

SECTION 515: SHOTCRETE

535.1 DESCRIPTION

This Work consists of constructing a pneumatically applied non-structural shotcrete onto rock or soil, or structural shotcrete onto formed surfaces in accordance with the contract and as directed by the City Engineer or designee.

These specifications refer to premixed cement and aggregate pneumatically applied by suitable equipment and competent operators.

535.2 MATERIALS

535.2.1 General

Structural shotcrete shall have a design strength of 4000 psi at 28 days and non-structural shotcrete shall have a design strength of 3000 psi at 28 days. The Contractor shall use a shotcrete mix that has been designed and proportioned in accordance with Section 510: Portland Cement Concrete Materials.

Bar reinforcement and welded wire fabric shall be provided in accordance with Section 510: Portland Cement Concrete Materials.

The Contractor shall use either wet-mix or dry-mix shotcrete. The Contractor shall reinforce shotcrete in accordance with the contract.

535.2.2 Fine Aggregate Quality Requirements

The Contractor shall provide fine aggregate with the following properties:

1. A soundness Loss of 12 or less when tested in accordance with AASHTO T 104 using magnesium sulfate solution and a test duration of five (5) cycles; and
2. A sand equivalent of at least 75 when tested in accordance with AASHTO T 176.

535.2.3 Fine Aggregate Gradation Requirements

Fine aggregates shall comply with Table 535.2.3:1, "Fine Aggregate Gradation" for either Grading No.1 or Grading No. 2.

Table 535.2.3:1
Fine Aggregate Gradation

Sieve Size, U.S Standard Square Mesh	Percent by Weight Passing Individual Sieves	
	Grading No. 1	Grading No. 2
¾ inch	---	---
½ inch	---	100
3/8 inch	100	90-100
No. 4	95-100	70-85
No. 8	80-98	50-70
No. 16	50-85	35-55
No. 30	25-60	20-35
No. 50	10-30	8-20

No. 100	2-10	2-10
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535.2.4 Water

The Contractor shall provide concrete mix water in the shotcrete mix that is free of elements that could stain the mix and in accordance with the Section 500: Portland Cement Concrete Materials of these specifications.

535.2.5 Anchor Bars

The Contractor shall provide anchor bars as specified in the plans.

535.2.6 Welded Wire Mesh

The Contractor shall provide non-galvanized eight (8) gauge steel with a four (4) inch × four (4) inch mesh (4 × 4-W2.1 × W2.1) in accordance with Section 500: Portland Cement Concrete Materials for welded wire mesh. For structural applications, the Contractor shall use welded wire mesh in accordance with the contract and as approved by the City Engineer or designee. The Contractor shall ensure that all wire mesh has been rigidly fixed in place to prevent rebound when struck by the shotcrete.

535.2.7 Fiber Reinforcement

Synthetic Fibers shall meet the requirements of ASTM C1116. The Contractor shall provide a certification of conformance.

Steel fibers should meet the requirements set forth in ASTM A820. The Contractor shall provide a certification of conformance.

535.2.8 Prepackaged Product

For non-structural shotcrete; a pre-mixed and prepackaged concrete product, with or without steel fibers, specifically manufactured as a shotcrete product for on-site mixed shotcrete, may be used if approved by the City Engineer or designee. The material shall meet the requirements of ASTM C1480 and have a minimum strength of 3,000 psi at 28 days for non-structural Shotcrete.

535.2.9 Acceptance Sampling and Testing for Structural and Non-Structural Shotcrete

The Contractor shall apply shotcrete to approved test panels. The Contractor shall orient the spray nozzle to the test panel in the same position as that used on the actual Project. The Contractor shall provide test panels constructed in accordance with the requirements of ASTM C 1140. The Contractor shall use test panels with the following characteristics:

1. Minimum dimensions of 30 inch² × eight (8) inch deep;
2. Constructed from wood and sealed plywood; and
3. 45° sloped sides to allow rebound to escape.

