Soil Dynamics

Lecture 15

Diaphragm Theory - Part I

In a Problem Format

Question #01.

Which of the following are known as resisting elements?

A. Columns.

B. Shear walls.

C. Connections.

D. All the above.

Answer to #01.

D.

Elements that resist story shears are known as *resisting elements*.

Resisting elements are columns, shear walls, connections and structural systems, such as braced frames or moment-resisting frames.

Question #02.

Which of the following elements resist lateral forces?

I. Shear walls.
II. Horizontal diaphragms.
III. Moment-resisting frames.
IV. Braced frames.

A. I only.

B. II only.

C. II, III and IV.

D. I, III and IV.

<u>Answer to #02.</u>

D.

Resisting elements (for example, columns, shear walls, braced frames, moment-resisting frames and connections) resist lateral forces.

Horizontal diaphragms (for example, floors and ceilings) distribute the lateral forces to the resisting elements.

Question #03.

The base shear in a shear wall building is resisted by,

A. The parallel walls only.

B. The perpendicular walls only.

C. All walls.

D. The horizontal diaphragms and all walls.

Answer to #03.

A.

The base shear is the total force delivered to the structure at the base. In perpendicular walls, the forces are tensile and compressive, while in parallel walls the forces are shear. Therefore, in shear wall buildings, parallel walls resist the base shear.

Question #04.

The transverse seismic loading is,

A. perpendicular to the shorter dimension of the building.

B. parallel to the shorter dimension of the building.

C. parallel to the longer dimension of the building.

D. independent of the dimensions of the building.

Answer to #04.

B.

The direction of seismic loading applied to a structure is typically either in the transverse (that is, the short dimension) or longitudinal (that is, the long dimension) direction. Therefore, transverse seismic loading describes a loading that is parallel to the shorter dimension of the structure.

Question #05.

The base shear force distribution to the floors above the base should,

A. decrease linearly with height above the base.

B. increase linearly with height above the base.

C. be uniform at each floor.

D. be concentrated at the roof.

Answer to #05.

B.

CBC Section 1630.5 states that the base shear forces should be distributed throughout the height of the structure, in conformance with CBC Formulas 30-13, 30-14 and 30-15. At each level, the distributed force F_x increases linearly as the height above the base increases.

Question #06.

The walls perpendicular to the direction of lateral force,

I. are affected by ground acceleration force.
II. have no resistance to bending moment.
III. contribute inertia load to the diaphragm.

A. I and II.

B. I and III.

C. II and III.

D. I, II and III.

Answer to #06.

B.

Walls that are perpendicular to the lateral force are affected by ground acceleration forces and carry tensile and compressive forces. They resist the bending moment. Perpendicular walls transfer their own inertia forces to the base of the structure.

Question #07.

Consider a one-story building (roof plus four walls).

Which walls contribute inertia load to the diaphragm shear?

A. The walls that are perpendicular to the applied seismic force.

B. The walls that are parallel to the applied seismic force.

C. Both (A) and (B).

D. None of these walls.

Answer to #07.

A.

The walls perpendicular to the direction of the seismic forces resist the bending moment, and they also contribute inertia load to the diaphragm shear.

Question #08.

Consider a one-story building (roof plus four walls).

Which of the following elements contribute inertia load to the base shear?

- **I. the roof.**
- **II. the walls that are perpendicular to the applied seismic force.**
- **III. the walls that are parallel to the applied seismic force.**

A. I only.

B. I and II.

C. I and III.

D. I, II and III.

<u>Answer to #08.</u>

D.

All the inertia forces resulting from the mass of the structure along with all masses attached to or contained by the structure should be carried from their origins to the foundations.

Roof diaphragms transmit inertia forces from their own weight plus the weight of the perpendicular walls to the vertical resisting elements.

The vertical shear-resisting elements are the parallel walls that transfer forces from the roof diaphragms, plus their own inertia forces, to the base of structures.

Question #09.

The minimum base shear calculation can be obtained from which of the following equations?

