Chapter 6

Seismic Code Requirements for Building Structures
2007 CBC & 2006 IBC Chapter 16
ASCE 7-05 Chapter 12

Topics to be covered

- Basis for Design
- Structural Systems (Building Frames, Shear Walls, & Dual)
- Actual and Design Seismic Force
- Selection of Lateral Force Procedure (ELF, Dynamic, and Alternative Simplified Methods)
- Seismic Design Parameters (Road Map with 19 Parameters)
- Base Shear Calculations ($V$)
- Distribution of Base Shear ($F_x$)
- Redundancy Factor ($\rho$)
- Combinations of Structural Systems
- Drift and Building Separations
- P-Delta ($P - \Delta$) Effects

15 Sample Problems with Detailed Solutions

38 Supplemental Practice Problems with Detailed Solutions
§11.1.1 Purpose: The specified earthquake loads are based upon post-elastic energy dissipation in the structure, and because of this fact, the requirements for design, detailing, and construction shall be satisfied even for structures and members for which load combinations that do not contain earthquake loads indicate larger demands than combinations that include earthquake loads. The purpose of the earthquake provisions is primarily to safeguard against major structural failures and loss of life, not to limit damage or maintain function.

Structures designed in conformance with the seismic design provisions prescribed by the current Code should be able to:

1. Resist minor ground motion without damage.
2. Resist moderate ground motion without structural damage but with some nonstructural damage.
3. Resist major ground motion without collapse but with possible structural and nonstructural damage.
4. The seismic provisions in the ASCE 7-05 will consider the potential geological and seismic hazards in Seismic Design Categories C through F from:
   - Slope instability
   - Liquefaction
   - Differential settlement
   - Surface displacement due to faulting or lateral spreading.

How does the building Code attempt to accomplish this objective when resisting earthquake ground motion?

1. Design the structure for forces less than those corresponding to elastic response generated by the design earthquake.
2. Rely on ductility and detailing to prevent collapse.
3. Allow the energy imparted by the earthquake to be absorbed by the structure without destroying it.
4. It is assumed that the input energy is absorbed (dissipated) upon post-elastic energy dissipation in the structure.

It should be noted that the amount or level of structural damage depends on the following primary parameters:

<table>
<thead>
<tr>
<th>Earthquake Parameters</th>
<th>Site Parameters</th>
<th>Structural Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnitude</td>
<td>Soil characteristics</td>
<td>Natural period of the building</td>
</tr>
<tr>
<td>Duration</td>
<td>Distance to fault(s)</td>
<td>Building configuration (regular vs. irregular)</td>
</tr>
<tr>
<td>Frequency</td>
<td>Natural period of the site and its relation to structural period (resonance)</td>
<td>Type of lateral-force resisting system (LFRS) and detailing (MRF, braced frames, shear walls)</td>
</tr>
<tr>
<td>Length of fault</td>
<td></td>
<td>Construction material (steel, concrete, wood, masonry)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quality control of construction</td>
</tr>
</tbody>
</table>

TABLE 6-1 PARAMETERS AFFECTING STRUCTURAL DAMAGE
6-2 STRUCTURAL SYSTEMS

In Chapter 3 of this manual, loads were classified as vertical (gravity) and lateral loads (horizontal). The classification of the structural systems in the current Code is based on which portion of the system is responsible of resisting (carrying) the vertical load and which portion is responsible of carrying the lateral load. The following abbreviations will be used in relation to classification of structural systems:

- **SMF** = Special moment frame
- **IMF** = Intermediate moment frame
- **MMWF** = Masonry moment wall frame
- **OMF** = Ordinary moment frame
- **EBF** = Eccentrically braced frame
- **CBF** = Concentrally braced frame

§11.2 of ASCE 7 gives the definitions of the different structural systems as follows:

1- **Building Frame System**: A structural system with an essentially complete space frame providing support for vertical loads. Seismic force resistance is provided by shear walls or braced frames.

2- **Dual System**: A structural system with an essentially complete space frame providing support for vertical loads. Seismic force resistance is provided by moment resisting frames and shear walls or braced frames as prescribed in Section 12.2.5.1.

