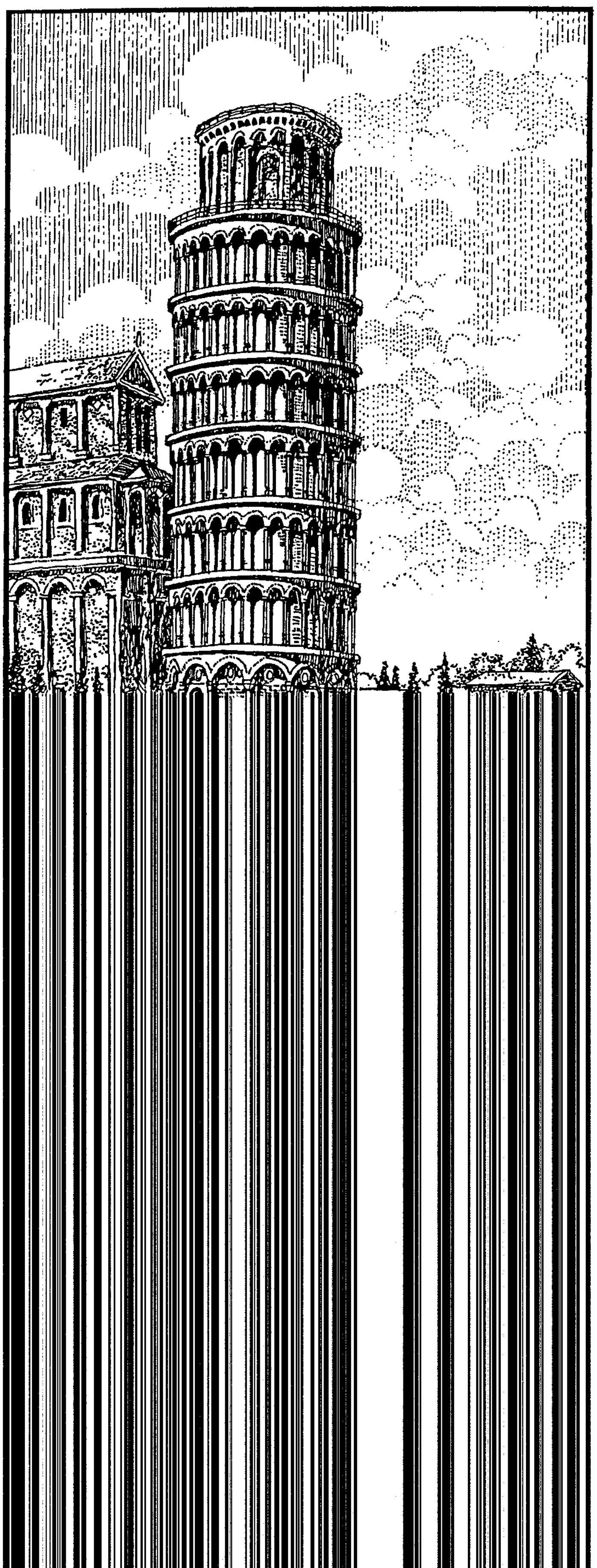
STRUCTURES
Mock Exam Answers

Do not open until you have completed the exam.



Preface

This booklet contains the answers and explanations to the *Structures Mock Exam*, which is contained in a separate booklet. We urge you to answer all the questions in the *Structures Mock Exam* before you look at the answers.

If you have any questions about the mock exam, or if you wish us to review and make appropriate comments about your answers, do not hesitate to contact us.

We wish you success on the exam.

Mock Exam Answers

1-A Questions involving shear and moment diagrams often appear on the exam. Among the concepts which should be understood are: (1) the slope of the moment diagram is equal to the value of the shear at that point and (2) the bending moment is maximum where the shear passes through zero. In this case, the slope of the moment diagram is constant and positive between points 1 and 2, and therefore the shear is constant and positive between 1 and 2. From 2 to 3, the slope of the moment diagram is also constant and positive, but less than the slope between 1 and 2. Therefore, the shear has a constant positive value between 2 and 3, which is less than that between 1 and 2. At point 3, the moment is maximum, and therefore the shear passes through zero at point 3. Between 3 and 4, the slope of the moment diagram is constant and negative, and therefore the shear is constant and negative between 3 and 4. The only shear diagram which meets all these criteria is shown in correct choice A.

2-B If a deflection question should appear on the exam, it is likely that the necessary deflection formula will be provided. In this case, we are given the formula $\Delta = 5wL^4/384EI$. Since wL = W, the total load on the beam, the formula becomes $\Delta = 5WL^3/384EI$.

Δ = 1.0 inch
W = 1500#/ft. x 28 feet = 42,000#
L^3 = (28 feet x 12 in./ft.)^3
= 37,933,056 $in.^3$
E = 29,000,000 psi

$$\text{Thus, } 1.0 = \frac{5(42{,}000)(37{,}933{,}056)}{384(29{,}000{,}000)(I)}$$

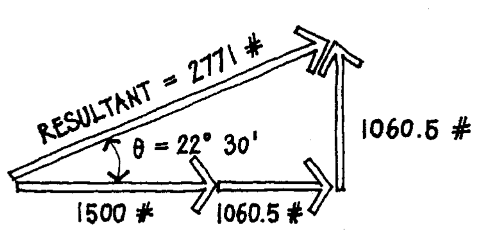
$$I = \frac{5(42{,}000)(37{,}933{,}056)}{384(29{,}000{,}000)(1.0)}$$

= 715.3 $in.^4$ (answer B)

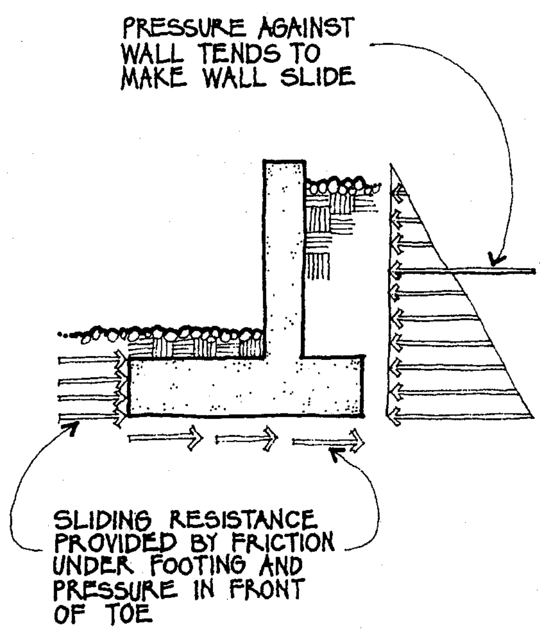
3-B Statement A is incorrect because reinforced concrete columns must be designed for a minimum amount of eccentricity, which is equivalent to bending moment, even if the load theoretically is axial. C is also incorrect; the strength reduction factor Ø is equal to 0.75 for spiral columns and 0.70 for tied columns, because of the greater toughness of spiral columns. Spiral columns are usually more expensive than tied columns because the spiral reinforcement costs more to fabricate (incorrect answer D). Only B is correct; a spiral column has about 14 percent more axial load capacity than a tied column with the same cross-sectional area and vertical reinforcement.

4-B In a moment-resisting steel frame, the moments in the beams produce tension in one beam flange and compression in the other flange. To transfer these forces from the beam flanges to the columns, moment-resisting connections are used, which must have adequate strength and not allow any slippage. For these reasons, the beam flanges are usually attached directly to the columns with full penetration groove welds (C), or with cover plates welded to the columns and welded (D) or bolted with high-strength bolts in slip-critical connections (A) to the beam flanges. ASTM A307 machine bolts are generally *not* used for moment-resisting connections because they rely on bearing to develop their strength, and in so doing allow some movement. B is therefore the correct answer.

5-C To solve this problem, we resolve the 1500# force acting at 45° with the horizontal into its horizontal and vertical components. Its horizontal component = 1500 cos 45° = 1500(.707) = 1060.5# to the right, and its vertical component = 1500 sin 45° = 1500(.707) = 1060.5# upward. The sum of the horizontal forces is 1500# + 1060.5# = 2560.5# to the right. The only vertical force is 1060.5# upward. The resultant is $\sqrt{2560.5^2 + 1060.5^2}$ = 2771#. Tan θ = 1060.5/2560.5 = 0.414, from which θ = 22.5°, as shown below. C is therefore the correct answer.



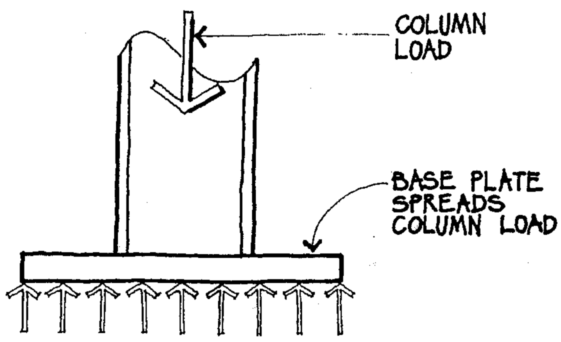
6-D The resistance of a retaining wall to sliding is provided by friction between the footing and the underlying soil and by earth pressure in front of the toe.



Where these are insufficient, additional sliding resistance may be obtained by constructing the footing with an integral key (A), or by making the footing wider (B) or deeper (C). Increasing the amount of reinforcing steel in the footing has no effect on sliding resistance. D is therefore the correct answer.

7-C There are five types of portland cement. Type III provides high early strength, usually in a few days, which allows the formwork to be removed earlier (C is correct). Type III cement is more costly than normal cements (A is incorrect). A given compressive strength can be obtained with any type of cement (B is incorrect), and all types of cement are readily available (D is incorrect).

8-D The principal purpose of a base plate under a steel column is to spread the column load over a relatively large area of the concrete foundation, so that the bearing pressure on the concrete is not excessive (correct answer D).



The thickness of the base plate is determined by assuming the bearing pressure to be uniform and considering the portions of the plate outside of the column to cantilever from the column edges.

9-A A Vierendeel truss has no diagonals. Therefore, large openings, such as doors and windows, may be made within the depth of a Vierendeel truss without conflicting with diagonal members (III is incorrect). A conventional triangulated truss tends to have less deflection and use less material than a comparable Vierendeel truss (I and II are correct). Both conventional and Vierendeel trusses can have loads applied between panel points (IV is incorrect), although this results in bending stress in the chord member. A is therefore the correct answer.

10-A The best definition of *live load* is that given in correct answer A. B is incorrect because a continuously-applied load is usually considered to be dead load. C is incorrect because live load does not include wind or earthquake load. D is not as inclusive as A, and is therefore incorrect, because live load may include loads other than occupants and movable furniture.

11-D To transfer the flexural tensile and compressive forces in the beam flanges to the columns of a rigid frame, the flanges may be attached directly with full penetration groove welds (II) or with cover plates welded to the columns and bolted (III) or welded to the beam flanges. Two clip angles bolted to the beam web may be adequate to transfer shear, but are not adequate to transfer moment (I is incorrect). Likewise, a seat angle may transfer shear, but is inadequate to transfer moment (IV is incorrect). Therefore, the correct choices are II and III (answer D).

12-A In this question, we are not asking which building type has the greatest structural cost, but for which building type is the structural cost the *lowest percentage* of the total cost of construction. As a rule of thumb, the structural cost for commercial or office buildings averages about 25 percent of the total cost of construction (D is incorrect). For buildings with minimal architectural and mechanical requirements, such as warehouses and parking garages, the structural cost may be 50 percent or more of the total cost of construction (B and C are incorrect). For buildings which have complex or expensive architectural and mechanical requirements, such as hospitals, the structural cost may be only 10 or 15 percent of the total cost of construction. The correct answer is therefore A.

