NCSEA Structural Engineering Exam Review Course

Lateral Forces Review

Lateral Forces – August 2017

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Topics

- Wind
- Horizontal Seismic
- Vertical Seismic
- Dynamic Earth Pressure

Wind

Problem 1: For the image shown, determine the exposure category for a typical residential structure located near the center of the picture.

Exposure Category B

- Exposure categories are addressed in Section 26.7.3 of ASCE 7-10. Exposure categories are controlled by the surface roughness designation.
- Surface roughness B: Urban and suburban areas (closely spaced obstructions, single-family dwellings or larger)

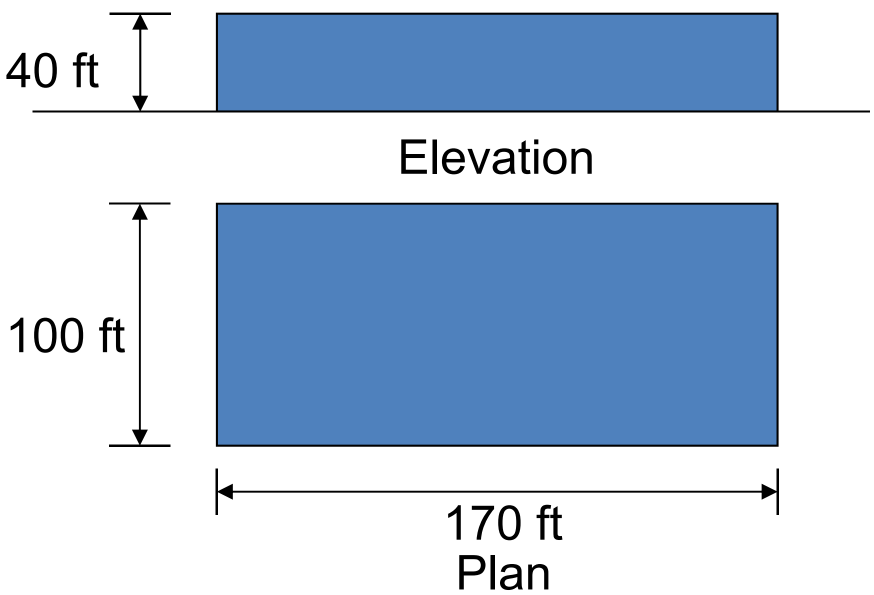
Photo Credit: FEMA (Ed Edahl)

Wind

- Additional comments
  - Surface roughness C: Open terrain with scattered obstructions less than 30 ft high, flat open country, and grasslands
  - Surface roughness D: Flat and smooth, unobstructed areas and water surfaces (including all water surfaces in hurricane prone regions)

Wind

Problem 2: For the office building shown and located on an Exposure Category B site, determine the MWFRS velocity pressure *q* at the mean roof height *h*. The design wind speed is 120 mph. Neglect topographic effects.



$h=40\ \text{ft}$

$K_z=K_{40}=0.76\ \ (\text{Table } 27.3\text{-}1)$

$K_{zt}=1.0\ \ (\text{Figure } 26.8\text{-}1)$

$K_d=0.85\ \ (\text{Table } 26.6\text{-}1)$

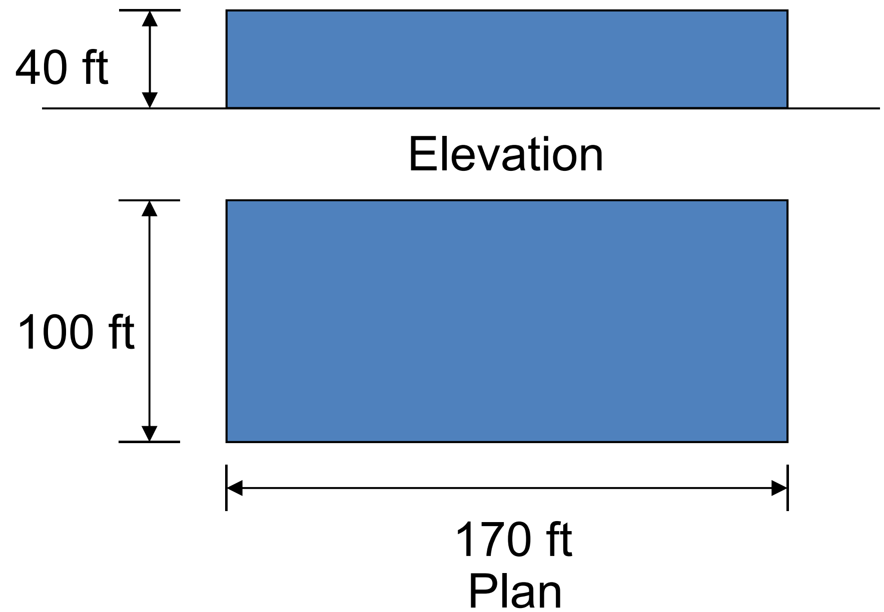
$q_z=0.00256K_zK_{zt}K_dV^2\ \ (\text{Eq. } 27.3\text{-}1)$

