UNIFIED FACILITIES GUIDE SPECIFICATIONS

References are in agreement with UMRL dated October 2015
****

SECTION TABLE OF CONTENTS

DIVISION 03 - CONCRETE

SECTION 03 37 13

SHOTCRETE

11/09

-- End of Section Table of Contents --

****

USACE / NAVFAC / AFCEC / NASA | **UFGS-03 37 13 (November 2009)**

Preparing Activity: USACE | **Superseding UFGS-03 37 13 (April 2006)**

UNIFIED FACILITIES GUIDE SPECIFICATIONS

References are in agreement with UMRL dated October 2015

****

SECTION 03 37 13

SHOTCRETE
11/09

****

NOTE: This guide specification covers the requirements for materials, proportioning, application, and curing of shotcrete. This section was originally developed for USACE Civil Works projects.

Adhere to UFC 1-300-02 Unified Facilities Guide Specifications (UFGS) Format Standard when editing this guide specification or preparing new project specification sections. Edit this guide specification for project specific requirements by adding, deleting, or revising text. For bracketed items, choose applicable items(s) or insert appropriate information.

Remove information and requirements not required in respective project, whether or not brackets are present.

Comments, suggestions and recommended changes for this guide specification are welcome and should be submitted as a Criteria Change Request (CCR).

****

PART 1 GENERAL

****

NOTE: The content of this specification is such that guidance given in EM 1110-2-2005, STANDARD PRACTICE FOR SHOTCRETE, is applicable.

****

1.1 UNIT PRICES

****

NOTE: If Section 01 22 00.00 10 PRICE AND PAYMENT PROCEDURES is included in the project specifications, this paragraph title (UNIT PRICES) should be deleted from this section and the remaining appropriately edited subparagraphs below

should be inserted into Section 01 22 00.00 10.
****

1.1.1 Shotcrete

1.1.1.1 Payment

Payment will be made for all costs associated with furnishing, delivering, and placing shotcrete.

1.1.1.2 Measurement

Shotcrete will be measured for payment based upon [the quantity in cubic meters yards of solid material gunned through the nozzles.] [the quantity per cubic meter yard, based on [a unit length] [the area] shotcreted to the thickness shown on the contract drawings.]

1.1.1.3 Unit of Measure

Unit of measure: cubic meter yard.

1.2 REFERENCES

****
NOTE: This paragraph is used to list the publications cited in the text of the guide specification. The publications are referred to in the text by basic designation only and listed in this paragraph by organization, designation, date, and title.

Use the Reference Wizard's Check Reference feature when you add a RID outside of the Section's Reference Article to automatically place the reference in the Reference Article. Also use the Reference Wizard's Check Reference feature to update the issue dates.

References not used in the text will automatically be deleted from this section of the project specification when you choose to reconcile references in the publish print process.
****

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN CONCRETE INSTITUTE INTERNATIONAL (ACI)

ACI CP-60	(2009) Craftman Workbook for ACI Certification of Shotcrete Nozzleman

ASTM INTERNATIONAL (ASTM)

ASTM A820/A820M	(2011) Standard Specification for Steel Fibers for Fiber-Reinforced Concrete
ASTM C1077	(2015) Standard Practice for Laboratories

	Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation
ASTM C1140/C1140M	(2011) Standard Practice for Preparing and Testing Specimens from Shotcrete Test Panels
ASTM C1141/C1141M	(2008) Standard Specification for Admixtures for Shotcrete
ASTM C1240	(2014) Standard Specification for Silica Fume Used in Cementitious Mixtures
ASTM C1260	(2014) Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)
ASTM C136/C136M	(2014) Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates
ASTM C150/C150M	(2015) Standard Specification for Portland Cement
ASTM C1567	(2013) Standard Test Method for Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)
ASTM C1609/C1609M	(2012) Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third-Point Landing)
ASTM C171	(2007) Standard Specification for Sheet Materials for Curing Concrete
ASTM C231/C231M	(2014) Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
ASTM C266	(2013) Standard Test Method for Time of Setting of Hydraulic-Cement Paste by Gillmore Needles
ASTM C309	(2011) Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete
ASTM C33/C33M	(2013) Standard Specification for Concrete Aggregates
ASTM C42/C42M	(2013) Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
ASTM C566	(2013) Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying

