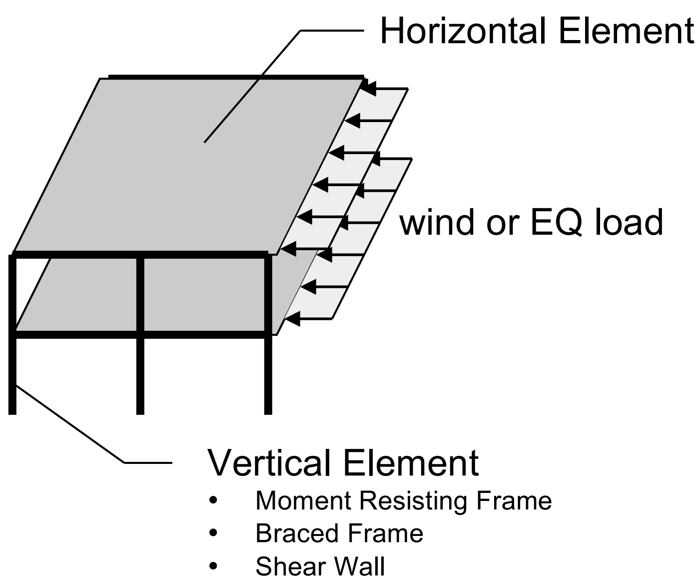
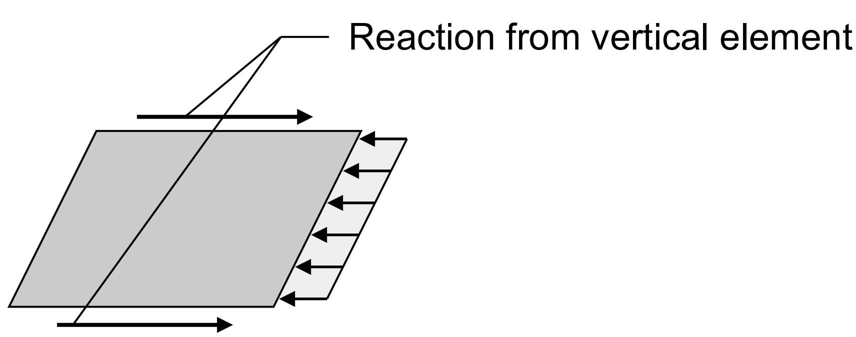
CE 160 Labs 9 and 10
Lateral Force Load Path and Lateral Force Resisting Systems for Wind and Seismic Loads

The Lateral Force Resisting System (LFRS) is comprised of horizontal and vertical elements



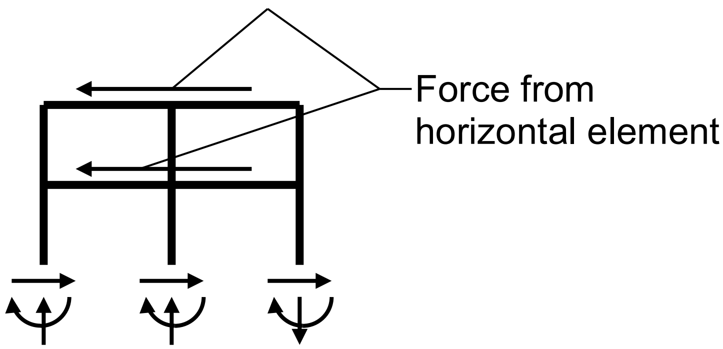
Horizontal Element (Diaphragm)



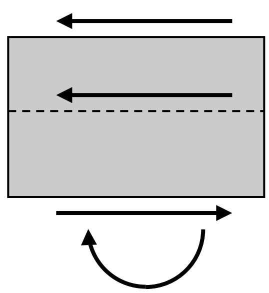
Horizontal element carries wind or EQ load in bending to vertical elements (acts as a deep beam)

Common Vertical Elements

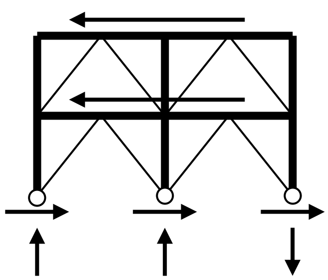
Moment Resisting Frame



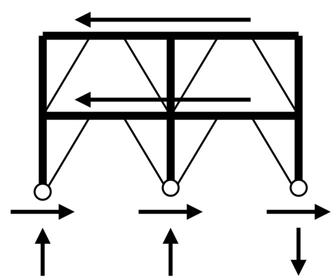
Shear Wall



Concentric Braced Frame



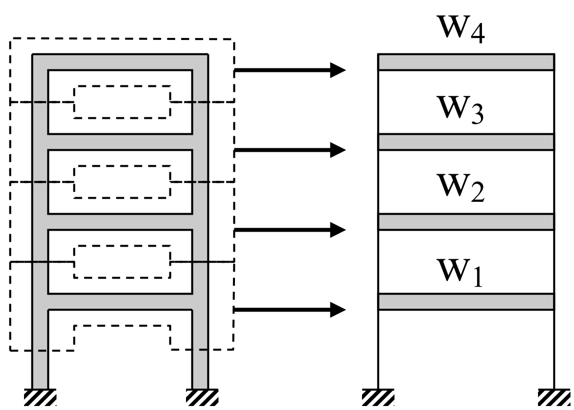
Eccentric Braced Frame



IBC Equivalent Static Seismic Force Procedure for Buildings

Dynamic Model of a Building

Weights of walls are lumped at floor/roof levels

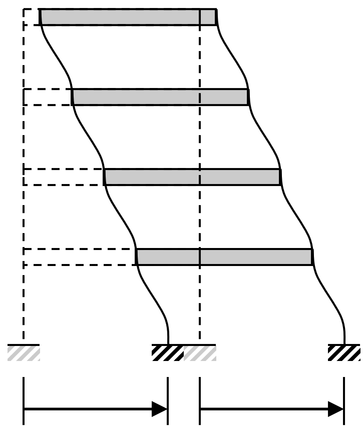


(W = $w_1 + w_2 + w_3 + w_4$)

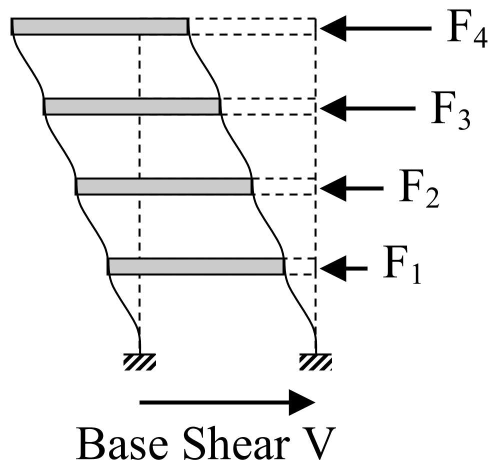
- The weight of each level, w_i, is the weight of the floor or roof level plus half the weight of the interior and exterior walls above the level and below the level (regions shown dotted above).

- The seismic weight, W, is the sum of the weight of all of the levels which is the total dead load of entire building. This is why the dead load table (Lab #4) is one of the first things a structural engineer constructs when starting to analyze a building.

Equivalent Static Seismic Forces



Actual deformation
due to ground acceleration



$(V = F_1 + F_2 + F_3 + F_4)$

Approximate deformation
due to equivalent static forces

The Base Shear (V) depends on:

- The fundamental period of vibration of the building;
- The maximum earthquake acceleration at base of the building;
- The energy dissipating capacity of the Lateral Force Resisting System (LFRS);
- The expected performance level of the building due to earthquake loads.