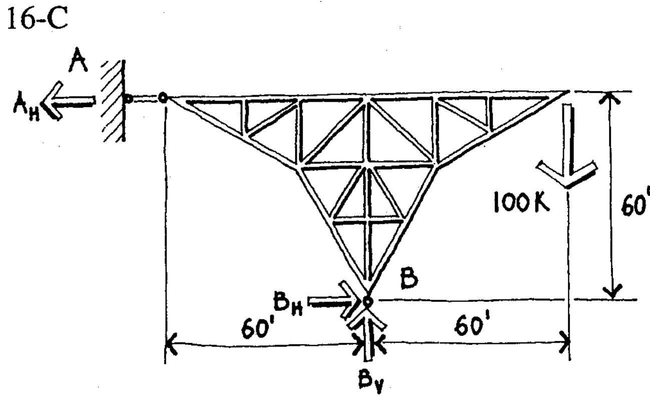
13-C This problem requires a trial-and-error solution. Try a 6 x 8.
l/d= (16 ft. x 12 in./ft.) ÷ 5.5 in.
= 34.9
$(l/d)^2 = 34.9^2 = 1218$
Allowable stress = $0.30E/(l/d)^2$
= $(0.30 \times 1.6 \times 10^6) \div 1218 = 394$ psi
Required column area
= 40,000# ÷ 394 psi = 101.5 sq.in.
The area of a 6 x 8 = 5.5 in. x 7.5 in.
= 41.25 sq.in. A 6 x 8 is therefore inadequate.

Next we try an 8 x 8.
l/d = (16 x 12) ÷ 7.5 = 25.6
$(l/d)^2 = 25.6^2 = 655.36$
Allowable stress
= $(0.30 \times 1.6 \times 10^6) \div 655.36$
= 732.4 psi
Required column area
= 40,000# ÷ 732.4 psi = 54.6 sq.in.
The area of an 8 x 8 = 7.5 x 7.5 = 56.25 sq.in. The smallest column that may be used is therefore an 8 x 8, answer C.

14-B A structural system is an arrangement of structural components which resists a building's vertical and/or horizontal loads. There are many factors which influence the choice of structural system, including the building's spans and loads. This question tests your understanding of the appropriateness of various structural systems for the given conditions. The one-way concrete joist and beam system (I) is generally economical for spans of 35 to 40 feet, and would therefore not be economical in this case. Similarly, the flat slab system (III) is appropriate for spans of about 25 to 30 feet, and would not be economical. Prestressed concrete systems, such as those in choices II and IV, are usually able to span longer distances. The correct answer is therefore B.

15-B The *staggered truss* system (correct answer B) consists of story-high trusses spanning transversely between exterior columns and arranged in a staggered pattern. It is often an efficient and economical structural system for high-rise apartment buildings.

16-C



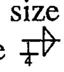
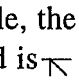
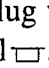
The exam often includes a few problems in statics, similar to this one, which can be solved by using the basic equations of static equilibrium: ΣH = 0, ΣV = 0, ΣM = 0. In this case, there is a pin at B, which means that there are vertical and horizontal reactions there, but no moment. At A, the horizontal bar pinned at both ends can resist an axial horizontal reaction only, but no vertical reaction or moment. We take moments about B to solve for A_H.

$\Sigma M_B = 0$
$+100 \text{ kips}(60 \text{ ft.}) - A_H(60 \text{ ft.}) = 0$
$A_H = 100 \text{ kips}$
$\Sigma H = 0$
$-A_H + B_H = 0$
$B_H = A_H = 100 \text{ kips}$
$\Sigma V = 0$
$-100 \text{ kips} + B_V = 0$
$B_V = 100 \text{ kips}$

The reactions are shown correctly in choice C.

17-D For concentrated columns loads, the most common type of footing is a square pad centered under the column, which results in a uniform soil pressure acting upward on the footing. However, if the column is located close to a property line, the footing cannot be centered under the column, and the resulting eccentricity between the center of the column and the center of the footing would cause the soil pressure distribution to be non-uniform. This could result in undesirable footing settlement, or an uneconomically large footing. To avoid these problems, a *combined footing*, as shown in the sketch, is often used, in which the resultant of the column loads coincides with the centroid of the combined footing. D is correct.

18-B The exam includes both numerical and conceptual questions, although there are usually more of the latter. This question tests your understanding of the concept of deflection. All beam deflection formulas are essentially in the form $\Delta = KL^3/EI$, where K is a constant which depends on the load and the loading condition. Thus, to *reduce the deflection*, one must *increase the moment of inertia I* (correct answer B). A and D are incorrect because all steel, regardless of yield strength, has the same modulus of elasticity E. C is also incorrect: while a beam with a greater section modulus has a greater ability to resist flexural stress, it does not necessarily have a greater value of moment of inertia I.

19-A The weld symbol along the horizontal line indicates the size and type of weld; in this case  refers to a 1/4 inch fillet weld both sides. A darkened flag () indicates a field weld, as opposed to one made in the shop. Thus, the weld symbol in this question indicates a 1/4 inch fillet weld both sides made in the field (A is correct, B is incorrect). A full penetration groove weld (C) is designated by a symbol which approximates the shape of the weld. For example, the symbol for a bevel groove weld is . A plug weld (D) is indicated by the symbol .

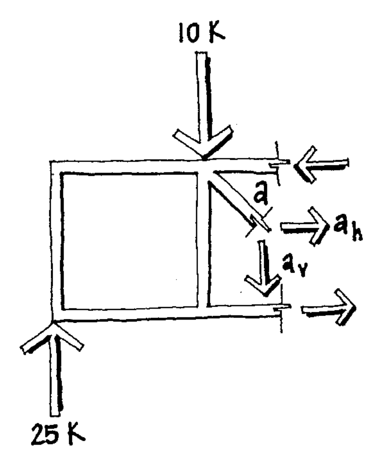
20-A Statements I and II are correct. Statement III is incorrect; the horizontal thrust at each end of a cable is *inversely* proportional to the sag of the cable. Thus, the greater the sag, the smaller the thrust. A is therefore the correct answer.

21-B The allowable shear value of a 1" diameter A325-N bolt is 16.5 kips in single shear and 33.0 kips in double shear (see Table 1-D of the AISC Manual, which is on page 37 of the *Structures Mock Exam*). The 5 bolts connected to the web of the W24 x 76 are in double shear (5 x 33.0 = 165 kips), and the 10 bolts connected to the web of the W27 x 102 are in single shear (10 x 16.5 = 165 kips). We must also check bearing stress; from page 38 of the *Structures Mock Exam*, the bearing value of a 1" diameter bolt is 69.6 kips for 1 inch of thickness. Since the web thickness of the W24 x 76 is 0.440", each bolt has a bearing value of 69.6 x 0.440 = 30.6 kips, which is less than the shear value of 33.0 kips and therefore governs. The capacity of the connection is 30.6 kips per bolt times 5 bolts = 153 kips (answer B).

22-C Hooke's Law states that up to a certain unit stress, called the *elastic limit*, unit stress is directly proportional to unit strain. This constant ratio of unit stress to unit strain for a given material is called the *modulus of elasticity* (C) and is represented by the letter E.

23-D The workability of concrete, that is, the ease with which it can be placed and consolidated, is an important quality which is usually determined in the field by the *slump test* (correct answer D). In this test, a standard mold is filled with fresh concrete; after being filled, the mold is removed and the amount that the concrete slumps is measured. Stiff mixes have less slump, while more fluid mixes have greater slump. The other three choices in this question are all tests of the compressive strength of concrete, not workability. The principal way to measure the compressive strength of concrete is the *cylinder test* (A). The *core test* (B) and the *impact hammer test* (C) are tests to determine the compressive strength of hardened concrete.

24-D Exam questions involving trusses may be conceptual, or they may require calculations, as in this question. We first determine the value of each reaction. By symmetry, each reaction is equal to one-half of the total load on the truss = (10 + 10 + 10 + 10 + 10) ÷ 2 = 25 kips. We next cut a section through the truss panel which contains member a, as shown below, assuming member a to be stressed in tension (pulling away from the joint).



$\Sigma V = 0$
$+25$ kips - 10 kips - $a_v = 0$
$a_v = +15$ kips
Since member a is inclined at 45°,
$a_h = a_v = +15$ kips.

Therefore, the internal axial force in member a $= \sqrt{15^2 + 15^2} = 21.2$ kips. Since we assumed member a to be in tension, and the sign of its internal force comes out positive, our assumption is correct and member a is in tension (D is correct).

25-D A *space frame* is a series of trusses which intersect in a grid pattern and are connected at their points of intersection. Space frames are often economical for enclosing large, square, column-free spaces, as in this question. The key to their economy is the use of repetitive members and connections (I). Other advantages include greater stiffness (II) and reduced depth (III). However, space frames are statically indeterminate and their structural analysis is complex (IV is incorrect). D is therefore the correct answer.

26-B Materials expand when heated and contract when cooled. The amount of expansion or contraction is equal to the product of three factors: the coefficient of thermal expansion of the material, the length of the member, and the temperature change. Thus Δ (expansion) = (0.0000065) x (24 ft. x 12 in./ft.) x (90 - 60) = 0.056" (answer B).

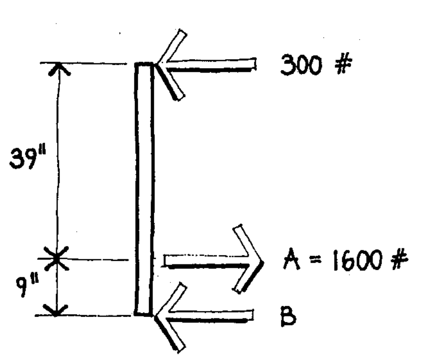
27-B Simple beams differ from continuous beams in a number of ways: the maximum positive moment in the simple beam is greater (A), the maximum deflection of the simple beam is greater (C), and the continuous beam has negative moment over its interior supports, while the simple beam never has any negative moment (D). Thus, A, C, and D are all correct statements. B is the incorrect statement we are looking for: the maximum shear in the simple beam is wL/2, which is less than that in the continuous beam, which is 5wL/8.

28-C A drilled caisson bears on the soil at its bottom and is constructed by pouring concrete into a drilled shaft. The bottom of the shaft is often enlarged, or belled, in order to increase the bearing area and hence the bearing capacity of the caisson (correct answer C).

29-A Questions testing your understanding of structural behavior often appear on the exam. Structural steel columns fail by buckling. The ratio Kl/r is a measure of the buckling tendency of a steel column; the larger the value of Kl/r, the greater the tendency of the column to buckle, resulting in a lower column capacity. In this ratio, K is a constant determined by the end conditions of the column (I), that is, whether the column ends are pinned or fixed and whether the column is free to translate (move laterally). l is the actual unbraced length of the column and Kl is the effective length (II is incorrect). The radius of gyration r is a property of the column cross-section and is independent of the yield strength of the steel (III is incorrect). Since only I is a correct statement, A is the correct answer.

30-C The shear capacity of a reinforced concrete beam depends on its width, its depth, and the ultimate 28-day compressive strength of the concrete (C is correct). If the shear capacity is insufficient to resist the shear force, web reinforcement may be added. The cross-sectional area of the longitudinal tension reinforcing is irrelevant in this regard (A is incorrect), and the beam's load and span affect the shear *force* on the beam, not its shear *capacity* (B and D are incorrect).

31-B Handrail problems, such as this one, sometimes appear on the exam. Such problems are easily solvable using the basic principles of statics. In this problem, we solve for the force in bolt A by taking moments about bolt B.



