Construction Specification 33 – Shotcrete

1. Scope

The work shall consist of furnishing, mixing, applying and curing shotcrete. Except as otherwise specified, either a dry mix or wet mix process may be used.

2. Material

Portland cement shall conform to the requirements of Material Specification 531 PORTLAND CEMENT 531 for the specified type.

Aggregates shall conform to the requirements of Material Specification AGGREGATES FOR PORTLAND CEMENT CONCRETE 522 unless otherwise specified. Gradation shall be one of the three options specified by ACI 506R, table 2.1, unless otherwise specified.

Admixtures, if specified, shall meet the requirements indicated. Nonchloride chemical admixtures shall conform to ASTM C 494. Air-entraining admixtures shall conform to ASTM C 260. Fly ash or pozzolanic material shall conform to ASTM C 618. Calcium chloride shall conform to ASTM D 98 and shall be in flake or pellet form.

Water used in mixing or curing shotcrete shall be clean and free from injurious amounts of oil, salt, acid, alkali, organic matter, or other deleterious substances.

Curing compound shall conform to the requirement of Material Specification CONCRETE CURING COMPOUND 534.

3. Strength and Quality

The compressive strength of shotcrete at the age of 28 days shall be not less than specified in Section 19 of this specification.

Shotcrete shall be uniform and dense, free from "drummy" areas that indicate laminations, voids, sand pockets, or disbonded material.

4. Consistency

The proportion of water added to the mixture shall be accurately controlled to produce thorough and uniform hydration of the shotcrete. The consistency of the shotcrete shall be such that the surface of the shotcrete in place shall have a rich, glossy appearance and that the shotcrete shall adhere to the supporting surface without flowing, slumping, or sloughing. For application to vertical or overhanging surfaces, the mix proportions shall be adjusted so that the placed shotcrete will adhere to a minimum thickness of 0.75 inch without sagging or sloughing. For adjustment of consistency, fly ash or pozzolanic material can be added to the mixture in amounts of no more than 20 percent (by weight) of cement in the mixture.

5. Inspection and Testing

Procedures for preparing shotcrete test panels and the testing specimens sawed or cored from panels will be performed in accordance with ASTM Method C 1140. The compression test specimens will be cores taken from the test panels or from the structure.

Similar panels not less than 18 inches square and not less than 6 inches thick shall be made periodically as directed by the engineer during the progress of the work.

Cores taken from the test panels shall receive standard curing in lime-saturated water at 73.4°F$\pm$3.0°F within 24 hours after removal. Cores shall continue to receive the prescribed initial cure treatment until standard curing is commenced.

For each strength test, three cores will be tested in compression. The test result will be the average of the strengths of the three specimens except that if one specimen shows manifest evidence of improper sampling, coring, or testing, it will be discarded and the strengths of the remaining two specimens will be averaged. If more than one specimen representing a test shows such defects, the entire test will

be discarded.

The contractor shall furnish the forms and make the required test panels and shall provide such facilities, material, and assistance as may be necessary for curing, handling, and protecting the panels. Test panels shall be cast only when the engineer is present.

6. Nozzle Operator Qualifications

The nozzle operator shall be able to document a minimum of 3,000 hours of experience as a nozzle operator and shall have completed at least one similar application as a nozzle operator, unless otherwise specified.

The nozzle operator and application crewmembers shall be required to meet pre-construction testing requirements administered by the engineer on a test panel or an area. The engineer will carefully observe shooting of the test panel or area and note if the nozzle operator examinee:

a. Cleans the shooting surface with air and water before shooting.
b. Applies a bonding coat on the shooting surface ahead of the heavier shotcrete applications
c. Directs shotcrete application around reinforcement in a manner that prevents buildup on the face of the reinforcement and allows the shotcrete to flow and compact tightly around the back of the reinforcement.
d. If applicable, directs the finisher or nozzle helper to cut out any sags, sand, or rebound pockets.
e. If applicable and where necessary, directs the finisher or nozzle helper to broom the shotcrete surface before application of additional layers.