ASTM C595/C595M	(2015; E 2015) Standard Specification for Blended Hydraulic Cements
ASTM C618	(2012a) Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
ASTM C685/C685M	(2014) Concrete Made by Volumetric Batching and Continuous Mixing
ASTM C881/C881M	(2014) Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete
ASTM C94/C94M	(2015) Standard Specification for Ready-Mixed Concrete
ASTM C989/C989M	(2014) Standard Specification for Slag Cement for Use in Concrete and Mortars

U.S. ARMY CORPS OF ENGINEERS (USACE)

COE CRD-C 400	(1963) Requirements for Water for Use in Mixing or Curing Concrete

1.3 SUBMITTALS

****

NOTE: Review submittal description (SD) definitions in Section 01 33 00 SUBMITTAL PROCEDURES and edit the following list to reflect only the submittals required for the project.

The Guide Specification technical editors have designated those items that require Government approval, due to their complexity or criticality, with a "G." Generally, other submittal items can be reviewed by the Contractor's Quality Control System. Only add a “G” to an item, if the submittal is sufficiently important or complex in context of the project.

For submittals requiring Government approval on Army projects, a code of up to three characters within the submittal tags may be used following the "G" designation to indicate the approving authority. Codes for Army projects using the Resident Management System (RMS) are: "AE" for Architect-Engineer; "DO" for District Office (Engineering Division or other organization in the District Office); "AO" for Area Office; "RO" for Resident Office; and "PO" for Project Office. Codes following the "G" typically are not used for Navy, Air Force, and NASA projects.

An "S" following a submittal item indicates that the submittal is required for the Sustainability Notebook to fulfill federally mandated sustainable requirements in accordance with Section 01 33 29

SUSTAINABILITY REPORTING.

Choose the first bracketed item for Navy, Air Force and NASA projects, or choose the second bracketed item for Army projects.

****

Government approval is required for submittals with a "G" designation; submittals not having a "G" designation are for [Contractor Quality Control approval.] [information only. When used, a designation following the "G" designation identifies the office that will review the submittal for the Government.] Submittals with an "S" are for inclusion in the Sustainability Notebook, in conformance to Section 01 33 29 SUSTAINABILITY REPORTING. Submit the following in accordance with Section 01 33 00 SUBMITTAL PROCEDURES:

SD-06 Test Reports

Mixture Proportions; G[, [_____]]
Aggregates
Accelerator Compatibility; G[, [_____]]
Preconstruction Test Panels

SD-07 Certificates

Portland Cement
Pozzolans
Silica Fume
Accelerating Admixtures
Curing Materials
Steel Fiber Reinforcement
Qualifications; G[, [_____]]

1.4 QUALITY ASSURANCE

Provide facilities and labor, as may be necessary, for obtaining and testing representative test samples. Shotcrete shall be sampled and tested by the method given in paragraph STRENGTH TESTING in PART 3.

1.4.1 Qualifications

Shotcrete will be produced by either the Dry or Wet Method. Submit a resume for each nozzleman certifying that each has not less than 1 year's experience for the particular type of shotcrete to be applied. The resume shall include company name, address, and telephone number, name of supervisor, and detailed description of work performed. All nozzlemen shall be certified in accordance with ACI CP-60. Qualifications of additional nozzlemen throughout the job shall be similarly submitted for approval.

1.4.2 Preconstruction Test Panels

Specimens of the preconstruction test panels shall be made by each application crew using the equipment, materials, mixture proportions, and procedures for each mixture being considered, and for each shooting position to be encountered in the job. Submit cores and sawed concrete beams taken from test panels and test them. [Provide the same reinforcement as in the structure in at least one-half of the panel to test for proper embedment of reinforcing steel.] Fabricate the test panels to

the same thickness as the structure, but not less than 100 mm 4 inches. [At least five 75 mm 3-inch diameter cores from each panel shall be taken for testing for compressive strength in accordance with ASTM C1140/C1140M when nonfiber-reinforced shotcrete is used. The compressive strength of the cores shall meet the requirements specified in paragraph COMPRESSIVE STRENGTH above.] [Three 100 by 100 by 350 mm 4 by 4 by 14 inch beams shall be obtained in accordance with ASTM C1140/C1140Mfrom the test panels when fiber-reinforced shotcrete is used. The flexural strength [and toughness index] of the fiber-reinforced shotcrete beams shall meet the requirements specified in paragraph FLEXURAL STRENGTH above [and TOUGHNESS INDEX above].]

