



Seismic Design and Qualification Methods:

An Interpretation of the IBC 2015 & ASC 7 Codes

> Introduction

Historically, the seismic design of mechanical equipment was primarily focused on the equipment supports, and the attachments. The intent of the seismic design provisions in building codes was to reduce the hazard to life by sliding or falling equipment during an earthquake.

Today, mechanical systems often serve vital functions in critical building facilities such as hospitals, communication centers, and emergency response centers. The mechanical systems serving these types of facilities must be operational after an event, as non-functioning equipment could constitute a hazard to life. Therefore, the seismic design for this higher level of earthquake safety must assure functionality as well as position retention.

As a result, the 2015 International Building Code® (IBC) incorporates both functionality and position retention within the structural design requirements.

Factory assembled cooling towers are considered nonstructural components that are permanently attached to building structures for their support and attachment. Therefore, the cooling tower structural design falls within the scope of building codes.

This section will discuss the basis of seismic design requirements, define the seismic variables, discuss the seismic qualifications methods, and provide an example with a suggested specification.

> Basis of Seismic Design Requirements

The International Building Code® (IBC) is a model code developed by the International Code Council® (ICC) and available for adoption by jurisdictions internationally. The IBC was first issued in 2000 and is updated triennially. The latest edition is 2015.

Up to six editions of the IBC (2000, 2003, 2006, 2009, 2012, or 2015) have been adopted and are effective at the local or state level in all 50 states and the District of Columbia. Once adopted, the IBC provisions become enforceable regulations governing the design of buildings and structures.

The IBC defines design requirements for buildings, structures, and parts thereof. Contained within the structural design provisions of the IBC are requirements for cooling towers that may be subjected to various types of environmental factors, such as wind loads and seismic loads. The 2014 IBC refers extensively to and incorporates many provisions of ASCE/SEI 7-10, the consensus standard published by the American Society of Civil Engineers (ASCE).

> Seismic Design Requirements for Factory Assembled Cooling Towers

As noted above, factory assembled cooling towers typically are permanently attached to buildings. This means cooling towers are subject to the seismic design requirements for “nonstructural components,” which are defined as elements of mechanical, electrical, or architectural systems within buildings.

Several key variables must be looked at to determine the seismic design requirements for cooling towers. These variables are unique for a given project and independent of the cooling tower type. Per the IBC, the variables should be provided in the project structural documents and filtered into the cooling tower specification by the engineer of record.

> Determining if a Seismic Resistant Cooling Tower is Required

The following 7 step procedure can be used to determine seismic design requirements for a building (therefore the cooling tower), select the appropriate cooling tower, and provide a suggested specification.

As the paper outlines the procedure, the sidebar follows the procedure for a specific application and provides a sample specification for the cooling tower.

Step 1: Determine the Risk Category of the Building

Risk Category is a classification ranging from I to IV for buildings and other structures based on the level of risk and the nature of use. Category I buildings represent a low hazard to life in the event of failure while Category IV buildings are considered essential facilities.

Important Note: Risk category classifications are not consistent in the three editions of the IBC, and thus may vary from jurisdiction to jurisdiction depending on the edition adopted. It is important that design professionals include the edition of the IBC in project specifications.

The 2015 edition of the IBC defines the Risk Category in **Table 1604.5** which has been reproduced on the following page.

Example:

The example throughout this document illustrates the process to determine whether a seismic resistant cooling tower is required for an application and how to select the tower.

A 400 ton cooling tower is required for a 5-story hospital with emergency treatment facilities located in Glenrock, Wyoming (zip code 82637). The cooling tower will be installed on the roof of the 5-story hospital. Determine the seismic requirements that must be included in the cooling tower specification for this project.

Step 1: Determine the Risk Category of the facility

From **Table 1604.5** on the following page: Risk Category of Buildings and Other Structures, a hospital with emergency treatment services is Risk Category IV.



