CHAPTER 2

Load Combinations

2.1 Introduction

In accordance with IBC 1605.1, structural members of buildings and other structures must be designed to resist the load combinations of IBC 1605.2, 1605.3.1 or 1605.3.2. Load combinations that are specified in Chapters 18 through 23 of the IBC, which contain provisions for soils and foundations, concrete, aluminum, masonry, steel and wood, must also be considered. The structural elements identified in ASCE/SEI Chapters 12, 13 and 15 must be designed for the load combinations with overstrength of ASCE/SEI 2.3.6 or 2.4.5. These load combinations and their applicability are examined in Section 2.5 of this publication.

IBC 1605.2 contains the load combinations that are to be used when strength design or load and resistance factor design is utilized. Load combinations using allowable stress design are given in IBC 1605.3. Both sets of combinations are covered in Sections 2.3 and 2.4 of this publication, respectively. The combinations of IBC 1605.2 or 1605.3 can also be used to check overall structural stability, including stability against overturning, sliding and buoyancy (IBC 1605.1.1).

It is important to understand the difference between permanent loads and variable loads and their role in load combinations. Permanent loads, such as dead loads, do not change or change very slightly over time. Live loads, roof live loads, snow loads, rain loads, wind loads and earthquake loads are all examples of variable loads. These loads are not considered to be permanent because of their inherent degree of variability with respect to time (see the definition of "Loads" in IBC 202).

According to IBC 1605.1, load combinations must be investigated with one or more of the variable loads set equal to zero. It is possible that the most critical load effects on a member occur when one or more variable loads are not present.

ASCE/SEI 2.3 and 2.4 contain load combinations for strength design and allowable stress design, respectively. The load combinations are essentially the same as those in IBC 1605.2 and 1605.3 with some exceptions. Differences in the IBC and ASCE/SEI 7 load combinations are covered in the following sections. In ASCE/SEI 7-16, the load combinations with seismic load effects have been removed from ASCE/SEI Chapter 12 and placed in ASCE/SEI Chapter 2 in sections separate from the basic load combinations.

Prior to examining the various load combinations, a brief introduction on load effects is given in Section 2.2.

2.2 Load Effects

The load effects that are included in the IBC and ASCE/SEI 7 load combinations are summarized in Table 2.1. More details on these load effects can be found in those documents, as well as in subsequent chapters of this publication (see the Notes column in Table 2.1, which gives specific locations where more information can be found on the various load effects).

Table 2.1 Summary of Load Effects

Notation	Load Effect	Notes
D	Dead load	See IBC 1606 and Chapter 3 of this publication
D_i	Weight of ice	See IBC 1614, Chapter 10 of ASCE/SEI 7 and Chapter 4 of this publication
E	Seismic load effect defined in ASCE/SEI 12.4.2	See IBC 1613, ASCE/SEI 12.4.2 and Chapter 6 of this publication
E_m	Seismic load effect including over-strength defined in ASCE/SEI 12.4.3	See IBC 1613, ASCE/SEI 12.4.3 and Chapter 6 of this publication
F	Load due to fluids with well-defined pressures and maximum heights	—
F_a	Flood load	See IBC 1612, Chapter 5 of ASCE/SEI 7 and Chapter 7 of this publication
H	Load due to lateral earth pressures, ground water pressure or pressure of bulk materials	See IBC 1610 and Chapter 3 of this publication for soil lateral loads
L	Roof live load greater than 20 psf and floor live load	See IBC 1607 and Chapter 3 of this publication
L_r	Roof live load of 20 psf or less	See IBC 1607 and Chapter 3 of this publication
R	Rain load	See IBC 1611 and Chapter 3 of this publication
S	Snow load	See IBC 1608, Chapter 7 of ASCE/SEI 7 and Chapter 4 of this publication
T	Cumulative effects of self-straining forces and effects	See ASCE/SEI 2.3.4 and 2.4.4
W	Load due to wind pressure	See IBC 1609, Chapters 26 to 31 of ASCE/SEI 7 and Chapter 5 of this publication
W_i	Wind-on-ice load	See IBC 1614, Chapter 10 of ASCE/SEI 7 and Chapter 4 of this publication

2.3 Load Combinations Using Strength Design or Load and Resistance Factor Design

The basic load combinations where strength design or, equivalently, load and resistance factor design is used are given in IBC 1605.2 and summarized in Table 2.2. These equations establish the minimum required strength that needs to be provided in the members of a building or structure.