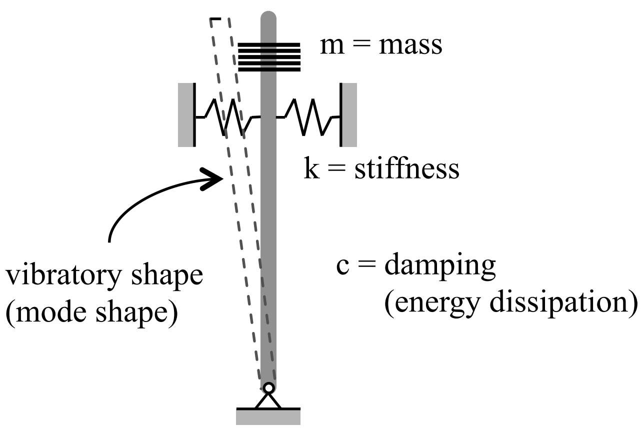
Estimating the Fundamental Period of Vibration of the Building

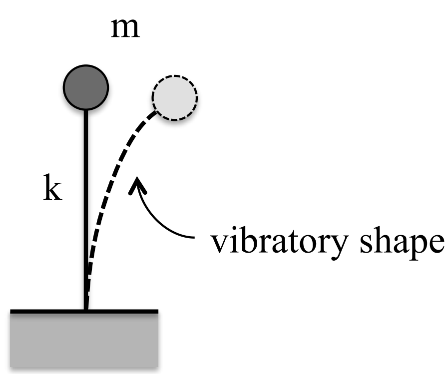
Period of Vibration of a Single Degree of Freedom System

Properties of structures subjected to vibration that are important in defining their response to dynamic loading are:

- Mass (m),
- Stiffness, (k) and
- Damping or energy dissipation (c).

Consider two types of Single Degree of Freedom Models





The period of vibration (T) is the time in seconds it takes to make one complete cycle of free vibration.

The deformed shape when the system is vibrating called the mode shape.

From a dynamic analysis (CE 165, CE 212), it can be shown that the period is:

$$\boldsymbol{T = 2\pi\sqrt{\frac{m}{k}}}$$

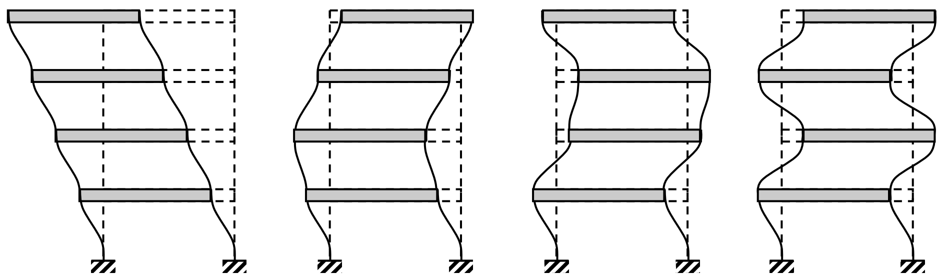
So we can see from the relationship and from our model that if:

- The **mass increases** then the **period is longer** (vibration is slower);
- The **mass decreases** then the **period is shorter** (vibration is faster);
- The **stiffness increases** then the **period is shorter** (vibration is faster);
- The **stiffness decreases** then the **period is longer** (vibration is slower);

The vibration eventually stops due to damping.

Vibration of a Multiple Degree of Freedom System

A four-story building has four vibratory mode shapes with four associated periods of vibration



First mode shape
Longest period of vibration
(Fundamental Period, T)

2nd mode

3rd mode

4th mode shape
Shortest period of vibration

The fundamental period tends to dominate the dynamic response to earthquake loading and is the most important property of the building for seismic response.

IBC Estimate of Fundamental Period of the Building

The estimate of the fundamental period depends on the total building height and type of lateral force resisting system:

$$T = C_t h_n^x \qquad \text{(in seconds)}$$

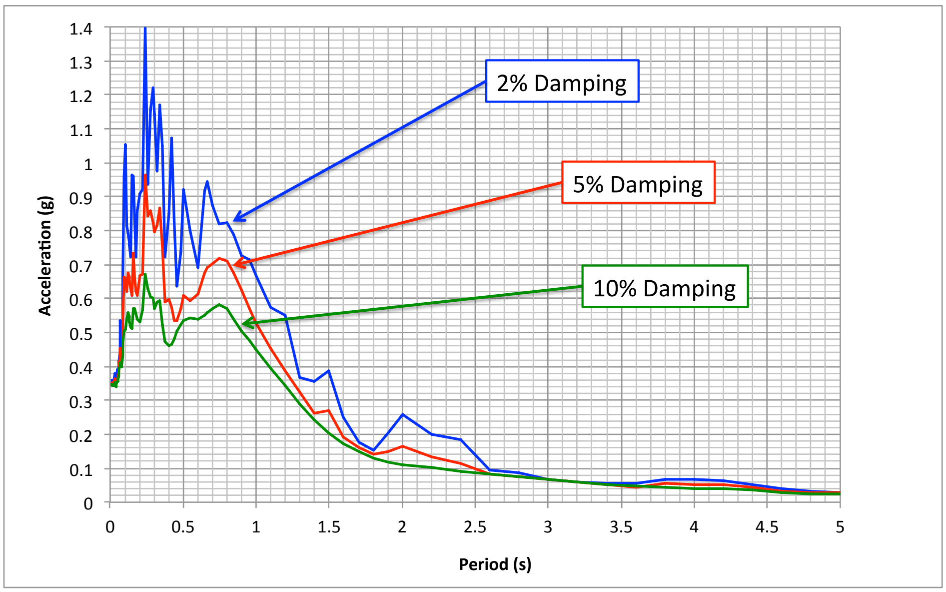
where: h_n = average roof height above base of building in feet
x = exponent based on type of lateral force resisting system
= 0.8 for steel moment resisting frames
= 0.9 for concrete moment resisting frames
= 0.75 for eccentrically braced steel frames
= 0.75 for all other systems (shear walls, concentric frames, etc.)
C_t = coefficient based on type of lateral force resisting system
= 0.028 for steel moment resisting frames
= 0.016 for concrete moment resisting frames
= 0.030 for eccentrically braced steel frames
= 0.020 for all other systems (shear walls, concentrically braced frames, etc.)

Earthquake Acceleration at the Base of the Building

The acceleration that the building will experience is found using the **Response Spectrum** of the earthquake motion.

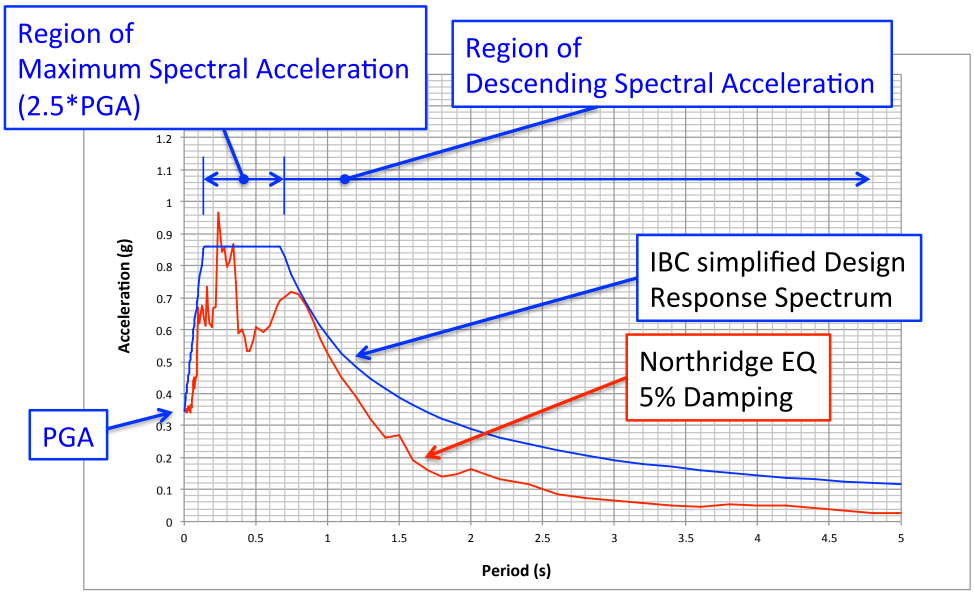
A response spectrum of an earthquake motion is a plot of the maximum acceleration that a series of single degree of freedom systems will experience when subjected to that earthquake motion.

