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Seismic load calculations per the NYS 2002 code

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SEISMIC LOAD CALCULATIONS PER THE NYS 2002 CODE

By

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Introduction

- Seismic loads are calculated differently for the **PRIMARY SYSTEM** (i.e. the lateral-load-resisting-system) than for **PARTS & COMPONENTS** such as architectural, mechanical and electrical fixtures.

- For seismic load calculations on PARTS & COMPONENTS, see IBC section 1621

- The seismic design category (**SDC**) determines the applicable *seismic analysis procedure, the seismic detailing requirements*, *quality-assurance plans*, and *height limitations* for building structures.

The **SDC** depends on:

- Building location
- Building use and occupancy (i.e. seismic use group, SUG: see IBC Table 1604.5)
- Soil type

The are SIX SDC's identified in the IBC:

Seismic Design Categories (SDC)	Application
A	• Applies to structures (irrespective of use) in regions where ground motions are minor even for very long periods
B	• Applies to SUG I and SUG II structures in regions where moderately destructive ground shaking is anticipated.
C	• Applies to SUG III structures in regions where moderately destructive ground shaking is anticipated • Applies to SUG I and II structures in regions where somewhat more severe ground shaking is anticipated.
D	• Applies to SUG I, II and III structures in regions where destructive ground shaking is anticipated, BUT not located close to major active faults
E	• Applies to SUG I and II structures in regions located close to major active faults
F	• Applies to SUG III structures in regions located close to major active faults.

There are three Seismic Use Groups (SUGs):

SEISMIC USE GROUP (SUG)	TYPE OF OCCUPANCY	SEISMIC IMPORTANCE FACTOR, I_E
SUG I	Standard Occupancy Buildings	1.0
SUG II	Assembly Buildings	1.25
SUG III	Essential Facilities & Hazardous Facilities	1.50

Table S-1: Determining the Seismic Design Category[1]

STEP	Column 2 **SHORT-PERIOD** ground motion, Ss	Column 3 **LONG-PERIOD** ground motion, S_1
Determine spectral response accelerations from contour maps (Fig 1615) or from the website with the URL given below*	At short (0.2-second) period, $\mathbf{S_s}$ (Site Class B) (given as a fraction or % of **g**)	At long (1-second) period, $\mathbf{S_1}$ (Site Class B) (given as a fraction or % of **g**)
Determine Site Class: (Usually specified by the Geo-technical Engineer in the Soils Report) or Table 1615.1.1		
• If Site Class is F	Do SITE-SPECIFIC design	Do SITE-SPECIFIC design
• If data available for shear wave velocity, standard penetration resistance (SPT), and undrained shear strength	Choose from Site Class A to E	Choose from Site Class A to E
• If no soil data available	Use Site Class D	Use Site Class D
Determine site coefficient for acceleration or velocity (%**g**)	Determine $\mathbf{F_a}$ from IBC Table 1615.1.2 (1)	Determine $\mathbf{F_v}$ from IBC Table 1615.1.2 (2)
Determine soil-modified spectral response acceleration (%**g**)	$\mathbf{S_{MS}} = F_a \, S_s$ Equation 16-16	$\mathbf{S_{M1}} = F_v \, S_1$ Equation 16-17
Calculate the design spectral response acceleration (%**g**)	$\mathbf{S_{DS}} = 2/3 \, S_{MS}$ Equation 16-18	$\mathbf{S_{D1}} = 2/3 \, S_{M1}$ Equation 16-19
Determine Seismic Use Group (SUG) of the structure from IBC **section 1616.2 and determine the Importance factor $\mathbf{I_E}$ from Table 1604.5**	SUG I = Standard Occupancy Buildings SUG II = Assembly Buildings SUG III = Essential Facilities & Harzardous Facilities	SUG I = Standard Occupancy Buildings SUG II = Assembly Buildings SUG III = Essential Facilities & Harzardous Facilities
Determine Seismic Design Category (SDC)	A, B, C, or D* as a function of SUG and S_{DS} from IBC Table 1616.3(1)	A, B, C, or D* as a function of SUG and S_{D1} from IBC Table 1616.3(2)
Choose most severe SDC	COMPARE Column 2 with Column 3 from previous line **NOTE:** • SDC = "E" for SUG I & II with mapped $S_1 > 0.75g$ • SDC = "F" for SUG III with mapped $S_1 > 0.75g$	

* http://eqhazmaps.usgs.gov/html/zipcode.html

NOTE:

- Best to shoot for SDC of A, B, or C, but the SDC value for any building will depend largely on the **soil conditions at the site** and the structural properties of the building
- If SDC = D, E of F, consult the IBC Code for several additional requirements!!!!

IF S_s ≤ 15%g and **S_1 ≤ 4%g** ⇒ **SDC = "A" ⇒ Refer to IBC Section 1616.4**
IF S_{DS} ≤ 16.7%g and **S_{D1} ≤ 6.7%g** ⇒ **SDC = "A" ⇒ Refer to IBC Section 1616.4**

SEISMIC ANALYSIS OF BUILDINGS USING THE NYS 2002 CODE

There are several methods for Seismic Analysis in the NYS 2002 Code. The appropriate method of analysis to be used is determined from Table S-2 and will depend on the SDC determined from *Table S-1*

Table S-2: SEISMIC DESIGN CATEGORIES & DESIGN REQUIREMENTS

The seismic design category (SDC) determines the applicable seismic analysis procedure. The table below gives the applicable analysis procedure as a function of the SDC.

MINIMUM PERMISSIBLE ANALYSIS PROCEDURE (1616.6)	APPLICABLE STRUCTURE & SDC
Minimum Lateral Force Procedure (IBC section 1616.4.1)	• SDC **A** structures
Simplified Procedure (IBC section 1617.5)	• SDC **B**, **C**, **D**, **E** & **F** structures with the following characteristics: ✓ SUG I structures of light frame construction, three stories or less in height, excluding basements ✓ SUG I structures of any material, other than light frame, two stories or less in height (excluding basements) with flexible diaphragm at every level
Equivalent Lateral Force Procedure (IBC section 1617.4)	• SDC **B** & **C** structures, except those eligible for the simplified method above • SDC **D**, **E** & **F** *REGULAR*** structures *up to* 240 ft in height
Dynamic Analysis Procedure (IBC section 1618) IBC dynamic analysis procedures: • Modal Response Spectra Analysis • Elastic Time-history Analysis • Inelastic Time-history Analysis	• SDC **D**, **E** & **F** *REGULAR*** structures *exceeding* 240 ft in height • SDC **D**, **E** & **F** structures *greater than or equal* to FIVE stories or 65 ft in height with: ✓ Vertical *Irregularity*** type 1a, 1b (stiffness), 2 (weight)) or 3 (vertical geometric). **See Table 1616.5.2** or ✓ Plan *Irregularity*** type 1a or 1b (torsion). **See Table 1616.5.1**
Equivalent Lateral Force Procedure with dynamic characteristics included in analytical model	• SDC **D**, **E** & **F** structures with: ✓ Vertical *Irregularity*** type 4 (in-plane lateral system) & 5 (weak story). **See Table 1616.5.2** or ✓ Plan *Irregularity*** type 2 (re-entrant corners), 3 (diaphragm), 4 (out-of-plane offsets) & 5 (non-parallel systems). **See Table 1616.5.1**
Dynamic Analysis Procedure with Site-specific Response Spectrum	• SDC **D**, **E** & **F** structures that have **all** of the following characteristics: ✓ Design spectral acceleration, $S_{D1} \geq 0.2$ ✓ Site Class E or F ✓ Structure Period, $T \geq 0.7$ sec

** See section 1616.5 for definition of *REGULAR* and *IRREGULAR* structures

EQUIVALENT LATERAL FORCE (ELF) METHOD FOR CALCULATING SEISMIC BASE SHEAR, V

The **FACTORED** Seismic Base Shear is given as: $\mathbf{V = C_s\, W}$

NOTE: The design seismic forces shall be applied separately in each of TWO orthogonal directions.

