CONSTRUCTION SPECIFICATION FOR STRUCTURE REHABILITATION - SHOTCRETE

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931.01 SCOPE

This specification covers the requirements for concrete structure rehabilitation using shotcrete.

931.02 REFERENCES

This specification refers to the following standards, specifications, or publications:

Ontario Provincial Standard Specifications, Construction:

OPSS 904 Concrete Structures
OPSS 905 Steel Reinforcement for Concrete
OPSS 919 Formwork and Falsework
OPSS 928 Structure Rehabilitation - Concrete Removal
OPSS 929 Abrasive Blast Cleaning - Concrete Construction
OPSS 932 Crack Repair - Concrete

Ontario Provincial Standard Specifications, Material:

OPSS 1002 Aggregates - Concrete
OPSS 1301 Cementing Materials

OPSS 1302 Water
OPSS 1303 Admixtures for Concrete
OPSS 1306 Burlap
OPSS 1315 White Pigmented Curing Compounds for Concrete
OPSS 1350 Concrete - Materials and Production
OPSS 1440 Steel Reinforcement for Concrete

Ontario Ministry of Transportation Publications

Structure Rehabilitation Manual

MTO Laboratory Testing Manual:
LS-430 Method of Test for Bond Strength by Tensile Load
LS-433 Method of Test for Electrical Indication of Concrete's Ability to Resist Chloride Penetration

MTO Forms:
PH-CC-433A Concrete Mix Design Submission Form A
PH-CC-701 Request to Proceed
PH-CC-702 Notice to Proceed

CSA Standards

A23.1:19/A23.2:19 Concrete Materials and Methods of Concrete Construction/Test Methods and Standard Practice for Concrete*
A23.2-14C Obtaining and Testing Drilled Cores for Compressive Strength Testing
A3001 Cementitious Materials for Use in Concrete**
* [Part of A23.1:19/A23.2:19 - Concrete Materials and Methods of Concrete Construction/Methods of Test and Standard Practices for Concrete]
** [Part of A3000-18 - Cementitious Materials Compendium]

ASTM International

A153 / A153M - 16a Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware
A1022 / A1022M - 16b Standard Specification for Deformed and Plain Stainless Steel Wire and Welded Wire for Concrete Reinforcement
A1064 / A1064M - 18a Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete
D4285-83(2018) Method of Indicating Oil or Water in Compressed Air

931.03 DEFINITIONS

For the purpose of this specification, the following definitions apply:

Cold Weather means those conditions when the air temperature is less than or equal to 10°C. It is also considered to exist when the air temperature is at or is likely to be less than 10°C within 96 hours after concrete placement. Temperature refers to shade temperature.

Dry Mix Shotcrete means the dry materials are prebagged and mixed and placed into a stream of compressed air. Material is carried by the compressed air through a delivery hose to the nozzle where water is added. Water is added to the mixture as it is jetted from the nozzle.

Hot Weather means those conditions when the air temperature is greater than or equal to 28°C. It is also considered to exist when the air temperature is at or is likely to be greater than 28°C within 24 hours after concrete placement. Temperature refers to shade temperature.

Nozzleman means the qualified worker on the shotcrete crew who has obtained ministry approval for Shotcrete Nozzleman Certification who manipulates the nozzle, controls consistency and controls final disposition of the material.

Rehabilitation means any modification, alteration, or improvement to a structure or its components that is designed to correct defects or deficiencies.

Structure means any bridge, structural culvert, tunnel, retaining wall, wharf, dock, guide way or any part thereof or other reinforced concrete component designed to carry loads.

Saturated Surface Dry means concrete is fully saturated without free standing water.

Wet Mix Shotcrete means shotcrete in which all of the materials, including water, are mixed before introduction into the delivery hose. Compressed air is introduced to the material flow at the nozzle.

931.04 DESIGN AND SUBMISSION REQUIREMENTS

931.04.01 Submission Requirements

931.04.01.01 Mix Design for Dry Mix Shotcrete

A minimum of seven Days prior to the application of shotcrete, the mix design including sources of all materials and the name of the supplier for the pre-bagged dry mix shotcrete shall be submitted to the Contract Administrator.

In addition, the following information shall be submitted with the mix design:

a) A certificate from the cement supplier stating that the cement is certified to be free from early stiffening tendencies.

b) Performance test data from the manufacturer of the prebagged material, where testing was carried out by a laboratory independent of the manufacturer, or test data from another MTO Contract, verifying that the pre-bagged material is capable of meeting the requirements of this specification.

