7. Seismic Design

Lesson Objectives:

1) Describe code based seismic design in accordance with ASCE 7-16 and IBC 2012.
2) Compute "mapped" and design spectral accelerations.
3) Categorize and identify the seismic design category and importance factors for building structures.
4) Qualitatively describe the equivalent lateral force method and identify when it is appropriate to use as well as its limitations.
5) Compute the seismic coefficient and design base shear values.
6) Quantitatively construct a site-specific response spectrum.
7) Compute and apply the vertical distribution of seismic forces.

Background Reading:

1) Read ____.

Introduction:

1) Within seismic design, the seismic load demand on a structure can be calculated via two simplistic methods.
   a. ____
   b. ____
2) For structures which have regular configurations, uniform mass, and stiffness and strength distributions, the equivalent lateral force (ELF) method is most commonly used.
   a. The focus of second half of these notes is the ELF method.
3) However, sometimes linear or nonlinear dynamic time history analysis is performed to verify a particular design.
   a. Typically done for _______ buildings, _______________ structures, and when a _________________________ is required.

Modal Analysis with the Fundamental Mode Only:

1) The basis for the equivalent lateral force method common in most building codes (including ASCE 7-16) is on both modal analysis and response spectrum analysis concepts.
2) As previously expressed, the maximum base shear contributed for a particular mode n of a structure subjected to a horizontal base excitation can be written as:

3) Sketch:

4) In this above equation:

5) In the equation _______ is based on the effective ________________________. Therefore one can define the effective ______________________________ as:

6) Recall the relationship between the ____:

7) Substitution of these two relations into the first equation, one can write an expression for the maximum base shear for the nth mode as:

8) Therefore the maximum restoring force due to the nth mode, _______________, developed within the structure can be written as:

9) Which can be rewritten as:

10) Using this equation above, the lateral ___________________ acting on each story (level i) can be expressed in terms of the story weight as:

11) Therefore it the response of a structure is dominated by its **fundamental mode**, one can estimate the maximum base shear and restoring forces induced by an earthquake as:

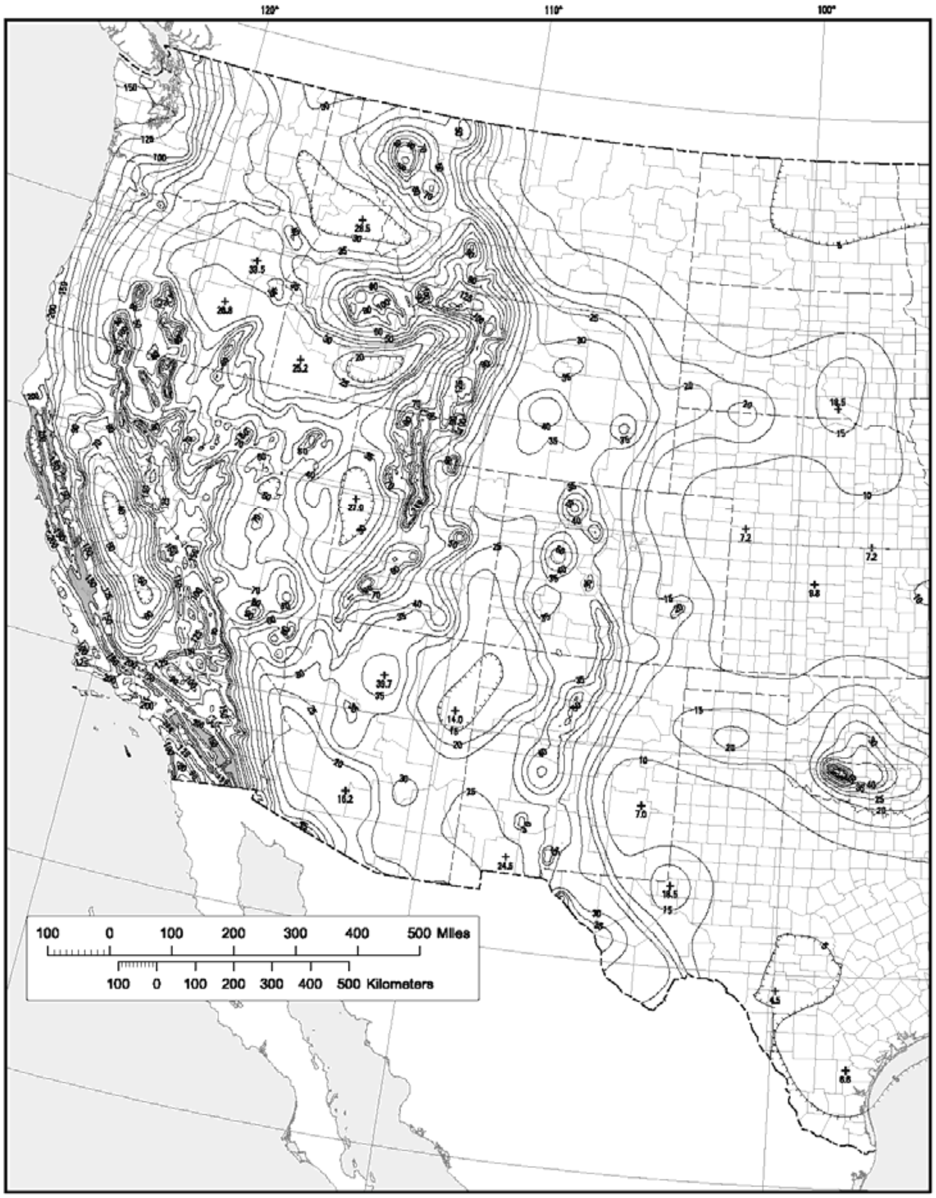
12) Let's revisit this when the seismic values are ready to be distributed to each floor.

Code Based Seismic Design Loads

1) Now let's focus on how to obtain design loads as prescribed by ASCE 7-16 and IBC 2012.
2) Note a new revision within the live loads and seismic hazard maps are incorporated into the revised version, ASCE 7-16.
   a. New to the ASCE 7-16 cycle is a new chapter on tsunami design.

Analysis Procedure – Determination of Design Accelerations:

1) The first step in the determination of the design acceleration is to determine the mapped maximum considered earthquake (MCE) spectral response values.
   a. MCE has a return period of ______________________________.
   b. This is considered a "rare event".
   c. This equates to a ______ probability of exceedance in ______ years.
2) Two "mapped" spectral values are determined, namely ___________________________.
   a. _________________ considered to the short period acceleration at ____________.
   b. _________________ considered to the long period acceleration at ____________.
3) These values can be obtained via IBC 2012 Figures 1613.1(1) through 1613.3.1(6), where a few examples are illustrated below in Figures 1-4.
4) An alternative approach to determine the mapped and design accelerations is to use the online USGS tools. Screenshots and links are available in Figures 5 and 6.
   a. Note this is a very powerful tool and can also minimally compute a design spectrum.
5) When determining the spectral accelerations, Seismic Design Category A may be permitted as an assignment if ____.
   a. This is considered as a building located in a region with a very low probability of experiencing damaging earthquake effects.



Notes:

Maps prepared by United States Geological Survey (USGS) in collaboration with the Federal Emergency Management Agency (FEMA)-funded Building Seismic Safety Council (BSSC) and the American Society of Civil Engineers (ASCE). The basis is explained in commentaries prepared by BSSC and ASCE and in the references.