W = Total Dead Load (including cladding loads) **PLUS** other loads listed below:

- **25%** of Floor Live Load for Warehouses and Structures used for storage of goods, wares or merchandise. (PUBLIC GARAGES & OPEN PARKING STRUCTURES ARE EXCEPTED)
- Partition load or 10 psf, whichever is greater. (**NOTE**: This only applies when an allowance for partition load was included in the floor load calculations/design)
- Total operating weight of permanent equipment.
- **20%** of the flat roof or balanced Snow load, P_f, where the roof snow load ≥ 30 psf

C_s = Seismic Response Coefficient = $\mathbf{S_{DS} / [\, R/ I_E\,] \leq S_{D1} / [\, T\ \ R/ I_E\,]}$
$\mathbf{\geq 0.044\, S_{DS}\ I_E}$

For Buildings in SDC **"E" or "F"** , and those buildings and structures with $\mathbf{S_1 \geq 60\%g}$, **Cs shall be** $\mathbf{\geq 0.5\, S_1/(R / I_E)}$

Where,

I_E = Importance Factor from IBC Table 1604.5

S_{DS} = Short period design spectral response acceleration (see Table S-1 on page 3)
S_{D1} = One-second design spectral response acceleration (see Table S-1 on page 3)
S_1 = Mapped one-second spectral acceleration

R = Structural System Response Modification Factor from **Table 1617.6**

The FIVE basic structural systems in Table 1617.6 are:

- **Bearing Wall Systems**: Lateral force resisting system (LFRS) that supports BOTH gravity and lateral loads. Therefore, "R" values are smaller because performance is not as good as Building frame system because it supports DUAL loading

- **Building Frame System**: LFRS that supports ONLY lateral load. It has better structural performance because it supports a SINGLE load; therefore, "R" values are higher than Bearing Wall systems.

- **Moment Resisting Frames**

- **Dual Systems** (Combined shear wall and moment-resisting frame)

- **Inverted pendulum and cantilever column systems**

T = <u>*Approximate*</u> Fundamental period of the building = $\mathbf{T_a = C_T (h_n^{3/4})}$

If a more exact analytical method is used to determine the fundamental period of the building, the calculated period used in determining the seismic loads MUST NOT EXCEED T_{max}., where:

T_{max} = Maximum Period = $C_u T_a$, where C_u is obtained from Table 1617.4.2

$\mathbf{h_n}$ = height (in feet) from the base to the highest level (i.e. the roof) of the building

Table S-3: C_T Values for various structural systems from *IBC section 1617.4.2.1*

STRUCTURAL SYSTEM	C_T
Steel Moment Resisting Frames resisting 100% of the lateral seismic load	0.035
Concrete Moment Resisting Frames resisting 100% of the lateral seismic load	0.03
Eccentric Braced Frames (EBF) or Dual Systems with Eccentric Braced Frames	0.03
Buildings with Shear Walls, Concentric Braced Frames (CBF) AND **all other buildings.**	0.02

VERTICAL DISTRIBUTION OF SEISMIC BASE SHEAR, V

Lateral Force at any level of the **VERTICAL LFRS** ,

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

where, $$C_{vx} = \left\{ W_x (h_x)^k \right\} \Big/ \left\{ \sum_{i=1}^{n} W_i (h_i)^k \right\}$$

W_i and W_x = Portion of the total Gravity Load of the building (**W**) that is LUMPED or CONCENTRATED at level **i** or **x** **(includes weight of floor or roof plus weight of perimeter or interior walls tributary to that level)**

NOTE:
The weight of tributary walls at a particular level, ***x*** is the sum of the weights of the walls mid-way to the floor above level ***x*** and mid-way to the floor below level ***x***

h_i and h_x = height (in feet) from the base to level **i** or **x**

k = An exponent related to the building period (refer to *Table S-4*)
(*This exponent takes into account the whiplash effects in tall slender buildings*)
:
TABLE S-4: **k** values

Building Period, T in seconds	**k**
≤ 0.5	1 (*No whiplash effect*)
0.5<**T**<2.5	{1 + 0.5(**T**-0.5)}
≥ 2.5	2

Level **i** = any level in the building (**i = 1** for first level above the base)
Level **x** = that level which is under design consideration
Level **n** = the uppermost level of the building

STORY SHEAR DUE TO SEISMIC FORCES

The Seismic design story shear force, $\mathbf{V_x} = \sum_{\mathbf{i=x}}^{\mathbf{n}} \mathbf{F_i}$

where,

$\mathbf{F_i}$	= lateral force induced at level **i**
Level **i**	= any level in the building **i = 1** for first level above the base
Level **x**	= that level which is under design consideration
Level **n**	= the uppermost level of the building

The seismic story shear is distributed among the lateral load resisting elements in that story based on the relative lateral stiffness of the lateral load resisting elements and the diaphragm.

BUILDINGS WITH IRREGULARITIES (IBC Tables 1616.5.1 & 1616.5.2)

- For buildings that are structurally irregular in PLAN, use Table 1616.5.1 to determine ADDITIONAL requirements that must be satisfied;
- Knowing the TYPE of irregularity and the Seismic Design Category (SDC), go to the appropriate "Referenced Code Section" from the middle column of Table 1616.5.1 to determine the requirements that must be satisfied
- For buildings that have VERTICAL structural irregularity, use Table 1616.5.2 to determine ADDITIONAL requirements that must be satisfied;
- Knowing the TYPE of irregularity and the Seismic Design Category (SDC), go to the appropriate "Referenced Code Section" from the middle column of Table 1616.5.2 to determine the requirements that must be satisfied.