7. Measuring Material

The proportions of the shotcrete mix shall be controlled on the basis of the weight of each component material, unless otherwise specified in Section 19 of this specification, except that water may be measured by volume. Material shall have the following batch

tolerances of the mix proportion weights: cement, plus or minus 2 percent; aggregate, plus or minus 4 percent; and admixtures, plus or minus 6 percent. Weighing equipment used shall be accurate to within 0.4 percent of scale capacity.

8. Equipment

The contractor shall furnish all equipment necessary for batching, mixing, and placing the shotcrete. The equipment shall meet the following requirements.

The placing equipment for dry mix shotcrete shall be designed and equipped to receive the dry mix, introduce the mix into a stream of compressed oil free dry air, convey the mix pneumatically through a delivery hose to a nozzle at the point of discharge, inject water under pressure into the suspended stream of dry sand and cement within the nozzle, and spray the resulting shotcrete mix onto the surface of the work at a uniform rate and at a controlled velocity. The placing equipment shall be equipped with accurate gauges to indicate the air pressure and water pressure and with devices capable of accurately controlling the air pressure at any level between 50 pounds per square inch and 80 pounds per square inch, the water pressure at any level between 50 pounds per square inch and 100 pounds per square inch, and the rate of application of water at the nozzle.

The placing equipment for wet mix shotcrete shall be designed and equipped to receive the shotcrete from the mixer, convey it through a delivery hose to a nozzle at the point of discharge, accelerate it in the nozzle by means of compressed oil-free dry air, and spray it onto the surface of the work. It shall be capable of delivering shotcrete to the nozzle uniformly and continuously and discharging it from the nozzle at a uniform rate and at a controlled velocity sufficient for all parts of the work.

Batch and continuous mixing equipment shall include a power-driven mixer capable of thoroughly mixing the material at a rate adequate to ensure uniform feeding of the mixture to the placing equipment and a feeding apparatus capable of supplying the mixture to the placing

equipment at an adequate and uniform rate.

9. Mixing

Dry Mix Shotcrete – The cement and admixtures and other additives (except accelerator) shall be mixed into a predampened homogeneous mass that thoroughly coats the aggregate before being fed through a vibratory screen into the placing equipment. Proper predampening shall be indicated by the ball-in-hand test as follows: When a small amount of mix is tightly squeezed, the resulting ball holds together or cracks slightly, but essentially remains whole. The mix has too little predampening moisture if the ball crumbles into discrete particles when the hand is opened and/or color is light gray. If moisture comes off on the hand, too much predampening moisture is in the mix. The properly predampened dry mix shall be used within 45 minutes after mixing (15 minutes in hot weather conditions where the temperature is over 85°F). Any material that dries out or cakes after mixing shall be wasted. Rebound mate- rial shall not be remixed or reused.

Wet Mix Shotcrete – Air-entrainment and chemical admixtures may only be used in wet mix concrete. The cement, sand, admixtures (except accelerator), and water shall be thoroughly mixed in the mixer drum sufficiently to produce shotcrete of the required consistency. It must be uniform within each batch and uniform from batch to batch when discharged into the placing equipment. Accelerators, if specified, shall be mixed at the nozzle. Ready-mix concrete shall conform to the requirements of ASTM C 94 unless otherwise specified.

The entire contents of the mixer shall be discharged from the drum before material for a succeeding batch is placed therein. A mix that becomes difficult to pump shall be discarded; otherwise, a batch shall be gunned within 1.5 hours of batching in normal weather and within 45 minutes during hot weather conditions (temperatures over 85°F). Rebound material shall not be remixed or reused.