The Contractor shall use at least one (1) pre-construction trial to do the following:

1. Obtain test cores to confirm compliance with the required hardened properties in accordance with the approved mix design.
2. For structural Shotcrete only, pre-qualify the proposed nozzle operator and strike-off persons. The City of Rio Rancho will not allow nozzle operators and strike-off persons who have not been pre-qualified to apply shotcrete on the Project. Each nozzle operator and strike-off person shall shoot pre-construction test panels in the presence of the City Engineer or designee. Each shotcrete operation shall have staff with a minimum of the following qualifications:
 - 2.1. Supervisor, at least one (1) year of experience as a shotcrete nozzle operator and at least two (2) years of experience on shotcrete Projects.
 - 2.2. Nozzle operator and delivery equipment operators, at least one (1) year of apprenticeship on similar applications with the same type of equipment.
 - 2.3. Nozzle operators shall be ACI Certified Shotcrete Nozzle Operators.

The Contractor shall perform curing, coring, and testing of the shotcrete test panels and specimens at a Private Testing Laboratory (PTL) approved by the City Engineer or designee for concrete mix designs.

The Contractor shall provide one half of the test panels with reinforcement and anchors representative of the same size and spacing required in the contract for the actual Work. The Contractor shall provide the remaining panels with no reinforcement to allow for extraction of shotcrete test cores for compliance testing.

Each nozzle operator proposed for use on the Project shall shoot at least one (1) test panel at each orientation.

The Contractor shall obtain three (3) cores from each test panel for testing at the designated ages for the specified performance parameters. The Contractor shall extract an additional minimum of three (3) four (4) inch diameter cores from locations of intersecting reinforcing steel and mesh to check the adequacy of consolidation of shotcrete around and behind the reinforcement. One (1) of these shall be taken at an anchor location.

The PTL will evaluate the quality of the extracted cores and test panels and provide a written report to the City Engineer or designee. If the PTL or City Engineer or designee rejects a prequalification test panel, the Contractor shall have the nozzle operator shoot a second test panel. If the second test panel is also rejected, the Contractor shall not allow the nozzle operator to shoot on the Project until the operator completes an appropriate training program and prepares an acceptable test panel.

The Contractor shall transport test panels in the wooden forms with care to not crack or damage the specimens.

The Contractor shall place the test panels in a moist room in the Laboratory that is maintained at a temperature of $73\text{ }^{\circ}\text{F} \pm 3\text{ }^{\circ}\text{F}$, and a relative humidity of $98 \pm \text{two percent (2\%)}$. After three (3) days, the Contractor shall remove the test panels from the wooden forms and return them to the moist room until testing time.

If there are changes in materials, equipment, or nozzle operators during the work, additional test panels will be provided by the Contractor as directed by the City Engineer or designee.

535.2.9.1 Production Testing for Structural Shotcrete

The Contractor shall shoot two (2) construction test panels for each nozzle orientation and for each nozzle operator each day of shotcrete production in the presence of the City Engineer or designee. The Contractor shall shoot one (1) set of panels for each nozzle operator in the morning and one (1) set of panels for each nozzle operator in the afternoon for a full day's production.

The Contractor shall produce test panels in accordance with ASTM C 1140, a minimum twelve (12) inch² × eight (8) inch deep. The Contractor shall use test panels constructed of wood and sealed plywood with 45° sloped sides to permit escape of rebound. The Contractor shall provide construction test panels that contain no reinforcement or embedment elements.

The Contractor shall store, handle, and cure construction test panels the same as specified for pre-construction test panels. The Contractor shall prepare test specimens the same as specified for pre-construction test specimens.

The Contractor shall use compressive strength test specimens that are four (4) inch × eight (8) inch cores (length/diameter ratio of 2:1). The mean compressive strength is acceptable if the average of three (3) cores tested at the specified age is equal to or greater than 85% of the specified strength, with no individual strength test being less than 75% of the specified strength.

The Contractor shall correct unacceptable shotcrete sections at no additional cost to the City.