ANALYSIS FOR TORSIONAL MOMENTS DUE TO SEISMIC FORCES

Two types of torsion must be considered in the analysis of buildings with **RIGID DIAPHRAGMS** (for FLEXURAL DIAPHRAGMS, torsion is not a consideration):

- Accidental Torsion
- Natural Torsion

The total torsional moment in the horizontal plane of the building at level **x** due to accidental and natural torsion is calculated as follows:

$$M_{Tx} = A_x (M_{tx} + M_{tax}) = A_x F_x e_x$$

M_{tx} = Torsional moment resulting from eccentricity of the resultant Seismic load from the center of rigidity of the building at level **x** (*Natural Torsion*)

M_{tax} = Accidental Torsional moment at level **x** (*Accidental Torsion*)

$$e_x = e \pm 0.05\,B$$

e_x = design eccentricity at level **x**

e = distance between the CENTER OF MASS (CM) and the CENTER OF RIGIDITY (CR) at the level being considered. (Natural Torsional Eccentricity)

0.05 B = Accidental Torsional Eccenticity

The X- and Y-coordinate location of the **CENTER OF RIGIDITY** at any level measured from an arbitrarily chosen origin can be determined by taking statical moments of the rigidities of the LFRS about the chosen origin using the following formulas:

$$Xcr = \frac{\sum_{i=1}^{n} Kyi \quad Xi}{\sum_{i=1}^{n} Kyi}$$

$$Ycr = \frac{\sum_{i=1}^{N} Kxi \quad Yi}{\sum_{i=1}^{N} Kxi}$$

The X- and Y-coordinate location of the locus of the **CENTER OF MASS** for the MULTI-STORY building measured from an arbitrarily chosen origin on plan can be determined by taking the statical moments of the weights of the floors and LFRS about the chosen origin using the following formulas:

$$Xcm = \frac{\sum_{i=2nd}^{Roof} W_i \; X_{cmi}}{\sum_{i=2nd}^{Roof} W_i}$$

$$Ycm = \frac{\sum_{i=2nd}^{Roof} W_i \; Y_{cmi}}{\sum_{i=2nd}^{Roof} Wi}$$

K_{xi} = stiffness of the lateral load-resisting elements that are parallel to the X-axis **with its centroid located at a perpendicular distance** Y_i from the chosen origin.

K_{yi} = stiffness of the lateral load-resisting elements that are parallel to the Y-axis **with its centroid located at a perpendicular distance** X_i from the chosen origin.

W_i = weight of floors and LFRS at each floor level with its center of mass at the floor level located at coordinates (X_{cmi}, Y_{cmi}) from the chosen origin.

K_{yi} = stiffness of the lateral load-resisting elements that are parallel to the Y-axis **with its centroid located at a perpendicular distance** X_i from the chosen origin.

n = Total number of lateral force-resisting elements parallel to the Y-axis

N = Total number of lateral force-resisting elements parallel to the X-axis

B = plan dimension of the building **PERPENDICULAR** to the direction of the seismic force.

The dynamic amplification factor for torsion, Ax, is give as:

A_x = $(\delta_{max}/1.2\ \delta_{avg})^2 \le 3.0$ **for buildings with Type 1 Plan irregularity** in SDC C, D, E or F

= **1.0** for ALL others

δ max = maximum lateral deflection at level ***x*** due to seismic forces

δ avg = average of the lateral deflections at the extreme points of the structure at level ***x***

Lateral Forces in LFRS due to Torsion

The lateral force in LFRS due to twist, $F_{Ti} = K_i\, d_i = K_i\,(Z_i\,\theta)$

The torsional equilibrium equation is written as:

Twisting moment, M_{Tx} $= \sum F_{Ti} \times Z_i$
$= \sum K_i\,(Z_i\,\theta) \times Z_i$
$= \sum K_i\,Z_i^2\,\theta$

Therefore, the diaphragm rotation, $\theta = M_{Tx} / \sum K_i\,Z_i^2$

The lateral force in the LFRS due to torsion, $\mathbf{F_{Ti}} = K_i\,(Z_i\,\theta)\ \mathbf{= M_{Tx}\ [\ K_i\,Z_i / \sum K_i\,Z_i^2\ ]}$

Z_i **=** Distance measured from the center of rigidity (CR) to the centroid of the LFRS, **perpendicular** to the longitudinal direction of the LFRS (use absolute values of Z_i)

K_i **=** Stiffness of the LFRS in the longitudinal direction

d_i = Lateral deflection of LFRS due to torsion

θ = Rotation of horizontal diaphragm about the CR due to torsion

LATERAL DEFLECTION DUE TO SEISMIC LOADS

The **INELASTIC** deflection of level ***x*** at the center of mass, $\delta_x = C_d \, \delta_{xe} / I_E$
where,

C_d = deflection amplification factor from Table 1617.6

δ_{xe} = lateral deflections from **ELASTIC** analysis caused by the Seismic forces at each level, F_x applied to the building

The story drift $\Delta_x = \delta_x - \delta_{x-1} \le \Delta_a$

- The Allowable Story Drifts, Δ_a are given in IBC Table 1617.3 as a function of the Seismic Use Group (SUG) and the story height, h_{sx}; refer to Table 1604.5 (or page 2 of these notes) for the Seismic Use Groups (SUG)
- For drift calculations, the redundancy factor, ρ is taken as 1.0

SEISMIC RELATIVE DISPLACEMENTS (IBC section 1621.1.5)
(e.g. relative lateral displacements between cladding connections)

The relative lateral displacement, D_p between two connection points -- one at an upper level x and the other at a lower level y-- on the same structure is determined as follows:

$$D_p = \delta_x - \delta_y \leq (X - Y)\,\Delta_a / h_{sx}$$

This displacement must be less than the allowable relative displacement to accommodate seismic movements

- δ_x and δ_y are the lateral displacements at levels **x** and **y,** and **X** and **Y** are the heights of levels **x** and **y**, respectively, measured from the base of the structure
- $\mathbf{h_{sx}}$ is the story height below level **x**

SEISMIC FORCES ON PARTS and COMPONENTS (IBC sections 1620 & 1621)

- For the calculation of seismic forces on STRUCTURAL components, refer to IBC section 1620.
- For the calculation of seismic forces on ARCHTECTURAL, MECHANICAL, and ELECTRICAL components, refer to IBC section 1621

HORIZONTAL DIAPHRAGMS SEISMIC FORCES, F_{px}
(IBC section 1620)

- Apart from the seismic lateral force, F_x, on the VERTICAL LFRS discussed earlier, the seismic forces, F_{px}, on the HORIZONTAL diaphragms need to be calculated separately to be used in the design of the diaphragms (i.e. roof or floors), drag struts or collectors, and associated connections.

- Note that the F_{px} at a particular level may be larger than the F_x at the level, because of the different dynamic response of HORIZONTAL DIAPHRAGMS and VERTICAL LFRS to earthquakes.

- The seismic lateral force, F_{px}, acting on a floor or roof diaphragm (in the plane of the diaphragm) is calculated in accordance with ***IBC section 1620.3.3 or ASCE 7-02 section 9.5.2.6.2.7***

- To obtain the equivalent uniformly distributed seismic lateral load on the diaphragm, divide the diaphragm lateral force by the length of the diaphragm *perpendicular* to the seismic force.

- These forces can be used to design the diaphragm assuming the floor or roof diaphragm acts like a deep horizontal beam that bends between the vertical lateral-load-resisting systems.