The certificate and supporting test data shall be current within 12 months at the time the mix design is submitted to the Contract Administrator.

931.04.01.02 Mix Design for Wet Mix Shotcrete

The wet mix shotcrete shall be designed to meet the requirements of this specification. The mix design shall be submitted according to the Mix Design clause of OPSS 1350.

Documentation verifying certification of the concrete production facility by the Ready Mixed Concrete Association of Ontario (RMCAO) shall be submitted with the completed MTO form PH-CC-433A (Form A).

931.04.01.03 Shotcrete Equipment

A minimum of seven Days prior to the application of shotcrete, the following information shall be submitted to the Contract Administrator:

a) Equipment type and capacity

b) Nozzle type and size

c) Continuous feed predampener details, if the dry mix process is used

931.04.01.04 Nozzleman

A minimum of seven Days prior to the commencement of the shotcreting operation, the names of the nozzlemen and proof of their qualification with photo identification shall be submitted to the Contract Administrator.

931.04.01.05 Cold Weather Protection

In cold weather, a temperature control plan shall be submitted to the Contract Administrator a minimum of seven Days prior to the application of shotcrete. The submission shall be according to the Temperature Control Plans clause of OPSS 904.

When requested by the Contract Administrator, samples of insulation materials shall also be submitted.

931.04.01.06 Hot Weather Shotcreting

In hot weather, a plan describing the methods to be used to control the shotcrete temperature shall be submitted to the Contract Administrator a minimum of seven Days prior to the application of shotcrete.

931.04.01.07 Curing

A minimum of seven Days prior to the application of shotcrete, a description of the methods to be used for fog-misting and curing the shotcrete, including equipment and procedures to be used, shall be submitted to the Contract Administrator.

931.05 MATERIALS

931.05.01 Admixtures

Admixtures shall be according to OPSS 1303.

931.05.02 Aggregates

Aggregates shall be according to OPSS 1002.

931.05.03 Anchors

Anchors for the attachment of the welded steel wire reinforcement to the concrete surface shall be galvanized according to ASTM A153 and shall be of adequate length and strength to resist a pull-out force of 1.0 kN. When stainless welded steel wire reinforcement if used, anchors and tie wires shall be made of the same type of stainless steel.

931.05.04 Burlap

Burlap shall be according to OPSS 1306.

931.05.05 Cementing Material

Cementing materials shall be according to OPSS 1301 and CSA A3001.

931.05.06 Curing Compound

Curing compound shall be according to OPSS 1315.

931.05.07 Formwork

Formwork shall be according to OPSS 919.

931.05.08 Proprietary Patching Materials

Proprietary patching materials shall be from the Owner's prequalified product list. The list of proprietary patching materials shall be obtained from the Contract Administrator.

931.05.09 Shotcrete

931.05.09.01 General

Shotcrete shall have a minimum 28-day compressive strength of 35 MPa and maximum rapid chloride permeability less than or equal to1000 coulombs, when tested at the age of 28-32 Days. The shotcrete mix shall contain 8% silica fume by mass of total cementing materials. Fibres shall not be used in the shotcrete.

Dry mix shotcrete shall be used, unless otherwise specified in the Contract Documents.

931.05.09.02 Additional Requirements for Dry Mix Shotcrete

For dry mix shotcrete, the shotcrete mix shall be supplied pre-bagged and unopened. Each bag shall be stamped with the following:

a) name of the manufacturer

b) mix identification

c) manufacturer's batch number

d) date of packaging

The pre-bagged mix shall contain cementing materials and aggregates. The bags shall be maintained in a dry condition up to the time of use and shall be stored within a temperature range of 10°C to 30°C. Material from bags that contain lumps of hydrated shotcrete or appear to be frozen or otherwise damaged shall not be used in the work. The pre-bagged mix shall be used within the six months of date of packaging.

931.05.09.03 Additional Requirements for Wet Mix Shotcrete

Silica fume shall be added to the concrete mix in the form of a blended cement containing silica fume.

931.05.10 Tie Wire

Tie wire shall be according to OPSS 905.

931.05.11 Water

Water used for production, fog-misting, curing and pre-soaking of burlap shall be according to OPSS 1302.

931.05.12 Welded Steel Wire Reinforcement

The welded steel wire reinforcement shall be welded galvanized or stainless steel according to OPSS 1440. Dimensions shall be 51 mm x 51 mm, W 5.5 x W 5.5. Galvanized steel wire shall be according to ASTM A1064. Stainless steel wire reinforcement shall be in according to ASTM A1022.