Ground motion values contoured on these maps incorporate:

- a target risk of structural collapse equal to 1% in 50 years based upon a generic structural fragility
- a factor of 1.1 to adjust from a geometric mean to the maximum response regardless of direction
- deterministic upper limits imposed near large, active faults, which are taken as 1.8 times the estimated median response to the characteristic earthquake for the governing fault (1.8 is used to represent the 84th percentile response), but not less than 150% g.

As such, the values are different from those on the uniform-hazard 2014 USGS National Seismic Hazard Maps posted at: https://doi.org/10.5066/F7HT2MHG.

Larger, more detailed versions of these maps are not provided because it is recommended that the corresponding USGS web tool (https://doi.org/10.5066/F7NK3C76) be used to determine the mapped value for a specified location.

FIGURE 22-1 S_S Risk-Targeted Maximum Considered Earthquake (MCE_R) Ground Motion Parameter for the Conterminous United States for 0.2-s Spectral Response Acceleration (5% of Critical Damping)

Sources: ASCE (2010); Building Seismic Safety Council (2009); Huang, Whittaker, and Luco (2008); Luco and colleagues (2007); Peterson and colleagues (2014).

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Figure 1. Mapped maximum considered earthquake MCE spectral response acceleration at short periods for the US mainland (part one).

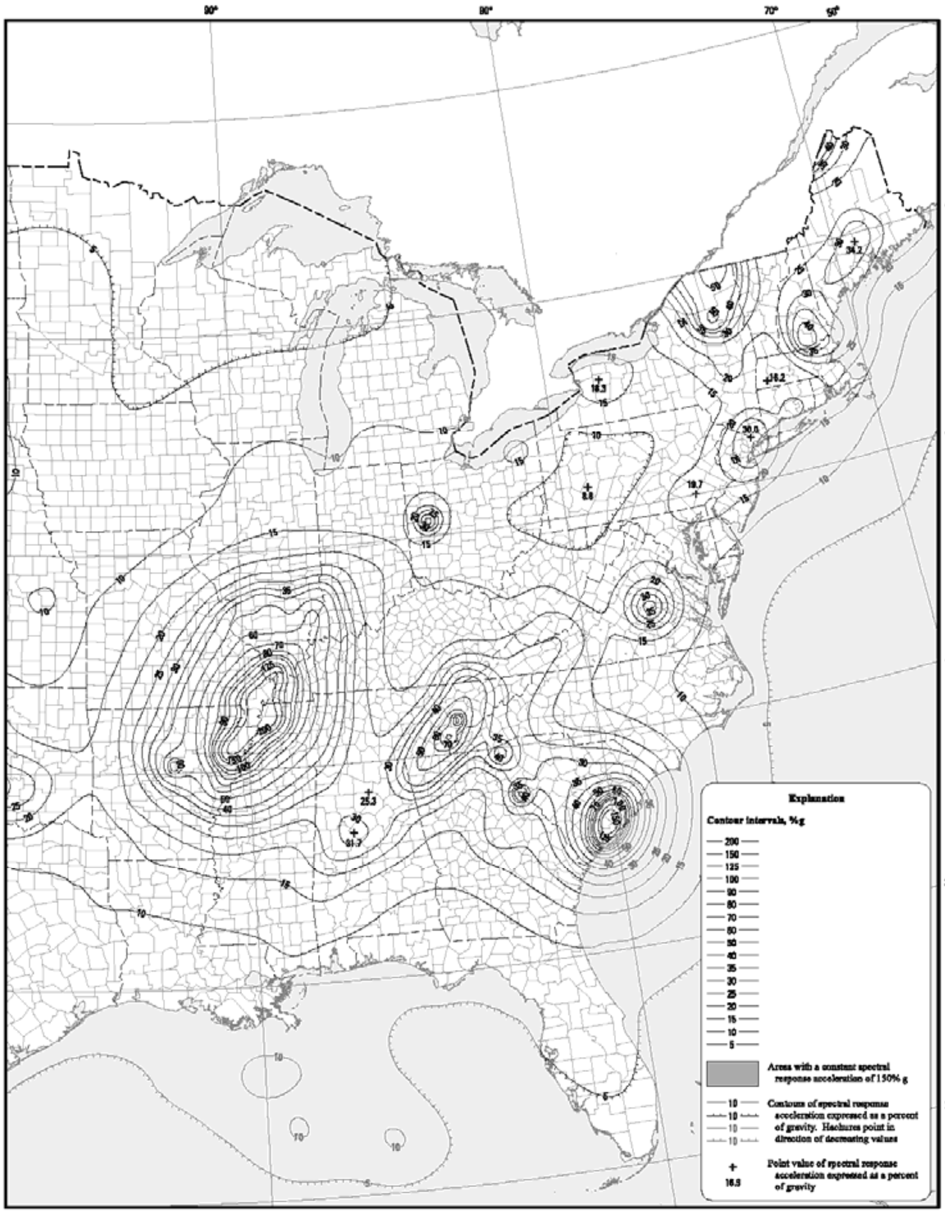
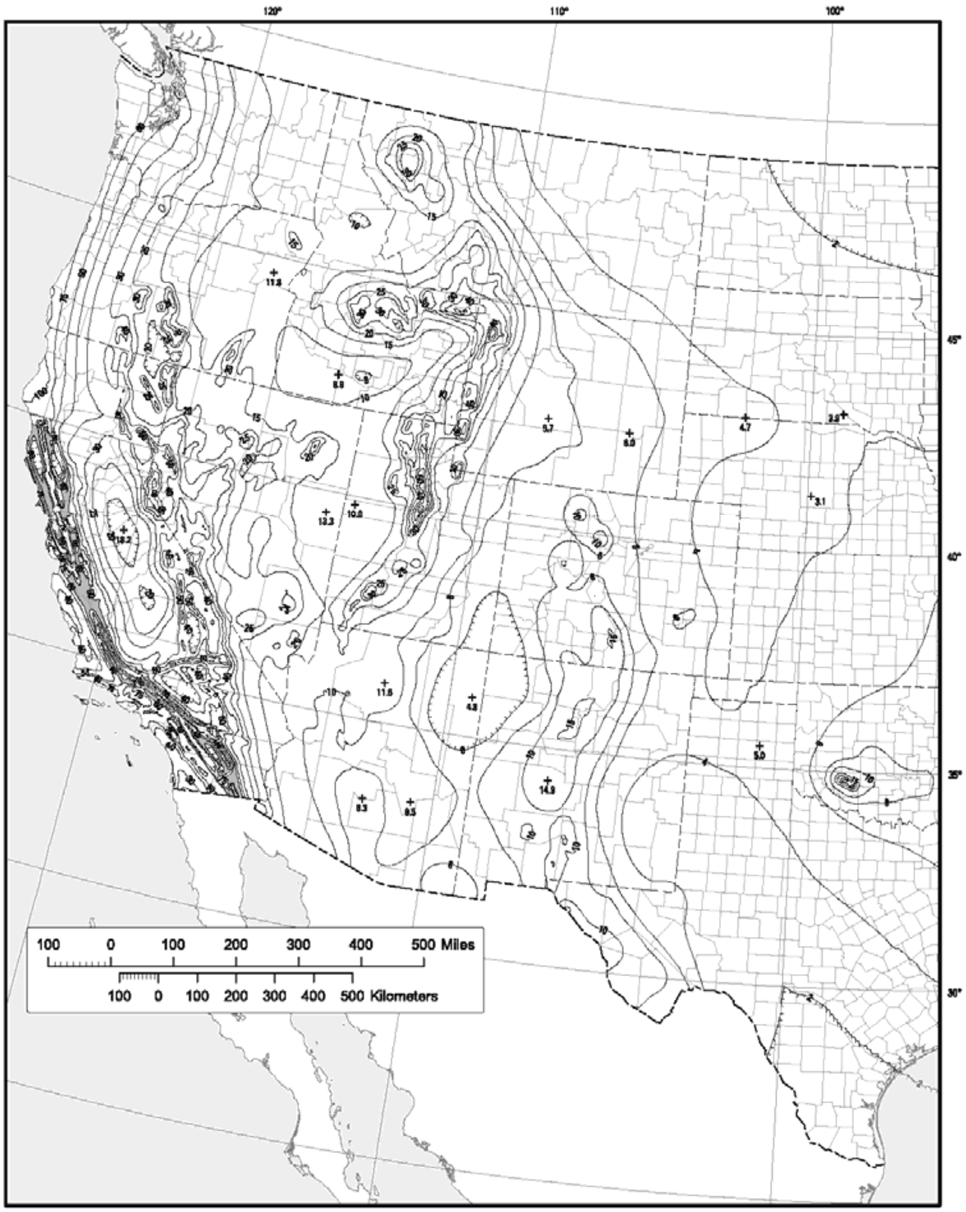