3- **Shear Wall-Frame Interactive System**: A structural system that uses combinations of ordinary reinforced concrete shear walls and ordinary reinforced concrete moment frames designed to resist lateral forces in proportion to their rigidities considering interaction between shear walls and frames on all levels.

4- **Space Frame System**: A 3-D structural system composed of interconnected members, other than bearing walls, that is capable of supporting vertical loads and, where designed for such an application, is capable of providing resistance to seismic forces.

Also, the different types of frames are defined as follows:

1- **Braced Frame**: An essentially vertical truss, or its equivalent, of the concentric or eccentric type that is provided in a building frame system or dual system to resist seismic forces.

2- **Concentrally Braced Frame (CBF)**: A braced frame in which the members are subjected primarily to axial forces. CBFs are categorized as ordinary concentrically braced frames (OCBF) or special concentrically braced frames (SCBF).

3- **Eccentrically Braced Frame (EBF)**: A diagonally braced frame in which at least one end of each brace frames into a beam a short distance from a beam-column or from another diagonal brace.

4- **Moment Frame**: A frame in which members and joints resist lateral forces by flexure as well as along the axis of the members. Moment frames are categorized as intermediate moment frames (IMF), ordinary moment frames (OMF), and special moment frames (SMF).

Table 12.2-1 of ASCE 7 lists the design coefficients and factors for **EIGHT categories** [A through H] total of about **83 systems**.
In general, structural systems can be categorized as follows in regard to resisting lateral forces:

**TABLE 6-3 LATERAL-FORCE-RESISTING SYSTEMS (LRFS)**

<table>
<thead>
<tr>
<th>Shear Wall System</th>
<th>Frame System</th>
<th>Unbraced (UBF)</th>
<th>Dual System</th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ A system where the shear wall is designed to resist lateral forces parallel to the plane of the wall</td>
<td>➢ A vertical truss system to resist lateral forces</td>
<td>➢ A vertical truss system to resist lateral forces</td>
<td>➢ The total seismic force resistance is to be provided by the combination of the moment frames and the shear walls or braced frames in proportion to their rigidities.</td>
</tr>
<tr>
<td>➢ Also known as vertical diaphragm or structural wall system</td>
<td>➢ The members are subjected primarily to axial forces.</td>
<td>➢ A system consists of beams and columns to carry gravity (vertical) loads</td>
<td>➢ For a dual system, the moment frames shall be capable of resisting at least 25 percent of the design seismic forces.</td>
</tr>
</tbody>
</table>

![Diagram of shear wall systems and frame systems](image-url)
A- Bearing Wall System: A structural system without a complete vertical load-carrying space frame. Bearing walls or bracing systems provide support for all or most gravity loads. Resistance to lateral load is provided by shear walls or braced frames. 

The following table shows the difference between the shear walls and braced frames

<table>
<thead>
<tr>
<th>TABLE 6-4 BEARING WALL SYSTEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-Bearing Wall Systems (1-15 in Table 12.2-1)</td>
</tr>
<tr>
<td>➢ Carry vertical (gravity) loads</td>
</tr>
<tr>
<td>➢ Resist horizontal (lateral) loads</td>
</tr>
<tr>
<td>➢ Examples: concrete and masonry shear walls, light-framed walls with shear panels.</td>
</tr>
</tbody>
</table>

**Figure 6-2** Bearing Wall System

The following table shows the height limitations of some of the bearing wall systems listed in Table 12.2-1 for the SIX DESIGN CATEGORIES (SDC):

<table>
<thead>
<tr>
<th>TABLE 6-5 BEARING WALL SYSTEMS (Systems 1 through 15 in Table 12.2-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-Bearing Wall Systems</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>1. Special reinforced concrete shear walls</td>
</tr>
<tr>
<td>2. Ordinary reinforced concrete shear walls</td>
</tr>
<tr>
<td>7. Special reinforced masonry shear walls</td>
</tr>
<tr>
<td>8. Intermediate reinforced masonry shear walls</td>
</tr>
<tr>
<td>9. Ordinary reinforced masonry shear walls</td>
</tr>
<tr>
<td>13. Light frame walls with wood structural panels</td>
</tr>
</tbody>
</table>

**NL = No limit**  **NP = Not permitted**

<sup>d</sup> See Section 12.2.5.4 for a description of building systems limited to buildings with a height of 240 ft (73.2 m) or less.

