



**NIST Technical Note
NIST TN 2236**

Evaluation of DAD_ETABS Procedure and Software for the Design of High-Rise Steel Buildings for Wind

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Abstract

The National Institute of Standards and Technology has developed advanced Database-Assisted Design (DAD) procedures for the design of structural members subjected to direction-dependent wind loads. Recently, a DAD_ETABS procedure that uses the ETABS software was developed with a view to facilitating the use of the DAD approach in structural engineering practice. DAD_ETABS is a powerful software package enabling DAD's unique safety and economy features to be part of general structural design practice. The purpose of this report is to review the main features of the DAD_ETABS structural design procedure and software, and to assess them from the point of view of the potential use in structural engineering design practice. The report presents a review of the procedure and the results of testing the performance of the DAD_ETABS software by performing an independent structural design of an example high-rise steel building. An assessment of the software and its potential for routine use in structural engineering design practice is then presented, followed by a set of recommendations on future work aimed at enhancing the software's capabilities as a widely used practical design tool.

Key words

Database-Assisted Design (DAD); Dynamic Analysis; ETABS; High-rise buildings; Structural Design; Wind effects.

Acknowledgments

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Table of Contents

List of Tables	iv
List of Figures	v
Disclaimer	vi
1. Introduction	1
2. Overview of the DAD_ETABS Procedure	2
3. Design of a high-rise steel building using DAD_ETABS version 1.0 software	6
3.1 Running DAD_ETABS	7
3.2 General input information (Main panel 1)	8
3.1. 3.3 Wind load calculation (Main panel 2)	9
3.2. 3.4. Dynamic analysis and response surfaces of design parameters (Main panel 3)	13
3.3. 3.5 Design wind effects in local wind climate (Main panel 4)	14
3.4. 3.6 Design results and plot (Main panel 5)	15
4. Assessment of DAD_ETABS for High-Rise Steel Buildings and Recommendations	20
4.1. 4.1 Comments on the DAD_ETABS design procedure	20
4.2. 4.2 Comments on DAD_ETABS program	21
References	26

List of Tables

Table 1. Section properties for the structural members in the 45-story building.	7
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List of Figures

Figure 1. Flowchart describing the DAD_ETABS design procedure (The processes in dark boxes are performed by ETABS).....	4
Figure 2. An example of response surface: Member Demand-to-Capacity Index (Park and Yeo 2018).....	4
Figure 3. Design DCI values as a function of MRIs (Saini et al. 2022).	5
Figure 4. Plan and isometric view of the building (Saini et al. 2022).....	6
Figure 5. An example of folders prepared for a design project using DAD_ETABS.	7
Figure 6. Pop-up panel for path to ETABS program and selection of structural type.	8
Figure 7. Main panel 1 of DAD_ETABS.	9
Figure 8. Option for use of saved inputs.	9
Figure 9. Main panel 2 of DAD_ETABS.	11
Figure 10. Panel for information on aerodynamic pressure data to calculate the floor wind loads.....	11
Figure 11. Pressure tap layout of the aerodynamic pressure data used in this design example (Venanzi 2005).....	12
Figure 12. Local axes (x , y and ϑ), building orientation (α_0), and wind direction (θ_w) of a building (Park and Yeo 2018).	12
Figure 13. Dynamic analysis and response surfaces (Main panel 3).	14
Figure 14. Design wind effects in local wind climate (Main panel 4).	15
Figure 15. Design results (Main panel 5).	16
Figure 16. DCI results: (a) response surface and (b) design curve (Saini et al. 2022).	17
Figure 17. Inter-story drift results: (a) response surface and (b) design curve (Saini et al. 2022).	18
Figure 18. Acceleration results: (a) response surface and (b) design curve (Saini et al. 2022).	19
Figure 19. Design details from ETABS.....	24
Figure 20. Design interaction ratios from ETABS	25

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1. Introduction

The National Institute of Standards and Technology (NIST) has developed advanced Database-Assisted Design (DAD) procedures for the design of structural members subjected to direction-dependent wind loads (e.g., Yeo 2010, Simiu and Yeo 2015, Park and Yeo 2016). Recently, a DAD_ETABS procedure that uses the ETABS software (CSI 2020) was developed with a view to facilitating the use of the DAD approach in structural engineering practice (Saini et al. 2022). DAD_ETABS is a powerful software package enabling DAD's unique safety and economy features to be part of general structural design practice.

The purpose of this report is to review the main features of the DAD_ETABS structural design procedure and the associated DAD_ETABS software¹ (Saini et al. 2022), and to assess them from the point of view of their potential use in structural engineering design practice. The report presents the testing results of practicality of the DAD_ETABS software by performing an independent structural design of a high-rise steel building.

The report is structured as follows. An overview of the DAD_ETABS design procedure is presented in Section 2. Details of an example design based on the DAD_ETABS software are described in Section 3. Section 4 contains assessments and recommendations concerning the DAD_ETABS design procedure and software, respectively.

¹ The DAD_ETABS version 1.0 software and its manual can be downloaded from https://www.itl.nist.gov/div898/winds/wind_effects.htm.

2. Overview of the DAD_ETABS Procedure

DAD is a computer-intensive, advanced structural design technique that makes full use of local extreme directionality wind climate data and measured simultaneous aerodynamic pressure coefficient time series. DAD employs time-domain methods. Figure 1 describes the sequence of the structural design processes in DAD_ETABS. Like its DAD predecessors (e.g., Yeo 2010, Simiu and Yeo 2015, Park and Yeo 2016), DAD_ETABS requires the wind engineering laboratory and the structural design office to perform the following tasks:

Wind Engineering Tasks. The wind engineering laboratory delivers to the structural engineering office:

- (i) The matrix of extreme directional wind speeds, $[V_{ij}]$, at the building site, where the elements are mean hourly wind speeds with direction j (e.g., 0, 10, 20, ..., 350 °) in successive storm events $i = 1, 2, \dots, i_{\max}$.
- (ii) Time series of the aerodynamic wind loading at the centers of mass of the building floors, induced by a sufficient number of wind velocities V_{mn} (for example, if the speeds and directions of the velocities being considered are 20, 30, ..., 70 m/s and directions 0, 10, 20, ..., 350 °, i.e., corresponding to a total of $6 \times 36 = 216$ cases, the velocity with speed 30 m/s and direction 0 ° is identified by the indexes $m = 2, n = 1$). This task makes use of aerodynamic coefficient time series measured simultaneously at multiple taps on the building model facades.
- (iii) Estimates of the uncertainties in the data of (i) and (ii).

Unlike in conventional practice, the DAD_ETABS procedure does not require the wind engineering laboratory to perform estimates of structural dynamics effects, which in DAD_ETABS are the exclusive province of the structural engineer.

A distinguishing feature of DAD_ETABS is the construction of *Response Surfaces*, i.e., of properties of the structure that describe the dependence of peak wind effects R_p on wind speed and direction (the subscript p identifies the wind effect, e.g., the Demand-to-Capacity Index (DCI), Inter-story drift ratio (ISDR), acceleration being considered)) – see Figure 2 for an example.

Structural Engineering Tasks. The structural engineering office performs:

- (i) Preliminary design of the building.
- (ii) Dynamic analyses that yield time series of the inertial forces and torsional moments induced at the centers of mass of the structures' floors by each of the aerodynamic loads determined in Wind Engineering Task (ii).
- (iii) Construction of Response Surfaces of peak wind effects (DCIs, ISDRs, accelerations) determined from time series of wind effects $R_{p\ mn}$ induced jointly by the applicable internal forces/moments, displacements and accelerations obtained from the dynamic analyses in Structural Engineering Task (ii). The response surfaces have the contours of peak wind effects (peak of $R_p(V_{mn})$) in the input space of speed m and direction n of wind V , as shown in Figure 2.
- (iv) Estimation of the peak wind effects of interest $R_p(N)$ with N -year MRIs specified by the performance criteria. A matrix $[R_{p\ ij}]$ of the peak wind effects induced by directional speeds of local wind climate data is constructed by replacing the elements of the matrix $[V_{ij}]$ of

directional wind speeds at the building site by the ordinates $R_p(V_{ij})$ based on the relevant surface R_p of interest. Since it is the strongest wind effect occurring during any given storm i that is of interest from a structural engineering viewpoint, only the elements $\max_j(R_{p\ ij})$ are taken into account. These elements are the components of the vector $\{\max_j(R_{p\ ij})\}$ representing the sample of the largest peak responses induced in the structure by the storm events $i = 1, 2, \dots, i_{\max}$. Finally, the response $R_p(N)$ with the specified MRI N is obtained by applying to that sample an appropriate Extreme Value estimation procedure.