PART 2 PRODUCTS

2.1 MATERIALS

2.1.1 Cementitious Materials

****
NOTE: See the appropriate DM to select the proper requirements for the Cementitious Materials Options. Other cementitious materials may be added if specifically recommended and approved in the concrete materials DM.
****

Cementitious materials shall be portland cement, blended hydraulic cement, portland cement in combination with pozzolan or ground granulated blast-furnace slag (GGBFS) [or [_____]], or [portland cement in combination with silica fume] conforming to appropriate specifications listed below.

2.1.1.1 Portland Cement

Portland cement shall meet the requirements of ASTM C150/C150M Type [I], [II], [III], [V] [low alkali] [with tricalcium aluminate limited to [5] [8] percent if Type III is used]. Submit certificate of compliance with all specification requirements.

2.1.1.2 Blended Hydraulic Cement

ASTM C595/C595M Type IS, IP[(MS)].

2.1.1.3 Pozzolan Other Than Silica Fume

Pozzolans shall conform to ASTM C618, Class [C], [F], with the optional requirements for [available alkalies from Table 1A] multiple factor, drying shrinkage, and uniformity [and [moderate] [severe] sulfate resistance requirements] of Table 2A. Submit certificate of compliance for fly ash and other pozzolans with all specification requirements.

2.1.1.4 [Ground Granulated Blast-Furnace Slag

Ground granulated blast-furnace slag shall conform to ASTM C989/C989M, Grade [_____].]

2.1.1.5 [Silica Fume

Silica may be furnished as a dry, densified material or as a slurry. Silica fume, unprocessed, or before processing into a slurry or a densified material, shall conform to ASTM C1240.] Submit certificate of compliance

for silica fume with all specification requirements.

2.1.2 Aggregates

****

NOTE: This note may be disregarded for regions where Alkali-Silica Reactivity (ASR) is not a concern. Some aggregate sources may exhibit an ASR potential. ASR is a potentially deleterious reaction between alkalis present in concrete and some siliceous aggregates, reference EM 1110-2-2000 paragraph 2-3b(6) and appendix D. Where ASR is known or suspected to pose a concern for concrete durability, it is recommended that aggregates proposed for use in concrete be evaluated to determine ASR potential and an effective mitigation. EM 1110-2-2000, provides recommendations for evaluating and mitigating ASR in concrete mixtures. Aggregate evaluations may not be practical for projects requiring small quantities of concrete (less than 200 cubic meters 250 cubic yards).

Section 32 13 11 CONCRETE PAVEMENT FOR AIRFIELDS AND OTHER HEAVY-DUTY PAVEMENTS, paragraph 2.2.1.2 Alkali-Silica Reactivity, provides a specification method for the Contractor to evaluate and mitigate ASR in concrete mixtures. The expansion limits specified in Section 32 13 11 are requirements for pavements and exterior slab construction. For structural concrete applications the measured expansion shall be less than 0.10 percent. It may not be economical or practical to specify different test limit requirements for use on the same project. In which case the lower limit required by the application should be used.

The designer may use the specification method in Section 32 13 11 by incorporating the relevant paragraphs into this specification, or may use the following requirements (retain either the 0.10 or the 0.08 percent expansion limits as appropriate) included in the set of brackets highlighted thus "[.]".

****

Submit Supplier's test reports for aggregates showing the materials meet the requirements of this specification. Aggregates shall conform to ASTM C33/C33M with the combined grading of coarse and fine aggregates conforming to the grading shown below.

