3 Building width (30.48), 2.4 No. of stories (60), and 2.5 Orientation angle (deg.) (270.00). A 'Read from ETABS Model' button is centered.
- 3. Analysis type:** Two radio buttons: 'Linear time history analysis' (selected) and 'Non linear time history analysis'.
- 4. Load combinations:** Two columns of input fields. Column 4.1 'Specify load factors' has values of 1.00 for Dead load (DL), Super-imposed dead load (SDL), Live load (LL), and Wind load (WL). Column 4.2 'For strength design' and column 4.3 'For serviceability design' both have a text box containing the formula '1 DL + 1 SDL + 1 LL + 1 WD'. Each of these two columns has 'Reset' and 'Add' buttons below the text box.

At the bottom of the window are 'Previous' and 'Next' navigation buttons.

Figure 5.3 Interface for entering the details of the buildings including dimensions and load types.

5. Wind tunnel test data:
 - 5.1. Enter 500 for model length scale.
 - 5.2. Enter 23.2 m/s for the reference wind speed at rooftop elevation of the building model.
 - 5.3. Enter 250 Hz for the sampling rate.
 - 5.4. Enter 3000 for no. of sampling points
 - 5.5. Wind directions can be either by defining an array in vector form or MATLAB notation.
Enter 0 60 120 180 for wind directions.
 - 5.6. Enter 200 for discarded initial portion of time series.

The screenshot shows the 'DAD ETABS' software window with the title 'DAD ETABS for mid- and high-rise structures'. The interface is divided into several sections for data entry:

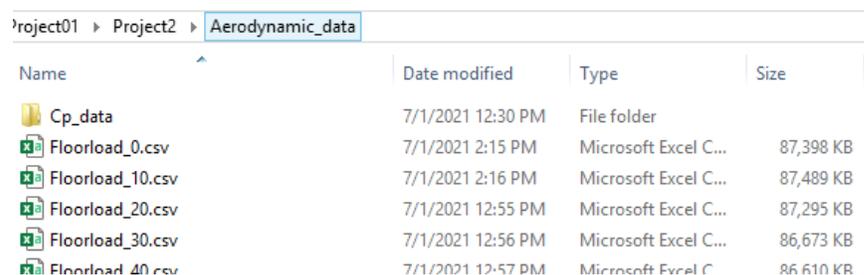
- 5. Wind tunnel test data:** A table with six rows for inputting test parameters. The values entered are: 500 for Model length scale, 23.2 for Reference wind speed, 250 for Sampling rate, 3000 for No. of sampling points, 0 60 120 180 for Wind directions, and 200 for Discarded initial portion of time series. A 'Confirm' button is at the bottom right.
- 6. Floor wind loads at model scale (force per unit length):** Two radio buttons are present. The first, 'Open the calculated floor wind loads', is selected. Next to it is a text box containing the file path 'D:\Etabs\Project01\Project2\Aerodynamic_da' and a 'Browse' button. The second radio button is 'Calculate floor wind loads from pressures measured in taps on building model facade'.
- 7. Wind speed range:** A single text box for '7.1 Wind speeds for response surfaces' contains the values '20 50 70'.
- 8. Lower limit requirement:** A checkbox for 'ASCE 7-based overturning moments' is unchecked. To its right is an empty text box and a 'Browse' button. Below this is the label 'Limiting value'.

At the bottom of the window, there are 'Previous' and 'Next' navigation buttons.

Figure 5.4 Details related to wind tunnel tests to be entered in the software.

6. Floor wind loads at model scale:

6.1. Enter the path for calculated floor wind loads using the browse button. For this example, the wind load files are present in the aerodynamic data folder. The user can select any file named Floorload_ \$angle.csv



Name	Date modified	Type	Size
Cp_data	7/1/2021 12:30 PM	File folder	
Floorload_0.csv	7/1/2021 2:15 PM	Microsoft Excel C...	87,398 KB
Floorload_10.csv	7/1/2021 2:16 PM	Microsoft Excel C...	87,489 KB
Floorload_20.csv	7/1/2021 12:55 PM	Microsoft Excel C...	87,295 KB
Floorload_30.csv	7/1/2021 12:56 PM	Microsoft Excel C...	86,673 KB
Floorload_40.csv	7/1/2021 12:57 PM	Microsoft Excel C...	86,610 KB

Figure 5.5 Graphic showing the details of wind load data at model scale.