$q_z=0.00256(K_z)(1.0)(0.85)(120)^2=31.3K_z\ \ \text{psf}$

$q_h=q_{40}=31.3(K_{40})=31.3(0.76)=23.8\ \ \text{psf}$

Wind

Problem 3: For the enclosed office building shown and located on an Exposure Category B site, determine the internal pressure p_i acting on all interior surfaces. The design wind speed is 120 mph.



$$q_i = q_h = 23.8 \ psf \quad \text{(Previous problem)}$$

$$GC_{pi} = \pm 0.18 \quad (Table \ 26.11-1)$$

$$p_i = \pm q_i (GC_{pi}) = \pm 23.8(0.18) = \pm 4.28 \ psf$$

Wind

Problem 4: For the sign shown, determine the net horizontal wind force on the 20 ft × 30 ft element. The design wind speed is 120 mph. The site is exposure B and the sign is rigid. Neglect topographic effects. Note that Case C loading does not apply for B/s<2.

$F = q_h G C_f A_s$ (Equation 29.4-1)

$q_h = 23.8$ psf (Previous problem)

$G = 0.85$ (Section 26.9)

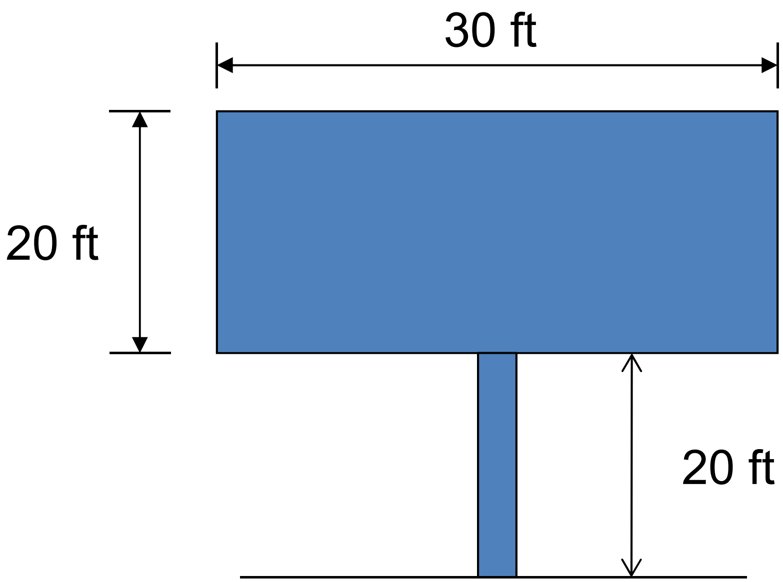
$B/s = 30/20 = 1.5$

$s/h = 20/40 = 0.5$

$C_f = 1.725$ (Figure 29.4-1)

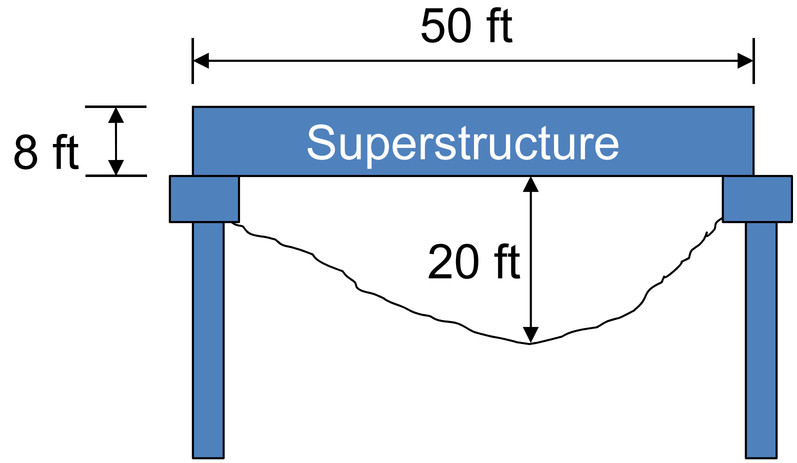
$A_s = 30(20) = 600$ ft^2

$F = q_h G C_f A_s = 23.8(0.85)(1.725)(600) = 20{,}900$ lbs



Wind

Problem 5: For the simply supported bridge shown, determine the total horizontal wind force perpendicular to the 8 ft deep superstructure (includes beam depth, slab depth, and barrier depth at bridge edges). The base design wind velocity is 100 mph.



$$F = P_B A$$

$$P_B = 50 \text{ psf} \quad (\text{Table } 3.8.1.2.1-1, \text{ beams})$$

$$A = 50(8) = 400 \text{ ft}^2$$

$$F = P_B A = (50)(400) = 20{,}000 \text{ lbs}$$

Horizontal Seismic

Problem 6: For the design of the cooling tower attachment detail to the roof of the building shown, determine the unfactored seismic lateral load. S_{DS} = 1.0, I_P = 1.0, W_P = 8 kips. The tower is braced below its center of mass.