For SDC B and C:

$\mathbf{F_{px}} = F_x$

$\geq F_{px\ minimum} = 0.2\, S_{DS}\, I_E\, W_{px}$

For SDC D, E and F:

$$F_{px} = \mathbf{W_{px}} \left(\sum_{i=x}^{n} \mathbf{F_i} \right) \Bigg/ \left\{ \sum_{i=1}^{n} \mathbf{W_i} \right\}$$

$\geq F_{px\ minimum} = 0.2\, S_{DS}\, I_E\, W_{px}$

$\leq F_{px\ maximum} = 0.4\, S_{DS}\, I_E\, W_{px}$

NOTE:

- $\mathbf{F_{px}}$ is applied INDIVIDUALLY to each diaphragm level)
- $\mathbf{F_x}$ is applied SIMULTANEOUSLY to each diaphragm

$\mathbf{F_{px}}$ = Horizontal force on diaphragm at level, ***x***
$\mathbf{F_i}$ = Lateral force at level ***i***, determined using the formula for $\mathbf{F_x}$ **(see page 91)**
$\mathbf{W_{px}}$ = Weight of horizontal diaphragm and walls tributary to diaphragm at level ***x***

SEISMIC FORCES ON STRUCTURAL COMPONENTS (IBC section 1620)

SDC A: No Seismic forces on Structural Components

SDC B or C:

Connections

Seismic force, $F_p = 0.133\ S_{DS}\ W_p \quad \geq 0.05\ W_p$

Where,

S_{DS} = design spectral response acceleration at short periods
W_p = weight of the smaller of the two components being connected together

The Supports of Beams, Girders or Trusses

These supports shall be designed for a minimum seismic force,

$F_p \geq 0.05$ (dead plus live load reaction of beam, girder or truss)

Anchorage of Bearing or Shear Walls to Roof or Floor Diaphragms

These anchorages shall be designed for an out of plane force (i.e, perpendicular to the plane of the wall),

$F_p = 0.10\ W_w$
$\geq 0.40\ I_E\ S_{DS}\ W_w$

$\geq 400\ I_E\ S_{DS}$ in Ib/ft length of wall

$\geq 1.2\ I_E\ S_{DS}\ W_w$ (for **SDC C** only !!!)

where ,

W_w = weight of wall
I_E and S_{DS} are as defined previously

SEISMIC FORCES ON PARAPETS & ARCHITECTURAL COMPONENTS (IBC section 1621)

The seismic force on PARAPETS and other ARCHITECTURAL components and their connections, applied at the center of gravity of the component, is:

$$F_p = \frac{0.4\, a_p\, S_{DS}\, W_p}{(R/I_p)} (1 + 2\, z/h)$$

$$\geq 0.3\, S_{DS}\, I_p\, W_p$$

$$\leq 1.6\, S_{DS}\, I_p\, W_p$$

where,

a_p = Component amplification factor from IBC Table 1621.2 or 1621.3 (varies from 1.0 to 2.5)

I_p = Component importance factor (either 1.0 or 1.5) from Section 1621.1.6

h = Mean or average roof height of structure relative to the base elevation

R_p = Component response modification factor (varies from 1.0 to 5.0) from IBC Table 1621.2 or 1621.3

S_{DS} = Design spectral response acceleration at short period, determined for the building

W_p = Operating weight of the component

z = Height from base of building structure to point of attachment of the component

= 0 for components below the base elevation of the building
= h for components at or above the roof level

SEPARATIONS BETWEEN ADJACENT BUILDINGS

The minimum separation, δ_{MT}, between adjacent buildings to prevent the buildings from banging into each other is given by,

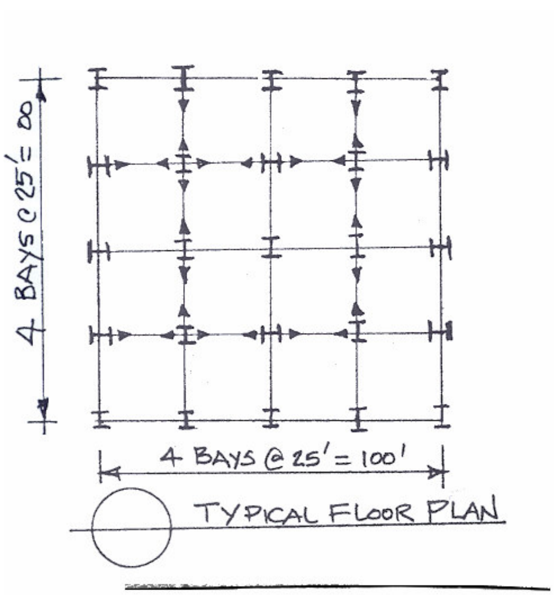
$$\delta_{MT} = \sqrt{[(\delta_{M1})^2 + (\delta_{M2})^2]}$$

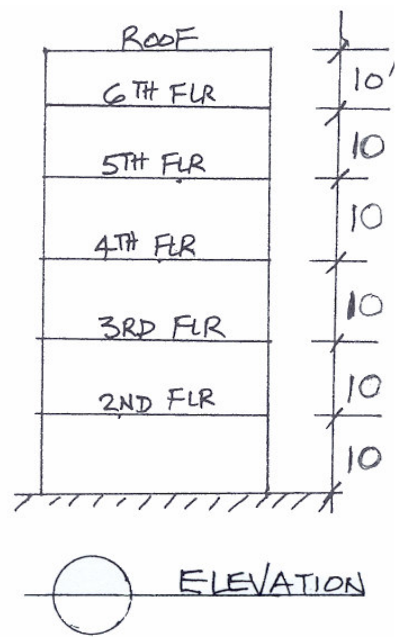
Where δ_{M1} and δ_{M2} are the lateral displacement of the adjacent buildings due lateral earthquake forces, taking into account cracked section

EXAMPLE 2S: SEISMIC FORCE CALCULATION

Given a SIX-story office building 100-ft x 100-ft in plan with MOMENT RESISTING FRAMES as shown below and located in Rochester, New York, determine the seismic forces assuming the following design parameters:

Roof Dead Load	**= 25 psf**
Snow Load	**= 30 psf**
Floor Dead Load	**= 75 psf**
Cladding (Glazing)	**= 20 psf**





SOLUTION:

Step 1: **Determine the Seismic Design Category (SDC) using Table S-1**

Table S-1: Determining the Seismic Design Category[1]