7. Wind speed range:

7.1. The number of wind speeds can be entered in a way like the way wind direction are entered. Enter wind speeds of 20, 50, and 70 m/s.

8. Lower limit requirement:

8.1. Check the button for ASCE 7-based overturning moments. Calculated moments about the two principal axes can be entered using the browse button. This file is present in the building data folder with the name `moment_ovtn_ASCE.mat`. For this example, this has been unchecked.

9. Calculation options:

9.1. Select the DAD toggle and select observed peak approach.

10. Response surface: The input files for this step are present in building data folder.

10.1. Demand to capacity ratio: browse the path to text file consisting of the IDs of members of interest.

10.2. Inter-story drift ratio (IDR): browse the path to text file consisting of the IDs of joints along a column line.

10.3. Acceleration: browse the path to text file consisting of the IDs of joints along a column line.

After entering all the data, user must perform the structural analysis by pressing the perform analysis button. Once the button is pressed, ETABS program will start developing models for the combinations of wind directions and wind speeds. Once ETABS finishes all the analysis,

a prompt window will pop-up showing that all the analysis has been successfully finished. In case of previously saved data, the user can directly proceed to the next step by clicking the next button.

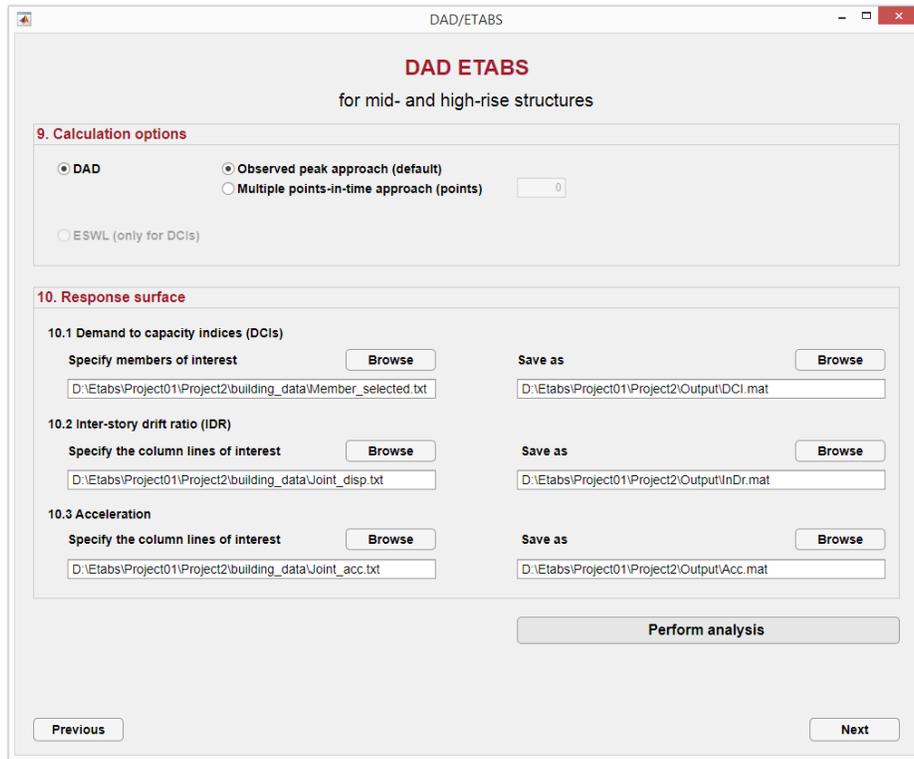


Figure 5.6 User interface showing the information needed to perform the analysis.

11. Determine wind effects with specific MRIs: The response surfaces and the matrices of directional wind speeds at the site are used to determine, by accounting for wind directionality, the design DCIs with the specified design MRI for the cross sections of interest.