$$a_p = 2.5 \quad \text{(Table 13.6-1, cooling tower)}$$

$$R_p = 3.0 \quad \text{(Table 13.6-1, cooling tower)}$$

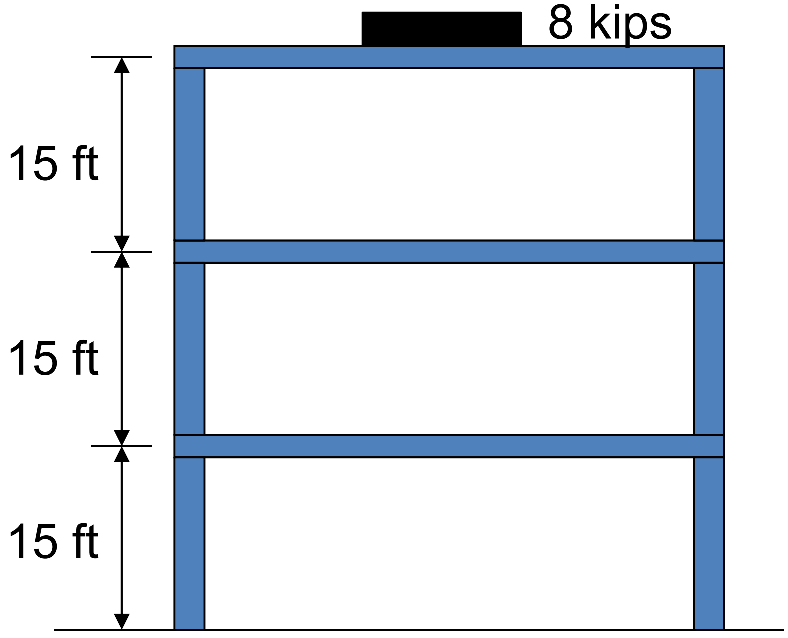
$$F_p = \frac{0.4 a_p S_{DS} W_p}{R_p / I_p}\left(1 + 2\frac{z}{h}\right) \quad \text{(Eq. 13.3-1)}$$

$$F_p = \frac{0.4(2.5)(1.0)(8)}{(3.0)/(1.0)}\left(1 + 2\frac{45}{45}\right) = 8 \text{ k}$$

$$F_{p,min} = 0.3 S_{DS} I_p W_p = 0.3(1.0)(1.0)(8) = 2.4 \text{ k (ok)}$$

$$F_{p,max} = 1.6 S_{DS} I_p W_p = 1.6(1.0)(1.0)(8) = 12.8 \text{ k (ok)}$$

$$F_p = 8 \text{ k}$$



Horizontal Seismic

Problem 7: For the design of the cantilever parapet shown, determine the unfactored seismic lateral load. S_{DS} = 1.0, I_P = 1.0, W_P = 81 psf. The parapet is braced below its center of mass.

$$a_p = 2.5 \quad \text{(Table 13.5-1, cantilever parapet)}$$

$$R_p = 2.5 \quad \text{(Table 13.5-1, cantilever parapet)}$$

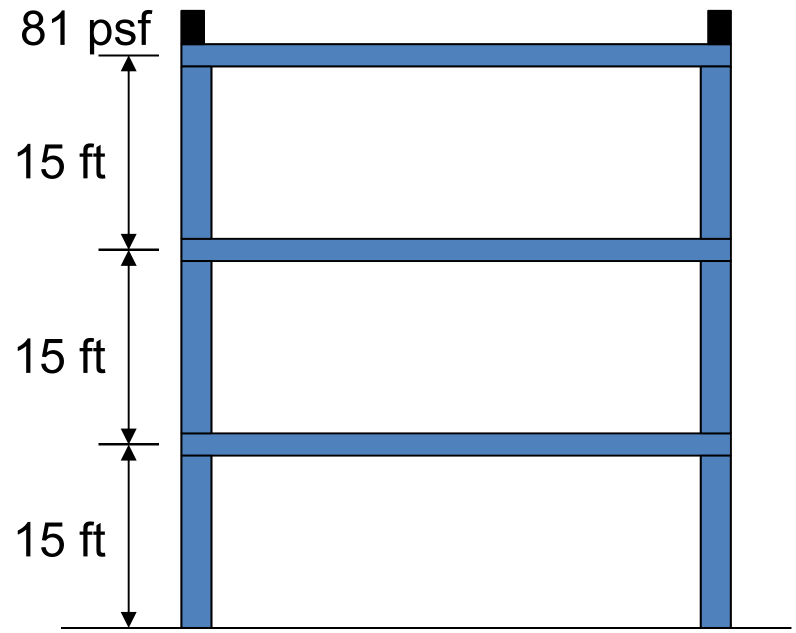
$$F_p = \frac{0.4 a_p S_{DS} W_p}{R_p / I_p}\left(1 + 2\frac{z}{h}\right) \quad \text{(Eq. 13.3-1)}$$