A. $$V = \left(\frac{2.5 C_a I}{R}\right) W$$

B. $$V = 0.7\, C_a\, I\, W$$

C. $$V = 0.11\, C_a\, I\, W$$

D. $$V = \left(\frac{C_V I}{R T}\right) W$$

Answer to #09.

C.

Based on the CBC Section 1630.2.1, the minimum total design base shear should be obtained from CBC Formula 30-6,

$$V = 0.11\, C_a\, I\, W$$

In addition, for a seismic zone 4, the minimum total design base shear should be calculated from CBC Formula 30-7,

$$V = \left(\frac{0.8 Z N_v I}{R} \right) W$$

Question #10.

In the CBC formula shown below, what is F_t ?

$$F_x = \frac{\left(V - F_t\right) w_x h_x}{\sum_{i=1}^{n} w_i h_i}$$

A. the stiffness of the top (roof) level.

B. the fundamental mode response.

C. the higher mode response.

D. The top story drift.

Answer to #10.

C.

The CBC Formula 30-15 distributes the base shear force to each story in accordance with the distribution of mass at that level.

F_t represents a concentrated force at the top level (that is, the roof) that is a supplemental force to F_x at that level.

F_t accounts for the response to higher modes, which is more significant for longer period structures.

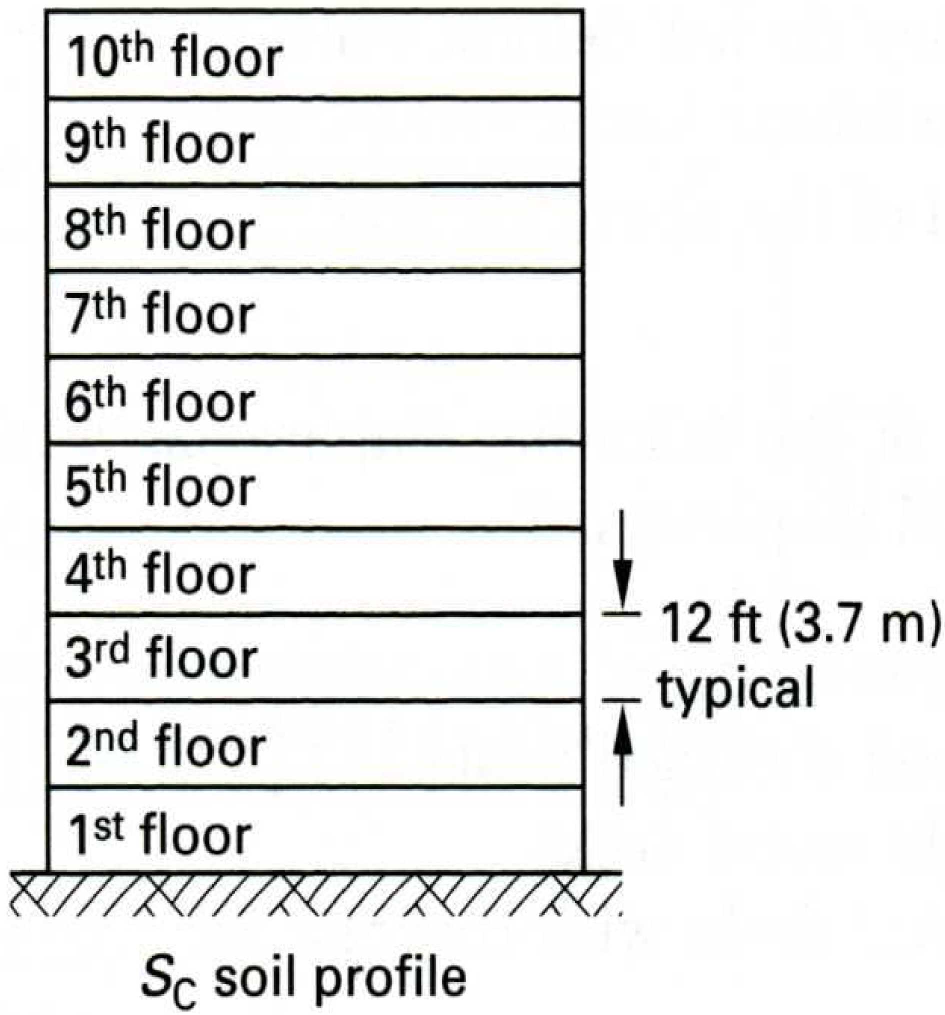
Based on CBC Section 1630.5, F_t should be determined from CBC Formula 30-14,

$$F_t = 0.07\ TV$$

Question #11.