<sup>e</sup> See Section 12.2.5.4 for building systems limited to buildings with a height of 160 ft (48.8 m) or less.

* SDC “A” is not listed in Table 12.2-1 because in this SDC the $S_{DS} < 0.167g$ and $S_{DI} < 0.067g$ which indicates that the structures in this SDC are the least vulnerable to earthquake forces compared to other SDC. Therefore, “NL” for SDC “B” also means “NL” for SDC “A”
6-3 HEIGHT LIMITS

Table 12.2-1 gives the height limits for the structural systems listed and in the SIX Seismic Design Categories (SDC). Note that “NL” means no limit and “NP” means not permitted.

§12.2.5.4 Increased Building Height Limit for Steel Braced Frames and Special Reinforced Concrete Shear Walls. The height limits in Table 12.2-1 are permitted to be increased from 160 ft (50 m) to 240 ft (75 m) for structures assigned to Seismic Design Categories D or E and from 100 ft (30 m) to 160 ft (50 m) for structures assigned to Seismic Design Category F that have steel braced frames or special reinforced concrete cast-in-place shear walls and that meet both of the following requirements:

1- The structure shall not have an extreme torsional irregularity as defined in Table 12.2-1 (horizontal structural irregularity Type 1b).
2- The braced frames or shear walls in any one plane shall resist no more than 60 percent of the total seismic forces in each direction, neglecting accidental torsional effects.

6-4 2007 CBC/ ASCE 7-05 CLASSIFICATION OF STRUCTURES

§12.3.2 Irregular and Regular Classification. Structures shall be classified as regular or irregular based upon the criteria in this section. Such classification shall be based on horizontal and vertical configurations.

§12.3.2.1 Horizontal Irregularity. Structures having one or more of the irregularity types listed in Table 12.3-1 shall be designated as having horizontal structural irregularity. Such structures assigned to the seismic design categories listed in Table 12.3-1 shall comply with the requirements in the sections referenced in that table.

**TABLE 6-12 REGULAR AND IRREGULAR STRUCTURES**

<table>
<thead>
<tr>
<th>Regular Structures</th>
<th>Irregular Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ Regular structures have no significant physical discontinuities in plan or vertical configuration or in their lateral-force-resisting systems such as the irregular features.</td>
<td>➢ Irregular structures have significant physical discontinuities in configuration or in their lateral-force-resisting systems. Irregular features. There are <strong>SEVEN</strong> vertical and <strong>SIX</strong> horizontal Irregularities.</td>
</tr>
</tbody>
</table>

➢ Vertical irregularities: Examine the side view of the structure

➢ Plan (Horizontal ) irregularities: Examine the plan view of the structure
### TABLE 12.3-1 HORIZONTAL STRUCTURAL IRREGULARITIES

<table>
<thead>
<tr>
<th>Irregularity Type and Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1a. Torsional Irregularity</strong> is defined to exist where the maximum story drift, computed including accidental torsion, 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.</td>
</tr>
<tr>
<td><strong>1b. Extreme Torsional Irregularity</strong> is defined to exist where the maximum story drift, computed including accidental torsion, 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.</td>
</tr>
<tr>
<td><strong>2. Reentrant Corner Irregularity</strong> 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.</td>
</tr>
<tr>
<td><strong>3. Diaphragm Discontinuity Irregularity</strong> is defined to exist where there are diaphragms with abrupt discontinuities or variations in stiffness, including those having cutout or open areas greater than 50% of the gross enclosed diaphragm area, or changes in effective diaphragm stiffness of more than 50% from one story to the next.</td>
</tr>
<tr>
<td><strong>4. Out-of-Plane Offsets Irregularity</strong> is defined to exist where there are discontinuities in a lateral force-resistance path, such as out-of-plane offsets of the vertical elements.</td>
</tr>
<tr>
<td><strong>5. Nonparallel Systems-Irregularity</strong> is defined to exist where the vertical lateral force-resisting elements are not parallel to or symmetric about the major orthogonal axes of the seismic force-resisting system.</td>
</tr>
</tbody>
</table>
### TABLE 6-13 HORIZONTAL STRUCTURAL IRREGULARITIES

