NCARB

ARE 4.0 EXAM GUIDE

Structural Systems

This document, effective August 2015, supersedes all previous editions of the ARE® 4.0 Exam Guide: Structural Systems. Please check NCARB's web site, www.ncarb.org, regularly for updates to the ARE 4.0 Exam Guides and for the most current information regarding the ARE.

STRUCTURAL SYSTEMS

OVERVIEW

DIVISION STATEMENT

Identification and incorporation of general structural and lateral force principles in the design and construction of buildings.

Content Areas

1. GENERAL STRUCTURES
   (50-54 percent of scored items)
2. SEISMIC FORCES
   (18-22 percent of scored items)
3. WIND FORCES
   (18-22 percent of scored items)
4. LATERAL FORCES
   (7-9 percent of scored items)

Vignette

STRUCTURAL LAYOUT

Design a schematic framing plan for a one-story building with a mutli-level roof.

NOTE

For the purposes of this examination and its preparation, the following design methods have been used:

- for wood, Allowable Stress Design Method
- for steel, Strength Design Method (Load and Resistance Factor Design)
- for concrete, Strength Design Method (Ultimate Strength Design)

STRUCTURAL SYSTEMS

KNOWLEDGE / SKILLS

The division has been broken down into a listing of knowledge and skills directly related to each major content area.

1. GENERAL STRUCTURES
(50-54 percent of scored items)

A. Principles
Apply general structural principles to building design and construction.

1. **Building Design**
   Analyze and investigate the structural loads and conditions that affect building design through use of engineering principles and functional requirements.
2. **Building Systems and their Integration**
   Determine appropriate building structural systems and components.
3. **Implications of Design Decisions**
   Evaluate the impact of structural design decisions on other building design issues.

B. Materials & Technology
Analyze the implications of design decisions in the selection of systems, materials, and construction details related to general structural design.

1. **Construction Details and Constructability**
   Analyze the impact of structural decisions on the construction process.
2. **Construction Materials**
   Apply knowledge of the properties of materials that affect their structural characteristics.

C. Codes & Regulations
Incorporate building codes, specialty codes, and other regulatory requirements in the design of general structural systems.

1. **Government and Regulatory Requirements**
   Assess and apply building codes and other regulations that affect structural systems.

STRUCTURAL SYSTEMS

KNOWLEDGE / SKILLS

2. SEISMIC FORCES
(18-22 percent of scored items)

A. Principles
Apply seismic forces principles to building design and construction.

1. **Building Design**
   Analyze and investigate seismic loads and conditions that affect building design through use of engineering principles and functional requirements.
2. **Building Systems and their Integration**
   Determine appropriate seismic load resisting systems and components.
3. **Implications of Design Decisions**
   Evaluate the impact of seismic load design decisions on other building design issues.

B. Materials & Technology
Analyze the implications of design decisions in the selection of systems, materials, and construction details related to seismic forces design.

1. **Construction Details and Constructability**
   Analyze construction details and non-structural elements relative to their resistance to seismic forces.
2. **Construction Materials**
   Consider construction materials relative to their resistance to seismic forces.

C. Codes & Regulations
Incorporate building codes, specialty codes, and other regulatory requirements related to seismic forces.

1. **Government and Regulatory Requirements**
   Assess and apply building codes and regulations with respect to the design of structures for resistance to seismic forces.

3. WIND FORCES
(18-22 percent of scored items)

A. Principles
Apply lateral forces principles to the design and construction of buildings to resist wind forces.

1. **Building Design**
   Analyze and investigate wind loads and conditions that affect building design through use of engineering principles and functional requirements.
2. **Building Systems and their Integration**
   Determine appropriate wind load resisting systems and components.
3. **Implications of Design Decisions**
   Evaluate the impact of wind load design decisions on other building design issues.

B. Materials & Technology
Analyze the implications of design decisions in the selection of systems, materials, and construction details related to wind forces.

1. **Construction Details and Constructability**
   Analyze construction details and non-structural elements relative to their resistance to wind forces
2. **Construction Materials**
   Consider construction materials relative to their resistance to wind forces.

C. Codes & Regulations
Incorporate building codes and other regulatory requirements related to wind forces.

1. **Government and Regulatory Requirements**
   Assess and apply building codes and regulations with respect to the design of structures for resistance to wind forces.

STRUCTURAL SYSTEMS

KNOWLEDGE / SKILLS

4. LATERAL FORCES
(7-9 percent of scored items)

A. Principles
Apply lateral forces principles to the design and construction of buildings.

1. **Building Design**
   Analyze and investigate lateral loads and conditions that affect building design through use of engineering principles and functional requirements.

2. **Building Systems and their Integration**
   Determine appropriate lateral load resisting systems and components.

3. **Implications of Design Decisions**
   Evaluate the impact of lateral load design decisions on other building design issues.

B. Materials & Technology
Analyze the implications of design decisions in the selection of systems, materials, and construction details related to lateral forces.

1. **Construction Details and Constructability**
   Analyze construction details and non-structural elements relative to their resistance to lateral forces.

2. **Construction Materials**
   Consider construction materials relative to their resistance to lateral forces.

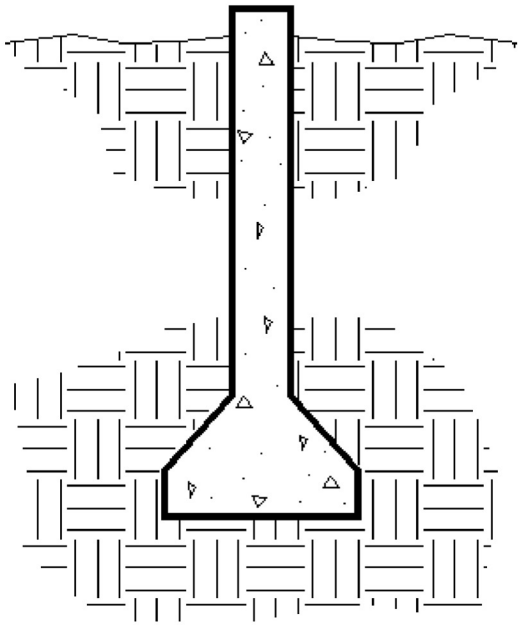
STRUCTURAL SYSTEMS

SAMPLE MULTIPLE-CHOICE QUESTIONS

Go to page 13 for answers.

