Seismic Loads Based on IBC 2015/ASCE 7-10

Based on Section 1613.1 of IBC 2015, **"**Every structure, and portion thereof, including nonstructural components that are permanently attached to structures and their supports and attachments, shall be designed and constructed to resist the effects of earthquake motions in accordance with ASCE 7, excluding Chapter 14 and Appendix 11A. The *seismic design category* for a structure is permitted to be determined in accordance with Section 1613 or ASCE 7".

Exceptions:

1. Detached one- and two-family dwellings, assigned to *Seismic Design Category* A, B or C, or located where the mapped short-period spectral response acceleration, S_S, is less than 0.4 g.

2. Agricultural storage structures intended only for incidental human occupancy.

3. Structures that require special consideration of their response characteristics and environment that are not addressed by this code or ASCE 7 and for which other regulations provide seismic criteria, such as vehicular bridges, electrical transmission towers, hydraulic structures, buried utility lines and their

IBC 2015 Safety Concept

IBC 2015 intends to design structures for "collapse prevention" in the event of an earthquake with a 2 % probability of being exceeded in 50 years

Introduction

Seismic Response Spectra:

- A response spectrum provides the maximum response of a Single Degree Of Freedom (SDOF) system, for a given damping ratio and a range of periods, for a specific earthquake.
- A design response spectrum is a smoothed spectrum used to calculate the expected seismic response of a structure

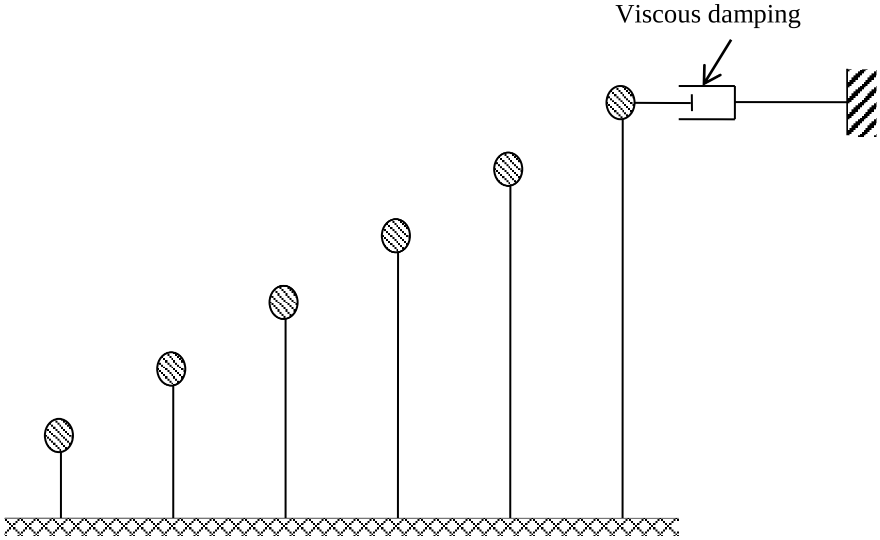
Figure (1) shows six inverted, damped pendulums, each of which has a different fundamental period of vibration. To derive a point on a response spectrum, one of these pendulum structures is analytically subjected to the vibrations recorded during a particular earthquake. The largest acceleration of this pendulum structure during the entire record of a particular earthquake can be plotted as shown in Figure 1(b). Repeating this for each of the other pendulum structures shown in Figure 1(a) and plotting and connecting the peak values for each of the pendulum structures produces an acceleration response spectrum.

Generally, the vertical axis of the spectrum is normalized by expressing the computed accelerations in terms of the acceleration due to gravity g.

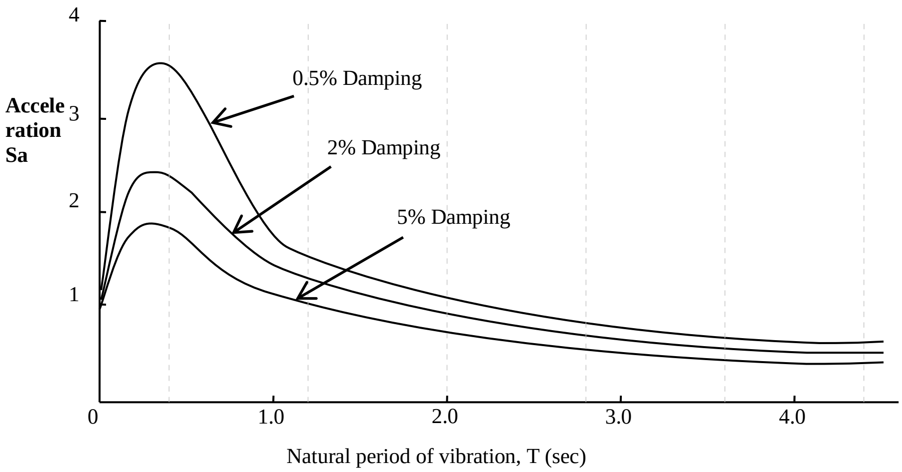
In Figure (2), displacement, velocity, and acceleration spectra for a given earthquake are shown. In this figure, structures with short periods of 0.2 to 0.5 seconds are almost rigid and are most affected by ground accelerations. Structures with medium periods ranging from 0.5 to 2.5 seconds are affected most by velocities. Structures with long periods greater than 2.5 seconds, such as tall buildings or long span bridges, are most affected by displacements.

Reference:

Wight, J. and MacGregor, J "Reinforced Concrete Mechanics and Design" 6th Edition, Pearson, NJ, 2012.