535.3 CONSTRUCTION REQUIREMENTS

535.3.1 Equipment

535.3.1.1 Shotcrete Placing Equipment

The Contractor shall apply wet mix shotcrete with one (1) of the following methods:

1. The "thick-stream" method, which involves the use of a regular concrete pump with air addition at the discharge nozzle to pneumatically apply the shotcrete on the receiving surface. The "thick-stream" method usually uses a two (2) inch to 2-1/2 inch internal diameter delivery hose.
2. The "thin-stream" method, which normally involves the use of a pressurized chamber to pneumatically send the shotcrete down the delivery hose to the receiving surface. The "thin-stream" method normally uses a hose with a maximum 1-1/2 inch internal diameter.

The Contractor shall only use the "thin-stream" method for non-structural shotcrete if pre-construction testing confirms the capability to properly consolidate shotcrete, fully encase reinforcing steel, and produce a material that meets the required hardened properties.

The Contractor shall use shotcrete delivery equipment in accordance with ACI 506R and that is capable of delivering a steady stream of uniformly mixed material to the discharge nozzle at the proper velocity and rate of discharge.

The preferred type of the wet-mix shotcrete delivery system uses positive displacement pumps equipped with hydraulic or mechanically powered pistons (similar to conventional concrete piston pumps), surge-reduction devices, and compressed air added at the discharge nozzle. The Contractor

may use pneumatic-feed guns, rotary-type feed guns (similar to dry-mix guns), and peristaltic squeeze-type pumps if the Contractor demonstrates that the guns can produce shotcrete in accordance with the performance requirements and the City Engineer or designee approves.

The Contractor shall carefully monitor the air ring at the nozzle for signs of blockage of individual air holes. If non-uniform discharge of shotcrete becomes apparent, the Contractor shall stop shooting and clean the air ring or take other appropriate corrective actions.

The Contractor shall thoroughly clean the delivery equipment at the end of each shift. The Contractor shall remove build-up of coatings in the delivery hose and nozzle liner. The Contractor shall regularly inspect the air ring and nozzle and replace as necessary.

535.3.1.2 Auxiliary Shotcrete Equipment

The Contractor shall supply a clean, dry air supply capable of maintaining sufficient nozzle velocity and simultaneous operation of a blow pipe.

The Contractor shall use an air supply system with a moisture and oil trap.

The Contractor shall provide auxiliary shotcrete equipment, such as air delivery hoses, blow pipes, couplings, admixture dispensers, and fiber feeders, in accordance with the recommendations of ACI 506R.

535.3.2 Batching and Mixing Shotcrete

535.3.2.1 Wet Mix Process

The Contractor shall batch, mix, and supply wet mix shotcrete using one (1) of the following systems:

1. Central Mixing with transit delivery; or
2. Transit mixing and delivery.

535.3.2.1.1 Central Mixing and Supply

The Contractor shall batch and mix ingredients and provide inspected transit mixers in accordance with Section 500 Portland Cement Concrete Materials and Section 505 Concrete Placement and Finishing.

The Contractor may only re-temper the shotcrete once with superplasticizer added directly to the transit mixer during the period of discharge to maintain workability (slump) of shotcrete. The Contractor shall mix the shotcrete for a minimum period of five (5) min at the rated mixing speed after adding the superplasticizer to the transit mixer.

The Contractor shall shoot shotcrete within ninety (90) minutes of adding mix water to the batch. The Contractor shall use appropriate shotcrete batch sizes per load to meet this requirement.

535.3.2.1.2 Transit Mixing and Supply

The Contractor shall apply central mixing requirements to transit mixing, except add ingredients directly to the transit mixer, not the central mixer. The Contractor shall not charge transit mixers to more than 70% of their rated capacity.

535.3.2.2 Dry Mix Process for Non-Structural Shotcrete

The Contractor shall batch the cement and aggregate by weight directly at the Project site within the tolerances required in Section 500 Portland Cement Concrete Materials.

The Contractor shall pre-dampen the dry mix before flow into the main hopper and immediately after flow out of the packaging to ensure uniform shotcrete free of dry pockets.

The Contractor shall not use pre-dampened cement/aggregate mixtures that are more than ninety (90) minutes old or that are unable to produce the specified hardened properties.