1. The most important factor affecting the strength of concrete is the

- ☐ weather conditions during curing
- ☐ volume of the mixture
- ☐ water-to-cement ratio
- ☐ amount of vibration of the mix



2. The drilled pier (caisson) shown above is belled in order to

- ☐ prevent water infiltration
- ☐ prevent caving
- ☐ increase the bearing area
- ☐ increase frictional resistance

3. A slump cone is used primarily to provide an indication of which of the following characteristics of concrete?

- ☐ Strength and workability
- ☐ Durability and finish
- ☐ Air entrainment and chemical resistance
- ☐ Appearance and color

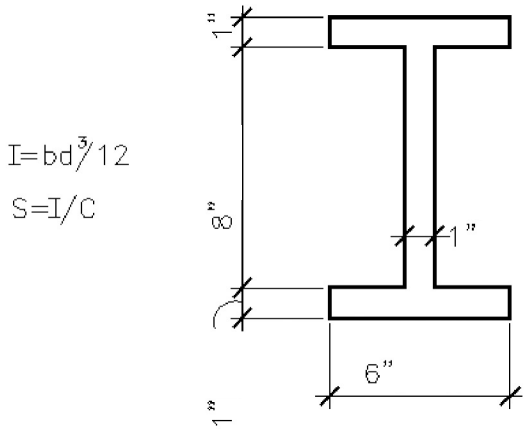
4. The most frequently used footing type at the exterior wall for load-bearing wall support systems is

- ☐ mat footings
- ☐ pile footings
- ☐ continuous wall footings
- ☐ isolated pad footings

STRUCTURAL SYSTEMS

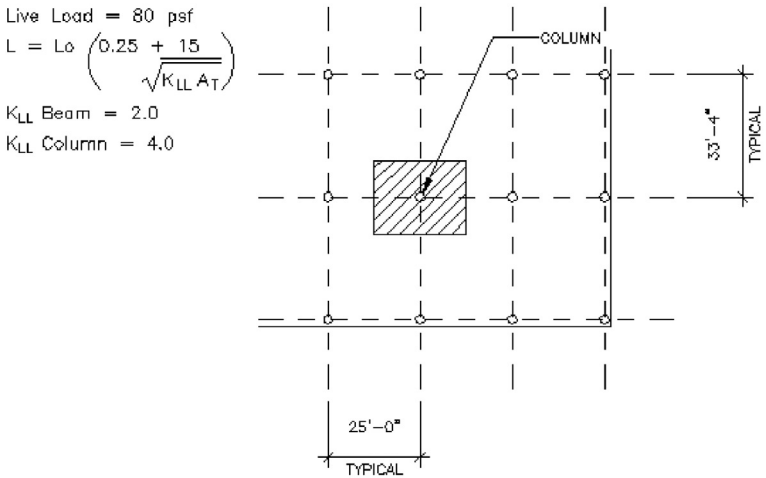
SAMPLE MULTIPLE-CHOICE QUESTIONS

Go to page 13 for answers.



5. What is the section modulus for the geometric section illustrated above?

_____ in^3



6. When considering permitted live load reductions for the column shown above, what is the live load for the floor supported by the column?

_____ kips

7. If the soil bearing capacity is 3000 psf and the applied load is 48,000 lbs, what is the minimum required area of the footing?

_____ sf

STRUCTURAL SYSTEMS

SAMPLE MULTIPLE-CHOICE QUESTIONS

Go to page 13 for answers.

8. Which of the following best defines the P-delta effect?

- ☐ Lateral forces on the foundations
- ☐ Bending forces in the vertical members
- ☐ Horizontal forces in the roof sections
- ☐ Moment forces at the joint

9. Concrete should reach its design compressive strength in how many days?

- ☐ 3
- ☐ 7
- ☐ 28
- ☐ 32

10. Steel roof joists are manufactured with camber to

- ☐ provide positive roof drainage
- ☐ compensate for deflection
- ☐ support a variety or roof deck systems
- ☐ increase lateral stability

11. In a renovation of an existing residential building, in which piping of conduit needs to be run through a 2 x 12 (actual) wood floor joist, which of the following is the minimum dimension required by the IBC from the top or bottom of the joist to the bored hole?

- ☐ 1.0 in
- ☐ 1.5 in
- ☐ 2.0 in
- ☐ 2.5 in

12. An 18th century farmhouse on the National Historic Register with exposed timber framing is to be restored and opened for tours. Which of the following is the most historically correct method of addressing the lack of live-load capacity of the floor framing?

- ☐ Replace the undersized framing with new adequately sized members.
- ☐ Sister the existing joists and beams.
- ☐ Limit the number of visitors in spaces to the available live load.
- ☐ Reduce the span of the floor framing.

13. Cast-in-place concrete beams and columns with No. 11 rebar or smaller reinforcing bars that are not exposed to weather or in contact with the ground should have a minimum coverage of concrete over the bars of

- ☐ 1/2 in
- ☐ 3/4 in
- ☐ 1 in
- ☐ 1 1/2 in

STRUCTURAL SYSTEMS

SAMPLE MULTIPLE-CHOICE QUESTIONS

Go to page 13 for answers.