10. Forms

Forms shall be structurally adequate and of such design that rebound or accumulated loose sand can freely escape or be readily removed. Shooting strips shall be used at corners, edges, and on the surface where necessary to obtain true lines and proper thickness. Where practicable, ground wires shall be installed as guides to accurately establish the specified contour of the finished surface of shotcrete. Ground wires shall be set and used as guides for templates in forming curved and molded surfaces. When shotcrete is to be placed on a horizontal or sloping surface, headers and ground wires shall be provided to the extent necessary to ensure control of slab thickness. Ground wires shall be tightened and kept taut, secure, and true to line and plane during placement of shotcrete and shall be removed when placement is completed.

Header boards are required where the drawings indicate a square edge and at required joints. Form surfaces shall be thoroughly cleaned and a form release agent applied before shotcrete is placed.

11. Preparation of Surfaces to Receive Shotcrete

All surfaces to receive or support shotcrete shall be carefully prepared and conditioned. All such pre- pared surfaces shall be inspected and approved by the engineer before the application of shotcrete.

Earth surfaces to which shotcrete is to be applied shall be firmly compacted and neatly trimmed to line and grade.

Asphaltic concrete surfaces shall be thoroughly cleaned of any growths, earth, or any other material that would affect bond or be detrimental to the shotcrete.

Concrete, mortar, or rock surfaces shall be thoroughly cleaned by water blasting or sand blasting to remove all dirt, laitance, weak or unbonded mortar, loose material, grease, or other deleterious sub- stances.

Surfaces on which the shotcrete is to be placed shall be sufficiently rough to ensure the adherence of the shotcrete. Offsets that would cause an abrupt and substantial change in thickness of the shotcrete shall be removed or tapered.

All surfaces shall be maintained in a moistened condition for 3 hours before application of shotcrete. Shotcrete shall not be applied to mud, dried earth, uncompacted fill, rebound material, or surfaces on which free water exists unless otherwise specified in Section 19. All ice, snow, and frost shall be removed, and the temperature of all surfaces to be in contact with the new shotcrete shall be no colder than 40°F.

12. Placing

The contractor shall have all equipment and material required for curing available at the site and ready for use before placement of shotcrete begins. No shotcrete shall be placed except in the presence of the engineer or authorized representative. The contractor shall give reasonable notice to the engineer each time shotcrete placement is scheduled. Such notice shall be far enough in advance to give the engineer adequate time to inspect the surfaces to which the shotcrete is to be applied, the forms, steel reinforcement, and other preparations for compliance with the specifications before the start of placement operations.

During placement of shotcrete, the air pressure shall be adjusted as required to control rebound and density of shotcrete. For a given application, once the optimum operating pressures have been established, they shall be maintained constantly throughout the application. For dry mix shotcrete, the air pressure at the material outlet or air inlet on the gun shall be not less than 40 pounds per square inch plus 5 pounds per square inch for each 50 feet of length of the discharge hose greater than 100 feet and 5 pounds per square inch for each 25 feet the nozzle is above the gun (shotcrete delivery equipment). The water pressure at the nozzle shall be not less than 15 pounds per square inch greater than the air pressure at the material outlet or air inlet on the gun.

For most applications the placing nozzle shall be held between 2 and 6 feet from and approximately normal to the surface of the work. At a longer distance the nozzle velocity may need to be increased so that the impact velocity suits the requirements of the application. Corners shall be filled first.

Shotcrete shall be applied in a single thickness or to a layer thickness no greater than that which will cause sagging, sloughing, or dropout. Sags and sloughs shall be cut out and regunned. Replacement shall be accomplished before the previously placed shotcrete has completely set. When shotcrete is placed on a vertical surface, application shall be started at the bottom and be completed at the top.

In any case when the placing of shotcrete is interrupted for more than 1 hour, the edge of the layer shall be sloped off at an angle of about 45 degrees to the surface being shot, and the sloped part shall be covered with a double layer of 6-ounce burlap and kept continuously moist until the application of shotcrete is resumed. Before applying new material, the sloped part shall be thoroughly cleaned and wetted by means of an air and water blast or an equally effective method approved by the engineer.

Material that rebounds and accumulates on forms, subgrade surfaces, or reinforcing steel ahead of the shotcrete being placed shall be removed and discarded.