(a) Damped pendulums of varying natural frequencies



(b) Acceleration response spectrum

Figure (1): Earthquake Response

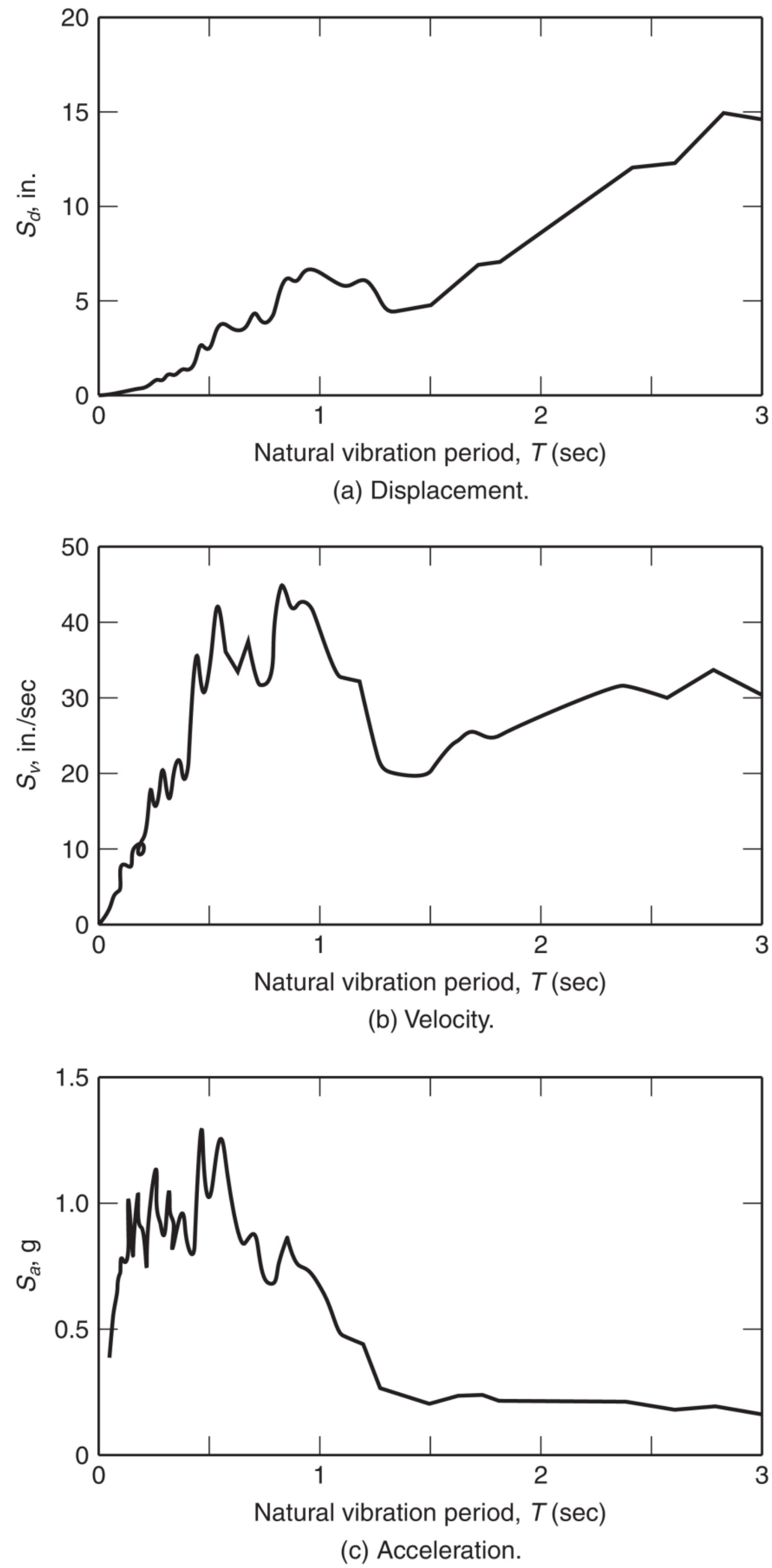


Figure (2): (a) displacement, (b) velocity and (c) acceleration spectra for a given earthquake

Analysis Procedure

1- Determination of maximum considered earthquake and design spectral response accelerations:

- Determine the mapped Maximum Considered Earthquake MCE spectral response accelerations, S_s for short period (0.2 sec.) and S_1 for long period (1.0 sec.) using the spectral acceleration maps (see Figures 3 and 4). Where S_1 is less than or equal to 0.04 and S_s is less than or equal to 0.15, the structure is permitted to be assigned to *Seismic Design Category* A.

- Determine the site class based on the soil properties. The site shall be classified as *Site Class* A, B, C, D, E or F in accordance with Chapter 20 of ASCE 7. Where the soil properties are not known in sufficient detail to determine the site class, Site Class D shall be used unless the geotechnical data determines Site Class E or F soils are present at the site.

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	>2,000 psf
D. Stiff soil	600 to 1,200 ft/s	15 to 50	1,000 to 2,000 psf
E. Soft clay soil	<600 ft/s	<15	<1,000 psf
	Any profile with more than 10 ft of soil having the following characteristics: —Plasticity index $PI > 20$, —Moisture content $w \geq 40\%$, —Undrained shear strength $\bar{s}_u < 500$ psf		
F. Soils requiring site response analysis in accordance with Section 21.1	See Section 20.3.1		

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

Determine the maximum considered earthquake spectral response accelerations adjusted for site class effects, S_{MS} at short period and S_{M1} at long period in accordance with IBC 1613.3.3.

$$S_{MS} = F_a \, S_s$$
$$S_{M1} = F_v \, S_1$$

where:

F_a = Site coefficient defined in IBC Table 1613.3.3(1).

F_v = Site coefficient defined in IBC Table 1613.3.3(2).