<table>
<thead>
<tr>
<th>#</th>
<th>Type</th>
<th>Definition</th>
<th>Illustration</th>
</tr>
</thead>
</table>
| 1a | Torsional Irregularity        | ➢ The maximum story drift at one end is more than 1.2 times the average of the story drifts of the two ends of the structure  
\[
\delta_2 > 1.2 \left( \frac{\delta_1 + \delta_2}{2} \right) = 0.6 (\delta_1 + \delta_2)
\]  |
|    |                               |                                                                           | la. Torsional |
| 1b | Extreme Torsional Irregularity | ➢ The maximum story drift at one end is more than 1.4 times the average of the story drifts of the two ends of the structure  
\[
\delta_2 > 1.4 \left( \frac{\delta_1 + \delta_2}{2} \right) = 0.7 (\delta_1 + \delta_2)
\]  |
|    |                               |                                                                           | lb. Extreme Torsional |
| 2  | Reentrant Corner Irregularity  | ➢ Where both projections of the structure beyond a re-entrant corner are greater than 15% of the plan dimension of the structure in the given direction. 
projection “a” > 0.15 x, and projection “b” > 0.15 y  |
|    |                               |                                                                           | 2. Reentrant Corner |
| 3  | Diaphragm Discontinuity Irregularity | ➢ Area of opening “ab” > 0.5 of the area “XY”, OR  
➢ Changes in effective diaphragm stiffness  
> 50% from one story to the next.  |
|    |                               |                                                                           | 3. Diaphragm Discontinuity |
| 4  | Out-of-plane Offsets Irregularity | ➢ Discontinuities in lateral-force-resisting path, such as out-of-plane offsets of vertical elements.  |
|    |                               |                                                                           | 4. Out-of-plane Offset |
| 5  | Nonparallel Systems Irregularity | ➢ Vertical lateral-force-resisting elements are not parallel to OR symmetric about the major orthogonal axes of the lateral-force-resisting system.  |
|    |                               |                                                                           | 5. Non Parallel System |
6-6  ROAD MAP FOR EQUIVALENT LATERAL FORCE (ELF) PROCEDURE

1- Site classification characteristics: A, B, C, D, E, & F Tables 1613.5.2 & 1613.5.5

2- Maximum considered earthquake spectral response accelerations $S_I$ & $S_s$

3- Site Coefficients $F_a$ & $F_v$ Tables 1613.5.3(1) & 1613.5.3(2)

4- Adjusted maximum considered earthquake spectral response accelerations
   $S_{MS} = F_a S_s$  
   $S_{MI} = F_v S_I$  
   (Equation 16-37)

5- Design spectral response acceleration parameters
   $S_{DS} = 2/3 S_{MS}$  
   $S_{DI} = 2/3 S_{MI}$  
   (Equation 16-39)

6- Period of the structure $T$
   Equations: 12.8-7, 12.8-8, 12.8-9, 15.4-6 with the limitation

7- Occupancy importance factor: $I$, Table 11.5-1 ASCE 7-05

8- Seismic design category (SDC): Tables 1613.5.6(1) & 1613.5.6(2)

9- Lateral-force-resisting systems (LFRS): §11.2 & Table 12.2-1, ASCE 7-05

10- Response modification coefficient, $R$, Table 12.2-1, ASCE 7-05

11- Seismic dead load: $W$, §12.7-2, ASCE 7-05

12- Seismic Response Coefficient, $C_s$, §12.8 ASCE7-05

13- Seismic base shear: $V$ §12.8 ASCE7-05

14- Vertical distribution of base shear: $F_x$ §12.8.3 ASCE7-05

15- Horizontal and vertical components of $E$: $E_h$ & $E_v$ §12.4 ASCE7-05

16- Redundancy factor: $\rho$, §12.3.4 ASCE 7-05

17- Overstrength factor: $\Omega_0$, Table 12.2-1, ASCE 7-05

18- Deflection control: $\delta_x = C_d \delta_{xc}/I$, Table 12.2-1 & §12.12.1

19- Combinations of systems: Table 12.2-1, §12.2.3.1 & §12.2.3.2
§12.8.1.3 Maximum $S_s$ Value in Determination of $C_s$. For regular structures five stories or less in height and having a period, $T$, of 0.5 s or less, $C_s$ is permitted to be calculated using a value of 1.5 for $S_s$.