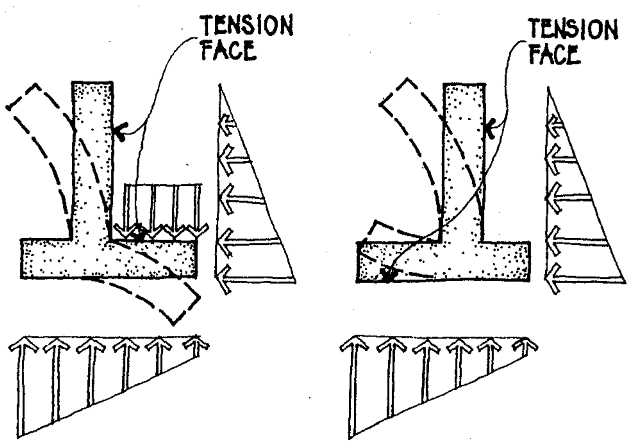
$\Sigma M_B = 0$
$-300\#(39" + 9") + A(9") = 0$
$A = (300 \times 48) \div 9 = 1600\#$

Bolt A is in *tension*, since the force acts *away* from the vertical post (correct answer B).

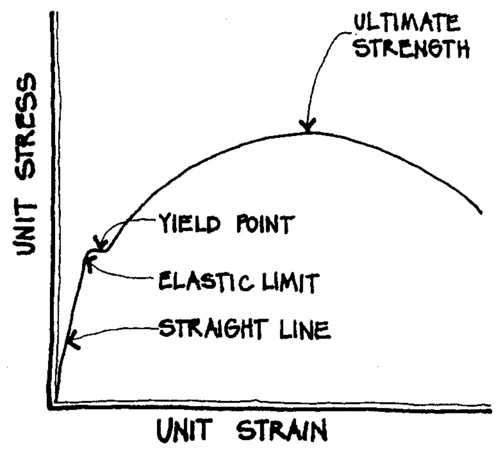
32-C In this question, you must determine the maximum bending moment that can be resisted by a 6 x 12 wood beam. Using the formula $F_b = M/S$, we rearrange the terms so that $M = F_bS$
$= 1600\#/\text{in.}^2 \times 121.229 \text{ in.}^3$
$= 193,966$ in.-lbs.
We convert this to ft.-lbs. by dividing by 12. 193,966 ÷ 12 = 16,164 ft.-lbs. (answer C).

33-A The *waffle slab* system (correct answer A) is appropriate for heavy loads and square bays, as in this question, and for spans up to about 40 feet. The *flat slab* system (B) is economical for heavy loads, but not for spans much over 25 or 30 feet. The *flat plate* system (C) has inexpensive formwork, but is not generally economical for heavy loads or spans over 20 to 25 feet. The *one-way slab and beam* system (D) might be economical, but the square bays and heavy loads in this question favor a two-way framing system, such as the waffle slab.

34-A Reinforcing steel must be placed in the tension face of a reinforced concrete structure, that is, the face which elongates or stretches under load. Thus, by visualizing the shape of the deflected structure, one can determine where the reinforcing steel should be placed. In the diagrams on the following page, the retaining walls are acted on by the loads shown, causing them to deflect as indicated by the dashed lines.



I and III II and IV



In I and III, the face of the wall closest to the earth and the upper face of the footing are in tension. Therefore, I has the reinforcing steel correctly placed, while III does not, since the steel is shown closest to the bottom face of the footing. In II and IV, the face of the wall closest to the earth and the bottom face of the footing are in tension. II shows the correct placement of the reinforcing steel, while IV does not, since the steel is shown in the face of the wall furthest from the earth. Since I and II show the correct placement of reinforcing steel, A is the correct answer.

35-D Candidates should have some familiarity with typical stress-strain diagrams, such as that shown above right for steel in tension. The *elastic limit* (correct answer D) is defined as the maximum unit stress that can be developed in a material without causing permanent deformation when the stress is released. The *modulus of elasticity* (A) is the ratio of unit stress to unit strain for the straight-line portion of the diagram, when the unit stress is below the elastic limit. The *ultimate strength* (B) is the maximum unit stress that can be developed in a material, and the *yield point* (C) is defined as the unit stress at which a material continues to deform without an increase in load.

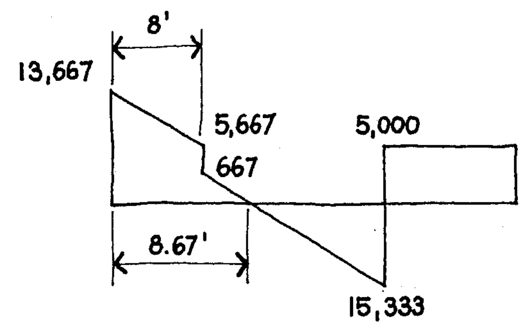
36-A A *statically determinate* beam is one whose reactions can be determined by using the basic equations of static equilibrium ($\Sigma H = 0$, $\Sigma V = 0$, $\Sigma M = 0$). Examples include simple beams and overhanging beams on two supports (IV). Beams whose reactions cannot be determined from the equations of equilibrium only, but require additional equations, are called *statically indeterminate* beams. These include beams fixed at both ends (I), beams fixed at one end and simply supported at the other end (II), and continuous beams (III). A is the correct answer.

37-D Statement A is incorrect because the adhesive is at least as strong as the wood, and a glued laminated beam will therefore tend to fail within a lamination rather than along the glue line. B is also incorrect; the allowable stresses for a glued laminated beam loaded perpendicular to the wide faces of the laminations are greater than those for a beam loaded parallel to those faces. The modulus of elasticity E of a glued laminated beam is the same as that of a sawn member of the same species; therefore, for the same load, span, and cross-section, their deflections will be the same (C is incorrect). D is correct; better grade lumber is often used in the outer laminations, where the flexural stresses are higher.

38-D Candidates should be able to determine the reactions of any statically determinate beam subject to any load. To determine the reaction at R_1, we take moments about R_2.

$\Sigma M_{R2} = 0$
$+(5000\# \times 8 \text{ ft.}) - (5000\# \times 16 \text{ ft.}) - (1000\#/\text{ft.} \times 24 \text{ ft.} \times \frac{24 \text{ ft.}}{2}) + (R_1 \times 24 \text{ ft.}) = 0$
$R_1 = (-40{,}000 + 80{,}000 + 288{,}000) \div 24$
$= 328{,}000 \div 24$
$= 13{,}667\#$ (answer D).

39-A Having determined that R_1 = 13,667#, we must now calculate the maximum moment in the beam. If you remember (which you should) that the maximum moment occurs where the shear passes through zero, you can now construct the shear diagram.



The shear at the left end is equal to the value of R_1 = 13,667#. As we move to the right along the beam, the shear decreases at the rate of 1000# per ft. (the magnitude of the uniform load). At 8 feet to the right of the left end, the shear = 13,667# - 8 ft.(1000#/ft.) = 5667#. At that point, the 5000# concentrated load causes the shear to decrease by 5000#, to 667#. Move another 0.67 ft. to the right, and the shear drops 1000#/ft. x 0.67 ft. = 667#, to a value of zero. Therefore, at 8.67 feet to the right of the left end, the moment is maximum. At that point, the moment = $(13{,}667\# \times 8.67 \text{ ft.}) - (1000\#/\text{ft.} \times 8.67 \text{ ft.} \times \frac{8.67 \text{ ft.}}{2}) - (5000\# \times 0.67 \text{ ft.}) =$ 118,493 ft.-lbs. - 37,584 ft.-lbs. - 3350 ft.-lbs. = 77,559 ft.-lbs. (correct answer A). Although we sketched the complete shear diagram for this beam, it isn't absolutely necessary to do so; simply determine the point of zero shear and calculate the moment at that point. This may seem like a rather lengthy procedure, but with a little practice you should be able to do it pretty quickly. Since problems of this kind often appear on the exam, try solving a few beams with various loadings to improve your skill.

40-D Remember the basic formula for unit stress f = P/A? Similarly, unit foundation pressure f = P/A, where P is the total load on the foundation and A is the area of the footing. Transposing, required footing area A = foundation load P ÷ allowable soil bearing pressure f = (120,000# + 150,000#) ÷ 4000#/ft.^{2} = 67.5 sq.ft. Most column pads are square, as are the four choices in this question. To determine the required side dimension of the square pad, we calculate $\sqrt{67.5}$ = 8.22 feet, and we therefore select answer D, 8'-3" x 8'-3".

41-C The ideal steel column to resist buckling is one whose radius of gyration r is the same in both directions, such as a pipe column or tubular section, rather than a wide flange section (C is correct). All the other statements are incorrect. The buckling tendency of a steel column depends on its end conditions, its length, and its radius of gyration, not on its yield point (A). The maximum allowable slenderness ratio Kl/r is 200, not 50 (B). And if the value of r is different in each direction, as with a wide flange section, the *lower* value is used to compute Kl/r (D).

42-D The nature of long span construction requires a comprehensive quality control program, including proper field inspection and testing (I). Snow drifts, partial snow loads, and the effects of wind and earthquake demand special attention in long span structures (II). The effects of temperature, creep, and shrinkage are more pronounced in long span structures (III). And long span structures are sensitive to secondary stresses caused by deflection and the interaction of building elements (IV). Since all four factors are more critical for long span buildings than for conventional buildings, D is the correct answer.

43-D The problem of selecting a steel joist has come up on some exams, and solving such a problem is very easy if you know how to use the Steel Joist Institute tables, such as that on page 39 of the *Structures Mock Exam.* In this case, the total load supported by each joist is equal to (20 + 30) lbs./sq.ft. x 6 feet = 300 pounds per linear foot. The live load per joist is equal to 30 x 6 = 180 pounds per linear foot. You will note that each joist in the table has two numbers corresponding to each span: the upper number represents the total load in pounds per linear foot which the joist can safely support, and the lower number represents the live load in pounds per linear foot which will produce a deflection of 1/360 of the span. In order to satisfy both load and deflection criteria in this problem, we must find a joist whose upper number is at least 300 and whose lower number is at least 180, and further, we must select the lightest such joist. For the 40LH12, we read 330 and 157, and the joist is therefore adequate for stress (330 > 300), but inadequate for deflection (157 < 180). For the 40LH13, we read 390 and 185, and for the 44LH13, we read 404 and 212. For the 48LH12, we read 336 and

191 for a span of 81 feet, and these numbers would be slightly higher for an 80-foot span. Thus, all three of these joists satisfy both load and deflection criteria. From the second column in the table, the 40LH13 and 44LH13 each weighs 30 pounds per linear foot, while the 48LH12 weighs 25 pounds per linear foot. The 48LH12 (correct answer D) is therefore the lightest joist which satisfies the criteria in the problem. Although this procedure may seem involved, in actual practice it can be done rather quickly.

44-A Candidates should understand basic structural terminology. The *stiffness* of a member refers to its *resistance to deformation* (correct answer A). For a member with axial load, the stiffness is a function of the modulus of elasticity E of the material and the cross-sectional area A of the member. For a flexural member, the stiffness refers to its resistance to deflection and depends on E and on the moment of inertia I of the member.

45-C Exam questions on reinforced concrete design are more likely to be conceptual that numerical. This question tests your understanding of several reinforced concrete design concepts. Failure due to crushing of the concrete is sudden and without warning, while failure due to yielding of the tensile steel is more gradual and gives adequate warning of approaching collapse. In order to assure that failure due to yielding of the steel takes place before failure of the concrete, the code sets an upper limit on the reinforcement ratio of 0.75 of the ratio that would produce a balanced design. A is therefore a correct statement and C is an incorrect statement. B and D are also correct; the reinforcing steel is generally assumed to resist all the tensile stresses, and the ultimate load factors are greater for live load than for dead load because a specified live load is more apt to be exceeded than dead load, which is fixed. Since C is the only incorrect statement, it is the answer to this question.