535.3.2.3 Batching and Mixing Steel Fibers

The Contractor shall submit the procedure used for adding steel fibers to the shotcrete to the City Engineer or designee for approval. The Contractor shall demonstrate the procedure in the field to the satisfaction of the City Engineer or designee before starting production operations.

If fiber addition takes place at the nozzle, the Contractor shall uniformly distribute fibers throughout the mortar matrix without isolated concentrations (clumping or balling).

If adding fibers to the dry or wet mix during the batching and mixing process, the Contractor shall use a screen with a mesh of from 1-1/2 inch to 2-1/2 inch to prevent fiber balls from entering the shotcrete line. The City Engineer or designee will not require batching through a screen if the Contractor demonstrates that fiber balls are not forming.

The Contractor shall not add fibers to the dry or wet mix too quickly (so they can be blended with the other ingredients without forming balls or clumps). The Contractor shall use a vibrating screen or sift to pass bulk fibers (that have a tendency to stick) into the mix as individual elements and not as clumps.

535.3.2.4 Preparation and Hardware

535.3.2.4.1 Subsurface Preparation

The Contractor shall locate and remove loose, spalled, deteriorated, and delaminated concrete, stone, or other substrate. The Contractor shall use hammer sounding to locate specific de-laminated areas of concrete or rock. The Contractor shall not damage areas of sound concrete or reinforcing steel during concrete removal operations.

The Contractor shall remove concrete using one (1) or more of the following methods:

1. Chip with light duty pneumatic, or electric, chipping hammers (not to exceed 15 lbs.).
2. Scarifiers, scabblers or other suitable mechanical means.
3. High-pressure (15,000 psi to 40,000 psi) water jetting. (If using water jetting, do not allow water to collect so that surrounding areas are not contaminated or damaged).

If the Contractor exposes corroded reinforcing steel, the Contractor shall continue concrete removal until there is a minimum 3/4 inch clearance around the exposed, corroded reinforcing bar. The Contractor shall not damage the bond to adjacent non-exposed reinforcing steel during concrete removal.

The Contractor shall taper the perimeter of removed concrete areas at approximately 45° angles. The Contractor shall sawcut the outer edges of chipped areas to a minimum depth of 3/4 inch to avoid feather edging.

The Contractor shall use abrasive blast cleaning to remove fractured surface concrete and traces of unsound material or contaminants, such as oil, grease, dirt, slurry or materials that could interfere with the bond of the freshly placed shotcrete. The Contractor shall apply shotcrete to abrasive blast cleaned areas within fourth-eight (48) hours or re-blast them. The City Engineer or designee may waive the requirement for abrasive blast cleaning where the Contractor performed concrete removal with high-pressure water blasting and the prepared surface is free of residual slurry or other material detrimental to an acceptable shotcrete bond.

The Contractor shall install reinforcement in slope blankets that do not contain steel reinforcement. Unless otherwise specified, the reinforcement will consist of No. 4 steel reinforcing bars placed with maximum spacing of 12 inch for vertical and horizontal bars. The Contractor shall rigidly attach this reinforcement to the underlying forms or concrete structure. The Contractor shall remove dust, debris, or laitance generated by this process in accordance with these abrasive blast cleaning procedures.

535.3.2.4.2 Repair or Replacement of Steel Reinforcement

If the Contractor exposes corroded reinforcing steel during concrete removal, the Contractor shall remove corrosion using abrasive grit blasting.

The Contractor shall remove and replace reinforcing steel displaying deep pitting or loss of more than 20% of cross-sectional area as directed by the City Engineer or designee. If pitting is isolated, the Contractor shall reinforce the steel by adding appropriately placed reinforcing bars of suitable length (the existing reinforcing steel need not be cut).

535.3.2.4.3 Steel Reinforcement

The Contractor shall use a minimum lap splice length of reinforcing steel that is in accordance with the AASHTO LRFD Bridge Design Specification. The Contractor shall place these bars in accordance with ACI 506R, Sections 5.4 and 5.5. In particular, the Contractor shall not bundle bars in lapped splices; place them so the minimum spacing around each bar is three (3) times the maximum aggregate size to allow for proper shotcrete encapsulation.