A ten story office building with a special moment-resisting steel frame in a seismic zone 4, has a near-source factor N_v = 1.0. The total weight of each story is 150,000 lb_m.

Determine the base shear V.



A. 65,500 lb_f.

B. 77,800 lb_f.

C. 106,000 lb_f.

D. 137,500 lb_f.

Answer to #11.

B.

For seismic zone 4, CBC Table 16-1, *Z* = 0.4. For an office building, CBC Table 16-K gives *I* = 1.0. For a special moment-resisting steel frame, CBC Table 16-N gives *R* = 8.5. CBC Section 1630.2.2, Item 1, gives *Ct* = 0.035. Also, CBC Table 16-R gives the seismic response coefficient *Cv* = 0.56 *Nv* for a soil profile SC, and *Z* = 0.4.

$$h_n = (10\ \textbf{floors})(12\ \textbf{feet}) = 120\ \textbf{feet}$$

$$T = C_t (h_n)^{3/4} = (0.035)(120\ \textbf{feet})^{3/4} = 1.27\ \textbf{sec}$$

$$\therefore \quad C_V = (0.56)(1.0) = 0.56$$

$$\textbf{and} \quad W = (10\ \textbf{floors})(150{,}000\ lb_f) = 1{,}500{,}000\ lb_f$$

Using CBCFormula 30-4,

$$V = \left(\frac{C_V I}{RT}\right) W = \left(\frac{(0.56)(1.0)}{(8.5)(1.27)}\right)(1{,}500{,}000\ lb_f) = 77{,}800\ lb_f$$

Question #12.

Use the data in Question #11 to determine the concentrated force at the roof level. Assume that the base shear is $V = 90{,}000\ lb_f$.

A. 0 lb_f.

B. 3,200 lb_f.

C. 8,000 lb_f.

D. 9,500 lb_f.

Answer to #12.

C.

Using Question #11 and its solution, T = 1.27 sec. Since this period is larger than 0.7 sec, use CBC Section 1630.5, Formula 30-14,

$$F_t = 0.07TV = (0.07)(1.27\ s)(90,000\ lb_f) = 8,000\ lb_f$$

Check that $F_t \leq 0.25V$,

$$0.25V = (0.25)(90,000\ lb_f) = 22,500\ lb_f$$

Since $8,000\ lb_f < 22,500\ lb_f$, the value of F_t is,

$$F_t = 8,000\ lb_f$$

Question #13.

Based on the CBC, what minimum design force should the floor and roof diaphragms resist when Z = 0.3, I = 1.0 and the soil profile type is SB ?

A. 0.15 w_{px}.

B. 0.30 w_{px}.

C. 0.60 w_{px}.

D. 1.00 w_{px}.

Answer to #13.

A.

CBC Section 1633.2.9, Item 2, the force F_{px} should not be less than 0.5 C_a I w_{px}.

From CBC Table 16-Q, the value of seismic coefficient $C_a = 0.30$ for the soil profile type S_B and $Z = 0.3$.

Question #14.

The three buildings below have special moment-resisting steel structures, located in a seismic zone 4. The closest distance of the structures to known faults is 9.32 miles. These known faults are assumed not to produce earthquakes larger than a 6.3 magnitude, and they have a low rate of seismic activity (that is *SR* = 2 mm/year).