13- Seismic Base Shear, $V$ §12.8 ASCE7-05

§12.8.1 Seismic Base Shear. The seismic base shear, $V$, in a given direction shall be determined in accordance with the following equation:

$$ V = C_s W $$

(12.8-1)

where:

$C_s =$ the seismic response coefficient determined in accordance with Section 12.8.1.1
$W =$ the effective seismic weight per Section 12.7.2.

### TABLE 6-24 STEPS OF THE EQUIVALENT LATERAL FORCE (ELF) PROCEDURE

<table>
<thead>
<tr>
<th>Step 1</th>
<th>Calculate the structural period “$T$” using:</th>
</tr>
</thead>
<tbody>
<tr>
<td>i)</td>
<td>Approximate Method: $T_a = C_f h_n$</td>
</tr>
<tr>
<td>ii)</td>
<td>$T_a = 0.1 N$</td>
</tr>
<tr>
<td>iii)</td>
<td>$T_a = \frac{0.0019}{\sqrt{C_w}} h_n$</td>
</tr>
</tbody>
</table>
| iv)    | Rayleigh Method (<note>Always check the limit if applicable $T \leq C_u T_a$</note>)

$$ T = 2\pi \left[ \sum_{i=1}^{n} w_i \delta_i^2 \right]^{-\frac{1}{2}} \left( \sum_{i=1}^{n} f_i \delta_i \right) $$

| Step 2 | Calculate the period “$T_S$” $T_S = \frac{S_{DL}S_{DS}}{S_{DS}}$ ($T_S$ is not part of any base shear equations, its used for comparison only) |

| Step 3 | Calculate the period “$T_0$” $T_0 = 0.2 \frac{S_{DL}}{S_{DS}}$ |

| Step 4 | If $T < T_0$, the acceleration is given as $S_a = S_{DS} \left( 0.4 + 0.6 \frac{T}{T_0} \right)$ and the base shear will be as follows: $V = \frac{S_a W}{(R/I)}$ |

| Step 5 | If $T_0 \leq T < T_S$, Eq. (12.8-2) governs and there is no need to check the minimum values of (Eq. 12.8-5) & (Eq. 12.8-6). |

| Step 6 | If $T_S < T \leq T_L$, Eq. (12.8-3) governs and the minimum values of (Eq. 12.8-5) & (Eq. 12.8-6) should be checked. |

| Step 7 | If $T > T_L$, Eq.(12.8-4) governs |
Figure 6-15  Equivalent Lateral Force Procedure (ELF)
§12.8.3 Vertical Distribution of Seismic Forces. The lateral seismic force \((F_x)\) (kip or kN) induced at any level shall be determined from the following equations:

\[
F_x = C_{vx} V
\]

and

\[
C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k}
\]

Where:
- \(C_{vx}\) = vertical distribution factor,
- \(V\) = total design lateral force or shear at the base of the structure (kip or kN)
- \(w_i\) and \(w_x\) = the portion of the total effective seismic weight of the structure \((W)\) located or assigned to Level \(i\) or \(x\)
- \(h_i\) and \(h_x\) = the height (ft or m) from the base to Level \(i\) or \(x\)
- \(k\) = an exponent related to the structure period as follows: for structures having a period of 0.5 s or less, \(k = 1\) for structures having a period of 2.5 s or more, \(k = 2\) for structures having a period between 0.5 and 2.5 s, \(k\) shall be 2 or shall be determined by linear interpolation between 1 and 2

**NOTE:** The justification of the exponent \(k > 1\) for buildings having a period greater than 0.5 seconds can be explained as follows: Tall buildings (> 4 stories and higher depending on the structure type and story height) will have higher modes of vibration under the seismic force effect. To account for the higher mode effects, a parabolic mode shape is assumed where larger forces will be assigned to upper levels of the structure.