The Contractor shall tightly secure intersecting reinforcing steel bars to each other using 12 gauge or heavier tie wire and adequately support them to minimize vibration during shotcrete placement. The Contractor shall place welded wire mesh fabric in accordance with the contract. The Contractor shall lap sheets of adjoining mesh by at least two (2) spaces in both directions at intersections, and securely fasten.

The Contractor shall fasten mesh to preset or existing anchors and reinforce using 12 gauge or heavier tie wire on a grid not less than 12 inch². The Contractor shall avoid large knots of tie wire that could result in sand pockets and voids during shotcreting.

The Contractor shall provide a minimum clearance of 3/4 inch behind installed reinforcing steel or mesh and existing concrete forms or bare rock.

535.3.2.4.4 Structural Anchors

Unless otherwise specified in the contract, the Contractor shall place anchor bars (for structural applications) at a maximum spacing of twenty-four (24) inches on a grid pattern over the entire area. The Contractor shall provide the types of anchors in accordance with the contract and either mechanically set or grout, as specified. The anchors shall be located so there is no damage to existing steel reinforcing or conduits in the concrete.

The Contractor shall ensure anchors develop the minimum pullout force in accordance with the contract. The Contractor shall randomly test anchors in the presence of the City Engineer or designee at a frequency in accordance with the contract to verify pullout force. The City Engineer or designee will not accept a pullout force less than 150 lbs.

If anchors fail to meet the minimum acceptable pullout value, the Contractor shall remove and replace immediately and take corrective action. Also, the Contractor shall test the anchors in the same relative location as those that failed. The City Engineer or designee will determine the area for corrective measures.

535.3.2.4.5 Non-Structural Anchors

For non-structural applications (slope blankets, etc.), the Contractor shall install anchor bars at ten (10) foot centers on a grid pattern over the entire area in one (1) inch diameter holes drilled into the rock or soil approximately twenty-four (24) inches deep.

The Contractor shall completely fill the drilled hole with neat cement grout using a grout tube extending to the bottom of the hole.

The Contractor shall push the anchor bar into the grout-filled hole and center it such that the short leg of the "L"-shaped bar points upward and parallel to the slope and is located approximately 1-1/2 inches from the rock or soil surface.

535.3.2.4.6 Weep Holes

For slope blankets, the Contractor shall provide weep holes throughout the shotcrete mat on maximum ten (10) foot centers, horizontally and vertically.

The weep hole drains will consist of two (2) inch diameter Schedule 40 PVC slotted drainpipe, two (2) feet in length, placed within predrilled holes and sloped five percent (5%) to drain. The exposed end will extend from one (1) inch to three (3) inch outside the slope.

The City Engineer or designee will not allow pre-drilled holes with diameters larger than three (3) inches.

The Contractor shall install the slotted drainpipe before placing shotcrete. During placement of shotcrete, the Contractor shall protect weep holes and drainpipes against contamination.

535.3.2.4.7 Alignment Control and Cover

The Contractor shall implement alignment control (to establish control over line and grade), and maintain the minimum specified shotcrete thickness and cover of reinforcing steel as specified in the contract.

The Contractor shall perform alignment control with shooting wires (also called ground wires), guide strips, depth gauges, or forms. The Contractor shall submit the proposed means of alignment control to the City Engineer or designee for review and approval prior to shotcrete placement.

The Contractor shall use shooting wires that are at least “piano wire”–sized high-strength steel wire combined with a turnbuckle and spring coil. The Contractor shall remove shooting wires after completion of shotcreting and screeding operations.

The Contractor shall not let guide strips and forms impede the ability of the nozzle operator to produce uniform, dense, properly consolidated shotcrete. The Contractor shall not use alignment control material that causes the formation of sand-pockets and voids.

If using depth gauges for alignment control, the Contractor shall space no greater than four (4) foot in a grid pattern. The Contractor shall cut back metal depth gauges to 1/4 inch below the finished surface.

