

*Soil Dynamics*

*Lecture 13*

*Seismic Codes*

*California Building Code – Part III*

*In a Problem Format*

### List of Symbols.

- $a_p$  is the in-structure component of the amplification factor.
- $C_a$  is the seismic response coefficient for proximity.
- $C_p$  is the horizontal force factor.
- $C_t$  is a numerical coefficient for the period.
- $C_v$  is the seismic response coefficient.
- $F_p$  is total (design or service) lateral seismic force.
- $F_t$  is the concentrated force at the top of the structure.
- $h_n$  is defined as the height of the building above the base to the  $n^{\text{th}}$  level.
- $I$  is the seismic importance factor.
- $N_a$  is the near source factor for  $C_a$ .
- $N_v$  is the near source factor for  $C_v$ .
- $R$  is the response modification factor; it reflects the inherent over-strength and global ductility capacity of different lateral-force resisting systems.
- $R_p$  is the component response modification factor; the horizontal force factor.
- $S$  is the soil profile classification, such as,  $S_A$ ,  $S_B$ ,  $S_C$ ,  $S_D$ ,  $S_E$  and  $S_F$ ).
- $T$  is the fundamental period.
- $V$  is the base shear force.
- $W$  is the weight of the entire structure (dead + live loads).
- $Z$  is the seismic zone influence factor.
- $\Omega_o$  is the seismic force amplification factor.
- $\Delta_s$  is the inter-story drift.

**Question #01.**

**For special moment-resisting space frames, what are the values of  $a_p$  and  $R_p$  (the in-structure component of the amplification factor, and the total design or service lateral seismic force respectively), for the attachment of suspended ceilings?**

***NB:* attachments include the anchorages and the required bracings.**

- A. 1.0 and 3.0.**
- B. 1.0 and 4.0.**
- C. 2.5 and 3.0.**
- D. 2.5 and 4.0.**

**Answer to #01.**

**A.**

**The CBC Table 16-O gives  $a_p$  and  $R_p$  values for elements of the structure, for non-structural components and for equipment.**

**Anchorage for suspended ceilings has an  $a_p$  value of 1.0 and an  $R_p$  value of 3.0.**

**Question #02.**

**You are going to design a billboard structure next to a major highway. The structure will be placed on its own foundation (versus sitting upon another building).**

**What value of the seismic force over-strength factor  $\Omega_o$  should be used?**

- A. 2.**
- B. 3.**
- C. 4.**
- D. 5.**

**Answer to #02.**

**A.**

**Signs and billboards are known as non-building structures.**

**CBC Table 16-P states that the seismic force over-strength factor  $\Omega_o = 2$ .**

**Question #03.**

**Non-building structures that are not “rigid structures” and “tanks with supported bottoms” should be designed to resist design seismic forces not less than,**

- A.  $0.11 C_a I W$**
- B.  $0.56 C_a I W$**
- C.  $0.70 C_a I W$**
- D.  $3.00 C_a W / R$**

**Answer to #03.**

**B.**

**Non-building structures include all self-supporting structures other than buildings that carry gravity loads and resist seismic forces.**

**Provisions for “rigid structures” and “tanks with supported bottoms” are given in the CBC sections 1634.3 and 1634.4 respectively.**

**Based on the CBC Section 1634.5, other non-building structures excluding rigid structures and tanks with supported bottoms should be designed to resist design seismic forces not less than those forces determined from CBC Formula 34-2,**

