SECTION 033713 - SHOTCRETE

Revise this Section by deleting and inserting text to meet Project-specific requirements.

1. GENERAL
   * + 1. RELATED DOCUMENTS
          1. Drawings and general provisions of the Contract, including General and Supplementary Conditions and Division 01 Specification Sections, apply to this Section.
       2. SUMMARY
          1. Section Includes:

Dry-mix shotcrete.

Wet-mix shotcrete.

* + - 1. DEFINITIONS

Retain terms that remain after this Section has been edited for a project.

* + - * 1. Shotcrete: Mortar or concrete pneumatically projected onto a surface at high velocity.
        2. Dry-Mix Shotcrete: Shotcrete with most of the mixing water added at nozzle.
        3. Wet-Mix Shotcrete: Shotcrete with ingredients, including mixing water, mixed before introduction into delivery hose.
      1. PREINSTALLATION MEETINGS

Retain "Preinstallation Conference" Paragraph below if Work of this Section is extensive or complex enough to justify a conference.

* + - * 1. Preinstallation Conference: Conduct conference at Project site.

Require representatives of each entity directly concerned with shotcrete to attend, including the following:

Contractor's superintendent.

Independent testing agency responsible for shotcrete design mixtures.

Ready-mix concrete manufacturer.

Shotcrete Installer.

Review methods and procedures related to shotcrete, but not limited to, the following:

Revise nine subparagraphs below to suit Project.

Qualification data, equipment, and facilities needed to make progress and avoid delays.

Shotcrete finishes and finishing.

Cold- and hot-weather shotcreting procedures.

Curing procedures

Construction joints.

Forms and form-removal limitations.

Reinforcement accessory installation.

Shotcrete repair procedures.

Protection of shotcrete.

Retain subparagraph below if warranted by complexity of design mixtures and quality control of shotcrete materials.

Before submitting design mixtures, review each shotcrete design mixture and examine procedures for ensuring quality of shotcrete materials.

* + - 1. SUBMITTALS
         1. Submittals for this section are subject to the re-evaluation fee identified in Article 4 of the General Conditions.
         2. Manufacturer’s installation instructions shall be provided along with product data.
         3. Submittals shall be provided in the order in which they are specified and tabbed (for combined submittals).
         4. Product Data: For each type of product.

Include reinforcement and forming accessories, shotcrete materials, admixtures, and curing compounds.

USE PARAGRAPH BELOW WITH EPD REQUIREMENT WHEN PROJECT ESTIMATE IS $1M OR MORE.

* + - * 1. Submit an Environmental Product Declaration (EPD) from the manufacturer for each concrete mix within this specification section, if available. A statement of the contractor’s good faith effort to obtain the EPD shall be provided if not available.

Manufacturer-provided EPDs must be Product Specific Type III (Third-Party Reviewed), in adherence with ISO 14025 *Environmental labels and declarations*, ISO 14044 *Environmental management – Life cycle assessment*, and ISO 21930 *Core rules for environmental product declarations of construction products and services*.

* + - * 1. Design Mixtures: For each shotcrete mixture. Submit alternative design mixtures when characteristics of materials, Project conditions, weather, test results, or other circumstances warrant adjustments.

Retain subparagraph below to suit Project.

For predampened dry-mix mixtures, indicate amounts of mixing water to be added to the dry-mix materials before mixing and conveying through the delivery hose.

Revise "Shop Drawings" Paragraph below to suit Project.

* + - * 1. Shop Drawings: For shotcrete installation.

Include plans, elevations, sections, and support and anchor details.

Detail fabrication, bending, and placing of reinforcement; number and location of splices; and special reinforcement required for openings through shotcrete structures.

Retain first subparagraph below if applicable.

Detail formwork fabrication, assembly, and support.

Indicate locations of proposed construction joints.

Consider retaining first option in "Samples" Paragraph below for high-water-pressure uses, such as swimming pools. If a design-reference sample has been selected by Director’s Representative, consider deleting third option below.

* + - * 1. Samples: For **[waterstops, approximately 24 inches long] [and] [each exposed product and for each color and finish specified, approximately 24 by 24 by 2 inches in size]**.

Coordinate "Qualification Data" Paragraph below with qualification requirements in "Quality Assurance" Article.

* + - * 1. Qualification Data: For **[Installer] [testing agency] [and] [preconstruction testing service]**.

Retain "Material Certificates" Paragraph below to require submittal of material certificates from manufacturers.

* + - * 1. Material Certificates: For each of the following:

Revise seven subparagraphs below to suit Project.

Cementitious materials.

Admixtures.

Form materials.

Steel reinforcement and accessories.

Use subparagraph below for projects over $100,000. See Article 1.5 below.

Documentation to confirm compliance with General Conditions Article 25.4 Domestic Steel.

Fiber reinforcement.

Waterstops.

Curing compounds.

Aggregates.

Retain "Preconstruction Test Reports" Paragraph below if specifying preconstruction testing in "Preconstruction Testing" Article as Contractor's responsibility.

* + - * 1. Preconstruction Test Reports: For shotcrete.

Retain "Field quality-control reports" Paragraph below if Contractor is responsible for field quality-control testing and inspecting.

* + - * 1. Field quality-control reports.
      1. QUALITY ASSURANCE

Retain "Installer Qualifications" Paragraph below if required; revise to suit Project. Retain first option if preconstruction core grading is required and retained in "Preconstruction Testing" Article. Preconstruction core grading is usually reserved for complex and critical projects. Before retaining ACI Shotcrete Nozzleman options, verify availability in Project area. See the Evaluations.