535.3.3 Quality Assurance and Quality Control Testing

535.3.3.1 Quality Assurance

The City Engineer or designee will implement a Quality Assurance Program for the shotcrete Work. The program will include the following:

1. Review of Contractor submittals;
2. Review of the approval of Contractor-proposed materials, supply, equipment, and crew. In particular, evaluation in the pre-construction testing program of shotcrete nozzle operator and strike-off person proposed for use on the Project; the City Engineer or designee will allow only nozzle operators and strike-off persons approved in writing by the City Engineer or designee to perform Work;
3. Examination and approval (before application of any shotcrete) of areas prepared for shotcreting, including installation of anchors, reinforcement, and alignment control devices;
4. Provision of Inspectors to monitor shotcrete installation and authority to require removal and replacement of defective shotcrete while still plastic;
5. Regular monitoring of Quality Control testing results;
6. Implementation of a program for in-place evaluation and acceptance or rejection, if test results indicate shotcrete is unacceptable; and
7. Implementation of a program of remedial work at the Contractor’s expense, if the Quality Assurance Program deems it necessary.

535.3.3.2 Quality Control Testing

The Contractor shall provide an independent testing Laboratory to establish and maintain a Quality Control program for the shotcrete work to ensure compliance. Such a program will include, but not be limited to, the following:

1. Maintenance of test records for Quality Control operations; and
2. Physical testing in accordance with Section 535.2.9.1 for the confirmation of compliance with the specified hardened shotcrete properties.

535.3.4 Safety and Cleanup

535.3.4.1 Preparation

The Contractor shall implement a safety program during shotcreting to do the following:

1. Protect the structural integrity of structural elements (by shoring or other suitable means) during concrete and reinforcing steel removal operations.
2. Protect personnel from falling debris, blasting grit, and high-pressure water jets during concrete removal processes.

The Contractor shall submit a disposal plan to the City Engineer or designee for approval and shall properly dispose of debris, blasting grit, and hydro-demolition and water-jetting slurry in accordance with the approved plan.

535.3.4.2 Shotcrete Operations

The Contractor shall implement a safety program using hoarding, shrouds, screens, or other appropriate measures to protect personnel and surrounding property from pneumatically applied shotcrete over-spray and rebound materials during the shotcrete application process.

Personnel working near the shotcreting operation, including nozzle operator, strike-off persons, nozzle operator's helpers, supervisors, and Inspectors, shall wear appropriate protective equipment. Such equipment includes, but is not limited to, safety helmet, safety boots, gloves, appropriate clothing, safety glasses with side enclosures, and dust masks.

Nozzle operator's helpers shall keep a supply of water, cloth or towel, and backup safety glasses available for the nozzle operator so satisfactory vision can be maintained during shooting operations. The Contractor shall provide sufficient lighting so the nozzle operator has a clear view of the work.

The Contractor shall provide readily available eyebaths and wash facilities in the immediate vicinity of the shotcrete application. The shotcrete crew shall apply appropriate skin protection and adopt work hygiene to protect against cement or accelerator alkali burn.

The Contractor shall install sufficient lighting and ventilation to provide the nozzle operator and helpers with clear, unhindered view of the shooting area. The Contractor shall terminate work and adopt corrective measures if, in the opinion of their Project Safety Officer, visibility is unsuitable for the safe application of quality shotcrete.

535.3.4 Shotcrete Application and Finishing

535.3.4.1 Shotcrete Application

The City Engineer or designee will review and approve areas prepared for shotcrete application before application of shotcrete.

The Contractor shall flush surfaces with water at least one (1) hour before application of shotcrete. The Contractor shall allow flushed surfaces to dry back to saturated surface-dry condition before application of shotcrete. If necessary, the Contractor shall use a blowpipe with oil-free compressed air to facilitate removal of surface water. For very porous and dry substrates, the Contractor shall saturate the substrate the day before shotcreting and then re-wet before shooting as described above.