14. A balcony is hung from steel roof framing over a hotel atrium. Which of the following is the minimum code required increase in live load due to impact?

- ☐ 0 percent
- ☐ 25 percent
- ☐ 33 percent
- ☐ 50 percent

15. Which of the following is generally the most economical material for the hoistway wall of an elevator in a wood-frame, two-story apartment building?

- ☐ Reinforced concrete
- ☐ Gypsum shaft wall
- ☐ Pre-fabricated concrete
- ☐ Concrete blocks

16. A one-way slab is used typically in which of the following types of buildings?

- ☐ Museum
- ☐ Parking
- ☐ Library
- ☐ Warehouse

17. Which of the following would be most appropriate for a high-rise building in a high-risk seismic zone?

- ☐ A building on stilts
- ☐ A building with an L-shaped plan
- ☐ A building with a symmetrical T-shaped plan
- ☐ A building with a symmetrical square plan

18. Which of the following primary structural systems are used to resist lateral loads? **Check the four that apply.**

- ☐ A. Shear walls
- ☐ B. Braced frames
- ☐ C. Hinged frames
- ☐ D. Moment-resisting frames
- ☐ E. Horizontal diaphragms
- ☐ F. Precast systems

19. Which of the following are criteria for base isolation systems? **Check the three that apply.**

- ☐ A. The system must allow lateral movement.
- ☐ B. The system must control the movement between ground and structure.
- ☐ C. Energy must be dissipated in the isolators.
- ☐ D. The system must amplify ground accelerations.
- ☐ E. The system must maintain a rigid connection for pedestrian exit discharge.
- ☐ F. Energy must be concentrated to a point above the original grade.

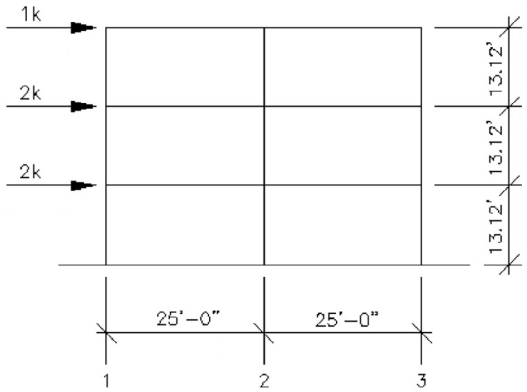
20. An eccentrically braced frame (EBF) utilized to resist lateral seismic forces in a building is a

- ☐ frame in which diagonal members are connected to a beam a short distance from the column joint
- ☐ frame in which members are subjected primarily to axial forces
- ☐ frame in which members and joints are capable of resisting forces by flexure as well as along the axis of the member
- ☐ braced frame whose plan location results in torsion

STRUCTURAL SYSTEMS

SAMPLE MULTIPLE-CHOICE QUESTIONS

Go to page 13 for answers.

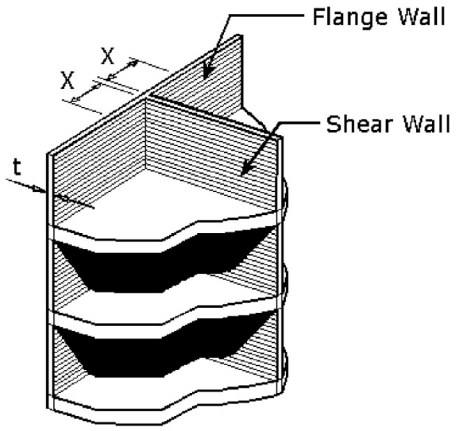


21. For the rigid frame structure shown, the approximate horizontal shear at the base of column 2 (assuming all column stiffnesses are equal) is

_____ k

22. Base isolation in an office building is most effective for which of the following building heights, assuming that the areas per floor are the same?

- ☐ One-story
- ☐ Four-story
- ☐ Twenty-story
- ☐ Forty-story



X = Effective flange width

23. In the CMU stem-flanged shear wall arrangement shown, the minimum dimension X recommended to achieve shear transfer is

- ☐ 3t
- ☐ 6t
- ☐ 9t
- ☐ 12t

24. Buckling of a column can be reduced by which of the following? **Check the four that apply.**

- ☐ A. Increasing the size of the member
- ☐ B. Rotating the column
- ☐ C. Bracing the column
- ☐ D. Changing the type of end restraints
- ☐ E. Reducing the length of the column
- ☐ F. Reducing the radius of gyration

SAMPLE MULTIPLE-CHOICE QUESTIONS

Go to page 13 for answers.

25. A loss of soil shear strength resulting in the movement of the surficial soil layers of a building site in a direction parallel to the ground surface under earthquake conditions is most likely caused by

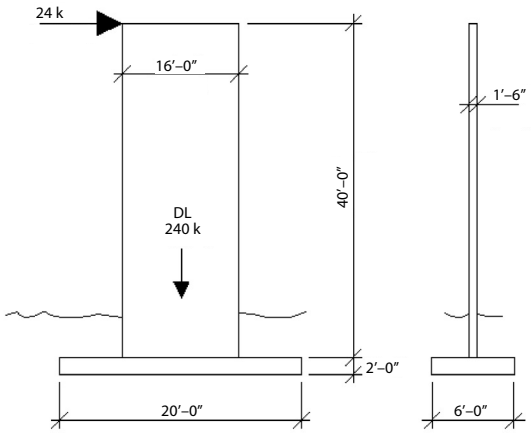
- ☐ a high water table
- ☐ liquefiable soils
- ☐ a low bearing capacity
- ☐ a gently sloping site

26. The recommended deflection criteria due to wind loading on a brick veneer wall utilizing a metal stud back-up system is

- ☐ L/360
- ☐ L/400
- ☐ L/600
- ☐ L/720

27. Which of the following professionals has primary legal responsibility for the performance of a building in an earthquake?