$$F_p = \frac{0.4(2.5)(1.0)(81)}{(2.5)/(1.0)}\left(1 + 2\frac{45}{45}\right) = 97.2 \text{ psf}$$

$$F_{p,min} = 0.3 S_{DS} I_p W_p = 0.3(1.0)(1.0)(81) = 24.3 \text{ psf (ok)}$$

$$F_{p,max} = 1.6 S_{DS} I_p W_p = 1.6(1.0)(1.0)(81) = 130.0 \text{ psf (ok)}$$

$$F_p = 97.2 \text{ psf}$$



Horizontal Seismic

Problem 8: Determine the out-of-plane seismic load on the first and second story load bearing tilt-up walls shown. SDC B, S_{DS} = 0.25, h = 30 ft, I_e = 1.0, flexible roof diaphragm, rigid floor diaphragm, wall weight W_{wall} = 100 psf.

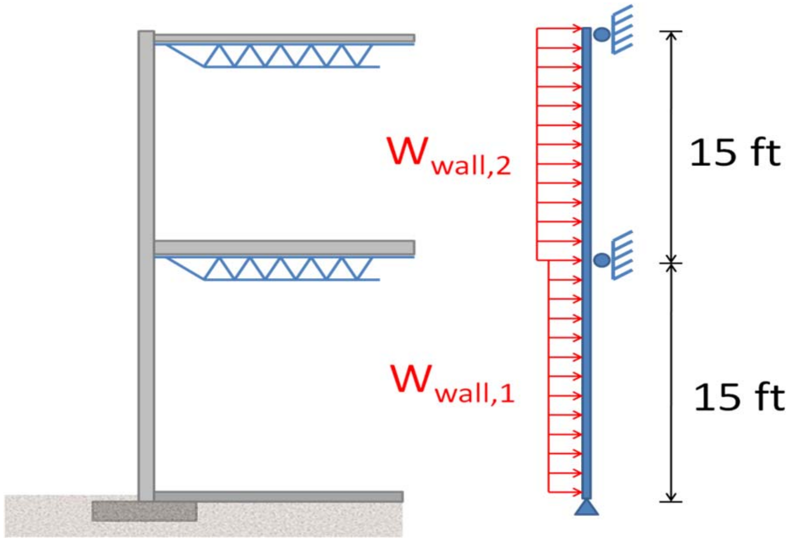
$$w_{wall} = w_{wall,1} = w_{wall,2}$$

$$w_{wall} = 0.4 S_{DS} I_e W_{wall} \quad \text{(Section 12.11.1)}$$

$$w_{wall} = 0.4(0.25)(1)(100) = 10 \text{ psf}$$

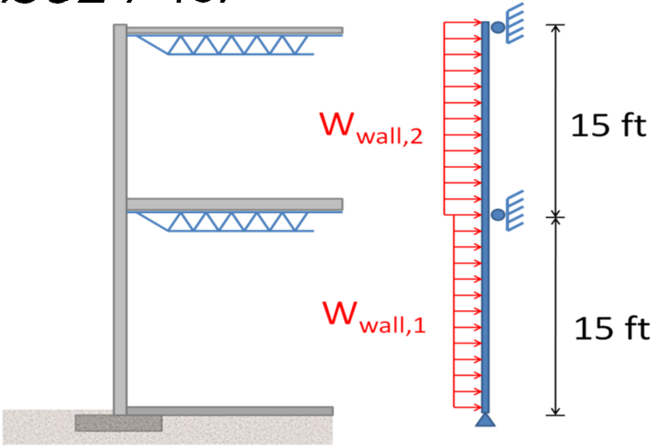
$$w_{wall} = 10 \text{ psf} \leq 0.1 W_{wall} = 0.1(100) = 10 \text{ psf} \quad \text{(ok)}$$

$$w_{wall} = 10 \text{ psf}$$



Horizontal Seismic

Problem 9: Determine the out-of-plane anchorage force at the roof and floor diaphragms which span 50 ft between lines of resistance. SDC B, S_{DS} = 0.25, h = 30 ft, I_e = 1.0, flexible roof diaphragm, rigid floor diaphragm, wall weight W_{wall} = 100 psf. See Section 12.11.2 of ASCE 7-10.



$$k_a = 1 + L_f / 100 = 1 + 50/100 = 1.5 \leq 2.0 \quad \text{(ok)}$$

$$F_p = 0.4 S_{DS} k_a I_e W_p \geq 0.2 k_a I_e W_p$$

$$F_{p,anchorage,roof} = 0.4(0.25)(1.5)(1.0)(100) = 15 \text{ psf} \geq 0.2(1.5)(1.0)(100) = 30 \text{ psf} \quad \text{(use 30 psf)}$$