FIGURE 22-1 (*Continued*). S_S Risk-Targeted Maximum Considered Earthquake (MCE_R) Ground Motion Parameter for the Conterminous United States for 0.2-s Spectral Response Acceleration (5% of Critical Damping)

Figure 2. Mapped maximum considered earthquake MCE spectral response acceleration at short periods for the US mainland (part two).



Notes:

Maps prepared by United States Geological Survey (USGS) in collaboration with the Federal Emergency Management Agency (FEMA)-funded Building Seismic Safety Council (BSSC) and the American Society of Civil Engineers (ASCE). The basis is explained in commentaries prepared by BSSC and ASCE and in the references.

Ground motion values contoured on these maps incorporate:

- a target risk of structural collapse equal to 1% in 50 years based upon a generic structural fragility
- a factor of 1.3 to adjust from a geometric mean to the maximum response regardless of direction
- deterministic upper limits imposed near large, active faults, which are taken as 1.8 times the estimated median response to the characteristic earthquake for the governing fault (1.8 is used to represent the 84th percentile response), but not less than 60% *g*.

As such, the values are different from those on the uniform-hazard 2014 USGS National Seismic Hazard Maps posted at: https://doi.org/10.5066/F7HT2MHG.

Larger, more detailed versions of these maps are not provided because it is recommended that the corresponding USGS web tool (https://doi.org/10.5066/F7NK3C76) be used to determine the mapped value for a specified location.

FIGURE 22-2 S_1 Risk-Targeted Maximum Considered Earthquake (MCE_R) Ground Motion Parameter for the Conterminous United States for 1.0-s Spectral Response Acceleration (5% of Critical Damping)

Sources: ASCE (2010); Building Seismic Safety Council (2009); Huang, Whittaker, and Luco (2008); Luco and colleagues (2007); Peterson and colleagues (2014).

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Figure 3. Mapped maximum considered earthquake MCE spectral response acceleration at long periods for the US mainland (part one).

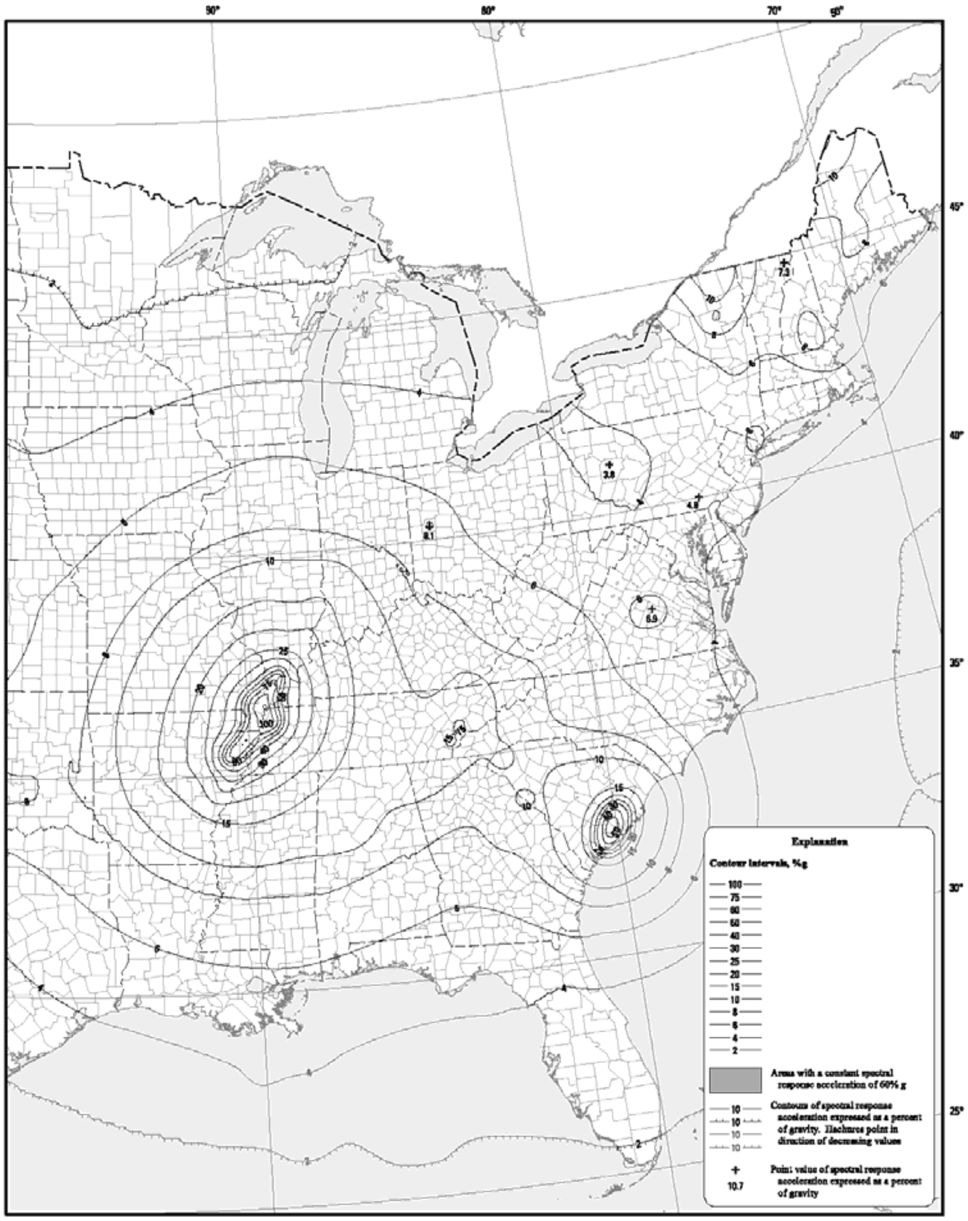

FIGURE 22-2 (*Continued*). S_1 Risk-Targeted Maximum Considered Earthquake (MCE_R) Ground Motion Parameter for the Conterminous United States for 1.0-s Spectral Response Acceleration (5% of Critical Damping)

Figure 4. Mapped maximum considered earthquake MCE spectral response acceleration at long periods for the US mainland (part two).