13. Finishing

Rebound material shall be carefully swept off the finished shotcrete surface and discarded before it becomes too hard for removal. After the shotcrete has been placed to the depth required, the surface shall be checked with a straightedge or template and any low spots shall be brought up to grade by placing additional shotcrete. The finished surface of the shotcrete shall be left as a natural gun finish unless screeding or further finishing, or both, are specified in Section 19 of this specification.

When specified, screeding shall be accomplished as follows:

- Place shotcrete a fraction beyond the guide strips, ground wires, or forms.
- Allow the surface of the shotcrete to stiffen to the point it will not pull or crack under screeding or troweling.
- Trim, slice, or scrape excess material to true line and grade and remove the placing guides.

A natural rod finish shall consist of the removal, by floating, of the impressions left after the guide strips or ground wires have been removed. A *natural broom finish* shall be that finish resulting from brooming the natural rod finish. A *float finish* shall be that finish resulting from floating the natural rod finish with a wood or rubber float.

14. Curing

Shotcrete shall be prevented from drying for a curing period of at least 7 days after it is placed. The exposed surface shall be kept continuously moist for the entire period or until curing compound is applied as specified below. Moisture shall be maintained by sprinkling, flooding, or fog spraying, or by covering with continuously moistened canvas, cloth mats, straw, sand, or other approved material. Wood forms left in place during the curing period shall be kept wet. Formed surfaces shall be thoroughly wetted immediately after forms are removed and shall be kept wet until patching and repairs are completed. Water or covering shall be applied in such a way that the shotcrete surface is not eroded or otherwise damaged.

Water for curing shall be clean and free from any substances that cause discoloration of the shotcrete where the finished surface will be exposed to view.

Except as otherwise specified in Section 17d of this specification and except for surfaces to which additional shotcrete is to be applied, shotcrete may be coated with curing compound as an alternative to the continued application of moisture.

The compound shall be sprayed on the moist shotcrete surface as soon as rebound has been removed and any required repairs are completed, or as soon as water curing is discontinued.

The curing compound shall be thoroughly mixed immediately before applied and continuously agitated during application. It shall be applied at a uniform rate of not less than 1 gallon per 100 square feet of surface for natural gun finishes. Curing compound shall be applied in two applications, one in each direction. If a natural rod, broom, or float finish is specified, the curing compound application rate shall be at least 1 gallon per 150 square feet. Curing compound shall not check, crack, or peel, and shall be free from pinholes or other imperfections.

Curing compound shall not be applied to a subgrade surface or other surfaces requiring bond with subsequently placed shotcrete, such as construction joints, reinforcing steel, and other embedded items.

A surface subjected to heavy rainfall or running water within 3 hours after the compound has been applied or a surface damaged by subsequent construction operations during the curing period shall be resprayed in the same manner as for the original applications. A surface covered by the membrane shall not be trafficked unless protected from damage and/or wear.

15. Replacement or Repair

When shotcrete lacks uniformity; exhibits segregation, honeycombing, or laminations; or contains dry patches, slugs, voids, or sand pockets, the contractor shall remove and replace the defective shotcrete. The engineer's concurrence in the extent of removal and replacement is required.

Before starting significant removal and replacement work, the contractor shall obtain the engineer's approval of the plan for making the repair. Such approval shall not be considered a waiver of the contracting officer's or owner's right to require complete removal of

defective work if the completed repair does not produce shotcrete of the required quality and appearance.

Repair work shall be performed only when the engineer is present.

Repair shall be made with shotcrete conforming to this specification. When removal of defective shotcrete is required, reinforcement damaged or destroyed shall be replaced before replacement of the shotcrete. At the edges of removed sections, the sound shotcrete shall be carefully trimmed to the extent required to expose sufficient reinforcement for effecting competent splices. The sound shotcrete at the edges of removed sections shall be trimmed to a slope of about 45 degrees with the surface of the work and shall be thoroughly moistened before placement of the new shotcrete.