(v) Iterative steps of structural design.

In current practice, the structural engineer performs the free vibration computations that yield the structure's fundamental frequencies of vibration, following which the wind engineer performs simplified estimates of peak inertial loads that disregard the curvature of the fundamental modal shapes and the effects of higher modes of vibration. A design iteration requires the structural engineer to determine a new set of fundamental frequencies, which is conveyed to and used by the wind engineer, who estimates on their basis a new set of inertial loads. This back-and-forth process repeated at each iteration discourages in practice efforts to perform the number of iterations required for optimization purposes. In the proposed approach shown in Figure 1, DAD_ETABS eliminates the unwieldy division of tasks in current practice of the structural dynamics tasks between the wind and the structural engineer. The division of tasks between the wind and the structural engineer inherent in DAD_ETABS enhances the transparency of the wind and structural engineering phases of the design. This enables the effective scrutiny of the design by the project stakeholders, and creates clear lines of accountability for the wind engineers -- who are responsible for delivering time series of aerodynamic pressure coefficients, time series data and extreme directional wind speeds, as well as estimates of their uncertainties, -- and the structural designers, who are responsible for producing the time series of the aerodynamic loads, sizing the structural members, and satisfying performance design criteria. To illustrate the DAD_ETABS procedure consider the following toy example, wherein the matrix of the directional wind speeds (in ms^{-1}) at the site of the structure is

$$[V_{ij}] = \begin{bmatrix} 34 & \mathbf{45} & 32 & 44 \\ 37 & 39 & 36 & \mathbf{51} \\ 42 & 44 & 35 & \mathbf{46} \end{bmatrix} \quad (1)$$

(Simiu and Yeo 2019). This 3×4 matrix corresponds to three storm events and four wind directions, that is, $i = 1, 2, 3$ and $j = 1, 2, 3, 4$. The numbers in bold type are the largest directional speed in each of those storm events. Assume that, for the member being considered, the matrix of the demand-to-capacity indexes (DCIs) obtained from the response surface is

$$[DCI_{ij}] = \begin{bmatrix} 0.81 & \mathbf{1.03} & 0.67 & 0.78 \\ 0.90 & 0.76 & 0.87 & \mathbf{1.06} \\ \mathbf{1.15} & 0.99 & 0.84 & 0.86 \end{bmatrix}. \quad (2)$$

For example, 0.81 is the DCI induced in the member being considered by the 34 ms^{-1} speed. The vector $\max_j(DCI_{ij})$ is $\{1.03, 1.06, 1.15\}$, and constitutes the sample from which the demand-to-capacity index with the specified MRI is determined through an Extreme Value estimation procedure. Note in this example that for the third storm it is the wind effect in the first of the four directions (i.e., 1.15) that dominates, whereas in the wind velocities matrix it is the wind speed in the fourth direction (i.e., 46 m/s) that is largest during the storm. Such

differences explain why the MRIs of the wind effects can differ from the MRIs of the wind speeds.

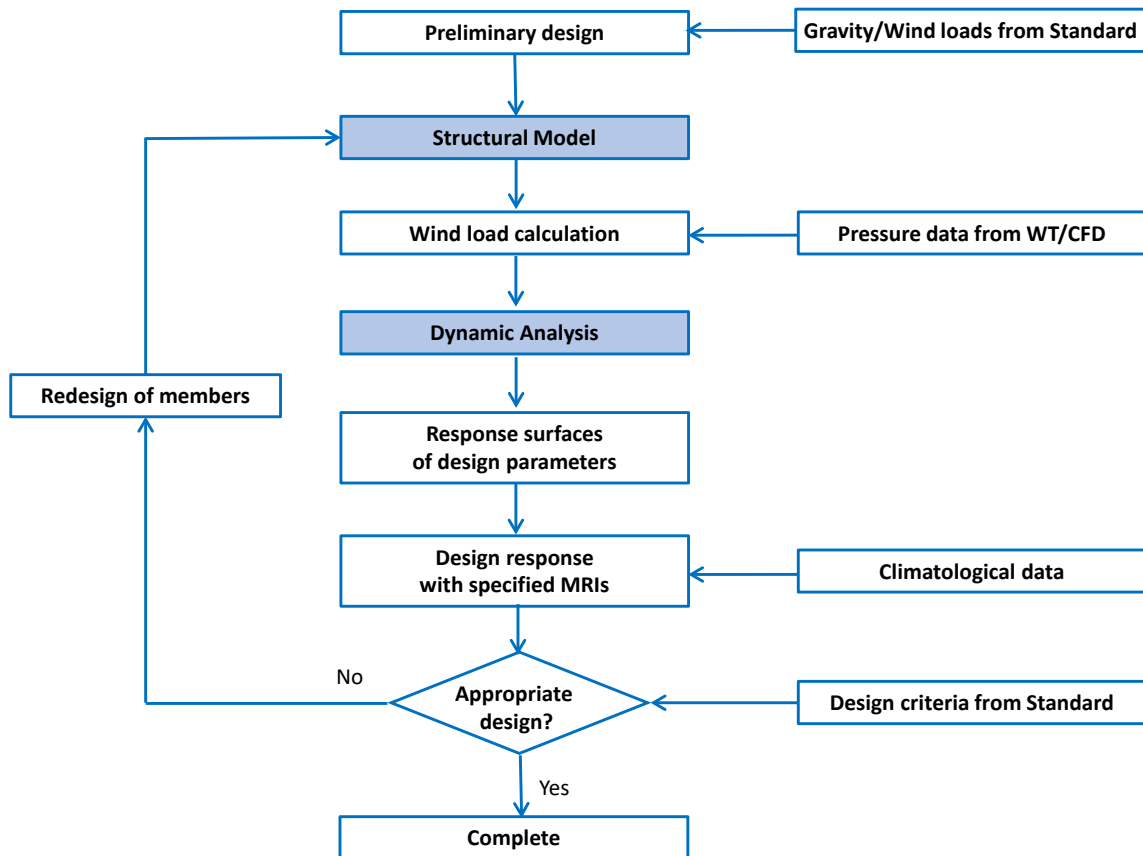


Figure 1. Flowchart describing the DAD_ETABS design procedure (The processes in dark boxes are performed by ETABS).

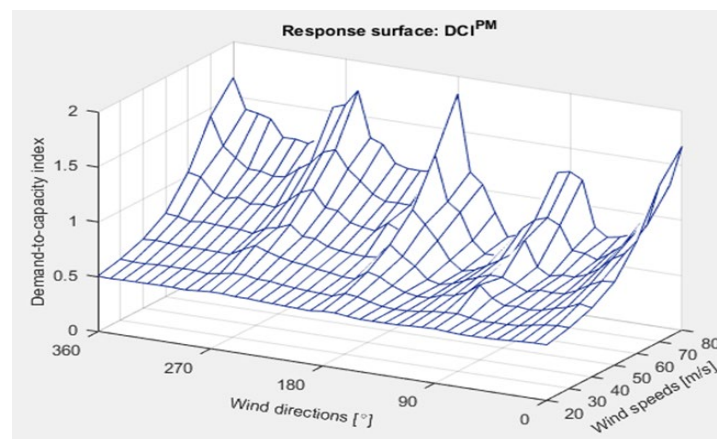


Figure 2. An example of response surface: Member Demand-to-Capacity Index (Park and Yeo 2018).

Figure 3 shows the peak DCI of a structural member as a function of MRI. The vector $\max_j(\text{DCI}_{ij})$ is a data sample from which the DCI with any specified MRI can be estimated by using any appropriate statistical procedure. If a non-parametric approach is adopted, the data are rank-ordered (highest to lowest), e.g., $\text{DCI}^{\text{pk}} = \{1.15, 1.06, 1.03\}$, and the MRI in years corresponding to the k -th highest DCI is

$$\bar{N}_k = \left[1 - \exp\left(-\frac{\lambda k}{n+1}\right) \right]^{-1} \quad (3)$$

where n is the sample size and λ is the mean annual rate of arrival of the storms. In the example, $n = 3$, $k = 1, 2$, and 3 .