NOTES:

1. Steps 1 through 4 are shown to illustrate the use of seismic design provisions contained in the IBC. In application, the seismic design criteria including the Risk Category, Importance Factor, SDS, SD1, and Seismic Design Category should be provided by the Engineer of Record.
2. The figures, tables and sections referred in the analysis can be found in the 2009 IBC.



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Risk Category	Nature of Occupancy
I	Buildings and other structures that represent a low hazard to human life in the event of failure, including but not limited to: <ul style="list-style-type: none"> • Agricultural facilities • Certain temporary facilities • Minor Storage facilities
II	Buildings and other structures except those listed in Risk Categories I, III or IV
III	Buildings and other structures that represent a substantial hazard to human life in the event of failure, including but not limited to: <ul style="list-style-type: none"> • Building and other structures whose primary occupancy is public assembly with an occupant load greater than 300. • Buildings and other structures containing Group E with an occupant load greater than 250. • Building and other structures containing educational occupancies for students above the 12th grade with an occupant load greater than 500. • Group I-2 occupancies with an occupant load of 50 or more resident care recipients but not having surgery or emergency treatment facilities. • Group I-3 occupancies. • Any other occupancy with an occupant load greater than 5000^a. • Power-generating stations, water treatment facilities for potable water, waste water treatment facilities and other public utility facilities not included in Risk Category IV. • Buildings and other structures not included in Risk Category IV containing sufficient quantities of toxic or explosive materials that: Exceed maximum allowable quantities per control area as given in Table 307.1 (1) or 307.1(2) or per outdoor control area in accordance with the <i>International Fire Code</i>; are sufficient to pose a threat to the public if released^b.
IV	Buildings and other structures designated as essential facilities, including but not limited to: <ul style="list-style-type: none"> • Group I-2 occupancies having surgery or emergency treatment facilities. • Fire, rescue, ambulance and police stations and emergency vehicle garages. • Designated earthquake, hurricane or other emergency shelters. • Designated emergency preparedness, communications and operations centers and other facilities required for emergency response. • Power-generating stations and other public utility facilities required as emergency backup facilities for Risk Category IV structures. • Buildings and other structures containing quantities of highly toxic materials that: Exceed maximum allowable quantities per control area as given in 307.1(2) or per outdoor control area in accordance with the <i>International Fire Code</i>; and are sufficient to pose a threat to the public if released^b. • Aviation control towers, air traffic control centers and emergency aircraft hangers. • Buildings and other structures having critical national defense functions. • Water storage facilities and pump structures required to maintain water pressure for fire suppression.

Table 1604.5: Risk Category of Buildings and Other Structures



NOTES:

- a. For purposes of occupant load calculation, occupancies required by **Table 1004.1.3** to use gross floor area calculations shall be permitted to use net floor areas to determine the total occupant load.
- b. Where approved by the building official, the classification of buildings and other structures as Risk Category III or IV based on their quantities of toxic, highly toxic or explosive materials is permitted to be reduced to Category II, provided it can be demonstrated by a hazard assessment in accordance with Section 1.5.3 of ASCE 7 that a release of the toxic, highly toxic or explosive materials is not sufficient to pose a threat to the public.

Step 2: Determine the Importance Factor

All cooling towers are assigned a component importance factor, I_p , equal to 1.0 or 1.5. Towers that are needed for continued operation of an essential facility (a building with an Risk Category IV) or are required to function after an earthquake are assigned an importance factor of 1.5. All other towers receive a factor of 1.0.

Towers with an importance factor of 1.5 are further classified as “designated seismic system” components and may require certification that the unit will fully function following a seismic event.

Step 3: Determine the Seismic Design Category

The Seismic Design Category (SDC) is a structure classification ranging from A to F that is based on the following factors:

- Risk Category
- Design Spectral Accelerations (S_{DS} & S_{D1}) – Defined below.

The most severe of the S_{DS} and the S_{D1} is used to determine the SDC.

Step 3a: Calculate the S_{DS} and S_{D1}

The design spectral accelerations (at short periods, S_{DS} , and at 1-second period, S_{D1}) are dependent on site class (defined below) and maximum ground shaking intensity (defined below) at a given location.