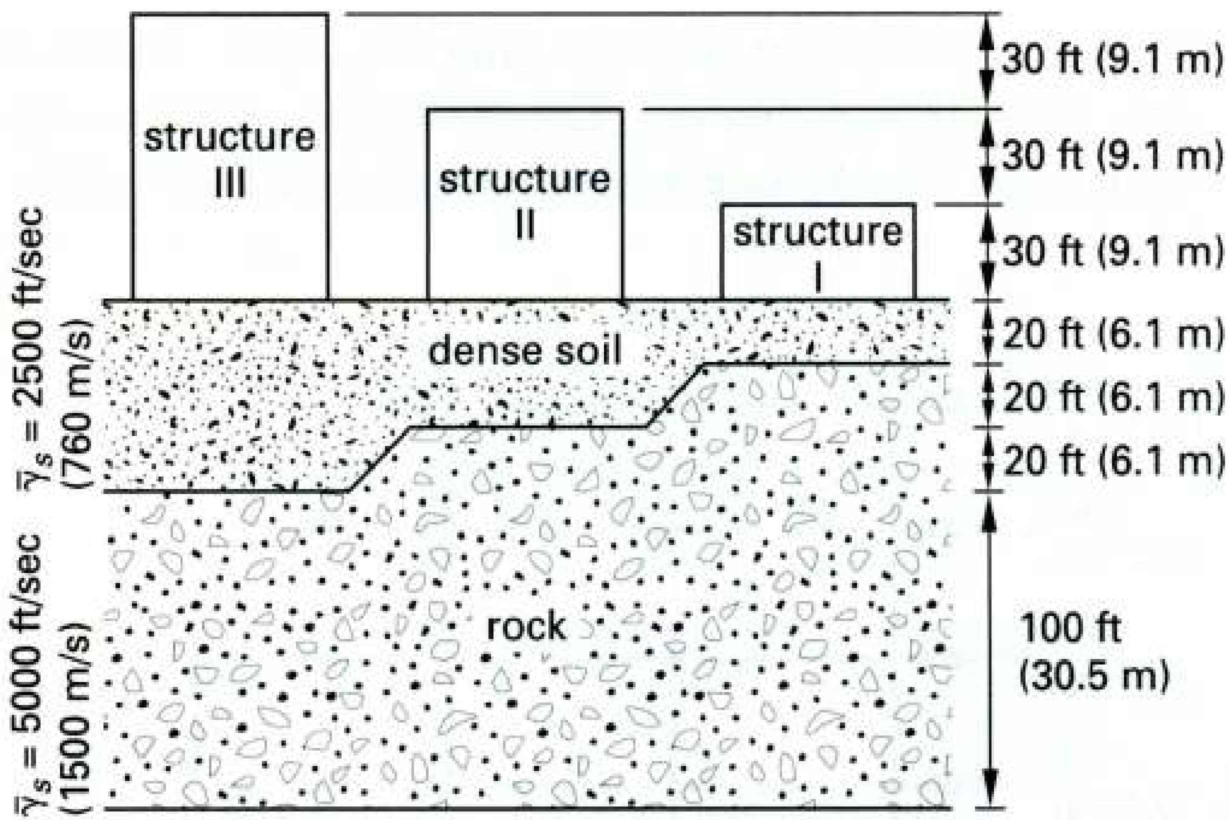
Which building has the largest natural period?

A. I.

B. II.

C. III.

D. They are all equal.



<u>Answer to #14.</u>

C.

CBC Section 1630.2.2, Item 1, C_t = 0.035 for all special steel moment-resisting buildings.

CBC Formula 30-8,

$$\boldsymbol{T} = \boldsymbol{C_t} \left(\boldsymbol{h_n}\right)^{3/4}$$

$$\therefore \quad \boldsymbol{T_I} = \boldsymbol{C_t}\left(\boldsymbol{h_n}\right)^{3/4} = (0.035)(30\ \boldsymbol{ft})^{3/4} = 0.45\ \boldsymbol{sec}$$

$$\therefore \quad \boldsymbol{T_{II}} = \boldsymbol{C_t}\left(\boldsymbol{h_n}\right)^{3/4} = (0.035)(60\ \boldsymbol{ft})^{3/4} = 0.75\ \boldsymbol{sec}$$

$$\therefore \quad \boldsymbol{T_{III}} = \boldsymbol{C_t}\left(\boldsymbol{h_n}\right)^{3/4} = (0.035)(90\ \boldsymbol{ft})^{3/4} = 1.00\ \boldsymbol{sec}$$

Therefore, $\boldsymbol{T_{III}}$ has the largest natural period.