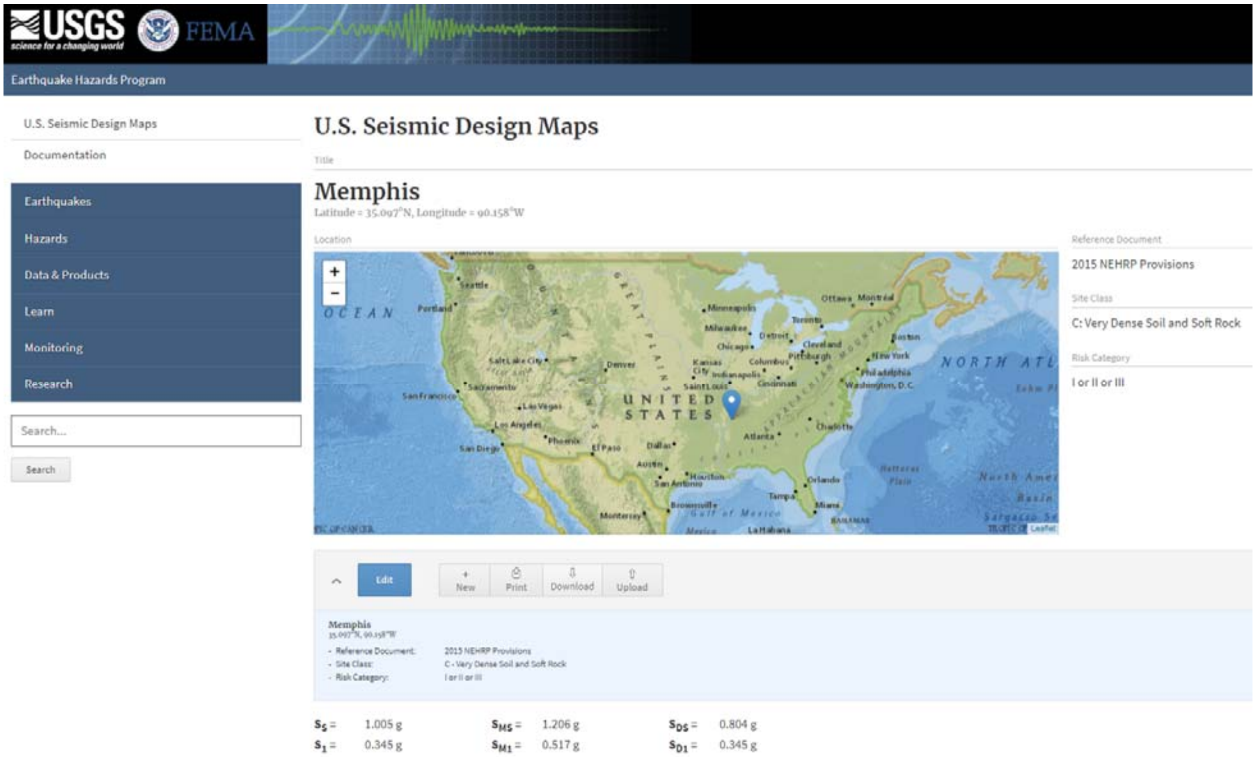

Figure 5. Online seismic design maps for US and its territories. Available at: https://earthquake.usgs.gov/designmaps/beta/us/

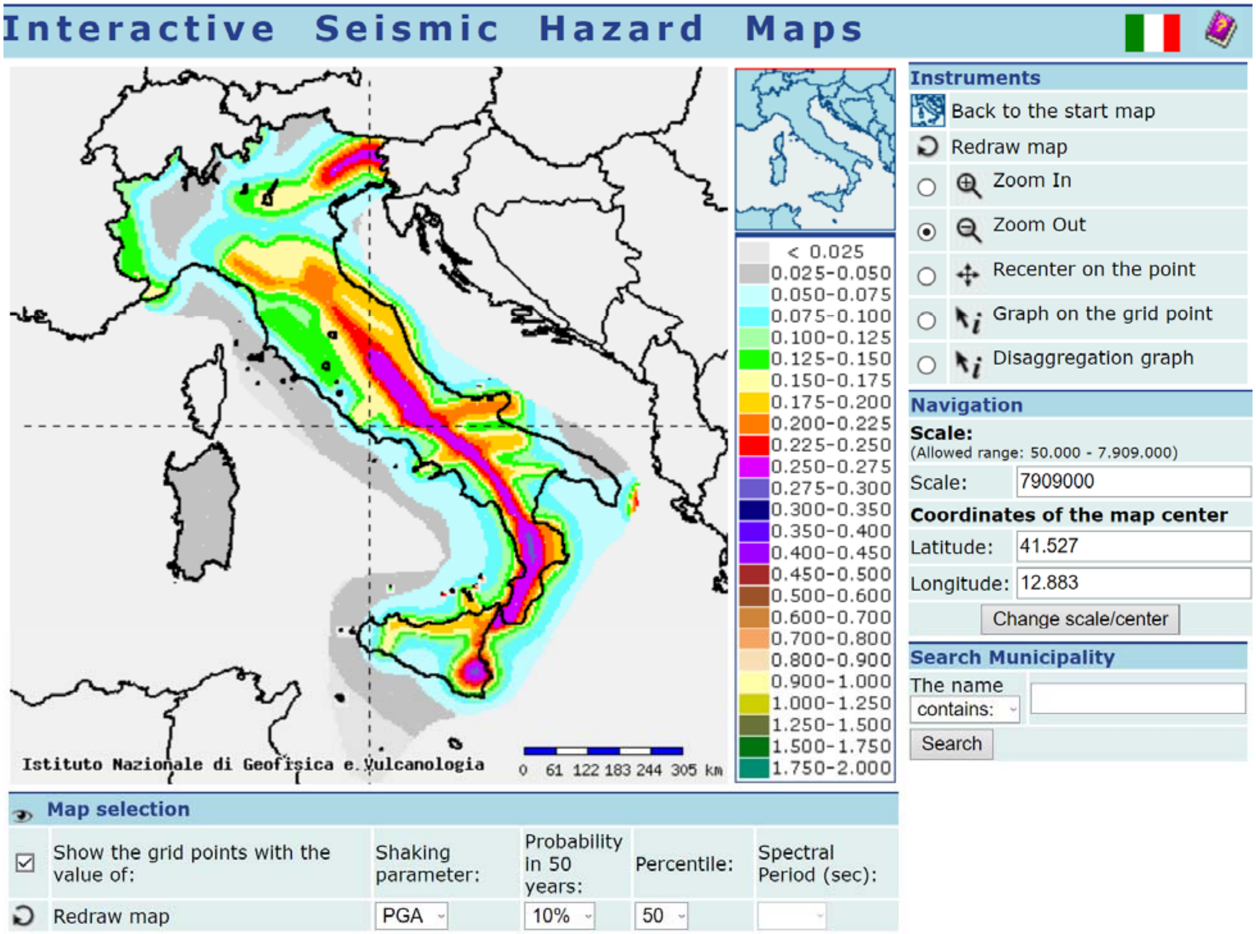

Figure 6. Example seismic design values for Italy. Other mapping tools are available for other countries. Available at: http://esse1-gis.mi.ingv.it/s1_en.php

6) After the mapped accelerations are determined, the ____________________ must be specified. The site class is based on the local soil conditions (commonly as __________) and can be classified as A-F in accordance with ASCE 7-16 Chapter 20. See Table 1.