11.1. Select the wind climatological data 1 toggle: browse the path to mat file from Climatological_data_1 folder.

12. Design responses for specified MRIs panel:

12.1. Set the MRIs for demand-to-capacity index [years] to 1250.

12.2. Set the MRIs for inter-story drift ratio [years] to 50.

12.3. Set the MRIs for acceleration [years] to 20.

After entering the information, click on the compute design responses with specific MRIs button.

The screenshot shows the 'DAD ETABS' software window. The title bar reads 'DAD/ETABS'. The main window title is 'DAD ETABS for mid- and high-rise structures'. The interface is divided into two main sections:

- 11. Wind climatological data:** This section has three radio button options:
 - Wind climatological data 1:** Selected. The text box contains 'D:\Etabs\Project01\Project2\Climatological_data_1\Nhurr_Miami(182).mat'. A 'Browse' button is to its right.
 - Wind climatological data 2:** Not selected. The text box is empty. A 'Browse' button is to its right.
 - Wind climatological data 3:** Not selected. The text box is empty. A 'Browse' button is to its right.
- 12. Design responses for specified MRIs:** This section contains three rows of input fields and 'Save as' buttons:
 - 12.1 Enter MRIs (years) for demand to capacity indices (DCIs):** Input field contains '1250'. 'Save as' button is to the right, with a text box containing 'D:\Etabs\Project01\Project2\Output\DCI_MRI.mat'.
 - 12.2 Enter MRIs (years) for inter-story drift ratio:** Input field contains '50'. 'Save as' button is to the right, with a text box containing 'D:\Etabs\Project01\Project2\Output\InDr_MRI.mat'.
 - 12.3 Enter MRIs (years) for acceleration:** Input field contains '50'. 'Save as' button is to the right, with a text box containing 'D:\Etabs\Project01\Project2\Output\Acc_MRI.mat'.

At the bottom of the window, there are 'Previous' and 'Next' buttons. A large 'Compute design responses with specified MRIs' button is located at the bottom right of the main content area.

Figure 5.7 Details needed to perform wind directionality analysis.

13. Results: the final page consist of the results. By selecting the response type, the user can check the DCI indices, drift ratios and acceleration values for any specified MRIs. When the user wants to plot the result, one can click on the corresponding button to plot the response and design surfaces. Some of the example results are shown below.

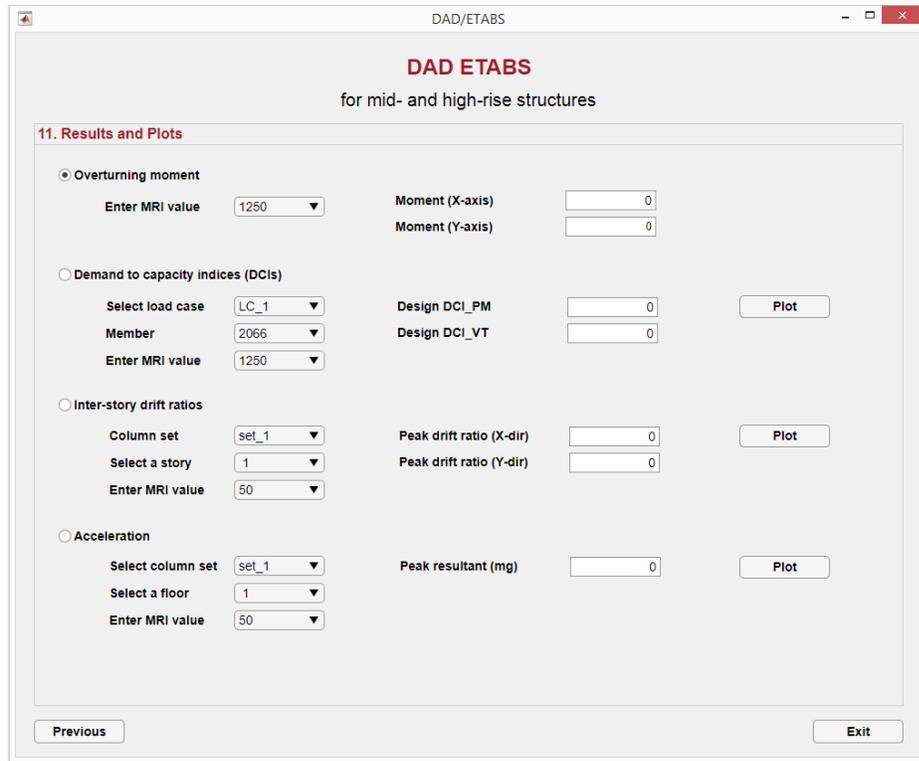


Figure 5.8 Results section of the software showing different outputs.