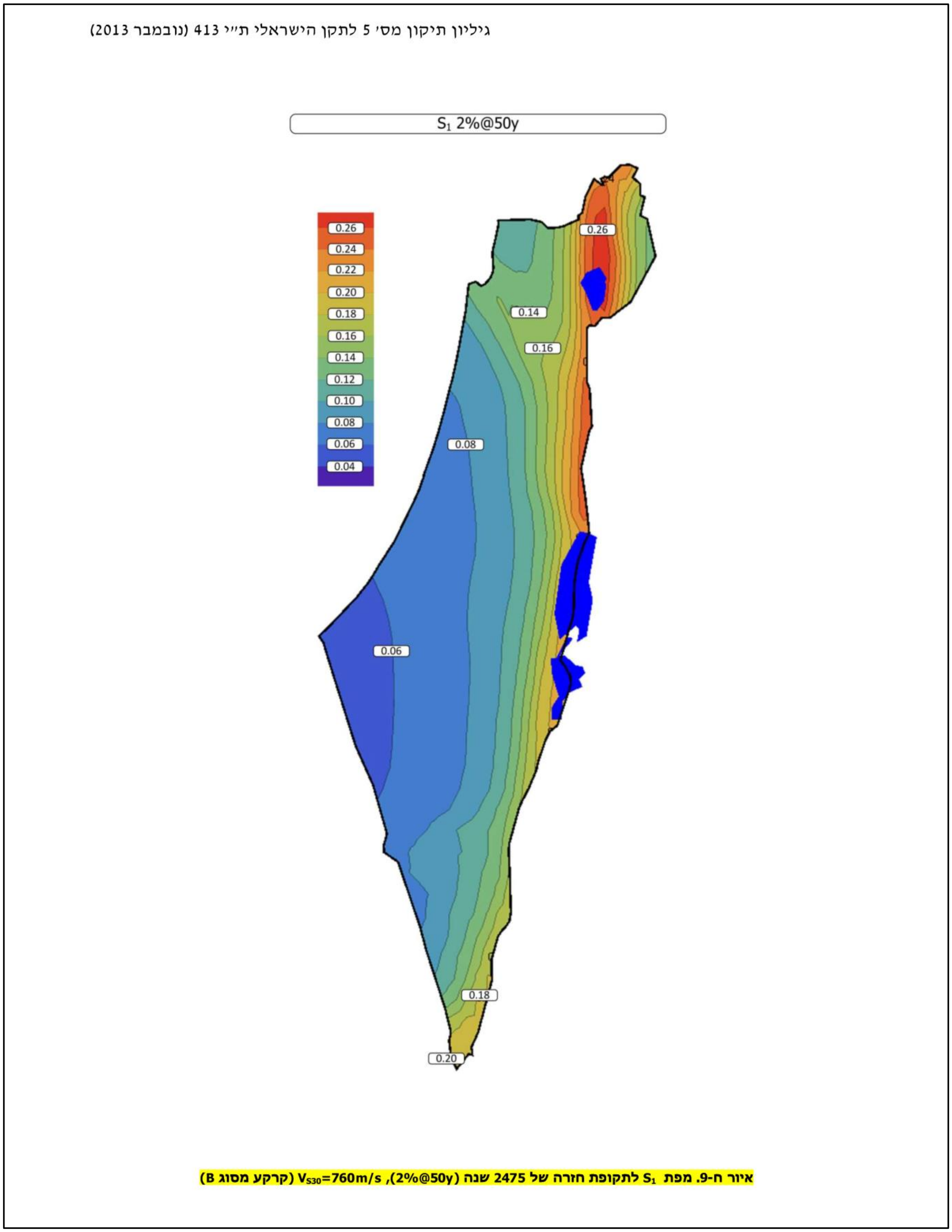


Figure (3): Long period spectral acceleration for Palestine

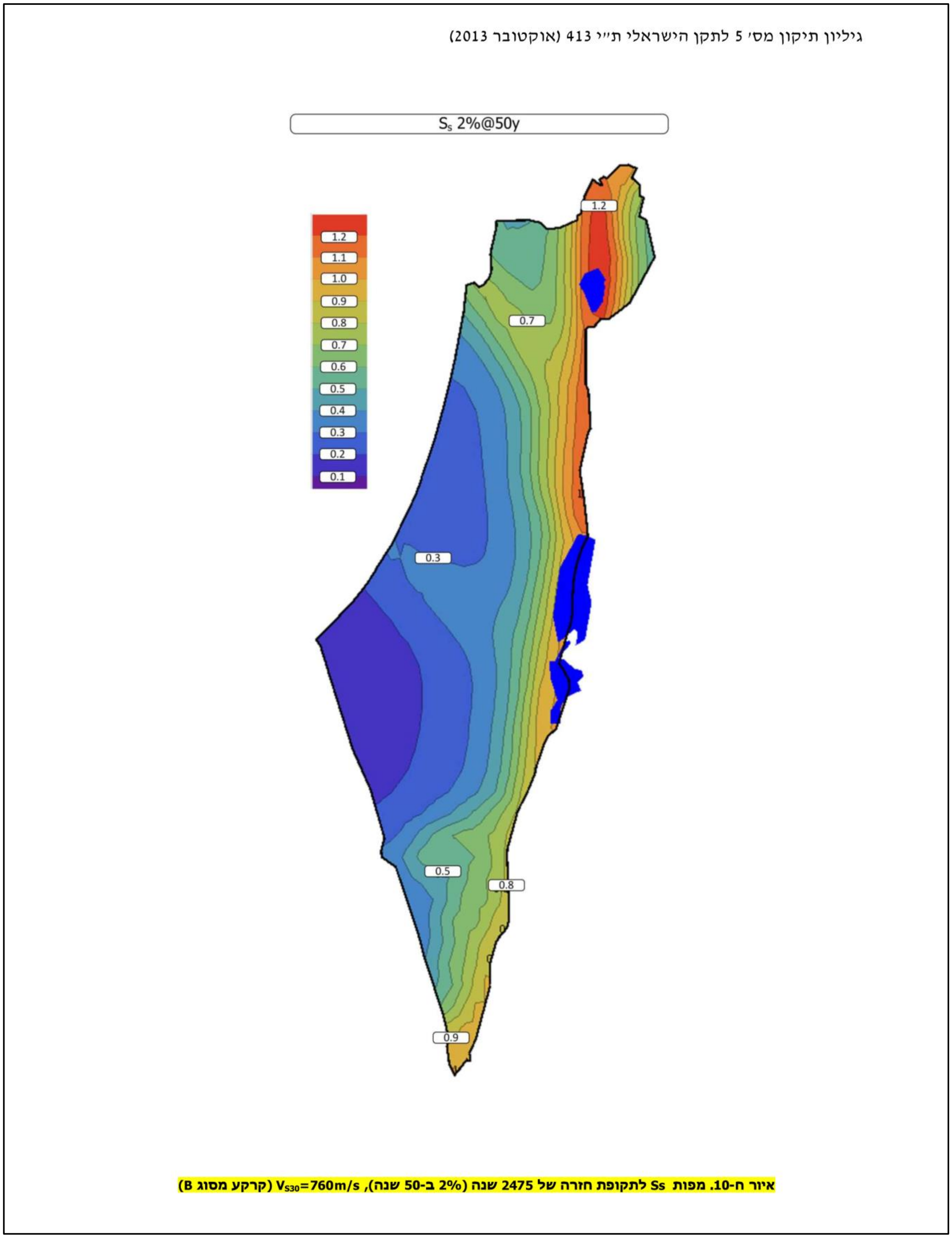


Figure (4): Short period spectral acceleration for Palestine

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

SITE CLASS	MAPPED SPECTRAL RESPONSE ACCELERATION AT SHORT PERIOD				
	$S_s \le 0.25$	$S_s = 0.50$	$S_s = 0.75$	$S_s = 1.00$	$S_s \ge 1.25$
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 1613.3.3(2)
VALUES OF SITE COEFFICIENT F_V [a]

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

- Determine the 5% damped design spectral response accelerations S_{DS} at short period and S_{D1} at long period in accordance with IBC 1613.3.4.

$$S_{DS} = (2/3)\, S_{MS}$$

$$S_{D1} = (2/3)\, S_{M1}$$

where:

S_{MS} = The maximum considered earthquake spectral response accelerations for short period as determined in section 1613.3.3.

S_{M1} = The maximum considered earthquake spectral response accelerations for long period as determined in section 1613.3.3.

2- Determination of seismic design category and Importance factor:

Risk categories of buildings and other structures are shown in IBC Table 1604.5. Importance factors, I_e , are shown in ASCE 7-10 Table 1.5-2. Structures classified as *Risk Category* I, II or III that are located where the mapped spectral response acceleration parameter at 1-second period, S_1, is greater than or equal to 0.75 shall be assigned to *Seismic Design Category* E. Structures classified as *Risk Category* IV that are located where the mapped spectral response acceleration parameter at 1-second period, S_1, is greater than or equal to 0.75 shall be assigned to *Seismic Design Category* F. All other structures shall be assigned to a *seismic design category* based on their *risk category* and the design spectral response acceleration parameters, S_{DS} and S_{D1}, determined in accordance with Section 1613.3.4 or the site-specific procedures of ASCE 7. Each building and structure shall be assigned to the more severe *seismic design category* in accordance with Table 1613.3.5(1) or 1613.5.5(2), irrespective of the fundamental period of vibration of the structure.

TABLE 1604.5
RISK CATEGORY OF BUILDINGS AND OTHER STRUCTURES

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: • Agricultural facilities. • Certain temporary facilities. • Minor storage facilities.
II	Buildings and other structures except those listed in Risk Categories I, III and IV.
III	Buildings and other structures that represent a substantial hazard to human life in the event of failure, including but not limited to: • Buildings and other structures whose primary occupancy is public assembly with an occupant load greater than 300. • Buildings and other structures containing Group E occupancies with an occupant load greater than 250. • Buildings 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 5,000.[a] • Power-generating stations, water treatment facilities for potable water, wastewater treatment facilities and other public utility facilities not included in Risk Category IV. • Buildings and other structures not included in Risk Category IV containing 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 *International Fire Code*; and 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: • 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 Table 307.1(2) or per outdoor control area in accordance with the *International Fire Code*; and Are sufficient to pose a threat to the public if released.[b] • Aviation control towers, air traffic control centers and emergency aircraft hangars. • Buildings and other structures having critical national defense functions. • Water storage facilities and pump structures required to maintain water pressure for fire suppression.

a. For purposes of occupant load calculation, occupancies required by Table 1004.1.2 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 Risk 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.

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

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	1.25	1.00	1.25
IV	1.20	1.25	1.00	1.50

[a]The component importance factor, I_p, applicable to earthquake loads, is not included in this table because it is dependent 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 1613.3.5(1)
SEISMIC DESIGN CATEGORY BASED ON SHORT-PERIOD (0.2 second) RESPONSE ACCELERATION

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 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

3- Determination of the Seismic Base Shear:

The structural analysis shall consist of one of the types permitted in ASCE 7-10 Table 12.6-1, based on the structure's seismic design category, structural system, dynamic properties, and regularity, or with the approval of the authority having jurisdiction, an alternative generally accepted procedure is permitted to be used. The analysis procedure selected shall be completed in accordance with the requirements of the corresponding section referenced in Table 12.6-1. Structural Irregularities are shown in Tables 12.3.1, and Table 12.3.2 and Figures (5) and (6).