- ☐ Building code official
- ☐ Structural engineer
- ☐ Architect
- ☐ Geotechnical consultant



28. What is the factor of safety against overturning for the concrete shear wall shown if resisted only by gravity forces? Assume the weight of concrete equals 150 lb/ft^3, and the dead load equals 240 kips. Ignore the weight of the soil over the footing.

- ☐ 1.5
- ☐ 2.0
- ☐ 3.7
- ☐ 4.2

29. A primary cause of failure of concrete masonry walls during hurricanes is

- ☐ poorly filled mortar joints
- ☐ improper base and sill flashing
- ☐ an inadequate number of wall anchors
- ☐ a lack of vertical reinforcement

STRUCTURAL SYSTEMS

SAMPLE MULTIPLE-CHOICE QUESTIONS

Go to page 13 for answers.

30. The earthquake regulations of model codes are intended to provide resistance to which of the following?

- ☐ Ground shaking
- ☐ Earth slides
- ☐ Ground rupture in fault zones
- ☐ Settlement

31. A structure will have a better chance of surviving an earthquake if which of the following is true?

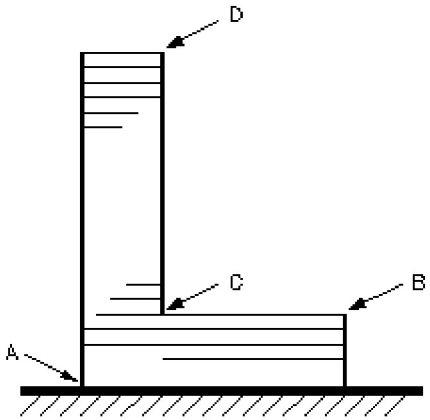
- ☐ Principal members change section abruptly.
- ☐ The load-bearing members are not equally loaded.
- ☐ All columns and walls are discontinuous.
- ☐ The structure has redundancy.

32. Which of the following considerations in structural design is based on probability as a result of historical analysis?

- ☐ Water pressures
- ☐ Wind forces
- ☐ Dead loads
- ☐ Soil pressures

33. According to model codes, connections of masonry web shear walls to masonry flange walls must be accomplished using which of the following details? **Check the three that apply.**

- ☐ A. Running bond
- ☐ B. Bond beams
- ☐ C. Stacked bond
- ☐ D. Steel dowels
- ☐ E. High-strength mortar
- ☐ F. Metal plate strap anchors



34. In the elevation of a multi-storied building subject to earthquake forces shown above, at which location is stress concentration most likely to be a problem?

- ☐ A
- ☐ B
- ☐ C
- ☐ D

35. A building form that is ideal for resistance to earthquake forces would be characterized by which of the following? **Check the two that apply.**

- ☐ A. Symmetrical about a reentrant corner
- ☐ B. Symmetrical in plan
- ☐ C. Heavier at the base than at the top
- ☐ D. Asymmetrical in plan
- ☐ E. Long linear plan
- ☐ F. Asymmetrical in elevation

STRUCTURAL SYSTEMS

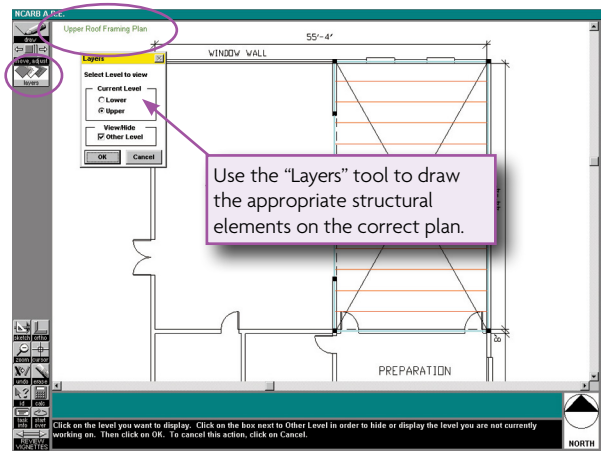
SAMPLE MULTIPLE-CHOICE ANSWERS

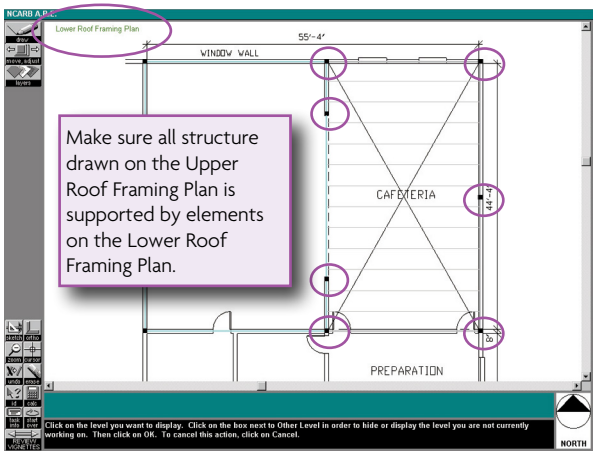
1. water-to-cement ratio
2. increase the bearing area
3. Strength and workability
4. continuous wall footings
5. 57.3 in^3
6. 67 kips
7. 16 sf
8. Bending forces in the vertical members
9. 28
10. compensate for deflection
11. 2.0 in
12. Limit the number of visitors in spaces to the available live load.
13. 1 1/2 in
14. 33 percent
15. Gypsum shaft wall
16. Parking
17. A building with a symmetrical square plan
18. A, B, D, E
19. A, B, C
20. frame in which diagonal members are connected to a beam a short distance from the column joint
21. 2.50 k
22. Four-story
23. 6t
24. A, C, D, E
25. liquefiable soils
26. L/600
27. Architect
28. 4.2
29. a lack of vertical reinforcement
30. Ground shaking
31. The structure has redundancy.
32. Wind forces
33. A, B, F
34. C
35. B, C

STRUCTURAL SYSTEMS

STRUCTURAL LAYOUT VIGNETTE

General Tips for Taking Structural Layout





Directions

Use the drawing tools provided to create a two-level roof framing solution over the program areas shown. The layout you design should be structurally sound, efficient, and responsive to program requirements.