These load combinations apply only to strength limit states; serviceability limit states for deflection, vibration, drift, camber, expansion and contraction and durability are given in Appendix C of ASCE/SEI 7.

The load factors were developed using a first-order probabilistic analysis and a broad survey of the reliabilities inherent in contemporary design practice. The equations in Table 2.2 are meant to be used in the design of any structural member regardless of material in conjunction with the appropriate nominal resistance factors set forth in the individual material specifications. References 2.1 and 2.2 provide information on the development of these load factors along with additional background material.

Factored loads are determined by multiplying nominal loads (that is, loads specified in Chapter 16 of the IBC) by a load factor, which is typically greater than or less than 1.0. Earthquake and wind load effects are an exception to this: a load factor of 1.0 is used to determine the maximum effects from these loads because they are considered strength-level loads.

Table 2.2 Summary of Load Combinations Using Strength Design or Load and Resistance Factor Design (IBC 1605.2)

IBC Equation No.	Load Combination
16-1	$1.4(D + F)$
16-2	$1.2(D + F) + 1.6(L + H) + 0.5(L_r \text{ or } S \text{ or } R)$
16-3	$1.2(D + F) + 1.6(L_r \text{ or } S \text{ or } R) + 1.6H + (f_1 L \text{ or } 0.5W)$
16-4	$1.2(D + F) + 1.0W + f_1 L + 1.6H + 0.5(L_r \text{ or } S \text{ or } R)$
16-5	$1.2(D + F) + 1.0E + f_1 L + 1.6H + f_2 S$
16-6	$0.9D + 1.0W + 1.6H$
16-7	$0.9(D + F) + 1.0E + 1.6H$

f_1 = 1 for places of public assembly live loads in excess of 100 psf and for parking garages
= 0.5 for other live loads
f_2 = 0.7 for roof configurations (such as sawtooth) that do not shed snow off the structure
= 0.2 for other roof configurations

Load combinations are constructed by adding to the dead load one or more of the variable loads at its maximum value, which is typically indicated by a load factor of 1.6. Also included in the combinations are other variable loads with load factors less than 1.0; these are companion loads that represent arbitrary point-in-time values for those loads. Certain types of variable loads, such as wind and earthquake loads, act in more than one direction on a building or structure, and the appropriate sign of the variable load must be considered in the load combinations.

The seismic load effect, E, that is to be used in IBC Equation 16-5 (ASCE/SEI load combination 6) is equal to the following (see ASCE/SEI 12.4.2):

$$E = E_h + E_v$$

where E_h = horizontal seismic load effect defined in ASCE/SEI 12.4.2.1 = ρQ_E

E_v = vertical seismic load effect defined in ASCE/SEI 12.4.2.2 = $0.2S_{DS}D$

ρ = redundancy factor defined in ASCE/SEI 12.3.4

Q_E = effects of horizontal seismic forces applied to the structure

S_{DS} = design spectral response acceleration parameter at short periods

Thus, IBC Equation 16-5 (ASCE/SEI load combination 6) can be written as follows:

$$(1.2 + 0.2S_{DS})D + 1.2F + \rho Q_E + f_1 L + 1.6H + f_2 S$$

In IBC Equation 16-7 (ASCE/SEI load combination 7), the seismic load effect that is to be used is $E = E_h - E_v$ (see ASCE/SEI 12.4.2). Therefore, this equation can be written as follows:

$$(0.9 - 0.2S_{DS})D + 0.9F + \rho Q_E + 1.6H$$

According to the first exception in ASCE/SEI 12.4.2.2, the vertical seismic load effect, E_v, can be determined from the following equation, which is applicable to structures that have significant response to vertical ground motion:

$$E_v = 0.3S_{av}D$$

In this equation, S_{av} is the design vertical response spectral acceleration, which is equal to two-thirds the value of the MCE_R vertical response acceleration S_{aMv} determined in accordance with ASCE/SEI 11.9.2. This provision is invoked only by ASCE/SEI Chapter 15 for certain nonbuilding structures.