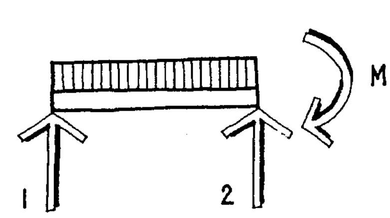
46-C The modulus of elasticity E of a material is defined as the ratio of unit stress to unit strain when the unit stress is below the elastic limit. Since unit stress = P/A and unit strain = Δ/L,

$E = (P/A) \div (\Delta/L) = PL/A\Delta$

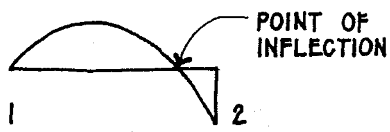
$= (50{,}000\# \times 10 \text{ ft.} \times 12 \text{ in./ft.}) \div \left[\frac{\pi(2 \text{ in.})^2}{4} \times 0.159 \text{ in.}\right]$

$= 6{,}000{,}000 \div 0.4995 = 12{,}012{,}000$ psi (answer C).

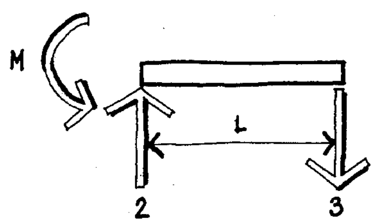
47-A The moment over the interior supports of a continuous beam is always negative when the beam supports downward loads (B is correct). We isolate span 1-2.



The moment at 1 is zero, the moment at 2 is negative (tension at the top, compression at the bottom), and the moment diagram is parabolic since the load is uniform. The moment diagram for span 1-2 is therefore as shown below.



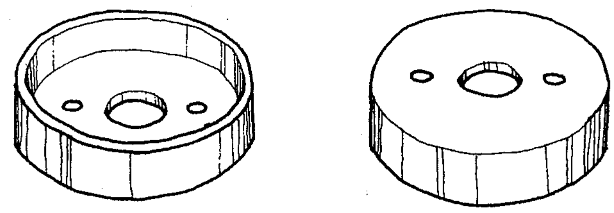
There is positive moment from 1 to the point of inflection and negative moment from there to 2. A is therefore the incorrect statement we are looking for. We now isolate span 2-3 and take moments about 2, assuming that the reaction at 3 is downward.



$\Sigma M_2 = 0$
$-M + (R_3 \times L) = 0$
$R_3 = +M/L$

Since R_3 comes out positive, our assumption that it acts downward is correct (C is correct). The moment in span 2-3 is always negative and varies from zero at 3 to M at 2 (D is correct).

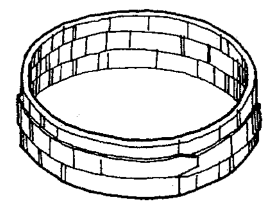
48-B *Shear plates* (A), shown above right, are made of pressed steel or malleable iron and are used for wood-to-steel connections using one shear plate or for wood-to-wood connections using two shear plates.



FRONT BACK

SHEAR PLATE

Split rings (B), shown below, are used only for wood-to-wood connections. Circular grooves are precut into the contacting faces of the wood members to be joined so that half of the ring fits into each member, while a bolt is used to hold the two members together.



SPLIT RING

Machine bolts and *wood screws* (C and D) may be used for either wood-to-wood or wood-to-steel connections. Thus, the only connectors *not* used for wood-to-steel joints are split rings (choice B).

49-D This is a typical steel beam problem which you should be able to solve very easily. The maximum moment in a simple beam supporting a uniform load is equal to $wL^2/8$ (a formula you should probably memorize). Thus, maximum moment M = 1800#/ft. x $(30 \text{ ft.})^2 \div 8$ = 202,500 ft.-lbs. We

ALLOWABLE STRESS DESIGN SELECTION TABLE
For shapes used as beams S_x

F_y = 50 ksi							F_y = 36 ksi		
L_c	L_u	M_R	S_x	Shape	Depth d	F'_y	L_c	L_u	M_R
Ft	Ft	Kip-ft	In.³		In.	Ksi	Ft	Ft	Kip-ft
8.1	**8.6**	**484**	**176**	**W 24× 76**	**23⅞**	—	**9.5**	**11.8**	**348**
9.3	20.2	481	175	W 16×100	17		[illegible]	28.1	347
9.1	20.2	338	123	W 14× 82	14¼	—	10.7	28.1	244
10.9	26.0	325	118	W 12× 87	12½	—	12.8	36.2	234
6.8	10.4	322	117	W 18× 65	18⅜	—	8.0	14.4	232
9.2	13.9	322	117	W 16× 67	16⅜	—	10.8	19.3	232
5.0	**6.3**	**314**	**114**	**W 24× 55**	**23⅝**	—	**7.0**	**7.5**	**226**
9.0	18.6	308	112	W 14× 74	14⅛	—	10.6	25.9	222
5.9	6.7	305	111	W 21× 57	21	—	6.9	9.4	220
6.8	9.6	297	108	W 18× 60	18¼	—	8.0	13.3	214
10.8	24.0	294	107	W 12× 79	12⅜	62.6	12.8	33.3	212
9.0	17.2	283	103	W 14× 68	14	—	10.6	23.9	204
6.7	**8.7**	**270**	**98.3**	**W 18× 55**	**18⅛**		**7.9**	**12.1**	**195**

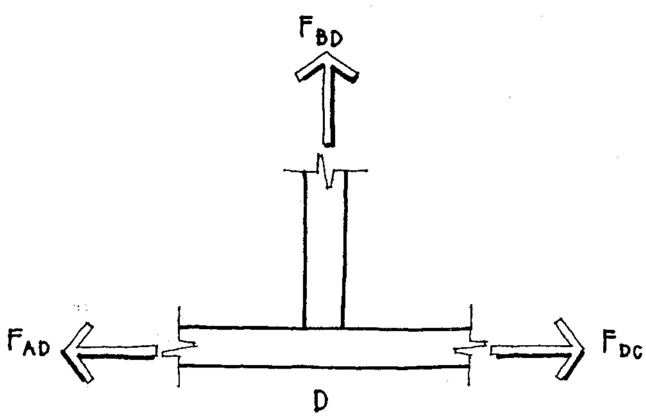
S=101.25 →

← M=202.5

convert this to in.-lbs. by multiplying by 12 = 202,500 x 12 = 2,430,000 in.-lbs. The required section modulus S = M/F_b, where F_b is the allowable bending stress (24,000 psi for ASTM A36 members with full lateral support). Therefore S = 2,430,000 ÷ 24,000 = 101.25 in.³. Using the table above, we locate the first group of beams which have a value of S equal to or greater than 101.25. The beam in boldface type at the top of the group is the lightest beam that is adequate, in this case a W24 x 55 (correct answer D). While this is a pretty simple procedure, an even simpler procedure is to locate the group of beams which have a value of moment M_R equal to or greater than 202.5 and select the beam in boldface type at the top of the group, again a W24 x 55.

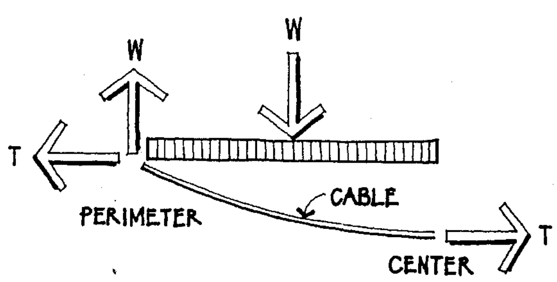
50-C To select a steel beam which is laterally supported, the simplest procedure is usually that described in the preceding question. But what if the beam is laterally unsupported, as in this question? In that case, we use a chart from the AISC Manual, such as that reproduced on page 41 of the *Structures Mock Exam.* We enter the chart with an unbraced length of 10 feet on the bottom scale and then proceed upward to meet the horizontal line corresponding to a moment of 202.5 ft.-kips on the left-hand scale. Any beam above and to the right of the point so located is adequate, but the first such beam shown as a solid line is the lightest in weight, in this case a W21 x 62 (correct answer C).

51-A The truss in this question is called a *King Post truss*, in which the internal force in the vertical member is zero (correct answer A). To prove this, we isolate joint D and apply the basic equation of static equilibrium $\Sigma V = 0$.



Since the only vertical force acting at the joint is $F_{B\text{-}D}$, it follows that $F_{B\text{-}D} = 0$.

52-C Each radial cable supports vertical load and resists tension, as shown below.



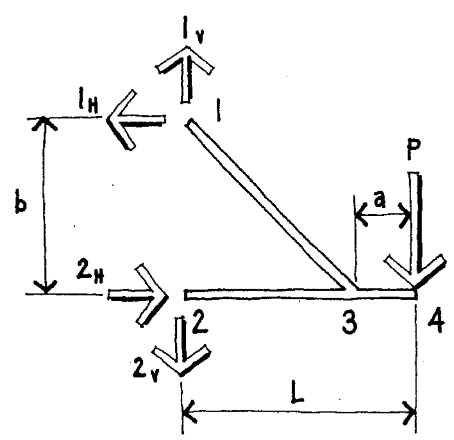
For equilibrium, the center ring must be *lower* than the perimeter ring (A is incorrect). Each cable *pulls* on the center ring, which tends to expand it, thus stressing it in tension. Each cable also *pulls* on the perimeter ring, which compresses it (C is correct, B and D are incorrect).

53-A The allowable stresses for wood members and fasteners tabulated in building codes apply to normal duration of loading. For shorter durations of load, the allowable stresses may be increased; the shorter the duration, the greater the allowable stresses (correct answer A). For example, for two months' duration, as for snow, the allowable stresses may be increased 15 percent.

54-B One of the most fundamental concepts in structures is that of *equilibrium*. For an object to be in equilibrium, it must have no unbalanced force acting on it (A and D are correct). It must also have no unbalanced moment acting on it (C is correct). B is incorrect, and is therefore the answer to this question, because if there is a resultant force on an object, it will not be in equilibrium.

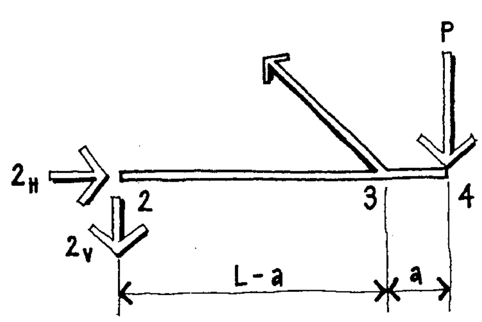
55-A Unlike structural steel, which has a constant value of modulus of elasticity, the modulus of elasticity of concrete varies with its strength and unit weight (I is correct). A reinforced concrete beam continues to deflect after it reaches its initial deflection (II is correct). III is incorrect because adding compressive reinforcement reduces the creep and hence the long-term deflection of a reinforced concrete beam. Since I and II are correct statements, A is the correct answer.

56-D In this problem, we must determine the directions of the reactions but not their magnitudes. We draw a free body diagram and assume the reactions act in the directions shown.



$\Sigma M_2=0$
$+(P \times L) - (1_H \times b) = 0$
$1_H = +PL/b$

Since 1_H comes out positive, our assumption that it acts to the left is correct. From $\Sigma H = 0$, $2_H = 1_H$ and acts to the right. We next draw a free body diagram of horizontal member 2-3-4.



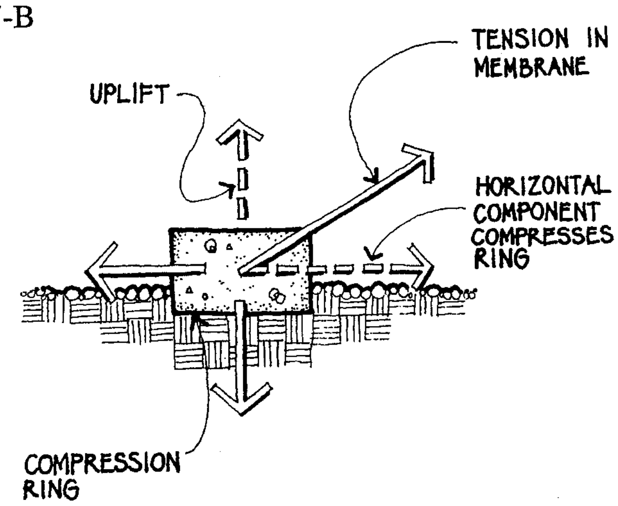
$\Sigma M_3=0$
$+(P \times a) - 2_v \times (L - a) = 0$
$2_v = +Pa/(L - a)$

Since 2_v comes out positive, our assumption that it acts downward is correct.