Your design is to be expressed by superimposing the necessary structural members on the background floor plan provided. Draw the structural elements for the lower roof framing on the lower level (Lower Roof Framing Plan). Switch layers using the layers icon and draw all additional structural elements required for the roof framing on the upper level (Upper Roof Framing Plan). Return to the lower level and make sure that all upper level elements are fully supported from below. For scoring, your solution must be drawn on these two separate layers.

Your layout should show the location of columns and/or load-bearing walls, the placement of beams, and the placement and spacing of roof joists. You may not add walls. All walls are assumed to be non-load-bearing unless you designate them otherwise. If your layout includes load-bearing walls, you must use the drawing tool provided to designate existing walls as load-bearing walls. For scoring, only walls so designated will be counted as load-bearing walls. To designate decking, you should draw the rectangular boundary of each area of the roof that is to receive decking and orient the direction arrow to indicate its span direction.

Before beginning your solution, you should review the program information that can be accessed through the Vignette Index screen and familiarize yourself with the floor plan on the work screen.

STRUCTURAL SYSTEMS

STRUCTURAL LAYOUT VIGNETTE

Program

The preliminary floor plan for an urban mini-mall has been completed and approved, and you are now required to develop a roof framing layout for the building or portion of the building shown on the work screen. The layout must accommodate the conditions and requirements given below.

Site/Foundation

1. The site has no seismic activity and wind pressures are negligible.
2. The soils and foundation system should be assumed adequate for all standard and normal loads.
3. The distribution of concentrated or special loads need not be considered.

Construction/Materials

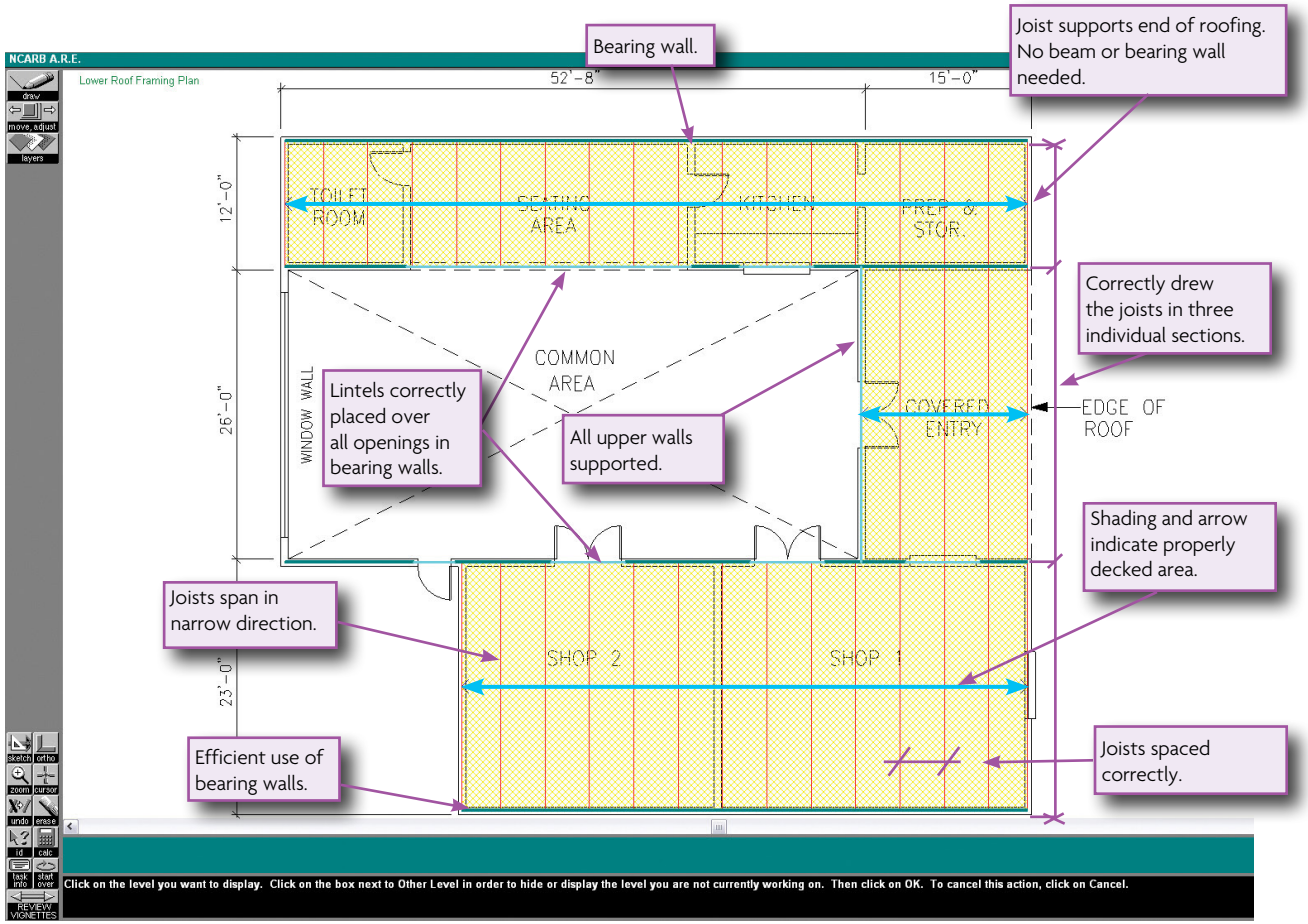
1. Structural steel/open web steel joist construction has been chosen for the roof structure type.
2. Steel beam sections are to be rolled or built-up.
3. The metal roof deck is capable of carrying the design loads on spans up to and including 4 ft.
4. Joists are sized to carry roof loads only.