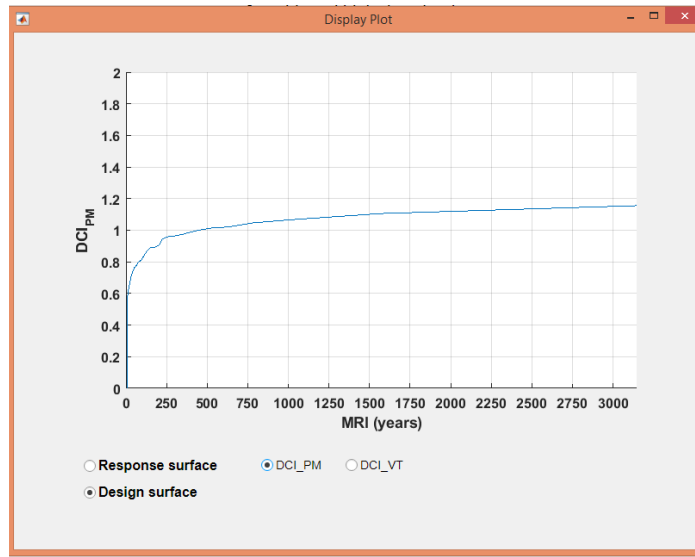


Figure 3. Design DCI values as a function of MRIs (Saini et al. 2022).

3. Design of a high-rise steel building using DAD_ETABS version 1.0 software

The design of a 45-story building (Figure 4) by DAD_ETABS v. 1.0 software was presented in a detailed report by Saini et al. (2022). This section includes or summarizes material and results from that report and presents results of independent structural design performed with a view to evaluating the adaptability of the DAD_ETABS software to and its practicality in current structural engineering practice in design of high-rise buildings for wind.

The building is assumed to be located near New York City in terrain with Exposure C, and was designed for a 1,700-yr Mean Recurrence Interval of the strength limit state. The height, width and depth of this 45-story building are, respectively, 182.88 m, 45.72 m and 30.48 m. The building has an outrigger and belt truss structural system at the 14th, 15th, 30th, 31st, 44th and 45th stories. It has three types of columns and beams (core, external core, and internal core) and two types of bracings (core and outrigger). Each type of structural member has constant dimensions for 15 successive floors. The columns and bracings are made of built-up hollow structural sections (HSS) and the beams are rolled W-sections (ANSI/AISC 2010). The floor slabs at all floor levels are assumed to be rigid diaphragms. In addition to the self-weight, a live load of 2.4 kN/m² and superimposed dead loads of 0.72 kN/m² are assigned on each floor. The dead load from the cladding is applied only on the exterior beams.

Table 1 provides the section details of the structural members used for the building. The orientation of the building is 270 degrees clockwise from North. Further details are available in Saini et al. (2022).

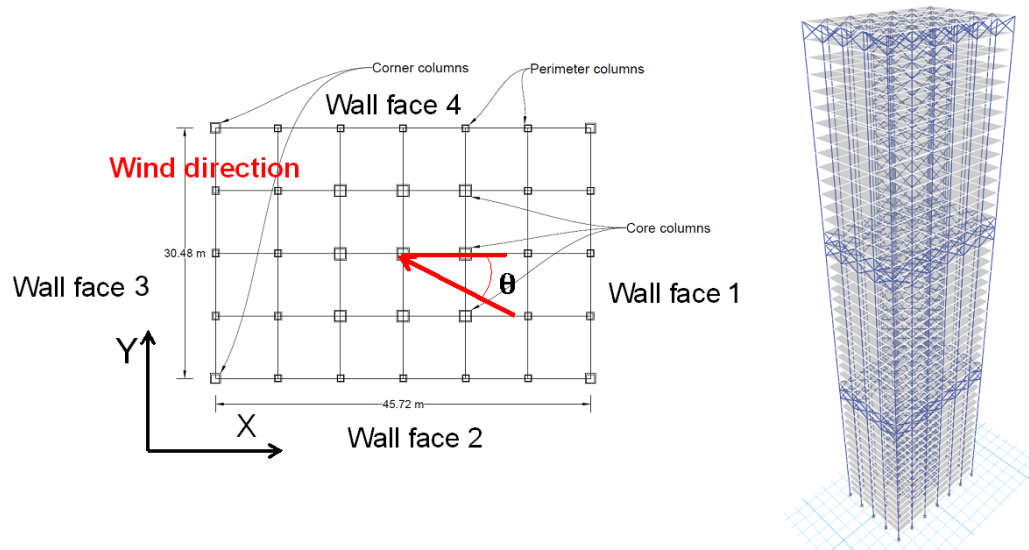


Figure 4. Plan and isometric view of the building (Saini et al. 2022).

Table 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

3.1. Running DAD_ETABS

A typical design project for DAD_ETABS consists of five folders which store (i) pressure coefficient time series data at multiple taps on the building model facades, (ii) information on the geometry and structural properties of the building, (iii) climatological directional wind speed data at the building site, (iv) ETABS model files and (v) design output results, as illustrated in Figure 5. The data in the first four folders should be prepared before performing the DAD_ETABS design procedure.

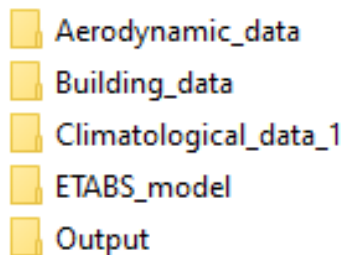


Figure 5. An example of folders prepared for a design project using DAD_ETABS.

After executing “DAD_ETABS.exe” (or “DAD_ETABS_P1.mlapp” in the source code), the user can provide on a pop-up panel the paths to the ETABS executable and API dll files, as shown in Figure 6. This example used the following paths to ETABS version 18:

for ETABS executable

'C:\Program Files\Computers and Structures\ETABS 18\ETABS.exe', and

for API dll file

'C:\Program Files\Computers and Structures\ETABS 18\ETABSv1.dll'.

The current version of DAD_ETABS does not work satisfactorily with ETABS versions 19 and 20.

After the “Start” button is clicked in the pop-up panel (Figure 6), the user can access the five main panels of the DAD_ETABS software, described in Sections 3.2 to 3.6. Each panel has

multiple input units in which the user can provide information required for using the software. The current version of DAD_ETABS can be used for the design of steel structures only, in SI units.

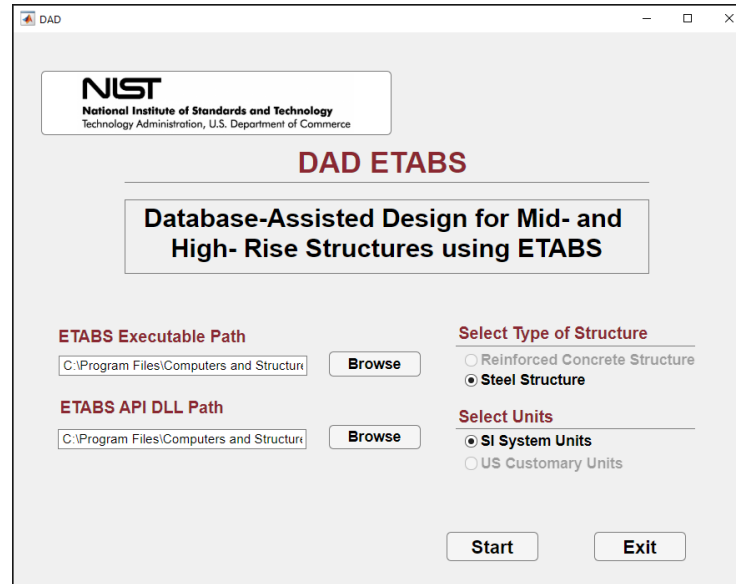


Figure 6. Pop-up panel for path to ETABS program and selection of structural type.

3.2. General input information (Main panel 1)

Figure 7 shows the main panel 1 of the DAD_ETABS software. The user provides the path to the ETABS model of the building in Input unit 1 and building information in Input unit 2 of Main panel 1. Input unit 3 determines whether the analysis is linear or non-linear. The DAD_ETABS currently performs only linear analyses. In Input unit 4, load combinations are specified using dead load, super-imposed dead load, and wind load factors for strength and serviceability design. An “add” button in Input units 4.2 and 4.3 allows consideration of more than one load combination. In the version of the software presented herein only one load combination is considered. The load factor for the wind load used in conjunction with the specified MRIs of peak wind effects is unity. A saved input can be restored using a pop-up panel (Figure 8).