$\Sigma V= 0$
$+1_v - 2_v - P = 0$
$1_v = 2_v + P$

Since 1_v comes out positive, our assumption that it acts upward is correct. The directions of the reactions are shown correctly in answer D.

57-B



A membrane can only resist tension. The vertical component of the tension in the membrane is an uplift force (III), while the horizontal component compresses the perimeter ring (I), making B the correct answer.

58-B The pressure exerted by a liquid is equal to the unit weight of the liquid multiplied by the depth of the liquid. At the top of the tank, the pressure is 62.4#/cu.ft. x 0 ft. = 0. At one foot down, the pressure is 62.4 x 1 = 62.4#/sq.ft., at two feet down, the pressure is 62.4 x 2 = 124.8#/sq.ft., and so on. At the bottom of the tank, the pressure is 62.4 x 10 = 624#/sq.ft. Thus, the pressure varies linearly, from zero at the top to 624#/sq.ft. at the bottom, as shown correctly in answer B.

59-C Questions involving grade marks for sawn lumber or plywood may appear on the exam. The mark in this question indicates that the panel was produced under American Plywood Association (APA) performance standards, which deal with how the panel must perform, rather than from what or how it was manufactured. Statement III is therefore incorrect. The other three statements are correct; 32/16 means that the panel can span 32 inches when used as roof sheathing and 16 inches when used as subflooring. Exposure 1 panels are manufactured with waterproof exterior glue, but are not considered exterior panels suitable for permanent exposure to the weather. C is therefore the correct answer.

60-A The stub girder system is a steel beam-and-girder system in which the floor beams sit on top of the main girders, rather than framing into them. Short lengths of stub girders the same depth as the floor beams are welded to the tops of the main girders to provide a connection to the slab for composite action (A is correct). The advantages of the stub girder system are reduced weight of steel and reduced story height. See page 33.

61-B In answering this question, we first review a few basic definitions and formulas. Unit stress is equal to axial load P divided by cross-sectional area A, or P/A. Unit strain is equal to total strain Δ divided by length L, or Δ/L. Modulus of elasticity E is equal to unit stress divided by unit strain, or $E = (P/A) \div (\Delta/L) = PL/A\Delta$. Transposing, $\Delta = PL/AE$. Thus, the change of length Δ is directly proportional to the load P (I) and the length L (II) and inversely proportional to the cross-sectional area A (IV) and the modulus of elasticity E (V). The moment of inertia (III) does not affect the change of length. B is therefore the correct answer.

62-C You may believe that this is such a simple, basic problem that there must be a trick to it. No, there is no trick; this is just a straightforward problem, like most exam problems. The unit stress in the bar is simply P/A, where P is the load of 50,000 pounds and A is the cross-sectional area of the two-inch-diameter bar = $\pi(2)^2/4 = 3.14$ square inches. So the unit stress is equal to 50,000 lbs. $\div$ 3.14 square inches = 15,915 psi (answer C). The length of the bar is irrelevant.

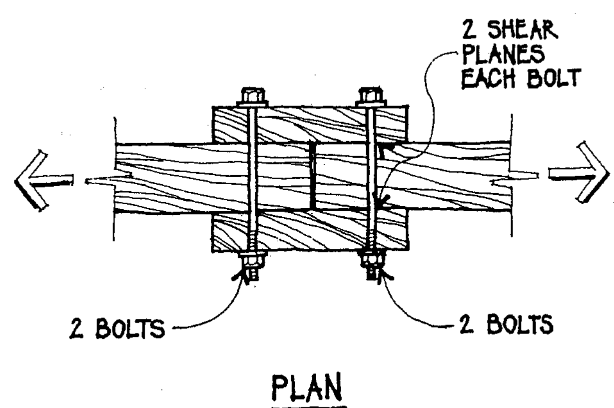
63-B The *flexural* stress in a rectangular beam varies from a maximum value at the outer fibers to zero at the neutral axis, as shown in answer A. The *shear* stress varies parabolically, from zero at the outer fibers to a maximum value at the neutral axis, as shown in correct answer B. Answers C and D are arbitrary diagrams.

64-A Most building codes require the dead load resisting moment to be at least 1.5 times the overturning moment caused by earth pressure, making A the correct answer. If the dead load resisting moment were less than 1.5 times the overturning moment, the simplest solution would be to make the footing wider. Making the footing deeper would increase the dead load resisting moment slightly, and increasing the amount of reinforcing steel would have no effect on the dead load resisting moment.

65-C In composite design, a steel beam and the concrete slab above it are connected so that they act together as a single structural unit to resist bending stresses. The concrete slab becomes part of the top flange and resists compressive bending stresses (C is correct). Connectors welded to the top flange of the steel beam resist shear, not flexural stresses (A is incorrect). Adding these connectors changes the beam from non-composite to composite and makes the beam stiffer. However, since composite design usually allows the designer to use shallower beams, it is necessary to check deflections (D is incorrect). Composite construction is most efficient with heavy loads and long spans (B is incorrect).

66-D Statement A is correct; the greatest drying shrinkage in wood members occurs across the grain, rather than parallel to the grain. B is also correct; in most designs, the expansion and contraction of wood caused by temperature change is negligible. Glued laminated members generally shrink less than sawn timber members because the individual laminations are thin and easily seasoned, which reduces shrinkage (C is correct). D is the incorrect statement, since the shrinkage of wood is generally greater in heavier pieces than in lighter pieces of the same species.

67-D



The bolts in this question are in *double shear*, since there are two planes through each bolt which resist shear. From Table 23-I-F of the Uniform Building Code, which is reproduced on page 42 of the *Structures Mock Exam*, the allowable load for each 7/8" bolt in double shear parallel to grain when the thickness of the main member is 3-1/2" (nominal 4") is 3580#. The total load which can be transferred by two bolts is therefore 3580 x 2 = 7160# (correct answer D).

68-B Stirrups are small U-shaped bars, such as #3 or #4, which are placed vertically in a reinforced concrete beam to reinforce the web where the shear stresses are excessive (correct answer B). A is incorrect, since compressive reinforcement consists of longitudinal bars placed in the compressive area of a beam to resist part of the compressive stress. Reinforcement is anchored by mechanical devices and/or embedment (C is incorrect), and lateral buckling of compressive reinforcement is prevented by the use of ties, not stirrups (D is incorrect).

69-D All steel, regardless of strength or other properties, has the same value of *modulus of elasticity* E, about 29,000,000 psi (D is correct). The other properties in this question—yield point, ultimate strength, and weldability—vary depending on the type of steel.

70-D All four statements are correct (answer D). Air-supported membranes which enclose a space are pressurized by fans (I). Since the internal air pressure is slightly greater than the outside pressure, airlocks or special doors are required to get in and out of the space (II). Loss of pressure can cause the roof to deflate (IV); however, in that event, the velocity of the fans could be increased so that the deflation would take place over a long period of time. Large air-supported fabric structures are usually reinforced with steel cables (III).

71-D A three-hinged gabled frame has a hinge at the center and at each support and is statically determinate (A is correct). The hinges at the supports permit rotation (B is correct), and the hinge at the center also permits rotation, which prevents any moment from being developed at the center (C is correct). D is the incorrect statement and is therefore the answer to this question: the maximum moment does occur at the intersection of the column and the sloping beam, but this moment is generally *less* than in a rectangular rigid frame.

72-A A parallel chord truss is analogous to a steel beam: the truss chords are like the beam's flanges, while the truss web members are similar to the beam's web. Just as the beam flange forces increase toward the center of the span, the forces in the truss chords increase toward the center of the span. And just as the shear in the beam web decreases toward the center of the span, similarly the forces in the truss web members decrease toward the center of the span. A is therefore the correct answer.

73-C The top chord of a simply-supported truss is stressed in compression. As with all steel compression members, the capacity of the truss chord is based on its Kl/r value. K is usually assumed to be 1 and the value of r is the *lower* value, which may be with respect to either the x-x or the y-y axis (correct answer C).

74-D Exam questions sometimes test candidates' understanding of the economics of various structural systems and components. This is that kind of question. The connections used in structural steel systems comprise a significant part of the cost of these systems, and can even influence the type of structural steel system selected (A is correct). It is true that fillet welds are usually more economical than full penetration welds (B is correct). Shop connections are usually preferred over field connections because they are less costly (C is correct). In addition, good quality control is easier to achieve in the shop than in the field. Depending on the circumstances, welded connections are not necessarily more economical than bolted connections. D is therefore the incorrect statement.

75-B This can be a troublesome question because the choices are similar, but have subtle differences. When a rigid frame supports a uniform vertical load, the horizontal member deflects downward, as in choices A, B, and C. D is the shape of the deflected frame when it resists a lateral load, such as wind or earthquake, and is therefore incorrect. C is the deflected shape of a simple beam supported by columns, not a rigid frame, and is therefore incorrect. A is the deflected shape of a rigid frame with hinged bases, not fixed (note that the column bases are rotated, not vertical). B is similar to A, but note that the bottoms of the columns are vertical where they meet the ground, which indicates a fixed condition. B is therefore the correct choice.

76-B In this question, the concrete is specified to have a 28-day compressive strength of 4000 psi. At 7 days, its strength should be approximately 60 to 70 percent of its 28-day strength, or 2400 to 2800 psi. The 7-day strength is given as 3000 psi, and so we can safely assume that the 28-day strength will equal or exceed the specified value of 4000 psi. Therefore, we should take no action (correct answer B). If the 7-day strength were unusually low, we might consider redesigning the concrete mix (A). If we were seriously concerned about low-strength test results, we might order tests of cores drilled from the area in question (C). As a last resort, if the core tests indicated low strength, we might order load tests of the concrete (D).

77-C Each force produces a moment about point O equal to the magnitude of the force multiplied by its distance from point O. The total moment is equal to the algebraic sum of the moments caused by all the forces. The 1000# horizontal force produces a clockwise moment equal to 1000# x 4 feet = 4000 ft.-lbs. The 1000# vertical force produces no moment, since its line of action passes through point O. The moment caused by the 1000# force at 30° is determined by resolving the force into its vertical and horizontal components. The vertical component is 1000 sin 30° = 500#, and the horizontal component is 1000 cos 30°

= 866#. The vertical component causes no moment, since its line of action passes through point O. The horizontal component produces a clockwise moment of 866# x 4 feet = 3464 ft.-lbs. The total moment is the algebraic sum of the moments = 4000 + 3464 = 7464 ft.-lbs. (answer C).

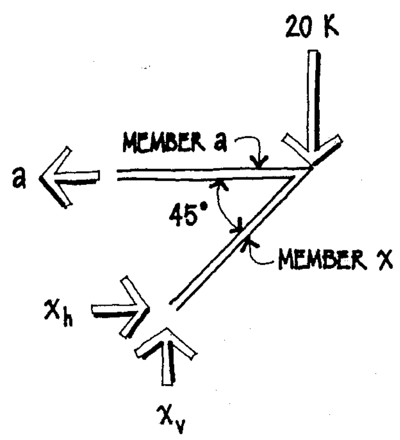
78-D This is a question requiring construction experience and judgment. First of all, concrete should never be placed on frozen ground (A), because when the ground thaws, it shrinks, which is likely to cause cracking. Providing a heated enclosure (B) or thawing the ground (C) are possibilities. However, excavating the frozen ground (D) is the best choice. This not only solves the present construction problem, but it also places the footings below the zone of frost penetration, thus preventing frost damage in the future.

79-A In this question, definitions of four different long-span roof systems are given, and you are asked to select the one which refers to a lamella roof. Answer A correctly defines a *lamella* roof. B is the definition of a *space frame*, and C and D describe systems which have been used but do not have specific names.

