Analysis of Wind Loads on Buildings and Signs: A Computer Program Based on ASCE 7

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ABSTRACT

This paper presents the description of a computer program for the analysis of wind loads on buildings and signs. The material used to develop this program was derived mainly from the American Society of Civil Engineers Standard, Minimum Design Loads for Buildings and Other Structures[1] (better known as ASCE 7). The program was developed using an object-oriented programming methodology, Microsoft Visual Basic, and runs on any Microsoft Windows graphical environment platform. The program is intended for educational purposes and it is currently used in a structural analysis course taught at Texas A&M University-Kingsville[2]. The response from the students after using the program has been very positive and encouraging (this has been expressed in the student rating surveys in the "comments" section). The students primarily complement the program's interface, which is very user-friendly. Furthermore, the program is very practical and can be used to compute the wind pressures that act on signs and buildings, particularly wind pressures on flat roof buildings and hipped roof buildings. The main objective of the paper is to present the program to other potential users in academia and industry.

INTRODUCTION

In order to design a structure, it is necessary to first specify the most severe loads that will probably act on it. The design loading for most structures is often specified in building codes, such as the Uniform Building Code[3]. The loading specifications, particularly for wind loads, in these building codes are usually based on Chapter 6 of the American Society of Civil Engineers Standard, Minimum Design Loads for Buildings and Other Structures[1] - from hereon referred to as ASCE 7. The computer program described in this paper, which calculates wind loads on buildings and signs, is based on ASCE 7.

The analysis presented in ASCE 7 to determine wind loads is complex, involving tedious calculations. Students in Structural Analysis at Texas A&M University-Kingsville (TAMUK) had been required to perform these calculations by hand[2] prior to the development of the program presented here. This required the instructor to spend a large portion of the course teaching the

calculation procedures rather than helping the students understand the nature and effect of these loads on structures. The present project is intended to be responsive to this effort by using computers to perform the tedious calculations. The main advantage of computers is their speed and consistency.

The computer program was developed using Microsoft Visual Basic 6.0 because it is one of the most popular object-oriented programming languages and it allows the programmer to use many of the features typically found in the Microsoft Windows graphical environment. This program was developed because there is no simple computer programs that isolate the wind load problem, though there are a number of "canned" programs that perform these calculations, including sophisticated structural analysis ones such as SAP2000[4].

ASCE 7 is the main source for the load calculations implemented in the wind loads analysis computer program. The program is intended for use as a tool along with the ASCE 7 Standard and it is not intended to replace, but to complement and supplement the wind loads analysis part of ASCE 7.

OVERVIEW OF ASCE 7

ASCE 7 allows three procedures for determining the minimum design wind loads on buildings and other structures, particularly for the main wind-force resisting systems and components and cladding elements. Method 1 is a simplified analytical procedure based on the second method but limited to building systems meeting a specific criteria; Method 2 is an analytical method and is more general than Method 1; and Method 3 is based on wind tunnel testing procedures. In this section, we present a brief overview of the calculations involved in the determination of wind loads on the main wind-force resisting systems covered in the computer program, which are based on Method 2. Even though Method 2 in ASCE 7 covers a wide range of structural configurations, due to the complexity of different building systems in this project we only focus on the load analysis for the main wind-force resisting systems of three types of structural systems; flat or gable roofs and billboard signs. These three systems are amongst the most popular systems and are simple; which allow the students to develop an understanding of the overall analysis process.

For any case, the first step in obtaining the wind loads is to determine the appropriate dynamic wind pressure. This pressure is obtained by treating the air as a perfect fluid and noting that when wind strikes an object (a bluff body) in its path, the kinetic energy of the moving air particles is converted to an effective dynamic wind pressure. This effective dynamic wind pressure, q, at any height above ground is given by the following equation (Equation 6-13 in ASCE 7):

$$q_z = 0.00256 K_z K_{zt} K_d V^2 I \qquad \text{(lb/ft}^2) \tag{1}$$

where,

$q =$ effective dynamic velocity pressure to be used in the appropriate equation to evaluate the effective static wind pressure for main wind-force resisting systems (MWFRS); q_z is q at any height z above ground

$K_z =$ exposure velocity pressure coefficient, which reflects the change in wind speed with

height and terrain roughness, see ASCE 7, Section 6.5.6.4

K_{zt} = topographic factor, which accounts for wind speed-up over hills and escarpments, see ASCE 7, Section 6.5.7.2