Site Class is based on the site soil properties, which can range from Hard Rock (Site Class A) to Peat and Clays (Site Class F). To determine site class, refer to Chapter 20 of the ASCE/SEI 7-10. The 2015 IBC states: “Where the soil properties are not known in sufficient detail to determine the site class, Site Class D shall be used unless the building official or geotechnical data determine that Site Class E or F soil is likely to be present at the site.”

Ground Shaking Intensity can be obtained from probabilistic seismic hazard maps provided in the IBC. However, due to the fine gradation of acceleration values in some regions, such as the West Coast of the United States, it is more expedient and accurate to use software tools provided by the U.S. Geological Survey (USGS). The link to the USGS software is <http://earthquake.usgs.gov/designmaps>.

Input values for the U.S. Seismic Design Maps Application are map coordinates for the project site.

Step 2: Determine the Component Importance Factor Required

Since the building is an essential facility (Risk Category IV) and the cooling towers are required to function after an earthquake, the importance factor is equal to 1.5.

Step 3a: Calculate the S_{DS} and S_{D1}

To determine the Design Spectral Accelerations, the Spectral Acceleration for short period and 1-second period (S_s and S_1), Site coefficient for short period and 1-second period (F_a and F_v) are required. Below are examples of the short period and 1 second period hazard maps provided by the USGS.



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To calculate the Design Spectral Accelerations, the following equations are used:

Design Spectral Acceleration - At short periods (0.2 second)

The design spectral acceleration, S_{DS} , is determined using the following equations:

$$S_{DS} = 2/3 * S_{MS}$$

Where S_{MS} is the maximum considered earthquake spectral response acceleration for short period as determined in the following equation:

$$S_{MS} = F_a * S_s$$

Combining both equations results in:

$$S_{DS} = 2/3 * F_a * S_s$$

Where:

S_s is the mapped spectral accelerations for short periods as determined in Section 1613.3.1 of the Code or using the USGS software.

F_a is the site coefficient defined in **Table 1613.3.3(1)** of the 2015 IBC which is reproduced below (The tables are identical in the 2012, 2009, 2006, and 2003 versions of the code; it varies slightly in the 2000 version). Reference **Table 1613.3.3(1)** from the 2015 IBC is reproduced below.

Site Class	Mapped Spectral Response Acceleration at Short Period				
	$S_s \leq 0.25$	$S_s = 0.50$	$S_s = 0.75$	$S_s = 1.00$	$S_s \geq 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	Note b	Note b	Note b	Note b	Note b

Table 1613.3.3(1). Values of Site Coefficient F_a

These values can also be found using the web tool at the following website: <http://earthquake.usgs.gov/designmaps/us/application.php>



NOTES:

- a. Use straight-line interpolation for intermediate values of mapped spectral response acceleration for short period, S_s .
- b. Values shall be determined in accordance with Section 11.4.7 of ASCE 7.

Design Spectral Acceleration At 1-Second Periods

The design spectral acceleration, S_{D1} , is determined using the following equations:

$$S_{D1} = 2/3 * S_{M1}$$

Where S_{M1} is the maximum considered earthquake spectral response acceleration for 1-second period as determined in the following equation:

$$S_{M1} = F_v * S_1$$

Combining both equations results in:

$$S_{D1} = 2/3 * F_v * S_1$$

Where:

S_1 is the mapped spectral accelerations for 1-second period as determined in Section 1613.3.1 of the Code or using the USGS software.

F_v is the site coefficient defined in **Table 1613.3.3(2)** of the 2015 IBC. (The tables are identical in the 2012, 2009, 2006, and 2003 versions of the code; it varies slightly in the 2000 version.) Reference **Table 1613.3.3(2)** from the 2015 IBC is reproduced below.