General Requirements

1. All portions of the roof framing are flat.
2. Cantilevers are prohibited.
3. Structural members must not extend beyond the building envelope, except to frame a designated covered entry.
4. Columns may be located within walls, including the window wall and the clerestory window wall.
5. Walls shown on the background floor plan may be designated as bearing walls. Additional bearing walls are not allowed.
6. Lintels are required to be shown in bearing walls only. Other lintels shall not be indicated.
7. The opening located between the common area and the seating area must be unobstructed and column-free.
8. The common area must be column-free.
9. The window wall and the clerestory window extend to the underside of the structure above. All other openings have a head height of 7 ft above finish floor.
10. The roof over the high ceiling space must be higher than the roof over the low ceiling spaces.
    - THE COMMON AREA REQUIRES A HIGH CEILING WITH A TOP OF STRUCTURE HEIGHT OF 18 FT.
    - THE REMAINING SPACES REQUIRE A LOW CEILING WITH A TOP OF STRUCTURE HEIGHT OF 12 FT.
11. The structure must accommodate a clerestory window to be located along the full length of the north wall of the common area.

STRUCTURAL SYSTEMS

STRUCTURAL LAYOUT VIGNETTE - Sample Passing Solution



Lower Roof Framing Plan

The entire lower roof framing plan is covered by roof structure and decking. The four long parallel walls running east/west have been designated as bearing walls, and the joists are running perpendicular to them. Joists are drawn at the ends of the roof areas, so the lack of a bearing wall or beam at the open ends of the structural bays is acceptable. The decking covers the entire trussed area on this level, and lintels are provided at all door and window openings in the bearing walls.

Procedural Tips

- When solving this vignette, first draw the structural elements for the lower roof framing on the lower level. Then switch layers using the **layers** tool, and draw all additional structural elements required for the upper roof framing on the upper level. For scoring, your solution must be drawn on these two separate layers.
- When elements overlap, you may have trouble selecting a particular element. If this happens, keep clicking (without moving the mouse) until the desired element highlights.

Warnings

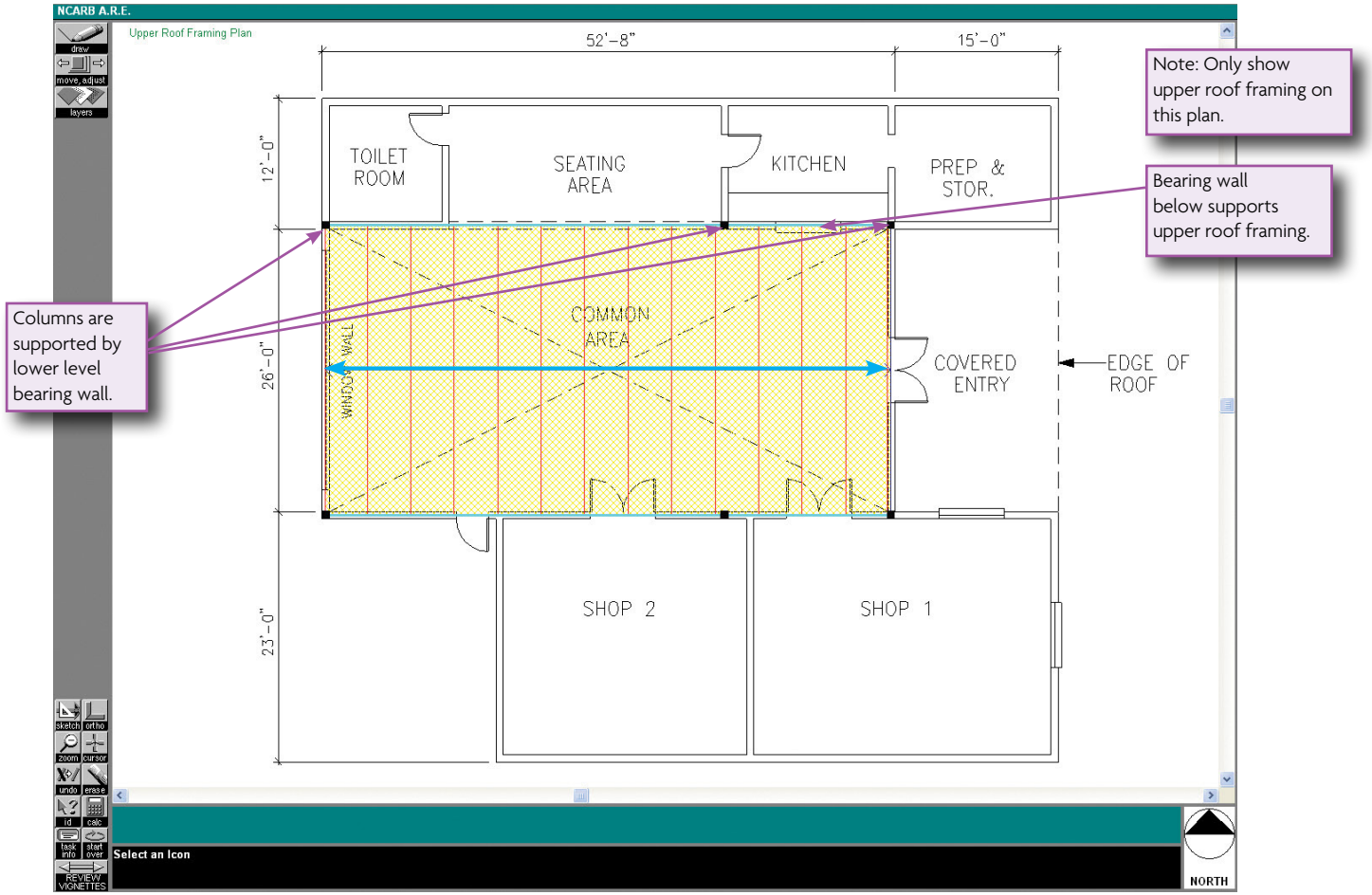
- The joist tool works like a 2-point rectangle. Choose the **draw** tool, select joist, direction and spacing from the menu and draw a rectangle covering the entire area desired. Do not draw individual joists.
- The decking tool also works like a 2-point rectangle. Choose the **draw** tool, select decking and direction from the menu and draw a rectangle covering the entire area desired. The shaded 2-point rectangles you draw describe the areas covered by decking.