In the second exception in ASCE/SEI 12.4.2.2, E_v is permitted to be taken as zero for either of the following conditions:

- In ASCE/SEI Equations 12.4-1, 12.4-2, 12.4-5 and 12.4-6 for structures assigned to Seismic Design Category (SDC) B
- In ASCE/SEI Equation 12.4-2 when determining demands on the soil-structure interface of foundations

Fluid load effects, *F*, occur in tanks and other storage containers due to stored liquid products. The stored liquid is generally considered to have characteristics of both a dead load and a live load. It is not a purely permanent load because the tank or storage container can go through cycles of being emptied and refilled. The fluid load effect is included in IBC Equations 16-1 through 16-5 where it adds to the effects from the other loads. It is also included in IBC Equation 16-7 where it counteracts the effects from uplift due to seismic load effects, *E*. Because the wind load effects, *W*, can be present when the tank is either full or empty, *F* is not incorporated in IBC Equation 16-6; that is, the maximum effects occur when *F* is set equal to zero.

Two exceptions are given in IBC 1605.2. According to the first exception, factored load combinations that are specified in other provisions of the IBC take precedence to those listed in IBC 1605.2.

The second exception is applicable where the effect of *H* resists the primary variable load effect. In cases where *H* is not permanent, the load factor on *H* must be taken equal to zero (that is, *H* is not permitted to resist the primary variable load effect if it is not permanent). The 1.6 load factor on *H* accounts for the higher degree of uncertainty in lateral forces from bulk materials (which are included in *H*) compared to that from fluids, *F*, especially when considering the dynamic effects that are introduced as the bulk material is set in motion by filling operations.

The load combinations given in IBC 1605.2 are the same as those in ASCE/SEI 2.3.1 with the following exceptions:

- The variable f_1 that is present in IBC Equations 16-3, 16-4 and 16-5 is not found in ASCE/SEI combinations 3, 4 and 6. Instead, the load factor on the live load, *L*, in the ASCE/SEI 7 combinations is equal to 1.0 with the exception that the load factor on *L* is permitted to equal 0.5 for all occupancies where the live load is less than or equal to 100 psf, except for parking garages or areas occupied as places of public assembly (see exception 1 in ASCE/SEI 2.3.1 and 2.3.6). This exception makes these load combinations the same in ASCE/SEI 7 and the IBC.
- The variable f_2 that is present in IBC Equation 16-5 is not found in ASCE/SEI combination 6. Instead, a load factor of 0.2 is applied to *S* in the ASCE/SEI 7 combination. The second exception in ASCE/SEI 2.3.6 states that in ASCE/SEI combination 6, *S* must be taken as either the flat roof snow load, p_f, or the sloped roof snow load, p_s. This essentially means that the balanced snow load defined in ASCE/SEI 7.3 for flat roofs and in ASCE/SEI 7.4 for sloped

roofs can be used in ASCE/SEI combination 6. Note that S in ASCE/SEI combinations 2 and 4 is defined in the same way (see exception 2 in ASCE/SEI 2.3.1). Drift loads and unbalanced snow loads are covered by ASCE/SEI combination 3.

According to IBC 1605.2.1, the load combinations of ASCE/SEI 2.3.2 are to be used where flood loads, F_a, must be considered in design (flood loads are determined by Chapter 5 of ASCE/SEI 7 and are covered in Chapter 7 of this publication). In particular, the following modifications are to be made:

- V Zones or Coastal A Zones

  $1.0W$ in IBC Equations 16-4 and 16-6 must be replaced by $1.0W + 2.0F_a$

- Noncoastal A Zones

  $1.0W$ in IBC Equations 16-4 and 16-6 must be replaced by $0.5W + 1.0F_a$

Definitions of Coastal High Hazard Areas (V Zones) and Coastal A Zones are given in ASCE/SEI 5.2 (see Chapter 7 of this publication).

The load factors on F_a are based on a statistical analysis of flood loads associated with hydrostatic pressures, pressures due to steady overland flow, and hydrodynamic pressures due to waves, all of which are specified in ASCE/SEI 5.4.

In cases where self-straining loads, T, must be considered, their effects in combination with other loads are to be determined by ASCE/SEI 2.3.4 (IBC 1605.2.1). Instead of calculating self-straining effects based on upper bound values of this variable like other load effects, the most probable effect expected at any arbitrary point in time is used. More information, including load combinations that should be considered in design, is given in ASCE/SEI C2.3.4.