* + - * 1. Installer Qualifications: A qualified installer employing nozzle operators for Project, each of whom **[attains mean core grades not exceeding 2.5, according to ACI 506.2, on preconstruction tests] [is ACI Shotcrete Nozzleman certified in Dry-Mix Process for Vertical Position] [is ACI Shotcrete Nozzleman certified in Dry-Mix Process for Vertical and Overhead Positions] [is ACI Shotcrete Nozzleman certified in Wet-Mix Process for Vertical Position] [and] [is ACI Shotcrete Nozzleman certified in Wet-Mix Process for Vertical and Overhead Positions]** as appropriate to the required shotcrete work.

Retain "Testing Agency Qualifications" Paragraph below if Contractor selects testing agency or if Contractor is required to provide services of a qualified testing agency in "Preconstruction Testing" or "Field Quality Control" Article.

* + - * 1. Testing Agency Qualifications: Qualified according to ASTM C1077 and ASTM E329 for testing indicated.
        2. Standard: Comply with ACI 506.2, "Specification for Shotcrete," unless otherwise indicated.

Consider retaining "Shotcrete Testing Service" Paragraph below for structural shotcrete or for structural-concrete repair with shotcrete.

* + - * 1. Shotcrete Testing Service: Engage a qualified independent testing agency to perform material evaluation tests and to design shotcrete mixtures.

Retain "Mockups" Paragraph below if required; revise to suit Project. Shotcrete mockups can be expensive because small batches are uneconomical to prepare.

* + - * 1. Mockups: Build mockups to verify selections made under Sample submittals, to demonstrate aesthetic effects, and to set quality standards for materials and execution.

Indicate portion of Work represented by mockup on Drawings or draw mockup as separate element.

Build mockups for each finish required and for each design mixture, shooting orientation, and nozzle operator.

Build mockups in the location and of the size indicated or, if not indicated, as directed by Director’s Representative.

Demonstrate curing and protecting of shotcrete, finishes, and joints, as applicable.

Retain first subparagraph below if final appearance is important.

In presence of Director’s Representative, damage part of the exposed-face surface for each color and finish, and demonstrate materials and techniques proposed for repair of holes and surface blemishes to match adjacent undamaged surfaces.

Approval of mockups does not constitute approval of deviations from the Contract Documents contained in mockups unless Director’s Representative specifically approves such deviations in writing.

Subject to compliance with requirements, approved mockups may become part of the completed Work if undisturbed at time of Substantial Completion.

Use paragraph below for projects over $100,000. Paragraph is taken from Article 25.4 of the General Conditions.

* + - * 1. If the value of the contract exceeds $100,000 all structural steel, reinforcing steel and other major steel items to be incorporated in the Work of this Contract shall be produced and made in whole or substantial part in the United States, its territories or possessions.
      1. PRECONSTRUCTION TESTING

Retain this article for preconstruction testing. Project-specific preconstruction testing of assemblies can be expensive but may be the best means of proving that performance requirements are met.

* + - * 1. Preconstruction Testing Service: **[Director’s Representative will engage] [Engage]** a qualified testing agency to perform preconstruction testing on shotcrete.

Revise test-panel size and thickness in first subparagraph below to suit Project.

Produce and test shotcrete test panels before shotcrete placement according to requirements in ACI 506.2 for each design mixture, shooting orientation, and nozzle operator. Produce test panels with dimensions of 24 by 24 inches minimum and of average thickness of shotcrete, but not less than 3-1/2 inches.

From each test panel, testing agency shall obtain six test specimens: one set of three specimens unreinforced, and one set of three specimens reinforced. Agency will perform the following:

Strength Testing: Test each set of unreinforced specimens for compressive strength according to ASTM C42.

Retain "Core Grading" Subparagraph below if retaining core-grading option in "Installer Qualifications" Paragraph in "Quality Assurance" Article.

Core Grading: Visually inspect each set of reinforced shotcrete cores taken from test panels and determine mean core grades according to ACI 506.2.

* + - 1. DELIVERY, STORAGE, AND HANDLING

Retain option in "Steel Reinforcement" Paragraph below if zinc-coated steel reinforcement and anchors are required.

* + - * 1. Steel Reinforcement: Deliver, store, and handle steel reinforcement to prevent bending and damage.**[ Avoid damaging coatings on steel reinforcement.]**

Retain "Waterstops" Paragraph below if applicable.

* + - * 1. Waterstops: Store waterstops under cover to protect from moisture, sunlight, dirt, oil, and other contaminants.

1. PRODUCTS
   * + 1. FORM MATERIALS
          1. Forms: Form-facing panels that will provide continuous, straight, smooth, concrete surfaces. Furnish panels in largest practical sizes to minimize number of joints.
       2. REINFORCING MATERIALS
          1. Reinforcing Bars: ASTM A615, Grade 60, deformed.

Retain "Low-Alloy-Steel Reinforcing Bars" Paragraph below for bar reinforcement that will be welded.

* + - * 1. Low-Alloy-Steel Reinforcing Bars: ASTM A706, deformed.

Retain "Galvanized Reinforcing Bars" Paragraph below for galvanized-steel reinforcement. Retain type of reinforcement from first set of options and zinc coating class from second set. Class I has at least 50 percent more zinc weight than Class II.