931.06 EQUIPMENT

931.06.01 Compressor - Air Blasting

The compressor for air blasting shall have a minimum capacity of 3.5 m³/min. The compressed air shall be free from oil and other contaminants according to ASTM D4285.

931.06.02 Fog Misting Equipment

Fog misting equipment for the curing of shotcrete shall be according to OPSS 904.

931.06.03 Hand Finishing Equipment

Where hand finishing is required, only magnesium, wood or sponge rubber floats shall be used.

931.06.04 Mixers

931.06.04.01 Dry Mix Process

A continuous feed predampener shall be used, except for shotcrete which contains an accelerator. The predampening equipment shall be capable of bringing the dry bagged material to a consistent and suitable moisture content and shall operate at sufficient capacity to allow work to proceed without delays.

The delivery equipment shall be capable of discharging the mixture into the delivery hose at a rate sufficient to ensure a continuous smooth stream of uniformly mixed shotcrete mixture being delivered to the nozzle, at the velocity required to ensure maximum consolidation and full encapsulation of the reinforcement.

The discharge nozzle shall be equipped with a manually operated water injection system, for directing an even distribution of liquid through the mixture, with uniform appearance and consistency of shotcrete throughout to ensure that the water is thoroughly mixed with the other materials.

931.06.04.02 Wet Mix Process

Truck mixers shall be according to the Delivery Equipment subsection of OPSS 1350. The shotcrete delivery equipment shall be capable of delivering the pre-mixed materials accurately, uniformly and continuously through the delivery hose, at the velocity required to ensure maximum consolidation and full encapsulation of the reinforcement.

931.06.05 Straight Edge

The straight edge shall be 1.0 m long, commercially made and metal.

931.07 CONSTRUCTION

931.07.01 General

Locations and extent of repair shall be as determined during the layout of repair areas according to OPSS 928 and as directed by the Contract Administrator.

931.07.02 Operational Constraints

The Contract Administrator shall be notified of the intent to apply shotcrete three Business Days prior to the commencement of the shotcreting operation.

A Request to Proceed shall be submitted to the Contract Administrator at the completion of the surface preparation operation and prior to the commencement of the application of shotcrete.

The application of shotcrete shall not proceed until a Noticed to Proceed has been received from the Contract Administrator.

Prior to the application of shotcrete, protection for traffic from overspray and any rebound shall be in place.

No shotcrete shall be placed until all curing materials have been delivered to the site, and, in cold weather, all cold weather protection materials have been delivered to the site.

Shotcreting shall not be carried out when the air temperature or existing concrete surface temperature is less than 10°C or is likely to be less than 10°C, or is greater than 30°C or likely to be greater than 30°C throughout the duration of the shotcreting operation unless protection is provided in accordance with the Contractor's submitted plan.

Prior to shotcreting, the Contractor shall demonstrate to the Contract Administrator that the substrate temperatures meet the Contract requirements by measuring the substrate temperatures using a contact thermometer, and recording them.

Shotcrete shall not be placed against frozen surfaces. All surfaces against which shotcrete is to be placed shall be free of standing water. Shotcrete shall be protected from contact with rain or snow.

The air in contact with the repaired surfaces shall be maintained at temperatures greater than 10°C for a minimum of 96 hours after the application of shotcrete. Unvented heaters shall not be used.

Shotcreting operations shall be suspended during weather conditions that may adversely affect the quality of the work. This includes but is not limited to wind causing segregation of ingredients, rain or snow.

Prior to seasonal shutdown, operations shall be scheduled in such a manner as to ensure that the shotcreting operations are completed in all areas where concrete removal has commenced. No reinforcing steel shall be left exposed during seasonal shutdown.

931.07.03 Surface Preparation

All concrete surfaces against which shotcrete is to be placed shall be clean, solid and free from loose or unsound fragments, coatings and any other foreign substances or debris, and shall be sufficiently rough to ensure that a full bond is developed with the new shotcrete.

All existing concrete surfaces to be covered by shotcrete shall be uniformly roughened by means of scabbling, chipping or bush hammering. A surface profile of 5 ± 2 mm shall be achieved by exposing the aggregates across the entire surface.

All concrete surfaces, including areas 50 mm beyond the perimeter of the removal area, and existing reinforcing steel to receive shotcrete shall be abrasive blast cleaned according to OPSS 929 prior to installation of welded galvanized steel wire reinforcement or stainless steel wire reinforcement.