Site Class	Mapped Spectral Response Acceleration at 1-Second Period(s)				
	$S_1 \leq 0.1$	$S_1 = 0.20$	$S_1 = 0.30$	$S_1 = 0.40$	$S_1 \geq 0.50$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	Note b	Note b	Note b	Note b	Note b

Table 1613.3.3(2). Values of Site Coefficient F_v ^a



NOTES:

- Use straight-line interpolation for intermediate values of mapped spectral response acceleration for 1-second period, S_1 .
- Values shall be determined in accordance with Section 11.4.7 of ASCE 7.

Go to <http://earthquake.usgs.gov/designmaps/us/application.php> to use the web tool:

- Under Design Code Reference Document, select 2012 IBC.
- Select the site's soil classification.
- Select the Risk Category. For this example, IV was selected.
- Enter the site's Longitude and Latitude or enter an address.
- The web tool returns the S_s , S_1 , and calculates the S_{MS} , S_{M1} , S_{DS} , and S_{D1} . For this example:

$$S_s = 0.481 \text{ g}$$

$$S_1 = 0.163 \text{ g}$$

$$S_{MS} = 0.577 \text{ g}$$

$$S_{M1} = 0.267 \text{ g}$$

$$S_{DS} = 0.385 \text{ g}$$

$$S_{D1} = 0.178 \text{ g}$$



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Step 3b: Determine the assigned Seismic Design Category (SDC)

Risk Category I, II or III structures located where the mapped spectral response acceleration parameter at 1-second period, S_{D1} , is greater than or equal to 0.75 shall be assigned to Seismic Design Category E.

Risk Category IV structures located where the mapped spectral response acceleration parameter at 1-second period, S_{D1} , is greater than or equal to 0.75 shall be assigned to Seismic Design Category F.

For all other structures, knowing the S_{DS} , S_{D1} , and Risk Category, the SDC can be determined using the following tables (The tables are identical in the 2012, 2009, 2006, and 2003 versions of the code; it varies slightly in the 2000 version). According to Section 1613.3.5, the Seismic Design Category is based on the most severe as defined from the short-period and 1-second response tables. The 2015 version of the tables is reproduced below.

Value of S_{DS}	Risk Category		
	I or II	III	IV
$S_{DS} < 0.167g$	A	A	A
$0.167g \leq S_{DS} < 0.33g$	B	B	C
$0.33g \leq S_{DS} < 0.50g$	C	C	D
$0.50g \leq S_{DS}$	D	D	D

Table 1613.3.5(1). Seismic Design Category Based on Short Period Response Accelerations

Value of S_{D1}	Risk Category		
	I or II	III	IV
$S_{D1} < 0.067g$	A	A	A
$0.067g \leq S_{D1} < 0.133g$	B	B	C
$0.133g \leq S_{D1} < 0.20g$	C	C	D
$0.20g \leq S_{D1}$	D	D	D

Table 1613.3.5(2). Seismic Design Category Based on 1-Second Period Response Accelerations

Step 3b: Determine the Seismic Design Category.

From, **Table 1613.3.5(1)**: Seismic Design Category Based on Short-Period Response Accelerations, the Seismic Design Category is D.

From, **Table 1613.3.5(2)**: Seismic Design Category Based on 1-Second Response Accelerations, the Seismic Design Category is D.

According to Section 1613.3.5, the Seismic Design Category is based on the most severe category. In this example, the seismic design category is D.

Step 4: Determine if the Cooling Tower is Exempt from IBC Seismic Requirements

Cooling towers that meet the following conditions are exempt from seismic design requirements of the IBC.

1. All towers in Seismic Design Categories A and B.
2. Towers in Seismic Design Category C provided I_p is equal to 1.0.

All other cooling towers require seismic certification per IBC.

Step 5: Determine the Location of the Cooling Tower

The elevation of the cooling tower structure within a building has an impact on the design seismic acceleration. As the installed elevation of the cooling tower increases relative to the building height, the ground seismic accelerations are amplified. This amplification is determined utilizing a ratio of the installation elevation to total building height (z/h).

