

Civil Engineering FE CBT Exam

Knowledge: Construction Engineering with 15 Example Problems

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1 Project Administration

Project administration encompasses the managerial, legal, contractual, and organizational frameworks that govern a construction project from inception through final completion and closeout.

1.1 Project Delivery Methods

A project delivery method defines the contractual relationships, risk allocations, and functional roles among three primary project stakeholders: the **Owner**, the **Design Professional (Engineer/Architect)**, and the **Contractor**.

Primary Project Delivery Frameworks

1. Design-Bid-Build (DBB) — Traditional Method:

- *Structure:* Three sequential phases. The Owner executes two separate, independent contracts: one with the Engineer for complete design/specifications, and one with the General Contractor (GC) for construction following competitive bidding.
- *Key Feature:* Conventional DBB normally completes design before construction. Early bid packages or preconstruction advice are possible. The contractor controls means and methods and its subcontractors.
- *Advantages:* Maximum cost transparency, well-established legal precedent, competitive pricing driven by market bidding, clear owner control over design.
- *Disadvantages:* Usually a longer sequential schedule and potential designer–contractor disputes; the owner generally retains design responsibility.

2. Design-Build (DB):

- *Structure:* Single-point responsibility. The Owner executes a single contract with a Design-Build entity (a joint venture, single firm, or contractor-led team) that handles both design and construction.
- *Key Feature:* Enables **fast-tracking** (overlapping design and construction phases, such as beginning site excavation before building interior design is finalized).
- *Advantages:* Single point of accountability, reduced overall project schedule, early contractor constructability input, minimized change orders due to design errors.
- *Disadvantages:* Owner gives up direct control over design details, reduced price transparency prior to contract execution, potential conflict of interest between cost-saving and design quality.

3. Construction Manager at Risk (CMR / CMAR):

- *Structure:* The Owner retains the Engineer for design and separately hires a Construction Manager early in the preconstruction phase. The CM acts as a consultant during design and transitions to the General Contractor during construction.
- *Key Feature:* The CM provides a **Guaranteed Maximum Price (GMP)** to the Owner prior to construction start.
- *Advantages:* Early cost certainty via GMP, constructability reviews during design, fast-tracking potential, transparent open-book accounting.

4. Construction Manager Agency (CMa):

- *Structure:* The CM acts purely as a fee-based advisor to the Owner. The Owner holds individual contracts directly with trade contractors (Multiple Prime Contractors).
- *Key Feature:* The CM Agency assumes *no financial risk* for construction costs or trade performance.

1.2 Contract Procurement & Payment Types

Project procurement dictates how contractors are selected and compensated:

- **Lump Sum (Fixed Price):** The contractor performs the defined work for an agreed price and bears ordinary cost-overrun risk. Contract changes, differing conditions, and other adjustment clauses may shift particular costs.
- **Unit Price:** Compensation is based on fixed price rates for specified units of work (e.g., \$120 per cubic yard of concrete, \$45 per linear foot of trenching). Total cost varies based on actual field-measured quantities. Standard in heavy civil and highway infrastructure projects where exact quantities are uncertain prior to excavation.
- **Cost Plus Fee (Cost Plus Fixed Fee / Percentage):** The owner reimburses the contractor for actual direct project costs plus a fee for overhead and profit. Used when project scope is poorly defined or emergency repairs are required.

1.3 Submittals, Procurement Protocols & Legal Clauses

During preconstruction and construction, precise administrative workflows govern execution:

1. **Submittals:** The Contractor must submit technical documentation to the Engineer for review prior to procurement or fabrication:
 - *Shop Drawings:* Detailed fabrication and assembly diagrams created by fabricators/subcontractors (e.g., structural steel connection details, rebar bending schedules).
 - *Product Data:* Manufacturer specification sheets, installation requirements, and performance parameters.
 - *Mill Certificates:* Certified material test reports confirming chemical and mechanical properties of steel or cement batches.
 - *Samples:* Physical samples of materials (brick, carpet, tile, paint) for aesthetic and quality approval.

Critical Rule: Engineer approval of submittals confirms only **general conformance with design intent**. Submittal review does **not** relieve the contractor of responsibility for accurate dimensions, quantities, or field constructability.
2. **Preconstruction Conference:** Held after contract execution but **prior to issuing the Notice to Proceed (NTP)**. Attendees include the Owner, Engineer, GC, major subcontractors, and utility representatives to establish communication channels, submittal schedules, pay application procedures, and safety protocols.
3. **Substantial Completion vs. Final Completion:**
 - *Substantial Completion:* Work is sufficiently complete for the owner to occupy or use it for its intended purpose. Warranty commencement follows the contract; statutory repose follows governing law. Remaining deficiencies form a punch list.
 - *Final Completion:* All punch-list items are resolved, final lien releases are collected from subcontractors, and final retainage is released.

5. **Indemnification Clause:** A contractual allocation of specified losses and liabilities. Covered parties, negligence limits, and any separate duty to defend depend on the clause and governing law.

6. **Ethics & Bid Rigging:**

- *Collusion / Bid Rigging:* Illegal conspiracy among competing contractors to manipulate bidding processes, artificially inflate prices, or divide market territories.
- *Bid Shopping:* The unethical practice where a general contractor uses the lowest subcontractor bid to pressure other subcontractors into lowering their prices after the main contract is awarded.

2 Construction Operations and Methods

Construction operations encompass physical site activities, federal safety mandates, heavy equipment productivity analysis, crane lifting dynamics, and temporary environmental protection.

2.1 OSHA Worker Safety Regulations & Trench Excavation

The Occupational Safety and Health Administration (OSHA) governs site safety under Code of Federal Regulations (CFR) Title 29, specifically Part 1926 (*Safety and Health Regulations for Construction*).