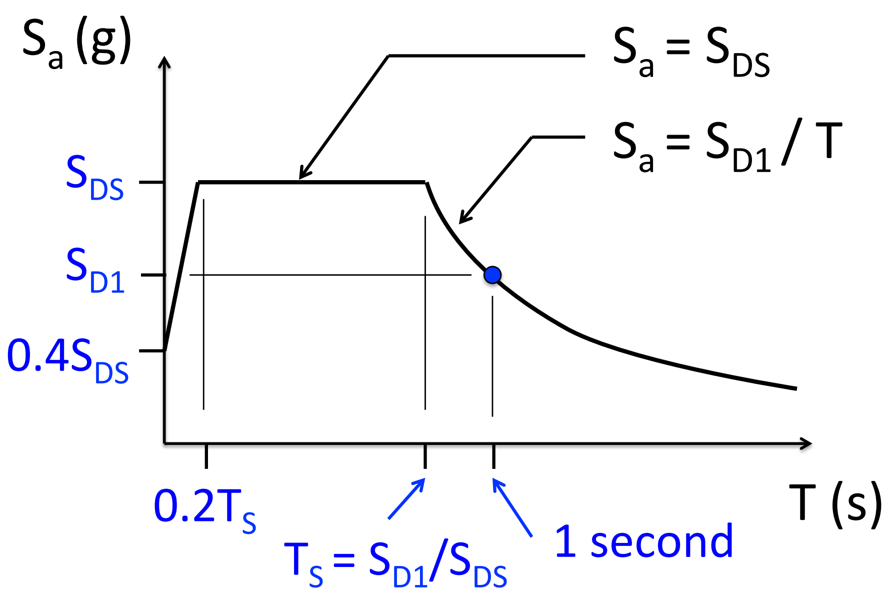
Example of the 1994 Northridge Earthquake Response Spectrum



IBC Design Response Spectrum

The building code contains a simplified response spectrum that is compiled from and represents the characteristics of many known earthquake motions. This is known as the **IBC Design Response Spectrum** and it can be constructed for any site based on the **seismicity of the site** and the **soil conditions** at the site.



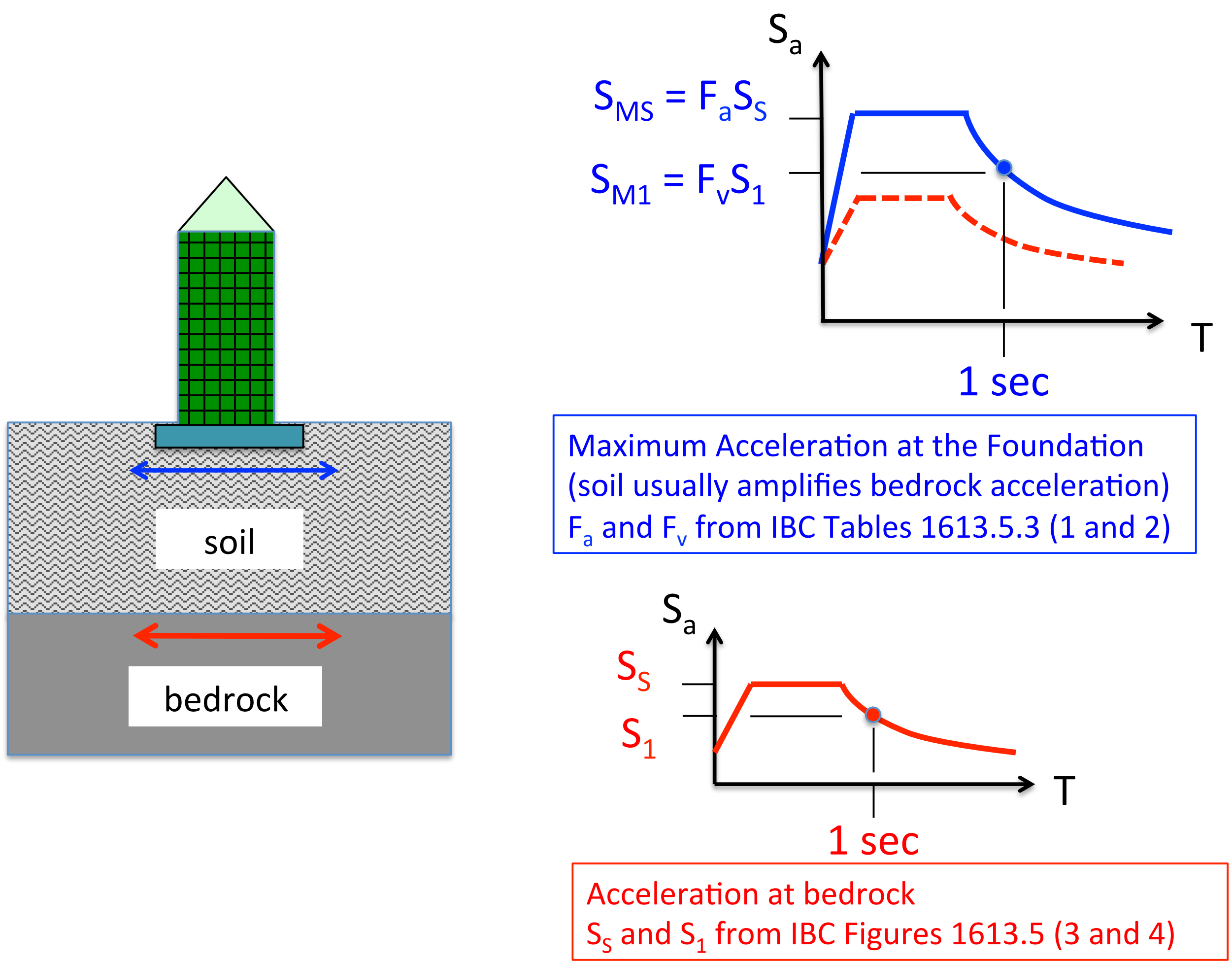


S_{DS} = Design Short Period Spectral Acceleration
S_{D1} = Design One-Second Period Spectral Acceleration

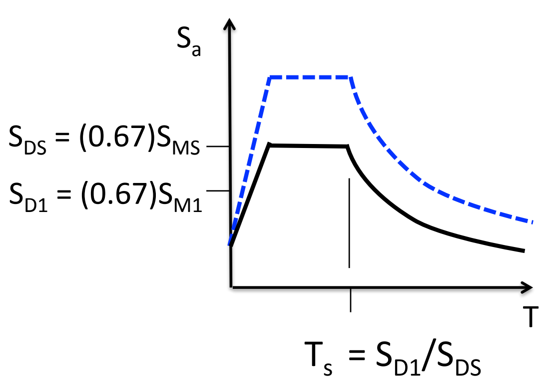
S_{DS} and S_{D1} are computed from the **seismicity** and **soil conditions** at the site.

Finding the IBC Design Response Spectrum for a building site

The figure below shows how design response spectrum is constructed based on the seismicity of the site and the soil conditions at the site.



The Design Response Spectrum is found by multiplying the Maximum Acceleration Response Spectrum values by two-thirds (0.67)