STEP	Column 2 **SHORT-PERIOD** ground motion, Ss	Column 3 **LONG-PERIOD** ground motion, S_1
Determine spectral response accelerations from website (2% PE in 50 years)	S_s = 0.25 **g** (Use the fraction of **g** , i.e. 0.25 in the calculations)	**S_1** = 0.072 **g** (Use the fraction of **g** , i.e. 0.072 in the calculations)
Determine Site Class: (Usually specified by the Geo-technical Engineer in the Soils Report) or Table 1615.1.1		
• If Site Class is F	Do SITE-SPECIFIC design	Do SITE-SPECIFIC design
• If data available for shear wave velocity, standard penetration resistance (SPT), and undrained shear strength	Choose from Site Class A to E	Choose from Site Class A to E
• If no soil data available	**Use Site Class D**	**Use Site Class D**
Determine site coefficient for acceleration or velocity (%**g**)	**F_a** = 1.6 from IBC Table 1615.1.2 (1)	**F_v** = 2.4 From IBC Table 1615.1.2 (2)
Determine soil-modified spectral response acceleration (%**g**)	**S_{MS}** = F_a S_s = 1.6 x 0.25 = 0.40 Equation 16-16	**S_{M1}** = F_v S_1 = 2.4 x 0.072 = 0.17 Equation 16-17
Calculate the design spectral response acceleration (%**g**)	**S_{DS}** = 2/3 S_{MS} = 2/3 x 0.405 = **0.27** Equation 16-18	**S_{D1}** = 2/3 S_{M1} = 2/3 x 0.17 = **0.12** Equation 16-19
Determine Seismic Use Group (SUG) of the structure from **IBC Section 1616.2** and determine the Importance factor **I_E from Table 1604.5**	**SUG I = Standard Occupancy Buildings ⇒** I_E = 1.0 SUG II = Assembly Buildings SUG III = Essential Facilities & Harzardous Facilities	**SUG I = Standard Occupancy Buildings ⇒** I_E= 1.0 SUG II = Assembly Buildings SUG III = Essential Facilities & Harzardous Facilities
Determine Seismic Design Category (SDC)	**SDC = B** based on SUG and S_{DS} from IBC Table 1616.3(1)	**SDC = B** based on SUG and S_{D1} from IBC Table 1616.3(2)
Choose most severe SDC (i.e. the HIGHER SDC value)	COMPARE Column 2 with Column 3 from previous line ⇒ **USE SDC = B** **NOTE:** • SDC = "E" for SUG I & II with mapped S_1 > 0.75g • SDC = "F" for SUG III with mapped S_1 > 0.75g	

Step 2: **Determine the Method of Seismic Analysis to be used from *Table S-2* in these Notes**

From *Table S-2,*

given the SDC = B ⇒ Equivalent lateral Force Method (IBC 1617.4)

Step 3: **Calculate the Dead Load at EACH level,** W_i**, and the TOTAL dead load,** W

LEVEL	Height from base, h_i	Weight, W_i
Roof	**60 ft**	**25psf x 100ft x 100 ft +** **20% x 30 psf x 100 ft x 100 ft +** **20 psf x 2 x(100 ft + 100 ft) x 10 ft/2 =** 350 kips
6th	**50 ft**	**75psf x 100ft x 100 ft +** **20 psf x 2 x(100 ft + 100 ft) x (10 ft+10 ft)/2 =** 830 kips
5th	**40 ft**	**75psf x 100ft x 100 ft +** **20 psf x 2 x(100 ft + 100 ft) x (10 ft+10 ft)/2 =** 830 kips
4th	**30 ft**	**75psf x 100ft x 100 ft +** **20 psf x 2 x(100 ft + 100 ft) x (10 ft+10 ft)/2 =** 830 kips
3rd	**20 ft**	**75psf x 100ft x 100 ft +** **20 psf x 2 x(100 ft + 100 ft) x (10 ft+10 ft)/2 =** 830 kips
2nd	**10 ft**	**75psf x 100ft x 100 ft +** **20 psf x 2 x(100 ft + 100 ft) x (10 ft+10 ft)/2 =** 830 kips

$\sum W_i =$ 4500 kips

Step 4: **Determine the Seismic Coefficient C_s**

R = 4.0 (for ORDINARY STEEL MOMENT RESISTING FRAMES)
(from IBC Table 1617.6)

C_T **= 0.035** (from Table S-3 for MOMENT RESISTING FRAMES)

h_n = roof height = 60 ft

T =T_a = Approximate period of the building = $C_T\ (h_n^{3/4})$

$= 0.035 \times (60^{3/4}) = 0.75$ **second**

If a more rational method is used to calculate the period of the structure, the Code limits the period to: $T_{max} = Ca\ T_a = 1.7 \times 0.75 = 1.28$ **second**

In lieu of a more rational method, use the Approximate period, $T_a = 0.75$ seconds

C_s = Seismic Response Coefficient = S_{DS} / [R/ I_E] = **0.27** / (4/1.0) **=** 0.068

$\leq S_{D1}$ / [T * R/ I_E] = **0.12** / [0.75 x 4/1.0] = **0.04**

$\geq$ 0.044 * S_{DS} * I_E = 0.044 x 0.27 x 1.0 = 0.012

$\Rightarrow$ $C_s = 0.04$

Step 5: **Calculate the Seismic Base Shear,** V

V = C_s **W = 0.04 x 4500 kips =** 180 kips
(This is the seismic force in both the N-S and E-W directions)

Step 6: **Determine the Vertical Distribution of the Seismic Base Shear (i.e. determine F_x at EACH level)**

For T = 0.75 seconds, from *Table S-4* in the Notes, we get k = **1+0.5(0.75-0.5)** =1.13

LEVEL	Height from base, h_i	Dead Weight at EACH level, W_i	$W_i(h_i)^k$	$C_{vx} = W_i(h_i)^k/\sum W_i(h_i)^k$	$F_x = C_{vx} V$
Roof	**60 ft**	**350 kips**	**35,760**	**0.154**	28 kips
6th	**50 ft**	**830 kips**	**69,010**	**0.296**	54 kips
5th	**40 ft**	**830 kips**	**53,630**	**0.23**	42 kips
4th	**30 ft**	**830 kips**	**38,750**	**0.166**	30 kips
3rd	**20 ft**	**830 kips**	**24,510**	**0.105**	19 kips
2nd	**10 ft**	**830 kips**	**11,2006**	**0.048**	9 kips
			$\sum$ =232,860		**$\sum$ = 180 kips**

- The Fx forces calculated above, are the forces acting at EACH level of the building acting in both the N-S and the E-W directions.
- If the building has RIGID DIAPHRAGMS (as most buildings do), the Fx forces will be distributed to the moment frames in that direction in proportion to the moment frame stiffnesses.
- If the building has a FLEXIBLE DIAPHRAGM, the forces are distributed in proportion to the area of the building tributary to each moment frame.

Step 7: Determine the Torsional Moments due to Seismic Forces, F_x, at each level

Torsion occurs ONLY in buildings with RIGID FLOOR and ROOF DIAPHRAGMS.