$$V = 0.56 C_a I W$$

**Note that for seismic zone 4, the total design base shear should also not be less than CBC Formula 34-3,**

$$V = ( 1.60 Z N_v I / R ) W$$

**Question #04.**

**You are required to design a rigid non-building structure with a period  $T = 0.04$  s.**

**Which CBC formula would you use to obtain the lateral base force  $V$ ?**

**A.  $V = 0.70 C_a I W$**

**B.  $V = 0.11 C_a I W$**

**C.  $V = Z I C W$**

**D.  $V = C_v I W / R T$**

**Answer to #04.**

**A.**

**For non-building structures, the CBC provisions of Section 1634 should be used.**

**Rigid structures are defined as those with a period  $T < 0.06$  s.**

**In the lateral force design, CBC Section 1634.3 Formula 34-1 should be used,**

$$V = 0.70 C_a I W$$

**The value of  $C_a$  in the formula is based on CBC Table 16-Q for the different soil types.**

**Question #05.**

**The fundamental period  $T$  of a non-building structure should be determined by which of the following CBC methods?**

- A. Method A.**
- B. Method B.**
- C. Either method.**
- D. Neither method.**

*Answer to #05.*

**B.**

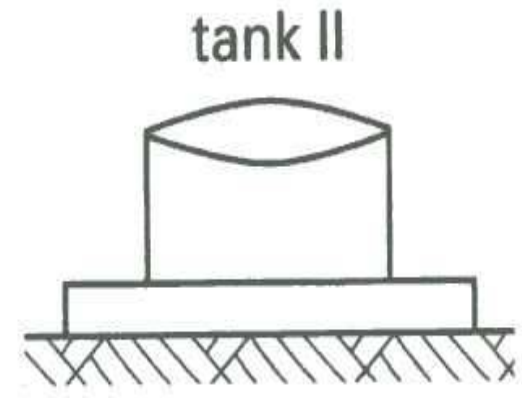
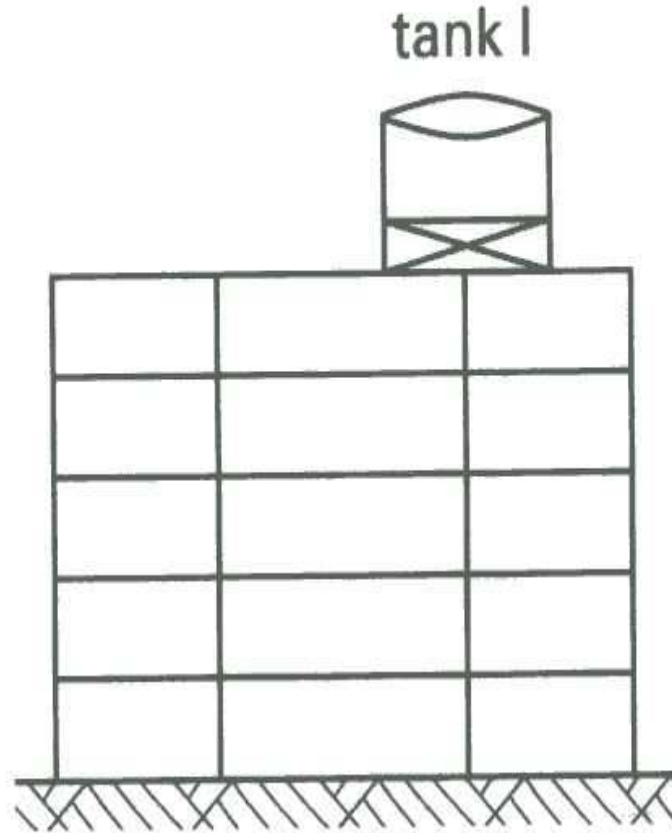
**Based on CBC Section 1634.1.4, the fundamental period  $T$  of non-building structures should be calculated using rational methods such as Method B of Section 1630.2.2, Item 2.**

**Question #06.**

Two water tanks are shown, with the left one sitting on a building's roof, and the right one self-supporting on its own foundations.

Which tank is considered a non-building structure?

- A. I only.
- B. II only.
- C. I and II.
- D. Neither.