Table 12.6-1 Permitted Analytical Procedures

Seismic Design Category	Structural Characteristics	Equivalent Lateral Force Analysis, Section 12.8[a]	Modal Response Spectrum Analysis, Section 12.9[a]	Seismic Response History Procedures, Chapter 16[a]
B, C	All structures	P	P	P
D, E, F	Risk Category I or II buildings not exceeding 2 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 in structural height	P	P	P
	Structures exceeding 160 ft in structural height with no structural irregularities and with $T < 3.5T_s$	P	P	P
	Structures not exceeding 160 ft 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 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 Section 16.2.2	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 12.7.3 12.8.4.3 12.12.1 Table 12.6-1 Section 16.2.2	E and F 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 having 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 Section 16.2.2	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 Section 16.2.2	C, D, E, and F B, C, D, E, and F D, E, and F B, C, D, E, and F

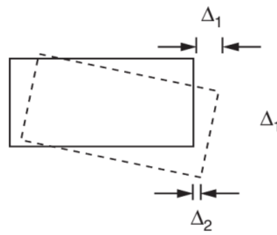
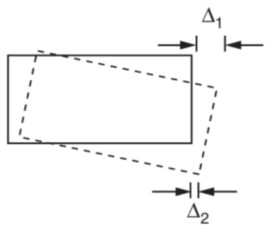
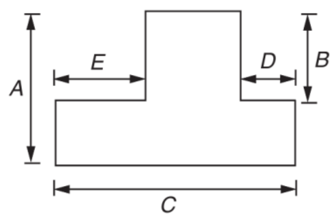
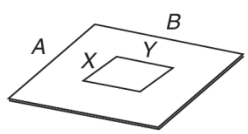
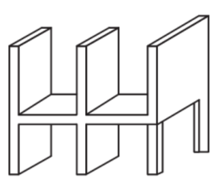
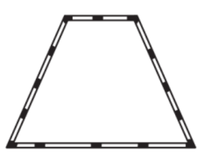
Types of irregularity	Graphic interpretation	Remedial measures	Seismic design category application
1a. Torsional irregularity	 Story drift $\Delta_1 > 1.2 \frac{(\Delta_1+\Delta_2)}{2}$	6 5	D, E, F C, D, E, F
1b. Extreme torsion	 Story drift $\Delta_1 > 1.4 \frac{(\Delta_1+\Delta_2)}{2}$	6 5 2 (NP)	D C, D E, F
2. Reentrant corners	 Projection beyond reentrant corners $B > 15\%\ A$ $D > 15\%\ C$ $E > 15\%\ C$	6	D, E, F
3. Diaphragm discontinuity	 Area $XY > 50\%\ AB$	6	D, E, F
4. Out-of-plane offsets	 Out-of-plane offset	6 3	D, E, F B, C, D, E, F
5. Nonparallel system	 Nonparallel system	7	C, D, E, F

Figure (5): Horizontal Structural Irregularities

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 elements irregularity is defined to exist where there is an in-plane offset of a vertical seismic force-resisting element resulting in overturning demands on a supporting beam, column, truss, or slab.	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

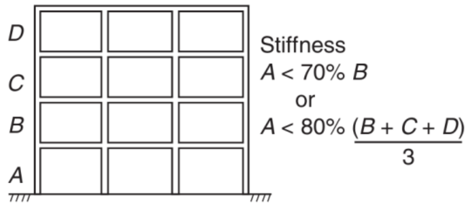
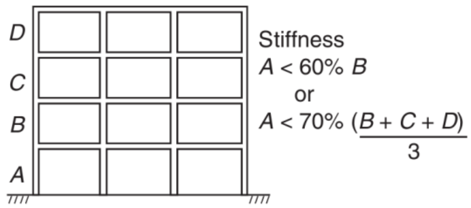
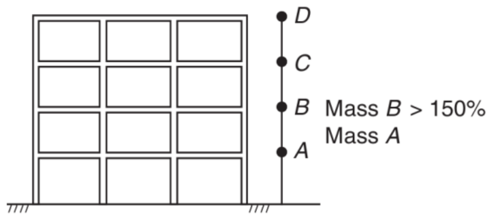
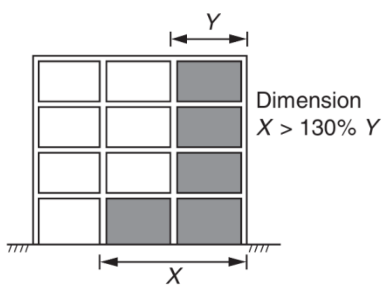
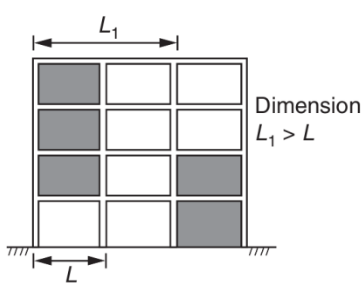
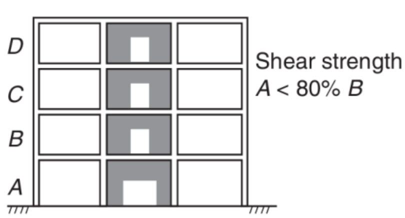
Type of irregularity	Graphic interpretation	Remedial measures	Seismic design category application
1a. Stiffness irregularity (soft story)		1	D, E, F
1b. Stiffness irregularity (extreme soft story)		1 2 (NP)	D E, F
2. Weight (mass) irregularity		1	D, E, F
3. Vertical geometric irregularity		1	D, E, F
4. In-plane discontinuity in vertical lateral-force-resisting systems		1, 3	B, C, D, E, F
5. Discontinuity in capacity (weak story)		4 5 2 (NP)	B, C, D, E, F D, E, F E, F

Figure (6): Vertical Structural Irregularities

3.1 Equivalent Lateral Force Analysis:

Section 12.8 of ASCE 7-10 shall be used.

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

$$V = C_s W$$

where:

W = effective seismic weight

The effective seismic weight, *W*, of a structure shall include the dead load above the base and other loads above the base as listed below:

1. In areas used for storage, a minimum of 25 percent of the floor live load shall be included.

Exceptions

a. Where the inclusion of storage loads adds no more than 5% to the effective seismic weight at that level, it need not be included in the effective seismic weight.

b. Floor live load in public garages and open parking structures need not be included.

2. Where provision for partitions is required in the floor load design, the actual partition weight or a minimum weight of 50 kg/m^2 of floor area, whichever is greater.
3. Total operating weight of permanent equipment.

C_s = Seismic response coefficient

$$= \frac{S_{DS}}{(R/I_e)}$$

R = response modification factor, given in ASCE 7-10 Table 12.2-1

I_e = importance factor

The value of C_s shall not exceed the following:

$$C_s = \frac{S_{D1}}{T\,(R/I_e)} \quad \text{for} \quad T \le T_L$$

$$C_s = \frac{S_{D1}\, T_L}{T^2 \left(R / I_e\right)} \quad \text{for} \quad T > T_L$$

The value of C_s shall not be less than:

$$C_s = 0.044\, S_{DS}\, I_e \quad \geq 0.01$$

For structures located where S_1 is equal to or greater than 0.6g, C_s shall not be less than

$$C_s = \frac{0.5\, S_1}{\left(R / I_e\right)}$$

where:

T = fundamental period of the structure

T_L = long-period transition period, which is the transition period between the velocity and displacement-controlled portions of the design spectrum (given in Figure 7 for Palestine).

