LESSON 5 - LATERAL LOADS:

A. PRIMARY TYPES OF LATERAL LOADS:

1.) WIND LOADS
2.) SEISMIC LOADS

- CONSIDERED SEPARATELY:
  - Do not design for simultaneous 50 yr. wind storm
  - Larger of the two controls

B. WIND LOADS:

- Resultant forces caused by wind pressure on structure

- IN DESIGN WIND IS REPRESENTED AS A STATIC PRESSURE

  BASIC PRESSURE: \( p_s = \frac{m V^2}{2} \)

  \( m \) = mass density of air
  \( V \) = Wind velocity

- FACTORS AFFECTING WIND PRESSURES:
  1.) Wind Velocity
  2.) Air Pressure
  3.) Ground Roughness
  4.) Shape of Structure

  * BERNOULLI'S PRINCIPLE
**TERMINOLOGY IN WIND DESIGN**

**MWFRS** - Main Wind Force Resisting System

Structural System designed to resist lateral load from wind.

**Components & Cladding** - Other structural & non-structural elements exposed to wind, not part of MWFRS

**WIND LOAD SELECTION METHOD:**

**METHOD 1 - SIMPLIFIED PROCEDURE**

LIMITED TO LOW-RISE BUILDINGS

**METHOD 2 - ANALYTICAL PROCEDURE**

ALLOWABLE FOR ALL HEIGHTS

**METHOD 3 - WIND TUNNEL PROCEDURE**

SPECIAL DESIGNS

Low-Rise Building: Mean Roof Height ≤ 60ft

__CE3202: Method 2 - MWFRS__
Computing Design Wind Loads - Analytical Method

\[ q_s = \frac{MV^2}{Z} \]

- Must account for other factors:
  \[ q_2 = q_s K_z K_{fe} K_d \]
  \[ q_2 = 0.00256 V^2 K_z K_{fe} K_d \]

- \( K_z \): Velocity Pressure Exposure Coefficient
  \( \rightarrow \) Includes 2 Effects
  1) Height above ground
  2) Exposure:
     B - Urban, Suburban, Forest
     C - Open Terrain, Some Obstructions
     D - Near Water, Unobstructed
     (see Handout Table 27.3-1)

- \( K_{fe} \): Topographical Factor (Hills):
  \( K_{fe} = 1 \) on flat ground
  \( K_{fe} > 1 \) if structure on hill
  (see Handout Fig. 26.8-1)

- \( K_d \): Directionality Factor
  Reduces load due to low probability of full pressure development.
  Often \( K_d = 0.85 \) for buildings
  (see Handout Table 26.6-1)

What pressure do we apply to external surfaces?

\[ P = q_s (G \cdot C_p) \]

- \( q_s = q_2 \) for windward wall
- \( q_s = q_4 \) for leeward wall

\[ q = 0.65 \text{ for rigid structures} \]

- \( G \): External Pressure Coefficient
  Establishes fraction of velocity pressure \( q_2 \)
  \( P = q_2 G \cdot C_p \) to be applied to each surface of structure
  (Handout Fig. 27.4-1)
internal pressure  (Not in your textbook)

$g_i = g_h$ for enclosed buildings (positive & negative internal pressure)

$(G_{Cpi}) = \text{internal pressure coefficient} \; \text{Figure 6-5}

= \pm 0.18 \quad \text{Enclosed Buildings}

+ = \text{toward wall}

- = \text{away from wall}

Combined Internal + External (Windward and Leeward walls)

Use worst case
$q_z \text{ vs. } q_h$

$z =$ height above grade, varies from $0$ to height of structure

$h =$ value of $z$ equal to the average roof height

$q_h = q_z \left| \frac{z}{z=h} \right.$

Simplified procedure only uses $h$.

Windward side: varies over height
Other sides: same over height

Windward

Wind

$P_z = q_z \cdot G \cdot \rho$

$P_2 = q_2 \cdot G \cdot \rho$

$P_1 = q_1 \cdot G \cdot \rho$

Leeward

$F_7 = P_1 A_7$

$F_{7,11} = P_{11} A_{11}$

$V_8 \Rightarrow E \cdot \text{Windward} + E \cdot \text{Leeward}$

$M_{ot} = E \cdot M_A$
C: SEISMIC LOAD
- Effect of ground motion due to earthquakes
- Highly complex, dynamic load influenced by:
  1. Seismic characteristics of site (Seismicity)
  2. Soil characteristics of site
  3. Mass of structure
  4. Stiffness of structure
  5. Ductility of structure

- Multiple graduate classes on earthquake engineering:
  Is there a simplified method that will work for many structures? Yes?