PERCENT BY MASS PASSING INDIVIDUAL SIEVES			
SIEVE SIZE	GRADING NO. 1	GRADING NO. 2	GRADING NO. 3*
19.0 mm3/4 inch	--	--	100

12.5 mm1/2 inch	--	100	80-95
9.5 mm3/8 inch	100	90-100	70-90
4.75 mmNo. 4	95-100	75-85	50-70
2.36 mmNo. 8	80-100	50-70	35-55
1.18 mmNo. 16	50-85	35-55	20-40
600 µmeterNo. 30	25-60	20-35	10-30
300 µmeterNo. 50	10-30	8-20	5-17
150 µmeterNo. 100	2-10	2-10	2-10

* Fine and coarse aggregates shall be [batched separately to avoid segregation.] "[tested and evaluated for alkali-aggregate reactivity in accordance with ASTM C1260. The fine and coarse aggregates shall be evaluated separately and in combination, which matches the Contractor's proposed mix design proportioning. All results of the separate and combination testing shall have a measured expansion less than 0.10 (0.08) percent at 16 days after casting. Should the test data indicate an expansion of 0.10 (0.08) percent or greater, the aggregate(s) shall be rejected or additional testing using ASTM C1260 and ASTM C1567 shall be performed. The additional testing using ASTM C1260 and ASTM C1567 shall be performed using the low alkali portland cement in combination with ground granulated blast furnace (GGBF) slag, or Class F fly ash. GGBF slag shall be used in the range of 40 to 50 percent of the total cementitious material by mass. Class F fly ash shall be used in the range of 25 to 40 percent of the total cementitious material by mass.]"

2.1.3 Water

Use fresh, clean, potable mixing water or nonpotable water which meets the requirements of COE CRD-C 400.

2.1.4 Admixtures

a. Admixtures to be used, when required or approved, shall comply with the appropriate sections of ASTM C1141/C1141M. Except as otherwise accepted, soluble admixtures shall be dissolved in water before introduction into the shotcrete mixture.

b. When accelerating admixtures complying with ASTM C1141/C1141M, Type II, Grade 1, are to be used, establish the accelerator compatibility of the job cement and the proposed accelerators using ASTM C266, except as modified herein. The powdered accelerator shall be blended with 50 grams 1.25 ounces of cement until uniform and 15 milliliters 0.004 gal of water shall then be added. The liquid accelerator shall first be mixed with 15 mm 0.004 gal of water and then added to 50 grams 1.25 ounces of cement. Three percent of the proposed accelerator by mass of cement shall be used as a starting point. Mixing shall be accomplished within 15 seconds. The specimen shall be molded within 1 minute of

adding the mixing water. If initial set is 2 minutes or less and a final set is 10 minutes or less, the accelerator is considered compatible. If these values are not achieved in the first test, additional tests shall be run using 2 percent and 4 percent of accelerator. Submit document establishing the compatibility of the job cement and the proposed accelerators and certificate of compliance for accelerating admixtures with all specification requirements.

2.1.5 Curing Materials

Submit certificate of compliance for curing materials with all specification requirements. Curing materials shall meet the following requirements.

2.1.5.1 Impervious Sheet Materials

ASTM C171, type optional except polyethylene film, if used, shall be white opaque.

2.1.5.2 Membrane-Forming Curing Compound

ASTM C309, Type 1-D or Type 2.

2.1.6 Reinforcement

2.1.6.1 Steel Fiber Reinforcement

Steel fiber reinforcement shall meet the requirements of ASTM A820/A820M. Submit certificate of compliance for fiber reinforcement with all specification requirements.

2.1.6.2 Other Types of Reinforcement

[Section 03 20 00.00 10 CONCRETE REINFORCING] [03 30 00 CAST-IN-PLACE CONCRETE] [_____] for all other types of reinforcement.

2.1.7 Air Content

Air-entraining admixture shall be used in such proportion that the air content of the shotcrete prior to gunning shall be [_____] plus or minus (±) 1.0 percent as determined by ASTM C231/C231M.

2.1.8 Air Supply

Provide a supply of clean, dry air adequate for maintaining sufficient nozzle velocity for all parts of the work and, if required, for simultaneous operation of a suitable blowpipe for clearing away rebound.

2.2 MIXTURE PROPORTIONS

****

NOTE: Consult the appropriate DM to fill in the blanks.