Finding the design earthquake acceleration for a building

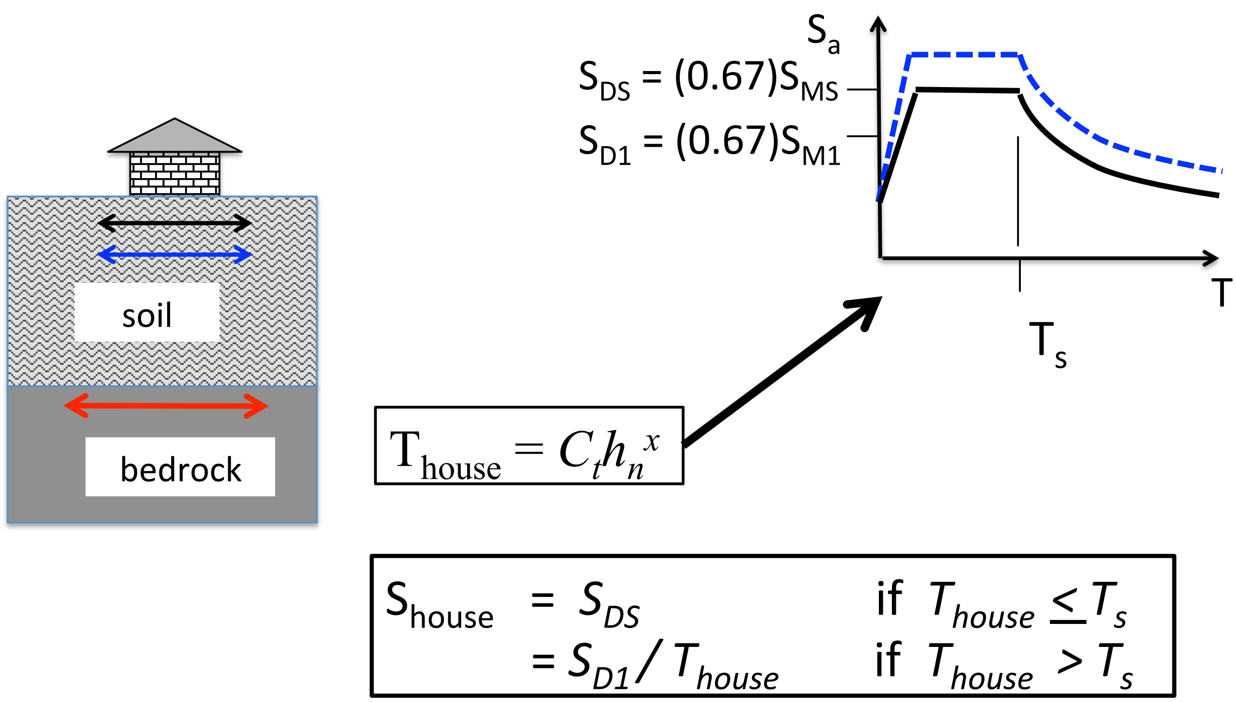
Once the response spectrum is found for the site based on the seismicity and the soil conditions at the site the design acceleration for the building can be found using the **occupancy category of the building** and the **fundamental period of vibration** of the building.

Recall that the fundamental period of vibration of the building is found using:

$$\boldsymbol{T = C_t h_n^x}$$

An importance factor (I_e) is assigned to a building based on its occupancy category. An importance factor greater that 1.0 is assigned to buildings that we would like to perform better in the event of an earthquake. The importance factor for different occupancy categories can be found in **IBC Table 1604.5 and ASCE 7 Table 1.5-2.**

The figure below illustrates the process for a standard occupancy building **($I_e = 1.0$)**

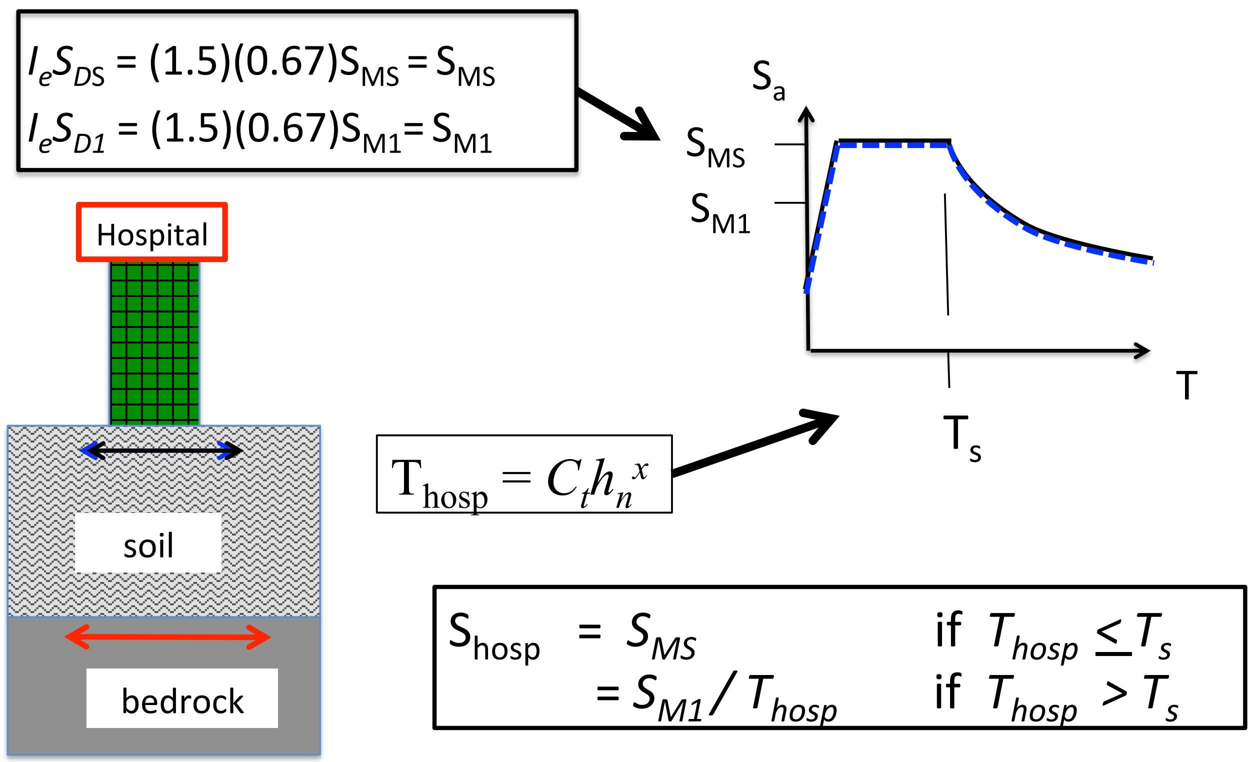


Note that the largest importance factor is 1.5 for essential facilities (hospitals, fire stations, etc.); which, in effect, sets the design accelerations to the maximum credible accelerations (S_{MS} or S_{M1}).

$$I_e S_{DS} = (1.5)\frac{2}{3}(S_{MS}) = \boldsymbol{S_{MS}}$$

$$I_e S_{D1} = (1.5)\frac{2}{3}(S_{M1}) = \boldsymbol{S_{M1}}$$

The figure below illustrates the process for an essential facility (***I_e = 1.5***)



The USGS website now calculates S_{MS}, S_{DS}, S_{M1}, and S_{D1} and shows the response spectra for specific sites

Design Maps Summary Report 4/17/14, 2:18 PM

USGS Design Maps Summary Report

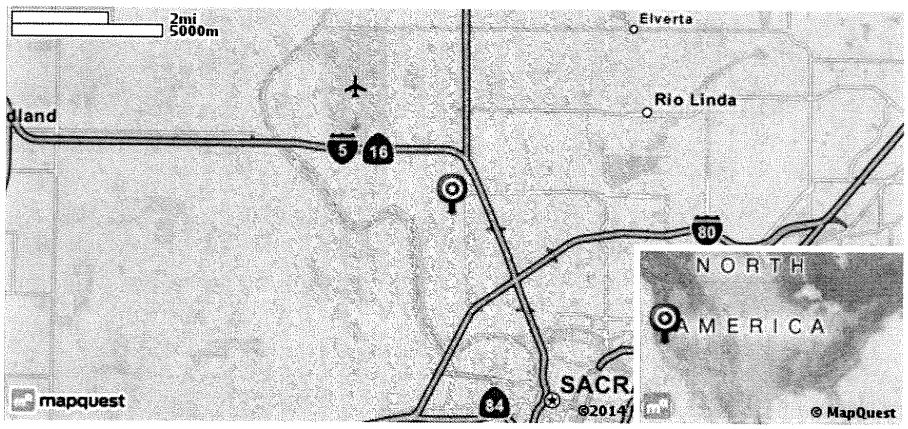
User–Specified Input

Building Code Reference Document 2006/2009 International Building Code
(which utilizes USGS hazard data available in 2002)

Site Coordinates 38.6475°N, 121.54589°W

Site Soil Classification Site Class C – "Very Dense Soil and Soft Rock"