The Contractor shall apply shotcrete in accordance with ACI 506R, except that if using silica-fume modified shotcrete; the Contractor may apply the full thickness of shotcrete in a single layer. The Contractor shall use the minimum number of layers required to build up the full thickness of shotcrete without sagging, separation, or sloughing. Wherever possible, the Contractor shall apply shotcrete to the full thickness in a single layer.

If using multiple-layer shotcrete construction, the Contractor shall prepare the first layer with one (1) of the following methods before applying a subsequent layer:

1. Broom the stiffening layer with a stiff bristle broom to remove loose material, rebound, over-spray, or glaze, before the shotcrete attains initial set.
2. If the shotcrete has set, delay surface preparation at least twenty-four (24) hours, then prepare the surface by sandblasting or high-pressure water blasting to remove loose material, rebound, hardened over-spray, glaze, or other material detrimental to good bond.

When successive layers of shotcrete are necessary to build up full shotcrete thickness, the Contractor shall prevent the first layer from drying out with fogging or wetting. The Contractor shall only use curing compound with the approval of the City Engineer or designee. If using a curing compound, the Contractor shall remove it by abrasive blast cleaning or high-pressure water blasting, before application of the next layer of shotcrete. The Contractor shall clean the first layer of shotcrete of surface water and ensure it is in a saturated surface-dry condition when applying the next shotcrete layer.

The Contractor shall exercise care to protect adjacent surfaces from buildup of rebound and over-spray. The City Engineer or designee will not allow rebound and over-spray in or on the completed work. The Contractor shall remove rebound and over-spray from surfaces to receive shotcrete while the material is still plastic, using blowpipes, scrapers, wire brushes, or other suitable tools. The Contractor shall remove hardened rebound and overspray with abrasive blast cleaning, chipping hammers, high-pressure water blasting or other suitable techniques before applying additional shotcrete.

The Contractor shall provide scaffolding or other devices so the nozzle operator and helpers have free, unhindered access to the work area.

The Contractor shall apply shotcrete from the nozzle in accordance with ACI 506R.

The Contractor shall not apply shotcrete during periods of rain or high wind, unless suitable protection is provided.

The Contractor shall apply shotcrete in accordance with the Contract using shooting wires, depth gauges, guide strips, forms, or other suitable devices. The Contractor shall apply the minimum cover of shotcrete to reinforcing steel in accordance with the contract. The Contractor shall cut back metal depth gauges to within 1/4 inch of the shotcrete surface, to prevent corrosion staining of the surface.

When applying a 3/8 inch maximum aggregate size shotcrete, the Department will allow a final flash coat layer (1/4 inch to 3/4 inch thick) using 1/4 inch aggregate shotcrete.

The Contractor shall provide construction joints as required in the contract.

535.3.4.2 Shotcrete Finishing

The Contractor shall leave shotcrete in the natural gun finish unless otherwise specified in the contract.

If the contract requires finishing, the Contractor shall cut back shotcrete to line and grade using cutting rods, screeds, or other suitable devices. Any low spots or depressions shall be brought up to proper grade by placing additional material. The Contractor shall allow shotcrete to stiffen sufficiently before cutting and trimming, to prevent the formation of tears, cracks, and delaminations. The Contractor shall remove shooting wires on completion of cutting and trimming.

The Contractor shall apply one (1) or more of the following finishes, if required:

1. Wood float finish, either as a preliminary finish for other surface treatments, or as a granular texture finish.
2. Rubber float finish, applied to either a flash coat or wood float finish, to produce a finer textured granular finish.
3. Brush finish, a fine hairbrush float finish that leaves a finely textured, sandy finish.
4. Steel trowel finish that leaves a dense, smooth hard finish.

The Contractor shall trim back shotcrete and over-spray from adjacent non-prepared concrete surfaces. The Contractor shall provide the edges of shotcrete repairs with a minimum square saw-cut edge 3/4 inch deep; finish shotcrete up to this edge. The Contractor shall not featheredge shotcrete (including flash coats).

535.3.4.3 Curing and Protection

On completion of finishing, the Contractor shall immediately prevent shotcrete from drying out by fogging or wetting.