7) A breakdown of the site classes include:

   a. ____
   b. ____
   c. ____
   d. ____
   e. ____
   f. ____

8) If the soil conditions are not known, a designer may use site _______________ (as default) unless the building officials or geotechnical data determines site class E or F is present.
9) Using the mapped accelerations and site classification, the maximum considered earthquake spectral response accelerations can be adjusted for the site class effects at the short period (________) and long period (________).

10) Note the above values correspond to a hazard represented as ________________________ ____.
11) To determine the 5% damped of critical **design spectral response accelerations**, denoted as _______________________ at short and long periods, respectively; the following equations from IBC 1613.3.4 can be utilized (using Tables 2 and 3):

12) The design earthquake event considers an approximate return period of _______________ and corresponds to a _________ probability of exceedance in _________ years.

Table 1. Site classification table obtained from ASCE 7-16.

Table 20.3-1 Site Classification

Site Class	$\bar{v}_s$	$\bar{N}$ or $\bar{N}_{ch}$	$\bar{s}_u$
A. Hard rock	>5,000 ft/s	NA	NA
B. Rock	2,500 to 5,000 ft/s	NA	NA
C. Very dense soil and soft rock	1,200 to 2,500 ft/s	>50 blows/ft	>2,000 lb/ft^2
D. Stiff soil	600 to 1,200 ft/s	15 to 50 blows/ft	1,000 to 2,000 lb/ft^2
E. Soft clay soil	<600 ft/s	<15 blows/ft	<1,000 lb/ft^2
	Any profile with more than 10 ft of soil that has the following characteristics: — Plasticity index $PI > 20$, — Moisture content $w \geq 40\%$, — Undrained shear strength $\bar{s}_u < 500$ lb/ft^2		
F. Soils requiring site response analysis in accordance with Section 21.1	See Section 20.3.1		

Note: For SI: 1 ft = 0.3048 m; 1 ft/s = 0.3048 m/s; 1 lb/ft^2 = 0.0479 kN/m^2.

Table 2. Short period site coefficient table obtained from IBC 2012.

TABLE 1613.3.3(1)
VALUES OF SITE COEFFICIENT F_a [a]

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

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

Table 3. Long period site coefficient table obtained from IBC 2012.

TABLE 1613.3.3(2)
VALUES OF SITE COEFFICIENT F_V [a]

SITE CLASS	MAPPED SPECTRAL RESPONSE ACCELERATION AT 1-SECOND PERIOD				
	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \geq 0.5$
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

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

Analysis Procedure –Seismic Design Category and Importance Factor:

1) The risk associated with each use of buildings and other structures is not constant.
    a. For example: one-story residential house versus a nuclear power facility.
    b. Various risk categories are defined in IBC Table 1604.5 and
    c. These can be found in ASCE 7-16 Table 1604.5 or similarly in FEMA P-749 Chapter 5 Table 3.
    d. Refer to Tables 4 and 5.
2) To account for the associated risks, Importance factors, _____, are introduced and can be found in ASCE 7-16 Table 1.5-2. Refer to Table 6.
3) Seismic design categories (___________) can be assigned and determined as a function of the “mapped” spectral accelerations and the risk category.
4) Definitions of seismic design categories is shown in Table 7. These definitions are obtained from FEMA P-749, but are very close to the brief descriptions in ASCE/IBC procedures.
5) The seismic design category will govern which analytical procedures are appropriate.

Table 4. Risk classification of representative buildings obtained from ASCE 7-16.

Table 1.5-1 Risk Category of Buildings and Other Structures for Flood, Wind, Snow, Earthquake, and Ice Loads

Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life	III
Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure	
Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where the quantity of the material exceeds a threshold quantity established by the Authority Having Jurisdiction and is sufficient to pose a threat to the public if released[a]	
Buildings and other structures designated as essential facilities	IV
Buildings and other structures, the failure of which could pose a substantial hazard to the community	
Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity of the material exceeds a threshold quantity established by the Authority Having Jurisdiction and is sufficient to pose a threat to the public if released[a]	
Buildings and other structures required to maintain the functionality of other Risk Category IV structures	

[a]Buildings and other structures containing toxic, highly toxic, or explosive substances shall be eligible for classification to a lower Risk Category if it can be demonstrated to the satisfaction of the Authority Having Jurisdiction by a hazard assessment as described in Section 1.5.3 that a release of the substances is commensurate with the risk associated with that Risk Category.

Table 5. Occupancy classifications for representative buildings obtained from FEMA P-749.

Table 3 Occupancy

Category	Representative Buildings	Acceptable Risk
I	Buildings and structures that normally are not subject to human occupancy (e.g., equipment storage sheds, barns, and other agricultural buildings) and that do not contain equipment or systems necessary for disaster response or hazardous materials.	Low probability of earthquake-induced collapse.
II	Most buildings and structures of ordinary occupancy (e.g., residential, commercial, and industrial buildings) except those buildings contained in other categories.	Low probability of earthquake-induced collapse. Limited probability that shaking-imposed damage to nonstructural components will pose a significant risk to building occupants.
III	Buildings and structures that: • Have large numbers of occupants (e.g., high-rise office buildings, sports arenas, and large theaters), • Shelter persons with limited mobility (e.g., jails, schools, and some healthcare facilities); • Support lifelines and utilities important to a community's welfare; or • Contain materials that pose some risk to the public if released.	Reduced risk of earthquake-induced collapse relative to Occupancy Category II structures. Reduced risk of shaking-imposed damage to nonstructural components relative to Occupancy Category II structures. Low risk of release of hazardous materials or loss of function of critical lifelines and utilities.
IV	Buildings and structures that: • Are essential to post-earthquake response (e.g., hospitals, police stations, fire stations, and emergency communications centers) or • House very large quantities of hazardous materials.	Very low risk of earthquake induced-collapse. Low risk that the building or structure will be damaged sufficiently to impair use in post-earthquake response and recovery efforts. Very low risk of release of hazardous materials.

Table 6. Importance factors obtained from ASCE 7-16.

Table 1.5-2 Importance Factors by Risk Category of Buildings and Other Structures for Snow, Ice, and Earthquake Loads

Risk Category from Table 1.5-1	Snow Importance Factor, I_s	Ice Importance Factor—Thickness, I_i	Ice Importance Factor—Wind, I_w	Seismic Importance Factor, I_e
I	0.80	0.80	1.00	1.00
II	1.00	1.00	1.00	1.00
III	1.10	1.15	1.00	1.25
IV	1.20	1.25	1.00	1.50

Note: The component importance factor, I_p, applicable to earthquake loads, is not included in this table because it depends on the importance of the individual component rather than that of the building as a whole, or its occupancy. Refer to Section 13.1.3.

Table 7. Seismic design category obtained from FEMA P-749.