**Answer to #06.**

**B.**

**CBC Section 1634.1.1 defines a non-building structure as a self-supporting structure that is other than a building, that carries gravity loads and resists lateral loads.**

**The tank on the left is supported by the building, whereas the tank on the right is considered a non-building structure.**

**Question #07.**

**An 80 foot tall special moment-resisting steel frame is eight-stories high. Its fundamental period  $T = 0.7$  s.**

**Using CBC, what is the maximum allowed design level response displacement  $\Delta_S$  (the total story drift)?**

- A. 0.30 inches**
- B. 0.40 inches**
- C. 0.48 inches**
- D. 0.60 inches**

**Answer to #07.**

**B.**

**The  $\Delta_s$  is the design level response displacement (total story drift) that occurs when the structure is subjected to the design seismic forces. Based on CBC Section 1630.10.1, the story drift should be computed using the maximum in-elastic (plastic) response displacement  $\Delta_M$ . Its value can be obtained from Formula 30-17,**

$$\Delta_M = 0.70 R \Delta_S$$

**CBC 1630.10.2 states that the calculated story drift using  $\Delta_M$  should not exceed 0.020 times the story height for structures having a fundamental period of 0.70 s or greater,**

$$\Delta_M = 0.020 h = (0.020) (80 \text{ feet} / 8 \text{ stories})(12 \text{ in/ft}) = 2.4 \text{ inches}$$

**CBC Table 16-N gives  $R = 8.5$  for special moment-resisting steel frames.**

**Formula 30-17,  $\Delta_M = 0.70 R \Delta_S$ , therefore,**

$$\Delta_S = \Delta_M / 0.70 R = (2.4 \text{ s}) / (0.70)(8.5) = \underline{\underline{0.40 \text{ inches}}}$$

**Question #08.**

**The calculated story drift of one level relative to the level above or below (called the inter-story drift) due to the design lateral force shall include:**

- I. Torsional deflections.**
- II. Translational deflections.**
- III. Bending deflections.**

- A. I only.**
- B. I and II.**
- C. I and III.**
- D. II and III.**

**Answer to #08.**

**B.**

**The inter-story drift is defined as the lateral displacement of one level relative to the level above or below.**

**In order to compute the inter-story drift, the maximum inelastic response displacement  $\Delta_M$  should be used,  $\Delta_M = 0.70 R \Delta_S$**

**The resulting deformation  $\Delta_S$  should be determined at all critical locations in the structure according to CBC Section 1630.9.1.**

**The calculated drift  $\Delta_S$  as per CBC Section 1630.9.1 should include torsional and translational deflections.**

**Question #09.**

**A structure in seismic zone 4 has an  $R = 8.5$ .**

**What may be the maximum design height of this structure?**

- A. 65 feet.**
- B. 160 feet.**
- C. 240 feet.**
- D. No limit.**

**Answer to #09.**

**D.**

**The structural systems and the  $R$  factors are listed in CBC Table 16-N.**

**Table 16-N gives an  $R = 8.5$  for special moment-resisting frames and some dual systems with special moment-resisting frames.**

**In all seismic zones, there is no height limit applicable to these systems.**

**Question #10.**

**A regular structure is proposed for a high-rise in a seismic zone 3. A static analysis is performed to design this high-rise.**

**What could be the maximum design height?**

- A. 65 feet.**
- B. 160 feet.**
- C. 240 feet.**
- D. No limit.**

**Answer to #10.**

**C.**

**CBC Section 1629.8.3, item 2 states that for regular structures, when the static lateral force procedure is used, the maximum design height of the structure should be 240 feet.**

**Question #11.**

**An ordinary steel-braced frame structure will be designed as an office building in San Francisco.**

**Based on CBC requirements, what should the maximum allowable height be for this building?**

- A. 65 feet.**
- B. 160 feet.**
- C. 240 feet.**
- D. No limit.**

**Answer to #11.**

**B.**

**Ordinary steel and reinforced concrete braced frames are classified as building frame systems.**

**Based on CBC Table 16-N, a 160 foot height limit is applicable to those systems with steel in all seismic zones. However, reinforced concrete ordinary frame systems are prohibited in seismic zones 3 and 4.**

**Question #12.**

**A property owner desires to build an apartment building in San Francisco for a total occupancy load of 6,000 persons. An irregular structure will be designed to meet the owner's need.**