### TABLE 6-25 VALUES OF THE EXPONENT “\(k\)”

<table>
<thead>
<tr>
<th>(T)</th>
<th>(\leq 0.5) sec</th>
<th>(0.5) sec &lt; (T) &lt; 2.5 sec</th>
<th>(\geq 2.5) sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>(k)</td>
<td>1.0</td>
<td>2.0 OR Linear Interpolation between 1 &amp; 2*</td>
<td>2.0</td>
</tr>
</tbody>
</table>

\*Linear Interpolation: If \(T = 0.8\) seconds.

The value of the exponent \(k\) based on linear interpolation is:

\[
\frac{T - 0.5}{2.5 - 0.5} = \frac{k - 1}{2 - 1} \Rightarrow k = 1 + \frac{(T - 0.5)}{2}
\]

\[
\Rightarrow \frac{0.8 - 0.5}{2.5 - 0.5} = \frac{k - 1}{2 - 1} \Rightarrow k = 1.15
\]
Simplified (Alternative) Lateral Force Procedure At a Glance

**Occupancy Category** | **Maximum Height** | **Soil Type (Site Class)** | **Structural Systems** | **Seismic Design Category (SDC)**
--- | --- | --- | --- | ---
I & II (See Table 1604.5) | Three Stories (See Table 12.14-1) | A to D (NO E & F Type) | 1- Bearing Wall 2-Building Frame (See Table 12.14-1) | Only Table 11.6-1 (based on $S_{DS}$ and $S_{S} \leq 1.5$ §12.14.8.1)

- $S_{DS} = 2/3 F_a S_s$ (§12.14.8.1)
- $F_a$ is permitted to be taken as 1.0 for rock sites & 1.4 for soil sites
- $S_s \leq 1.5$ (§12.14.8.1)
- $\rho = 1$
- $\Omega_o = 2.5$ (§12.14.3.2.1)
- Torsional moment due to $M_t$, i.e., NO $M_{ta}$
- Drift = 1% of building height unless computed to be less

The advantages of the simplified method could be summarized as follows:

a. NO need to calculate the period of the structure.
b. NO need to calculate the drift and it will be taken as 1% of the building height unless computed to be less per §12.14.8.5, i.e., the simplified method is used for buildings for which the drift is not controlling factor in design.
c. Redundancy factor “$\rho$” will be taken 1.0, i.e. NO need to consider it.
d. Simplified distribution (rectangular) of the base shear.

**Figure 6-27** Simplified (Alternative) Seismic Lateral Force Procedure
Seismic Base Shear, $V$, Alternate Simplified Design Procedure (§12.14.8.1)

Determine $S_S$ in accordance with §11.4.1 where $S_S \leq 1.5$

Calculate $S_{DS} = \frac{2}{3} F_a S_s$

$F_a = 1.0$ for rock sites
$= 1.4$ for soil sites, or
$= \text{value determined in accordance with } §11.4.3$

Determine the Response Modification Coefficient $R$ from Table 12.14-1 for the appropriate structural system based on Seismic Design Category (SDC)

Determine effective weight $W$ in accordance with §12.14.8.1

Determine base shear $V$ by Eq. 12.14-11

$$V = \frac{FS_{DS} W}{R}$$

$F = 1.0$ for one-story buildings
$= 1.1$ for two-story buildings
$= 1.2$ for three-story buildings

Figure 6-28 Flowchart for Simplified Determination of Seismic Base Shear
Sample Problem 6.1: Structural Period “Approximate Method”

**Given:** Three-story steel special concentrically braced frame (CBF) office building with a penthouse on the roof as shown is located in central California. The building with soil type C and SDC “C.” The story height is 12 feet. $S_{DS}$ & $S_{DI}$ are 0.42g and 0.26g respectively. The effective seismic dead load “W” for levels 1 & 2 is 120 kips each and for the roof including the penthouse is 90 kips.