Abrasive blast cleaned areas shall have shotcrete applied within 36 hours of abrasive blasting or shall be reblasted. In areas requiring reblasting, the welded galvanized steel wire reinforcement shall be removed prior to abrasive blast cleaning and shall be reinstalled after cleaning. When stainless steel wire reinforcement is used, it may be left in place during abrasive blast cleaning.

Following abrasive blast cleaning and immediately prior to pre-wetting the concrete surface, all dust and loose material shall be removed from the prepared surface of the repair area by using compressed air.

The concrete surface to receive shotcrete shall be maintained in a continuously wet condition for a period of at least two hours prior to the application of the shotcrete. Immediately prior to the placement of shotcrete, the concrete surface to receive shotcrete shall be brought to a saturated surface dry condition, with excess water removed from the surface using compressed air.

931.07.04 Placement of Welded Steel Wire Reinforcement

When welded steel wire reinforcement is specified in the Contract Documents, it shall not be installed until after the concrete surface and exposed reinforcing steel in the repair area has been abrasive blast cleaned. Welded steel wire reinforcement shall not be used in repair areas on which a cathodic protection system is to be installed.

The welded steel wire reinforcement shall be installed flat, tight and in the locations shown in the Contract Documents and in all repair areas greater than 0.1 m^2 that have a minimum dimension of 200 mm, using spacers and anchors or fastening to exposed reinforcing steel. The wire reinforcement shall be securely fastened to the exposed reinforcing steel by ties placed no greater than 300 mm apart, in a grid pattern.

When the exposed reinforcing steel is not capable of providing rigid support for the welded steel wire reinforcement or when the spacing of the reinforcement is greater than 300 mm, anchors shall be used to support the welded steel wire reinforcement. Anchors shall be placed no greater than 300 mm apart in a grid pattern. The clearance between the reinforcement and the existing concrete shall be greater than or equal to 20 mm. The edges of adjoining welded steel wire reinforcement sheets shall be overlapped by one wire spacing plus 50 mm.

The welded steel wire reinforcement shall be kept clean of any substance that may reduce the bond of the shotcrete to the wire surface.

931.07.05 MTO Nozzleman Certification Program

Shotcreting shall be carried out by a nozzleman who has successfully participated in the MTO Shotcrete Nozzleman Certification Program that is valid for the current construction season. Notwithstanding this prequalification, the nozzleman shall be replaced when in the opinion of the Contract Administrator; acceptable quality of work is not achieved or is not maintained.

931.07.06 Mixing and Delivery of Wet Mix Shotcrete

Wet mix shotcrete shall be mixed and delivered according to the Mixing Time and Mixing Rate, and Delivery subsections of OPSS 1350.

931.07.07 Placing

Prior to the application of shotcrete, all structural components and appurtenances not receiving shotcrete shall be protected from the shotcreting operation. Repair areas being prepared to receive shotcrete shall also be protected from contamination, rebound, overspray or anything that would inhibit the bond of the shotcrete.

Where practical, shotcrete shall be placed without the use of formwork. When the requirements of this specification cannot otherwise be met, formwork may be used and shall be according to OPSS 919. Formwork, where used, shall be adequately braced against excessive vibration and constructed to permit the escape of air and rebound material during the shotcreting operation.

During the application of shotcrete, a steady continuous flow of shotcrete shall be maintained.

For dry mix shotcrete, any predampened mixture which is not utilized within 30 minutes, shall be rejected and shall not be incorporated into the work. When wet mix shotcrete is transported to the site by means of agitating or mixing equipment, discharge of the concrete shall be completed within 1.5 hours after introduction of the mixing water to the cement and aggregates, except when the air temperature is greater than 28°C and the concrete temperature is greater than 25°C, the concrete shall be discharged within one hour after the introduction of the mixing water. Use of retarders does not change the specified concrete discharge time.

The total required depth of shotcrete shall be placed within the same Day.

Shotcrete shall be applied such that there is no sagging or separation of the material in place.

All rebound and overspray material shall be removed from the repair area as the work proceeds. Rebound, overspray or waste material shall not be worked back into the shotcrete or salvaged and re-used. The concrete surface surrounding the repair area shall be cleaned immediately after the application of shotcrete using suitable hand tools.

When shotcrete in a repair area cannot be applied in a single operation or delays are experienced, moist curing by means of continuous fog mist shall be applied immediately according to the Curing Subsection. If the previous layer has hardened, the surface of the shotcrete shall be thoroughly cleaned of any laitance, loose material, overspray or other material that may compromise the bond of subsequent layers by wire brushing and wetted prior to application of an additional layer of shotcrete.