* + - * 1. Galvanized Reinforcing Bars: **[ASTM A615, Grade 60] [ASTM A706]**, deformed bars, ASTM A767, **[Class I] [Class II]** zinc coated after fabrication and bending.
        2. Plain-Steel Wire: ASTM A1064, **[as drawn] [galvanized]**.
        3. Welded Wire Reinforcement: ASTM A1064, **[plain, fabricated from as-drawn steel wire] [plain, fabricated from galvanized-steel wire] [deformed]**, furnished in flat sheet.
        4. Supports: Bolsters, chairs, spacers, and other devices for spacing, supporting, and fastening reinforcing bars and welded wire fabric in place; manufactured according to CRSI's "Manual of Standard Practice" and as follows:

Retain or delete one of two subparagraphs below, or both; revise to suit Project.

For uncoated reinforcement, use **[all-plastic] [CRSI Class 1, plastic-protected] [or] [CRSI Class 2, stainless-steel]** bar supports.

For zinc-coated reinforcement, use **[galvanized wire or dielectric-polymer-coated wire] [or] [all-plastic]** bar supports.

Retain "Reinforcing Anchors" Paragraph below if devices are required to anchor steel reinforcement.

* + - * 1. Reinforcing Anchors: ASTM A36, unheaded rods or ASTM A307, Grade A, hex-head bolts; carbon steel; and carbon-steel nuts.

Finish: **[Plain, uncoated] [Hot-dip zinc coating, ASTM A153]**.

* + - * 1. Zinc Repair Material: ASTM A780, zinc-based solder, paint containing zinc dust, or sprayed zinc.
      1. SHOTCRETE MATERIALS

Retain both "Portland Cement" and "Blended Hydraulic Cement" paragraphs below if Contractor may use either portland cement with supplementary materials or blended hydraulic cement.

* + - * 1. Portland Cement: ASTM C150, **[Type I] [or] [Type III]**. Use only one brand and type of cement for Project.

Retain one or more of "Fly Ash," "Slag Cement," and "Silica Fume" subparagraphs below if supplementary cementing materials are permitted; coordinate with "Admixtures" Paragraph in this article. Fly ash and slag cement is blended with portland cement at ready-mix plant.

Fly Ash: ASTM C618, Class C or Class F.

Slag Cement: ASTM C989, Grade 100 or Grade 120.

Silica Fume: ASTM C1240, amorphous silica.

Retain "Blended Hydraulic Cement" Paragraph below if factory-blended hydraulic cement is permitted; verify availability of options before specifying. Fly ash, slag cement, or pozzolanic materials in the nonportland cement part of blended hydraulic cement may slow rate of concrete strengthening and affect color uniformity. If important, insert targeted percentages by mass of constituents to suit Project and according to the nomenclature in ASTM C595.

* + - * 1. Blended Hydraulic Cement: ASTM C595, **[Type IS, portland blast-furnace slag] [Type IP, portland-pozzolan] [Type IL, portland-limestone] [Type IT, ternary blended]** cement.
        2. Normal-Weight Aggregates: ASTM C33, from a single source, and as follows:

Generally, retain one option in "Combined Aggregate Size" Subparagraph below; if both are required, indicate locations of each on Drawings or by inserts. Grading No. 1 below is termed "fine-aggregate grading" according to ACI 506R and ASTM C1436; Grading No. 2 is termed "coarse-aggregate grading." These grading requirements vary from grading requirements in ASTM C33. See the Evaluations.

Combined Aggregate Size: ACI 506R or ASTM C1436, Grading **[No. 1] [No. 2]** sieve analysis.

Retain "Deleterious Substances" Subparagraph below if required. ASTM C33 bases allowed deleterious substances on whether the aggregate is fine or coarse. Deleterious-substance restriction in ASTM C33 is less controlled for fine aggregate; for coarse aggregate, it varies depending on climate severity and in-service location of concrete. Two-thirds of the United States lies within severe weathering region. ASTM C33 sets a default class of 3S for severe, 3M for moderate, and 1N for negligible weathering regions. See the Evaluations.

Deleterious Substances: As specified for **[fine aggregate] [coarse-aggregate Class 3S] [coarse-aggregate Class 3M] [coarse-aggregate Class 1N]** according to ASTM C33.

Retain "Lightweight Aggregates" Paragraph below if required. Use of lightweight aggregate is infrequent. Revise below to insert aggregate-size grading and descriptions of specific lightweight aggregates, such as pumice or expanded shale, if required.

* + - * 1. Lightweight Aggregates: ASTM C330.

Grading No. 1 in "Combined Aggregate Size" Subparagraph below is termed "fine-aggregate grading"; Grading No. 2 is termed "coarse-aggregate grading." These grading requirements vary from grading requirements in ASTM C330. See the Evaluations.

Combined Aggregate Size: ACI 506R, Grading **[No. 1] [No. 2]** sieve analysis.

* + - * 1. Water: Potable, complying with ASTM C94, and free from deleterious materials that may affect color stability, setting, or strength of shotcrete.

Retain "Carbon-Steel Fiber" Paragraph if using steel-fiber reinforcement. See Section 033000 "Cast-In-Place Concrete" for names of reinforcement-fiber manufacturers.

* + - * 1. Carbon-Steel Fiber: ASTM A820, **[Type I, cold-drawn wire] [or] [Type II, cut sheet]**, deformed.

Nominal Length: **[0.5 inch] [1 inch] [1.5 inches]**.

Aspect Ratio: **[35 to 40] [45 to 50] [60 to 65]**.

Retain "Synthetic Fiber" Paragraph below if using synthetic fiber reinforcement. Revise fiber type if polyester, nylon, or polypropylene fibers are required. See Section 033000 "Cast-In-Place Concrete" for names of reinforcement-fiber manufacturers.