Assuming the MOMENT Frames in the building have the same stiffness, K, and because of their symmetrical layout, the location of the CENTER OF RIGIDITY at any level will coincide with the CENTER OF MASS. The centers of rigidity are are calculated as follows:

MOMENT FRAME	K_{yi}	K_{xi}	X_i	Y_i	$K_{yi}\ X_i$	$K_{xi}\ Y_i$
M1 (N-S)	**K**		**25 ft**		**25 K**	
M2 (N-S)	**K**		**75 ft**		**75 K**	
M3 (E-W)		**K**		**25 ft**		**25 K**
M4 (E-W)		**K**		**75 ft**		**75 K**
	$\sum K_{yi}$ **= 2K**	$\sum K_{xi}$ **= 2K**			$\sum K_{yi}\ X_i$ **= 100K**	$\sum K_{xi}\ Y_i$ **= 100K**

Xi = Perpendicular distance to the centroid of the LFRS that are parallel to the Y-axis

Yi = Perpendicular distance to the centroid of the LFRS that are parallel to the X-axis

The locations of the centers of rigidity for each story are as follows:

$X_{cr} = \sum K_{yi}\ X_i / \sum K_{yi}$ **= 100K/2K = 50 ft** measured from the chosen origin

$Y_{cr} = \sum K_{xi}\ Y_i / \sum K_{xi}$ **= 100K/2K = 50 ft** measured from the chosen origin

The locations of the centers of mass for each story are as follows:

X_{CM} = 100'/2 = **50 ft** measured from the chosen origin

Y_{CM} = 100'/2 = **50 ft** measured from the chosen origin

The eccentricity, e is the distance b/w CENTER OF MASS and CENTER OF RIGIDITY

For **N-S** Seismic forces (i.e. seismic force parallel to Y-axis), $e = X_{cr} - X_{CM} = 50\text{-}50 = 0'$

For **E-W** Seismic forces (i.e. seismic force parallel to X-axis), $e = Y_{cr} - Y_{CM} = 50\text{-}50 = 0'$

B = 100 ft for N-S seismic forces

= 100 ft for E-W seismic forces

The design eccentricity at level **x**, $\mathbf{e_x = e \pm 5\%\ B}$

For **<u>N-S</u>** Seismic Forces**:**

$e_x = e + 5\%\ B = 0 + 0.05 \times 100\text{ ft} \times 1 = 5\text{ ft}$, or

$e_x = e - 5\%\ B = 0 - 0.05 \times 100\text{ ft} \times 1 = -5\text{ ft}$

For **<u>E-W</u>** Seismic Forces**:**

$e_x = e + 5\%\ B = 0 + 0.05 \times 100\text{ ft} \times 1 = 5\text{ ft}$, or

$e_x = e - 5\%\ B = 0 - 0.05 \times 100\text{ ft} \times 1 = -5\text{ ft}$

The Torsional Moment at each level due to Seismic force is:

$M_{Tx} = A_X F_x e_x = F_x e_x$

NOTE:

For this building, $\mathbf{A_X = 1.0}$ because there are NO Type 1 Torsional Irregularities in this building, the torsional amplification factor, (see section 1610.4.4.5 and Tables 1616.5.1 and 1616.5.2)

LEVEL, x	F_x **Lateral force at EACH level due to the base shear, V**	e_x (same value for N-S and E-W directions)	M_{Tx} (N-S) **Torsional moment at** EACH **level**	M_{Tx} (E-W) **Torsional moment at** EACH **level**
Roof	28 kips	5 ft	28 k x 5 ft = 140 ftk	28 k x 5 ft = 140 ftk
6th	54 kips	5 ft	54k x 5ft = 270 ftk	54k x 5ft = 270 ftk
5th	42 kips	5 ft	42k x 5ft = 210 ftk	42k x 5ft = 210 ftk
4th	30 kips	5 ft	30k x 5ft = 150 ftk	30k x 5ft = 150 ftk
3rd	19 kips	5 ft	19k x 5ft= 95 ftk	19k x 5ft= 95 ftk
2nd	9 kips	5 ft	9k x 5ft = 45 ftk	9k x 5ft = 45 ftk

Step 8: Determine the Seismic force at EACH level on the lateral load-resisting system due to F_x and M_{Tx}.

Assuming all the MOMENT FRAMES have the same stiffness, K, determine the distribution of the Torsional Moments to the MOMENT FRAMES in the building

MOMENT FRAME	K_i	Z_i	K_iZ_i	$K_i(Z_i)^2$	$K_iZ_i/(\sum K_iZ_i^2)$
M1 (N-S)	K	25 ft	25K	625K	25K/2500K = 0.01
M2 (N-S)	K	25 ft	25K	625K	0.01
M3 (E-W)	K	25 ft	25K	625K	0.01
M4 (E-W)	K	25 ft	25K	625K	0.01

$\sum$= 2500K

Z_i = Distance measured from the center of rigidity (CR) to the centroid of the LFRS, **perpendicular** to the longitudinal direction of the LFRS (use absolute values of Z_i)

K_i = Stiffness of the LFRS in the longitudinal direction

Forces at EACH level of EACH MOMENT FRAME:

Lateral forces in the N-S MOMENT FRAMES: M1 and M2

LEVEL	F_{xV} **(LATERAL FORCE at each level due to Base Shear, V)** $= \{K_i/(\sum K_{i\,N\text{-}S}\} F_x$	F_{xT} $= K_i Z_i/(\sum K_i Z_i^2)\, M_{TX}$ **(LATERAL FORCE at each level due to** Torsion **from** N-S **seismic force)**	F_x **(TOTAL LATERAL FORCE at each level) on moment frames M1 and M2** (FACTORED)
Roof	K/(K+K)x 28 kips= *14 k*	0.01 x 140 ftk = 2 k	***16 kips***
6th	K/(K+K)x 54 kips= *27 k*	0.01 x 270 ftk = 3 k	***30 kips***
5th	K/(K+K)x 42 kips= *21 k*	0.01 x 210 ftk = 2 k	***23 kips***
4th	K/(K+K)x 30 kips= *15 k*	0.01 x 150 ftk = 2 k	***17 kips***
3rd	K/(K+K)x 19 kips= *10 k*	0.01 x 95 ftk = 1 k	***11 kips***
2nd	K/(K+K)x 9 kips = *5 k*	0.01 x 45 ftk = 0.5 k	***6 kips***
	∑ = 92 kips		**∑ = 103 kips**

Because of the symmetry of the building and the moment frames, the forces in the E-W moment frames (M3 and M4) are equal to those for the N-S moment frames (M1 and M2) shown above.

NOTE:

The effects of torsion can increase the forces in the LFRS by upwards of 10% !!!