It is an accepted industry practice for equipment manufacturers to state seismic qualification using the terms, “restricted” and “unrestricted”. For cooling tower installations, a restricted seismic qualification means the cooling tower is qualified for installation on grade ($z/h=0$). On the other hand, an unrestricted seismic qualification means the tower is qualified as if the unit is installed on top of a building ($z/h=1$). In other words, for projects with restricted seismic qualification, the cooling tower must be installed on the ground. With an unrestricted seismic qualification, the cooling tower can be installed in any building location, from the roof to the ground level. These will normally be expressed as an S_{DS} for a restricted ($z/h=0$) or unrestricted ($z/h=1$) application.

Step 4: Determine if the Cooling Tower is Exempt from IBC Seismic Requirement

Since the Seismic Design Category is D and the Importance Factor is 1.5, the cooling tower is not exempt from the structural requirements of the IBC.

Step 5: Determine the Location of the Cooling Tower.

Since the cooling tower will be installed on the roof of the hospital, the S_{DS} determined in Step 3a would be compared to the unrestricted ($z/h=1$) S_{DS} for the desired product.



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Step 6: Select an Independently Certified Cooling Tower - Seismic Qualification Methods & Independent Certification

As mentioned earlier, the IBC refers extensively to ASCE/SEI 7, the consensus standard published by the American Society of Civil Engineers. The seismic design requirements for nonstructural components including mechanical equipment are contained in Chapter 13 of ASCE 7 Code. Specifically Section 13.2.1 requires mechanical equipment to be qualified using one of the following methods:

- a. Analysis
- b. Testing
- c. Experience data

A summary of each method follows:

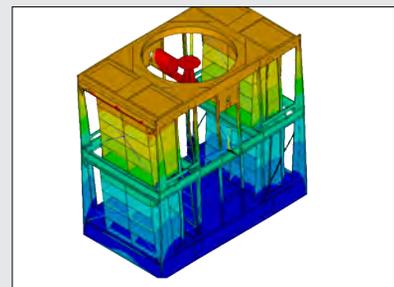
1. Analysis – A cooling tower is mathematically evaluated to determine if it can resist the code-prescribed, seismic design forces. Typically, an analysis of this type focuses on the anchorage only or on the anchorage and main structural components, depending on the component importance factor. Analysis cannot effectively address the non structural portions of a tower that affect functionality, such as the drive system, water distribution system, and heat transfer system. The analysis method is also more difficult for code bodies to review and accept/reject. It takes a great deal of time to examine the analysis and understand all the assumptions made and their validity.

2. Testing – A full-scale cooling tower is subjected to a simulated seismic event in a test laboratory. Typically, the test method is a shake-table test conducted in accordance with a code-recognized test procedure, such as the “Acceptance Criteria for Seismic Qualification by Shake Table Testing of Non-Structural Components and Systems” (AC156), published by ICC Evaluation Service (ICC ES), Inc. The standard is applicable to all types of equipment including mechanical and electrical equipment. This requires a test plan be developed for all the pre- and post-seismic test verification activities. Test results are unequivocal and much easier for a code body to review and accept/reject.

Step 6: Select the Cooling Tower

The cooling tower should have an unrestricted ($z/h=1$) S_{DS} of at least 0.385 based on an importance factor of 1.5 or higher based on shake table testing.

Since the towers need to be operational after an event, the best method to qualify the tower is independently certified shake table testing. Therefore the S_{DS} , I_p , and location of the tower should be compared to the same values in the equipment selected.



3. Experience Data – A cooling tower is qualified using actual earthquake performance data collected in accordance with a nationally recognized procedure. Though this method is used to some extent in the nuclear power industry, it is not used in commercial mechanical equipment applications due to the following limitations:

- a. Lack of a recognized data collection procedure and a national database with widespread access.
- b. Infrequency of strong motion earthquakes.
- c. Low probability of data being applicable to the current generation of products.
- d. Low probability that the actual seismic accelerations experienced by a unit in the field can be translated to current levels of seismic demand.