Tools you might find useful

- **Full-screen cursor** to help you line up structural elements.

STRUCTURAL SYSTEMS

STRUCTURAL LAYOUT VIGNETTE - Sample Passing Solution

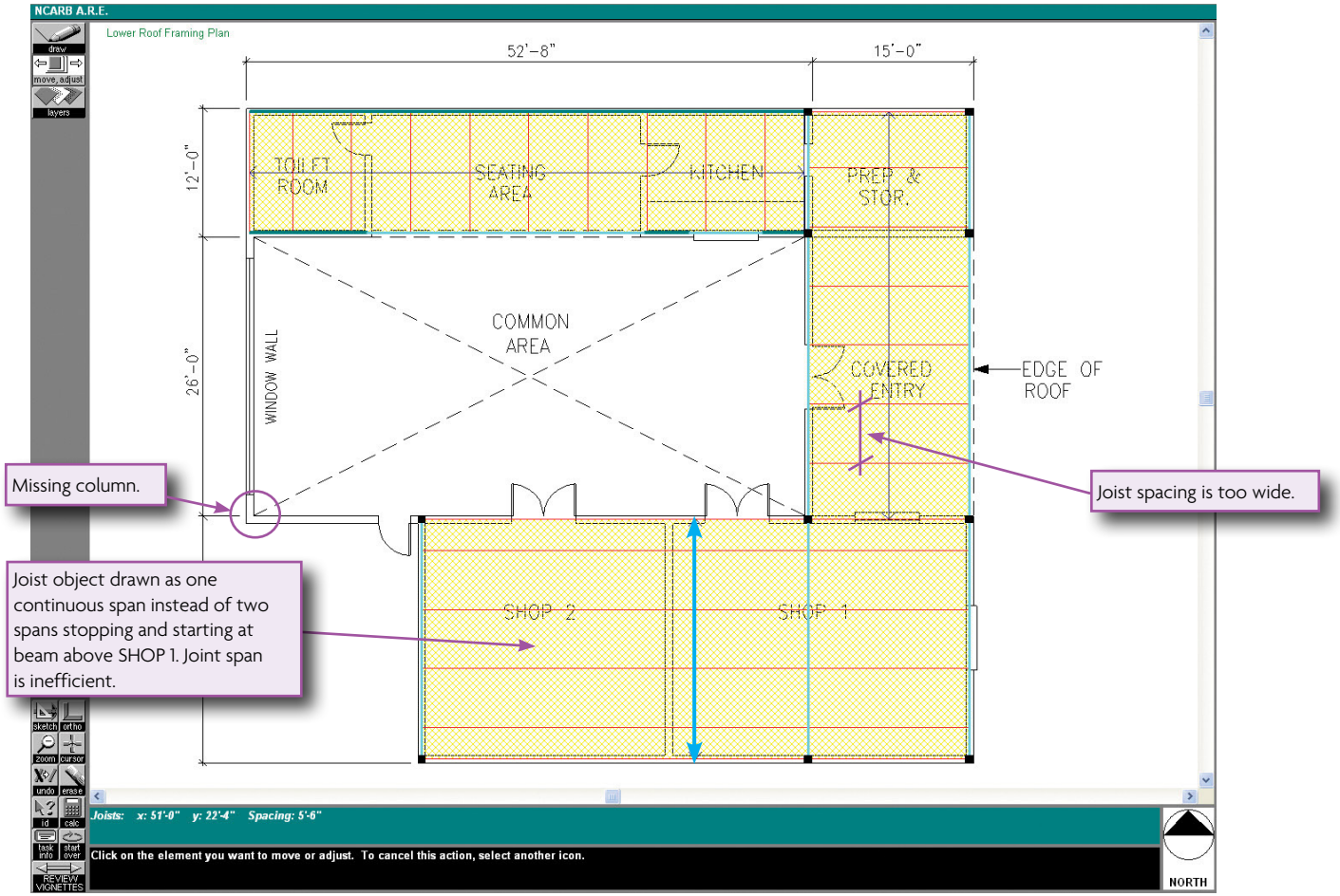


Upper Roof Framing Plan

Again the entire upper roof area is correctly framed and decked. The solution accommodates the clerestory window located along the full length of the north wall of the cafeteria. And all columns are supported on the bearing walls below.