K_d = wind directionality factor, see ASCE 7, Section 6.5.4.4

V = basic wind speed, which is a 3-second gust speed at 33 ft. above ground in Exposure Category C, and is approximately associated with an annual probability of 0.02 of being equal or exceeded (50-year mean recurrence interval), see ASCE 7 Figure 6-1

I = importance factor, which adjusts wind speed associated with annual probability of 0.02 (50-year mean recurrence interval) to other probabilities (25-year or 100-year mean recurrence interval), see ASCE 7 Table 6-1

Flat Roof Case

With the effective dynamic velocity pressure, we can calculate the design wind pressures for the main wind-force resisting system using the following equation (Equation 6-15, ASCE 7):

$$p = qGC_p - q_i(GC_{pi}) \qquad \text{(lb/ft}^2\text{)} \tag{2}$$

where,

$q = q_z$ for the windward wall at height z above the ground, and $q = q_h$ for the leeward wall, side walls, and roof. q_h is based on K_h, which is calculated using the mean building height h

G = gust effect factor and shall be taken as 0.85 or calculation base in Section 6.5.8.1, ASCE 7

C_p = a wall or roof external pressure coefficient, see ASCE 7, Figure 6-3

$q_i = q_h$

(GC_{pi}) = internal pressure coefficient, see ASCE 7, Table 6-7.

Gable Roof Case

The main difference between this case and the flat roof is the use of the mean roof height (h) and angle of roof (θ) in the calculation for dynamic wind pressure. This mainly affects the wind direction external pressure coefficients. The first step is to determine the appropriate velocity pressure q. Like the flat roof case, the velocity pressure, q, at any height above ground is obtained by using Equation (1) above.

Next, the design wind pressure for the main wind-force resisting system can be determined using Equation (2), with one modification, q_h is based on K_h, which is calculated using the mean roof height h, instead of the mean building height used for the flat roof case.

Signs (Billboards)

If the structure represents an aboveground sign (or a freestanding wall), the wind will produce a resultant force acting on the face of the sign, which is determined from Equation 6-20 of ASCE 7:

$$F = q_z GC_f A_f \qquad \text{(lb)} \tag{3}$$

where,

q_z = velocity pressure evaluated at height z of the centroid of area A_f calculated using Equation

(1) above

G = gust effect factor shall be taken as 0.85, or determined per ASCE 7, Section 6.5.8.1

C_f = net force coefficients, see ASCE 7, Table 6-11

A_f = projected area normal to wind, except where C_f is specified for the actual surface area, ft^2

To allow for normal and oblique wind directions, this resultant force is assumed to act normal to the face of the sign on a vertical line passing through the geometric center of the face of the sign or at a distance of 0.2 times the average width of the sign from this line.

OVERVIEW OF ANALYSIS OF WIND LOADS ON BUILDINGS AND SIGNS PROGRAM

In this section, we provide a brief overview of the Analysis of Wind Loads on Buildings and Signs program. The topics covered include input, processing, and output. We also discuss the related graphical user interface dialog boxes and views. The main window of the program is shown in Figure 1. It has three main buttons: Flat Roof Building, Gable Roof Building and Billboard Signs. These buttons represent the three load analysis modules covered in the program. This window may be moved, minimized, or closed using standard Microsoft Windows operations. The menus on the Menu Bar contain standard Microsoft Windows operations.

Figure 1: Analysis of Wind Loads on Buildings and Signs Program Main Window

Flat Roof Building

The flat roof building load analysis window is shown in Figure 2, which is activated by clicking on the corresponding button in the Main Window, Figure 1.

To analyze the loads on a flat roof building, first, the Project Name, Designer, Date and Description are entered. This information is not required for the program to run; all other information on the dialog window must be entered. Second, the values of building geometry such as length, width and height should be entered in feet. Third, the value of wind speed should be entered. This value can be obtained by clicking the Help button next to the Wind Speed dialog box, which brings up a basic wind speed map and provides basic wind speeds for the continental United States. Fourth, the types of exposure category, occupancy category and enclosure

classification must be chosen. A description of the exposure categories and cases appears when the user clicks the corresponding Help button. A description of the occupancy categories appears when the user clicks the Help button in the Occupancy Category dialog box. Choosing one of the occupancy categories selects the appropriate Importance Factor as shown on the screen to the right of the Occupancy Category dialog box. Finally, the enclosure classification should be selected. The next step is to run the analysis program by clicking the Solve button, which calculates the wind forces using the input information. The Clear All button clears the input information, the Close button stops this design case and goes back to the main window, and the Exit Program button stops the Analysis of Wind Loads on Buildings and Signs program.