Based on the preceding limitations, experience data is excluded as a viable qualification method. The remaining methods are not equally suitable for verification of all aspects of cooling tower seismic performance. For example, mathematical analysis is well suited for verification of anchorage resistance, but not reliable for verification of cooling tower functionality after a seismic event. The applicability of Analysis, Testing, and Experience Data for equipment is shown in the following table:

Seismic Design Category	Ip = 1.0	Ip = 1.5
A and B	Exempt	Exempt
C	Exempt	Testing Experience Data
D, E, and F	Analysis Testing Experience Data	Testing Experience Data

Applicable Methods of Seismic Qualification for Cooling Towers



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Step 7: Recommended Specification

In light of the IBC code requirements discussed previously, BAC suggests using the following specification.

“Seismic Specification: The cooling tower unit shall be designed, tested, and certified in accordance with the 2015 IBC and ASCE/SEI 7-10. The unit shall be suitable for application with Design Spectral Acceleration at Short Period (S_{DS}) for $z/h=1.0$ up to ___g with a Component Importance Factor (I_p) of 1.0 and 1.5. The unit shall be certified by the manufacturer as functional following an earthquake. The certification shall be based on full-scale, shake table testing conducted in accordance with ICC-ES Acceptance Criteria AC156, and shall be reviewed and approved by a licensed professional engineer independent of the manufacturer. Experience data or analysis is not acceptable to verify post-earthquake functionality for $I_p = 1.5$. Units not provided with evidence of shake table testing shall not be an acceptable alternative.”

Note that the specification covers an importance factor of 1.5 and defaults to an unrestricted ($z/h=1.0$) installation. This eliminates the concern of having to determine risk category, if compliance is required, or the installation location.

> Conclusion

The IBC sets forth criteria to identify facilities that are critical for the protection of human life during and immediately following a seismic event and prescribe structural design requirements to ensure the safe and continued operation of such facilities.

Mechanical systems often serve vital functions in critical facilities such as emergency response centers, communication centers, and hospitals. Following an earthquake, the continued operation of these facilities could be dependent on the ability of the mechanical systems to remain operable. Failure of equipment to function in these applications could constitute a hazard to life.

The most reliable method to assure post-event functionality of the equipment is shake table testing in accordance with AC 156. The Series 3000, Series 1500, PT2, FXV, VCA, CXVB, PFi, and PCC have been tested in accordance with AC 156. All are certified in accordance with ASCE 7 to withstand the seismic forces prescribed for the continued operation of essential facilities.

If seismic certification is required, the engineer should be able to provide the information listed on the following page. To learn more about BAC's comprehensive seismic design and qualification approach, please contact your local BAC representative.

Step 7: Recommended Specification

Seismic Specification: The cooling tower unit shall be designed, tested, and certified in accordance with the 2015 IBC and ASCE/SEI 7-10. The unit shall be suitable for application with Design Spectral Acceleration at Short Period (S_{DS}) for $z/h=1.0$ up to 0.384g with a Component Importance Factor (I_p) of 1.5. The unit shall be certified by the manufacturer as functional following an earthquake. The certification shall be based on full-scale, shake table testing conducted in accordance with ICC-ES Acceptance Criteria AC156, and shall be reviewed and approved by a licensed professional engineer independent of the manufacturer. Experience data or analysis is not acceptable to verify post-earthquake functionality for $I_p = 1.5$. Units not provided with evidence of shake table testing shall not be an acceptable alternative.

> Attachment 1: Site Specific Seismic Requirements

Per the IBC, these variables should be provided in the project structural documents and filtered into the cooling tower specification by the engineer of record.

Requirement	
Site Location (Latitude and Longitude)	
Equipment Importance Factor (I_p)	
Seismic Design Category (A-F)	
Acceleration at Short Period (S_{DS})	
Installation elevation ratio to structure height (z/h)	
Rigid or Flexible Support (i.e. on vibration isolators)	
IBC Edition	