An approximate value of T_a may be obtained from:

$$T_a = C_t\, h_n^{\ x}$$

where:

h_n = height of the building above the base in meters

C_t = building period coefficient given in Table 12.8-2

x = constant given in Table 12.8-2

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.

The calculated fundamental period, T, cannot exceed the product of the coefficient, C_u, in Table 12.8-1 times the approximate fundamental period, T_a.

Table 12.2-1 Design Coefficients and Factors for Seismic Force-Resisting Systems

Seismic Force-Resisting System	ASCE 7 Section Where Detailing Requirements Are Specified	Response Modification Coefficient, R^a	Overstrength Factor, Ω_0^g	Deflection Amplification Factor, C_d^b	Structural System Limitations Including Structural Height, h_n (ft) Limits[c] — Seismic Design Category B	C	D^d	E^d	F^e
A. BEARING WALL SYSTEMS									
1. Special reinforced concrete shear walls[l, m]	14.2	5	2½	5	NL	NL	160	160	100
2. Ordinary reinforced concrete shear walls[l]	14.2	4	2½	4	NL	NL	NP	NP	NP
3. Detailed plain concrete shear walls[l]	14.2	2	2½	2	NL	NP	NP	NP	NP
4. Ordinary plain concrete shear walls[l]	14.2	1½	2½	1½	NL	NP	NP	NP	NP
5. Intermediate precast shear walls [l]	14.2	4	2½	4	NL	NL	40[k]	40[k]	40[k]
6. Ordinary precast shear walls[l]	14.2	3	2½	3	NL	NP	NP	NP	NP
7. Special reinforced masonry shear walls	14.4	5	2½	3½	NL	NL	160	160	100
8. Intermediate reinforced masonry shear walls	14.4	3½	2½	2¼	NL	NL	NP	NP	NP
9. Ordinary reinforced masonry shear walls	14.4	2	2½	1¾	NL	160	NP	NP	NP
10. Detailed plain masonry shear walls	14.4	2	2½	1¾	NL	NP	NP	NP	NP
11. Ordinary plain masonry shear walls	14.4	1½	2½	1¼	NL	NP	NP	NP	NP
12. Prestressed masonry shear walls	14.4	1½	2½	1¾	NL	NP	NP	NP	NP
13. Ordinary reinforced AAC masonry shear walls	14.4	2	2½	2	NL	35	NP	NP	NP
14. Ordinary plain AAC masonry shear walls	14.4	1½	2½	1½	NL	NP	NP	NP	NP
15. Light-frame (wood) walls sheathed with wood structural panels rated for shear resistance or steel sheets	14.1 and 14.5	6½	3	4	NL	NL	65	65	65
16. Light-frame (cold-formed steel) walls sheathed with wood structural panels rated for shear resistance or steel sheets	14.1	6½	3	4	NL	NL	65	65	65
17. Light-frame walls with shear panels of all other materials	14.1 and 14.5	2	2½	2	NL	NL	35	NP	NP
18. Light-frame (cold-formed steel) wall systems using flat strap bracing	14.1	4	2	3½	NL	NL	65	65	65
B. BUILDING FRAME SYSTEMS									
1. Steel eccentrically braced frames	14.1	8	2	4	NL	NL	160	160	100
2. Steel special concentrically braced frames	14.1	6	2	5	NL	NL	160	160	100
3. Steel ordinary concentrically braced frames	14.1	3¼	2	3¼	NL	NL	35[j]	35[j]	NP[j]

Table 12.2-1 (*Continued*)

Seismic Force-Resisting System	ASCE 7 Section Where Detailing Requirements Are Specified	Response Modification Coefficient, R^a	Overstrength Factor, $\Omega_0{}^g$	Deflection Amplification Factor, $C_d{}^b$	Structural System Limitations Including Structural Height, h_n (ft) Limits[c] — Seismic Design Category: B	C	D^d	E^d	F^e
4. Special reinforced concrete shear walls[l,m]	14.2	6	2½	5	NL	NL	160	160	100
5. Ordinary reinforced concrete shear walls[l]	14.2	5	2½	4½	NL	NL	NP	NP	NP
6. Detailed plain concrete shear walls[l]	14.2 and 14.2.2.8	2	2½	2	NL	NP	NP	NP	NP
7. Ordinary plain concrete shear walls[l]	14.2	1½	2½	1½	NL	NP	NP	NP	NP
8. Intermediate precast shear walls[l]	14.2	5	2½	4½	NL	NL	40[k]	40[k]	40[k]
9. Ordinary precast shear walls[l]	14.2	4	2½	4	NL	NP	NP	NP	NP
10. Steel and concrete composite eccentrically braced frames	14.3	8	2 ½	4	NL	NL	160	160	100
11. Steel and concrete composite special concentrically braced frames	14.3	5	2	4½	NL	NL	160	160	100
12. Steel and concrete composite ordinary braced frames	14.3	3	2	3	NL	NL	NP	NP	NP
13. Steel and concrete composite plate shear walls	14.3	6½	2½	5½	NL	NL	160	160	100
14. Steel and concrete composite special shear walls	14.3	6	2½	5	NL	NL	160	160	100
15. Steel and concrete composite ordinary shear walls	14.3	5	2½	4½	NL	NL	NP	NP	NP
16. Special reinforced masonry shear walls	14.4	5½	2½	4	NL	NL	160	160	100
17. Intermediate reinforced masonry shear walls	14.4	4	2½	4	NL	NL	NP	NP	NP
18. Ordinary reinforced masonry shear walls	14.4	2	2½	2	NL	160	NP	NP	NP
19. Detailed plain masonry shear walls	14.4	2	2½	2	NL	NP	NP	NP	NP
20. Ordinary plain masonry shear walls	14.4	1½	2½	1¼	NL	NP	NP	NP	NP
21. Prestressed masonry shear walls	14.4	1½	2½	1¾	NL	NP	NP	NP	NP
22. Light-frame (wood) walls sheathed with wood structural panels rated for shear resistance	14.5	7	2½	4½	NL	NL	65	65	65
23. Light-frame (cold-formed steel) walls sheathed with wood structural panels rated for shear resistance or steel sheets	14.1	7	2½	4½	NL	NL	65	65	65
24. Light-frame walls with shear panels of all other materials	14.1and 14.5	2½	2½	2½	NL	NL	35	NP	NP
25. Steel buckling-restrained braced frames	14.1	8	2½	5	NL	NL	160	160	100
26. Steel special plate shear walls	14.1	7	2	6	NL	NL	160	160	100

Table 12.2-1 (*Continued*)