Table 2 Seismic Design Categories, Risk, and Seismic Design Criteria

SDC	Building Type and Expected MMI	Seismic Criteria
A	Buildings located in regions having a very small probability of experiencing damaging earthquake effects	No specific seismic design requirements but structures are required to have complete lateral-force-resisting systems and to meet basic structural integrity criteria.
B	Structures of ordinary occupancy that could experience moderate (MMI VI) intensity shaking	Structures must be designed to resist seismic forces.
C	Structures of ordinary occupancy that could experience strong (MMI VII) and important structures that could experience moderate (MMI VI) shaking	Structures must be designed to resist seismic forces. Critical nonstructural components must be provided with seismic restraint.
D	Structures of ordinary occupancy that could experience very strong shaking (MMI VIII) and important structures that could experience MMI VII shaking	Structures must be designed to resist seismic forces. Only structural systems capable of providing good performance are permitted. Nonstructural components that could cause injury must be provided with seismic restraint. Nonstructural systems required for life safety protection must be demonstrated to be capable of post-earthquake functionality. Special construction quality assurance measures are required.
E	Structures of ordinary occupancy located within a few kilometers of major active faults capable of producing MMI IX or more intense shaking	Structures must be designed to resist seismic forces. Only structural systems that are capable of providing superior performance permitted. Many types of irregularities are prohibited. Nonstructural components that could cause injury must be provided with seismic restraint. Nonstructural systems required for life safety protection must be demonstrated to be capable of post-earthquake functionality. Special construction quality assurance measures are required.
F	Critically important structures located within a few kilometers of major active faults capable of producing MMI IX or more intense shaking	Structures must be designed to resist seismic forces. Only structural systems capable of providing superior performance permitted are permitted. Many types of irregularities are prohibited. Nonstructural components that could cause injury must be provided with seismic restraint. Nonstructural systems required for facility function must be demonstrated to be capable of post-earthquake functionality. Special construction quality assurance measures are required.

Table 8. Seismic design category based on the short period response accelerations.

TABLE 1613.3.5(1)
SEISMIC DESIGN CATEGORY BASED ON SHORT-PERIOD (0.2 second) RESPONSE ACCELERATIONS

VALUE OF S_{DS}	RISK CATEGORY		
	I or II	III	IV
$S_{DS} < 0.167g$	A	A	A
$0.167g \le S_{DS} < 0.33g$	B	B	C
$0.33g \le S_{DS} < 0.50g$	C	C	D
$0.50g \le S_{DS}$	D	D	D

Table 9. Seismic design category based on the long period response accelerations.

TABLE 1613.3.5(2)
SEISMIC DESIGN CATEGORY BASED ON 1-SECOND PERIOD RESPONSE ACCELERATION

VALUE OF S_{D1}	RISK CATEGORY		
	I or II	III	IV
$S_{D1} < 0.067g$	A	A	A
$0.067g \le S_{D1} < 0.133g$	B	B	C
$0.133g \le S_{D1} < 0.20g$	C	C	D
$0.20g \le S_{D1}$	D	D	D

Analysis Procedure –Computation of Seismic Base Shear:

1) As mentioned in the previous section, the seismic design category will control on which analytical methods are appropriate.
2) Illustrated in ASCE Table 12.6-1 (Table 10).
3) Specified vertical and horizontal irregularities within this table can be found in ASCE Tables 12.3-1 and 12.3-2 (Tables 11 and 12).
4) One of the common methods (equivalent lateral force) will be detailed in the next section.

Table 10. Appropriate analytical procedure by seismic design category and structural characteristics. (Obtained from ASCE 7-16).

Table 12.6-1 Permitted Analytical Procedures

Seismic Design Category	Structural Characteristics	Equivalent Lateral Force Procedure, Section 12.8[a]	Modal Response Spectrum Analysis, Section 12.9.1, or Linear Response History Analysis, Section 12.9.2[a]	Nonlinear Response History Procedures, Chapter 16[a]
B, C	All structures	P	P	P
D, E, F	Risk Category I or II buildings not exceeding two stories above the base	P	P	P
	Structures of light-frame construction	P	P	P
	Structures with no structural irregularities and not exceeding 160 ft (48.8 m) in structural height	P	P	P
	Structures exceeding 160 ft (48.8 m) in structural height with no structural irregularities and with $T < 3.5T_s$	P	P	P
	Structures not exceeding 160 ft (48.8 m) in structural height and having only horizontal irregularities of Type 2, 3, 4, or 5 in Table 12.3-1 or vertical irregularities of Type 4, 5a, or 5b in Table 12.3-2	P	P	P
	All other structures	NP	P	P

[a]P: Permitted; NP: Not Permitted; $T_s = S_{D1}/S_{DS}$.

Table 11. Horizontal irregularities obtained from ASCE 7-16.

Table 12.3-1 Horizontal Structural Irregularities

Type	Description	Reference Section	Seismic Design Category Application
1a.	**Torsional Irregularity:** Torsional irregularity is defined to exist where the maximum story drift, computed including accidental torsion with $A_x = 1.0$, at one end of the structure transverse to an axis is more than 1.2 times the average of the story drifts at the two ends of the structure. Torsional irregularity requirements in the reference sections apply only to structures in which the diaphragms are rigid or semirigid.	12.3.3.4 12.7.3 12.8.4.3 12.12.1 Table 12.6-1 16.3.4	D, E, and F B, C, D, E, and F C, D, E, and F C, D, E, and F D, E, and F B, C, D, E, and F
1b.	**Extreme Torsional Irregularity:** Extreme torsional irregularity is defined to exist where the maximum story drift, computed including accidental torsion with $A_x = 1.0$, at one end of the structure transverse to an axis is more than 1.4 times the average of the story drifts at the two ends of the structure. Extreme torsional irregularity requirements in the reference sections apply only to structures in which the diaphragms are rigid or semirigid.	12.3.3.1 12.3.3.4 12.3.4.2 12.7.3 12.8.4.3 12.12.1 Table 12.6-1 16.3.4	E and F D D B, C, and D C and D C and D D B, C, and D
2.	**Reentrant Corner Irregularity:** Reentrant corner irregularity is defined to exist where both plan projections of the structure beyond a reentrant corner are greater than 15% of the plan dimension of the structure in the given direction.	12.3.3.4 Table 12.6-1	D, E, and F D, E, and F
3.	**Diaphragm Discontinuity Irregularity:** Diaphragm discontinuity irregularity is defined to exist where there is a diaphragm with an abrupt discontinuity or variation in stiffness, including one that has a cutout or open area greater than 50% of the gross enclosed diaphragm area, or a change in effective diaphragm stiffness of more than 50% from one story to the next.	12.3.3.4 Table 12.6-1	D, E, and F D, E, and F
4.	**Out-of-Plane Offset Irregularity:** Out-of-plane offset irregularity is defined to exist where there is a discontinuity in a lateral force-resistance path, such as an out-of-plane offset of at least one of the vertical elements.	12.3.3.3 12.3.3.4 12.7.3 Table 12.6-1 16.3.4	B, C, D, E, and F D, E, and F B, C, D, E, and F D, E, and F B, C, D, E, and F
5.	**Nonparallel System Irregularity:** Nonparallel system irregularity is defined to exist where vertical lateral force-resisting elements are not parallel to the major orthogonal axes of the seismic force-resisting system.	12.5.3 12.7.3 Table 12.6-1 16.3.4	C, D, E, and F B, C, D, E, and F D, E, and F B, C, D, E, and F

Table 12. Vertical irregularities obtained from ASCE 7-16.