Step 9: SEISMIC LOAD EFFECT (to be used in the load combinations)

The Seismic Load effect, $E = \rho\ Q_E \pm 0.2\ S_{DS}\ D$ **=** $\mathbf{E_h + E_v}$

Refer to the appendix for definitions of the terms in the equation above. For the current problem,

ρ **=** Redundancy factor = 1.0 (refer to the Appendix)

Q_E **=** horizontal earthquake force at each level

S_{DS} **= 0.27**

D **=** Dead load on MOMENT FRAMES at column lines

$E = \rho\ Q_E \pm 0.2\ S_{DS}\ D$ **=** $\mathbf{E_h + E_v}$

E_h = Horizontal Earthquake force $= \rho\ Q_E = 1.0\ Q_E$

E_v = Vertical Earthquake force $= \pm 0.2\ S_{DS}\ D = \pm 0.2 \times 0.27 \times D = 0.054\ D$ ↑↓

LEVEL	F_x **(TOTAL LATERAL FORCE at each level) on moment frames M1 and M2** (FACTORED)	E_h = Horizontal Earthquake force $= \rho\ Q_E = F_x$ (FACTORED)	E_v = Vertical Earthquake force $= \pm 0.2\ S_{DS}\ D$ (FACTORED)
Roof	16 kips	1.0 x 16 kips = 16 kips	$0.054\ D_{roof}$ ↑↓
6th	30 kips	1.0 x 30 kips = 30 kips	$0.054\ D_{6th}$ ↑↓
5th	23 kips	1.0 x 23 kips = 23 kips	$0.054\ D_{5th}$ ↑↓
4th	17 kips	1.0 x 17 kips = 17 kips	$0.054\ D_{4th}$ ↑↓
3rd	11 kips	1.0 x 11 kips = 11 kips	$0.054\ D_{3rd}$ ↑↓
2nd	6 kips	1.0 x 6 kips = 6 kips	$0.054\ D_{2nd}$ ↑↓

For instance, the axial loads on the EXTERIOR ground floor column in the MOMENT FRAME in this six-story building will be as follows:

D = summation of all the roof and floor dead loads from 2nd floor and above that tributary to the column $= D_{2nd} + D_{3rd} + D_{4th} + D_{5th} + D_{6th} + D_{roof}$ + column self weight $= \mathbf{\sum D}$

L = summation of the floor live loads from the 2nd floor and above that are tributary to the column $= L_{2nd} + L_{3rd} + L_{4th} + L_{5th} + L_{6th} = \mathbf{\sum L}$

S = the roof snow load tributary to the column = $\mathbf{S_{roof}}$

E = seismic load on the column $= \rho \mathbf{E}_h + \mathbf{E}_v = 1.0\mathbf{E}_h \pm 0.2\, S_{DS}\, D$ **(since $\rho = 1.0$)**

Where, for the EXTERIOR 1st story or ground floor column,

$\sum \mathbf{0.2\, S_{DS}\, D}$ = Axial load on the column resulting from the Vertical Earthquake force

$= 0.054\, D_{2nd} + 0.054\, D_{3rd} + 0.054\, D_{4th} + 0.054\, D_{5th} + 0.054\, D_{6th} + 0.054\, D_{roof}$

$\mathbf{= 0.054\, (D_{2nd} + D_{3rd} + D_{4th} + D_{5th} + D_{6th} + D_{roof})}$

$\rho \mathbf{E_h}$ = ρ x Axial load on exterior column resulting from the Horizontal Earthquake force

$= \rho\, (\sum F_x\, h_x)$/ (distance between exterior columns of moment frame)

= 1.0 x (16 k x 60' + 30 k x 50' + 23 k x 40' + 17 k x 30' + 11 k x 20' + 6 k x 10')/75'

= **55.6 k**

Using the two load combinations involving seismic loads, the factored load on the column will be:

16-5: $1.2\mathbf{D} + 1.0\mathbf{E} + f_1\mathbf{L} + f_2\mathbf{S}$

$\mathbf{= 1.2 \sum D + 1.0\, [55.6 \pm 0.054\, (D_{2nd} + D_{3rd} + D_{4th} + D_{5th} + D_{6th} + D_{roof})]} + f_1 \mathbf{\sum L} + f_2\, \mathbf{S_{roof}}$

16-6: $0.9\mathbf{D} + (1.6\mathbf{W}$ or $1.0\mathbf{E})$ (**D** must always oppose **W** or **E** in 16-6)

$\mathbf{= 0.9 \sum D - 1.0\, [55.6 \pm 0.054\, (D_{2nd} + D_{3rd} + D_{4th} + D_{5th} + D_{6th} + D_{roof})]} + f_1 \mathbf{\sum L} + f_2\, \mathbf{S_{roof}}$

Step 10: Horizontal Diaphragm Seismic Design Forces, F_{px}

Since **SDC = B** for this building, the F_{px} equation is:

$$F_{px} = F_x$$
$$\geq 0.2\ S_{DS}\ I_E\ W_p = 0.2 \times 0.27 \times 1.0 \times W_p = 0.054\ W_p$$

LEVEL	Horizontal seismic Force *on the building as a whole* at each level F_i	$\sum F_i$ (kips)	Dead Weight at EACH level, W_{px}	$\sum W_{px}$ (kips)	Equation for Diaphragm Force, F_{px} (see page 13)	Minimum F_{px} = $0.2\ S_{DS}\ I_E\ W_{px}$ (kips)	Maximum F_{px} = $0.4\ S_{DS}\ I_E\ W_{px}$ (kips)	**Horizontal Diaphragm Design Forces*** F_{px} **(kips)**
Roof	28 kips	28	350 kips	350	*28*	19	38	**28**
6th	54 kips	72	830 kips	1180	*54*	45	90	**54**
5th	42 kips	114	830 kips	2010	*42*	45	90	**45**
4th	30 kips	144	830 kips	2840	*30*	45	90	**45**
3rd	19 kips	163	830 kips	3670	*19*	45	90	**45**
2nd	9 kips	172	830 kips	4500	*9*	45	90	**45**

*The roof and floor diaphragms will be designed for these F_{px} forces

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7. Amrhein, J.E., Reinforced Masonry Engineering Handbook, 4^{th} Edition, Masonry Institute of America, 1983
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APPENDIX

LOAD COMBINATIONS (IBC Section 1605)

The IBC Load combinations for LIMIT STATES DESIGN (LSD, LRFD) are:

16-1: $1.4\mathbf{D}$
16-2: $1.2\mathbf{D} + 1.6\mathbf{L} + 0.5\ (\mathbf{L_r}$ or $\mathbf{S}$ or $\mathbf{R})$
16-3: $1.2\mathbf{D} + 1.6\ (\mathbf{L_r}$ or $\mathbf{S}$ or $\mathbf{R}) + (f_1\mathbf{L}$ or $0.8\mathbf{W})$
16-4: $1.2\mathbf{D} + 1.6\mathbf{W} + f_1\mathbf{L} + 0.5\ (\mathbf{L_r}$ or $\mathbf{S}$ or $\mathbf{R})$
16-5: $1.2\mathbf{D} + 1.0\mathbf{E} + f_1\mathbf{L} + f_2\mathbf{S}$
16-6: $0.9\mathbf{D} + (1.6\mathbf{W}$ or $1.0\mathbf{E})$ (**D** must always oppose **W** or **E** in 16-6)

Note:

$f_1 = 1.0$ for floors in places of public assembly; for live loads in excess of 100psf; for parking garage live load
$= 0.5$ for other live loads
$f_2 = 0.7$ for roof configurations (such as saw tooth) that do not shed snow off the structure
$= 0.2$ for other roof configurations