**If dynamic lateral force procedures are used, what should be the maximum allowable height?**

- A. 5 stories.**
- B. 65 feet.**
- C. 240 feet.**
- D. No limit.**

*Answer to #12.*

**D.**

**When the dynamic lateral force procedure is used, the CBC Section 1629.8.4 imposes no height restriction for irregular structures in any seismic zone.**

**Question #13.**

**An engineer computes the total base shear  $V$  for a regular structure using the static force procedure, and Method B for the building period  $T$ .**

**If a dynamic analysis is performed using the default spectral response of CBC Figure 16-3, what percentage reduction of the total base shear  $V$  does the CBC allow?**

- A. 0%**
- B. 10%**
- C. 25%**
- D. 75%**

**Answer to #13.**

**B.**

**According to the CBC Section 1631.5.4, Items 1 and 2, the base shear  $V$  for regular structures,  $V_{dynamic}$ , computed by dynamic analysis procedures, should be as follows,**

- greater than or equal to 80%  $V_{static}$  (where the ground motion representation complies with the CBC Section 1631.2, Item 2);**
- greater than or equal to 90%  $V_{static}$  (where the ground motion representation complies with the CBC Section 1631.2, Item 1).**

**Question #14.**

**For irregular structures, what percentage reduction of the total base shear  $V$  (calculated by the static force procedure) does the CBC allow, when a dynamic analysis is performed?**

- A. 0%**
- B. 10%**
- C. 25%**
- D. 50%**

**Answer to #14.**

**A.**

**According to CBC Section 1631.5.4, Item 3, the base shear  $V$  for irregular structures  $V_{dynamic}$ , computed by a dynamic analysis procedure should be greater than or equal to  $V_{static}$  (where  $V_{static}$  is determined according to CBC Section 1630.2).**

**Question #15.**

**An engineering firm is designing a hospital in a seismic zone 4. The building has a vertical irregular geometry, and its height is 65 feet.**

**Which lateral force procedure should be used?**

- A. Static.**
- B. Dynamic.**
- C. Either static or dynamic.**
- D. Neither.**

**Answer to #15.**

**C.**

**Irregular geometry structures in a seismic zone 4, requires,**

- that static force procedures be used following CBC Section 1629.8.3, Item 3, if the structure is not taller than 5 stories or 65 feet in height;**
- that a dynamic force procedure may be used following CBC Section 1629.8.4, Item 2, without a height limit.**

**Question #16.**

For the structure shown below,  $S_n$  represents the story strength of the  $n^{\text{th}}$  floor. The relative story strengths of different floors are given as follows,

$$80\% S_2 < S_1 < 90\% S_2$$

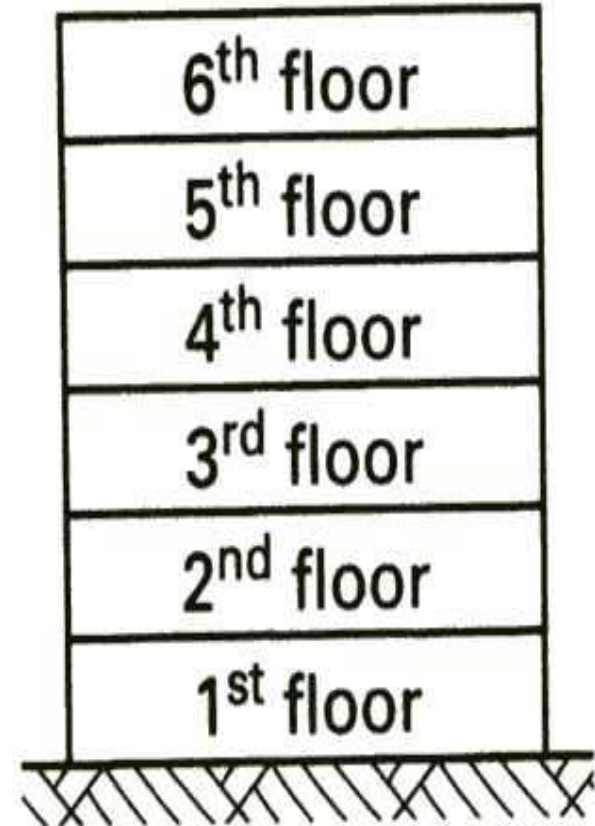
$$80\% S_3 < S_2 < 85\% S_3$$

$$70\% S_4 < S_3 < 80\% S_4$$

$$S_4 = 80\% S_5$$

Which floor should be identified as a weak story?