DAD ETABS
for mid- and high-rise structures

1. Model Path
F:\33_yeodh_DAD\HRDAD\HR_DAD_ETABS_v1\20220422_Test_project_files\F 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)	1.00
b) Super-imposed dead load (SDL)	1.00
c) Live load (LL)	1.00
d) Wind load (WL)	1.00

4.2 For strength design

1.2 DL + 1.2 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 7. Main panel 1 of DAD_ETABS.

User Question

? Saved data found for the selected model. Do you want to load the previously saved files?

Yes No

Figure 8. Option for use of saved inputs.

3.3. Wind load calculation (Main panel 2)

Main panel 2 of DAD_ETABS (Figure 9) calculates floor wind loads using directional pressure coefficient data measured in wind tunnel tests (in the present version the aerodynamic pressure coefficient datasets are obtained in wind tunnel tests).

The user chooses an option for calculating floor wind loads at floors in Input unit 6. The first available option is to use floor wind loads already calculated. The second option is to provide in a pop-up window aerodynamic pressure coefficient time series, coordinates of identified

pressure taps, and the interpolation method being used (Figure 10). The DAD_ETABS program accommodates pressure data with a layout of pressure taps arranged in a rectangular grid only, as shown in Figure 11. The “cubic” scheme recommended in Park and Yeo (2021) was used in the present version of the software. Note that the calculation of the floor wind loads is in this version of the software part of the tasks of the structural engineer in order to allow the complete presentation of a calculation example. However, the calculation of the floor aerodynamic loads can be assigned to the wind engineering laboratory.

The wind loads at each floor consist of four time-histories of the forces and torsional moment distributed on the edges of the floor and equivalent to the tributary forces acting at the virtual taps. The loads are saved in CSV-formatted files which can be read in ETABS using database tables operation via ETABS API (Application Programming Interface) under the control of MATLAB. This is the only option available in the current version of ETABS.

The wind velocities considered for the development of the response surfaces are selected in Input unit 7. The range of speeds used in the design example was from 20 m/s to 80 m/s in 10 m/s increments. However, in practice no speeds larger than $\max_i(V_{ij})$ need to be considered.

In Input unit 8, the overturning moments based on the wind loading provisions of the ASCE 7-22 Standard (ASCE 2022) are provided to check whether the counterparts determined from aerodynamic pressure datasets may not be less than 80 %, or 50 %, of the ASCE 7-22 estimates. If the calculated overturning moments are lower than these limits, the DAD_ETABS program adjusts the DCI to comply with the provision in Section 31.4.4 of ASCE 7-22. For example, if the ratio of overturning moment between DAD_ETABS and ASCE 7-22, denoted, respectively, by $M_o^{\text{DAD_ETABS}}$ and $M_o^{\text{ASCE 7-22}}$, is less than 0.8, the design peak DCI is adjusted in the following way (Yeo 2010):

$$DCI_{\text{adj}}^{\text{pk}} = \gamma DCI^{\text{pk}} \quad (4)$$

where the adjustment factor of DCI is defined as

$$\gamma = \frac{0.8}{\min\left(M_o^{\text{DAD_ETABS}}/M_o^{\text{ASCE 7-22}}, 0.8\right)}. \quad (5)$$

DAD ETABS
for mid- and high-rise structures

5. Wind tunnel test data

5.1 Model length scale (prototype/model)

5.2 Reference wind speed at rooftop elevation of the building model

5.3 Sampling rate (Hz)

5.4 No. of sampling points (data points)

5.5 Wind directions (degrees)

5.6 Discarded initial portion of time series (points)

Confirm

6. Floor wind loads at model scale (force per unit length)

☐ Open the calculated floor wind loads

☒ Calculate floor wind loads from pressures measured in taps on building model facade

7. Wind speed range

7.1 Wind speeds for response surfaces

8. Lower limit requirement

☐ ASCE 7-based overturning moments **Browse**

Limiting value

Previous **Next**

Figure 9. Main panel 2 of DAD_ETABS.

DAD ETABS
for mid- and high-rise structures

Floor wind loads at model scale from pressure tap data on building model facade

(a) Time series of pressure coefficients **Browse**

(b) Pressure tap identification **Browse**

(c) Pressure tap coordinates **Browse**

(d) Select interpolation method

Display **Calculate floor wind loads**

Figure 10. Panel for information on aerodynamic pressure data to calculate the floor wind loads.

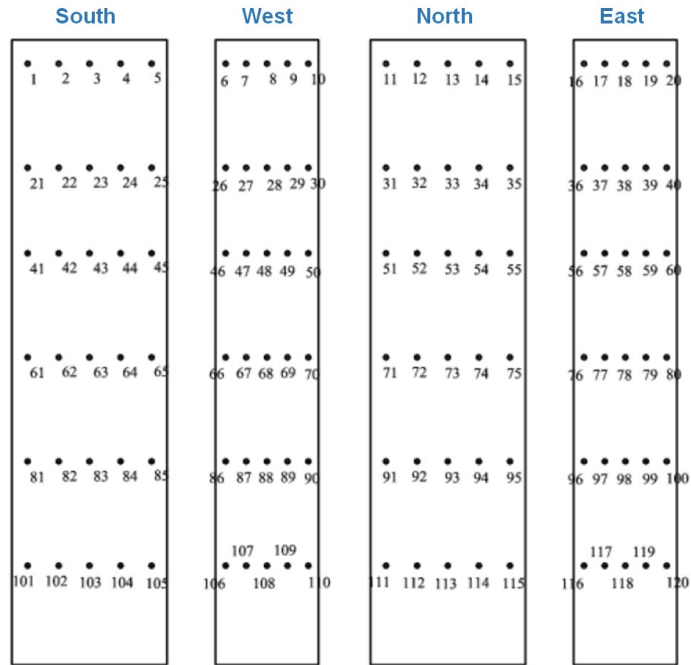


Figure 11. Pressure tap layout of the aerodynamic pressure data used in this design example (Venanzi 2005).

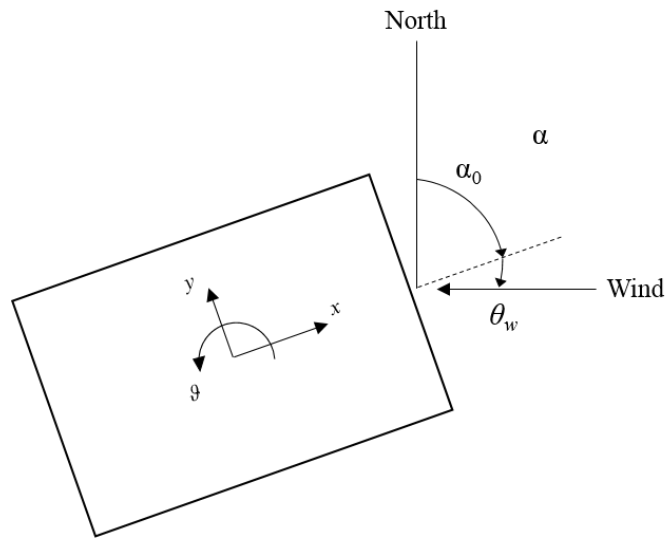


Figure 12. Local axes (x , y and θ), building orientation (α_0), and wind direction (θ_w) of a building (Park and Yeo 2018).

3.4. Dynamic analysis and response surfaces of design parameters (Main panel 3)

Main panel 3 of DAD_ETABS concerns the dynamic analyses of the building for the wind speeds and directions selected in Input units 7 and 5, respectively, as shown in Figure 13.

In Input unit 9, the user selects peak estimation methods (i.e., observed peak and multiple points-in-time peak approaches). In the design example, the multiple points-in-time approach with 10 points was selected to expedite computational time with no loss of accuracy, as recommended in Yeo (2013).

In Input unit 10, the user specifies structural members and column lines for constructing the response surfaces of the associated design parameters (e.g., DCI for the structural members, inter-story drift ratio and accelerations for the column lines).