* + - * 1. Synthetic Fiber: **[Monofilament] [or] [fibrillated] polypropylene fibers engineered and designed for use in shotcrete, complying with ASTM C1116, Type III, [1 to 1.5 inches] [1.5 to 2 inches] <Insert dimensions>** long.
        2. Ground Wire: High-strength steel wire, 0.8 to 1.0 mm in diameter.
        3. Joint Filler Strips: **[ASTM D1751, asphalt-saturated cellulosic fiber] [or] [ASTM D1752, cork or self-expanding cork]**.
        4. Admixtures: ASTM C1141, Class A (liquid) or Class B (nonliquid), but limited to the following admixture materials. Provide admixtures for shotcrete that contain no more than 0.1 percent chloride ions. Certify compatibility of admixtures with each other and with other cementitious materials.

Revise list below to suit Project. See the Evaluations.

Accelerating Admixture, Conventional: ASTM C494, Type C or Type E.

Pozzolanic Admixture: Fly ash, slag cement, and silica fume as limited in "Portland Cement" Paragraph in this article.

Retain "Coloring Admixture" Subparagraph below if colored shotcrete is required.

Coloring Admixture: ASTM C979, synthetic mineral-oxide pigment or colored, water-reducing admixture, free of carbon black; color stable, nonfading, and resistant to lime and other alkalis.

Air-Entraining Admixture: As limited in "Shotcrete Mixtures" Article.

* + - 1. WATERSTOPS

Consider retaining this article for high-water-pressure uses, such as swimming pools; revise to suit Project. See Section 031000 "Concrete Forming and Accessories" for additional waterstop types and options available and for names of waterstop manufacturers.

* + - * 1. Flexible Rubber Waterstops: CE CRD-C 513,**[ with factory-installed metal eyelets,]** for embedding in concrete to prevent passage of fluids through joints. Factory fabricate corners, intersections, and directional changes.

Retain profile from options in "Profile" Subparagraph below. Insert others if required.

Profile: **[Flat dumbbell without center bulb] [Ribbed without center bulb] [As indicated]**.

Dimensions: 4 inches by 3/16 inch thick; nontapered.

* + - * 1. Flexible PVC Waterstops: CE CRD-C 572,**[ with factory-installed metal eyelets,]** for embedding in concrete to prevent passage of fluids through joints. Factory fabricate corners, intersections, and directional changes.

Retain profile from options in "Profile" Subparagraph below. Insert others if required.

Profile: **[Flat dumbbell without center bulb] [Ribbed without center bulb] [As indicated]**.

Dimensions: 4 inches by 3/16 inch thick; nontapered.

* + - * 1. Self-Expanding Butyl Strip Waterstops: Manufactured rectangular or trapezoidal strip, butyl rubber with sodium bentonite or other hydrophilic polymers, for adhesive bonding to concrete, 3/4 by 1 inch.
        2. Self-Expanding Rubber Strip Waterstops: Manufactured rectangular or trapezoidal strip, bentonite-free, hydrophilic polymer-modified chloroprene rubber, for adhesive bonding to concrete; 3/8 by 3/4 inch.
      1. CURING MATERIALS

Retain curing aids and materials in this article to suit Project.

Revise "Absorptive Cover" Paragraph below if different products within cited standard are required.

* + - * 1. Absorptive Cover: AASHTO M 182, Class 3, burlap cloth made from jute or kenaf, weighing approximately 9 oz./sq. yd. dry, or cotton mats.
        2. Moisture-Retaining Cover: ASTM C171, polyethylene film or white burlap-polyethylene sheet.
        3. Water: Potable.

Retain one of two options in "Curing Compound" Paragraph below. Retain waterborne curing compounds if low VOC emissions are required.

* + - * 1. Curing Compound: ASTM C309, Type 1, Class B; clear, **[waterborne] [solvent-borne]**, membrane-forming curing compound.
      1. SHOTCRETE MIXTURES
         1. Source Limitations for Shotcrete: Obtain each color, size, type, and variety of shotcrete material and shotcrete mixture from single manufacturer with resources to provide shotcrete of consistent quality in appearance and physical properties.
         2. Design Mixtures: Prepare design mixtures for each type and strength of shotcrete, proportioned on the basis of laboratory trial mixture or field test data, or both, according to ACI 506.2.

Use a qualified independent testing agency for preparing and reporting proposed mixture designs based on laboratory trial mixture or field test data, or both.

Generally, retain "Cementitious Materials Replacing Portland Cement" or "Cementitious Materials, Maximum Content" Paragraph below if cementitious materials other than portland cement are permitted; revise to suit Project.

Retain "Cementitious Materials Replacing Portland Cement" Paragraph below if required for replacing part of the portland cement, which otherwise would be used in concrete, including shotcrete, with other cementitious materials.

* + - * 1. Cementitious Materials Replacing Portland Cement: Use fly ash, pozzolan, slag cement, and silica fume as needed to reduce the total amount of portland cement, which would otherwise be used, by not less than 40 percent.

Retain "Cementitious Materials, Maximum Content" Paragraph below to limit percentages of cementitious materials that can replace portland cement. Unless concrete is exposed to deicing chemicals, ACI 211.1, ACI 301, and ACI 318 do not limit amount of cementitious materials that can replace portland cement. More restrictive requirements than those governing concrete exposed to deicers may be needed to ensure uniform appearance and color consistency. Identify specific shotcrete mixture or parts of building or structure affected by such limits unless extending them to all shotcrete.