**Find:** The structure period “$T$” is most nearly:

(A) 0.29 s  
(B) 0.30 s  
(C) 0.44 s  
(D) 0.49 s

**Solution:**

*Which method should be used to calculate $T$?*

i) Approximate method Eq. (12.8-7): **YES**, enough information are given ($h_n$, type of structure to get $C_t$ & $x$)

ii) Approximate method Eq. (12.8-8): **NO**, only for concrete and steel moment resisting frames not exceeding 12 stories and the story height is at least 10 ft

$$T_a = 0.1 N$$  
(12.8-8)

iii) Rayleigh Method Eq. (15.4-6): **NO**, not enough information (forces & displacements)

$$T = 2\pi \sqrt{ \sum_{i=1}^{n} w_i \delta_i^2 + \left( g \sum_{i=1}^{n} f_i \delta_i \right) }$$  
(15.4-6)

$$T_a = C_t h_n^x$$  
(12.8-7)

For CBF, $C_t = 0.020$ & $x = 0.75$ (for all other structures, Table 12.8-2)

$$T_a = 0.020 \times (36)^{\frac{3}{4}} = 0.29 \text{ Sec}$$

**Time Saver** Using Table 6-19 → page 196 → CBF & $h_n = 35'$ (the closest to 36’) → 0.288 Sec

Answer B: wrong answer, 0.1 N = 0.30 s  
Answer C: wrong answer if $C_t = 0.030$ is chosen  
Answer D: wrong answer if $C_t = 0.028$ is chosen  

Answer: (A) ←

**Note:** When you pick the value of $C_t$, the type of the structure should match the description given in the Code.
Sample Problem 6.2: Base Shear (V) Calculation

Given: Same as Sample problem 6.1

Find: Static design base shear, “V” is most nearly:

(A) 51.3 kips
(B) 49.30 kips
(C) 27.54 kips
(D) 23.10 kips

Solution:

Which method should be used to calculate V?

i. ELF (§12.8): YES, number of stories, type of structure, soil type, occupancy category.
ii. Simplified (§12.14): MAYBE, if the requirements of section 12.14.1.1 are met.
iii. Dynamic: NO, not enough information (acceleration or response spectra).

Steps using ELF Method:

1) Calculate the structure period T
2) Calculate the period \( T_S = \frac{S_{DI}}{S_{DS}} \) (\( T_S \) is going to be used for comparison only)
3) If \( T < T_S \), Eq. (12.8-2) governs and no need to check the minimum values of V (Eqs. 12.8-5 & 12.8-6)

\[ I = 1.0, \ 2007 \ CBC \ Table \ 1604.5 \ & \ Table \ 11.5-1 \ (Occupancy \ Category \ II) \]
\[ R = 6.0, \ Table \ 12.2-1( \ Building \ Frame \ Systems- \ Special \ Steel \ CBF) \]

\[ T_S = \frac{0.26g}{0.42g} = 0.62 \ \text{Sec} > T = 0.29 \ \text{Sec} \] (from prob. 6.1), Eq. (12.8-2) governs

Also, \( T = 0.29s > T_0 = 0.20T_s = 0.20 \times 0.62 = 0.124s \)

\[ C_S = \frac{S_{DS}}{R} = \frac{0.42}{6/1} = 0.07 \quad (12.8-2) \]

\[ V = C_sW = 0.07 (120+120+90) = 0.07 (330) = 23.10 \text{ kips (Max.)} \quad (12.8-1) \]

Note: Eq. (12.8-3) yields a value greater than Eq. (12.8-2) which is the maximum specified by the Code.

\[ C_S = \frac{S_{DI}}{T} = \frac{0.26}{0.29 (6/1)} = 0.1494 \quad \text{for} \ T \leq T_L \quad (12.8-3) \]

\[ V = C_sW = 0.1494 (120+120+90) = 0.1494 (330) = 49.30 \text{ kips} \quad (12.8-1) \]

Answer: (D) ←

Note: Buildings up to 4 stories (low rise structures = short period structures) most likely will be controlled by the Eq. 12.8-2 (maximum)