After providing the information required in Input units 9 and 10, the user can perform the structural dynamic analyses of the building subjected to wind and gravity loads by clicking the ‘Perform Analysis’ button. For each of the selected wind directions, the DAD_ETABS program creates a separate subfolder (e.g., 36 subfolders corresponding to the selected 36 wind directions) within the “ETABS_model” folder (Figure 5), sets up the ETABS files associated with the case, and executes the ETABS program for structural analysis, through the ETABS API (Application Programming Interface) protocol. Inside each ETABS model, DAD_ETABS defines a linear modal time history load case for each wind speed. In this example, the 0 ° model will contain 7 load cases with the first being named WD_000_WS_20 for 20 m/s wind speed and the last being WD_000_WS_80 for 80 m/s.

The design example included in Saini et al. (2022) considered 40 members and two column lines for the purpose of constructing response surfaces of the design parameters for 7 wind speeds and 36 directions. Approximately 40 min were required to run an ETABS case for one wind velocity (wind speed and direction), extract from ETABS the time histories of ETABS outputs related to the design parameters, and save them to the user’s computer. The processing time can be broken down into ≈ 15 min. for the execution of the ETABS analysis and ≈ 25 min. for the extraction and storage of the results. The computational time in this example was ≈ 168 hours for the 252 wind loading cases [i.e., $40 \text{ min} \times 7 \text{ wind speeds} \times 36 \text{ wind directions} = 168 \text{ hours}$]. One desktop computer was used for performing this example design in the DAD_ETABS software. Comments on the reduction of the computational time are included in Section 4.

The screenshot shows the 'DAD ETABS' software window. The title bar reads 'DAD/ETABS'. The main header area contains the text 'DAD ETABS' in bold red font, followed by 'for mid- and high-rise structures' in a smaller black font. Below this, there are two main sections: '9. Calculation options' and '10. Response surface'. Section 9 includes radio buttons for 'DAD' (selected), 'Observed peak approach (default)', 'Multiple points-in-time approach (points)' (with a value of 10 in a text box), and 'ESWL (only for DCIs)'. Section 10 is titled '10. Response surface' and contains three sub-sections: '10.1 Demand to capacity indices (DCIs)', '10.2 Inter-story drift ratio (IDR)', and '10.3 Acceleration'. Each sub-section has a 'Specify members of interest' or 'Specify the column lines of interest' label with a 'Browse' button, and a 'Save as' label with a 'Browse' button. All text boxes contain the file path 'F:\33_yeodh_DAD\HRDAD\HR_DAD_ETABS_v1\20220422_Tes'. At the bottom of the main panel is a large 'Perform analysis' button. At the very bottom of the window are 'Previous' and 'Next' buttons.

Figure 13. Dynamic analysis and response surfaces (Main panel 3).

3.5. Design wind effects in local wind climate (Main panel 4)

Main panel 4 (Figure 14) allows the user to determine matrices of design wind effects m by substituting the ordinates of the respective response surface $R_m(V_{ij})$ for V_{ij} in the wind velocities matrix $[V_{ij}]$.

In Input unit 11, the user inputs the requisite wind velocity data. For details concerning mixed wind climates (e.g., hurricanes and thunderstorms), see Yeo (2011). In this design example, hurricane wind velocity data were used (see the NIST website: <https://www.itl.nist.gov/div898/winds/hurricane.htm>).

In Input unit 12, the user can specify MRIs for design DCIs, inter-story drift ratios, and accelerations and save their design results with the specified MRIs in MATLAB files.

3.6. Design results and plot (Main panel 5)

The final main page (Figure 15) shows design results (DCIs, inter-story drift ratios, and accelerations) and their visualizations. In Input unit 11, the DAD_ETABS provides overturning moments, DCIs, inter-story drift ratios, and acceleration with specified MRIs. The “Plot” button yields plots of response surfaces from all selected wind directions and speeds and the MRI-based design curve, as shown in Figures 16 to 18.

DAD ETABS
for mid- and high-rise structures

11. Wind climatological data

☒ Wind climatological data 1
F:\33_yeodh_DAD\HRDAD\HR_DAD_ETABS_v1\20220422_Test_project_f
Browse

☐ Wind climatological data 2
Browse

☐ Wind climatological data 3
Browse

12. Design responses for specified MRIs

12.1 Enter MRIs (years) for demand to capacity indices (DCIs)
1700
Save as Browse
F:\33_yeodh_DAD\HRDAD\HR_DAD_ETABS_v1\20220422_Tes

12.2 Enter MRIs (years) for inter-story drift ratio
25
Save as Browse
F:\33_yeodh_DAD\HRDAD\HR_DAD_ETABS_v1\20220422_Tes

12.3 Enter MRIs (years) for acceleration
10
Save as Browse
F:\33_yeodh_DAD\HRDAD\HR_DAD_ETABS_v1\20220422_Tes

Compute design responses with specified MRIs

Previous Next

Figure 14. Design wind effects in local wind climate (Main panel 4).

DAD/ETABS

DAD ETABS
for mid- and high-rise structures

11. Results and Plots

☒ **Overturning moment**

Enter MRI value: 1700

Moment (X-axis): 2.548e+09

Moment (Y-axis): 2.462e+09

☐ **Demand to capacity indices (DCIs)**

Select load case: LC_1

Member: 5257

Enter MRI value: 1700

Design DCI_PM: 0

Design DCI_VT: 0

Plot

☐ **Inter-story drift ratios**

Column set: set_1

Select a story: 1

Enter MRI value: 25

Peak drift ratio (X-dir): 0

Peak drift ratio (Y-dir): 0

Plot

☐ **Acceleration**

Select column set: set_1

Select a floor: 1

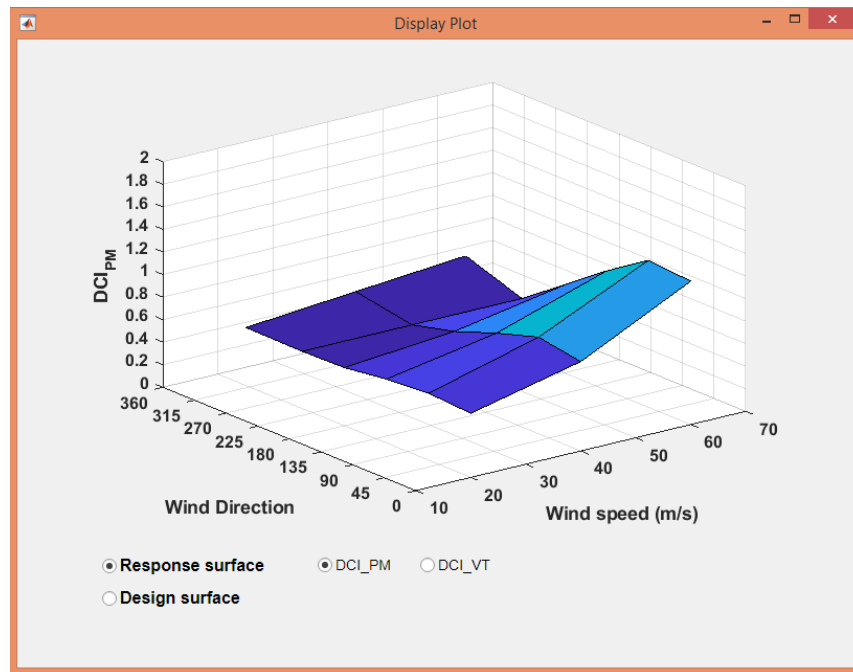
Enter MRI value: 10

Peak resultant (mg): 0

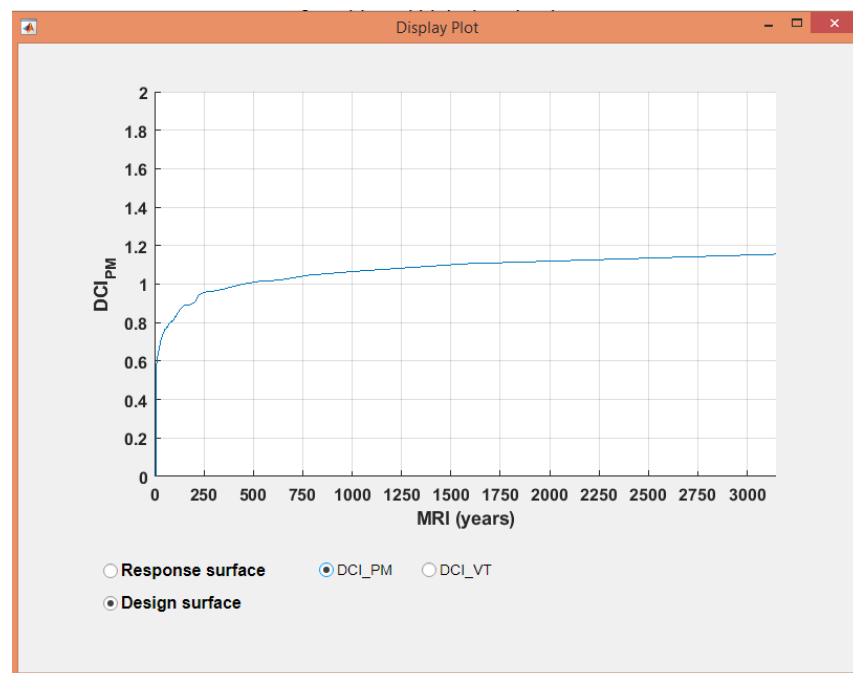
Plot

Previous Exit

Figure 15. Design results (Main panel 5).