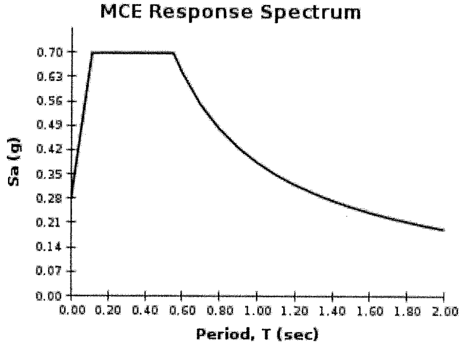
Occupancy Category I/II/III



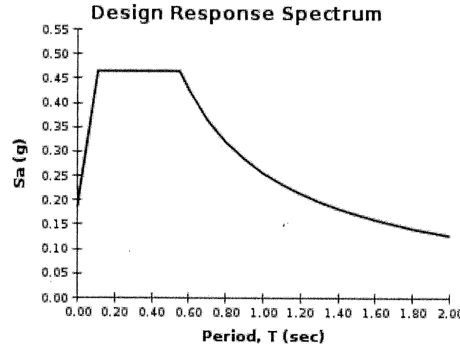
USGS–Provided Output

S_S = 0.602 g	S_{MS} = 0.698 g	S_{DS} = 0.465 g
S_1 = 0.248 g	S_{M1} = 0.384 g	S_{D1} = 0.256 g

MCE Response Spectrum



Design Response Spectrum

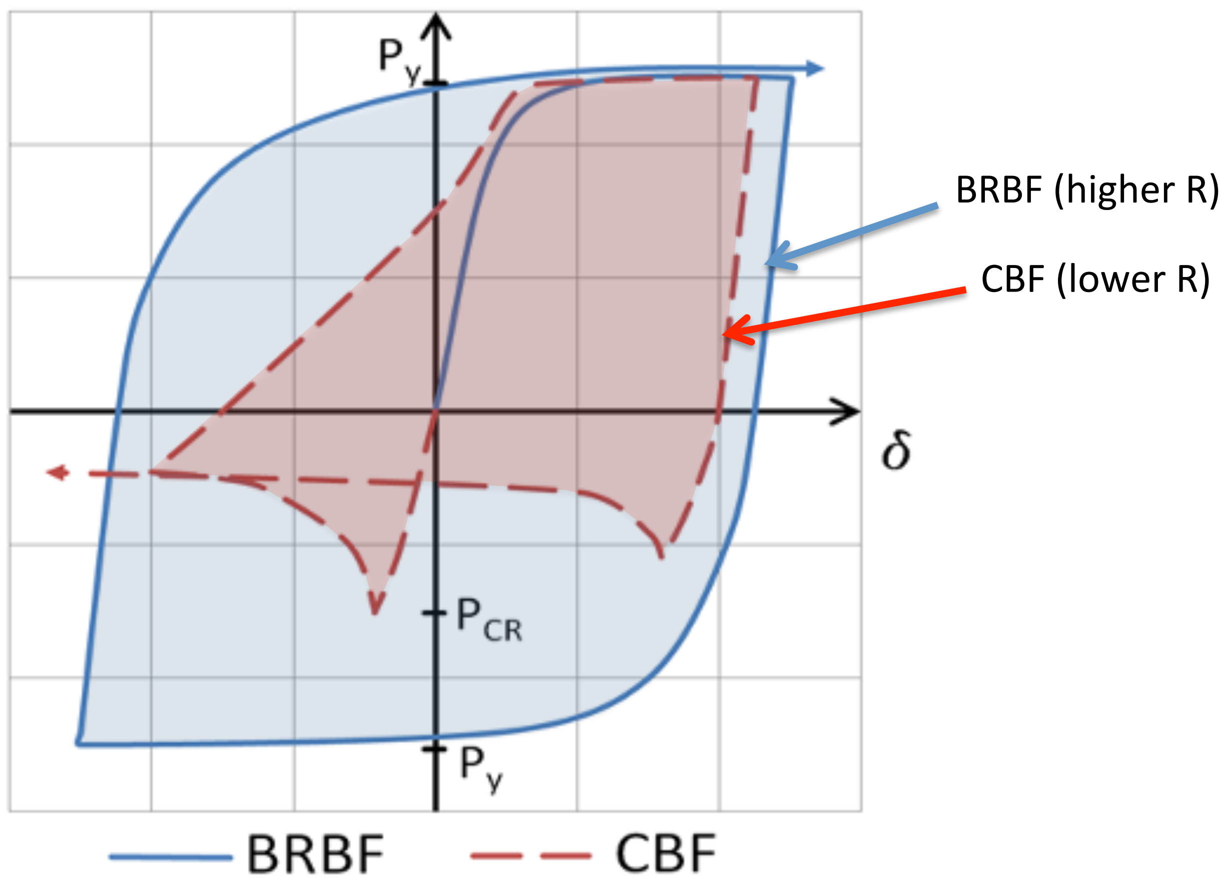


Energy Dissipating Capacity of the Lateral Force Resisting System

The base shear is adjusted for the earthquake energy dissipation of the Lateral Force Resisting System by dividing by a Response Modification Coefficient, R;

The Response Modification Coefficient is a measure of the energy dissipating characteristics of lateral force resisting system based on test results and performance in past earthquakes. The Response Modification Coefficient can be found in **ASCE 7 Table 12.2-1.**

A high R value is assigned to systems that can effectively dissipate earthquake energy.



IBC Base Shear

$$V = \begin{cases} \left[\dfrac{I_e(S_{DS})}{R}\right] W & for\ T \le T_S \\ \left[\dfrac{I_e(\ S_{D1})}{T(R)}\right] W & for\ T > T_S \end{cases}$$

where:

W = Total Seismic Weight of Building
Dead load plus portions of snow and live loads when appropriate by code.

I_e = Importance Factor: **IBC Table 1604.5 and ASCE 7 Table 1.5-2**

$T_s = S_{D1}/S_{DS}$ Control period from IBC design spectrum in seconds

T = Estimated Fundamental Period of Structure in seconds

S_{DS} and S_{D1} = Design Spectral Response Accelerations

S_S = Maximum Short Period (0.2 sec) Acceleration at bedrock: **IBC Fig. 1613.5(3)**
S_1 = Maximum One Second Period Acceleration at bedrock: **IBC Fig. 1613.5(4)**

$S_{MS} = F_a S_S$ = Maximum Short Period (0.2 sec) Acceleration at base of structure
$S_{M1} = F_v S_1$ = Maximum One-Second Period Acceleration at base of structure

F_a = Soil Amplification Factor: **IBC Table 1613.5.3(1)**
F_v = Soil Amplification Factor: **IBC Table 1613.5.3(2)**
Note that Soil Amplification Factors depend on the
IBC Site Class (**IBC Table 1613.5.2**) and S_S and S_1.
Linear interpolation of Tables 1613.5.3 is OK.

S_{DS} = Design Short Period Spectral Acceleration: $S_{DS} = (2/3)S_{MS}$
S_{D1} = Design One Second Period Spectral Acceleration: $S_{D1} = (2/3)S_{M1}$

R = Response Modification Coefficient: **ASCE 7 Table 12.2-1**

CE 160 Lab #9 Problem

$$V = \begin{cases} \left[\dfrac{I_e(S_{DS})}{R}\right]W & for\ T \le T_S \\ \left[\dfrac{I_e(\ S_{D1})}{T(R)}\right]W & for\ T > T_S \end{cases}$$

where $T_S = S_{D1}/S_{DS}$

From the USGS Design Maps website the design response spectrum for a building site (site class C near Sacramento, CA) is found (see page 12 of your Lab 9 and 10 notes).

If the fundamental period of vibration of the building is estimated to be 0.90 seconds, the building is in occupancy category II (I_e = 1.0), the lateral force resisting system is a steel concentrically braced frame (R = 6), and the seismic weight of the building is 2150 k, find the design seismic base shear for the building.

Example problem to illustrate the process of finding the IBC base shear

Our CE 160 Lab Example Building is a retail building located in Sacramento, CA. The geotechnical engineer has determined that the soil at the site can be classified as Site Class C. Recall that the roof weight was determined in Lab #4 to be 29 psf. In addition, the non-structural exterior curtain walls weigh 15 psf (including the concrete walls) and it is estimated that the interior partition walls will add 14 k to the seismic weight. Determine the IBC base shear for earthquake acceleration in the East-West direction for our example building.