Question #15.

The three buildings below have special moment-resisting steel structures, located in a seismic zone 4. The closest distance of the structures to known faults is 9.32 miles. These known faults are assumed not to produce earthquakes larger than a 6.3 magnitude, and they have a low rate of seismic activity (that is *SR* = 2 mm/year).

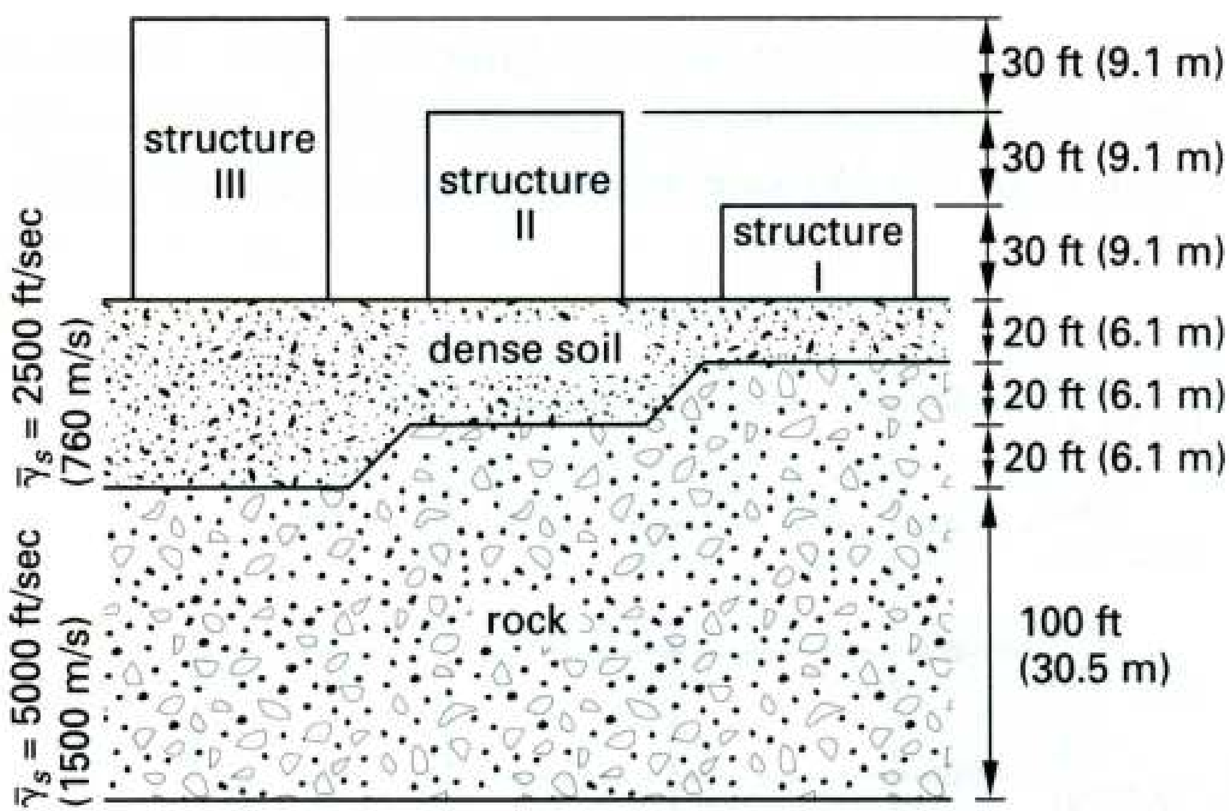
Which building has the highest seismic coefficient C_v ?

A. I.

B. II.

C. III.

D. They are all equal.



Answer to #15.

D.

For buildings I, II and III, the dense soil measured shear wave velocity is *γs* = 2,500 ft/sec, and the rock measured shear velocity is *γs* = 5,000 ft/sec. Based on CBC Section 1636.2.6 the averaging of the shear wave velocities is applicable only for the upper 100 feet.

CBC Section 1636.2.1 proposes using Formula 36-1 to obtain the average shear wave velocities for the buildings, as shown in the next slide.