**EQUIVALENT LATERAL FORCE PROCEDURE** (ASCE 7)

**Consider a spring:**

\[
F = AK \quad \text{Equivalent} \quad F = \Delta K
\]

*Structure is like a spring:*

- No giant hand holds the structure, but the inertial forces due to the mass of the floor oppose motion (specifically, change in motion)

\[
F = ma
\]

- Offset by structure stiffness
- Sum of these forces resisted by reaction at base, Base Shear $V$
Procedure to determine base shear:

1) Determine Spectral Response Acceleration Coefficients
2) Find Seismic Design Category
3) Determine Base Shear (maybe)
4) Find Story loads

1) Spectral Response Acceleration Parameter
   - Short Period
   - Long Period
   - Fundamental Natural Period ($T$) of the structure strongly affects its performance during seismic events,
     \[ T = \frac{1}{4n} \quad (n = \text{natural freq.}) \]

   Spectral response based on freq.
   - Building behavior
   - Type of response

   Tells us, given a building location, what is the maximum considered earthquake (MCE) for a structure with a given period.

2 Flavors:

- Short Period ($T=0.2$)
- One Second ($T=1s$)

Mapped (MCE) Spectral Response Acceleration Parameter

- $S_s$ (Handout, Fig.22.1)
- $S_1$ (Handout, Fig.22.2)

MCE Spectral Response Acceleration

- $S_{MS} = F_a \times S_s$
  - $F_a = \text{Site Coefficient}$
  - (Handout, Table 11.4-1)

- $S_{D1} = 2/3 \times S_{MS}$
- $S_{D2} = 2/3 \times S_{MA}$

Design Spectral Response Acceleration Parameter

- Site Class: Geologic profile of building site
  - A B C D E F
  - Hard Rock
  - Soft/Weak Soil
  - (best case)
  - (worst case)

  Don't know? Use D, unless you suspect worse.

(Table 11.8-1)
SEISMIC DESIGN CATEGORY
Depends on seismic hazard \( \rightarrow \) Occupancy Category

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less Severe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>More Severe</td>
</tr>
</tbody>
</table>

\( \rightarrow \) C - F: Require specialized geotech reports
\( \rightarrow \) D - F: Scope of Earthquake Engineering Class.

What category to use? See Tables 11.6-1
11.6-2
Use worst case.

FLOOR LOADINGS / SEISMIC DESIGN CATEGORY A

\[ F_x = 0.010 W_x \]
\[ F_x = \text{Lateral seismic load to be applied to floor } x \]
\[ W_x = \text{Dead load assigned to floor } x \]

\[ \text{All or Total DL! } W_x = \frac{\text{Dead Load (Unit Area)}}{\text{Area of Floor } x} \]

Example 3: F3 = 60', F2 = 45', F1 = 30', DL = 35 psf
Steel Frame
Location: Houghton, MI
Occupancy Category II
Site Class D

\[ S_0 = 0.119 \quad \text{Map} \]
\[ S_1 = 0.023 \quad \text{Map} \]
\[ S_{50} = F_a S_5 \quad \text{Fa} = 1.6 \quad \text{(Table 11.4-1)} \]
\[ S_m = 1.6(1.11) = 0.176 \text{ g} \]
\[ S_{50} = 2/3 S_{50} = 0.117 \text{ g} \]

Category A (Table 11.6-1)

\[ F_1 = F_2 = F_3 = 0.010 W_i \]
\[ W_i = (35 \text{ psf})(60')(80') = 168,000 \text{ lb} \]
\[ F_1 = 0.010 (168000) = 1680 \text{ lb} \]
Loadings, Seismic Design Categories B - C

1.) Find base shear:

\[ V = \frac{S_{DL} W}{T(R/I)} \]

\[ V_{\text{max}} = \frac{S_{DS} W}{R/I} \]

\[ V_{\text{min}} = 0.044 S_{DS} W \] (Minimum)

\[ W = \text{Seismic Weight (lb)} = \sum_{i=1}^{n} w_i \]

\[ n = \# \text{ floors} \]

\[ T = \text{Fundamental period of structure} \]