A working project can be saved at any time by choosing the File menu and selecting the Save command. The user can give the file any name with an extension of frb, i.e., *.frb. This file can later be reopened by choosing the File menu and selecting the Load command.

Figure 2: Flat Roof Building Window

Gable Roof Building

The analysis process for gable roof buildings is identical to that for flat roof buildings, except that for the gable roof case, Eave Height should be entered, followed by the values of Roof Slope. In addition, to save the project an extension of grb must be used, i.e., *.grb.

Billboard Signs

The window for load analysis of billboard signs is shown in Figure 3. These calculations apply to rigid signs as well as freestanding walls. Like the flat roof case, the Project Name, Designer, Date and Description are not required for the program to run, however all other information on the dialog window must be entered.

After entering the wind speed, one of the two sign dialog boxes must be selected. The values of H, W, L1 and L2 are required for case 1, while values H, W, and L are required for case 2. And like the last two cases, the analysis process for this case is identical, except that for signs the project is saved using an extension of bsd, i.e., *.bsd.
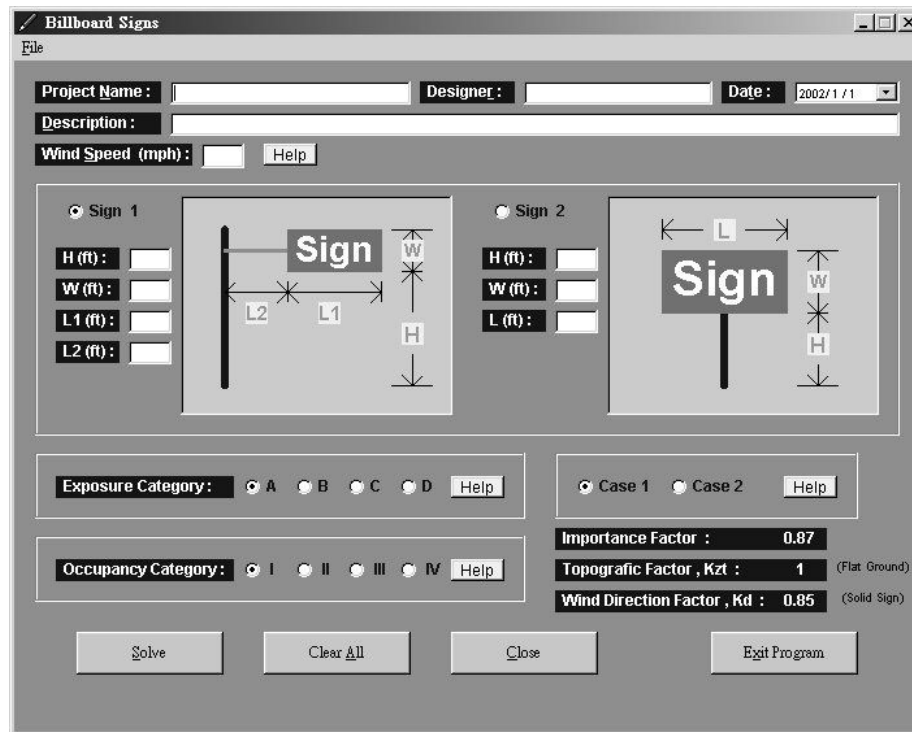
Figure 3: Billboard Signs Window

VERIFICATION OF THE COMPUTER PROGRAM CALCULATIONS

In this section, we use a gable roof building example from Guide to the Use of the Wind Load Provisions of ASCE 7-98[5] to verify the accuracy of the calculations performed by the Analysis of Wind Loads on Buildings and Signs program. The design wind pressures for a large, one-story commercial industrial building is determined. The building is located in flat, open farmland in Memphis; therefore, Exposure Category C is applicable. The building is not considered an essential facility or likely to be occupied by more than 300 persons at one time. Therefore, category II is appropriate, which requires an importance factor, I equal to 1.0, which corresponds to a 50-year mean return interval. Memphis is not located in a special wind region and its basic wind speed V is estimated at 90 miles per hour. The wind directionality factor, K_d is estimated to be 0.85 (see Table 6-6, page 61 of ASCE 7-98 Standard). The topographic factor, K_{zt} is estimated to be 1.0, which implies that there is no topographic effect. The external pressure coefficient, C_p is obtained from ASCE 7. The gust effect factor, G is estimated at 0.85. Finally, the internal pressure coefficient, GC_{pi} is obtained from ASCE 7.