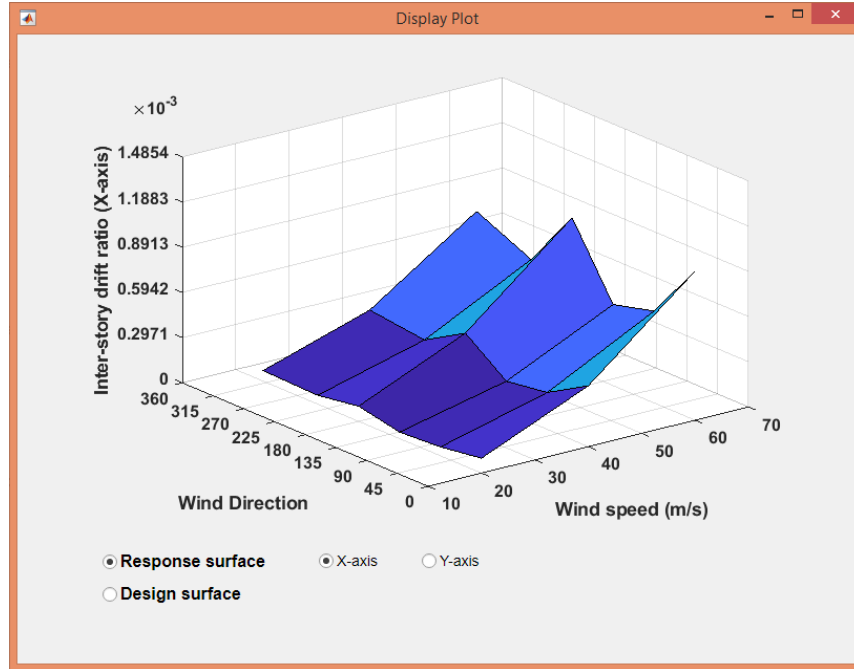


(a)

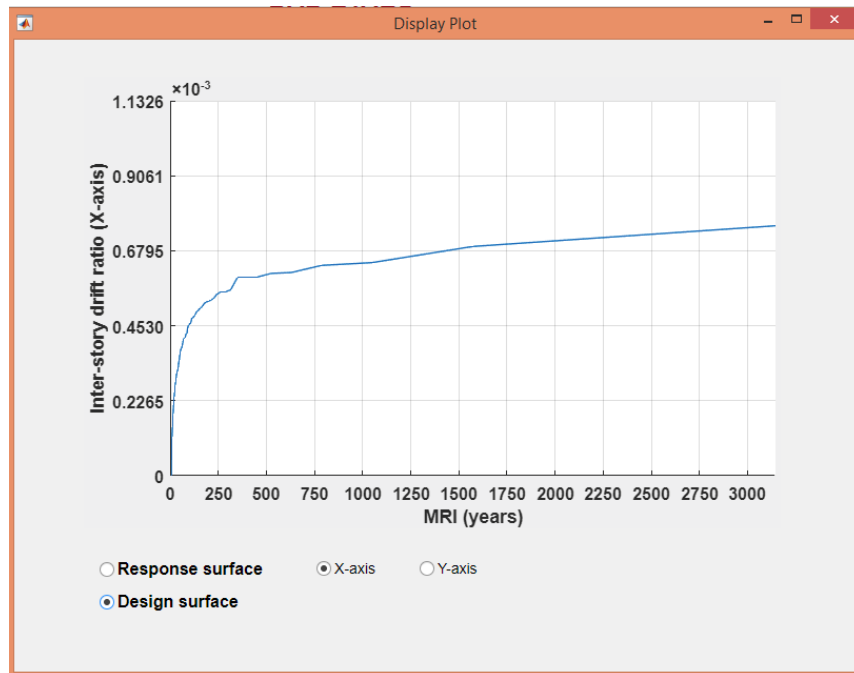


(b)

Figure 16. DCI results: (a) response surface and (b) design curve (Saini et al. 2022).

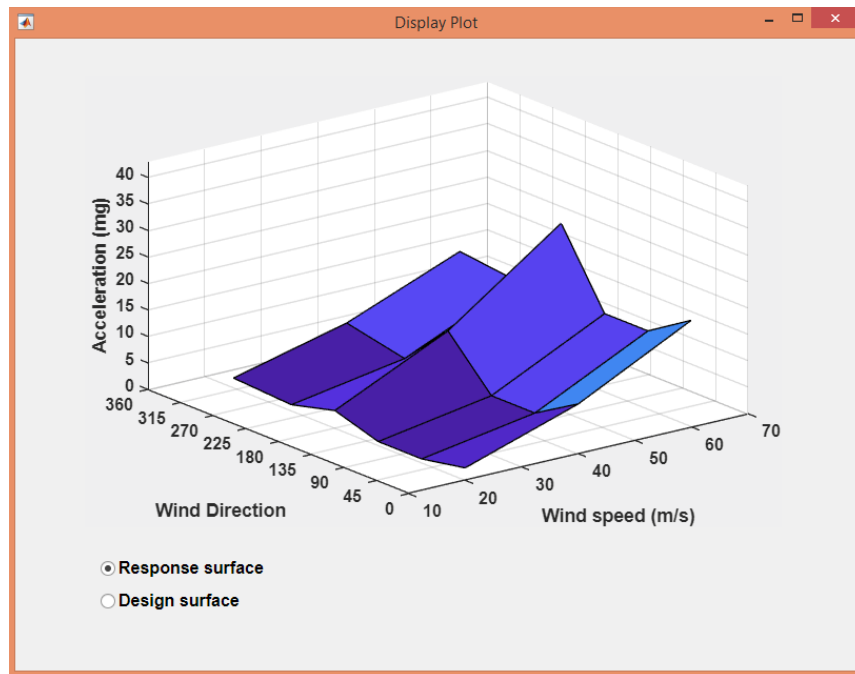


(a)

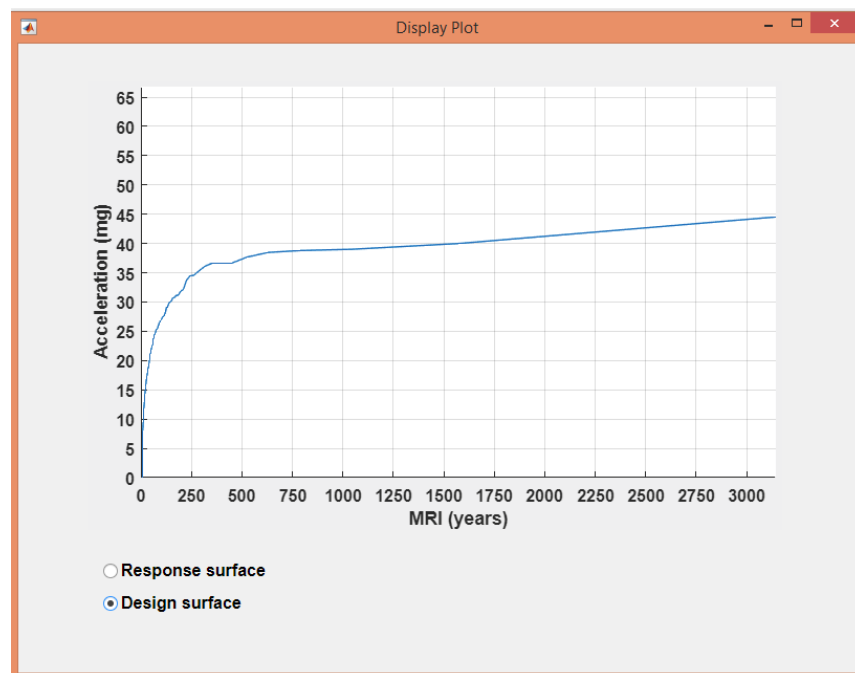


(b)

Figure 17. Inter-story drift results: (a) response surface and (b) design curve (Saini et al. 2022).