* + - * 1. Cementitious Materials, Maximum Content: Limit use of **[fly ash] [slag cement] [and] [silica fume]** to not exceed, in combination, 25 percent of portland cement by weight.
        2. Limit water-soluble chloride ions to maximum percentage by weight of cement or cementitious materials permitted by ACI 301.
        3. Admixtures: Use admixtures according to manufacturer's written instructions.

Retain "Coloring Admixture" Paragraph below for integrally colored shotcrete.

* + - * 1. Coloring Admixture: Add coloring admixture to shotcrete mixture according to manufacturer's written instructions and to result in hardened shotcrete color consistent with approved mockup.
        2. Design-Mixture Adjustments: Subject to compliance with requirements, shotcrete design-mixture adjustments may be proposed when characteristics of materials, Project conditions, weather, test results, or other circumstances warrant.

Copy "Shotcrete Mixture" Paragraph below and re-edit for each product.

Insert drawing designation. Use these designations on Drawings to identify each product.

* + - * 1. Shotcrete Mixture **<Insert drawing designation>**: Proportion mixture to provide shotcrete with the following properties:

Compressive Strength (28 Days): **[5000 psi] [4500 psi] [4000 psi] [3500 psi]**.

According to ACI 506.2, use of air-entraining admixtures in dry-mix shotcrete is not recommended.

Air Content: Add air-entraining admixture at manufacturer's prescribed rate to result in normal-weight wet-mix shotcrete having an air content before pumping of **[7] [8]** percent with a tolerance of plus or minus 1-1/2 percent.

Retain "Carbon-Steel Fiber" or "Synthetic Fiber" Paragraph below if required. Application rates are examples only; revise to suit Project.

Carbon-Steel Fiber: Uniformly disperse in shotcrete mix, according to manufacturer's written instructions, at a rate of **[50 lb/cu. yd.] [100 lb/cu. yd.]**.

Synthetic Fiber: Uniformly disperse in shotcrete mix, according to manufacturer's written instructions, at a rate of [**1.5 lb/cu. yd.] [5 lb/cu. yd.]**.

Color: **[As indicated by manufacturer's designation] [Match Director’s Representative's sample] [As selected by Director’s Representative from manufacturer's full range of industry colors]**.

Retain "Color of (Flash) (Finish) Coat" Subparagraph below if color requirement is different from base shotcrete and surface will not be painted.

Color of **[Flash] [Finish]** Coat: **[As indicated by manufacturer's designation] [Match Director’s Representative's sample] [As selected by Director’s Representative from manufacturer's full range of industry colors]**.

Insert paragraphs for other performance criteria, such as flexural strength and toughness values for fiber-reinforced shotcrete, or for absorption, if required.

* + - 1. SHOTCRETE EQUIPMENT
         1. Mixing Equipment: Capable of thoroughly mixing shotcrete materials in sufficient quantities to maintain continuous placement.

Retain "Dry-Mix Delivery Equipment" or "Wet-Mix Delivery Equipment" Paragraph below, or both, to suit Project.

* + - * 1. Dry-Mix Delivery Equipment: Capable of discharging aggregate-cement mixture into delivery hose under close control and maintaining continuous stream of uniformly mixed materials at required velocity to discharge nozzle. Equip discharge nozzle with manually operated water-injection system for directing even distribution of water to aggregate-cement mixture.

Provide uniform, steady supply of clean, compressed air to maintain constant nozzle velocity while simultaneously operating blow pipe for cleaning away rebound.

Provide water supply with uniform pressure at discharge nozzle to ensure uniform mixing with aggregate-cement mix. Provide water pump to system if line water pressure is inadequate.

* + - * 1. Wet-Mix Delivery Equipment: Capable of discharging aggregate-cement-water mixture accurately, uniformly, and continuously.
      1. BATCHING AND MIXING

Retain "Dry-Mix Process" or "Wet-Mix Process" Paragraph below, or both, to suit Project.

* + - * 1. Dry-Mix Process: Measure mixture proportions by weight batching according to ASTM C94 or by volume batching complying with ASTM C685 requirements.

In volume batching, adjust fine-aggregate volume for bulking. Test fine-aggregate moisture content at least once daily to determine extent of bulking.

Prepackaged shotcrete materials may be used at Contractor's option. Predampen prepackaged shotcrete materials and mix before use.

Retain option in "Wet-Mix Process" Paragraph below if steel or synthetic fibers are required.

* + - * 1. Wet-Mix Process: Measure, batch, mix, and deliver shotcrete according to ASTM C94**[ and ASTM C1116]** and furnish batch ticket information.

Comply with ASTM C685 when shotcrete ingredients are delivered dry and proportioned and mixed on-site.

1. EXECUTION
   * + 1. PREPARATION
          1. Concrete and Masonry Substrates: Before applying shotcrete, remove unsound or loose materials and contaminants that may inhibit shotcrete bonding. Chip or scarify areas to be repaired to extent necessary to provide sound substrate. Cut edges square and 1/2 inch deep at perimeter of work, tapering remaining shoulder at 1:1 slope into cavity to eliminate square shoulders. Dampen surfaces to saturated, surface-dry condition before shotcreting.

Abrasive blast or hydroblast existing surfaces that do not require chipping to remove paint, oil, grease, or other contaminants and to provide roughened surface for proper shotcrete bonding.

* + - * 1. Earth Substrates: Compact and trim to line and grade before placing shotcrete. Do not place shotcrete on frozen surfaces. Dampen surfaces to saturated, surface-dry condition before shotcreting.

Generally, retain option in "Rock Substrates" Paragraph below unless rock surface is known to have low absorption.