The shotcrete shall be placed level with the original concrete surface to provide a minimum of greater than or equal to 50 mm cover to the welded steel wire reinforcement or reinforcing steel unless otherwise specified in the Contract Drawings. Areas where the minimum cover requirements cannot be achieved shall be identified to the Contract Administrator.

At the end of the shotcreting operation, the shotcrete shall be terminated at a 1:1 slope. Before placing an adjacent section, this sloped portion shall be thoroughly cleaned by wire brushing or abrasive blasting to remove any laitance and then wetted.

931.07.08 Finishing

Unless otherwise specified in the Contract Documents, when the final layer of shotcrete has attained its initial set, the surface of the shotcrete shall be finished with hand finishing equipment.

When tested with a 1.0 m long straight edge, the maximum gap between the straight edge and any point on the surface shall be 6 mm.

931.07.09 Curing

Shotcrete shall be moist cured for a minimum period of four Days followed by three Days of curing with curing compound. Curing for at least the first 24 hours of the curing period shall be by fog mist.

Application of fog mist shall begin immediately after application of the final layer of shotcrete or, where hand finishing is specified, immediately after finishing of the shotcrete.

For the remainder of the moist curing period, for vertical applications, moist curing shall be by means of fog mist or wet burlap and for overhead applications the moist curing shall be by means of fog mist.

When wet burlap is used, the burlap shall be placed in a manner that will ensure that it is in full contact with the surface of the shotcrete for the full duration of the curing period. Curing with burlap and water shall be according to OPSS 904.

Immediately after removal of moist curing, the shotcrete surface shall be coated with a curing compound according to OPSS 904. Once the curing period is complete, curing compound shall be removed completely. The method of removal shall be by abrasive blast cleaning and it shall not result in any damage to the shotcrete surface. The removal process shall meet all environmental constraints as specified in the Contract Documents.

931.07.10 Cold Weather Protection

931.07.10.01 General

Shotcrete shall be protected during cold weather using the method submitted to and accepted by the Contract Administrator. Shotcrete work cannot commence until the Contract Administrator has reviewed and accepted the method submitted.

931.07.10.02 Control of Temperature

During cold weather, for a minimum period of seven Days following the shotcrete operation, the temperature of the shotcrete shall be monitored and controlled to ensure that the temperature is not less than 10°C. Measures shall be taken to ensure that the shotcrete temperature remains within the acceptable limits.

During cold weather, thermocouples, wires and unalterable digital temperature indicators with an accuracy of ±1.5°C shall be supplied to monitor the ambient air temperature and shotcrete temperature. The digital temperature indicators shall be left in place or provided upon request to the Contract Administrator to facilitate additional readings for verification purposes. A set of two thermocouples shall be embedded at a minimum of two locations for each day of shotcreting, as directed by the Contract Administrator. At each location one thermocouple shall be embedded at approximately the centre of the shotcrete application, and the second shall be placed within 10 mm of the surface of the shotcrete.

For cold weather conditions, protection of concrete shall be according to Table 1, as a minimum.

931.07.10.03 Cold Weather Temperature Records

Recording of ambient air temperature and shotcrete temperature shall begin at the start of placement. The ambient air and shotcrete temperature shall be recorded automatically at intervals no greater than one hour until the end of the monitoring period. The monitoring period shall be seven Days. Shotcrete and ambient air temperature readings shall be monitored and verified every 6 hours, or more frequently, for the first three Days and every 12 hours for the remainder of the monitoring period. The Contractor shall take necessary action to maintain the temperature within the specified limits.

The Contract Administrator shall be provided with the necessary access to the location and equipment to verify temperature readings.

Temperature records shall be forwarded to the Contract Administrator at the end of each day. At the end of the cold weather protection period, a complete temperature record consisting of a summary of the recorded temperatures and a graphical plot of temperature versus time shall be submitted to the Contract Administrator.

931.07.11 Sampling for Acceptance Testing of 28-Day Compressive Strength and Rapid Chloride Permeability

931.07.11.01 General

Core samples for acceptance testing of 28-Day compressive strength and rapid chloride permeability shall be removed from the shotcrete repairs at locations randomly selected by the Contract Administrator. Core samples shall be obtained for acceptance testing in the presence of the Contract Administrator.

The lot size, sublot size and number of cores per sublot shall be according to the Quality Assurance section.

931.07.11.02 Coring

Coring shall be carried out according to CSA A23.2-14C when the concrete is between 7 to 10 Days of age. Cores for compressive strength testing shall be 75 mm in diameter and a minimum of 100 mm long. Cores for rapid chloride permeability shall be 100 mm in diameter and a minimum of 75 mm long.