Find the Importance Factor

IBC Table 1604.5 and ASCE 7 Table 1.5-2

TABLE 1604.5
OCCUPANCY CATEGORY OF BUILDINGS AND OTHER STRUCTURES

OCCUPANCY 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 Occupancy 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: • Covered structures whose primary occupancy is public assembly with an occupant load greater than 300. • Buildings and other structures with elementary school, secondary school or day care facilities with an occupant load greater than 250. • Buildings and other structures with an occupant load greater than 500 for colleges or adult education facilities. • Health care facilities with an occupant load of 50 or more resident patients, but not having surgery or emergency treatment facilities. • Jails and detention facilities. • Any other occupancy with an occupant load greater than 5,000. • Power-generating stations, water treatment for potable water, waste water treatment facilities and other public utility facilities not included in Occupancy Category IV. • Buildings and other structures not included in Occupancy Category IV containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released.
IV	Buildings and other structures designated as essential facilities, including but not limited to: • Hospitals and other health care facilities having surgery or emergency treatment facilities. • Fire, rescue and police stations and emergency vehicle garages. • Designated earthquake, hurricane or other emergency shelters. • Designated emergency preparedness, communication, and operation centers and other facilities required for emergency response. • Power-generating stations and other public utility facilities required as emergency backup facilities for Occupancy Category IV structures. • Structures containing highly toxic materials as defined by Section 307 where the quantity of the material exceeds the maximum allowable quantities of Table 307.1.(2). • Aviation control towers, air traffic control centers and emergency aircraft hangars. • Buildings and other structures having critical national defense functions • Water treatment facilities required to maintain water pressure for fire suppression.

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.

Our example retail building is a Category II building so:

$$I_e = 1.0$$

Find the IBC Estimate of the Fundamental Period of the Building

$$T = C_t h_n^x \qquad (in\ seconds)$$

where: h_n = average roof height above base of building in feet

x = exponent based on type of lateral force resisting system

= 0.8 for steel moment resisting frames

= 0.9 for concrete moment resisting frames

= 0.75 for eccentrically braced steel frames

= 0.75 for all other systems (shear walls, concentric frames, etc.)

C_t = coefficient based on type of lateral force resisting system

= 0.028 for steel moment resisting frames

= 0.016 for concrete moment resisting frames

= 0.030 for eccentrically braced steel frames

= 0.020 for all other systems (shear walls, concentrically braced frames, etc.)

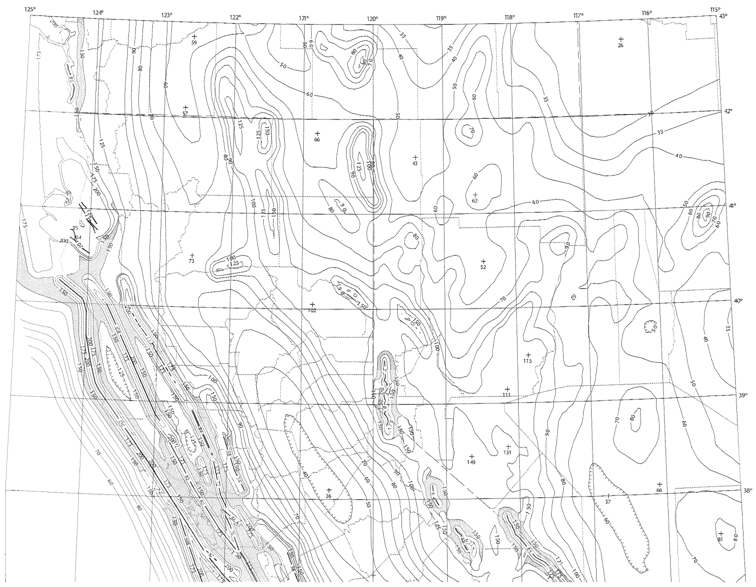
For our example building in the East-West Direction the Lateral Force Resisting System are Moment Resisting Frames on lines A, B, C, and D and the roof height is 20 feet.

$$\boldsymbol{T = C_t h_n^x = (0.028)(20)^{(0.8)} = 0.308\ seconds}$$

Find the Design Spectral Accelerations S_{DS} and S_{D1}

1. Find the Maximum Short and One-Second Period Ground Accelerations at Bedrock

S_S = Maximum Short Period (0.2 sec) Acceleration at bedrock: Fig. 1613.5(3)



For site use S_S = 0.60 (from USGS website)

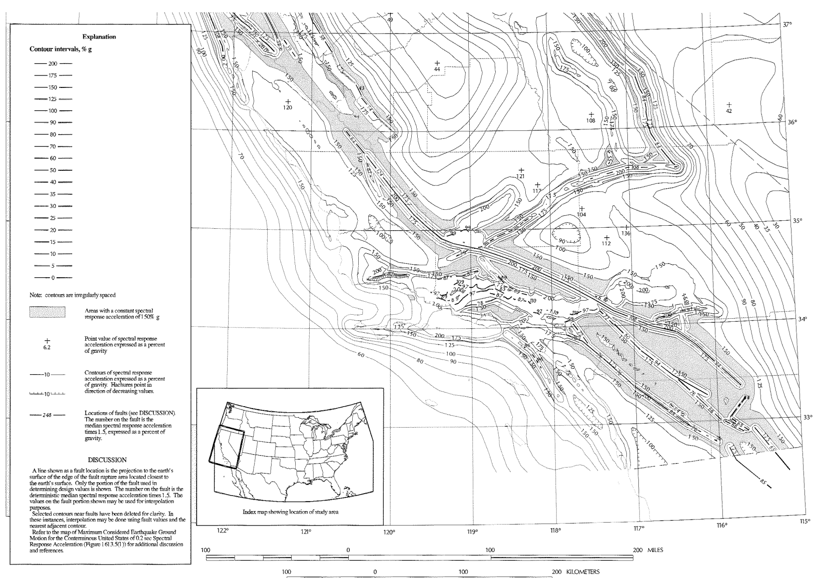
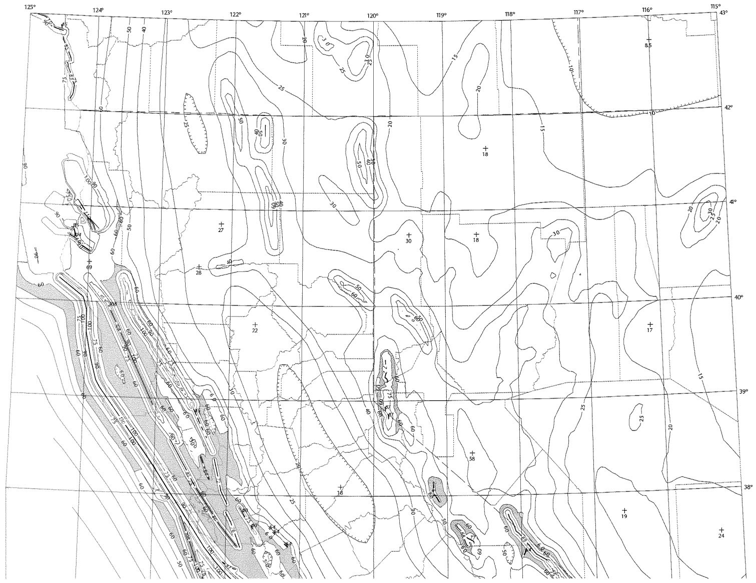


FIGURE 1613.5(3)—continued
MAXIMUM CONSIDERED EARTHQUAKE GROUND MOTION FOR REGION 1 OF
0.2 SEC SPECTRAL RESPONSE ACCELERATION (5% OF CRITICAL DAMPING), SITE CLASS B

S_1 = Maximum One-Second Period Acceleration at bedrock: Fig. 1613.5(4)



For site use S_1 = 0.25 (from USGS website)