Key Exam Concept: OSHA Safety Core Metrics for FE Civil

Examinees must memorize key safety thresholds frequently tested on the exam:

- **Trench Protection Threshold:** OSHA mandates protective systems (sloping, benching, shoring, or trench shields) for all excavations **5 feet (1.5 m) or greater in depth**, unless the excavation is made entirely in stable rock.
- **Competent Person Rule:** For excavations less than 5 feet deep, a designated *Competent Person* must inspect the trench. If soil conditions indicate collapse risk, protective systems are required regardless of depth.
- **Excavations Greater Than 20 Feet:** Protective systems require a registered PE design or applicable tabulated data approved by a registered PE.
- **Means of Egress:** A stairway, ladder, ramp, or other safe means of egress is required in trench excavations that are **4 feet (1.22 m) or deeper**. Egress must be located so that no worker travels more than **25 feet (7.6 m) laterally**.
- **Spoil Pile Clearance:** Excavated spoil piles and equipment must be placed at least **2 feet (0.61 m)** from the edge of the excavation.
- **Power Line Clearance:** For covered crane operations, OSHA Table A specifies a 10-ft clearance up to 50 kV; voltage and operation-specific rules govern.
- **Fall Protection:** Six feet is a general Subpart M trigger. Scaffolds, steel erection, and other operations have separate requirements and exceptions.
- **Scaffolding Safety Factor:** Scaffolding components must be capable of supporting, without failure, their own weight and at least **4 times** the maximum intended load (4 : 1 factor of safety).
- **Noise Exposure Limit:** Permissible exposure limit (PEL) is **90 dBA** for an 8-hour time-weighted average (TWA).

2.1.1 OSHA Soil Classification Hierarchy

OSHA categorizes cohesive and granular soils into three primary types to determine allowable benching and sloping configurations:

Table 1: OSHA Soil Classification & Maximum Allowable Slopes

Soil Type	Soil Description & Unconfined Compressive Strength	Max Allowable Slope	Angle
Stable Rock	Solid natural mineral matter that can be excavated with vertical sides.	Vertical (90°)	90°
Type A	Cohesive soil with $q_u \geq 1.5$ tsf, excluding fissured, disturbed, vibrated, or adversely layered soil.	3/4 : 1	53°
Type B	Cohesive soils with $0.5 \text{ tsf} < q_u < 1.5 \text{ tsf}$, or angular gravel, silt, sandy loam, previously disturbed soils.	1 : 1	45°
Type C	Cohesive soils with $q_u \leq 0.5$ tsf, or granular soils (sand, gravel), submerged soil, or seeping water.	1.5 : 1	34°

2.2 Equipment Productivity Analysis

Heavy earthmoving equipment operations (excavators, dump trucks, loaders, scrapers) require balancing production cycles to eliminate bottlenecks and minimize idle time.

2.2.1 Production Cycle Formula Framework

Equipment cycle times consist of fixed times (loading, dumping, turning) and variable times (haul travel, return travel):

$$\text{Cycle Time (CT)} = t_{\text{load}} + t_{\text{haul}} + t_{\text{dump}} + t_{\text{return}} \quad (1)$$

The **Ideal Fleet Productivity** (in bank or loose volume per hour) is governed by the limiting equipment component (either the loader/excavator rate or the truck fleet haul rate).

FE Reference Handbook Formula: Equipment Fleet Production Formulas**1. Loader / Excavator Production Rate (P_{exc}):**

$$P_{exc} = \frac{q_{bucket} \times f_{fill} \times 60 \text{ min/hr}}{CT_{exc} \text{ (min)}} \times E_{job} \quad (2)$$

where q_{bucket} is struck bucket capacity (yd^3), f_{fill} is bucket fill factor, and E_{job} is job efficiency factor (e.g., 50 min/hr efficiency = $50/60 = 0.833$).

2. Number of Excavator Passes to Fill a Truck (N_{passes}):

$$N_{passes} = \text{Integer Ceiling} \left(\frac{Q_{truck \text{ capacity}}}{q_{bucket} \times f_{fill}} \right) \quad (3)$$

3. Single Truck Cycle Time (CT_{truck}):

$$CT_{truck} = (N_{passes} \times CT_{exc}) + t_{haul} + t_{dump} + t_{return} \quad (4)$$

4. Balanced Fleet Size (N_{trucks}): To keep the excavator continuously loading without waiting:

$$N_{trucks} = \frac{CT_{truck}}{\text{Time to Load One Truck}} = \frac{CT_{truck}}{N_{passes} \times CT_{exc}} \quad (5)$$

Rule: If N_{trucks} is rounded down to an integer, the excavator will experience idle wait time. If rounded up, trucks will queue up waiting to be loaded.

2.3 Rigging Mechanics & Crane Equilibrium

Crane safety analysis relies on static equilibrium calculations ($\sum F_y = 0$, $\sum M = 0$) taken about the crane's **fulcrum point** (the centerline of the front outrigger or track pivot).

Crane Fulcrum Moment Equilibrium

For a crane carrying a lifted load P_L at radius d_L with boom weight W_B acting at centroid distance d_B :

$$\sum M_{fulcrum} = 0 \implies (W_{counterweight} \times d_{CW}) + (W_{machine} \times d_M) = (P_L \times d_L) + (W_B \times d_B) \quad (6)$$

Tipping Load: The ideal static limit occurs when rear support reaction becomes zero. Rated working loads must follow the manufacturer's load chart for the actual configuration; 75%/85% tipping fractions are not universal field limits.

2.4 Erosion and Sedimentation Control (ESC)

Construction sequencing must incorporate Best Management Practices (BMPs) to prevent surface soil erosion and off-site sediment transport into water bodies:

- **Silt Fence:** Temporary sediment barrier constructed of synthetic filter fabric anchored into a trench (6 in. minimum depth). Used for sheet flow conditions; prohibited across concentrated

across small swales or channels to reduce velocity and promote sediment deposition.

- **Sediment Basin / Trap:** Temporary impoundment pond designed to retain runoff and allow suspended soil particles to settle out.
- **Mulching & Vegetation:** Application of straw, wood chips, or hydroseeding to protect exposed soil surfaces from raindrop impact erosion.
- **Concrete Washout Station:** Enclosed, impermeable basin designed to collect slurry waste from concrete truck chutes, preventing high-pH alkaline runoff from infiltrating soil or storm sewers.

3 Project Controls and Scheduling

Project controls integrate activity sequencing, duration modeling, float determination, and financial variance monitoring via Earned Value Analysis.

3.1 Precedence Diagramming Method (PDM) & Relationships

Scheduling represents activities as nodes (Activity-on-Node, AON) connected by logical precedence arrows.

3.1.1 Precedence Relationship Types

- **Finish-to-Start (FS):** The standard relationship. Activity B cannot start until Activity A finishes ($ES_B \geq EF_A + \text{Lag}$).
- **Start-to-Start (SS):** Activity B cannot start until Activity A starts ($ES_B \geq ES_A + \text{Lag}$).
- **Finish-to-Finish (FF):** Activity B cannot finish until Activity A finishes ($EF_B \geq EF_A + \text{Lag}$).
- **Start-to-Finish (SF):** Activity B cannot finish until Activity A starts (rare).