****

Mixture proportions and test data from prior experience within [_____] years, if available, may be submitted for approval. If test data from experience are not available or accepted, specimens shall be made and tested from mixtures having three or more different proportions. The

recommended mixture proportions, sources of materials, and all test results shall be submitted for acceptance. [Mixture proportions for nonfiber-reinforced shotcrete shall be selected on the basis of compressive strength tests of cores obtained from test panels fabricated in accordance with ASTM C1140/C1140M and having minimum dimensions of 750 by 750 by 100 mm 30 by 30 by 4 inches. Cores shall be continuously moist cured until testing at [_____] days age. For mixture acceptance purposes, the average compressive strength of at least three cores shall be at least equal to 1.2 times the required compressive strength specified in paragraph COMPRESSIVE STRENGTH in PART 1.] [Mixture proportions for fiber-reinforced shotcrete shall be selected on the basis of flexural strength [and toughness index] of 100 by 100 by 350 mm 4 by 4 by 14 inch beams sawed from test panels which are fabricated in accordance with ASTM C1140/C1140M and having minimum dimensions of 750 by 750 by 100 mm 30 by 30 by 4 inches. Beams shall be continuously moist cured until testing at [_____] days age. For mixture acceptance purposes, the average flexural strength [and toughness index] of at least three beams shall be not less than the flexural strength [and toughness index] specified in paragraph FLEXURAL STRENGTH in PART 1 [and TOUGHNESS INDEX in PART 1].] Submit the recommended mixture proportions, sources of materials, and all test results, for approval.

2.3 SYSTEM STRENGTH

****

NOTE: Compressive strength should be specified for nonfiber-reinforced shotcrete and flexural strength should be specified for fiber-reinforced shotcrete. Consult EM 1110-2-2005 and the appropriate DM to fill in blanks.

If a flexural toughness index requirement is deemed necessary for fiber-reinforced shotcrete, the minimum toughness index necessary for anticipated service conditions should be specified. See EM 1110-2-2005 and ASTM C1116/C1116M for guidance.

****

Final acceptance of the shotcrete will be based on [compressive] [flexural] strength results obtained from [cores] [beams].

[2.3.1 Compressive Strength

The required compressive strength of cores shall not be less than [_____] MPa psi at [_____] days age when tested in accordance with ASTM C42/C42M. The average compressive strength of cores taken from the [structure] [test panel], representing a shift or not more than 40 cubic meters 50 cubic yards of shotcrete tested at [_____] days of age, shall equal or exceed the required compressive strength specified with no individual core less than 85 percent of the required compressive strength. When the length of a core is less than 1.94 times the diameter, the correction factors given in ASTM C42/C42M will be applied to obtain the compressive strength of individual cores.

][2.3.2 Flexural Strength

Obtain and test fiber-reinforced shotcrete beams in accordance with ASTM C1140/C1140M and a flexural strength of not less than [_____] MPa psi at [_____] days age.

][2.3.3 Toughness Index

The toughness index, [I10] [I20], of fiber-reinforced shotcrete beams shall be [_____] at [_____] days age when tested in accordance with ASTM C1609/C1609M.

]2.4 EQUIPMENT

****
NOTE: See the appropriate DM to select the proper air content for either Dry or Wet Nix method.
****

2.4.1 Dry Mix Batching and Mixing

Aggregate and cementitious materials may be batched by mass or by volume. Equipment for batching by mass shall be capable of the accuracy specified in ASTM C94/C94M. Volumetric equipment shall be capable of batching with the accuracy specified in ASTM C685/C685M. The mixing equipment shall be capable of thoroughly mixing the materials in sufficient quantity to maintain placing continuity and be capable of discharging all mixed material without any carryover from one batch to the next.

2.4.2 Delivery Equipment for Dry Mix

The equipment shall be capable of discharging the aggregate-cement mixture into the delivery hose and delivering a continuous smooth stream of uniformly mixed material to the discharge nozzle. The discharge nozzle shall be equipped with a manually operated water injection system (water ring) for directing an even distribution of water through the aggregate-cement mixture. The water valve shall be capable of ready adjustment to vary the quantity of water and shall be convenient to the nozzleman. The water pressure at the discharge nozzle shall be sufficiently greater than the operating air pressure to ensure that the water is completely mixed with the other materials. If the line water pressure is inadequate, a water pump shall be introduced into the line. The water pressure shall be steady (nonpulsating). The delivery equipment shall be thoroughly cleaned at the end of each shift. Equipment parts, especially the nozzle liner and water ring, shall be regularly inspected and replaced as required.