To avoid cutting reinforcing steel, all reinforcing steel in the area shall be located, using a covermeter, prior to taking any cores. Cores for compressive strength testing may contain welded steel wire reinforcement but shall not contain reinforcing steel. Cores for rapid chloride permeability testing shall not contain welded steel wire reinforcement or reinforcing steel.

The Contract number, lot number, sublot number, exact location of each individual core, date of shotcrete placement, and date of extraction shall be marked legibly on each core with durable ink immediately after removal.

Cores shall be placed in a plastic bag, sealed to prevent loss of moisture and provided to the Contract Administrator along with Form A of the concrete mix design and the form on which the field data for the cores is recorded, for testing by the Owner.

The filling of core holes shall be according to OPSS 1350.

931.07.12 Cracks

The Contractor shall inspect all concrete to identify and document any cracks including, their location, width, and density. The results of the inspection shall be reported to the Contract Administrator.

Based on criteria in the Field Inspection of Completed Work subsection, the Contractor shall identify areas requiring repair or replacement and shall identify the limits of such repair or replacement. This information shall be provided to the Contract Administrator along with a proposal for remedial action to be taken. No repairs shall proceed until the proposal has been accepted by the Contract Administrator in writing. Repair of cracks shall be according to OPSS 932 and shall be completed after the curing period has elapsed.

931.07.13 Management of Excess Materials

Management of excess material shall be according to the Contract Documents.

931.08 QUALITY ASSURANCE

931.08.01 Acceptance of Shotcrete

Shotcrete shall be acceptable if all of the requirements of this specification are met, including:

a) Tensile bond strength

b) 28-Day compressive strength

c) Rapid chloride permeability, and

d) There are no defects detected by inspection according to the Field Inspection subsection.

Unacceptable lots or sublots shall be deemed rejectable.

The replacement shotcrete for lots or sublots shall be evaluated for acceptance on the same basis as the original lots or sublots.

931.08.02 Field Inspection

931.08.02.01 Field Inspection Prior To and During Application

The Contract Administrator will inspect the plastic shotcrete during the application process and will reject all or a portion of the work based on the presence of one or more of the defects identified below:

a) Failure to achieve specified surface profile

b) Inadequate abrasive blast cleaning or failure to remove all dust and loose material prior to pre-wetting

c) Failure to meet 36 hour window between abrasive blast cleaning and application of shotcrete

d) Failure to adequately prewet or achieve a saturated surface dry condition of the concrete substrate prior to application of the shotcrete

e) Failure to properly control and remove build-up of shotcrete overspray and rebound

f) Incomplete consolidation around reinforcing steel, mesh and anchors

g) Excessive shotcrete rebound

h) Incorporation of sand lenses, excessive voids, delaminations, sags and sloughing

i) Failure to apply shotcrete to the required line, grade and tolerance

If plastic shotcrete is rejected by the Contract Administrator, the work shall stop and all necessary measures to correct deficiencies shall be taken while the shotcrete is in the plastic state.

931.08.02.02 Field Inspection of Completed Work

The Contract Administrator will inspect the completed work and will reject all or a portion of the work based on the presence of one or more of the defects identified below:

a) Debonding or hollow-sounding areas

b) Porous or rebound material visible in cores or in the field

c) Areas which have sagged visible in cores or in the field

d) Cracks with a width greater than 0.3 mm where the linear measurement of the crack is 2 m or greater per square meter area

Cracks greater than or equal to 0.3 mm in width shall be repaired according to this specification, if the linear measurement of the crack per square metre is less than 2 m.

931.08.03 Acceptance of Tensile Bond Strength, 28-Day Compressive Strength, and Rapid Chloride Permeability

931.08.03.01 Lot Size

A lot shall consist of the total quantity of shotcrete in the Contract Documents. Each lot will be divided into sublots of approximately equal size and no greater than 100 m². Separate sublots are required for vertical and overhead repairs. Separate sublots are required for individual structures.

The Contract Administrator will determine the sublot size after discussion with the Contractor and prior to the commencement of the shotcreting operation.

Testing for tensile bond strength, 28-Day compressive strength and rapid chloride permeability will not be required on a structure when the total measured vertical area of shotcrete on a structure is less than 20 m² or, total measured horizontal area of shotcrete on a structure is less than 20 m² or, for shotcrete on circular columns with spiral reinforcement.