* + - * 1. Rock Substrates: Clean rock surfaces of loose materials, mud, and other foreign matter that might weaken shotcrete bonding.**[ Dampen surfaces to saturated, surface-dry condition before shotcreting.]**
        2. Steel Substrates: Clean steel surfaces by abrasive blasting according to SSPC-SP 6/NACE No. 3, "Commercial Blast Cleaning."
        3. Protect adjacent construction and surfaces not required to receive shotcrete.
      1. FORMS
         1. Design, erect, support, brace, and maintain forms, according to ACI 301, to support shotcrete and construction loads and to facilitate shotcreting. Construct forms so shotcrete members and structures are secured to prevent excessive vibration or deflection during shotcreting.

Fabricate forms to be readily removable without impact, shock, or damage to shotcrete surfaces and adjacent materials.

Construct forms to required sizes, shapes, lines, and dimensions using ground wires and depth gages to obtain accurate alignment, location, and grades in finished structures. Construct forms to prevent mortar leakage but permit escape of air and rebound during shotcreting. Provide for openings, offsets, blocking, screeds, anchorages, inserts, and other features required in the Work.

* + - * 1. Form openings, chases, recesses, bulkheads, keyways, and screeds in formwork. Determine sizes and locations from trades providing such items. Accurately place and securely support items built into forms.
      1. STEEL REINFORCEMENT
         1. Comply with CRSI's "Manual of Standard Practice" for fabricating, placing, and supporting reinforcement.
         2. Clean reinforcement of loose rust and mill scale, earth, ice, and other materials that weaken shotcrete bonding.
         3. Securely embed reinforcing anchors into existing substrates, located as required.
         4. Accurately position, support, and secure reinforcement against displacement. Locate and support reinforcement with bar supports, bolsters, chairs, spacers, and other devices as required to maintain minimum concrete cover.
         5. Set wire ties with ends directed into shotcrete, not toward exposed shotcrete surfaces.
         6. Install welded wire reinforcement in largest practical sheets on bar supports spaced to minimize sagging. Lap edges and ends of adjoining sheets at least one mesh spacing. Offset laps of adjoining sheet widths to prevent continuous laps in either direction. Lace overlaps with wire.

Retain "Zinc-Coated Reinforcement" Paragraph below if using zinc-coated reinforcement.

* + - * 1. Zinc-Coated Reinforcement: Repair cut and damaged zinc coatings with zinc repair material according to ASTM A780. Use galvanized-steel wire ties to fasten zinc-coated steel reinforcement.
      1. JOINTS

Coordinate joint types, description, and location with Drawings.

* + - * 1. General: Construct joints at locations indicated or as approved by Director’s Representative.
        2. Construction Joints: Locate and install construction joints tapered to a 1:1 slope where joint is not subject to compression loads and square where joint is perpendicular to main reinforcement. Continue reinforcement through construction joints unless otherwise indicated.
        3. Contraction Joints: Construct contraction joints in shotcrete using saw cuts 1/8-inch- wide by one-third of slab depth or joint-filler strips 1/4-inch- wide by one-third of shotcrete depth unless otherwise indicated.

After shotcrete has cured, remove strip inserts and clean groove of loose debris.

Space joints at **[15 feet o.c.] [centers indicated]** horizontally and vertically.

Tool edges round on each side of strip inserts if floated or troweled finishes are required.

Where shooting over an existing substrate joint, align new shotcrete joint with existing joint.

* + - 1. INSTALLATION OF WATERSTOPS

Retain "Flexible Waterstops" or "Self-Expanding Strip Waterstops" Paragraph below, depending on type of waterstop required.

* + - * 1. Flexible Waterstops: Install in construction joints and at other joints indicated to form a continuous diaphragm. Install in longest lengths practicable. Support and protect exposed waterstops during progress of the Work. Field fabricate joints in waterstops according to manufacturer's written instructions.
        2. Self-Expanding Strip Waterstops: Install in construction joints and at other locations indicated, according to manufacturer's written instructions, adhesive bonding, mechanically fastening, and firmly pressing into place. Install in longest lengths practicable.
        3. Prevent waterstop displacement during shotcrete application.
      1. ALIGNMENT CONTROL
         1. Ground Wires: Install ground wires to establish thickness and planes of shotcrete surfaces. Install ground wires at corners and offsets not established by forms. Pull ground wires taut and position adjustment devices to permit additional tightening.
      2. EMBEDDED ITEMS
         1. Place and secure anchorage devices and other embedded items required for adjoining work that is attached to or supported by shotcrete. Use setting drawings, templates, diagrams, instructions, and directions furnished with items to be embedded.
      3. APPLICATION

Retain one or all options in this article to suit Project. Retain all options if leaving choice to Contractor.

* + - * 1. Apply shotcrete applied by **[dry-mix] [or] [wet-mix]** process and according to ACI 506.2.
        2. Apply temporary protective coverings and protect adjacent surfaces against deposit of rebound and overspray or impact from nozzle stream.
        3. Moisten wood forms immediately before placing shotcrete where form coatings are not used.
        4. Apply **[dry-mix shotcrete materials within 45 minutes after predampening] [and] [wet-mix shotcrete materials within 90 minutes after batching]**.
        5. Deposit shotcrete continuously in multiple passes, to required thickness, without cold joints and laminations developing. Place shotcrete with nozzle held perpendicular to receiving surface. Begin shotcreting in corners and recesses.

Remove and dispose of rebound and overspray materials during shotcreting to maintain clean surfaces and to prevent rebound entrapment.

Remove and dispose of cuttings during the trimming or rodding process to prevent unconsolidated material from falling onto lower reinforcement.