80-C In this question, four different diagrams are presented, and you are asked to select the one representing the flexural stresses in a reinforced concrete beam at failure. Diagram A represents the flexural stresses in a homogeneous rectangular beam, such as wood, and diagram B represents the flexural stresses in a reinforced concrete beam at working stresses. This is the basis of *working stress design*, which has been largely superseded by the *strength design* method. Diagram C correctly shows the flexural stresses in a reinforced concrete beam at failure, which is the basis of strength design. The bunched arrows represent the compressive stress in the concrete and the single arrow represents the tensile stress in the reinforcing steel. Diagram D represents the flexural stresses in a steel beam when the entire beam profile is stressed to the yield strength. This is the basis of *limit states design* in steel, which is analogous to the strength design method used for reinforced concrete.

81-B If the upper soils were strong enough to support the building loads, then footings at a shallow depth could be used. However, since the upper soils consist of loose fill, we must penetrate through the fill to bear on the dense sand below. Choices III and IV are therefore likely to be appropriate foundation systems (correct answer B). What about choices I and II? Wouldn't they also be appropriate? Not very likely; removal and recompaction of fill is usually economical up to a depth of about six feet, not 15 feet. And footings extending through the fill into the dense sand might be economical up to several feet in depth, but not 15 feet as in this question.

82-A This truss problem can be solved in various ways, but the simplest way is to isolate the joint where the 20 kip load is applied and draw a free body diagram.



Assume member a is stressed in tension (pulling away from the joint) and diagonal member x is stressed in compression (pushing toward the joint).

$\Sigma V = 0$
$-20 + x_v = 0$
$x_v = +20$ kips

Since member x slopes at 45°, $x_h = x_v =$ 20 kips
$\Sigma H = 0$
$+x_h - a = 0$
$a = +x_h = +20$ kips

Since all the signs come out positive, our assumptions about the directions of the stresses are correct, and member a is stressed in tension. A is therefore the correct answer.

83-B If you have a reasonable understanding of moment diagrams, this question should not be too difficult. The moment diagram for a member supporting a uniformly distributed load is parabolic. D is therefore incorrect; it shows the moment diagram when the frame resists a lateral load, such as wind or earthquake. There must be moment at the bases, since they are fixed, which makes A incorrect; A is actually the moment diagram for a frame with hinged bases. That leaves B and C, which are similar. But in C, the moment in the horizontal member is zero at each end, which would be true for a simple beam, but is not correct for a rigid frame. Therefore, B correctly shows the moment diagram.

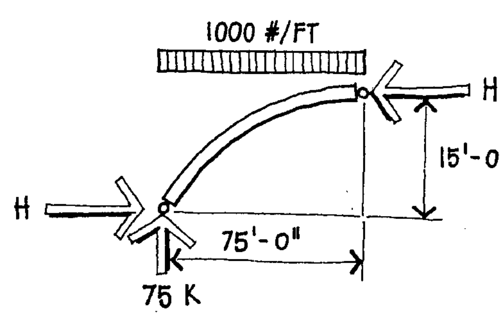
84-D It is practically impossible to make butt joints sufficiently strong or permanent to adequately join laminations end to end. Instead, scarf joints (I and II), finger joints (III), or other similar joints must be used (D is correct).

85-B The dead load of a structure acts continuously, but the live load can vary from zero to the full design load. In the design of the structural framing of a building, the live load must be arranged so as to produce the maximum moments. For a simple beam, the full design live load acting on the entire span will produce the maximum positive moment. For a continuous beam, the live load arrangements which will produce the maximum moments are as follows: (1) live load on two adjacent spans will produce the maximum negative moment over the support, and (2) live load on alternate spans will produce the maximum positive moment between supports. In this case, therefore, arrangement C (live load on spans 1-2 and 2-3) will produce the maximum negative moment over support 2, while arrangement B (live load on spans 1-2 and 3-4) will produce the maximum positive moment in spans 1-2 and 3-4. Arrangements A and D will not produce either maximum positive or negative moment. B is therefore the correct answer.

86-A Prestressed concrete is permanently loaded so as to cause stresses opposite in direction from those caused by dead and live loads. Prestressing results in more economical and efficient use of material, especially in repetitive long-span applications (II). Since prestressed members are completely in compression, tension cracks are prevented (I). However, offsetting these advantages are higher material and labor costs (III is incorrect) and the need for closer quality control than with conventional reinforced concrete (IV is incorrect). Since only I and II are correct, the answer is A.

87-C When a flat roof deflects under load, a concave surface results. Rain water can collect in such areas, increasing the deflection, which further increases the amount of ponded water, and so on. During intense rainstorms, therefore, the ponding of flat roofs can result in problems, including even collapse. Because of their long span and relative flexibility, long span open web joists are particularly vulnerable to this kind of trouble. Therefore, the joists should be cambered or pitched sufficiently so that rain water cannot build up. Building pitch into the top chords of the joists is one way to achieve slope, but is usually more expensive than using parallel chord joists which are sloped, or building in camber (I is incorrect, II and IV are correct). Although a slope of 1/8 inch per foot is sometimes used, one cannot be certain that such a minimum slope will always be sufficient to prevent ponding (III is incorrect). C is therefore the correct answer.

88-C A three-hinged arch is the only type of arch which is statically determinate. To calculate the horizontal thrust, we draw a free body diagram of the left half of the arch.



By symmetry, each vertical reaction is equal to one-half of the total vertical load on the arch = 1000 lbs./ft. x 150 ft./2 = 75,000# = 75 kips. Take moments about the center hinge, where the moment is equal to zero.

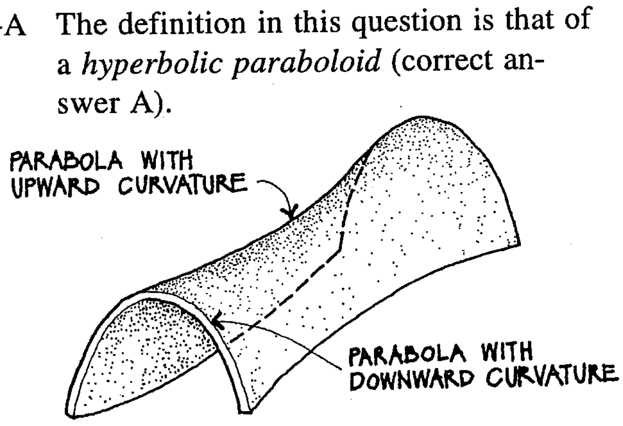
$\Sigma M = 0$

$(75 \text{ kips} \times 75 \text{ ft.}) - (1.0 \text{ kips/ft.} \times 75 \text{ ft.} \times \frac{75 \text{ ft.}}{2}) - (H \times 15 \text{ ft.}) = 0$

H = [(75 x 75) - (1 x 75 x 37.5)] ÷ 15
= (5625-2812.5) ÷ 15 = 187.5 kips
(answer C)

89-A The exam invariably includes some questions which test candidates' familiarity with structural terms, as in this question. A *composite deck* is steel decking manufactured with deformations which mechanically bond the deck to the concrete slab above it, so that the deck and slab act together as a single structural element to span between floor beams (correct answer A). C and D are incorrect because they describe a *composite beam,* not a composite deck, and B is also incorrect.

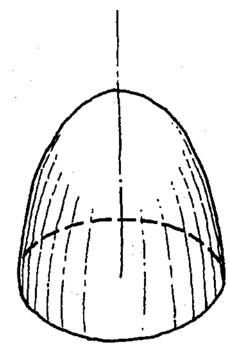
90-A The definition in this question is that of a *hyperbolic paraboloid* (correct answer A).



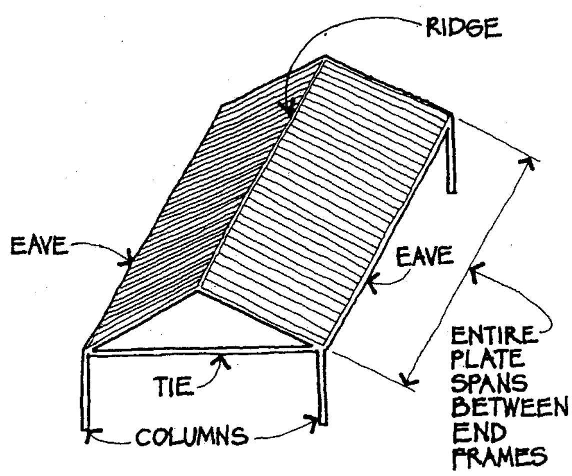
HYPERBOLIC PARABOLOID

The surface of a *parabolic dome* (B) is formed by rotating a parabola about its vertical axis (see above right).

A *membrane* (C) is a thin sheet of material, such as fabric, which can only develop tensile stresses. A *folded plate* (D) is a V-shaped structure in which the



PARABOLIC DOME



FOLDED PLATE

entire plate roof spans longitudinally between ends.

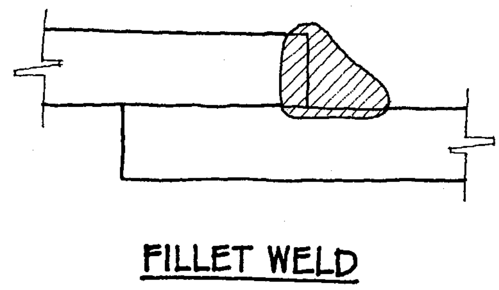
91-B A three-hinged arch is the only type of arch which is statically determinate, no matter what the loading is (B is correct). In the answer to Question 88, we show how the horizontal thrust at each end of a three-hinged arch is calculated.

92-D Identification marks are rolled into the surface of reinforcing bars to denote the producing mill, the bar size, the type of steel, and the minimum yield strength.

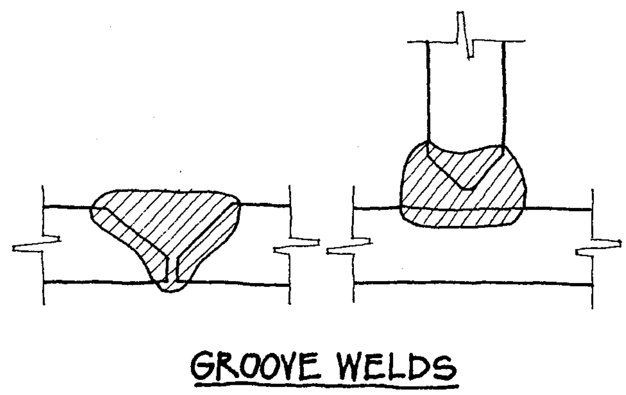
In this case, the producing mill has the symbol H, the bar size is #10, which is 1-1/4" in diameter, the type of steel is designated S, which means billet steel, and 60 means that the steel has a minimum yield strength of 60 ksi. The correct answer is therefore D.

93-A Openings in beams have the least effect on the beam's load-carrying capacity if they are located in areas of low stress. The two main types of stress in beams are shear stress and bending, or flexural, stress. The shear stress is usually greatest near the supports and least near midspan. Thus, an opening in an area of low shear stress would be near the center of the span (A, B, or C). For a simply-supported beam, the bending stresses are greatest near the middle of the span and least near the supports. Within the beam depth, the bending stresses are greatest near the top (compression in the concrete) and bottom (tension in the reinforcing steel) and least at about the mid-depth of the beam. Therefore, an opening in an area of low bending stress would be near the supports (D) or at the mid-depth of the beam (A). The only location which is in an area of both low shear stress and low bending stress is A.

94-C A *fillet weld* is placed in the right angle formed by two intersecting or lapping plates or members.



A *groove weld* is used to join two butting plates or members.



A *full penetration weld* is a groove weld whose depth is the same as the thickness of the member. Although fillet welds are not as strong as groove welds, they are more commonly used (C is correct). The reason is that groove welds require members to be fabricated to much closer tolerances than fillet welds. *Plug welds*, which consist of holes filled with weld metal, are sometimes used where other types of welds would be impractical.