Activity-on-Node (AON) Box Annotation Standard

In the NCEES FE Reference Handbook, an AON node box is formatted as follows:

Early Start (ES)	Duration (D)	Early Finish (EF)
Activity Description / Identification		
Late Start (LS)	Float (TF)	Late Finish (LF)

3.2 Critical Path Method (CPM) Algorithms

The Critical Path Method determines the overall project duration and float values through two sequential calculation passes:

3.2.1 Forward Pass (Calculates ES and EF)

Moving left-to-right from project start (Day 0 or Day 1 convention; NCEES uses 0-start convention):

1. For initial activities: $ES = 0$.
2. Activity Early Finish: $EF = ES + \text{Duration}$.
3. For successor activities with multiple predecessors:

$$ES_{\text{successor}} = \max(EF_{\text{predecessor 1}}, EF_{\text{predecessor 2}}, \dots) \quad (7)$$

3.2.2 Backward Pass (Calculates LF and LS)

Moving right-to-left from project completion:

1. For terminal activities: $LF = \text{Project Total Duration}$.
2. Activity Late Start: $LS = LF - \text{Duration}$.
3. For predecessor activities with multiple successors:

$$LF_{\text{predecessor}} = \min(LS_{\text{successor 1}}, LS_{\text{successor 2}}, \dots) \quad (8)$$

3.2.3 Float Calculations

Float represents schedule flexibility:

FE Reference Handbook Formula: Float Formulas (FE Reference Handbook)

Total Float (TF): The total time an activity can be delayed without delaying the *overall project completion date*.

$$TF = LS - ES = LF - EF \quad (9)$$

Free Float (FF): The time an activity can be delayed without delaying the *Early Start of any immediate successor activity*.

$$FF = \min(ES_{\text{successors}}) - EF \quad (10)$$

Critical Path: The longest dependent activity path determines the minimum duration in unconstrained CPM. Its activities have zero total float; imposed dates and constraints can change this interpretation.

3.3 PERT Probabilistic Scheduling

Program Evaluation and Review Technique (PERT) accounts for schedule uncertainty by modeling activity durations as beta probability distributions defined by three estimates:

- a = Optimistic duration.
- m = Most likely duration (mode of the distribution).
- b = Pessimistic duration.

These estimates do not have universal 1st/99th percentile meanings. State any percentile convention used; the variance relation below is an approximation.

Expected Activity Mean Duration (μ_{ij}):

$$\mu_{ij} = \frac{a_{ij} + 4m_{ij} + b_{ij}}{6} \quad (11)$$

Activity Variance (σ_{ij}^2) & Standard Deviation (σ_{ij}):

$$\sigma_{ij} = \frac{b_{ij} - a_{ij}}{6} \Rightarrow \sigma_{ij}^2 = \left(\frac{b_{ij} - a_{ij}}{6} \right)^2 \quad (12)$$

Project Mean and Variance: Sum along the chosen critical path. Adding variances assumes independent activity durations and a fixed path.

$$\mu_{\text{project}} = \sum_{(i,j) \in \text{CP}} \mu_{ij}, \quad \sigma_{\text{project}}^2 = \sum_{(i,j) \in \text{CP}} \sigma_{ij}^2 \Rightarrow \sigma_{\text{project}} = \sqrt{\sigma_{\text{project}}^2} \quad (13)$$

Probability of Meeting Target Schedule (T_d): Using standard normal distribution Z-score:

$$Z = \frac{T_d - \mu_{\text{project}}}{\sigma_{\text{project}}}$$

3.4 Earned Value Analysis (EVA)

Earned value combines scope, schedule, and cost. Completion fractions in the table are measured for each task and weighted by its budget; $EV = \sum_i BAC_i c_i$.

Table 2: Earned Value Analysis Core Variables & Definitions

Metric	FE Handbook Nomenclature & Description	Calculation Formula
BCWS	Budgeted Cost of Work Scheduled (Planned Value, PV): Budgeted dollar amount for work scheduled to be completed by the status date.	$\sum(\text{Planned \% Complete} \times \text{BAC})$
ACWP	Actual Cost of Work Performed (Actual Cost, AC): Total direct and indirect costs incurred for work completed by status date.	Recorded Financial Expenditures
BCWP	Budgeted Cost of Work Performed (Earned Value, EV): Budgeted value of work actually completed by status date.	$\sum(\text{Actual \% Complete} \times \text{BAC})$
BAC	Budget at Completion: Total original budgeted cost for the entire project.	Baseline Total Budget

FE Reference Handbook Formula: Earned Value Performance Metrics & Forecasting

1. Cost Variance (CV):

$$CV = BCWP - ACWP \quad \begin{cases} CV > 0 & \text{Under Budget (Favorable)} \\ CV < 0 & \text{Over Budget (Unfavorable)} \end{cases} \quad (15)$$

2. Schedule Variance (SV):

$$SV = BCWP - BCWS \quad \begin{cases} SV > 0 & \text{Ahead of Schedule (Favorable)} \\ SV < 0 & \text{Behind Schedule (Unfavorable)} \end{cases} \quad (16)$$

3. Cost Performance Index (CPI): Efficiency measure of budget utilization:

$$CPI = \frac{BCWP}{ACWP} \quad \begin{cases} CPI > 1.0 & \text{Under Budget Efficiency} \\ CPI < 1.0 & \text{Over Budget Efficiency} \end{cases} \quad (17)$$

4. Schedule Performance Index (SPI): Efficiency measure of schedule progress:

$$SPI = \frac{BCWP}{BCWS} \quad \begin{cases} SPI > 1.0 & \text{Ahead of Schedule Efficiency} \\ SPI < 1.0 & \text{Behind Schedule Efficiency} \end{cases} \quad (18)$$

5. Forecasting Metrics (Estimate to Complete & Estimate at Completion):

$$ETC \text{ (Estimate to Complete)} = \frac{BAC - BCWP}{CPI} \quad (19)$$

$$EAC \text{ (Estimate at Completion)} = ACWP + ETC = \frac{BAC}{CPI} \quad (20)$$

4 Construction Estimating

Construction estimating requires quantifying physical materials, computing earthwork cut/fill balances, and evaluating burdened labor productivity.