Any parts of the work having thickness less than that specified may be repaired by the placement of additional layers of shotcrete if such repair is expressly approved by the engineer.

The surface to which additional shotcrete is to be applied shall be prepared as required by Section 11 of this specification.

Curing as specified in Section 14 of this specification shall be applied to repaired areas immediately after the repairs are completed.

16. Placing in Cold Weather

When the atmospheric temperature may be expected to drop below 40°F at the time shotcrete is placed, or at any time during the curing period, the following provisions shall also apply:

a. Shotcrete placement shall be permitted when the air temperature is at least 40°F and rising. Placement shall be discontinued if the temperature falls to 40°F and is expected to continue to fall.
b. The temperature of the shotcrete at time of placing shall not be less than 50°F nor more than 90°F. The temperature of neither aggregates nor mixing water shall be more than 100°F just

before mixing with the cement.

c. When the daily minimum temperature is less than 40°F, shotcrete shall be insulated or housed and heated after placement. The temperature of the shotcrete and air adjacent to the shotcrete shall be maintained at not less than 50°F nor more than 90°F for the duration of the curing period.
d. Methods of insulating, housing, and heating the structure shall be in accordance with Standard Specification for Cold Weather Concreting, ACI Standard 306.1.
e. The use of accelerators or antifreeze compounds is not allowed unless otherwise specified.
f. When dry heat is used to protect shotcrete, means of maintaining an ambient humidity of at least 40 percent shall be provided unless the shotcrete has been coated with curing compound as specified in Section 14 of this specification or is covered tightly with an approved impervious material.

17. Placing in Hot Weather

The following provisions shall apply when climatic factors, such as high air temperature, reduced relative humidity, and increased wind velocities, are present or conditions are such that the temperature of placed shotcrete exceeds 90°F at or during the first 24 hours after placement:

a. The contractor shall maintain the temperature of the shotcrete below 90°F during mixing, conveying, and placing using the methods given in items b, c, and d.
b. An exposed shotcrete surface that tends to dry or set too rapidly shall be continuously moistened by means of a fog spray or otherwise protected from drying immediately after placement.
c. Shotcrete surfaces exposed to the air shall be covered as soon as the shotcrete has hardened sufficiently and shall be kept continuously wet for at least the first 24 hours of the curing period and for the entire curing period unless curing compound is applied as specified in subsection d.
d. If moist curing is discontinued before the end of the curing period, white pigmented curing compound shall be applied

immediately following the procedures specified in Section 14 of this specification.

18. Measurement and Payment

Method 1 – For items of work for which specific unit prices are established in the contract, the dimensions of the exposed surface of the shotcrete is measured to the neatness shown on the drawings and the surface area is computed to the nearest square foot. Payment is made at the contract unit price for shotcrete. Such payment constitutes full compensation for completion of the work including making and handling test panels, but not including reinforcing steel or other items listed for payment elsewhere in the contract.

Measurement and payment for furnishing and placing reinforcing steel are made as specified in Construction Specification STEEL REINFORCEMENT 34.

Method 2 – For items of work for which specific unit prices are established in the contract, cement and aggregates used in shotcrete and in authorized test panels are measured by the batch weights of the material charged into the mixer. No deduction is made for normal rebound; however, payment is not made for material wasted because the in-place shotcrete does not conform to the specifications. Payment is made at the contract unit prices for cement and aggregates for shotcrete. Such payment constitutes full compensation for completion of the work including making and handling test panels, but not including reinforcing steel or other items listed for payment elsewhere in the contract.

Measurement and payment for furnishing and placing reinforcing steel are made as specified in Construction Specification STEEL REINFORCEMENT 34.

All Methods – The following provisions apply to all methods of measurement and payment. Compensation for any item of work described in the contract, but not listed in the bid schedule, is included

in the payment for the item of work to which it is made subsidiary. Such items and the items to which they are made subsidiary are identified in Section 19 of this specification.

19. Items of Work and Construction Details

(210-VI-NEH, May 2001)