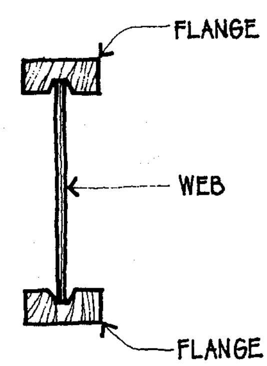
95-C Steel columns rest on and are generally welded to steel base plates, which transfer the column load by bearing on the concrete foundation. The bearing pressure under the base plate is equal to P/A, where P is the column load and A is the area of the base plate = 300,000# ÷ (20 in. x 20 in.) = 750 psi (correct answer C). This is as simple a calculation as you're likely to see on the exam.

96-D The horizontal shear is transferred from the column to the footing by shear in the anchor bolts (correct answer D). The vertical load, not the horizontal shear, is transferred from the column to the footing by bearing of the base plate on the footing (A is incorrect). If there were moment in the column, it might be resisted by tension in the anchor bolts and bearing of the base plate on the footing (C is incorrect). Friction between the base plate and the footing is generally not considered to resist load (B is incorrect).

97-B The flat slab floor system is a two-way reinforced concrete system which is supported directly on the columns, generally without any beams or girders. A and D are therefore correct statements. The flat slab system is usually economical for heavy loads, as in warehouses (C is correct). B is incorrect and is therefore the answer to this question; flat slabs are relatively thin and are therefore not economical in reinforcing steel.

98-A If a parabolic arch supports a uniformly distributed vertical load, it will be stressed only in compression, with no bending (A is correct). Under any other loading, it will be subject to some bending moment (C). B (pure bending) describes the stress in a beam, not an arch, and D (pure tension) describes the stress in a cable, not an arch.

99-D I-shaped wood joists have a profile that looks like this:

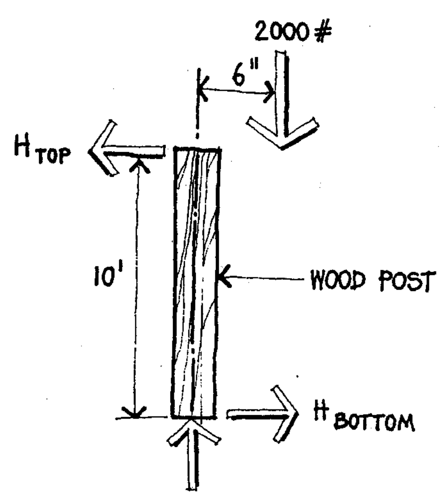


As with any I-shaped member, such as a steel plate girder, the flanges substantially resist the flexural tension and compression, the web resists the shear, and the connections between the flanges and the web resist horizontal shear (D is correct).

100-B Identifying hardware may not be your idea of fun, but questions like this sometimes appear on the exam and it's wise to be prepared. Connector 1 is a *plywood clip*, which is used to connect adjacent edges of plywood roof panels which are not supported by wood framing. Connector 2 is a *framing anchor*, which can be bent in various ways to connect wood framing. Connector 3 is a *joist hanger*, used to hang wood joists from flush headers. Connector 4 is a *post cap* and is used to secure a wood beam to a wood post. The connectors are correctly identified in choice B.

101-D In the post-and-beam, the maximum moment in the beam is equal to $wL^2/8$ and there is no moment in the columns. In the rigid frame, the beam ends are restrained by the columns, which reduces the maximum moment in the beam (II) and results in moment in the columns (I). The axial force in the columns is the same for both the rigid frame and the post-and-beam (III). The column bases of the rigid frame have a horizontal reaction, which the column bases of the post-and-beam do not (IV). Since all four statements are correct, the answer is D.

102-C This problem involves an eccentrically loaded wood post, that is, a post which supports vertical load applied at some distance from its center line.



To determine the horizontal reactions at the top and bottom of the post, we apply the basic equations of static equilibrium.

ΣM about the base = 0
+2000# x 6" - H_{top} x (10 ft. x 12"/ft.) = 0
H_{top} =12,000"# ÷ 120" = 100 pounds
$\Sigma H = 0$
$-H_{top} + H_{bottom} = 0$
$H_{top} = H_{bottom}$

Answer C is therefore correct. Note that the size and properties of the post are irrelevant in this question. This is sometimes the case on the exam; you don't necessarily need to use all the information given to answer a question.

103-D The compressive load on the post causes a unit stress of P/A = 2000# ÷ 25.375 in.^{2} = 79 psi. The eccentric moment is equal to 2000# x 6 in. = 12,000 in.-lbs. and causes a flexural stress equal to M/S = 12,000 in. lbs. ÷ 30.661 in.^{3} = 391 psi. The combined stress (compression + flexure) = 79 + 391 = 470 psi (answer D).

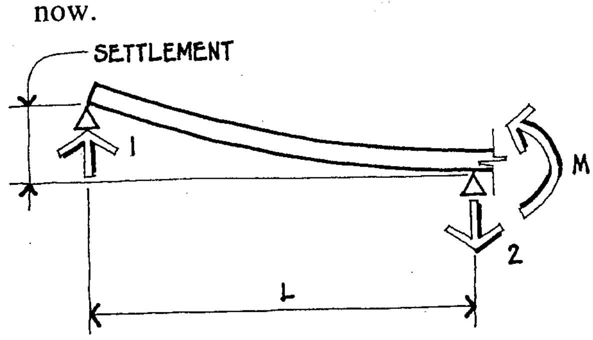
104-A Prestressing of concrete is done by either *pretensioning* or *posttensioning*. In pretensioning, high strength steel is tensioned *before* the concrete is cast. After the concrete hardens, the prestress wires are cut and the prestress force is applied to the concrete through bond. Therefore, no end anchorages are required (B is correct). Most precast, prestressed members are pretensioned and again, no end anchorages are required. A is therefore the untrue statement we are looking for. In posttensioning, the steel tendons are stressed *after* the concrete is cast on the site, by jacking against anchorages at the ends of the member (D is correct). Whether pretensioned or posttensioned, prestressing results in more efficient use of the material, making smaller sections possible (C is correct).

105-D Candidates should have some knowledge concerning the efficiency, economy, and appropriateness of various structural systems and components. In general, we try to keep everything as simple, regular, and conventional as possible. For example, since moment or rigid connections are more expensive than simple or shear connections, the number of moment connections should be kept to a minimum (I is incorrect). Rolled sections should be used wherever possible; while the use of built-up sections may save weight, the additional labor cost often results in a higher in-place cost (II is incorrect). III is also incorrect; high-strength steel is stronger than ASTM A36 steel, but it is also more costly and therefore not always the more economical choice. IV is the only correct statement (D is correct). Most steel floor decking today is composite because it is more economical than non-composite decking.

106-C Studies have shown that the optimum bay shape for steel framing is rectangular with a length-to-width ratio of about 1.3 (A and D are incorrect). The beams should preferably span in the long direction and the girders in the short direction (C is correct, B is incorrect).

107-A All structures tend to expand when the temperature increases and contract when the temperature decreases. Since the bottom of a dome is prevented by its foundation from expanding and moving outward when the temperature rises, the only way the dome can expand is to move upward (correct answer A).

108-B This looks impossible to solve, so you might be inclined to simply guess at the answer. But let's think about it. When support 2 settles, span 1-2 looks like this, ignoring the dead and live loads for now.

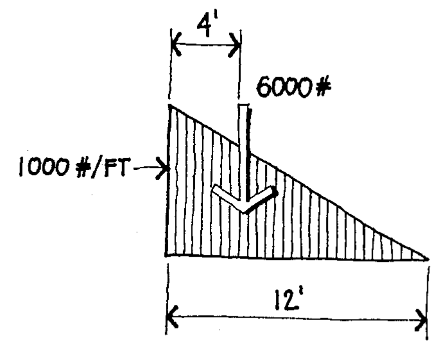


The settlement at 2 causes the beam to bend concave upward, which means that the top of the beam at support 2 is in compression, the bottom is in tension, and there is therefore an internal moment at 2 as shown. From $\Sigma M = 0$, the reaction at 1 must be upward, and from $\Sigma V = 0$, the reaction at 2 must be downward. Similarly, for span 2-3, the reaction at 3 is upward and the reaction at 2 is downward. Combining these reactions with those from dead and live loads, we can see that the settlement at support 2 causes the reactions at 1 and 3 to increase and the reaction at 2 to decrease (correct answer B).

109-C The change in length of a member subject to an axial load is directly proportional to its length and the load and inversely proportional to its cross-sectional area and the modulus of elasticity E. With the load, length, and area constant, the only variable in this problem is E. You should know that E for steel is 29,000,000 psi, and you should also know that E for aluminum is much lower, about 10,000,000 psi. The change of length of the aluminum wire is thus about 2.9 times (29,000,000 ÷ 10,000,000) that of the steel wire, or 0.10 x 2.9 = 0.29 inch (answer C).

110-A Reinforcing bars are limited in length and so it is often necessary to splice them, that is, to transfer the tension or compression from one reinforcing bar to another. Various splicing methods are used. In a *lap splice*, the reinforcing bars are lapped a distance sufficient to transfer the tensile or compressive force from one bar to another bar. The bars may be spaced or in contact. Various *mechanical splices*, called *couplers*, may be used to join two reinforcing bars end-to-end. Lapped or butted *welded splices* are another method of splicing. Of these methods, the lap splice is the most common and generally the most economical (correct answer A), provided it meets all requirements.

111-A On the structural test, you can expect to see a number of problems involving beams of various types (simple, cantilever, overhanging) supporting various loadings. You may be asked to determine the beam reactions, shears, or moments. The best preparation for this kind of problem is to practice solving a number of beams, such as this one. First, what is the resultant of the triangular load?



It is simply the area of the triangle, which is (1000#/ft. ÷ 2) x 12 ft. = 6000#, applied at the centroid of the triangle, which is 12 ft. ÷ 3 = 4 ft. from the left end.

ΣV = 0
+V - 6000# - 5000# = 0
V = 11,000#
ΣM = 0
(6000# x 4 ft.) + (5000# x 12 ft.) - M = 0
M = 24,000 + 60,000 = 84,000 ft.-lbs.
Therefore, choice A is correct.

112-D The load-carrying capacity of a wood column is determined by several factors: the modulus of elasticity E of the wood, which in turn depends on its species and grade; the allowable compressive stress

F_c, which also depends on the species and grade of the wood; the ratio l/d, where l is the unbraced height of the column and d is the least lateral dimension of the column; and the cross-sectional area of the column. Therefore A, B, and C are all correct. D is incorrect and therefore the answer to this question; the load-carrying capacity is not affected by the applied load. But the applied load may not exceed the load-carrying capacity.

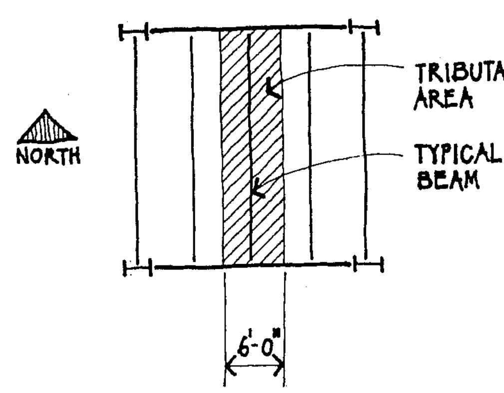
113-B Shear failure of a beam is most likely to occur where the vertical shear is maximum, which is adjacent to the supports (II is correct, I is incorrect). Horizontal shear stress in a beam varies from zero at the outermost fibers to a maximum value at the mid-depth of the beam (III is correct, IV is incorrect). Since only II and III are correct, the answer is B.

114-C A groove weld is placed between two butting plates or members and is usually stressed in direct compression or tension. A complete penetration groove weld is one whose depth is the same as the thickness of the member. The strength of a complete penetration groove weld is considered to be the same as that of the connected material (correct answer C).