931.08.03.02 Acceptance of Tensile Bond Strength

931.08.03.02.01 Basis of Acceptance of Tensile Bond Strength

The tensile bond strength of a sublot shall be considered acceptable when it meets all of the following:

a) The average of the three tensile bond strength tests shall be greater than or equal to 1.0 MPa

b) Each individual tensile bond strength test shall be equal to or greater than 0.6 MPa

Sublots with an average tensile bond greater than or equal to 0.8 MPa and less than 1.0 MPa shall be considered unacceptable but, with the agreement of the Owner, may be permitted to remain in the Work with a payment adjustment. The payment adjustment shall be calculated and applied according to the Basis of Payment section.

Sublots with an average tensile bond strength less than 0.8 MPa or an individual tensile bond strength less than 0.6 MPa shall be rejected.

931.08.03.02.02 Acceptance Testing of Tensile Bond Strength

Tensile bond strength shall be tested by the Owner according to LS-430 when the concrete is 7 to 10 Days of age. Tensile bond strength testing shall be carried out on three in-situ cores taken within 1 m of each other for each sublot. The core locations shall be randomly selected by the Contract Administrator. If a core comes loose during coring operation, another core shall be obtained within 300 mm of the original core location.

Individual test results shall be forwarded to the Contractor, as they become available.

931.08.03.03 Acceptance of 28-Day Compressive Strength

931.08.03.03.01 Acceptance Testing of 28-Day Compressive Strength

For each sublot, one set of three cores shall be taken to determine the 28-Day compressive strength. The 28-day compressive strength shall be determined according to CSA A 23.2-14C on moisture conditioned cores.

The 28-Day compressive strength of a sublot shall be considered acceptable when it meets the following requirements:

a) The average of the three 28-Day compressive strength tests shall be greater than or equal to 35 MPa.

b) No individual compressive strength test shall be less than 4.0 MPa below the specified strength.

Sublots with an average compressive strength greater than or equal to 31 MPa and less than 35 MPa shall be considered unacceptable but, with the agreement of the Owner, may be permitted to remain in the Work with a payment adjustment. The payment adjustment shall be calculated and applied according to the Basis of Payment section. Sublots with a compressive strength test less than 31 MPa shall be removed and replaced.

931.08.03.03.02 Referee Testing of 28-Day Compressive Strength

Referee testing for a sublot may only be invoked by the Contractor within five Business Days of receiving the test results for that sublot.

Referee testing shall be carried out according to the test method specified in the Acceptance Testing of 28-Day Compressive Strength subsection.

The referee laboratory shall be designated by the Owner based on the applicable roster. Referee test results shall be forwarded to the Contractor as they become available.

Referee testing of 28-day compressive strength for a sublot shall be done on a new set of three cores removed by the Contractor within 24 hours of invoking the referee testing. Cores for referee testing for each disputed sublot shall be taken in the presence of the Contract Administrator at a location no more than 1 m from the location that each of the disputed acceptance cores were removed. The core size, and core extraction shall be according to the Coring clause.

If the difference between the referee test result and the acceptance test result is less than or equal to the confirmation value, then the acceptance test result is confirmed, and the acceptance test result shall be used in the determination of acceptance and payment for the concrete. If the difference between the referee test result and the acceptance test result is greater than the confirmation value, the acceptance test result is not confirmed, and the acceptance test result shall be disregarded and not used in the determination of acceptance and payment.

The confirmation value for confirming the acceptance test result shall be the greater of 10% of the specified strength or 10% of the strength of the acceptance cores, expressed to one decimal place.

When acceptance results are eliminated from the analysis as a result of the referee process, the concrete shall be assessed based on the available strength results for the sublot.

The cost of referee testing shall be as specified in the Contract Documents. When the referee result confirms the acceptance test results, the Contractor shall be charged the cost of referee testing. When the referee result does not confirm the acceptance test result, the Owner shall bear the cost.

931.08.03.04 Acceptance of Rapid Chloride Permeability

931.08.03.04.01 Acceptance Testing of Rapid Chloride Permeability

For each sublot, two cores shall be taken for acceptance testing of rapid chloride permeability. Cores taken for rapid chloride permeability shall be tested according to LS-433. Acceptance testing shall be carried out at 28 to 32 days. One 50 mm long sample shall be cut from each core representing the sublot and tested to determine the acceptance of the sublot. The results from the two cores representing the sublot shall be averaged to determine the acceptability of the concrete within the sublot.