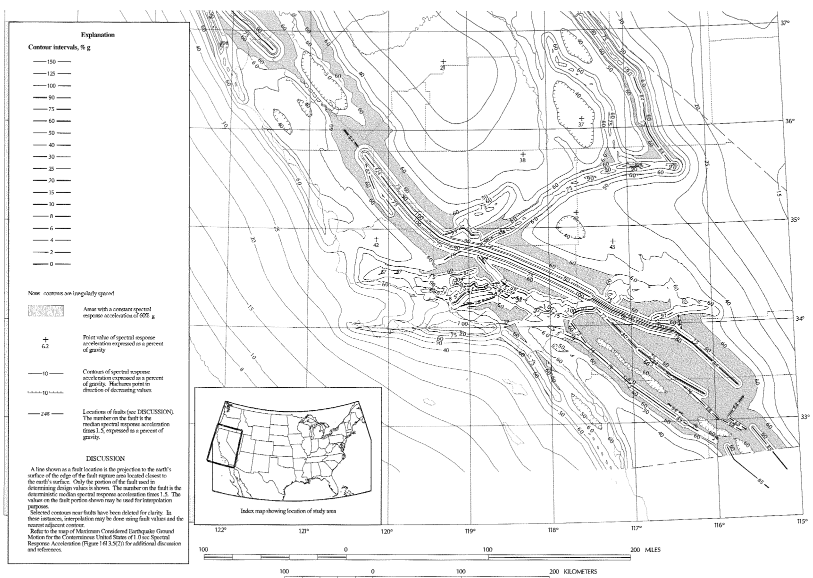


FIGURE 1613.5(4)—continued
MAXIMUM CONSIDERED EARTHQUAKE GROUND MOTION FOR REGION 1 OF
1.0 SEC SPECTRAL RESPONSE ACCELERATION (5% OF CRITICAL DAMPING), SITE CLASS B

2. **Effect of Soil Amplification of Bedrock Accelerations: Find F_a and F_v**

F_a = Soil Amplification Factor: Table 1613.5.3(1)
F_v = Soil Amplification Factor: Table 1613.5.3(2)

Note that Soil Amplification Factors depend on the IBC Site Class (Table 1613.5.2) and S_S and S_1.
Linear interpolation of Tables 1613.5.3 is OK.

For our Example -- Site Class C (from the geotechnical investigation of the site)

TABLE 1613.5.2
SITE CLASS DEFINITIONS

SITE CLASS	SOIL PROFILE NAME	AVERAGE PROPERTIES IN TOP 100 feet, SEE SECTION 1613.5.5		
		Soil shear wave velocity, $\bar{v}_s$, (ft/s)	Standard penetration resistance, $\bar{N}$	Soil undrained shear strength, $\bar{s}_u$, (psf)
A	Hard rock	$\bar{v}_s > 5{,}000$	N/A	N/A
B	Rock	$2{,}500 < \bar{v}_s \le 5{,}000$	N/A	N/A
C	Very dense soil and soft rock	$1{,}200 < \bar{v}_s \le 2{,}500$	$\bar{N} > 50$	$\bar{s}_u \ge 2{,}000$
D	Stiff soil profile	$600 \le \bar{v}_s \le 1{,}200$	$15 \le \bar{N} \le 50$	$1{,}000 \le \bar{s}_u \le 2{,}000$
E	Soft soil profile	$\bar{v}_s < 600$	$\bar{N} < 15$	$\bar{s}_u < 1{,}000$
E	—	Any profile with more than 10 feet of soil having the following characteristics: 1. Plasticity index $PI > 20$, 2. Moisture content $w \ge 40\%$, and 3. Undrained shear strength $\bar{s}_u < 500$ psf		
F	—	Any profile containing soils having one or more of the following characteristics: 1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils. 2. Peats and/or highly organic clays ($H >$ 10 feet of peat and/or highly organic clay where H = thickness of soil) 3. Very high plasticity clays ($H >$ 25 feet with plasticity index $PI >$ 75) 4. Very thick soft/medium stiff clays ($H >$ 120 feet)		

For SI: 1 foot = 304.8 mm, 1 square foot = 0.0929 m^2, 1 pound per square foot = 0.0479 kPa. N/A = Not applicable

Find F_a

TABLE 1613.5.3(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.

Site Class C and $S_S = 0.6$ so linearly interpolate between 1.2 ($S_S = 0.5$) and 1.1 ($S_S = 0.75$) from Table 1613.3.3(1)

$$\frac{0.75 - 0.6}{0.75 - 0.5} = \frac{1.1 - F_a}{1.1 - 1.2}$$

$F_a = 1.16$

Find F_v

TABLE 1613.5.3(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.

Site Class C and $S_1 = 0.25$ so linearly interpolate between 1.6 ($S_1 = 0.2$) and 1.5 ($S_1 = 0.3$) from Table 1613.3.3(2)

$$\frac{0.30 - 0.25}{0.30 - 0.20} = \frac{1.5 - F_v}{1.5 - 1.6}$$

$F_v = 1.55$

3. Calculate the Design Accelerations; S_{DS} and S_{D1}

$$S_{MS} = F_a S_S = (1.16)(0.6) = 0.696\ g$$

$$S_{M1} = F_v S_1 = (1.55)(0.25) = 0.3875\ g$$

$$S_{DS} = \frac{2}{3} S_{MS} = \frac{2}{3} F_a S_S = \frac{2}{3}(1.16)(0.6) = 0.464\ g$$

$$S_{D1} = \frac{2}{3} S_{M1} = \frac{2}{3} F_v S_1 = \frac{2}{3}(1.55)(0.25) = 0.258\ g$$

Checks with USGS website on page 12 (Now the website calculates S_{MS}, S_{DS}, S_{M1}, and S_{D1})

We can now calculate T_s:

$$T_s = \frac{S_{D1}}{S_{DS}} = \frac{0.258}{0.464} = 0.557\ seconds$$

Note that:

$$T = 0.308 < T_s = 0.557$$

so:

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

Find the Response Modification Coefficient

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

Continued

For our building in the East-West Direction the Lateral Force Resisting System is a Special Moment Resisting Frame

From ASCE 7 Table 12.2-1:

R = 8

Calculate East-West Base Shear

$$V = \frac{S_{DS}}{(R/I_e)}W = \frac{0.464}{(8/1.0)}W = (0.058)W$$

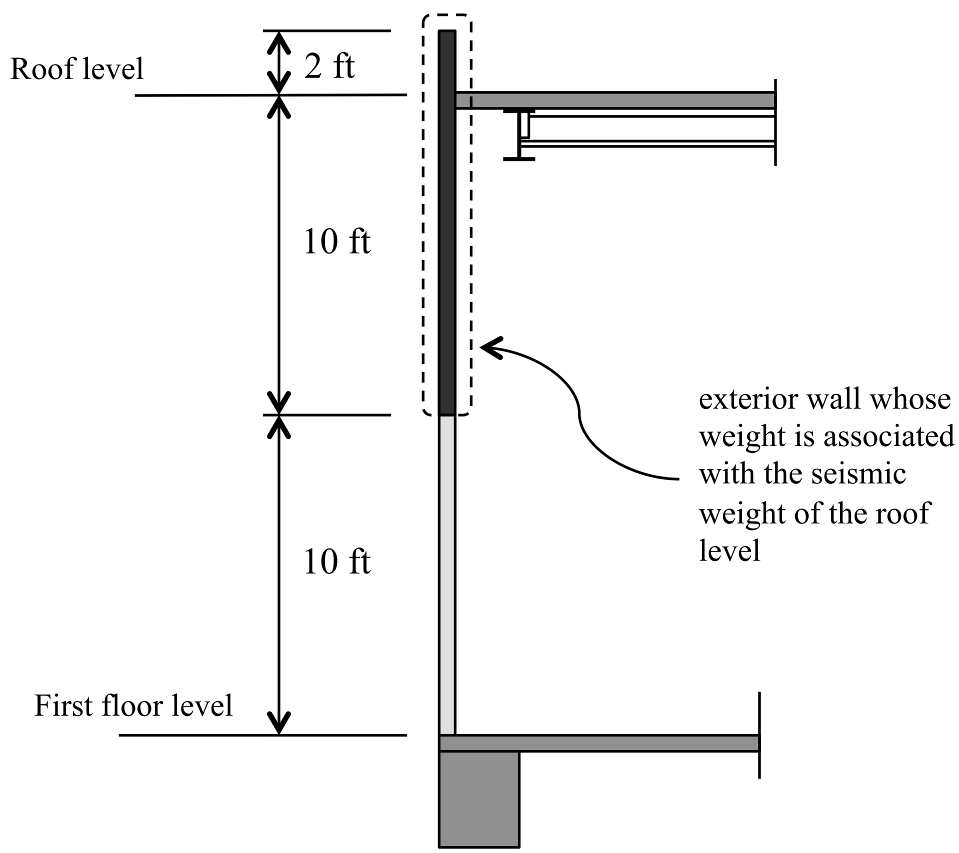
CE 160 Lab #10 Problem

Lab 10 -- Exercise 1

Find Seismic Weight, *W,* and then find East-West Base Shear, *V*.