For building I, the average shear wave velocity is,

$$\bar{\gamma}_s = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{\gamma_{si}}} = \frac{20\ ft + 100\ ft}{\frac{20\ ft}{2{,}500\ ft/s} + \frac{100\ ft}{5{,}000\ ft/s}} = 4{,}300\ ft/s$$

For building II,

$$\bar{\gamma}_s = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{\gamma_{si}}} = \frac{40\ ft + 100\ ft}{\frac{40\ ft}{2{,}500\ ft/s} + \frac{100\ ft}{5{,}000\ ft/s}} = 3{,}900\ ft/s$$

For building III,

$$\bar{\gamma}_s = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{\gamma_{si}}} = \frac{60\ ft + 100\ ft}{\frac{60\ ft}{2{,}500\ ft/s} + \frac{100\ ft}{5{,}000\ ft/s}} = 3{,}600\ ft/s$$

Based on CBC Section 1636.2 and Table 16-J, soil profile S_B can be classified for buildings I, II and III because the shear wave velocity of soil profile type S_B is between 2,500 ft/s and 5,000 ft/s.

However, CBC Section 1636.2.6, the rock categories, soil profile types S_A and S_B should not be used if there is more than 10 feet of soil between the rock surface and the foundation. Therefore, here S_C is the appropriate soil profile.

Based on CBC Table 16-U, for buildings I, II, III, the seismic source type is C because the maximum moment magnitude M is less than 6.5, and the slip rate is equal to 2 mm/yr. It is important to note that the CBC requires both maximum moment magnitude and slip rate conditions to be satisfied concurrently when determining the seismic source type.

CBC Table 16-R gives the seismic coefficient $Cv = 0.56\ Nv$ with a soil profile S_C in a zone 4. CBC Table 16-T, with a seismic source type C and the buildings 9.32 miles away from a known source, the near-source factor $Nv = 1.0$ for buildings I, II and III. Therefore,

$$Cv = (0.56)(1.0) = 0.56$$

Question #16.

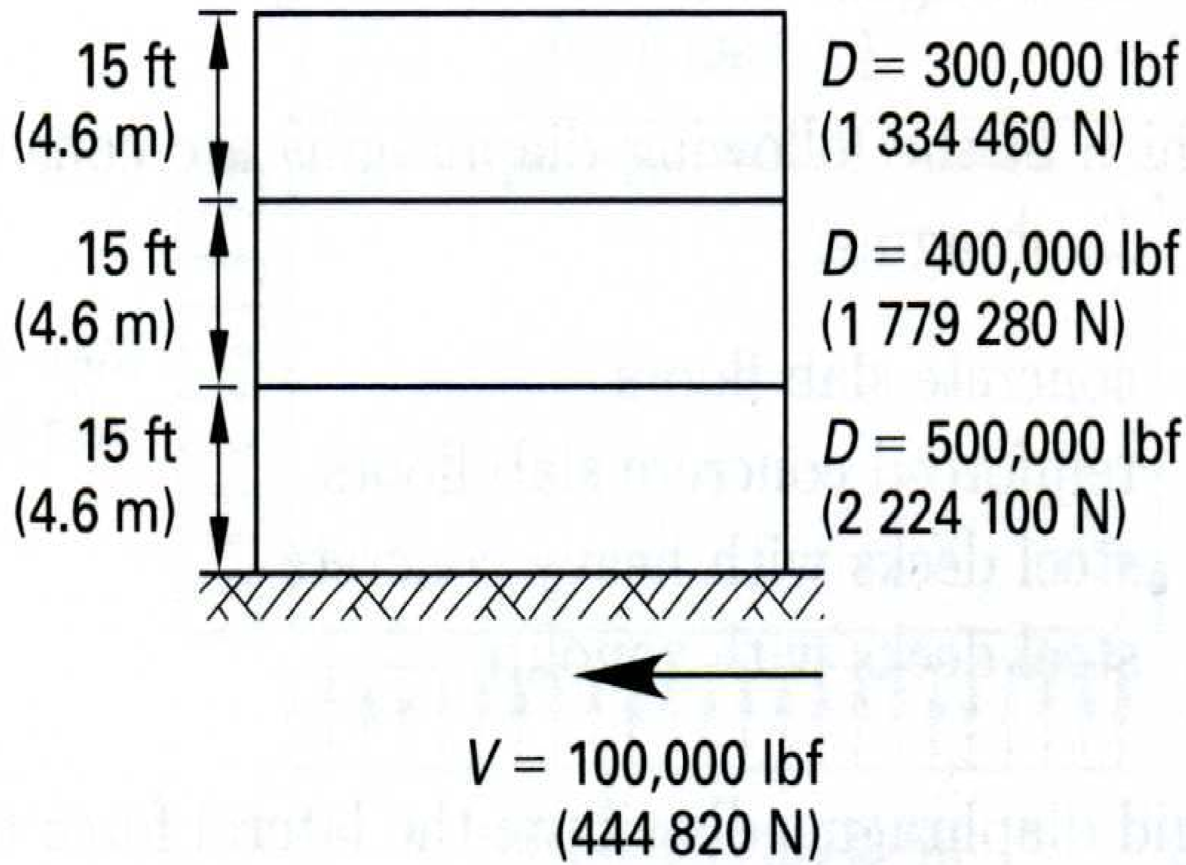
A three-story hospital in San Francisco is built with a special moment-resisting steel frame. The calculated design base shear is 100,000 lbf. The tributary dead loads of each story, including the walls, are given in the figure. What is the distributed base shear at the building's roof level?