STRUCTURAL SYSTEMS

STRUCTURAL LAYOUT VIGNETTE - Sample Failing Solution

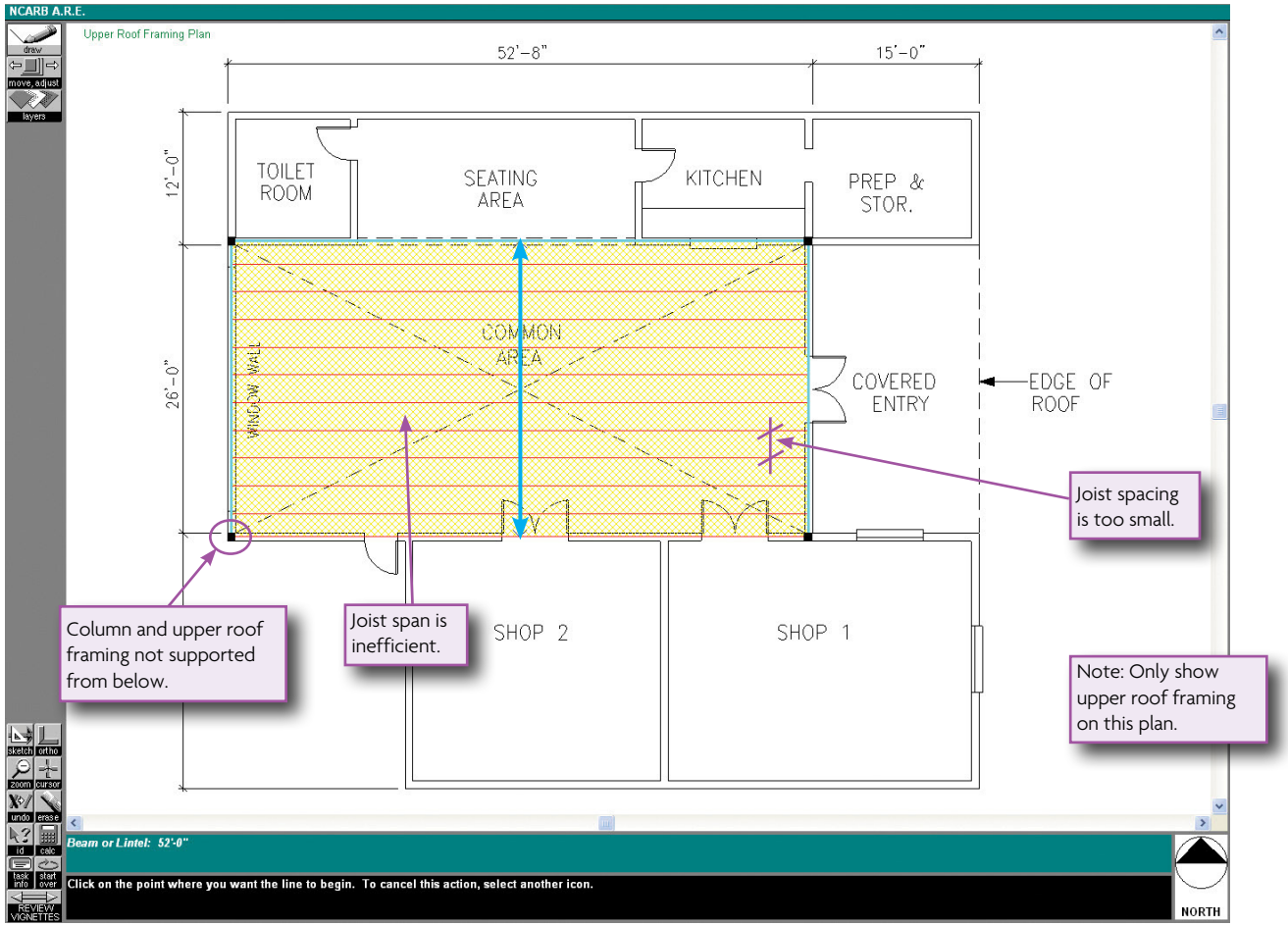


Lower Roof Framing Plan

This solution also has the entire area roofed but in a structurally unsound manner. The joist spacing has been drawn at five feet on center which exceeds the program limits. A column that would carry the loads from the upper roof framing down to the foundation is also missing.

STRUCTURAL SYSTEMS

STRUCTURAL LAYOUT VIGNETTE - Sample Failing Solution



Upper Roof Framing Plan

Once again, the joist spacing is incorrect, and the structure along the south wall of the common area is not supported from below.

STRUCTURAL SYSTEMS

REFERENCES

The following references are presented to assist candidates in preparation for the examination. This list represents texts that have content covered in this division of the examination. This is not intended to be an exhaustive list of all possible reference materials for the subject area. NCARB makes no guarantee that the various references are currently in print.

Architectural Graphic Standards
The American Institute of Architects
John Wiley & Sons, latest edition

Building Construction Illustrated
Francis D.K. Ching
John Wiley & Sons, latest edition

Building Structures
James Ambrose and Patrick Tripeny
John Wiley & Sons, latest edition

Design for Earthquakes
James Ambrose and Dimitry Vergun
John Wiley & Sons, 1999

Manual of Steel Construction
American Institute of Steel Construction, latest edition

Seismic and Wind Loads in Architectural Design and Architects
Study Guide: An Architect's Study Guide
Stanley W. Crawley and Delbert B. Ward
The American Institute of Architects, 2nd edition, 1990

The Seismic Design Handbook
Farzad Naeim
Kluwer Academic Publishers, 2nd edition, 2001

Simplified Building Design for Wind and Earthquake Forces
James Ambrose and Patrick Tripeny
John Wiley & Sons, 3rd edition, 1995

Simplified Engineering for Architects and Builders
James Ambrose and Patrick Tripeny
John Wiley & Sons, latest edition

Structural Design: A Practical Guide for Architects
James R. Underwood and Michele Chiuini
John Wiley & Sons, latest edition

Structures
Daniel Schodek and Martin Bechthold
Pearson/Prentice Hall, latest edition

Visual Dictionary of Architecture
Francis D.K. Ching
John Wiley & Sons, latest edition