2.4.3 Wet Mix Batching and Mixing

Batching and mixing shall be accomplished in accordance with the applicable provisions of ASTM C94/C94M. If volumetric batching and mixing are used, the materials shall be batched and mixed in accordance with the applicable provisions of ASTM C685/C685M. The mixing equipment shall be capable of thoroughly mixing the specified materials in sufficient quantity to maintain continuous placing. Ready-mix shotcrete complying with ASTM C94/C94M may be used.

2.4.4 Delivery Equipment for Wet Mix

The equipment shall be capable of delivering the premixed materials accurately, uniformly, and continuously through the delivery hose. Recommendations of the equipment manufacturer shall be followed on the type and size of nozzle to be used and on cleaning, inspection, and maintenance of the equipment.

PART 3 EXECUTION

3.1 PREPARATION OF SURFACES

3.1.1 Earth

Earth shall be compacted and trimmed to line and graded before placement of shotcrete. Surfaces to receive shotcrete shall be dampened.

3.1.2 Existing Concrete

All unsound and loose materials shall be removed by sandblasting, grinding, or high-pressure water jets before applying shotcrete. Any area to be repaired shall be chipped off or scarified to remove offsets which would cause an abrupt change in thickness without suitable reinforcement. Edges shall be tapered to leave no square shoulders at the perimeter of a cavity. The surface shall be dampened but without visible free water.

3.1.3 Rock

Rock surfaces shall be cleaned to remove loose or drummy material, mud, running water, and other foreign matter that will prevent bond of the shotcrete. The rock surface shall be dampened prior to placement of shotcrete.

3.1.4 Shotcrete

When a layer of shotcrete is to be covered by a succeeding layer at a later time, it shall first be allowed to develop its initial set. Then all laitance, loose material, and rebound shall be removed by brooming or scraping. Hardened laitance set shall be removed by sandblasting and the surface thoroughly cleaned.

3.1.5 Construction Joints

Unless otherwise specified, construction joints shall be tapered to a shallow edge form, about 25 mm 1 inch thick. If nontapered joints are specified, take special care to avoid or remove trapped rebound at the joint. The entire joint shall be thoroughly cleaned and wetted prior to the application of additional shotcrete.

3.2 PLACEMENT OF SHOTCRETE

3.2.1 General

Place shotcrete using suitable delivery equipment and procedures. The area to which shotcrete is to be applied shall be clean and free of rebound or overspray.

3.2.2 Placement Techniques

3.2.2.1 Placement Control

Thickness, method of support, air pressure, and water content of shotcrete shall be controlled to preclude sagging or sloughing off. Shotcreting shall be discontinued or suitable means shall be provided to screen the nozzle stream if wind or air currents cause separation of the nozzle stream during placement.

3.2.2.2 Corners

Horizontal and vertical corners and any area where rebound cannot escape or be blown free shall be filled first.

3.2.3 Placement Around Reinforcement

The nozzle shall be held at such distance and angle to place material behind reinforcement before any material is allowed to accumulate on the face of the reinforcement. In the dry-mix process, additional water may be added to the mixture when encasing reinforcement to facilitate a smooth flow of material behind the bars. Shotcrete shall not be placed through more than one layer of reinforcing steel rods or mesh in one application unless demonstrated by preconstruction tests that steel is properly encased.

3.2.4 Cover of Reinforcement

****
NOTE: Use 19 mm 3/4 inch if grading No. 1 in paragraph AGGREGATES is selected; otherwise, use 40 mm 1-1/2 inches.
****

The following minimum cover shall be provided.

a. For shotcrete used as linings, coatings, slab, or wall:[19 mm 3/4 inch.][40 mm 1-1/2 inches].

b. For required structural reinforcement in beams, girders, and columns: 40 mm 1-1/2 inches.

3.2.5 Placement Precautions

The following precautions shall be taken during placement.

a. Placement shall be stopped if drying or stiffening of the mixture takes place at any time prior to delivery to the nozzle.

b. Rebound or previously expended material shall not be used in the shotcrete mixture.

3.3 REPAIR OF DEFECTS

3.3.1 Defects

Defective areas larger than 31 000 square mm 48 square inches or 50 mm 2 inches deep shall be removed and replaced with fresh shotcrete. These defects include honeycombing, lamination, dry patches, voids, or sand pockets. Defective areas shall be removed in accordance with the procedures described in paragraph EXISTING CONCRETE and replaced with fresh shotcrete.