4.1 Concrete & Reinforcing Steel Takeoffs

Concrete volume is computed from geometric dimensions and converted from cubic feet to cubic yards ($27 \text{ ft}^3 = 1 \text{ yd}^3$).

FE Reference Handbook Formula: ASTM Standard Reinforcing Steel Bar Properties (FE Handbook)

For No. 3 through No. 8 bars, $d = (\text{bar number})/8$ inches. Larger bars use the tabulated nominal diameters below.

Bar Size Designation	Nominal Diameter (in.)	Area (in ²)	Weight (lb/ft)
#3	0.375	0.11	0.376
#4	0.500	0.20	0.668
#5	0.625	0.31	1.043
#6	0.750	0.44	1.502
#7	0.875	0.60	2.044
#8	1.000	0.79	2.670
#9	1.128	1.00	3.400
#10	1.270	1.27	4.303
#11	1.410	1.56	5.313
#14	1.693	2.25	7.650
#18	2.257	4.00	13.600

4.2 Structural Steel Section Takeoffs

Structural steel W-shapes are designated as **W**Depth $\times$ Weight per Foot (e.g., a W18 $\times$ 35 beam has an approximate depth of 18 inches and weighs 35 lb/ft).

- **Total Steel Weight (lb):** $\sum (\text{Length in ft} \times \text{Weight per foot in lb/ft} \times \text{Quantity})$.
- **Conversion to Tons:** $\text{Tons} = \frac{\text{Total Weight (lb)}}{2000 \text{ lb/ton}}$.
- **Drawing Notation "do.":** Stands for *ditto* (repeat the identical member size designated above/-below).

4.3 Earthwork Volume Formulas

In linear transportation and site grading projects, soil volumes between cross-sectional stations are computed using end-area techniques:

FE Reference Handbook Formula: Earthwork Formulas (FE Reference Handbook)

1. Average End Area Formula (V_{AEA}): Computes volume between two parallel cross-sectional areas A_1 and A_2 separated by distance L :

$$V(\text{ft}^3) = L \left(\frac{A_1 + A_2}{2} \right) \Rightarrow V(\text{yd}^3) = \frac{L}{27} \left(\frac{A_1 + A_2}{2} \right) = \frac{L(A_1 + A_2)}{54} \quad (21)$$

2. Prismoidal Formula ($V_{\text{prismoidal}}$): Provides greater mathematical accuracy when cross-sectional areas change rapidly:

$$V(\text{ft}^3) = \frac{L(A_1 + 4A_m + A_2)}{6} \quad (22)$$

where A_m is the actual area of the mid-section at distance $L/2$ (computed from averaged linear dimensions, *not* by averaging A_1 and A_2).

3. Area by Coordinates Formula: For a closed polygonal area with vertices $(X_A, Y_A), (X_B, Y_B), \dots, (X_N, Y_N)$:

$$\text{Area} = \frac{1}{2} |[X_A(Y_B - Y_N) + X_B(Y_C - Y_A) + X_C(Y_D - Y_B) + \dots + X_N(Y_A - Y_{N-1})]| \quad (23)$$

4. Trapezoidal Rule for Area: For cross-sections defined by vertical offsets $h_1, h_2, \dots, h_n$ spaced at constant width interval w :

$$\text{Area} = w \left(\frac{h_1 + h_n}{2} + h_2 + h_3 + \dots + h_{n-1} \right) \quad (24)$$

4.3.1 Mass Haul Diagrams

A **Mass Haul Diagram** plots cumulative earthwork volume (y-axis in cubic yards) versus stationing (x-axis along project alignment).

- **Cumulative Ordinate:** Cut volume is added (+), and Fill volume is subtracted (-).
- **Balance Line:** Any horizontal line intersecting the mass haul curve defines balance points where cut volume equals fill volume.
- **Loop Direction:** A loop above the balance line (rising then falling) indicates haul direction is **forward** (from left to right). A loop below the balance line indicates haul direction is **backward** (from right to left).
- **Shrinkage & Swell:** Earthwork calculations adjust fill volumes to account for soil compaction ($\text{Adjusted Fill} = \frac{\text{Bank Fill}}{1 - \text{Shrinkage Factor}}$).

4.4 Labor Costs & Burden Multipliers

Labor costs combine base wage rates, productivity rates, crew compositions, and labor burden:

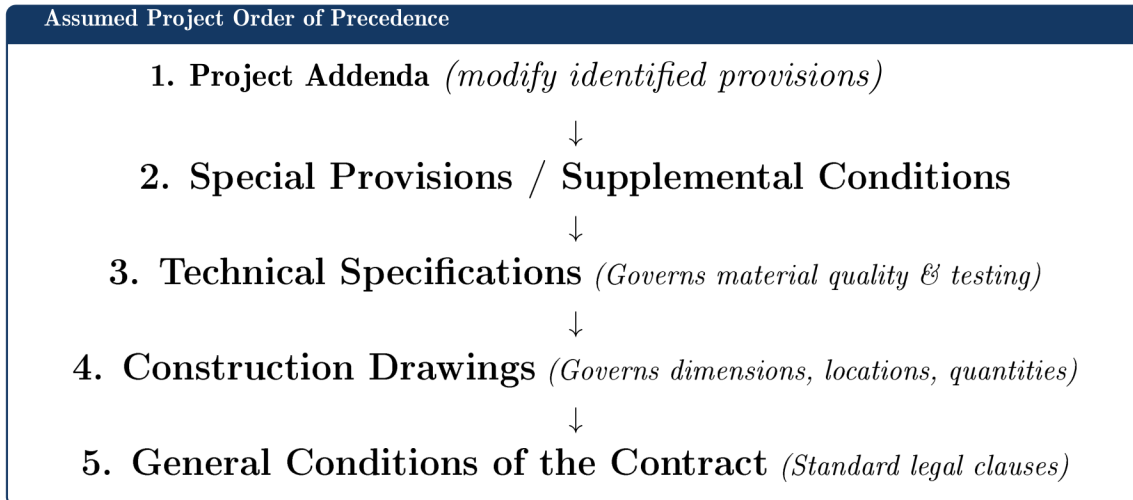
- **Productivity Rate:** Expressed as man-hours per unit of work (e.g., 9 man-hours/ton of rebar).
- **Labor Burden:** Payroll taxes, worker's compensation, health insurance, and fringe benefits expressed as a percentage of base wage (e.g., 60% burden multiplier = 1.60 Base Wage).

5 Interpretation of Engineering Drawings

Engineering drawings communicate structural, architectural, and civil specifications required for field construction.