The hand calculations can be found in the Guide to the Use of the Wind Load Provisions of ASCE 7-98[5], which are used to check the solution by the Analysis of Wind Loads on Buildings and Signs program. The following four figures, Figure 4 though Figure 7, present the calculations using our computer program. The values for the wind pressures obtained using our program are generally within one percent of those obtained by the hand calculations approach[5]. The reason for this discrepancy is that the hand calculations are based on tabulated values of K_z whereas the computer program uses a set of equations given in the commentary of ASCE 7.

Figure 4: Input Data for Wind Normal to the Ridge

Figure 5: Results of Calculations from Computer Program for Wind Normal to Ridge

Figure 6 (Gable Roof Building window)

Gable Roof Building

File

Project Name : Example   Designer : Yu-Cheng Chiu   Date : 2002/1/1

Description : Example 7, page 65 of GUIDE TO THE USE OF WIND LOAD PROVISIONS

Building Geometry :   Length (ft) : 250   (Length parallel to wind)   Width (ft) : 200   Eave Height (ft) : 20

Roof slope (degrees) : 18.43   Max Roof Height = 53.32   (ft)   Mean Roof Height = 36.66   (ft)

Wind Speed (mph) : 90   Help

Wind Direction :   ○ Wind Normal to Ridge   ● Wind Parallel to Ridge

Exposure Category :   ○ A   ○ B   ● C   ○ D   Help   ● Case 1   ○ Case 2   Help

Occupancy Category :   ○ I   ● II   ○ III   ○ IV   Help   Importance Factor : 1

Topografic Factor , Kzt : 1   (Flat Ground)

Enclosure Classification :   ○ Open Buildings   ○ Partially Enclose Buildings   ● Enclosed Buildings

Solve   Clear All   Close   Exit Program

Figure 6: Input Data for Wind Parallel to Ridge

Figure 7 (Calculation window)

Wind loads

Main Wind Force Resisting System Design Pressures :   Wind Parallel to Ridge

	(+GCpi) = 0.18	(-GC pi) = -0.18
Side Walls :	-13.93 (psf)	-7.46 (psf)
Leeward Wall :	-10.11 (psf)	-3.64 (psf)

Windward Wall :

Z (ft)	+GCpi Pressures (psf)	-GCpi Pressures (psf)
0-15	6.95	13.42
20	7.55	14.02
25	8.03	14.5
30	8.51	14.98
40	9.23	15.7
50	9.83	16.3
53.32	9.95	16.42

Roof :

Horiz distance from windward edge (ft) :

	(+GCpi) = 0.18	(-GC pi) = -0.18
0 to 18.33 :	-16.99 (psf)	-10.52 (psf)
18.33 to 36.66 :	-16.99 (psf)	-10.52 (psf)
36.66 to 73.32 :	-10.88 (psf)	-4.41 (psf)
> 73.32 :	-7.82 (psf)	-1.35 (psf)

PLAN   ELEVATION

Print   Close

Figure 7: Results of Calculations from Computer Program for Wind Parallel to Ridge

CONCLUSIONS

A program for the analysis of wind loads on buildings and signs was developed. This program is based on the wind load calculations found in the ASCE 7[1] standard. The program was written in Microsoft Visual Basic 6.0 using object-oriented programming methodology. ASCE 7 was chosen because it is nationally accepted and widely referenced by many building codes[6].

The Analysis of Wind Loads on Buildings and Signs Program is intended to complement the ASCE 7 standard, not replace it. Therefore, users should be familiar with ASCE 7 wind load specifications before using this program. Furthermore, professors interested in using this program for instruction purposes should contact the first author at: Hector.Estrada@tamuk.edu to receive a copy of the program.

The program is a Microsoft Windows based application and has the functionality of the Microsoft Windows programs. It allows the user to enter input data or load this data from a previously saved file, to be used in the calculation of wind loads on buildings and signs. Input and output data can be printed or stored on standard computer storage media.

The Analysis of Wind Loads on Buildings and Signs Program is an efficient tool for determining wind pressures on buildings and signs. Although the program produces accurate results for the example problems given in this paper, it is recommended that the program be tested before being used for any practical engineering calculations.

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