Table 12.3-2 Vertical Structural Irregularities

Type	Description	Reference Section	Seismic Design Category Application
1a.	**Stiffness–Soft Story Irregularity:** Stiffness–soft story irregularity is defined to exist where there is a story in which the lateral stiffness is less than 70% of that in the story above or less than 80% of the average stiffness of the three stories above.	Table 12.6-1	D, E, and F
1b.	**Stiffness–Extreme Soft Story Irregularity:** Stiffness–extreme soft story irregularity is defined to exist where there is a story in which the lateral stiffness is less than 60% of that in the story above or less than 70% of the average stiffness of the three stories above.	12.3.3.1 Table 12.6-1	E and F D, E, and F
2.	**Weight (Mass) Irregularity:** Weight (mass) irregularity is defined to exist where the effective mass of any story is more than 150% of the effective mass of an adjacent story. A roof that is lighter than the floor below need not be considered.	Table 12.6-1	D, E, and F
3.	**Vertical Geometric Irregularity:** Vertical geometric irregularity is defined to exist where the horizontal dimension of the seismic force-resisting system in any story is more than 130% of that in an adjacent story.	Table 12.6-1	D, E, and F
4.	**In-Plane Discontinuity in Vertical Lateral Force-Resisting Element Irregularity:** In-plane discontinuity in vertical lateral force-resisting element irregularity is defined to exist where there is an in-plane offset of a vertical seismic force-resisting element resulting in overturning demands on supporting structural elements.	12.3.3.3 12.3.3.4 Table 12.6-1	B, C, D, E, and F D, E, and F D, E, and F
5a.	**Discontinuity in Lateral Strength–Weak Story Irregularity:** Discontinuity in lateral strength–weak story irregularity is defined to exist where the story lateral strength is less than 80% of that in the story above. The story lateral strength is the total lateral strength of all seismic-resisting elements sharing the story shear for the direction under consideration.	12.3.3.1 Table 12.6-1	E and F D, E, and F
5b.	**Discontinuity in Lateral Strength–Extreme Weak Story Irregularity:** Discontinuity in lateral strength–extreme weak story irregularity is defined to exist where the story lateral strength is less than 65% of that in the story above. The story strength is the total strength of all seismic-resisting elements sharing the story shear for the direction under consideration.	12.3.3.1 12.3.3.2 Table 12.6-1	D, E, and F B and C D, E, and F

Analysis Procedure – Equivalent Lateral Force Analysis:

1) In IBC and ASCE design guidelines, an equivalent lateral force procedure can be utilized in design in lieu of dynamic analysis.
2) As outlined previously in these notes, this is based on the response spectrum concept.
3) The general equation for seismic base shear in a given direction can be expressed as:

4) This equation is similar to that under point 11 of Modal Analysis with the Fundamental Mode only.
    a. This represents the pseudo-acceleration response spectrum for 5% damped, as shown in Figure 7.

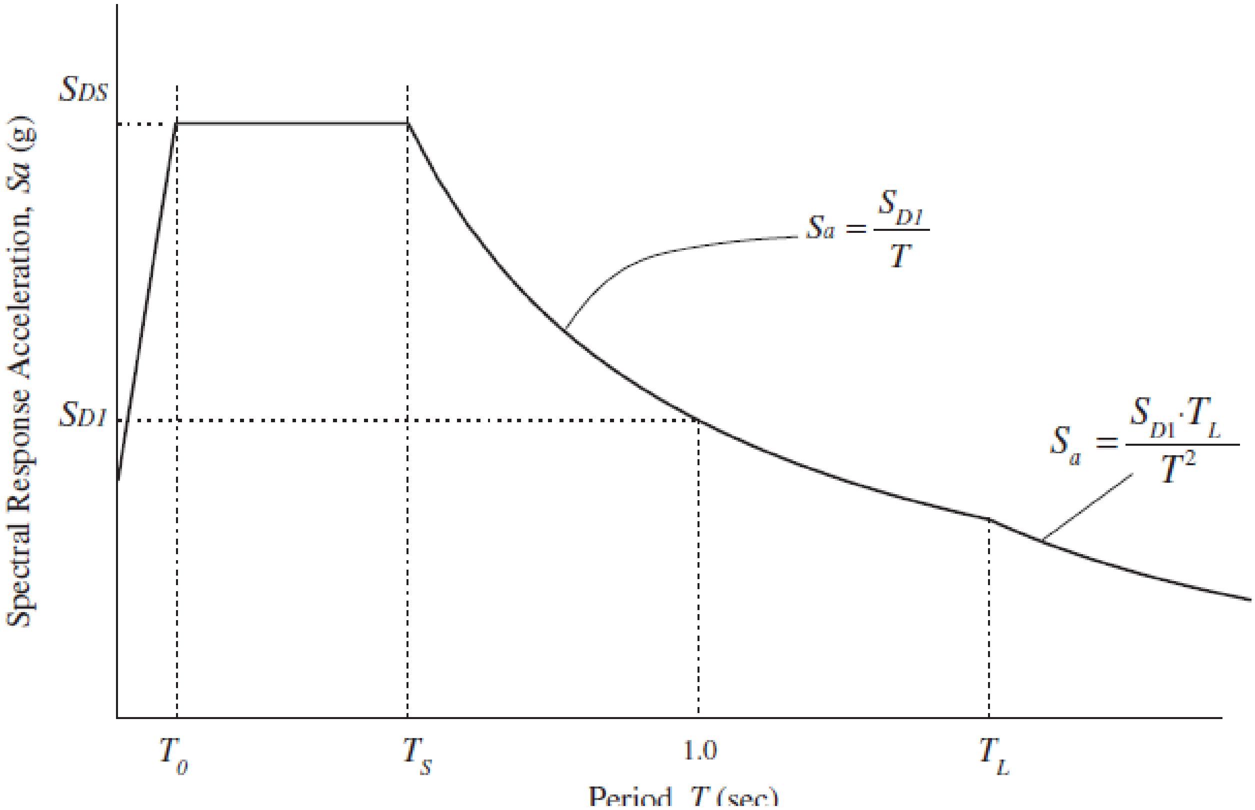

Figure 7. Design response spectra obtained from ASCE 7016.

5) The weight in this equation, W, is the effective seismic weight.
   a. Instead of having the effective modal weight for the fundamental mode, as done in modal analysis, the total weight of the structure is used.
   b. Why?
   c. This is meant to compensate for the ________________________ ignored in the equation in a "conservative way".
   d. Is this always effective? ____
6) In the calculation of the seismic weight, this should include the dead load above the base and other loads above the base as appropriate.
   a. This includes stipulates that for areas used for storage, a minimum of 25% of the floor live load shall be included.
      i. This is not needed if the inclusion of storage loads add no more than 5% to

the effective seismic weight at the level.

b. Floor live loads in public garages and open parking structures does not need to be included.

7) Where partitions are required in the floor load design, the actual weight of the partitions or a minimum weight as specified in the code is needed, whichever is greater.
8) This also includes the operating weight of any permanently installed equipment.
9) The above equation for the seismic response coefficient, it should be less than the following cases:

10) In the above equations, a response modification coefficient, R, is to account for the _______________________ of a structure.
    a. As described in earlier sections of notes, a more ductile structure has a higher value of R.
    b. However it is not exactly equal to the ductility capacity, but it also takes into consideration of the expected overstrength in a structure.
    c. The values of R for different types of structures are provided in ASCE 7-16 Table 12.14-1 (shown here as Table 13).
    d. Historically these values were set on empirical evidence and experience.
    e. However these values can be determined for systems and new structural systems using the systematic approach within FEMA P695. This approach has a target probability of collapse of a structure under a maximum considered earthquake (MCE) is not greater than 10%. This procedure requires extensive nonlinear time history analysis to compute these coefficients.
11) Another variable specified in the equations above is the fundamental period of a structure, T.
12) A period value is required to compute the base shear and the distributed lateral forces (to be described shortly). These values can be obtained using a structural model or through an approximate equation.
13) One equation for an approximate value of the period is given below:

14) These constants can be obtained determined from Table 12.8-2 in ASCE 7-16 or shown here in Table 14.