5.1 Document Precedence & Discrepancies

Contract documents govern the order of precedence. The hierarchy below is an assumed project convention, not a universal legal rule.



Assumed Project Rules:

- **Addenda** supersede the provisions they expressly modify; the contract governs conflicts.
- **Written Specifications** override visual Construction Drawings regarding material quality and acceptance criteria.
- **Large-scale detail drawings** override small-scale general plan drawings.
- **Explicit dimensions** written in text override scaled measurement on paper drawings.

5.2 Design Change Authority & Professional Ethics

The legal authority to make design modifications to signed and sealed construction documents is strictly regulated:

- **Seal Integrity:** Only a licensed **Professional Engineer (PE)** who possesses responsible charge over the design has the legal authority to revise, sign, and seal modifications to approved engineering drawings.
- **Contractor Limitations:** The Contractor cannot unilaterally modify structural designs, change rebar spacing, or alter load-bearing steel without formal approval via a signed Engineering Change Order (ECO) or Addendum issued by the Engineer of Record.

6 Example Problems and Solutions

This section contains 15 exam-realistic practice problems covering all five NCEES Construction Engineering subtopics, formatted in standard multiple-choice, multiple-select, and fill-in numerical entry formats.

Problem 1: Project Delivery Methods (Multiple Select)

Category: Project Administration

Various statements regarding project delivery frameworks are provided below. Select ALL statements that clearly represent advantages of the **Design-Build (DB)** delivery method over the traditional **Design-Bid-Build (DBB)** approach:

- A. Construction can begin before the total final design is 100% complete (fast-tracking).
- B. The Owner maintains complete direct control over the design details and specifications throughout.
- C. Single-point accountability reduces the owner's exposure to designer-contractor coordination disputes.
- D. Guarantees the lowest competitive market price through public open bidding.
- E. Early contractor constructability input can be integrated during the initial design phase.

Solution

Correct Answers: A, C, and E**Detailed Explanation:**

- A. CORRECT.** Fast-tracking (overlapping design and construction phases) is a primary advantage of Design-Build, allowing early site work/excavation to proceed while interior designs are finished.
- B. INCORRECT.** In DB, the Owner gives up direct control over design details to the DB entity. Direct design control is a characteristic of DBB.
- C. CORRECT.** The owner has one design-build contracting entity. This reduces divided accountability and coordination disputes; disagreements within the design-build team can still occur.
- D. INCORRECT.** DBB provides the maximum competitive price transparency via open bidding on completed plans. DB contracts are often negotiated based on qualifications and best value.
- E. CORRECT.** Because the contractor and designer are part of the same DB team from day one, constructability reviews occur continuously during design.

Problem 2: Indemnification Contract Clauses**Category: Project Administration**

A design contract indemnifies the owner for losses caused by the engineer's negligent professional services. Which risk does this provision cover?

- A. Financial damages and legal claims arising directly from negligent engineering design acts or omissions.
- B. Construction cost inflation caused by general economic market changes.
- C. Contractor insolvency or bankruptcy during foundation excavation.
- D. Injury claims caused exclusively by improper construction means and methods selected by the Contractor.

Solution**Correct Answer: A**

Detailed Explanation: Indemnification allocates specified liabilities, commonly those arising from negligent professional services. A separate defense obligation depends on the clause and applicable law. With a negligence-based design indemnity, A is the intended choice; the listed market and contractor risks are outside that stated scope.

Problem 3: Submittal Review Scope**Category: Project Administration**

A structural engineering consultant reviews shop drawings submitted by a steel fabricator for pre-engineered roof trusses. The engineer stamps the submittal as "Approved for General Conformance with Design Intent." Three weeks later during erection, a connection fails because the fabricator supplied 50 fewer bolts than required by the drawing details. Which party holds primary contractual responsibility for the dimensional and quantity error?

- A. The Structural Engineering Consultant, because their approval stamp legally absolved the fabricator.
- B. The Steel Fabricator and General Contractor, because submittal approval does not relieve them of responsibility for accurate quantities and fabrication details.
- C. The Project Owner, because they executed the contract with the fabricator.
- D. The Local Building Code Inspector who issued the initial building permit.

Solution**Correct Answer: B**

Detailed Explanation: General-conformance review does not transfer the contractor's primary duty to verify quantities, dimensions, and fabrication details. Thus B identifies the primary responsibility for the incorrect takeoff. It does not immunize an engineer from liability for a negligent review of matters within the engineer's actual contractual or professional duties.

Problem 4: OSHA Trench Protection Safety**Category: Construction Operations & Methods**

OSHA regulations require engineered trench protective systems (sloping, benching, shoring, or trench shields) to protect workers in excavations:

- A. For all trenches exceeding 10 feet in length, regardless of depth.
- B. For trenches 5 feet (1.5 m) deep or greater, unless the excavation is made entirely in stable rock.
- C. Only when excavation work inside the trench will exceed an 8-hour work shift.
- D. Only when trenches exceed 8 feet in depth and groundwater is actively seeping.

Solution**Correct Answer: B**

Detailed Explanation: Per OSHA 29 CFR 1926.652, protective systems are mandatory in excavations **5 feet deep or greater**, unless the trench is excavated entirely in solid, stable rock. (Note: For trenches less than 5 feet deep, protective systems are still required if a competent person identifies collapse hazards).

Problem 5: Excavator & Dump Truck Productivity**Category: Construction Operations & Methods**

An excavator equipped with a 1.5 yd^3 bucket loads soil into dump trucks at an average rate of $2.2 \text{ yd}^3/\text{min}$. The soil is hauled to a spoil site by a fleet of dump trucks, each having a struck capacity of 12 yd^3 . The round-trip travel time for a truck (haul, dump at spoil site, and return) takes exactly 15 minutes, excluding loading time.