$\omega = 1.3$ for wind load loads calculated per IBC section 1609.6 or ASCE 7
$= 1.0$ for other wind loads

Where,

E = Load Effect of *Horizontal* and *Vertical* Earthquake induced Forces
= $\rho\, Q_E + 0.2\, S_{DS}\, D$ or $\rho\, Q_E - 0.2\, S_{DS}\, D$

D = Dead Load Effect

Q_E = HORIZONTAL Earthquake Load Effect due to the base shear, V
(i.e. forces, reactions, moments, shears, etc. caused by the horizontal seismic force, Fx)

$0.2\, S_{DS}\, D$ **=** **Vertical Component of the Earthquake;**
(affects mostly columns and footings)

S_{DS} = Design spectral response acceleration at short period
(from IBC sections 1615.1.3 or 1615.2.5 or from Table S-1 of these Notes)

L = Floor Live Load Effect

S = Snow Load Effect

Lr	=	Roof Live Load (i.e. RLL)
W	=	Wind Load
S	=	Snow Load
R	=	Rain Load

ρ = Redundancy coefficient

For Seismic design Category (SDC) ***A, B, or C****:* $\rho = 1.0$

For SDC ***D, E, or F****:* $\rho = 2.0 - 20/[r_{max}(A_i)^{0.5}] \geq 1.0$, ≤ 1.5

r_{max} = maximum element-to-story shear ratio (see IBC section 1617.2.2 for the definition of r_{max} for various LFRS

NOTE:
A more redundant structure implies a more ductile structure. The redundancy factor depends on:

- Number of lateral-load-resisting-elements in the building
- Plan area of the building
- The ratio of the lateral force in a lateral-load-resisting element to the total lateral shear at a particular story level

SPECIAL SEISMIC LOAD COMBINATIONS:

- **For certain** special structures and elements**, use the maximum seismic load effect, E_m, specified in IBC section 1617.1.2 and the special load combinations of IBC section 1605.4.**
  The Special Seismic Load Effect, $E_m = \Omega_o Q_E \pm 0.2 S_{DS} D$
  Where Ω_o = Over-strength factor from IBC Table 1617.6

- **The special seismic load combinations of IBC section 1605.4 must be used "where specifically required by IBC sections 1613 through 1622 or by chapters 18 through 23." Examples of special structures and elements that this applies to include:**
  - **Collector Elements -- IBC sections 1620.1.6; 1620.3.4**
  - **Elements supporting discontinuous systems (e.g. columns supporting discontinuous shear walls) -- IBC sections 1620.1.9**

SEISMIC or EARTHQUAKE LOADS: Cause & Effects

- Earthquakes are caused by the relative movement of the tectonic plates in the earth's crust
- These movements which occurs suddenly originates at planes of weaknesses in the earth's crust called "faults" , causing a release of stress that has built up resulting in a release of massive amounts of energy.
- This energy causes motion of the ground which results in vibrations of buildings and other structures.
- The earthquake causes motion in all directions but the horizontal and vertical motions are of the most significance.
- The point at which the earthquake originates within the earth's crust is called the hypo-center
- The point on the earth's surface directly above the hypo-center is called the epicenter.

The ***theoretical elastic*** dynamic force exerted on a structure by an earthquake is obtained from Newton's second law of motion:

$F = ma = (W/g)\, a = W\, (a/g)$, where

M = mass of structure
a = acceleration of the structure induced by the earthquake
a/g = Seismic Coefficient
W = weight of the structure

- The IBC uses a modified version of the equation above to calculate the seismic base shear on a structure during an earthquake. The code equations takes into account damping (or internal friction of the material), structural and foundation properties.
- The base shear is then converted to some "fictitious" Code equivalent lateral forces at each level of the building. In fact, the lateral forces measured in buildings during actual earthquakes are usually larger than the Code equivalent forces. However, experience indicates that buildings that have been designed elastically to these Code equivalent forces have always performed well during actual earthquakes.
- During an earthquake event, the induced acceleration of the structure varies in an erratic manner but having low and high points as shown below.
- If the absolute maximum accelerations of buildings with various periods, T are plotted, we obtain a plot called the RESPONSE SPECTRUM.
- The IBC uses a modified form of the equation above, using a DESIGN RESPONSE SPECTRUM, to calculate the seismic base shear on a structure.

DIFFERENCES BETWEEN WIND & SEISMIC LOAD EFFECTS

- Both wind and seismic loads are dynamic in nature, but earthquakes are more so than wind

- Seismic forces on structures arises from ground motion and the inertial resistance of the structure to this motion

- Seismic forces on a structure depend on structural and foundation properties, and dynamic properties of the earthquake.

- Wind forces, however depend on the shape and surface area of the structure that is exposed to wind
- Because of the highly dynamic nature of earthquakes compared to wind, safety is NOT necessarily assured by using a stiffer structure for seismic resistance. In fact, the stiffer a structure is the more seismic forces the structure attracts!!!

- Therefore, in designing for earthquake forces, the structural stiffness as well as the ductility is equally important.

- The IBC code seismic forces are actually less than the elastic inertial forces induced by the earthquake, but buildings have been known to perform well in earthquakes because of the ductility of these structures

- Therefore when designing for earthquake effects, one must combine the IBC code seismic forces with the seismic detailing requirements in the materials sections of the code in order to assure adequate ductility.

- On the other hand, when designing for wind effects, stiffness is the most important criterion; ductility is not as important because of the lesser dynamic nature of wind.

- To calculate **seismic** forces, the base shear is calculated FIRST and then this base shear is converted into equivalent lateral forces at each level of the building using a linear or parabolic distribution based on the modal response of the structure

- For wind forces, the design wind pressures are calculated FIRST, followed by the calculation of the lateral forces at each level, and then the base shear

- Only ONE set of lateral forces is calculated for WIND

- For SEISMIC forces, TWO sets of lateral forces are required – one for the vertical LFRS and one for the horizontal diaphragms (i.e. roof and floors)-- because of the different dynamic behavior of the horizontal diaphragm as opposed to that of the vertical LFRS during an earthquake event.

DRAG STRUTS or COLLECTORS

Drag struts or collectors are structural elements in the plane of the horizontal diaphragms and parallel to the lateral force that transfers the lateral wind or seismic forces from the diaphragms to the LFRS. They also help prevent differential or incompatible horizontal displacements of diaphragms in buildings with irregular shapes. Without drag struts or collectors, tearing forces would develop at the interface between the various diaphragm segments (refer to the diagrams below). Note that these elements must be designed for the special seismic force, E_m.

CHORDS

Chords are structural elements along the perimeter of the horizontal diaphragm that resist the tension and compression couple from the in-plane bending of the diaphragm due to the lateral seismic or wind forces.

DUCTILITY

This is the ability of a structure or element to sustain large deformations under constant load without collapse. The load-deformation plot for a ductile structure or member has a long flat portion (see figure below)
The more ductile a structure is the better the seismic resistance the structure has. Ductility is usually achieved by proper DETAILING of the structure and its connections as prescribed in the materials sections of the IBC code.