DCI: The user can select the member and the corresponding DCIs will be shown in the boxes. For observing the response surfaces of DCIs, press the plot button.

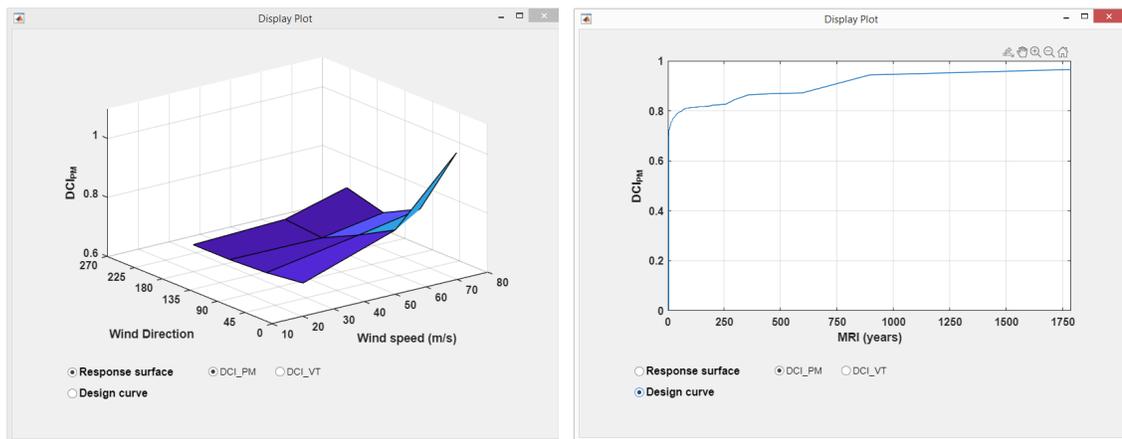


Figure 5.9 Response surface and design curve for DCI.

Inter-story drift ratios: The user can select the story number and the corresponding inter-story drift ratios will be shown in the boxes. For observing the response surfaces of inter-story drift ratio, press the plot button.

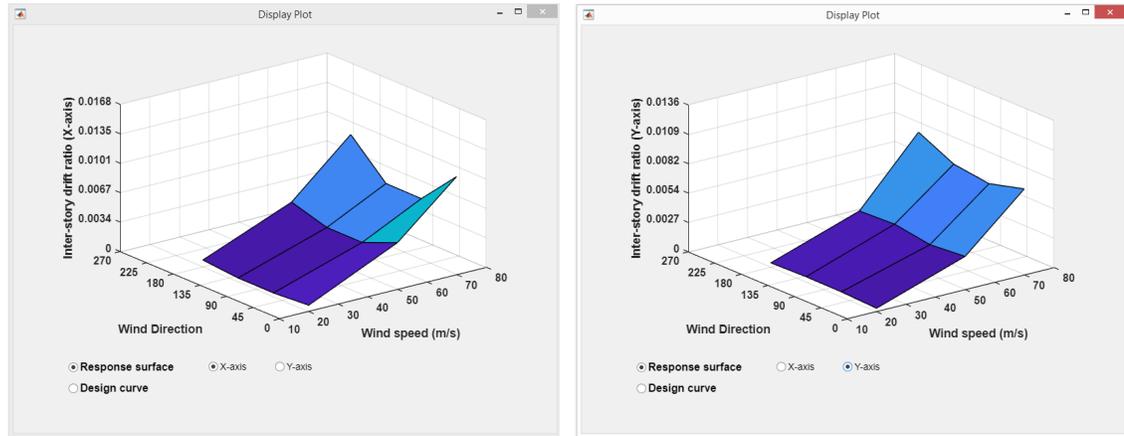


Figure 5.10 Response surface for inter-story drift ratios in x and y directions.