- A. 1<sup>st</sup> floor.
- B. 2<sup>nd</sup> floor.
- C. 3<sup>rd</sup> floor.
- D. 4<sup>th</sup> floor.



**Answer to #16.**

**C.**

**CBC Section 1629.9.1 and Table 16-L state that vertical structural irregularities of the weak story type exist where the story strength is less than 80% of that in the story above, or**

$$S_n < 80\% S_{n+1}$$

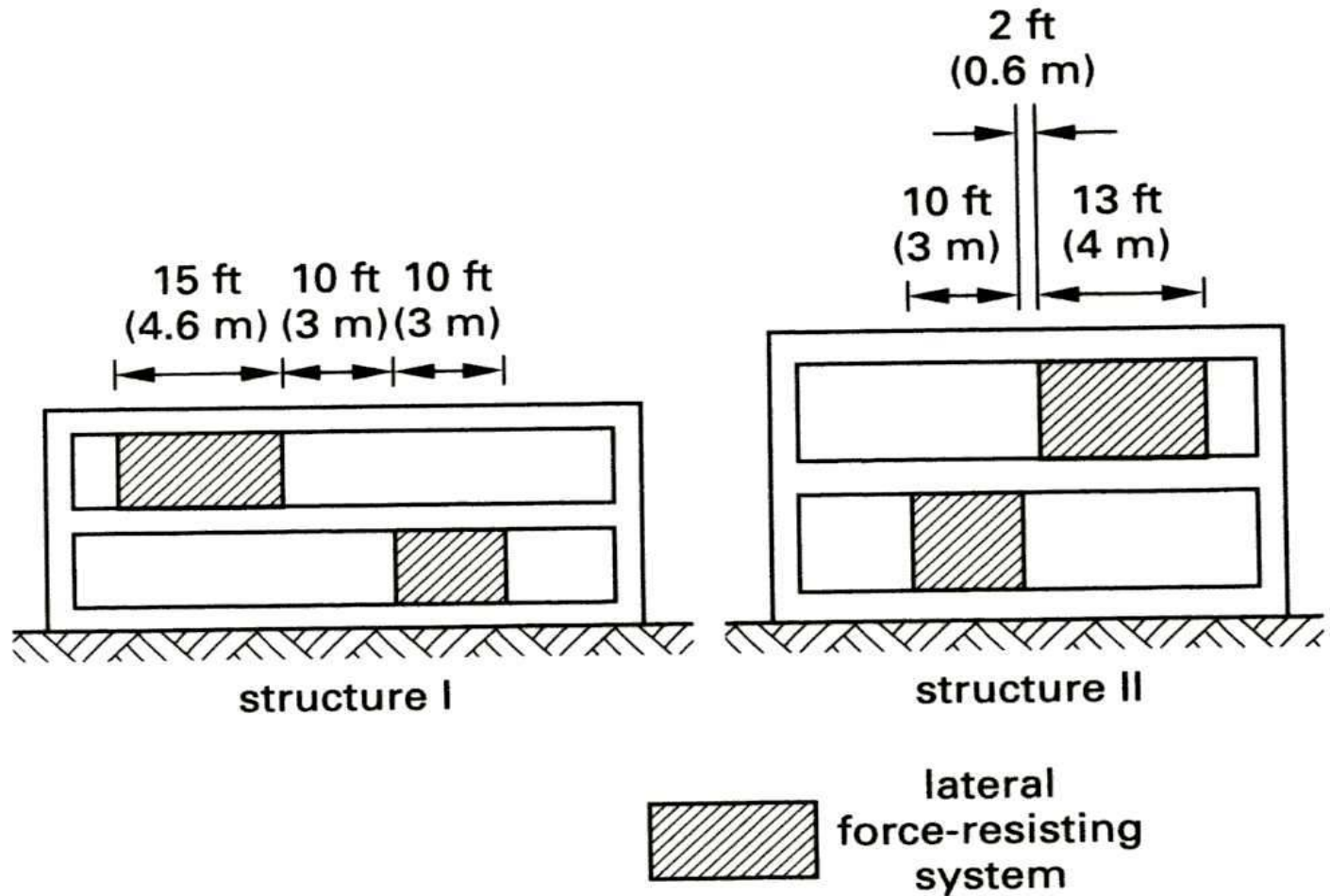
**Checking for each story shows that  $S_3 < 80\% S_4$**