If the Contract requires leaving shotcrete with a natural gun finish, the Contractor shall apply curing compounds at twice the application rate normally specified for smooth concrete finishes. The Contractor shall completely remove curing compounds by abrasive blasting or water blasting (with a pressure of 3,000 psi) before application of subsequent sealers.

Once the shotcrete achieves its final set, the Contractor shall keep it continuously moist for at least seven (7) days. The Contractor shall perform moist curing using one (1) or both of the following procedures:

1. Wrap the elements in wet burlap presoaked in water for twenty-four (24) hours before installation; wrap the wet burlap in plastic sheet to slow the drying rate of the burlap.
2. Install sprinklers, soaker hoses, or other devices that keep the shotcrete continuously wet. Do not use intermittent wetting procedures that allow the shotcrete to undergo cycles of wetting and drying during the curing period.

535.3.4.4 Hot and Cold Weather Protection

The Contractor shall apply shotcrete during periods of hot and cold weather in accordance with ACI 305R and ACI 306R.

If it is anticipated that shotcrete will be placed when the ambient temperature will fall below 35 °F, a Cold-Weather Shotcrete Plan must be prepared and submitted to the City Engineer or designee for approval at least 30 days before the intended application. The Cold Weather Shotcreting Plan must be reviewed and approved by the City Engineer or designee before shotcrete is permitted to be placed at temperatures below 35 °F.

The Contractor shall monitor the surface evaporation of the shotcrete in accordance with Section 505.3.7.2.3. The Contractor shall not proceed with shotcrete application if the average rate of surface evaporation of the shotcrete over any ten (10) minute period exceeds 0.2 lbs. per square foot per hour.

The Contractor shall not allow the prevailing ambient conditions (relative humidity, wind speed, air temperature, and direct exposure to sunlight) to cause either plastic shrinkage or early drying shrinkage cracking.

All cracked structural shotcrete, regardless of the cause, shall be removed and replaced at no cost to the City.

Subsequent efforts to prevent further cracking problems shall include, but not be limited to:

1. Rescheduling of the work to a time when more favorable ambient conditions prevail; and
2. Adopt corrective measures, such as installation of sunscreens, windbreaks, or fogging devices to protect the work.

During periods of cold weather, shotcreting may only proceed if the substrate to which the shotcrete is applied and the air temperature in contact with the shotcrete surfaces are both above 50 °F.

The Contractor shall maintain the air temperature in contact with the shotcrete surfaces at 60 °F or greater for at least four (4) days after application of shotcrete. The Contractor shall submit the means of maintaining the air temperature to the City Engineer or designee for approval. The Contractor shall not use unvented heaters.

The Contractor shall apply shotcrete at a temperature of between 50 °F and 90 °F. The Contractor shall use cooler mix temperatures during hot-weather shotcrete operations and warmer mix temperatures during cold-weather shotcrete operations.

535.3.4.5 Inspection and Remedial Work

The Contractor shall sound the surface of the cured shotcrete with a hammer to locate unsound areas.

The Contractor shall provide equipment, hardware, and means necessary to perform the inspection operations. The inspection accommodations are subject to the approval of the City Engineer or designee.

The Contractor shall cut out and replace sags or other defects with another layer. If welded wire mesh reinforcement is damaged or destroyed by such repairs, the Contractor shall repair the damaged area by overlapping and tying additional wire mesh in accordance with this section.

535.4 METHOD OF MEASUREMENT

The shotcrete will be measured using the dimensions shown in the contract with approved modifications by the City Engineer or designee.

535.5 BASIS OF PAYMENT

Payment by the unit price for shotcrete shall be considered full compensation for all labor, materials, and equipment associated with providing a complete in-place installation. This includes, but is not limited to cement, aggregate, water, reinforcement, furnishing and installing steel anchors, slotted pipe, ties, laboratory testing and test molds, test samples, submittals, boring, cores, grouting, removal of deteriorated or unsound concrete, mixing, placing, and curing shotcrete placed concrete.

Pay Item	Pay Unit
Structural Shotcrete	Square Yard
Non-structural Shotcrete	Square Yard