* + - * 1. Maintain reinforcement in position during shotcreting. Place shotcrete to completely encase reinforcement and other embedded items. Maintain steel reinforcement free of overspray, and prevent buildup against front face during shotcreting.
        2. Do not place subsequent lifts until previous lift of shotcrete is capable of supporting new shotcrete.
        3. Do not permit shotcrete to sag, slough, or dislodge.
        4. Remove hardened overspray, rebound, and laitance from shotcrete surfaces to receive additional layers of shotcrete; dampen surfaces before shotcreting.
        5. Do not disturb shotcrete surfaces before beginning finishing operations.
        6. Remove ground wires or other alignment-control devices after shotcrete placement.

If requiring Contractor to achieve core grades during shotcreting, retain "Shotcrete Core Grade" Paragraph below in addition to core grading during preconstruction testing. Further independent core grading can be verified in "Field Quality Control" Article.

* + - * 1. Shotcrete Core Grade: Apply shotcrete to achieve mean core grades not exceeding 2.5 according to ACI 506.2, with no single core grade exceeding 3.0.

Retain "Installation Tolerances" Paragraph below if required; revise to suit Project and shotcrete finish. See discussion of shotcrete tolerances in the Evaluations.

* + - * 1. Installation Tolerances: Place shotcrete without exceeding installation tolerances permitted by ACI 117, increased by a factor of two.
        2. Cold-Weather Shotcreting: Mix, place, and protect shotcrete according to ACI 306.1 and as follows. Protect shotcrete work from physical damage or reduced strength that could be caused by frost, freezing actions, or low temperatures.

Discontinue shotcreting when ambient temperature is 40 deg F and falling.

Uniformly heat water and aggregates before mixing to obtain a shotcrete shooting temperature of not less than 50 deg F and no more than 90 deg F.

Do not use frozen materials or materials containing ice or snow.

Do not place shotcrete on frozen surfaces or surfaces containing frozen materials.

Do not use calcium chloride, salt, or other materials containing antifreeze agents.

* + - * 1. Hot-Weather Shotcreting: Mix, place, and protect shotcrete according to ACI 305.1 when hot-weather conditions and high temperatures would seriously impair quality and strength of shotcrete, and as follows:

Cool ingredients before mixing to maintain, at time of placement, shotcrete temperature below **[100 deg F for dry mix] [and] [90 deg F for wet mix]**.

Reduce temperature of reinforcing steel and receiving surfaces below 100 deg F before shotcreting.

* + - 1. SURFACE FINISHES

Retain one or more finishes from this article; if retaining more than one, indicate location of each on Drawings or by inserts. See the Evaluations for discussion of shotcrete finishes.

* + - * 1. General: Finish shotcrete according to descriptions in ACI 506R.

Retain "Natural Finishes" Paragraph below for finishes without secondary coats, which are the most commonly used shotcrete finishes.

* + - * 1. Natural Finishes:

ACI 506R recommends that dry-mix shotcrete remain in its natural gun-finish state without further disturbance or finishing.

Gun Finish: Natural undisturbed finish as sprayed.

Rod Finish: Rough-textured finish obtained by screeding or cutting exposed face of shotcrete to plane with cutting rod, edge of trowel, or straightedge after initial set. Do not push or float with flat part of trowel.

Broom Finish: Rough-textured finish obtained by screeding or cutting exposed face of shotcrete to plane with cutting rod, edge of trowel, or straightedge after initial set; followed by uniform brooming.

Retain one of four finish paragraphs below if required. Flash or finish coats are often used for finer finishes or to cover surface fibers of fiber-reinforced shotcrete. Retain "Flash-Coat Finish" or "Finish-Coat Finish" Paragraph if no further finishing of flash or finish coat is required. Retain "Flash-Coat with Final Finish" or Finish-Coat with Final Finish" Paragraph if further finishing of flash or finish coat is required, such as for painted surfaces within hand reach and for swimming pool surfaces. Insert requirements for exposed-aggregate or artistic finishes such as rock sculpting if required. Insert flash- or finish-coat finish mixture and color requirements, if any, in "Shotcrete Mixtures" Article.

* + - * 1. Flash-Coat Finish: After screeding or cutting exposed face of shotcrete to plane after initial set, apply up to 1/4-inch coat of shotcrete using ACI 506R, Grading No. 1, fine-screened sand modified with maximum aggregate size not exceeding No. 4 sieve to provide a finely textured finish.
        2. Flash-Coat with Final Finish: After screeding or cutting exposed face of shotcrete to plane after initial set, apply up to 1/4-inch coat of shotcrete using ACI 506R, Grading No. 1, fine-screened sand modified with maximum aggregate size not exceeding No. 4 sieve, and apply **[wood-float] [rubber-float] [brush-float] [steel-trowel]** finish.
        3. Finish-Coat Finish: After screeding or cutting exposed face of shotcrete to plane after initial set, apply shotcrete finish coat, 1/4 to 1 inch thick, using ACI 506R, Grading No. 1, fine-screened sand modified with maximum aggregate size not exceeding No. 4 sieve to provide a finish of uniform texture and appearance.
        4. Finish-Coat with Final Finish: After screeding or cutting exposed face of shotcrete to plane after initial set, apply shotcrete finish coat, 1/4 to 1 inch thick, using ACI 506R, Grading No. 1, fine-screened sand modified with maximum aggregate size not exceeding No. 4 sieve, and apply **[wood-float] [rubber-float] [brush-float] [steel-trowel]** finish.
      1. CURING
         1. Protect freshly placed shotcrete from premature drying and excessive cold or hot temperatures.