Seismic Force-Resisting System	ASCE 7 Section Where Detailing Requirements Are Specified	Response Modification Coefficient, R[a]	Overstrength Factor, Ω_0[g]	Deflection Amplification Factor, C_d[b]	Structural System Limitations Including Structural Height, h_n (ft) Limits[c] — Seismic Design Category B	C	D[d]	E[d]	F[e]
C. MOMENT-RESISTING FRAME SYSTEMS									
1. Steel special moment frames	14.1 and 12.2.5.5	8	3	5½	NL	NL	NL	NL	NL
2. Steel special truss moment frames	14.1	7	3	5½	NL	NL	160	100	NP
3. Steel intermediate moment frames	12.2.5.7 and 14.1	4½	3	4	NL	NL	35[h]	NP[h]	NP[h]
4. Steel ordinary moment frames	12.2.5.6 and 14.1	3½	3	3	NL	NL	NP[i]	NP[i]	NP[i]
5. Special reinforced concrete moment frames[n]	12.2.5.5 and 14.2	8	3	5½	NL	NL	NL	NL	NL
6. Intermediate reinforced concrete moment frames	14.2	5	3	4½	NL	NL	NP	NP	NP
7. Ordinary reinforced concrete moment frames	14.2	3	3	2½	NL	NP	NP	NP	NP
8. Steel and concrete composite special moment frames	12.2.5.5 and 14.3	8	3	5½	NL	NL	NL	NL	NL
9. Steel and concrete composite intermediate moment frames	14.3	5	3	4½	NL	NL	NP	NP	NP
10. Steel and concrete composite partially restrained moment frames	14.3	6	3	5½	160	160	100	NP	NP
11. Steel and concrete composite ordinary moment frames	14.3	3	3	2½	NL	NP	NP	NP	NP
12. Cold-formed steel—special bolted moment frame[p]	14.1	3½	3[o]	3½	35	35	35	35	35
D. DUAL SYSTEMS WITH SPECIAL MOMENT FRAMES CAPABLE OF RESISTING AT LEAST 25% OF PRESCRIBED SEISMIC FORCES	12.2.5.1								
1. Steel eccentrically braced frames	14.1	8	2½	4	NL	NL	NL	NL	NL
2. Steel special concentrically braced frames	14.1	7	2½	5½	NL	NL	NL	NL	NL
3. Special reinforced concrete shear walls[l]	14.2	7	2½	5½	NL	NL	NL	NL	NL
4. Ordinary reinforced concrete shear walls[l]	14.2	6	2½	5	NL	NL	NP	NP	NP
5. Steel and concrete composite eccentrically braced frames	14.3	8	2½	4	NL	NL	NL	NL	NL
6. Steel and concrete composite special concentrically braced frames	14.3	6	2½	5	NL	NL	NL	NL	NL

Table 12.2-1 (*Continued*)

Seismic Force-Resisting System	ASCE 7 Section Where Detailing Requirements Are Specified	Response Modification Coefficient, R^a	Overstrength Factor, Ω_0^g	Deflection Amplification Factor, C_d^b	Structural System Limitations Including Structural Height, h_n (ft) Limits[c]				
					Seismic Design Category				
					B	C	D^d	E^d	F^e
7. Steel and concrete composite plate shear walls	14.3	7½	2½	6	NL	NL	NL	NL	NL
8. Steel and concrete composite special shear walls	14.3	7	2½	6	NL	NL	NL	NL	NL
9. Steel and concrete composite ordinary shear walls	14.3	6	2½	5	NL	NL	NP	NP	NP
10. Special reinforced masonry shear walls	14.4	5½	3	5	NL	NL	NL	NL	NL
11. Intermediate reinforced masonry shear walls	14.4	4	3	3½	NL	NL	NP	NP	NP
12. Steel buckling-restrained braced frames	14.1	8	2½	5	NL	NL	NL	NL	NL
13. Steel special plate shear walls	14.1	8	2½	6½	NL	NL	NL	NL	NL
E. DUAL SYSTEMS WITH INTERMEDIATE MOMENT FRAMES CAPABLE OF RESISTING AT LEAST 25% OF PRESCRIBED SEISMIC FORCES	12.2.5.1								
1. Steel special concentrically braced frames[f]	14.1	6	2½	5	NL	NL	35	NP	NP
2. Special reinforced concrete shear walls[l]	14.2	6½	2½	5	NL	NL	160	100	100
3. Ordinary reinforced masonry shear walls	14.4	3	3	2½	NL	160	NP	NP	NP
4. Intermediate reinforced masonry shear walls	14.4	3½	3	3	NL	NL	NP	NP	NP
5. Steel and concrete composite special concentrically braced frames	14.3	5½	2½	4½	NL	NL	160	100	NP
6. Steel and concrete composite ordinary braced frames	14.3	3½	2½	3	NL	NL	NP	NP	NP
7. Steel and concrete composite ordinary shear walls	14.3	5	3	4½	NL	NL	NP	NP	NP
8. Ordinary reinforced concrete shear walls[l]	14.2	5½	2½	4½	NL	NL	NP	NP	NP
F. SHEAR WALL-FRAME INTERACTIVE SYSTEM WITH ORDINARY REINFORCED CONCRETE MOMENT FRAMES AND ORDINARY REINFORCED CONCRETE SHEAR WALLS[l]	12.2.5.8 and 14.2	4½	2½	4	NL	NP	NP	NP	NP

Table 12.2-1 (*Continued*)

Seismic Force-Resisting System	ASCE 7 Section Where Detailing Requirements Are Specified	Response Modification Coefficient, R^a	Overstrength Factor, Ω_0^g	Deflection Amplification Factor, C_d^b	Structural System Limitations Including Structural Height, h_n (ft) Limits[c] — Seismic Design Category: B	C	D^d	E^d	F^e
G. CANTILEVERED COLUMN SYSTEMS DETAILED TO CONFORM TO THE REQUIREMENTS FOR:	12.2.5.2								
1. Steel special cantilever column systems	14.1	2½	1¼	2½	35	35	35	35	35
2. Steel ordinary cantilever column systems	14.1	1¼	1¼	1¼	35	35	NP[i]	NP[i]	NP[i]
3. Special reinforced concrete moment frames[n]	12.2.5.5 and 14.2	2½	1¼	2½	35	35	35	35	35
4. Intermediate reinforced concrete moment frames	14.2	1½	1¼	1½	35	35	NP	NP	NP
5. Ordinary reinforced concrete moment frames	14.2	1	1¼	1	35	NP	NP	NP	NP
6. Timber frames	14.5	1½	1½	1½	35	35	35	NP	NP
H. STEEL SYSTEMS NOT SPECIFICALLY DETAILED FOR SEISMIC RESISTANCE, EXCLUDING CANTILEVER COLUMN SYSTEMS	14.1	3	3	3	NL	NL	NP	NP	NP

[a]Response modification coefficient, R, for use throughout the standard. Note R reduces forces to a strength level, not an allowable stress level.
[b]Deflection amplification factor, C_d, for use in Sections 12.8.6, 12.8.7, and 12.9.2.
[c]NL = Not Limited and NP = Not Permitted. For metric units use 30.5 m for 100 ft and use 48.8 m for 160 ft.
[d]See Section 12.2.5.4 for a description of seismic force-resisting systems limited to buildings with a structural height, h_n, of 240 ft (73.2 m) or less.
[e]See Section 12.2.5.4 for seismic force-resisting systems limited to buildings with a structural height, h_n, of 160 ft (48.8 m) or less.
[f]Ordinary moment frame is permitted to be used in lieu of intermediate moment frame for Seismic Design Categories B or C.
[g]Where the tabulated value of the overstrength factor, Ω_0, is greater than or equal to 2½, Ω_o is permitted to be reduced by subtracting the value of 1/2 for structures with flexible diaphragms.
[h]See Section 12.2.5.7 for limitations in structures assigned to Seismic Design Categories D, E, or F.
[i] See Section 12.2.5.6 for limitations in structures assigned to Seismic Design Categories D, E, or F.
[j]Steel ordinary concentrically braced frames are permitted in single-story buildings up to a structural height, h_n, of 60 ft (18.3 m) where the dead load of the roof does not exceed 20 psf
(0.96 kN/m^2) and in penthouse structures.
[k]An increase in structural height, h_n, to 45 ft (13.7 m) is permitted for single story storage warehouse facilities.
[l]In Section 2.2 of ACI 318. A shear wall is defined as a structural wall.
[m]In Section 2.2 of ACI 318. The definition of "special structural wall" includes precast and cast-in-place construction.
[n]In Section 2.2 of ACI 318. The definition of "special moment frame" includes precast and cast-in-place construction.
[o]Alternately, the seismic load effect with overstrength, E_{mh}, is permitted to be based on the expected strength determined in accordance with AISI S110.
[p]Cold-formed steel – special bolted moment frames shall be limited to one-story in height in accordance with AISI S110.