(a)



(b)

Figure 18. Acceleration results: (a) response surface and (b) design curve (Saini et al. 2022).

4. Assessment of DAD_ETABS for High-Rise Steel Buildings and Recommendations

4.1. Comments on the DAD_ETABS design procedure

- DAD_ETABS requires the structural engineer to spend much more time on the wind analysis of structures than is required for methods used in current practice. For this reason, based on the capabilities used so far in the development of this report, the use of DAD_ETABS would be recommended primarily for unusual types of high-rise building, e.g., buildings with heights above 300 m. However, those capabilities can be significantly improved by reducing computation times. Even if only one desk computer were used, as was the case for the present work, and future hardware development did not result in higher computation speeds, computation times could be reduced by accounting for the fact that, typically, wind speeds and/or pressure coefficients are relatively low for certain directions. Perhaps more importantly, parallel computing would result in massive computation time reductions, and could be used even if the structural design office does not possess the requisite hardware by possibly resorting to cloud computing.
- The computer interface described herein will allow structural designers familiar with ETABS to benefit from the advantages of the Database-Assisted Design approach.
- Unlike methods used in current practice, DAD_ETABS has the capability of designing high-rise buildings so that the mean recurrence intervals (MRIs) of *wind loading effects* conform to those specified by performance requirements. In contrast, as pointed out by Irwin et al. (2013, pp. 27-28), the MRIs assumed in current practice for structural design purposes are not the MRIs of the *wind loading effects* of interest, but rather the MRIs of the *wind loads* that induce those *wind loading effects*. Designs performed in accordance with methods used in current practice thus do not satisfy performance requirements. In addition, as noted earlier, such designs typically fail to account for the curvature of the fundamental modal shapes, for higher modes of vibration, and for the imperfect correlations among moment and axial force time series in the interaction equations used for member sizing.
- For the design of buildings subjected to multiple wind hazards (e.g., hurricanes, thunderstorms, and synoptic winds), the DAD procedure must be based on directional extreme wind speed data associated with each type of wind hazard. Typically, such data are not available in the public domain.
- Directional extreme wind speed database of hurricanes for various locations in Gulf and east coasts of the U.S. is available at <https://www.itl.nist.gov/div898/winds/hurricane.htm>. However, this database is from hurricane simulations based on data measured up to 1970s (Batts et al. 1980).
- The NIST extreme wind speed database of non-hurricane winds is publicly available (https://www.itl.nist.gov/div898/winds/NIST_TN/nist_tn.htm) but does not have information on wind direction.

- The ASCE 7-22 Standard (ASCE 2022) specifies the MRIs for strength design of 300, 700, 1700, and 3000 years depending on Risk Category. The DAD procedure based on the non-parametric estimates for reliable estimation of wind effects (e.g., DCIs) with a large MRI requires at least 3 to 4 times longer time period of climatological database (e.g., 5,000 year long extreme wind speed database for DCIs corresponding to MRI of 1700 years), as recommended in Simiu and Yeo (2019). Parametric responses can be used that require far shorter sample sizes covering, e.g., 30 years, say.
- To check serviceability of the structural response of a building, the DAD procedure considers inter-story drift ratios and accelerations. Recent design guides (e.g., ATC 2019) recommend the use of the Deformation Damage Index (DDI), rather than of the inter-story drift ratio, for assessment of drift demands and potential damage in cladding and partition systems. The DDI can account for strain caused by vertical racking and warping of floors, unlike the inter-story drift (ATC 2019).
- To understand and perform the DAD procedure, the structural engineer should be able to interact knowledgeably with the wind engineer. Unlike Earthquake Engineering, only a handful of universities offer Wind Engineering courses. Also, most structural design practitioners are not familiar with design using time history of structural responses determined from dynamic analyses.
- Definitions of DCIs used in the DAD procedure should conform in the future to those used in ETABS.
- The current version of the DAD_ETABS procedure can perform linear analyses only. To include nonlinear analysis in the future version of DAD_ETABS, the design procedure should be modified accordingly. For example, the load factors cannot be included after structural analysis.

4.2. Comments on DAD_ETABS program

- MATLAB software is not frequently used by structural engineering firms. This could be a barrier for structural engineers to easily adopt the MATLAB-based DAD_ETABS software in their design work. For an ideal case, the DAD procedure could be imbedded into practical structural design software (e.g., ETABS) so that structural engineers fully use the advanced features of DAD and structural design details of the structural design software.
- The current DAD_ETABS program implements one load combination for strength and one load combination for serviceability. Additional load combinations based on the ASCE 7 Standard should be added in the software.
- The program is implemented for use of a single CPU for most calculation procedures, which results in a large amount of computational time. For example, it took ≈ 168 hours to perform the structural analysis for 252 wind loading cases ($= 7$ wind speeds $\times 36$ wind directions) and to save the ETABS results of selected 40 structural members and 2 column lines when a personal computer² was used. Additional time (≈ 1 hour) was required to complete the calculation of design parameters (i.e., DCIs,

² The specifications of the computer are Intel(R) Core(TM) i7-8850H CPU @ 2.60GHz and 16.0 GB RAM memory.

inter-story drifts, and accelerations) of the 40 structural members and 2 column lines using the hurricane climatological data. For design of all 4385 structural members and 4 corner column lines of the design building (Figure 4), it would take roughly ≈ 63 hours ($= 15 \text{ min.} \times 252 \text{ wind loading cases}$) to complete the ETABS analyses and ≈ 3687 hours ($= 25 \text{ min.} \times 252 \text{ wind loading cases} \times [4285 \text{ members} + 4 \text{ column lines} \times 45 \text{ stories}] / [40 \text{ members} + 2 \text{ column lines} \times 45 \text{ stories}]$) to extract from ETABS and save to the user's computer the time histories of ETABS outputs associated with the design parameters, such as axial forces, bending moments, shear forces, displacement, and accelerations. Additional time of ≈ 34 hours ($= 1 \text{ hr.} \times [4285 \text{ members} + 4 \text{ column lines} \times 45 \text{ stories}] / [40 \text{ members} + 2 \text{ column lines} \times 45 \text{ stories}]$) is also expected for complete structural design. Based on the observation above, the treatment of a large amount of data regarding time histories of ETABS results seems to be crucial to reduce the required computational time for DAD_ETABS. It is recommended to improve the way regarding how to deal with such large ETABS datasets in MATLAB. Use of computations in parallel nodes could reduce the calculation time, since structural analysis for each wind speed and direction case and the storage of the data are independently performed in ETABS. Also, the calculation of design parameters is recommended to be performed in a parallel mode of MATLAB.

- In the current DAD_ETABS software, structural dynamic analyses in ETABS are performed without a break for cases of all wind speeds and directions. Generally, it takes a significant amount of time for a computer to complete all the analyses. If, for any reason, the program stopped during the series of analyses, it should start over all the analyses from the beginning. A solution should be found for this problem in future versions of the program.
- The user cannot save input information as a separate input file. The DAD_ETABS program merely allows the user to upload a set of inputs last used in the program. An option to save input information in a file and to load the file will attend to this problem. The program cannot provide various options of structural P-Delta and linear/nonlinear analysis offered by ETABS. Future versions of the program should include these capabilities. This is also the case for other functions of ETABS, including graphic user interface and interactive data management. Also, the program provides limited information on design results (see Figure 15) and text-based interface for all raw design results. In the current setup, it is not possible to review individual member design in full detail. Only the product, the DCI values, can be obtained. A feature should be added allowing the review of member design in full detail
- The current software is compatible with ETABS version 18 only. The software should be updated to satisfactorily work with ETABS versions 19 and 20, as well.
- ETABS provides a summary sheet on the calculation as shown in Figure 19. This feature could be useful in DAD_ETABS.
- Figure 20 shows design interaction ratio (similar to DCI) overlaid on individual members in ETABS. This useful ETABS feature allows review of the design status at a glance using graphics. However, this can be difficult to implement, unless the design is performed in ETABS environment in lieu of in MATLAB.