Shotcrete generally stiffens on striking the substrate and seldom has free water on surface.

* + - * 1. Begin curing immediately after placing and finishing but not before free water, if any, has disappeared from shotcrete surface.
        2. Curing Exposed Surfaces: Cure shotcrete by one of the following methods:

Moisture Curing: Keep surfaces continuously moist for not less than seven days with the following materials:

Retain first three subparagraphs below if leaving choice to Contractor; revise to suit Project.

Water.

Continuous water-fog spray.

Water-saturated absorptive covers or moisture-retaining covers. Lap and seal sides and ends of covers with 12-inch lap over adjacent covers.

Curing Compound: Apply uniformly in continuous operation by power spray according to manufacturer's written instructions. Recoat areas subjected to heavy rainfall within three hours after initial application. Maintain continuity of coating and repair damage during curing period.

Generally, retain subparagraph below for natural gun or flash-coat finishes; revise to suit Project. For these finishes, ACI 506R recommends applying curing compound at a rate twice that recommended by the compound manufacturer.

Apply curing compound to natural gun and flash-coat finishes at rate of 1 gal./100 sq. ft..

* + - * 1. Curing Formed Surfaces: Cure formed shotcrete surfaces by moist curing with forms in place for full curing period or until forms are removed. If forms are removed, continue curing by methods specified above, as applicable.
      1. FORM REMOVAL
         1. Forms not supporting weight of shotcrete may be removed after curing for 24 consecutive hours at not less than 50 deg F, provided shotcrete is hard enough not to be damaged by form-removal operations and provided curing and protecting operations are maintained.

Leave forms supporting weight of shotcrete in place until shotcrete has attained design compressive strength. Determine compressive strength of in-place shotcrete by testing representative field-cured specimens of shotcrete.

Remove forms only if shores have been arranged to permit removal of forms without loosening or disturbing shores.

* + - * 1. Clean and repair surfaces of forms to be reused in the Work. Split, frayed, delaminated, or otherwise damaged form-facing materials are unacceptable for exposed surfaces. Apply new form-coating compound as specified for new formwork.
      1. FIELD QUALITY CONTROL

Retain "Testing Agency" Paragraph below to identify who shall perform tests and inspections. If retaining second option in "Testing Agency" Paragraph, retain "Field quality-control reports" Paragraph in "Informational Submittals" Article.

* + - * 1. Testing Agency: **[Director’s Representative will engage] [Engage]** a qualified testing agency to perform tests and inspections.
        2. Air Content: ASTM C173, volumetric method or ASTM C231, pressure method; one test for each compressive-strength test for each mixture of air-entrained, wet-mix shotcrete measured before pumping.
        3. Shotcrete Temperature: ASTM C1064; one test hourly when air temperature is 40 deg F and below and when 80 deg F and above, and one test for each set of compressive-strength specimens.
        4. Test Panels: Make a test panel, reinforced as in structure, for each shotcrete mixture and for each workday or for every 50 cu. yd. of shotcrete placed, whichever is less. Produce test panels with dimensions of 24 by 24 inches minimum and of average thickness of shotcrete, but not less than 4-1/2 inches. Testing agency will obtain sets of test specimens from each test panel.

Coordinate compressive testing requirements in "Compressive Strength Testing" Subparagraph and "In-Place Shotcrete Testing" Paragraph below. Retain one or both to suit Project.

Compressive Strength Testing: One set of three unreinforced specimens. Test each set of unreinforced specimens for compressive strength according to construction testing requirements in ACI 506.2.

Visual Core Grading: One set of three reinforced specimens. Visually inspect each set of reinforced shotcrete cores taken from test panels and determine mean core grades according to ACI 506.2.

Retain "In-Place Shotcrete Testing" Paragraph below if in-place testing is required.

* + - * 1. In-Place Shotcrete Testing: One set of three unreinforced cores for each mixture and for each workday or for every **<Insert quantity>** of shotcrete placed, whichever is less. Test cores for compressive strength according to ACI 506.2 and ASTM C42. Do not cut steel reinforcement.
        2. Strength of shotcrete will be considered satisfactory according to the following:

Specimen Cores: Mean compressive strength of each set of three unreinforced cores equals or exceeds 85 percent of specified compressive strength, with no individual core less than 75 percent of specified compressive strength.

Specimen Cubes: Mean compressive strength of each set of three unreinforced cubes shall equal or exceed design compressive strength with no individual cube less than 88 percent of specified compressive strength.

* + - * 1. Shotcrete will be considered defective if it does not pass tests and inspections.
        2. Prepare test and inspection reports.
      1. REPAIRS
         1. Remove and replace shotcrete that is delaminated or exhibits laminations, voids, or sand/rock pockets exceeding limits for specified core grade of shotcrete.

Remove unsound or loose materials and contaminants that may inhibit bond of shotcrete repairs.

Chip or scarify areas to be repaired to extent necessary to provide sound substrate. Cut edges square and 1/2 inch deep at perimeter of work, tapering remaining shoulder at 1:1 slope into cavity to eliminate square shoulders.

Retain option in subparagraph below if appearance is important.

Dampen surfaces and apply new shotcrete.**[ Match adjacent color and finish.]**

* + - * 1. Repair core holes from in-place testing according to repair provisions in ACI 301, except do not use shotcrete. Match adjacent color and finish.
      1. CLEANING
         1. Immediately remove and dispose of rebound and overspray materials from final shotcrete surfaces and areas not intended for shotcrete placement.
         2. Repair or replace damaged surfaces not scheduled for shotcrete application to the satisfaction of the Director’s Representative.

END OF SECTION 033713