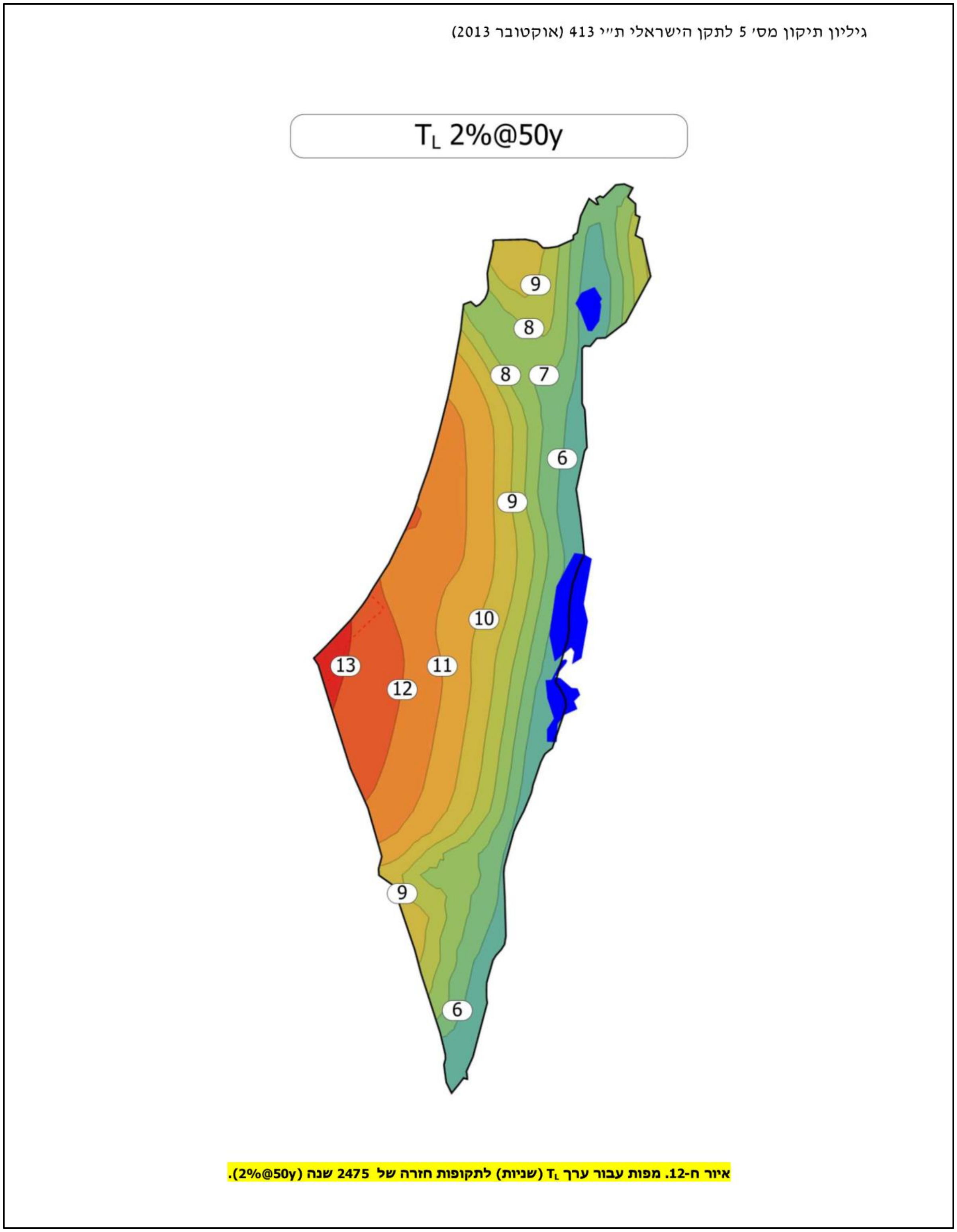


Figure (7): Long-period transition period for Palestine

Table 12.8-1: Coefficient for upper limit on calculated period

Design Spectral Response, 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

In cases where moment resisting frames do not exceed twelve stories in height and having an average story height of 3 m, an approximate period T_a in seconds in the following form can be used:

$$T_a = 0.1\,N$$

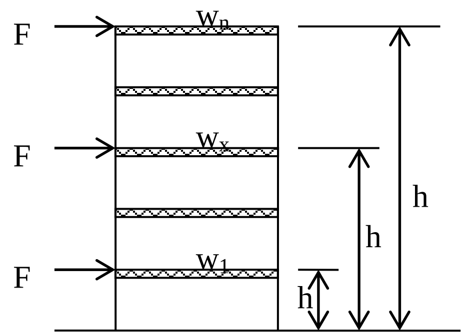
where: N = number of stories above the base

3.2 Vertical Distribution of Seismic Forces:

$$F_x = C_{vx} V$$

and

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



where:

F_x = Lateral force at level x

C_{vx} = Vertical distribution factor

V = total design lateral force or shear at the base of the building

w_x and w_i = the portions of W assigned to levels x and i

h_x and h_i = the height from base to level x or i

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

k = 1 for buildings with T less than or equal to 0.5 seconds

k = 2 for buildings with T more than or equal to 2.5 seconds

Interpolate between k = 1 and k = 2 for buildings with T between 0.5 and 2.5

3.3 Horizontal Distribution of Forces and Torsion:

Horizontally distribute the shear V_x

$$V_x = \sum_{i=1}^{x} F_i$$

where:

F_i = portion of the seismic base shear, V, induced at level i

Accidental Torsion, M_{ta}

$M_{ta} = V_x \left(0.05\, B\right)$

Where B is the building dimension perpendicular to the direction of seismic force

Total Torsion, $M_T = M_t \pm M_{ta}$

Where earthquake forces are applied concurrently in two orthogonal directions, the required 5 percent displacement of the center of mass need not applied in both of the orthogonal directions at the same time, but shall be applied in the direction that produces the greater effect.

3.4 Story Drift:

The design story drift, Δ, is defined as the difference between the deflection of the center of mass at the top and bottom of the story being considered.

$$\delta_x = \frac{C_d\ \delta_{xe}}{I_e}$$

Where:

C_d = deflection amplification factor, given in Table 12.2-1
δ_{xe} = deflection determined by elastic analysis.