Assuming an ideal job efficiency of 60 min/hr, the maximum idealized productivity of this system using **three** dump trucks, in yd^3/hr , is most nearly:

- A. $102 \text{ yd}^3/\text{hr}$
- B. $105.6 \text{ yd}^3/\text{hr}$
- C. $118 \text{ yd}^3/\text{hr}$
- D. $132 \text{ yd}^3/\text{hr}$

Solution**Correct Answer: B**

Step 1: Calculate the time required by the excavator to load one truck. Truck capacity = 12 yd^3 . Excavator loading rate = $2.2 \text{ yd}^3/\text{min}$.

$$t_{\text{load}} = \frac{12 \text{ yd}^3}{2.2 \text{ yd}^3/\text{min}} = 5.4545 \text{ minutes} \quad (25)$$

Step 2: Calculate the total cycle time for a single dump truck.

$$CT_{\text{truck}} = t_{\text{load}} + t_{\text{haul/dump/return}} = 5.4545 \text{ min} + 15.0 \text{ min} = 20.4545 \text{ minutes} \quad (26)$$

Step 3: Determine system bottleneck (Excavator vs. Truck Fleet Capacity). With 3 trucks operating, the time between truck arrivals at the excavator is:

$$t_{\text{arrival interval}} = \frac{CT_{\text{truck}}}{N_{\text{trucks}}} = \frac{20.4545 \text{ min}}{3} = 6.818 \text{ minutes} \quad (27)$$

Since the truck arrival interval (6.818 min) is **greater** than the excavator loading time (5.4545 min), the truck fleet is the bottleneck. The excavator will spend time idle waiting for trucks to return.

Step 4: Calculate system productivity based on 3 trucks. In one truck cycle (20.4545 min), 3 trucks each deliver 12 yd^3 , yielding a total delivered volume of 36 yd^3 :

$$\text{Productivity} = (36 \text{ yd}^3 / 20.4545 \text{ min})(60 \text{ min/hr}) = 105.6 \text{ yd}^3/\text{hr}.$$

Correct Answer: B

No integer-cycle rounding is applied because the stated loading and travel times define a continuous cycle.

Problem 6: Crane Fulcrum Equilibrium & Tipping Load**Category: Construction Operations & Methods**

A crane body and counterweight, **excluding the boom**, weigh $W_m = 60,000$ lb with their center 8 ft behind the front fulcrum. The boom weighs $W_b = 8,000$ lb, centered 15 ft ahead. The load radius is 35 ft. Ignoring dynamics, find the ideal tipping load P (including hook block), not the rated working load.

- A. 10,286 lb
- B. 13,714 lb
- C. 15,428 lb
- D. 18,200 lb

Solution**Correct Answer: A**

Step 1: Set up the moment equilibrium equation about the front fulcrum point. At the point of impending tipping, the rear outrigger reaction drops to zero ($R_{\text{rear}} = 0$).

Counterclockwise Resisting Moments (M_R) must equal Clockwise Overturning Moments (M_O):

$$\sum M_{\text{fulcrum}} = 0 \implies M_R = M_O \quad (29)$$

Step 2: Calculate Resisting Moment (M_R).

$$M_R = W_m \times d_m = 60,000 \text{ lb} \times 8 \text{ ft} = 480,000 \text{ ft-lb} \quad (30)$$

Step 3: Calculate Overturning Moment (M_O).

$$M_O = (W_b \times d_b) + (P_{\text{load}} \times d_L) \quad (31)$$

$$M_O = (8,000 \text{ lb} \times 15 \text{ ft}) + (P_{\text{load}} \times 35 \text{ ft}) = 120,000 + 35P_{\text{load}} \quad (32)$$

Step 4: Solve for Tipping Load P_{load} .

$$480,000 = 120,000 + 35P_{\text{load}} \implies 360,000 = 35P_{\text{load}} \quad (33)$$

$$P_{\text{load}} = \frac{360,000}{35} = 10,285.7 \text{ lb} \approx 10,286 \text{ lb} \quad (34)$$

Problem 7: Activity-on-Node Critical Path & Float**Category: Project Controls & Scheduling**

An Activity-on-Node (AON) project precedence network contains the following tasks with durations given in days:

Activity	Duration (Days)	Immediate Predecessors
A	6	None
B	4	A
C	3	A
D	5	B
E	2	C
F	7	C
G	4	D, E
H	2	G, F

The total duration of the **Critical Path** (in days) and the **Total Float** of Activity F are:

- A. Critical Path = 21 days; Total Float of F = 3 days
- B. Critical Path = 21 days; Total Float of F = 0 days
- C. Critical Path = 18 days; Total Float of F = 4 days
- D. Critical Path = 26 days; Total Float of F = 2 days

Solution

Correct Answer: A

Step 1: Perform Forward Pass (Calculate ES and EF for all nodes).

- **Activity A:** $ES = 0, EF = 0 + 6 = 6$.
- **Activity B:** Predecessor A $\implies ES = 6, EF = 6 + 4 = 10$.
- **Activity C:** Predecessor A $\implies ES = 6, EF = 6 + 3 = 9$.
- **Activity D:** Predecessor B $\implies ES = 10, EF = 10 + 5 = 15$.
- **Activity E:** Predecessor C $\implies ES = 9, EF = 9 + 2 = 11$.
- **Activity F:** Predecessor C $\implies ES = 9, EF = 9 + 7 = 16$.
- **Activity G:** Predecessors D ($EF = 15$) and E ($EF = 11$). $ES = \max(15, 11) = 15$. $EF = 15 + 4 = 19$.
- **Activity H:** Predecessors G ($EF = 19$) and F ($EF = 16$). $ES = \max(19, 16) = 19$. $EF = 19 + 2 = 21$.

Total Project Duration = 21 Days.

Step 2: Perform Backward Pass (Calculate LF and LS for Activity F).

- **Activity H:** $LF = 21, LS = 21 - 2 = 19$.
- **Activity F:** Successor is H ($LS = 19$). Thus $LF_F = 19$.
- $LS_F = LF_F - \text{Duration}_F = 19 - 7 = 12$.

Step 3: Calculate Total Float for Activity F.

$$TF_F = LS_F - ES_F = 12 - 9 = 3 \text{ Days} \quad (\text{or } LF_F - EF_F = 19 - 16 = 3 \text{ Days}) \quad (35)$$

The critical path follows $A \rightarrow B \rightarrow D \rightarrow G \rightarrow H$ ($6 + 4 + 5 + 4 + 2 = 21$ days, all $TF = 0$).