Design curve for inter-story drift ratios in x and y directions:

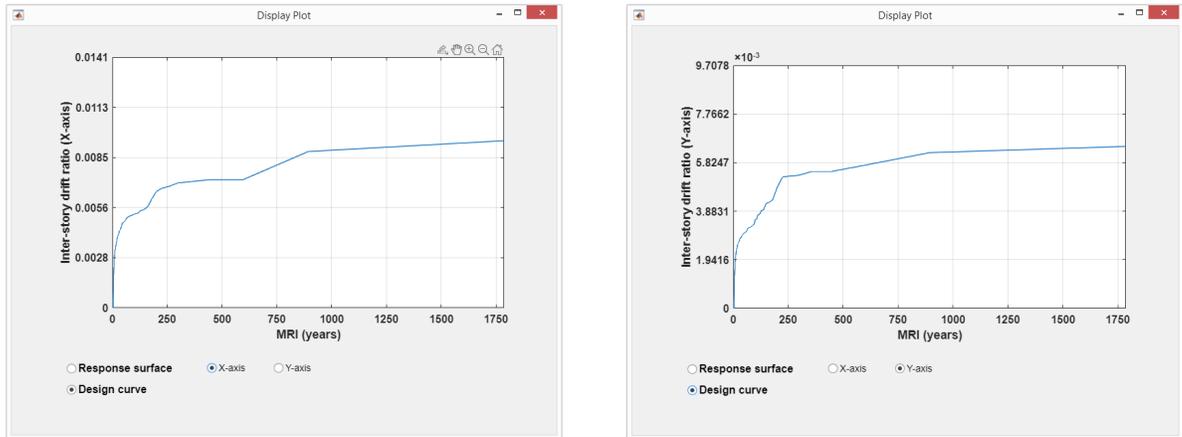


Figure 5.11 Design curve for inter-story drift ratios in x and y directions.

Acceleration: The user can select the floor number and the corresponding acceleration will be shown in the boxes. For observing the response surfaces of acceleration, press the plot button.

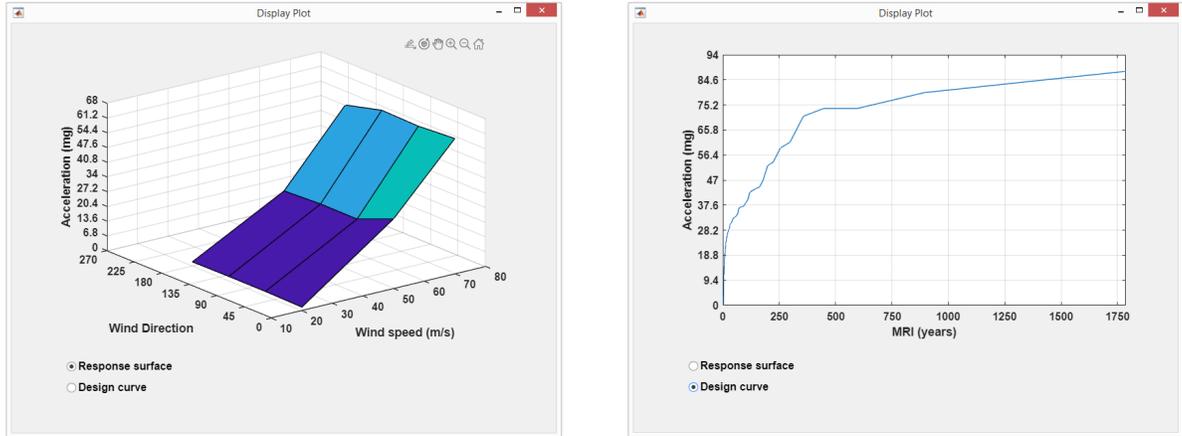


Figure 5.12 Response surface and design curve for acceleration.

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