3.5- P-delta Effect:

The P-delta effects can be ignored if the stability coefficient, θ, from the following expression is equal to or less than 0.10.

$$\theta = \frac{P_x\ \Delta\ I_e}{V_x\ h_{sx}\ C_d}$$

$$\theta_{\max} = \frac{0.50}{\beta C_d} \leq 0.25$$

Where:

P_x = Total unfactored vertical design load at and above level x
V_x = Seismic shear force acting between level x and $x-1$
h_{sx} = Story height below level x
Δ = Design story drift occurring simultaneously with V_x
β = Ratio of shear demand to shear capacity for the story between level x and $x-1$. Where the ratio β is not calculated, a value of β = 1.0 shall be used.

When the stability coefficient, θ, is greater than 0.10 but less than or equal to $\theta_{\max}$, P-delta effects are to be considered. To obtain the story drift for including the P-delta effects, the design story drift shall be multiplied by $1.0/(1-\theta)$.
When θ is greater than $\theta_{\max}$, the structure is potentially unstable and has to be redesigned.
Where the p-delta effect is included in an automated analysis, the equation for evaluating $\theta_{\max}$ shall still be satisfied, but the value of θ in the first equation using the results of the p-delta analysis is permitted to be divided by $(1+\theta)$ before checking the second equation.

3.6 Redundancy:

- The value of ρ is permitted to equal 1.0 for the following:

1. Structures assigned to Seismic Design Category B or C.
2. Drift calculation and P-delta effects.
3. Design of diaphragm collector elements.
4. Design of members or connections where the seismic load effects including over-strength factor are required for design.
5. Diaphragm loads.

- For structures assigned to Seismic Design Category D, E, or F, ρ shall equal 1.3 unless one of the following two conditions is met, whereby ρ is permitted to be taken as 1.0:

a. Each story resisting more than 35 percent of the base shear in the direction of interest shall comply with Table 12.3-3.
b. Structures that are regular in plan at all levels provided that the seismic force-resisting systems consist of at least two bays of seismic force-resisting perimeter framing on each side of the structure in each orthogonal direction at each story resisting more than 35 percent of the base shear. The number of bays for a shear wall shall be calculated as the length of shear wall divided by the story height or two times the length of shear wall divided by the story height, h_{sx} , for light-frame construction.

4. Seismic Load Effects and Combinations:

The seismic load effect, E shall be determined in accordance with the following:

- For use in combinations that include seismic loads, E shall be determined in accordance with

  $E = E_h + E_v$

  $E = E_h - E_v$

  where

  $E_h = \rho Q_E$ (effect of horizontal seismic forces)

  $E_v = 0.2 S_{DS} D$ (effect of vertical seismic forces)

  $E_{mh} = \Omega_\circ Q_E$ (effect of horizontal seismic forces including over-strength factor)

The vertical seismic load effect, $0.2 S_{DS} D$, is permitted to be taken as zero when S_{DS} is equal to or less than 0.125.

4.1 Basic combinations

5. $(1.2+0.2S_{DS})D+\rho Q_E+L+0.2S$

6. $(0.9-0.2S_{DS})D+\rho Q_E+1.6H$

4.2 Basic combinations with over-strength factor

5. $(1.2+0.2S_{DS})D+\Omega_{\circ} Q_E+L+0.2S$

6. $(0.9-0.2S_{DS})D+\Omega_{\circ} Q_E+1.6H$

Notes:

1-The load factor on L in combination 5 is permitted to equal 0.5 for all occupancies in which $L_{\circ}$ in Table 4-1 of ASCE 7-10 is less than or equal to 480 kg/m^2, with the exception of garages or areas occupied as places of public assembly.

2- The load on H shall be set equal to zero in combination 6 if the structural action due to H counteracts that due to E. Where lateral earth pressure provides resistance to structural actions from other forces, it shall not be included in H but shall be included in the design resistance.

4.3 Minimum upward force for horizontal cantilevers for seismic design categories D through F

In structures assigned to Seismic Design Category D, E, or F, horizontal cantilever structural members shall be designed for a minimum net upward force of 0.2 times the dead load in addition to the applicable load combinations.

Example (3):
For the same building shown in Example (2), evaluate the seismic forces at floor levels in the direction of shear walls A, B and C, using IBC 2015/ASCE 7-10. Note that the soil is dense with an average SPT value of 35 blows/foot.

Solution:

- Based on IS 413-5 (2013), $S_1 = 0.06$, $S_S = 0.10$ (Figures 3 and 4).

- Based on Table 20.3-1, site class is classified as "D".

- Using Tables 1613.3.3(1) and 1613.3.3(2), for site class "D", short-period site coefficient $F_a = 1.6$ and long-period site coefficient $F_v = 2.4$.

- Maximum considered earthquake spectral response accelerations adjusted for site class effects are evaluated.

$$S_{MS} = F_a S_s = 1.6(0.10) = 0.16g$$
$$S_{M1} = F_v S_1 = 2.4(0.06) = 0.144g$$

- The 5% damped design spectral response accelerations S_{DS} at short period and S_{D1} at long period in accordance are evaluated.

$$S_{DS} = \frac{2}{3} S_{MS} = \frac{2}{3}(0.16g) = 0.107g$$
$$S_{D1} = \frac{2}{3} S_{M1} = \frac{2}{3}(0.144g) = 0.096g$$

- Occupancy importance factor, I_e as evaluated from IBC **2015** Table 1604.5 and ASCE 7-10 Table 1.5.2 (risk category II).

- From Table 1613.3.5(1), Seismic Design Category (SDC) is A. From Table 1613.3.5(2), SDC is B. Therefore, seismic design category (SDC) is "B".

- For ordinary shear walls and using ASCE 7-10 Table 12.2-1, response modification coefficient $R = 5.0$.

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

$$V = C_s W$$

The value of C_s shall not exceed the following:
From example (2), $T = 1.293 \text{sec.}$
From Table 12.8-2, approximate period $T_a = 0.0488(24)^{0.75} = 0.529$ sec.
$C_u T_a = 1.70(0.529) = 0.90$ sec.
i.e., $T = 0.90$ sec.

$$C_s = \frac{S_{DS}}{(R/I_e)} = \frac{0.107}{5} = 0.0214$$

$$C_{s,\max} = \frac{S_{D1}}{T\,(R/I_e)} \quad \text{for} \quad T \le T_L \quad (T_L = 13.0\text{sec.}, \text{ Figure 7})$$

$$C_{s,\max} = \frac{0.096}{0.9(5.0)} = 0.0213$$

$$C_{s,\min} = 0.044\, S_{DS}\; I_e \quad \ge 0.01$$

Or, $C_{s,\min} = 0.044(0.096) = 0.0042 = 0.01$

i.e., $C_s = 0.0213$
The seismic base shear $V = 0.0213W$
$V = 0.0213(2160) = 46.0\, tons$

- Vertical distribution of forces:

$$F_x = C_{vx}\, V$$

$$C_{vx} = \frac{w_x\; h_x^{\;k}}{\sum_{i=1}^{n} w_i\; h^k{}_i}$$ and

$K = 1.20$ (from linear interpolation).

Vertical Distribution of Forces:

Level	w_i	h_x	$w_x(h_x)^{1.2}$	C_{vx}	F_x
8	270.0	24	12235.37	0.241293	11.10
7	270.0	21	10423.82	0.205567	9.46
6	270.0	18	8663.448	0.170851	7.86
5	270.0	15	6961.026	0.137278	6.31
4	270.0	12	5325.756	0.105029	4.83
3	270.0	9	3770.985	0.074367	3.42
2	270.0	6	2318.17	0.045716	2.10
1	270.0	3	1009.042	0.019899	0.92
0	$\sum$ **2160.0**		50707.62	1.00	46.00