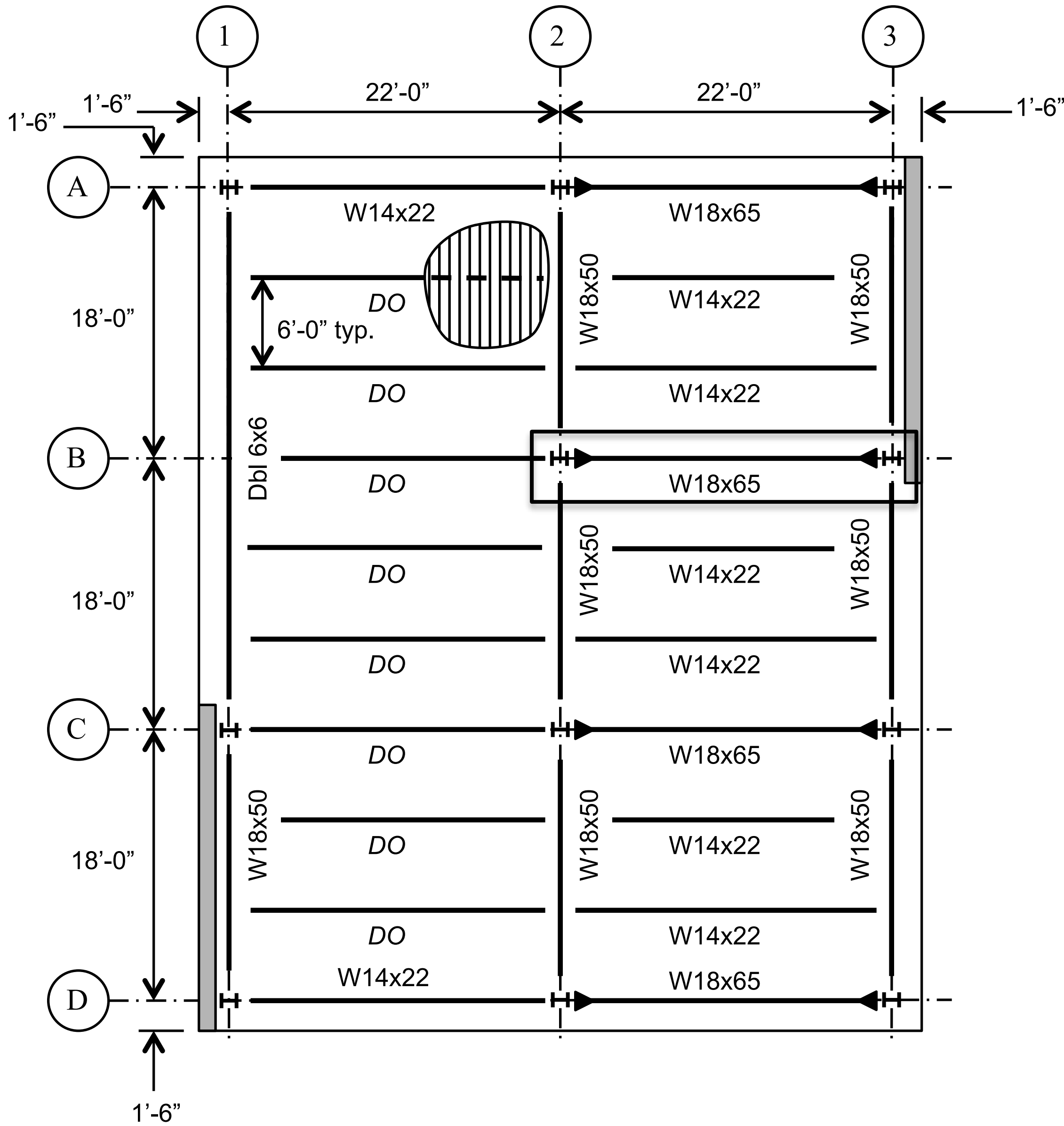
Note that:

W = weight of roof + weight of perimeter curtain walls + interior partition walls

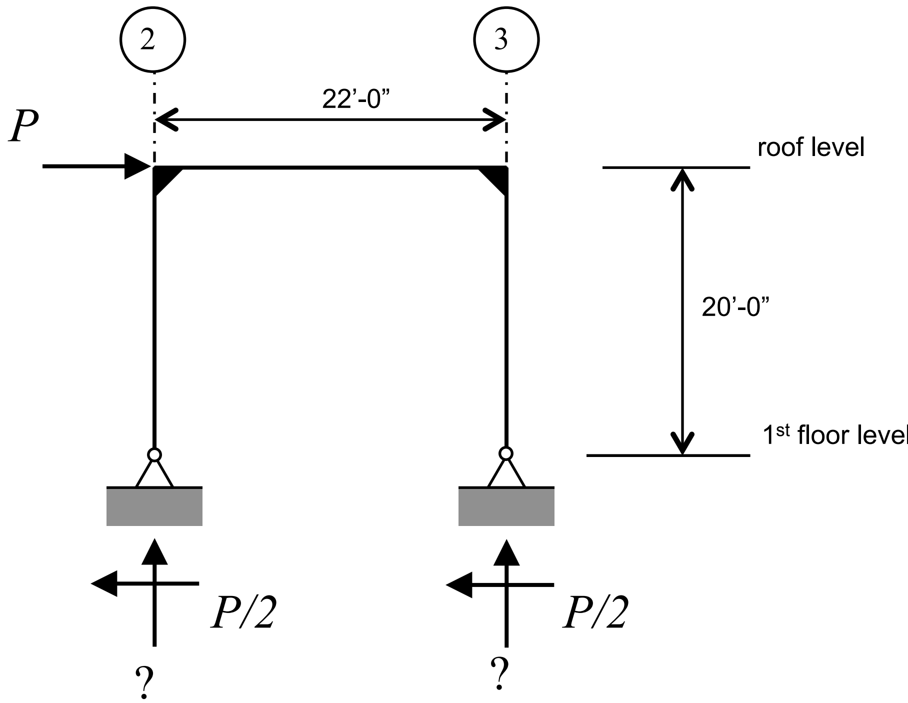


Lab 10 -- Exercise 2

Find the seismic load to the moment resisting frame on line B and construct **Shear, Moment, and Axial Force diagrams for the frame**.

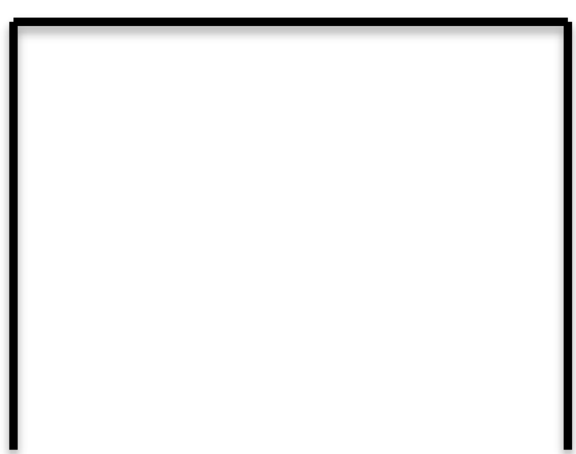


Assume that the shear force in each column is equal to half the earthquake force to the frame as shown below.



Draw your diagrams on the outline of the frame below and clearly choose a sign convention for each diagram.

Shear Diagram



Moment Diagram

Axial Force Diagram