A. 33,000 lbf.

B. 41,000 lbf.

C. 49,000 lbf.

D. 53,000 lbf.



Answer to #16.

B. $h_n = (3\ stories)(15\ feet/story) = 45\ feet$

CBC Section 1630.2.2, Item 1, $C_t = 0.035$. Using Formula 30-8,

$T = C_t(h_n)^{3/4} = (0.035)(45\ ft)^{3/4} = 0.6\ s$

Since 0.6 s < 0.7 s, CBCSection 1630.5 states that $F_t = 0$

level	h_x	w_x	$h_x w_x$
3 (roof)	45 ft	300 k	13,500 ft-k
2	30 ft	400 k	12,000 ft-k
1	15 ft	500 k	7,500 ft-k
		$\sum$	33,000 ft-k

The base shear at the roof level is given by CBCFormula 30-15,

$$F_x = \frac{(V - F_t)w_x h_x}{\sum_{i=1}^{n} w_i h_i} = \frac{(100-0)(13,500)}{(33,000)} = 41,000\ lb_f$$

Question #17.

For a concrete shear wall building, the shear at each level is shown in the figure below. The structure is located in a seismic zone 3.

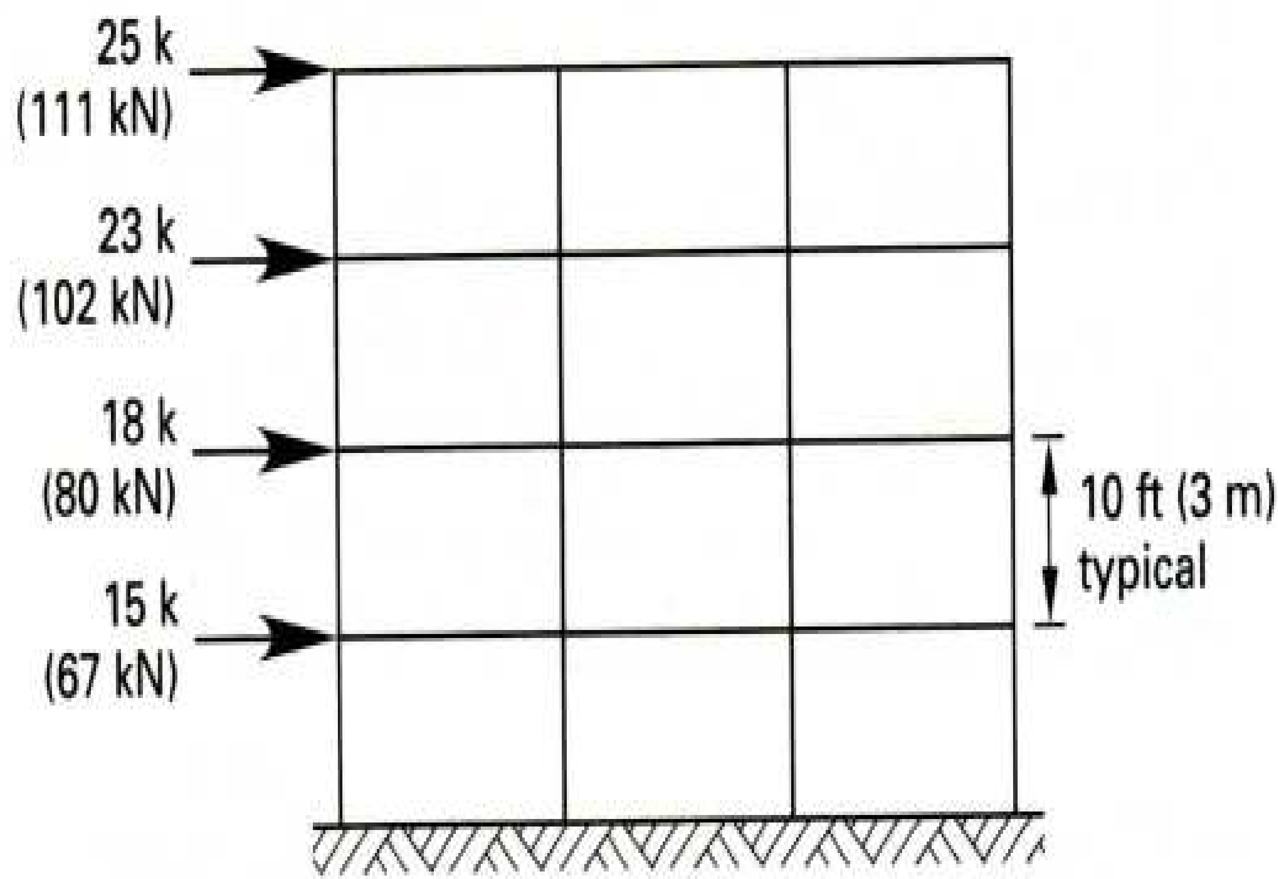
What is the overturning moment at the base?

A. 810 ft-k.

B. 1,620 ft-k.

C. 2,200 ft-k.

D. 3,240 ft-k.



Answer to #17.

C.

The overturning moment at the base is simply the sum of the overturning moments due to the seismic forces F_t and F_x at each level.

$$M_{overturning} = (25\,k)(40\,ft) + (23\,k)(30\,ft) + (18\,k)(20\,ft) + (15\,k)(10\,ft) = 2{,}200\,ft-k$$

Question #18.

Flexible diaphragms distribute the lateral force to the resisting elements in proportion to,

A. the relative rigidities of these elements.

B. the tributary area of these elements.

C. the base shear.

D. the deflection of these elements.

<u>Answer to #18.</u>

B.

Contrary to rigid diaphragms that distribute lateral forces in proportion to the rigidities of vertical resisting elements, flexible diaphragms (for example, wood or light gauge steel) distribute lateral forces to vertical resisting elements in proportion to the tributary area of the elements.

Question #19.

Which of the following diaphragms are incapable of distributing torsional moments to the vertical resisting elements?

A. flexible diaphragms.

B. rigid diaphragms.

C. Both (A) and (B).

D. diaphragms with no eccentricity.

<u>Answer to #19.</u>

A.

Flexible diaphragms are relatively thin structural elements that are anchored to the vertical resisting elements. They lack bending strength and depend on the stiffness of perpendicular walls to limit overall diaphragm deflection.

Flexible diaphragms are incapable of distributing torsional moments to vertical resisting elements.

Question #20.

Which of the following diaphragms are considered flexible diaphragms?

A. concrete slab floors.

B. reinforced concrete slab floors.

C. steel decks with heavy concrete.

D. steel decks with zenolite.

Answer to #20.

D.

Steel decks with zonolite are structurally relatively thin and are considered flexible diaphragms.