Problem 8: PERT Probabilistic Duration & Project Variance**Category: Project Controls & Scheduling**

A critical path activity has the following time estimates:

- Optimistic duration (a) = 8 days
- Most likely duration (m) = 12 days
- Pessimistic duration (b) = 22 days

Using the PERT beta distribution model, the **mean duration** (μ) and **variance** (σ^2) for this activity are most nearly:

- A. Mean = 13.0 days; Variance = 5.44 days²
- B. Mean = 14.0 days; Variance = 2.33 days²
- C. Mean = 13.0 days; Variance = 2.33 days²
- D. Mean = 12.0 days; Variance = 5.44 days²

Solution

Correct Answer: A

Step 1: Calculate Mean Duration (μ). Using the FE Reference Handbook PERT equation:

$$\mu = \frac{a + 4m + b}{6} = \frac{8 + 4(12) + 22}{6} = \frac{8 + 48 + 22}{6} = \frac{78}{6} = 13.0 \text{ days} \quad (36)$$

Step 2: Calculate Standard Deviation (σ) and Variance (σ^2).

$$\sigma = \frac{b - a}{6} = \frac{22 - 8}{6} = \frac{14}{6} = 2.3333 \text{ days} \quad (37)$$

$$\sigma^2 = (\sigma)^2 = (2.3333)^2 = 5.444 \text{ days}^2 \quad (38)$$

Problem 9: Earned Value Performance Tracking**Category: Project Controls & Scheduling**

A land development project has an original total budget (BAC) of \$150,000. At the end of Week 6, a project controls audit reveals the following status:

- Budgeted Cost of Work Scheduled (BCWS) = \$90,000
- Actual Cost of Work Performed (ACWP) = \$100,500
- Actual completion: 75% of the total budgeted work value.

The **Cost Performance Index (CPI)**, **Schedule Performance Index (SPI)**, and current status are:

- A. CPI = 1.12, SPI = 1.25; Under budget and ahead of schedule.
- B. CPI = 0.895, SPI = 0.895; Over budget and behind schedule.
- C. CPI = 1.12, SPI = 1.25; Over budget and behind schedule.
- D. CPI = 0.895, SPI = 1.12; Over budget and ahead of schedule.

Solution

Correct Answer: A

Step 1: Calculate Budgeted Cost of Work Performed (BCWP / Earned Value).

$$\text{BCWP} = \text{Actual \% Complete} \times \text{BAC} = 0.75 \times \$150,000 = \$112,500 \quad (39)$$

Step 2: Calculate Cost Performance Index (CPI).

$$\text{CPI} = \frac{\text{BCWP}}{\text{ACWP}} = \frac{\$112,500}{\$100,500} = 1.1194 \approx 1.12 \quad (40)$$

Since $\text{CPI} > 1.0$, the project is **under budget** (earning \$1.12 of work per \$1.00 spent).

Step 3: Calculate Schedule Performance Index (SPI).

$$\text{SPI} = \frac{\text{BCWP}}{\text{BCWS}} = \frac{\$112,500}{\$90,000} = 1.250 \quad (41)$$

Since $\text{SPI} > 1.0$, the project is **ahead of schedule**.

Problem 10: Foundation Concrete Takeoff**Category: Construction Estimating**

A rectangular building foundation features the following structural elements:

- Continuous wall footing: 2.0 ft wide $\times$ 1.0 ft thick, centered beneath the foundation wall.
- Foundation wall: outer dimensions 40 ft $\times$ 30 ft; 1.0 ft thick $\times$ 4.0 ft high.
- Interior floor slab: 4.0 inches thick slab on grade placed inside the perimeter walls.
- Interior spread footings: 3 isolated square footings, each 4.0 ft $\times$ 4.0 ft $\times$ 1.0 ft thick.

Ignoring rebar displacement and waste, the total required concrete volume, in **cubic yards**, is most nearly:

- A. 38.2 yd³
- B. 45.1 yd³
- C. 52.8 yd³
- D. 61.4 yd³

Solution

Correct Answer: B

Step 1: Calculate centerline perimeter (P_{cl}) of the continuous foundation wall.

Outer foundation-wall dimensions = 40 ft $\times$ 30 ft. Wall thickness = 1.0 ft. Centerline length = (40 - 1.0) = 39 ft long side, (30 - 1.0) = 29 ft short side.

$$P_{cl} = 2(39 \text{ ft}) + 2(29 \text{ ft}) = 78 + 58 = 136 \text{ linear feet} \quad (42)$$

Step 2: Concrete volume of continuous wall footing.

$$V_{\text{footing}} = P_{cl} \times \text{width} \times \text{thickness} = 136 \text{ ft} \times 2.0 \text{ ft} \times 1.0 \text{ ft} = 272.0 \text{ ft}^3 \quad (43)$$

Step 3: Concrete volume of foundation wall.

$$V_{\text{wall}} = P_{cl} \times \text{thickness} \times \text{height} = 136 \text{ ft} \times 1.0 \text{ ft} \times 4.0 \text{ ft} = 544.0 \text{ ft}^3 \quad (44)$$

Step 4: Concrete volume of interior slab on grade. Clear interior slab area = (40 - 2.0) $\times$ (30 - 2.0) = 38 ft $\times$ 28 ft = 1,064 ft². Slab thickness = 4 in. = 4/12 = 0.3333 ft.

$$V_{\text{slab}} = 1,064 \text{ ft}^2 \times 0.3333 \text{ ft} = 354.67 \text{ ft}^3 \quad (45)$$

Step 5: Concrete volume of 3 isolated spread footings.

$$V_{\text{spread}} = 3 \times (4.0 \text{ ft} \times 4.0 \text{ ft} \times 1.0 \text{ ft}) = 3 \times 16.0 = 48.0 \text{ ft}^3 \quad (46)$$

Step 6: Sum total volume and convert to cubic yards.

$$V_{\text{total,ft}^3} = 272.0 + 544.0 + 354.67 + 48.0 = 1,218.67 \text{ ft}^3$$

$$V_{\text{total,yd}^3} = 1,218.67 / 27 = 45.14 \text{ yd}^3 \quad 45.1 \text{ yd}^3$$

Correct Answer: B

Problem 11: Structural Steel Weight Takeoff**Category: Construction Estimating**

A structural steel floor framing plan contains the following member schedule:

- 2 Girders: W18 × 35, each 18 ft long.
- 1 Girder: W21 × 44, 18 ft long.
- 8 Beams: W16 × 36, each 25 ft long (designated with "do." on structural plan).

The total weight of steel required for these girders and beams, in **tons**, is most nearly:

- A. 4.6 tons
- B. 5.4 tons
- C. 9.2 tons
- D. 10.8 tons

Solution

Correct Answer: A

Step 1: Compute total weight for each member type.