15) Note that the calculated approximate fundamental period in the above equations cannot exceed the product of the coefficient (C_u) in Table 12.8-1 of ASCE 7-16 times the approximate fundamental period, T_a.
16) As a general rule of thumb for the anticipated ________________________, for a moment resisting frame that that does not exceed twelve stories with a minimum story height of 9 feet, an approximate period can be estimated as:

17) Where in the equation above, N is the number of stories above the base.
    a. This is a similar quantity provided in Structural Dynamics and in discussions.
    b. Note concrete and steel buildings are expected to behave differently!

Table 13. Response modification coefficients obtained from ASCE 7-16.

Table 12.14-1 Design Coefficients and Factors for Seismic Force-Resisting Systems for Simplified Design Procedure

Seismic Force-Resisting System	ASCE 7 Section Where Detailing Requirements Are Specified	Response Modification Coefficient, R^a	Limitations[b] Seismic Design Category B	C	D, E
A. BEARING WALL SYSTEMS					
1. Special reinforced concrete shear walls	14.2	5	P	P	P
2. Ordinary reinforced concrete shear walls	14.2	4	P	P	NP
3. Detailed plain concrete shear walls	14.2	2	P	NP	NP
4. Ordinary plain concrete shear walls	14.2	1½	P	NP	NP
5. Intermediate precast shear walls	14.2	4	P	P	40[c]
6. Ordinary precast shear walls	14.2	3	P	NP	NP
7. Special reinforced masonry shear walls	14.4	5	P	P	P
8. Intermediate reinforced masonry shear walls	14.4	3½	P	P	NP
9. Ordinary reinforced masonry shear walls	14.4	2	P	NP	NP
10. Detailed plain masonry shear walls	14.4	2	P	NP	NP
11. Ordinary plain masonry shear walls	14.4	1½	P	NP	NP
12. Prestressed masonry shear walls	14.4	1½	P	NP	NP
13. Light-frame (wood) walls sheathed with wood structural panels rated for shear resistance	14.5	6½	P	P	P
14. Light-frame (cold-formed steel) walls sheathed with wood structural panels rated for shear resistance or steel sheets	14.1	6½	P	P	P
15. Light-frame walls with shear panels of all other materials	14.1 and 14.5	2	P	P	NP[d]
16. Light-frame (cold-formed steel) wall systems using flat strap bracing	14.1	4	P	P	P
B. BUILDING FRAME SYSTEMS					
1. Steel eccentrically braced frames	14.1	8	P	P	P
2. Steel special concentrically braced frames	14.1	6	P	P	P
3. Steel ordinary concentrically braced frames	14.1	3¼	P	P	P
4. Special reinforced concrete shear walls	14.2	6	P	P	P
5. Ordinary reinforced concrete shear walls	14.2	5	P	P	NP
6. Detailed plain concrete shear walls	14.2 and 14.2.2.7	2	P	NP	NP
7. Ordinary plain concrete shear walls	14.2	1½	P	NP	NP
8. Intermediate precast shear walls	14.2	5	P	P	40[c]
9. Ordinary precast shear walls	14.2	4	P	NP	NP
10. Steel and concrete composite eccentrically braced frames	14.3	8	P	P	P
11. Steel and concrete composite special concentrically braced frames	14.3	5	P	P	P
12. Steel and concrete composite ordinary braced frames	14.3	3	P	P	NP
13. Steel and concrete composite plate shear walls	14.3	6½	P	P	P
14. Steel and concrete composite special shear walls	14.3	6	P	P	P
15. Steel and concrete composite ordinary shear walls	14.3	5	P	P	NP
16. Special reinforced masonry shear walls	14.4	5½	P	P	P
17. Intermediate reinforced masonry shear walls	14.4	4	P	P	NP
18. Ordinary reinforced masonry shear walls	14.4	2	P	NP	NP
19. Detailed plain masonry shear walls	14.4	2	P	NP	NP
20. Ordinary plain masonry shear walls	14.4	1½	P	NP	NP
21. Prestressed masonry shear walls	14.4	1½	P	NP	NP
22. Light-frame (wood) walls sheathed with wood structural panels rated for shear resistance	14.5	7	P	P	P
23. Light-frame (cold-formed steel) walls sheathed with wood structural panels rated for shear resistance or steel sheets	14.1	7	P	P	P
24. Light-frame walls with shear panels of all other materials	14.1 and 14.5	2½	P	P	NP[d]
25. Steel buckling-restrained braced frames	14.1	8	P	P	P
26. Steel special plate shear walls	14.1	7	P	P	P

[a]Response modification coefficient, R, for use throughout the standard.
[b]P = permitted; NP = not permitted.
[c]Light-frame walls with shear panels of all other materials are not permitted in Seismic Design Category E.
[d]Light-frame walls with shear panels of all other materials are permitted up to 35 ft (10.6 m) in structural height, h_n, in Seismic Design Category D and are not permitted in Seismic Design Category E.

Table 14. Approximate structural periods (fundamental mode) obtained from ASCE 7-16.

Table 12.8-2 Values of Approximate Period Parameters C_t and x

Structure Type	C_t	x
Moment-resisting frame systems in which the frames resist 100% of the required seismic force and are not enclosed or adjoined by components that are more rigid and will prevent the frames from deflecting where subjected to seismic forces:		
Steel moment-resisting frames	0.028 (0.0724)[a]	0.8
Concrete moment-resisting frames	0.016 (0.0466)[a]	0.9
Steel eccentrically braced frames in accordance with Table 12.2-1 lines B1 or D1	0.03 (0.0731)[a]	0.75
Steel buckling-restrained braced frames	0.03 (0.0731)[a]	0.75
All other structural systems	0.02 (0.0488)[a]	0.75

[a]Metric equivalents are shown in parentheses.

Table 15. Coefficient for the upper limit on the calculated period obtained from ASCE 7-16.

Table 12.8-1 Coefficient for Upper Limit on Calculated Period

Design Spectral Response Acceleration Parameter at 1 s, S_{D1}	Coefficient C_u
≥ 0.4	1.4
0.3	1.4
0.2	1.5
0.15	1.6
≤ 0.1	1.7

Equivalent Lateral Force Analysis: - Vertical Distribution of Seismic Force:

1) Once the design base shear, V, has been determine, the vertical distribution of later forces can be given by the following equations:

2) Parameter of ________ is the height from the base to level i.
3) Parameter of ________ is equal to unity ("1") for T = 0.5 seconds or less, is equal to 2 for T = 2.0 seconds or more; else between 0.5 and 2.5 seconds is taken as 2 or determined by linear interpolation.
4) In the above equation is once again related to the modal analysis. Refer to point 11 of Modal Analysis with the Fundamental Mode only within this section of notes.
5) The ______ denotes the mode shape.
    a. The exponent _____ is used to account for the higher-mode effects.
    b. In general, the higher mode effects are more ________________________ for a structure with a longer fundamental period.
    c. For structures with a ___________________fundamental period, it is implied that the higher-mode effects are not important since k = 1 and the corresponding mode shape is _____________________.

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