IBC 1605.2.1 requires that the load combinations of ASCE/SEI 2.3.3 be used where atmospheric ice loads must be considered in design. The following modifications to the load combinations must be made when a structure is subjected to atmospheric ice and wind-on-ice loads (atmospheric and wind-on-ice loads are determined by Chapter 10 of ASCE/SEI 7; see IBC 1614 and Chapter 4 of this publication):

- $0.5(L_r$ or S or $R)$ in ASCE/SEI combination 2 (IBC Equation 16-2) must be replaced by $0.2D_i + 0.5S$

- $1.0W + 0.5(L_r$ or S or $R)$ in ASCE/SEI combination 4 (IBC Equation 16-4) must be replaced by $D_i + W_i + 0.5S$

- $1.0W$ in ASCE/SEI combination 5 (IBC Equation 16-6) must be replaced by $D_i + W_i$

- $1.0W + L + 0.5(L_r$ or S or $R)$ in ASCE/SEI combination 4 (IBC Equation 16-4) must be replaced by D_i

See ASCE/SEI C2.3.3 for more information on the load factors used in these equations.

ASCE/SEI 2.3.5 provides information on how to develop strength design load criteria where no information on loads or load combinations is given in ASCE/SEI 7 or where performance-based design in accordance with ASCE/SEI 1.3.1.3 is being utilized. Detailed information on how to develop such load criteria that is consistent with the methodology used in ASCE/SEI 7 can be found in ASCE/SEI C2.3.5.

2.4 Load Combinations Using Allowable Stress Design

2.4.1 Overview

The basic load combinations where allowable stress design (working stress design) is used are given in IBC 1605.3. A set of basic load combinations is given in IBC 1605.3.1, and a set of alternative basic load combinations is given in IBC 1605.3.2. Both sets are examined below.

2.4.2 Basic Load Combinations

The basic load combinations of IBC 1605.3.1 are summarized in Table 2.3. A factor of 0.75 is applied where these combinations include more than one variable load because the probability is low that two or more of the variable loads will reach their maximum values at the same time.

Table 2.3 Summary of Basic Load Combinations Using Allowable Stress Design (IBC 1605.3.1)

Equation No.	Load Combination
16-8	$D + F$
16-9	$D + H + F + L$
16-10	$D + H + F + (L_r$ or S or $R)$
16-11	$D + H + F + 0.75L + 0.75(L_r$ or S or $R)$
16-12	$D + H + F + (0.6W$ or $0.7E)$
16-13	$D + H + F + 0.75(0.6W) + 0.75L + 0.75(L_r$ or S or $R)$
16-14	$D + H + F + 0.75(0.7E) + 0.75L + 0.75S$
16-15	$0.6D + 0.6W + H$
16-16	$0.6(D + F) + 0.7E + H$

A factor of 0.6 is applied to the dead load, D, in IBC Equations 16-15 and 16-16, which is meant to limit the dead load that resists horizontal loads to approximately two-thirds of its actual value. Previous editions of the legacy building codes specified that the overturning moment and sliding due to wind load could not exceed two-thirds of the dead load stabilizing moment. This provision was not typically applied to all members in the building. These load combinations apply to the design of all members in a structure and also provide for overall stability of a structure.

As noted in Section 2.3 of this publication, seismic load effect, E, is a strength-level load. A factor of 0.7, which is approximately equal to 1/1.4, is applied to E in IBC Equations 16-12, 16-14 and 16-16 to convert the strength-level effects to service-level effects. Similarly, a factor of 0.6 is applied to W in IBC Equations 16-12, 16-13 and 16-15.

The seismic load effect, E, that is to be used in IBC Equations 16-12 and 16-14 (ASCE/SEI load combinations 8 and 9) is equal to $E = E_h + E_v$ where all terms have been defined previously (see Section 2.3 of this publication). Thus, IBC Equations 16-12 and 16-14 (ASCE/SEI load combinations 8 and 9) can be written as follows:

- IBC Equation 16-12:

$$(1 + 0.14S_{DS})D + H + F + 0.7\rho Q_E$$

- IBC Equation 16-14:

$$(1 + 0.105S_{DS})D + H + F + 0.525\rho Q_E + 0.75L + 0.75S$$