

1.051 Structural Engineering Design

Recitation 1

CALCULATION OF WIND AND EARTHQUAKE LOADS ON STRUCTURES ACCORDING TO ASCE 7 & IBC

WIND LOADS

Buildings and their components are to be designed to withstand the code-specified wind loads. Calculating wind loads is important in design of the wind force-resisting system, including structural members, components, and cladding, against shear, sliding, overturning, and uplift actions.

Wind Load Calculation Procedures

The design wind loads for buildings and other structures shall be determined according to one of the following procedures:

- (1) Method 1 – Simplified procedure for low-rise simple diaphragm buildings
- (2) Method 2 – Analytical procedure for regular shaped building and structures
- (3) Method 3 – Wind tunnel procedure for geometrically complex buildings and structures

Method 1 – Simplified Procedure

The simplified procedure is used for determining and applying wind pressures in the design of simple diaphragm buildings with flat, gabled, and hipped roofs and having a mean roof height not exceeding the least horizontal dimension or 60 feet (18.3 m), whichever is less, and subject to additional limitations.

Following are the steps of the simplified procedure:

1. Determine the *basic wind speed*, V , in accordance with ASCE 7 Figure 6-1 or IBC Figure 1609, assuming the wind can come from any direction. ASCE 7 6.5.4 includes some provisions for the special wind regions indicated, near mountainous terrain, and near gorges.
2. Determine the *importance factor*, I , in accordance with ASCE 7 Table 6-1 & Table 1-1, or with IBC Table 1604.5.
3. Determine the *exposure category* in accordance with ASCE 7 Section 6.5.6 or IBC Section 1609.4.
4. Determine the *height and exposure adjustment coefficient*, λ , from ASCE 7 Figure 6-2 or IBC Table 1609.6.2.1 (4)
5. Determine p_{s30} , the simplified wind pressure for exposure B , at $h=30$ ft, for $I=1.0$, from ASCE 7 Figure 6-2 or IBC Table 1609.6.2.1.

Simplified design wind pressures, p_s , for the main wind force resisting systems of low-rise simple diaphragm buildings is determined by the following equation:

$$p_s = \lambda I p_{s30} \quad (1)$$

where p_s represents the net pressure (sum of internal and external) to be applied to the horizontal and vertical projections of building surfaces. For the horizontal pressures, p_s is the combination of the windward and leeward net pressures.

Method 2 – Analytical Procedure

Wind loads for buildings and structures that do not satisfy the conditions for using the simplified procedure can be calculated using the analytical procedure provided that it is a regular shaped building or structure, and it does not have response characteristics making it subject to across-wind loading, vortex shedding, instability due to galloping or flutter, or does not have a site location that require special consideration.

The steps of analytical procedure, described in ASCE 7 Section 6.5.3 only, are as follows:

1. Determine the *basic wind speed*, V , and *wind directionality factor*, K_d in accordance with ASCE 7 Section 6.5.4.
2. Determine the *importance factor*, I , in accordance with ASCE Section 6.5.5.
3. Determine the *exposure category or exposure categories* and *velocity pressure exposure coefficient*, K_z or K_h , as applicable, for each wind direction according to ASCE 7 Section 6.5.6.
4. Determine the *topographic factor*, K_{zt} , if applicable, according to ASCE 7 Section 6.5.7.
5. Determine the *gust effect factor* G or G_f , as applicable, in accordance with ASCE 7 Section 6.5.8.
6. Determine the *enclosure classification* in accordance with Section 6.5.9.
7. Determine the *internal pressure coefficient*, GC_{pi} in accordance with ASCE 7 Section 6.5.11.1.
8. Determine the *external pressure coefficients*, C_p or GC_{pf} , or *force coefficients*, C_f , as applicable, in accordance with ASCE 7 Section 6.5.11.2 or 6.5.11.3.
9. Determine the *velocity pressure*, q_z or q_h , as applicable, in accordance with ASCE 7 Section 6.5.10. The velocity pressure, q_z evaluated at height z is calculated by the following equation:

$$\begin{aligned} q_z &= 0.00256 K_z K_{zt} K_d V^2 I && (\text{lb/ft}^2) \\ q_z &= 0.613 K_z K_{zt} K_d V^2 I && (\text{N/m}^2; V \text{ in m/s}) \end{aligned} \quad (2)$$

10. Determine the *design wind pressure*, p or *design wind load*, F , as applicable, in accordance with ASCE 7 Section 6.5.12 and 6.5.13. The design wind pressure is given by the following equations:

For rigid buildings of all height

$$p = qGC_p - q_i(GC_{pi}) \quad (\text{lb/ft}^2) \quad (\text{N/m}^2) \quad (3a)$$

for flexible buildings

$$p = qG_f C_p - q_i(GC_{pi}) \quad (\text{lb/ft}^2) \quad (\text{N/m}^2) \quad (3b)$$

where

$q = q_z$ for windward walls evaluated at height z above the ground,

$q = q_h$ for leeward walls, side walls, and roofs evaluated at height h

$q_i = q_h$ for windward walls, side walls, leeward walls, and roofs of enclosed buildings

$q_i = q_z$ for positive internal pressure evaluation in partially enclosed buildings

For low-rise buildings

$$p = q_h[(GC_{pf}) - (GC_{pi})] \quad (\text{lb/ft}^2) \quad (\text{N/m}^2) \quad (3c)$$

The *design wind load*, F , on open buildings and other structures is determined by the following formula:

$$F = q_z GC_f A_f \quad (\text{lb}) \quad (\text{N}) \quad (4)$$

where

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

A_f =projected area normal to the wind (ft^2) (m^2)

EARTHQUAKE LOADS

Every building and its portions, as a minimum, shall be designed and constructed to resist the effects of earthquake ground motions as prescribed by the following provisions. Additions to existing structures shall also be designed and constructed to resist the earthquake ground motion effects. Special structures including vehicular bridges, transmission towers, piers and wharves, hydraulic structures, and nuclear reactors are beyond the scope of these provisions.