3.3.1.1 Repairs

All repairs shall be made within 1 week of the time the deficiency is discovered. All unacceptable materials shall be removed and repaired by the procedures described in the following two paragraphs. Voids and holes left by the removal of tie rods in all permanently exposed surfaces not to be backfilled and in surfaces to be exposed to water shall be reamed and

completely filled with dry-patching mortar as specified below.

3.3.1.2 Minor Patching

Minor patching may be accomplished with a dry-pack mixture, or with materials as approved by the Contracting Officer. Patches that exceed 0.003 cubic meters 0.1 cubic foot in volume shall receive a brush coat of approved epoxy resin meeting ASTM C881/C881M, Type II, as a prime coat. Care shall be taken not to spill epoxy or overcoat the repair surface so that the epoxy runs or is squeezed out onto the surface which will remain exposed to view. Epoxy resin shall be used in strict conformance with manufacturer's recommendations with special attention paid to pot life, safety, and thin film tack time.

3.3.2 Core Holes

Core holes shall not be repaired with shotcrete. Instead, they shall be filled solid with a dry-pack mixture after being cleaned and thoroughly dampened.

3.4 FINISHING

****
NOTE: See the appropriate DM for type of finish required. The specified finishes should also be shown on the contract drawings. Delete the finishes not required.
****

3.4.1 Natural Gun Finish

Unless otherwise specified, provide undisturbed final layer of shotcrete as applied from nozzle without hand finishing.

3.4.2 Cutting Screed

After the surface has taken its initial set (crumbling slightly when cut), excess material outside the forms and ground wires shall be sliced off with a downward cutting motion using a sharp-edged cutting screed.

3.4.3 Flash Coat

A thin coat of shotcrete containing finer sand applied from a distance greater than normal shall be applied to the surface as soon as possible after the screeding.

3.4.4 Float and Trowel Finish

Final surface finish shall be provided using [wood float] [rubber float] [steel trowel]. Troweling of thin sections of shotcrete shall be avoided unless both troweling and commencement of moisture curing take place within a relatively short period after placement of shotcrete.

3.4.5 Fiber-Reinforced Shotcrete

****
NOTE: Include this paragraph if the exposed steel fibers pose a safety hazard.
****

Finish the outer surface of the structure with a layer of nonfiber-reinforced shotcrete and provide an appropriate finish as denoted.

3.5 CURING AND PROTECTION

****
NOTE: See appropriate DM for protection durations and EM 1110-2-2005 on the proper use of accelerating admixture.
****

3.5.1 Initial Curing

Immediately after finishing, shotcrete shall be kept continuously moist for at least 3 days. One of the following materials or methods shall be used:

a. Ponding or continuous sprinkling.

b. Absorptive mat or fabric, sand, or other covering kept continuously wet.

c. Curing Compounds. On natural gun or flash finishes, use the coverage application requirement of 2.5 square meters/L 100 square feet/gallon or twice the manufacturer's requirement, whichever is less. Curing compounds shall not be used on any surfaces against which additional shotcrete or other cementitious finishing materials are to be bonded unless positive measures, such as sandblasting, are taken to completely remove curing compounds prior to the application of such additional materials.

3.5.2 Final Curing

Additional curing shall be provided immediately following the initial curing and before the shotcrete has dried. One of the following materials or methods shall be used:

a. Continue the method used in initial curing.

b. Application of impervious sheet material conforming to ASTM C171.

3.5.3 Formed Surface

If forms are to be removed during curing period, one of the curing materials or methods listed in paragraph INITIAL CURING shall be used immediately. Such curing shall be continued for the remainder of the curing period.

3.5.4 Duration of Curing

Curing shall be continued for the first 7 days after shotcreting or until the specified [compressive] [flexural] strength of the in-place shotcrete as determined by specimens obtained and tested in accordance with ASTM C42/C42M is achieved.

3.5.5 Temperature Considerations

The air temperature in contact with the shotcrete shall be continuously maintained at a temperature above 5 degrees C 40 degrees F for at least [3 days after placement.] [[_____] days after placement if an accelerator is

used.] No shotcrete shall be applied when the concrete surface or air in contact with the concrete surface is below 5 degrees C 40 degrees F.