- In Input unit 10 of Main panel (Figure 13), it is not convenient to select and list members of interest through a text file. Generally, the structural engineer needs to see the results for every member of the building. Additionally, if the engineer were to run the analysis for a subset of the members and then realize that additional members needed to be included, the analysis would have to be re-run in the DAD_ETABS program, which is inconvenient considering the length of the analysis time. It is recommended that the program create its own list of members, which can be conveniently taken from text file created by ETABS. Either Input unit 10.1 should autofill with every member in the building, read from the ETABS model, or there should be a toggle between entering a members selected list or running for every member.
- In Input unit 10 of Main panel 3 (Figure 13), the text file option for inter-story drift and acceleration is also unnecessary for practical structural design. Several possibilities are available for leveraging ETABS to create a more user-friendly interface. Instead of selected column lines from text files, all column lines should be listed in the drop-down menu in Input unit 10 of Main panel 3 (Figure 13). This will help the engineer pick what they want to review. The current setup restricts users.
- DAD_ETABS uses ETABS' default unique names, which consist of numbers. This can make it difficult to select and interpret the results. The unique names can be overwritten with a custom index that can indicate the member usage (beam, column, brace etc.) and location (level, grid intersection, beam line etc.). WPM has an internal standardized system and tools to assign each member a WPMIndex that becomes the unique name in ETABS. The WPMIndex is the same across all analysis models and BIM (Building Information Modeling) tools and is used to communicate geometry and design information between programs, under the BIM environment. Such detailed indexing is recommended in DAD_ETABS.
- The current setup of the program does not allow the user to use more than one climatological database (Input unit 11 of Main panel 4 in Figure 14).
- The program provides overturning moment only for global structural responses. More information is required for structural engineers to understand the structural behaviors induced by wind and gravity loads (Figure 15).
- The design curve plots use MRIs up to the longest period for DCIs, inter-story drifts, and accelerations (plot (b) in Figures 16 to 18). For the serviceability design, the appropriate MRIs are usually ranged from 5 year to 25 years (ATC 2019).
- Instead of selected members from text files, all members and all column lines should be listed in the drop-down menu in Input unit 11 of Main panel 5 (Figure 15). This will help engineer pick what they want to review. Current setup restricts users.
- In addition to overturning moment, other important features may be added, such as base shears, base torques, story shear and torque, peak displacement, peak acceleration, and peak drifts, which are important results that structural engineers frequently refer to.

ETABS Steel Frame Design

AISC 360-10 Steel Section Check (Strength Summary)

Element Details

Level	Element	Unique Name	Location (mm)	Combo	Element Type	Section	Classification
Story1	C38	135	3810	UDStIS2	Special Moment Frame	CL _{PER1}	Compact

LLRF and Demand/Capacity Ratio

L (mm)	LLRF	Stress Ratio Limit
4064.0	0.4	0.95

Analysis and Design Parameters

Provision	Analysis	2nd Order	Reduction
LRFD	Direct Analysis	General 2nd Order	Tau-b Fixed

Stiffness Reduction Factors

$\alpha P_r / P_y$	$\alpha P_r / P_e$	τ_b	EA factor	EI factor
0.608	0.028	0.95353	0.8	0.8

Design Code Parameters

Φ_b	Φ_c	Φ_{TY}	Φ_{TF}	Φ_V	Φ_{V-RI}	Φ_{VT}
0.9	0.9	0.9	0.75	0.9	1	1

Section Properties

A (cm ²)	J (cm ⁴)	I ₃₃ (cm ⁴)	I ₂₂ (cm ⁴)	A _{v3} (cm ²)	A _{v2} (cm ²)
871	711170.4	476220.8	476220.8	377.4	377.4

Design Properties

S ₃₃ (cm ³)	S ₂₂ (cm ³)	Z ₃₃ (cm ³)	Z ₂₂ (cm ³)	r ₃₃ (mm)	r ₂₂ (mm)	C _w (cm ⁶)
15624	15624	18693.5	18693.5	233.8	233.8	

Material Properties

E (MPa)	f _y (MPa)	R _y	C _{pr}	α
199947.98	344.74	1.1	1.15	NA

HSS Section Parameters

HSS Welding	Reduce HSS Thickness?
ERW	No

Stress Check forces and Moments

Location (mm)	P _u (kN)	M _{u33} (kN-m)	M _{u22} (kN-m)	V _{u2} (kN)	V _{u3} (kN)	T _u (kN-m)
3810	-18249.0494	80.0811	-0.0211	-20.9235	0.0056	0

Figure 19. Design details from ETABS

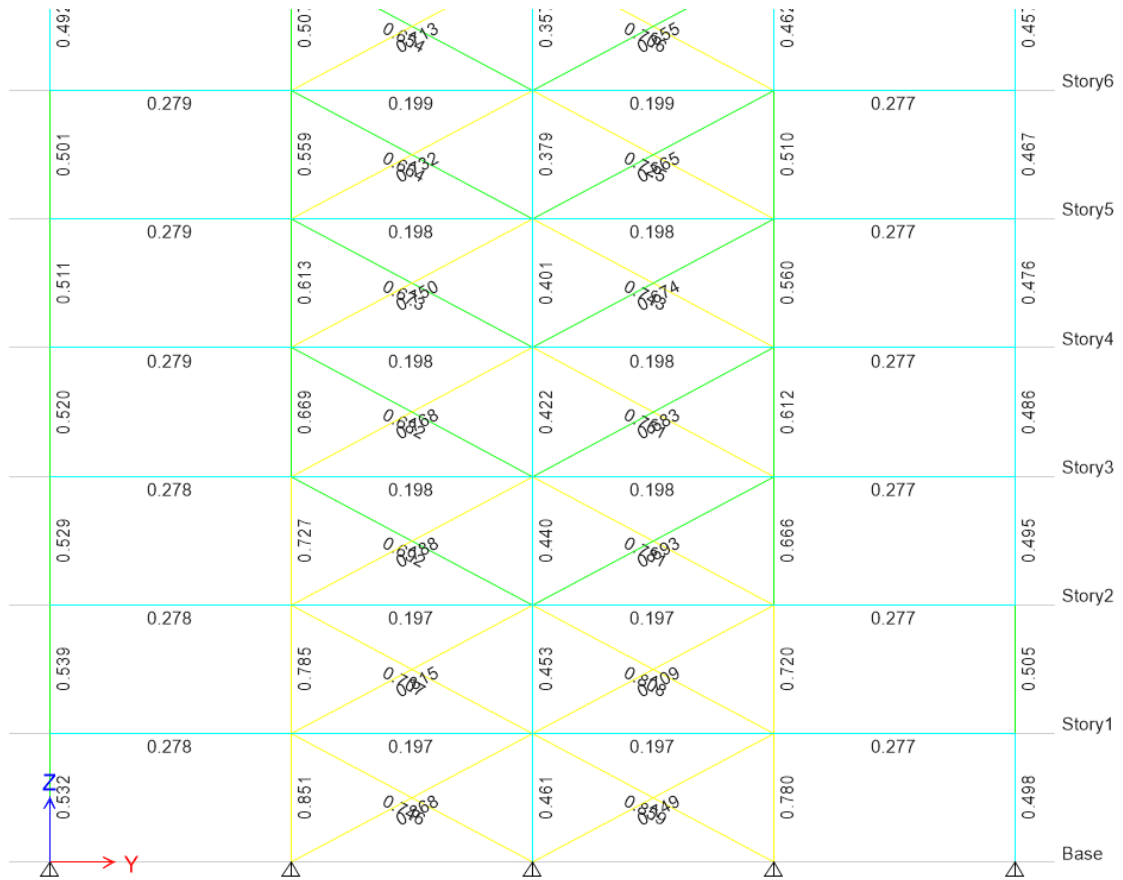


Figure 20. Design interaction ratios from ETABS

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