Estimated by: \[ T = C_t h_n x \]

Steel frame: \[ C_t = 0.028 \quad x = 0.8 \]

R/C frame: \[ C_t = 0.016 \quad x = 0.9 \]

Other: \[ C_t = 0.020 \quad x = 0.75 \]

“Other” includes braced frame or shear wall

\[ R = \text{Response Modification factor} \]

Gives “bonus points” for ductile structures

Ductile steel or R/C frame, \( R = 8 \)
Ordinary R/C shear wall, \( R = 4 \)
Ordinary Masonry shear wall, \( R = 2 \)

\[ I = \text{Importance factor} \]

Occupancy Category

\[ \text{I or II} \]

\[ I = 1.0 \]

\[ \text{III} \]

\[ I = 1.25 \]

\[ \text{IV} \]

\[ I = 1.5 \]

2.) Distribute loads:

\[ F_x = \frac{W_x h_x}{\sum_{i=1}^{n} w_i h_i} \]

\[ k = \begin{cases} 1 & \text{if } T \leq 0.5 \text{s} \\ 2 & \text{if } T \geq 2.5 \text{s} \\ 1 + \frac{T - 0.5}{2} & \text{otherwise} \end{cases} \]
Example

- DL = 35 psf
- Steel Frame
- Location: Kalamazoo, MI
- Occupancy Category II
- Site Class D

\[ S_5 = 0.12 \, g \]
\[ S_1 = 0.05 \, g \]

\[ F_a = 1.6 \]
\[ F_v = 2.4 \]

\[ S_{ms} = 1.6 \times (0.12 \times g) = 0.192 \, g \]
\[ S_{mi} = 2.4 \times (0.05 \times g) = 0.120 \, g \]

\[ S_{05} = \frac{2}{3} \times S_{ms} = 0.128 \, g \]
\[ S_{01} = \frac{2}{3} \times S_{mi} = 0.08 \, g \]

From \( S_{05} \) and Table 11.6-1, design cat. A
From \( S_{01} \) and Table 11.6-2, design cat. B

\[ V = \frac{S_{01} \times W}{T \times (R/I)} \]
\[ W = (60)(80)(3)(35) = 50,400 \, lb \]
\[ T = C \times h \times n = 0.025 \times (45)^{0.8} = 0.588 \]
\[ R = 8 \]
\[ I = 1 \]

\[ V = \frac{50,400 \times (0.08)}{(0.588) \times (8/1)} = 8570 \, lb \]

\[ V_{max} = \frac{S_{05} \times W}{R/I} \]
\[ V_{max} = \frac{0.128 \times 50,400}{8/1} = 8064 \, lb \]

\[ V_{min} = 0.044 \times S_{05} \times I \times W \]
\[ = 0.044 \times 128 \times (1.0) \times 50,400 = 2840 \, lb \]

\[ V = 8064 \, lb \]

\[ F_x = \sum_{i=1}^{n} \frac{w_{xi} \times h_i \times k_i}{2} \]
\[ k_i = 1 + \frac{t - 0.5}{2} \quad \text{if } T > 0.5 \text{ and } T < 2.5 \]
\[ k_i = 0.588 \]
\[ n = 3 \]
\[ k_i = 1 + \frac{0.588 - 0.5}{2} = 1.044 \]
Example CONTINUED...

\[
\sum_{i=1}^{3} w_i \cdot h_i = 80(60)(35)(15) \cdot 1.044 + (80)(60)(35) \cdot 30 \cdot 1.044 + (80)(60)(35) \cdot 45 \cdot 1.044
\]

\[
F_1 = \frac{80(60)(35) \cdot 15 \cdot 1.044}{1.76 \cdot 10^7} = 1.3045
\]

\[
F_2 = \frac{80(60)(35) \cdot 30 \cdot 1.044}{1.76 \cdot 10^7} = 2.6806
\]

\[
F_3 = \frac{80(60)(35) \cdot 45 \cdot 1.044}{1.76 \cdot 10^7} = 4.0961
\]

\[
\text{Loading:}
\begin{align*}
&4.1k \\
&2.7k \\
&1.3k \\
\end{align*}
\]

Check, \( \sum_{i=1}^{3} F_i = V \)

\[
(4.1 + 2.7 + 1.3) = 8.1k = 8.1k = V
\]

\( \text{OK} \)