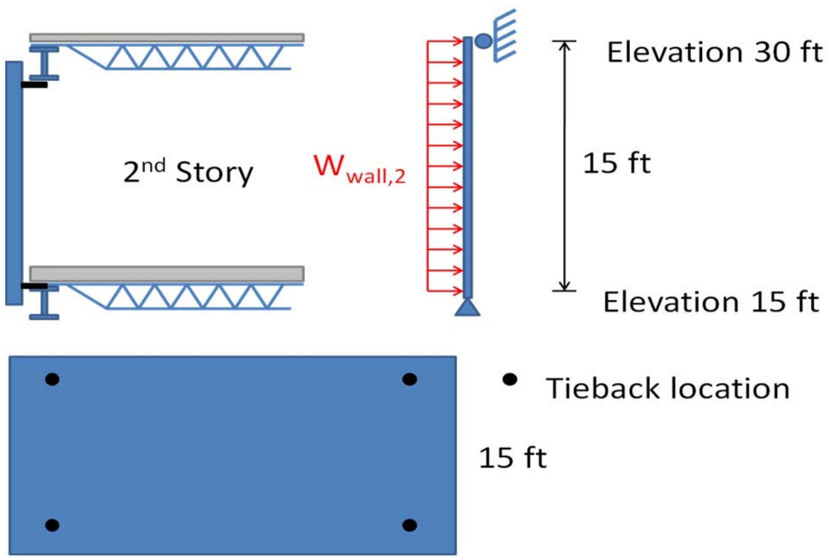
$$F_{p,anchorage,roof} = 30 \text{ psf}(15/2) = 225 \text{ lb/ft}$$

$$F_{p,anchorage,floor} = 0.4(0.25)(1.0)(1.0)(100) = 10 \text{ psf} \geq 0.2(1.0)(1.0)(100) = 20 \text{ psf} \quad \text{(use 20 psf)}$$

$$F_{p,anchorage,floor} = 20 \text{ psf}(15/2 + 15/2) = 300 \text{ lb/ft}$$

Horizontal Seismic

Problem 10: Determine the out-of-plane seismic load on the second-story nonstructural stacked precast wall panel shown. SDC D, S_{DS} = 0.60, h = 60 ft, I_e = 1.0, I_p = 1.0, rigid floor diaphragms shown in figure; wall weight W_{wall} = 100 psf.



Horizontal Seismic

Problem 10: Determine the out-of-plane seismic load on the second-story nonstructural stacked precast wall panel shown. SDC D, S_{DS} = 0.60, h = 60 ft, I_e = 1.0, I_p = 1.0, rigid floor diaphragms shown in figure; wall weight W_{wall} = 100 psf.

$$a_p = 1.0 \quad \text{(Table 13.5-1, exterior wall)}$$

$$R_p = 2.5 \quad \text{(Table 13.5-1, exterior wall)}$$

$$w = F_p = \frac{0.4 a_p S_{DS} W_p}{R_p / I_p}\left(1 + 2\frac{z}{h}\right) \quad \text{(Eq. 13.3-1)}$$

$$w_{z=15} = F_p = \frac{0.4(1.0)(0.60)(100)}{(2.5)/(1.0)}\left(1 + 2\frac{15}{60}\right) = 14.4 \quad \text{psf}$$

$$w_{z=30} = F_p = \frac{0.4(1.0)(0.60)(100)}{(2.5)/(1.0)}\left(1 + 2\frac{30}{60}\right) = 19.2 \quad \text{psf}$$

$$F_{p,min} = 0.3 S_{DS} I_p W_p = 0.3(0.60)(1)(100) = 18 \quad \text{psf}$$

$$\text{(ng for } z = 15 \text{ ft)}$$

$$F_{p,max} = 1.6 S_{DS} I_p W_p = 1.6(0.60)(1)(100) = 96 \quad \text{psf}$$

$$\text{(ok)}$$

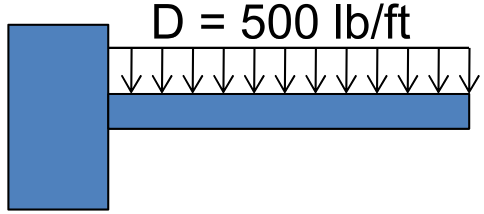
$$w_{z=15} = 18.0 \quad \text{psf}$$

$$w_{z=30} = 19.2 \quad \text{psf}$$

$$w_{wall,2} = \frac{18.0 + 19.2}{2} = 18.6 \quad \text{psf}$$

Vertical Seismic

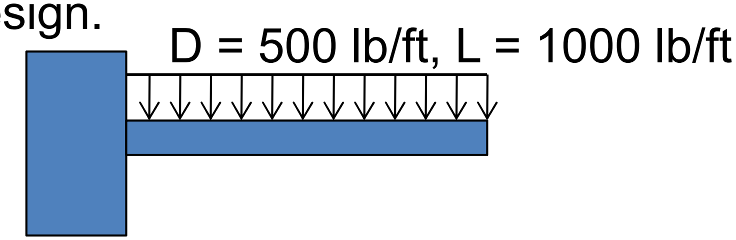
Problem 11: Determine the maximum factored seismic uplift for the nonprestressed cantilever beam shown. Consider all appropriate load combinations involving seismic per ASCE 7-10. SDC D, S_{DS} = 0.60, D = 500 lb/ft, strength design.