**Therefore, the third floor is a weak story.**

**Question #17.**

The horizontal dimensions of the lateral force-resisting systems for two different structures are shown below. Which of these two is defined as an irregular vertical structure.

- A. I only.
- B. II only.
- C. I and II.
- D. Neither.



**Answer to #17.**

**C.**

**CBC Table 16-L defines an “in-plane discontinuity in vertical lateral force-resisting element”, where the offset of the elements is greater than the length of the elements.**

**Assume that  $L_1$  is the length of the lateral force-resisting system in the first story, and  $L_2$  is the length of the element in the second story. If the offset length between stories is greater than the element lengths, vertical structural irregularities exist.**

**For building *I*, the offset length is  $10\text{ ft} + 2\text{ ft} = 12\text{ ft}$ , and the element lengths are  $L_1 = 10\text{ ft}$  and  $L_2 = 13\text{ ft}$ . Since  $12\text{ ft} > 10\text{ ft}$ , an irregularity exists. But  $12\text{ ft} < 13\text{ ft}$ , which does not meet the criteria. However, the previous comparison with  $L_1$  is sufficient to classify the structure as vertical irregular.**

**Therefore, both buildings are irregular structures. Structure I also qualifies as vertically irregular under Category C, Vertical Geometric Irregularity. Vertical geometric irregularity exists when the horizontal dimension of the lateral force-resisting system in any story is more than 130% of that in an adjacent story.**

**For building *I*, the element lengths are  $L_1 = 10$  ft and  $L_2 = 15$  ft.**

$$L_2 / L_1 = 15 \text{ ft} / 10 \text{ ft} = 1.5$$

**The horizontal dimension of the element in the second story is 150% of that in the first story, so the structure is vertically irregular.**

**For building *II*, the element lengths are  $L_1 = 10$  ft and  $L_2 = 13$  ft.**

$$L_2 / L_1 = 13 \text{ ft} / 10 \text{ ft} = 1.3$$

**The horizontal dimension of the element in the second story is 130% of that in the first story, which is not great enough to classify the structure as vertically irregular under this category.**

**Question #18.**

**A vertically irregular building has the fourth floor its story strength is less than 80% of the fifth floor.**

**Which type of irregularity applies?**

- A. A soft story.**
- B. A weak story.**
- C. A mass story.**
- D. None of the above.**

**Answer to #18.**

**B.**

**CBC Table 16-L categorizes the irregularity types, gives their definitions, and provides their appropriate CBC reference sections.**

**Based on Table 16-L and Section 1629.9.1, when the story strength is less than 80% that of the story above, the vertically irregular structure is identified as Type 5: Discontinuity in Capacity – Weak Story.**