3.6 TESTS

3.6.1 Strength Testing

****
NOTE: See the appropriate DM for locations of test specimens and ages of tests. Air content tests should only be specified on shotcrete produced by the wet-mix process.
****

Test specimens shall be initially cured onsite, then shall be transported in an approved manner to an approved testing laboratory meeting the requirements of ASTM C1077 within 48 hours of scheduled testing time.

3.6.1.1 Test Panel

One test panel shall be made for every 40 cubic meters 50 cubic yards of shotcrete placed but not less than one per each shift during which any shotcrete is placed. Panels shall have minimum dimensions of 450 by 450 by 100 mm 18 by 18 by 4 inches and shall be gunned in the same positions as the work represented during the course of the work by the Contractor's regular nozzleman. Panels shall be field cured in the same manner as in the job. [Three [_____] mm inch diameter cores shall be drilled from each panel at least 40 hours prior to testing and tested in accordance with ASTM C1140/C1140M.] [Two 100 by 100 by 350 mm 4 by 4 by 14 inch beams shall be saw cut from the test panels when fiber-reinforced shotcrete is used. The fiber-reinforced shotcrete beams shall be tested in accordance with ASTM C1140/C1140M. If the quality of shotcrete is questionable, the Government may saw or core the panel specimens to determine the shotcrete quality and if remedial action is necessary.]

3.6.1.2 [Test Cores

Test cores shall be drilled from the structure at least 40 hours prior to testing and tested in accordance with ASTM C1140/C1140M. A set of three cores shall be taken not less than once each shift that shotcrete is placed nor less than once for each 40 cubic meters 50 cubic yards of shotcrete placed through the nozzle. The diameter of core specimens shall be determined in accordance with ASTM C42/C42M.]

3.6.1.3 [Average Compressive Strength

The compressive strength of the shotcrete shall be determined from the average of three cores obtained from [a test panel] [the structure] representing a specific volume of shotcrete and tested on the [_____] day after [panel fabrication] [placement in the structure.]]

3.6.1.4 [Average Flexural Strength

The flexural strength of the shotcrete shall be determined from the average of two test specimens obtained from a test panel and tested on the [_____] day after panel fabrication.]

3.6.1.5 [Average Toughness Index

The toughness index of the shotcrete shall be determined from the average of two test specimens obtained from a test panel and tested on the [_____] day after panel fabrication.]

3.6.2 Aggregate Moisture

Prior to batching the shotcrete and at least once during a shift in which shotcrete is being batched, the coarse and fine aggregate moisture content shall be determined in accordance with ASTM C566. The batch weights of both the aggregates and mixing water shall be appropriately adjusted to account for the available free moisture in the aggregates. The amount of free moisture in the aggregates, expressed as kg pounds of water per cubic meter yard, shall be recorded on the batching ticket and delivered to the Contracting Officer prior to placement during the shift. The Contracting Officer will have the option to request additional aggregate moisture content tests for each of the required tests.

3.6.3 Grading

The grading of the coarse and fine aggregate shall be determined in accordance with ASTM C136/C136M. The fine and coarse aggregate grading shall be determined prior to batching the shotcrete and at least once during a shift in which shotcrete is being batched. The Contracting Officer will have the option to require one additional sieve analysis test for aggregate type.

3.6.4 Thickness

The minimum shotcrete thickness shall be as shown in the drawings. The unhardened shotcrete shall be checked for thickness using a probe by the nozzleman or laborer at the time of placement. These thickness checks shall be at 15-minute intervals and all low or thin areas shall be corrected by applying additional shotcrete.

3.6.5 Mixture Proportions

Record and check mixture proportions at least once per shift for weigh batching. Record and check mixture proportions as recommended by ASTM C685/C685M at least once per shift for volumetric batching and continuous mixing plants.

3.6.6 Preparations

Prior to each placement of shotcrete, the Contractor's inspector shall certify in writing or by an approved checkout form that cleanup and preparations are in accordance with the plans and specifications.

3.6.7 [Air Content

Air content tests shall be conducted on wet-mix shotcrete according to ASTM C231/C231M with a frequency of not less than once each shift nor less than once for each 40 cubic meters 50 cubic yards of shotcrete placed through the nozzle. Tests shall be conducted on samples taken as the wet shotcrete mixture is placed in the delivery equipment.]

-- End of Section --