When considering uplift on a cantilever beam, only Section 12.4.2.3 and Section 12.4.4 load combinations are considered. Since the beam is not prestressed, the maximum uplift is obtained from Section 12.4.4 by inspection. $w_u = -500(0.2) = -100 \text{ lb/ft}$

Vertical Seismic

Problem 12: Determine the maximum factored seismic downward load for the nonprestressed cantilever beam shown. Consider all appropriate load combinations involving seismic per ASCE 7-10. SDC D, S_{DS} = 0.60, D = 500 lb/ft, L = 1000 lb/ft, strength design.



When considering downward loading on a cantilever beam, only Section 12.4.2.3 load combinations are considered. Note live load factor taken as 1.0 since L_0 is not known (see notes in Section 12.4.2.3).

$$w_u = (1.2 + 0.2S_{DS})D + L$$

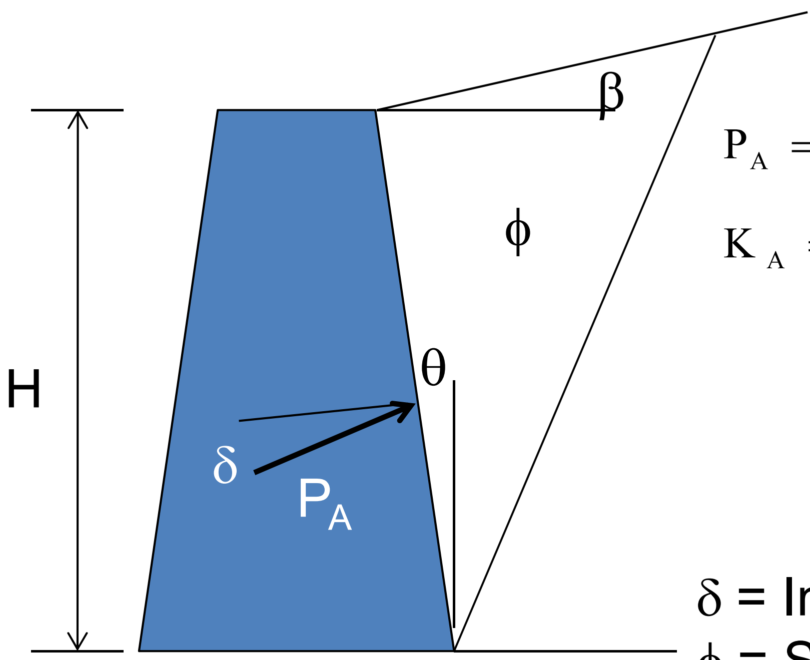
$$w_u = [1.2 + 0.2(0.6)]500 + 1000 = 1660 \quad \text{lb/ft}$$

Dynamic Earth Pressure

- Introduction as applied to retaining walls
  - Magnitude and distribution depends on mode
  - Minimum dynamic soil thrust is away from backfill
  - Shape of dynamic pressure distribution varies
  - Liquefaction not normally considered for bridge or building structures since drains can be used to mitigate the occurrence
  - Mononobe-Okabe (M-O) Method is most commonly used approach

Dynamic Earth Pressure

Coulomb Theory (active pressure—static)



$$P_A = 0.5 K_A \gamma H^2$$

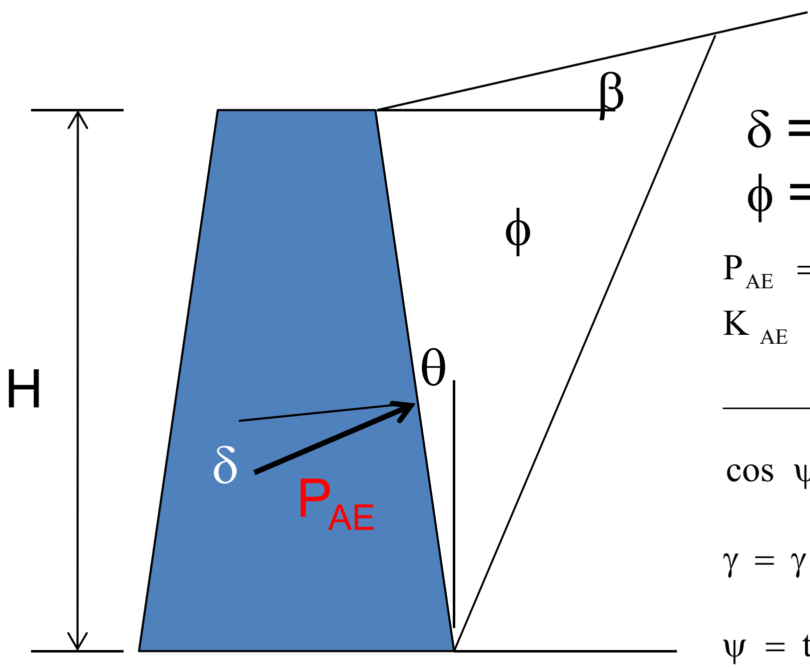
$$K_A = \frac{\cos^2(\phi - \theta)}{\cos^2\theta \cos(\delta + \theta)\left[1 + \sqrt{\frac{\sin(\delta + \phi)\sin(\phi - \beta)}{\cos(\delta + \theta)\cos(\beta - \theta)}}\right]^2}$$