**Question #19.**

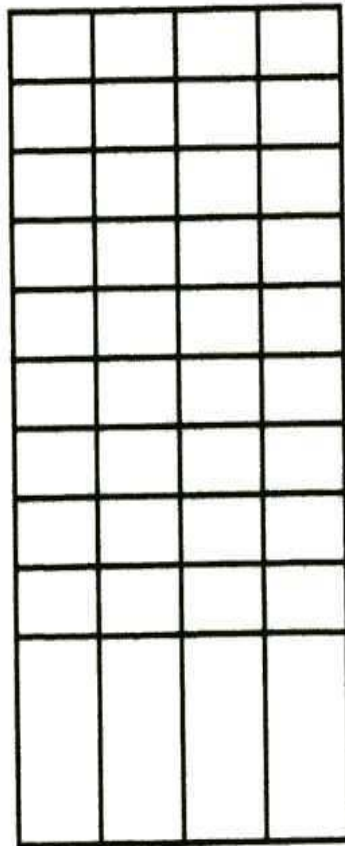
**Which of the following buildings has a soft story?**

**A. I only.**

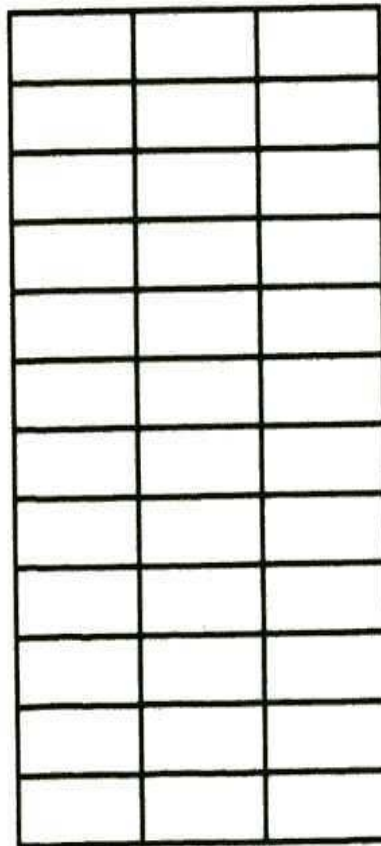
**B. I and II.**

**C. I and III.**

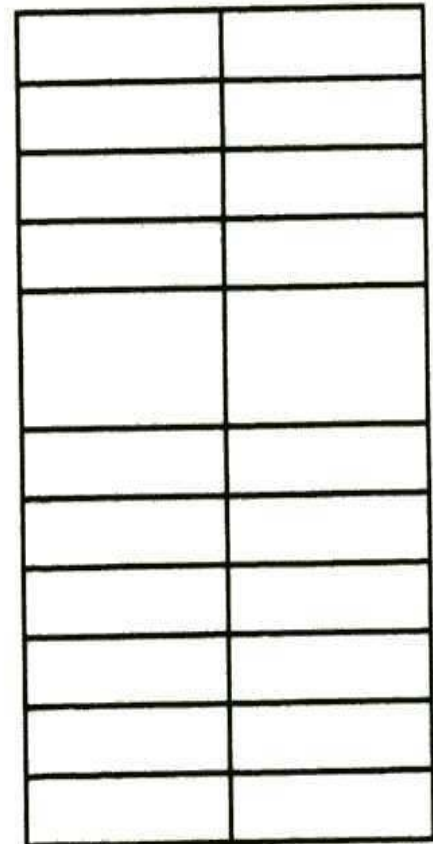
**D. II and III.**



**building I**



**building II**



**building III**

**Answer to #19.**

**C.**

**CBC Table 16-L defines a soft story as a type of vertical structural irregularity where the story stiffness is either less than 70% of that in the story above or less than 80% of the average stiffness of the three stories above.**

**By inspection, the first story of building *I* and the middle story of building *III* are considered soft stories.**

**Question #20.**

**In general, vertical irregular structures with more than two stories (or more than 30 feet in height) are prohibited by the CBC when the percentage of one story's strength to the strength of the story above it is less than,**

- A. 50%**
- B. 65%**
- C. 80%**
- D. 85%**

*Answer to #20.*

**B.**

**CBC Table 16-L defines vertical irregular structures Type 5, Discontinuity in Capacity – Weak Story, are those in which the story strength ratio of one story to the story above is less than 80%.**

**CBC Section 1629.9.1, Type 5 structures with more than two stories or more than 30 feet in height may not have a story strength ratio of less than 65%.**