- W18 × 35 (35 lb/ft): Weight = 2 members × 18 ft × 35 lb/ft = 1,260 lb.
- W21 × 44 (44 lb/ft): Weight = 1 member × 18 ft × 44 lb/ft = 792 lb.
- W16 × 36 (36 lb/ft): Weight = 8 members × 25 ft × 36 lb/ft = 7,200 lb.

Step 2: Sum total weight in pounds.

$$\text{Total Weight} = 1,260 \text{ lb} + 792 \text{ lb} + 7,200 \text{ lb} = 9,252 \text{ lb} \quad (49)$$

Step 3: Convert weight to tons (2,000 lb/ton).

$$\text{Weight in Tons} = \frac{9,252 \text{ lb}}{2,000 \text{ lb/ton}} = 4.626 \text{ tons} \approx 4.6 \text{ tons} \quad (50)$$

Problem 12: Earthwork Average End Area Fill Volume**Category: Construction Estimating**

Cross-sectional fill areas for a 1,000-foot highway alignment segment are measured at three stations:

- Station 10 + 00: Fill Area = 120 ft²
- Station 14 + 00: Fill Area = 180 ft²
- Station 20 + 00: Fill Area = 240 ft²

Using the Average End Area method, the total required fill volume between Station 10 + 00 and Station 20 + 00, in **cubic yards**, is most nearly:

- A. 4,444 yd³
- B. 6,889 yd³
- C. 7,333 yd³
- D. 11,111 yd³

Solution

Correct Answer: B

Step 1: Compute volume between Station 10 + 00 and 14 + 00 ($L_1 = 400$ ft).

$$V_1 = \frac{L_1}{54}(A_{10} + A_{14}) = \frac{400 \text{ ft}}{54}(120 + 180) = \frac{400}{54}(300) = 2,222.22 \text{ yd}^3 \quad (51)$$

Step 2: Compute volume between Station 14 + 00 and 20 + 00 ($L_2 = 600$ ft).

$$V_2 = \frac{L_2}{54}(A_{14} + A_{20}) = \frac{600 \text{ ft}}{54}(180 + 240) = \frac{600}{54}(420) = 4,666.67 \text{ yd}^3 \quad (52)$$

Step 3: Total Fill Volume.

$$V_{\text{total}} = V_1 + V_2 = 2,222.22 + 4,666.67 = 6,888.89 \text{ yd}^3 \approx 6,889 \text{ yd}^3 \quad (53)$$

Problem 13: Labor Productivity & Burden Costing**Category: Construction Operations & Estimating**

A labor productivity rate for placing reinforcing steel in concrete foundation walls is 9.0 man-hours/ton. A installation crew consists of:

- 1 Crew Foreman @ \$38.00/hour
- 3 Apprentice Ironworkers @ \$25.00/hour each

A labor burden multiplier of **60%** applies to all base hourly wages.

To install 45 tons of reinforcing steel, the total burdened labor cost is most nearly:

- A. \$11,400
- B. \$18,300
- C. \$27,500
- D. \$29,300

Solution

Correct Answer: B

Step 1: Calculate total man-hours required.

$$\text{Total Man-Hours} = 45 \text{ tons} \times 9.0 \text{ man-hours/ton} = 405 \text{ man-hours} \quad (54)$$

Step 2: Determine crew structure and crew hours. The crew consists of $1 + 3 = 4$ workers. Therefore, 1 Crew Hour = 4 Man-Hours.

$$\text{Crew Hours Required} = \frac{405 \text{ man-hours}}{4 \text{ workers}} = 101.25 \text{ crew hours} \quad (55)$$

Step 3: Calculate base hourly cost of the crew.

$$\text{Base Crew Hourly Wage} = \$38.00 + 3(\$25.00) = \$38.00 + \$75.00 = \$113.00/\text{hr} \quad (56)$$

Step 4: Apply 60% labor burden multiplier.

$$\text{Burdened Crew Hourly Rate} = \$113.00 \times (1 + 0.60) = \$113.00 \times 1.60 = \$180.80/\text{hr} \quad (57)$$

Step 5: Calculate total burdened labor cost.

$$\text{Total Labor Cost} = 101.25 \text{ crew hours} \times \$180.80/\text{crew hour} = \$18,306.00 \approx \$18,300 \quad (58)$$

Problem 14: Site Area by Coordinates**Category: Construction Estimating**

A land development site boundary forms a closed four-sided polygon defined by the following (X, Y) coordinate points in feet: $A(0, 0)$, $B(0, 100)$, $C(200, 150)$, and $D(200, 0)$.

The enclosed plan view area of this site, in **square feet**, is:

- A. 15,000 ft²
- B. 20,000 ft²
- C. 25,000 ft²
- D. 30,000 ft²

Solution**Correct Answer: C**

Using the FE Reference Handbook **Area by Coordinates** formula:

$$\text{Area} = \frac{1}{2} | [X_A(Y_B - Y_D) + X_B(Y_C - Y_A) + X_C(Y_D - Y_B) + X_D(Y_A - Y_C)] | \quad (59)$$

$$\text{Term 1} = 0(100 - 0) = 0 \quad (60)$$

$$\text{Term 2} = 0(150 - 0) = 0 \quad (61)$$

$$\text{Term 3} = 200(0 - 100) = -20,000 \quad (62)$$

$$\text{Term 4} = 200(0 - 150) = -30,000 \quad (63)$$

$$\text{Area} = \frac{1}{2} | -20,000 - 30,000 | = \frac{1}{2} | -50,000 | = 25,000 \text{ ft}^2 \quad (64)$$

Problem 15: Contract Document Priority Discrepancy**Category: Interpretation of Engineering Drawings**

During highway construction, a conflict is discovered regarding the concrete pavement thickness:

- Addendum No. 2 issued during bidding specifies a pavement thickness of **10 inches**.
- The Technical Specifications state a thickness of **9 inches**.
- The Plan Structural Profile Drawing shows a dimension of **8 inches**.
- The General Conditions state that standard state DOT specs govern.

Addendum No. 2 explicitly amends the slab thickness requirement. What thickness must the contractor construct?

- A. 8 inches, because drawings show physical dimensions.
- B. 9 inches, because written specifications override drawings.
- C. 10 inches, as expressly required by the project addendum.
- D. The average of the three dimensions (9 inches).

Solution**Correct Answer: C**

Detailed Explanation: Addendum No. 2 expressly changes the pavement thickness to 10 inches, so C follows from that amendment. Addenda supersede the provisions they modify; document priorities otherwise depend on the actual contract. No universal ranking of specifications, drawings, and general conditions is assumed.