δ = Interface friction angle between wall and soil

ϕ = Soil friction angle

Dynamic Earth Pressure

Coulomb Theory (active pressure—total)



δ = Interface friction angle (wall and soil)

ϕ = Soil friction angle

$$P_{AE} = 0.5 K_{AE} \gamma H^2 (1 - k_v)$$

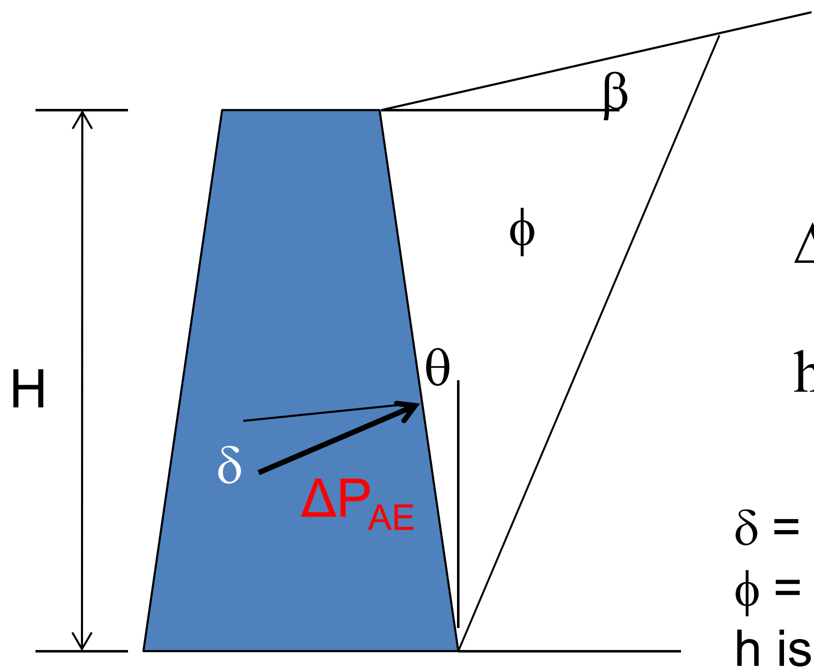
$$K_{AE} = \frac{\cos^2(\phi - \theta - \psi)}{\cos\psi \cos^2\theta \cos(\delta + \theta + \psi)\left[1 + \sqrt{\dfrac{\sin(\delta + \phi)\sin(\phi - \beta - \psi)}{\cos(\delta + \theta + \psi)\cos(\beta - \theta)}}\right]^2}$$

$$\gamma = \gamma_d$$

$$\psi = \tan^{-1}\left(\frac{k_h}{1 - k_v}\right)$$

Dynamic Earth Pressure

Coulomb Theory (active pressure—seismic)



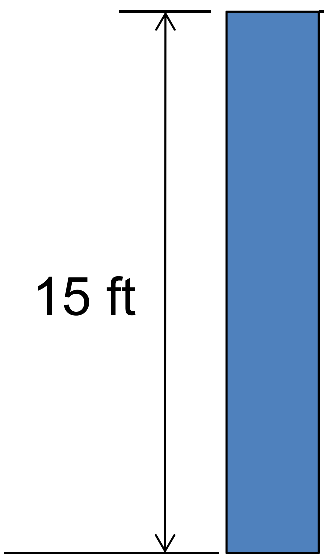
$$\Delta P_{AE} = P_{AE} - P_A$$

$$h = \frac{P_A (H/3) + \Delta P_{AE} (0.6H)}{P_{AE}}$$

δ = Interface friction angle between wall and soil
ϕ = Soil friction angle
h is vertical distance to P_{AE} (total active thrust)

Dynamic Earth Pressure

Problem 13: Determine the static active thrust P_A on the retaining wall shown. $\gamma = \gamma_d = 120\ \text{lb/ft}^3$, $\varphi = 34°$, $\delta = 17°$, $\beta = 0°$.