115-D The maximum size of coarse aggregate that may be used depends on the size of concrete members and the spacing of reinforcing bars. In general, the maximum size of coarse aggregate should not exceed 1/5 of the narrowest dimension between sides of forms (A) or 3/4 of the clear spacing between reinforcing bars (B). Usually, more water is required for smaller size coarse aggregates than for larger maximum sizes (C). For a given water-cement ratio, then, the amount of cement required increases as the maximum size of coarse aggregate decreases. Therefore, for economy, the maximum size of coarse aggregate should be as large as possible. D is the incorrect statement and therefore the answer to this question.

116-D A frame with diagonal braces (A) is a *braced frame,* not a rigid frame. A frame which supports a building's vertical loads (B) may or may not be a rigid frame. A rigid frame may have fixed bases (C), but it may also have hinged bases. The best, most inclusive answer is D: a *rigid frame* is a frame with rigid joints capable of resisting moment.

117-B Questions involving the concept of *tributary area* sometimes appear on the exam. In this case, the area tributary to each typical north-south beam extends halfway to each adjacent beam, as shown in the sketch below.

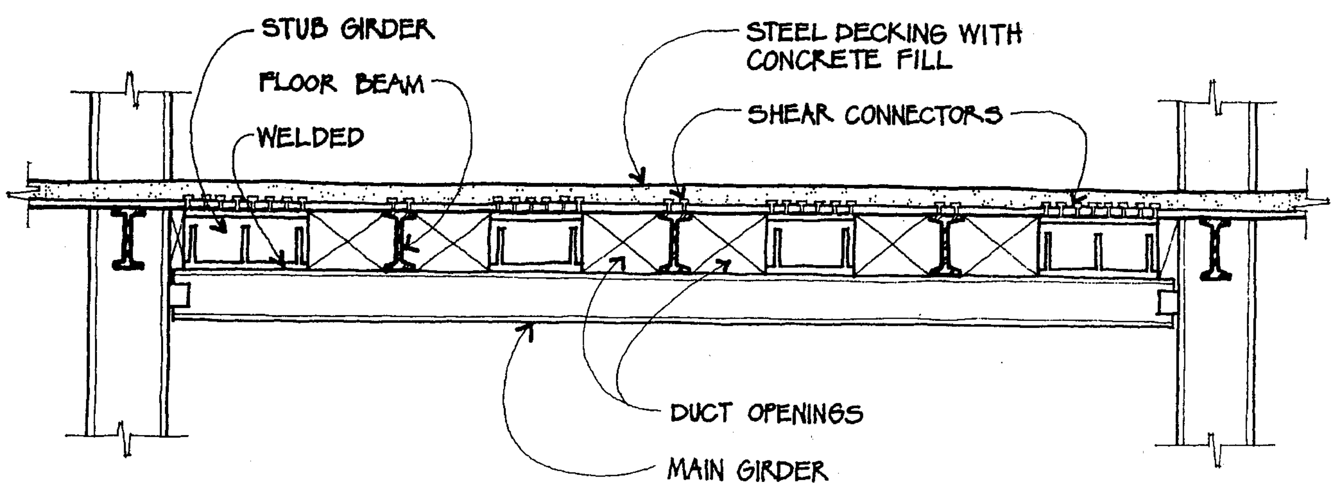


In other words, each north-south beam supports six feet of load. Therefore, the uniform load supported by each north-south beam is 6 ft. x (100 + 70)#/sq.ft. = 1020 lbs. per ft. The maximum moment in a uniformly loaded simple beam is $wL^2/8 = 1020(28)^2/8 = 99{,}960$ ft.-lbs. = 99.96 ft.-kips. B is the correct answer.

118-C The stub girder system consists of main steel girders framed between columns, above which short lengths of stub girders are welded. They are typically about 5 feet long and spaced about 5 feet apart. Shear connectors are welded to the tops of the stub girders to provide composite action with the concrete slab. Transverse to the stub girders are floor beams of the same depth, with shear connectors welded to their top flanges. The concrete slab above the stub girders acts with the main girder to form a sort of Vierendeel truss, in which the main girder is the bottom chord, the slab is the top chord, and the stub girders are the verticals. Note that the concrete floor slab may be either a structural concrete slab or a composite steel deck with concrete fill. C is therefore correct.

119-A One of the primary considerations in hospital design is providing maximum flexibility without interruption of service. In this regard, *interstitial trusses* about eight feet in depth (A) offer unusual layout flexibility by providing a walk-through ceiling space above each column-free hospital floor. This interstitial space is utilized for all mechanical and electrical services, which can be maintained or changed without disrupting normal hospital functions on the floor above or below.

120-C This question tests your ability to use a table from the AISC Manual, which is on page 43 of the *Structures Mock Exam,* to select the most economical column



STUB GIRDER SYSTEM

section. We read down the left column to a length of 16 feet and then read across to the allowable axial load in kips for each column section under the heading 36 (F_y = 36 ksi for ASTM A36 steel). For the W10 x 54, we read 251 kips; for the W10 x 49, we read 228 kips; for the W10 x 45, we read 180 kips; and for the W10 x 39, we read 154 kips. We select the W10 x 49 (choice C), since it is the lightest W10 column with a capacity of at least 200 kips.

121-B In scheme B, simulated continuity is provided by hanging the center beam from the outer beams, thereby reducing the positive moment in the end spans (I). In addition, the effective span of the center beam is reduced from L, the column spacing, to the distance between hinges, resulting in a smaller positive moment in the center span (II). Scheme B results in greater loads in the interior columns and smaller loads in the exterior columns (III is not correct). Since I and II are advantages of scheme B, B is the correct answer.

122-A The traditional method for structural steel design is *Allowable Stress Design* (ASD), in which the actual dead and live loads are unfactored, that is, not increased. The factor of safety is obtained by using allowable stresses which are less than the yield stress. For example, the allowable flexural stress is 0.66 times the yield stress, which results in a factor of safety of 1 ÷ 0.66, or 1.5. Therefore, I is correct. *Load and Resistance Factor Design*, sometimes called *limit states design*, is a newer method of designing steel structures, in which the various loads (dead, live, etc.) are multiplied by their respective load factors. The nominal strength, which is most often the yield strength, is multiplied by a resistance factor Ø, which is generally less than 1. Thus, II is correct. The primary objective of LRFD is to provide more uniform reliability for all steel structures under various loading conditions (III is incorrect). A is therefore the correct answer.

123-C Imperial (inch/pound) units are generally used in the United States, while SI (metric) units are most often used in Canada and many other countries. Although you may work exclusively in Imperial units, the examiners expect you to be able to make simple conversions, as in this question. We convert pounds per square inch (lbf/in^2) to kilopascals (kPa) by multiplying by 6.895. Thus, 20,000 pounds per square inch = 20,000 x 6.895 = 137,900 kilopascals (answer C).

124-B The maximum stress that a steel column can resist without buckling is a function of its *slenderness ratio* Kl/r, where K is a factor which depends on the column end conditions, l is the unbraced length of the column, and r is the *radius of gyration* of the column section, which is equal to $\sqrt{I/A}$. I is the moment of inertia of the column section (choice II) and A is the cross-sectional area of the column section (choice III). Therefore, B is the correct answer.

125-B Since formwork is the most costly element in reinforced concrete construction, it is economical to simplify the formwork by making all the columns the same size and all the beams the same size, if possible, and vary the amount of reinforcement (I is incorrect). It is also economical to use the largest bar size that will meet design requirements in order to reduce placing costs (II is incorrect). III and IV are correct (answer B); ties are less costly than spirals, and straight bars require less fabrication than bent bars and are therefore less expensive.

126-B In this question, the four choices are all well-known Chicago buildings of the late-19th century. Burnham and Root's 16-story *Monadnock Building* (A) was the last of the pure masonry towers, with six-foot-thick walls at its base. Louis Sullivan's *Carson Pirie Scott Store* (C), with its metal frame, broad windows, and unique decoration, was the most modern building of the Chicago School. For the *Marshall Field Warehouse* (D), H. H. Richardson designed exterior masonry piers and arches with interior framing of wood and iron. But it was Jenney's *Home Insurance Building* (correct answer B) that is considered the first iron- and steel-framed skyscraper. Although only 10 stories high, it was the predecessor of all the tall metal-framed buildings which followed.

127-C Since this question relates to a dome, you should immediately rule out the *Parthenon* (D) since it is a Greek structure and doesn't have a dome. The *Pantheon* (A), which has the largest dome of the ancient world, was built by the Romans using centering. *Hagia Sophia* (B) in Constantinople (now Istanbul) is a magnificent domed edifice built with centering. The dome of *Santa Maria del Fiore* in Florence was designed by Brunelleschi with a series of circumferential iron chains to act as tension rings and hold the dome in equilibrium, which permitted the dome to be constructed without the use of any temporary centering, a feat unparalleled in its time (correct answer C).

128-D *Pier Luigi Nervi* designed buildings which expressed their structure in bold and imaginative ways. His work is associated with all four structural concepts listed (correct answer D). He made use of *ferrocement* (I), a material consisting of layers of wire mesh embedded in concrete mortar. The *Palazzeto Dello Sport* has a prefabricated ribbed concrete shell dome (II), and the airplane hangars he built for the Italian Air Force in the 1930s had prefabricated concrete lamella roofs (III). Nervi's *Borgo Paper Plant* utilized a suspension bridge to achieve a span of 830 feet.

129-A Three of the buildings in this question are essentially hollow steel tubes which cantilever from their foundations when subject to lateral wind or earthquake forces. The *World Trade Center* in New York (B) has closely-spaced exterior columns connected by deep spandrels, so that the entire tower becomes an immense hollow cantilever tube. The *Sears Tower* in Chicago (C) consists of nine tubes which end at varying heights. The *John Hancock Building* in Chicago (D) is a gigantic trussed tube. Only the *Water Tower Building* in Chicago (correct answer A) is not a tubular steel building, but rather a very tall reinforced concrete skyscraper.

130-A For the *Dulles Airport* terminal, Eero Saarinen designed a concrete roof supported by steel cables suspended between huge concrete buttresses which lean outward to balance the inward pull of the cables (correct answer A).

131-D The *Pont du Gard*, the *Baths of Caracalla*, and the *Maison Carrée* are all examples of Roman architecture. The *Treasury of Atreus* (correct answer D) is a Greek *tholos* or beehive tomb dating from 1300 B.C.

132-B If the only load acting on a cable is its own weight, the shape which the cable assumes is a *catenary* (correct answer B), which is similar to a parabola. If the loads were uniformly distributed horizontally across the span, the cable would assume the shape of a *parabola* (incorrect answer A). C and D are also incorrect.

133-C A *thin shell* is a structure with a curved surface that supports load by compression, shear, and tension in its own plane (I, II, and III), but which is too thin to resist any bending stresses (IV is incorrect). C is therefore the correct answer. Among the more popular thin shell shapes are the dome, the cylindrical or barrel shell, the vault, and the hyperbolic paraboloid.

134-A The axial load-carrying capacity of a steel column is determined by the strength of the steel used in the column and the tendency of the column to buckle. The buckling tendency is a function of the length of the column (l), its radius of gyration (r), and the relative fixity of its ends (K). In this case, the base plate with two bolts has very little resistance to rotation and can therefore be considered pinned. Since the column is part of a moment-resisting steel frame, its top is more or less fixed against rotation, but it can translate (move horizontally). The correct answer is therefore A.

135-D The section modulus of a beam (S) is equal to the moment of inertia of the beam (I) divided by the distance from the outermost fiber of the beam to the neutral axis (c), or $S = I/c$. Since the maximum bending stress $f = M/S$, the greater the section modulus, the lower the bending stress for a given moment. Therefore, the section modulus is a measure of the beam's bending strength (D is correct).