The process of determining earthquake loads can be broken down to following basic steps:

- (a) determining the maximum considered earthquake and design spectral response accelerations
- (b) determining the seismic base shear in conjunction with the building or structure's dynamic characteristics (e.g. fundamental period)
- (c) distribution of the seismic base shear within the building or structure

General Procedure for Determining Maximum Considered Earthquake and Design Spectral Response Accelerations

Ground motion accelerations, represented by response spectra and coefficients derived from these spectra, shall be determined in accordance with:

- the general procedure described in ASCE 7 Section 9.4.12 or IBC Section 1615.1
- the site-specific procedure described in ASCE 7 Section 9.4.1.3 or IBC Section 1615.2.

Conditions on use of these methods depend on the seismic use group and site characteristics of the building or structure.

The procedure for determining the design spectral response accelerations is as follows:

1. Determine the mapped *maximum considered earthquake spectral response accelerations* at short periods, S_s and at 1-second period, S_1 using the spectral acceleration maps in ASCE 7 Figure 9.4.1.1a through 9.4.1.1j or IBC Figures 1615(1) through (10). Straight-line interpolation is allowed for sites in between contours. Acceleration values obtained from the maps are given in %g, where g is the gravitational acceleration.
2. Determine the *site class* in accordance with ASCE Section 9.4.1.2.1 or IBC 1615.1.1. Site class (A, B, C, D, E or F) is obtained based on the average shear wave velocity, v_s , average standard penetration resistance, N , or the average undrained shear strength, S_u . These parameters represent average values for the top 100 ft (30 m) of soil.

3. Determine the *maximum considered earthquake spectral response accelerations, adjusted for Site Class effects*, at short period, S_{MS} , and at 1-second period, S_{M1} , in accordance with ASCE Section 9.4.1.2.4 or IBC 1615.1.2.
4. Determine the design spectral response accelerations at short period, S_{DS} and 1-second period, S_{D1} in accordance with ASCE 7 Section 9.4.1.2.5 or 1615.3.
5. Using the parameters determined in the previous steps, construct the general response spectrum in accordance with ASCE 7 Section 9.4.1.2.6 or IBC Section 1615.4.

Determining the Seismic Base Shear

Structural Design Criteria, Analysis, and Procedures

Each structure shall be assigned a seismic use group (ASCE 7 Table 9.1.3), based on its corresponding occupancy category (determined from ASCE 7 Table 1-1) and a corresponding occupancy importance factor as indicated in ASCE 7 Table 9.1.4 and IBC Table 1604.5. All structures shall be assigned to a seismic design category based on their seismic use group and the design spectral response acceleration coefficients, S_{DS} and S_{D1} , in accordance with ASCE Table 9.4.2.1a or 9.4.2.1b, or IBC Table 1616.3(1) or 1616.3(2), whichever gives the most severe seismic design category.

The analysis procedures, which can be used within certain limitations, are as follows:

- (a) Index force analysis (ASCE 7 Section 9.5.3, IBC Section 1616.4)
- (b) Simplified analysis (ASCE 7 Section 9.5.4, IBC Section 1617.5)
- (c) Equivalent lateral force analysis (ASCE 7 Section 9.5.5, IBC Section 1617.4)
- (d) Modal response spectrum analysis (ASCE 7 Section 9.5.6, IBC Section 1618)
- (e) Linear response history analysis (ASCE 7 Section 9.5.7, IBC Section 1618)
- (f) Nonlinear response history analysis ((ASCE 7 Section 9.5.8, IBC Section 1618)

Equivalent lateral force analysis covers most structures encounter in daily design practices.

The seismic base shear, V , in a given direction is determined in accordance with the following equation:

$$V = C_s W$$

where

C_s = the seismic response coefficient determined in accordance with ASCE Section 9.5.5.2.1

W = the total dead load and applicable portions of other loads as indicated in Section 9.5.3.

Vertical distribution of the base shear can be determined as follows:

$$F_x = C_{vx} V$$

and

$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^n w_i h_i^k}$$

where

C_{vx} = vertical distribution factor

V = total design lateral force or base shear

w_i, w_x = the portion of the total gravity load of the structure located or assigned to level i or x .

h_i, h_x = the height from the base to Level i or x

k = an exponent related to the structure period as follows:

for structures having a period of 0.5 sec or less, $k = 1$ (linear)

for structures having a period of 2.5 sec or more, $k = 2$ (parabolic)

for structures having a period between 0.5 sec and 2.5 sec., k shall be 2 or shall be determined by linear interpolation between 1 and 2