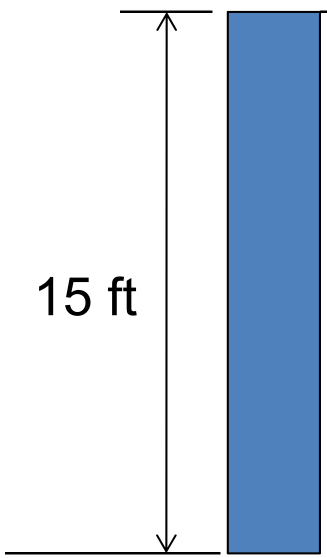
$$K_A = \frac{\cos^2(\varphi - \theta)}{\cos^2\theta\cos(\delta+\theta)\left[1+\sqrt{\dfrac{\sin(\delta+\varphi)\sin(\varphi-\beta)}{\cos(\delta+\theta)\cos(\beta-\theta)}}\right]^2}$$

$$K_A = \frac{\cos^2(34-0)}{\cos^2 0\cos(17+0)\left[1+\sqrt{\dfrac{\sin(17+34)\sin(34-0)}{\cos(17+0)\cos(0-0)}}\right]^2} = 0.256$$

$$P_A = 0.5K_A\gamma H^2 = 0.5(0.256)(120)(15)^2 = 3,456\ \ \text{lb/ft}$$

Dynamic Earth Pressure

Problem 14: Determine the total active thrust P_{AE} on the retaining wall shown considering seismic accelerations. $\gamma = \gamma_d = 120$ lb/ft^3, $\varphi = 34°$, $\delta = 17°$, $\beta = 0°$, $k_h = 0.3$, $k_v = 0.15$.



$$\psi = \tan^{-1}\left(\frac{k_h}{1-k_v}\right) = \tan^{-1}\left(\frac{0.3}{1-0.15}\right) = 19.4°$$

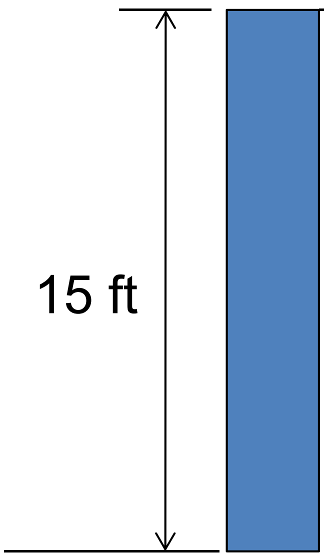
$$K_{AE} = \frac{\cos^2(\phi-\theta-\psi)}{\cos\psi\cos^2\theta\cos(\delta+\theta+\psi)\left[1+\sqrt{\frac{\sin(\delta+\phi)\sin(\phi-\beta-\psi)}{\cos(\delta+\theta+\psi)\cos(\beta-\theta)}}\right]^2}$$

$$K_{AE} = \frac{\cos^2(34-0-19.4)}{\cos 19.4\cos^2 0\cos(17+0+19.4)\left[1+\sqrt{\frac{\sin(17+34)\sin(34-0-19.4)}{\cos(17+0+19.4)\cos(0-0)}}\right]^2} = 0.553$$

$$P_{AE} = 0.5K_{AE}\gamma H^2(1-k_v) = 0.5(0.553)(120)(15)^2(1-0.15) = 6{,}346 \quad \text{lb/ft}$$

Dynamic Earth Pressure

Problem 15: Determine the overturning moment at the base of the retaining wall shown considering the total active thrust from seismic accelerations and using the Seed and Whitman simplified equation. $\gamma = \gamma_d = 120\ \text{lb/ft}^3$, $\varphi = 34°$, $\delta = 17°$, $\beta = 0°$, $k_h = 0.3$, $k_v = 0.15$.



$$P_A = 3{,}456 \quad \text{lb/ft} \quad (\text{previous problem})$$

$$\Delta P_{AE} = (3/8) k_h \gamma H^2 = (3/8)(0.3)(120)(15)^2 = 3{,}038 \quad \text{lb/ft}$$

$$h = \frac{P_A (H/3) + \Delta P_{AE} (0.6H)}{P_{AE}} = \frac{3{,}456(15/3) + 3{,}038[0.6(15)]}{3{,}456 + 3038} = 6.87 \quad \text{ft}$$

$$M_0 = (P_{AE})_{horizontal}\, h = (3{,}456 + 3{,}038)(6.87) = 44{,}600 \quad \text{lb-ft/ft}$$

Note that the Seed and Whitman simplified equation for the active pressure (seismic) is not presented on previous slides and is used here for illustration and since commonly used by geotechnical engineers.

Dynamic Earth Pressure

- Other information
  - AASHTO Appendix A11
  - ASCE 7-10 Section 11.8.3
  - AASHTO recommends k_h = peak ground acceleration but permits reduction for small tolerable deformations (A11.1.1.2)
  - For buildings, most geotechnical engineers use $k_h = S_{DS}/2.5$ as consistent with peak ground accelerations associated with the design earthquake (see 2009 NEHRP for discussion)

Structural Design Standards Relevant for Lateral Forces

- In order of precedence
  - International Building Code (2012 Edition)
  - Minimum Design Loads for Buildings and Other Structures (ASCE 7-10)
  - AASHTO LRFD Bridge Design Specifications (7th Edition, 2014)

Recommended References and Additional Study Materials

- Structural: Sample Questions + Solutions (NCEES, 2014)
- Seismic and Wind Forces: Structural Design Examples (Williams, ICC, 2007)
- 2012 IBC Structural/Seismic Design Manual: Code Application Examples (Volume 1, ICC, 2013)
- Guide to the Design of Out-of-Plane Wall Anchorage (Mays, ICC, 2010)