Sublots with rapid chloride permeability less than or equal to 1000 coulombs are considered acceptable. Sublots with a rapid chloride permeability greater than 1000 coulombs and less than or equal 2000 coulombs shall be considered unacceptable but, with the agreement of the Owner, may be permitted to remain in the Work with a payment adjustment. The payment adjustment shall be calculated and applied according to the Basis of Payment section. Sublots with rapid chloride permeability results greater than 2000 coulombs shall be rejected.

931.08.03.04.02 Referee Testing of Rapid Chloride Permeability

Referee testing for a sublot may only be invoked by the Contractor within five Business Days of receiving the test results for that sublot.

Referee testing for a sublot shall be done on a new set of two cores removed by the Contractor within 24 hours of invoking the referee testing. Cores for referee testing for each disputed sublot shall be taken in the presence of the Contract Administrator at a location no more than 1 m from the location that each of the disputed acceptance cores were removed. The core size and core extraction shall be according to the Coring subsection.

The cores shall be tested according to LS-433.

Referee test results shall be forwarded to the Contractor as they become available.

When the referee result is greater than the acceptance test result or no more than 300 coulombs below the acceptance test result, the acceptance test result is then confirmed and shall remain valid.

When the referee test result for the sublot is more than 300 coulombs below the acceptance test result, the acceptance test result is then not confirmed and the referee test result shall replace the acceptance test result in the acceptance requirements of this specification.

The cost of referee testing shall be as specified in the Contract Documents. When the referee result confirms the acceptance test results, the Contractor shall be charged the cost of referee testing. When the referee result does not confirm the acceptance test result, the Owner shall bear the cost.

931.09 MEASUREMENT FOR PAYMENT

931.09.01 Actual Measurement

931.09.01.01 Silica Fume Shotcrete

Measurement of silica fume shotcrete shall be by the volume in cubic metres of the concrete removed according to OPSS 928 except that, when the existing cover to the reinforcing steel is less than 50 mm, the depth used in calculating the volume shall be adjusted by adding the difference between the 50 mm required and the existing cover.

No measurement will be made for areas of shotcrete that were removed according to the Remedial Work subsection.

No measurement will be made for shotcrete required to patch areas of concrete removal where the removal was not approved by the Contract Administrator.

931.10 BASIS OF PAYMENT

931.10.01 Silica Fume Shotcrete - Item

Payment at the Contract price for the above tender item shall be full compensation for all labour, Equipment and Material to do the work, including abrasive blast cleaning of the concrete surfaces.

Payment for the work of abrasive blast cleaning of reinforcing steel will be administered under OPSS 929.

When the Contract does not contain a separate tender item for providing access to the work, the Contract price for the shotcrete items requiring the access shall include full compensation for all labour, equipment and materials to do the work.

Where the work does not conform to the quality requirements specified for compressive strength, tensile bond or rapid chloride permeability, a payment adjustment for each sublot will be made.

931.10.01.01 Payment Adjustment

The payment reduction factor (Pr_i) for each sublot will be calculated by the following equation:

$$Pr_i = 1.0 - \left((0.525 - 0.015S) + \left(\frac{(C - 1000)}{15000} \right) + (0.30 - 0.30B) \right)$$

Where:

S = The average 28-day compressive strength (MPa) for each sublot. (For the purpose of calculating the payment adjustment for shotcrete, a value of 35 MPa shall be used for "S" when the average compressive strength is greater than or equal to 35 MPa.)

B = The average tensile bond strength (MPa) for each sublot. (For the purpose of calculating the payment adjustment, a value of 1.0 MPa shall be used for "B" when the average tensile bond strength is equal to or greater than 1.0 MPa.)

C = The average rapid chloride permeability (coulombs) for each sublot. (For the purpose of calculating the payment reduction for shotcrete, a value of 1000 coulombs shall be used for "C" when the average chloride permeability is less than or equal to 1000 coulombs.)

The payment reduction factor for the lot (Pr) is calculated by the equation:

$$\mathrm{Pr} = \frac{(Pr_1 \times LQ_1) + (Pr_2 \times LQ_2) \cdots (Pr_n \times LQ_n))}{(LQ_1 + LQ_2 \cdots LQ_n)}$$

Where:

Pr_i = Payment reduction factor for sublot i.
LQ_i = Quantity of sublot i (m^3)
n = The total number of sublots.

The total payment adjustment (Pa) for the lot is calculated by the equation:

Pa = Quantity x Tender Unit Price x Pr

TABLE 1
Minimum Cold Weather Protective Measures

Anticipated Minimum Air Temperature (°C)	**Protective Measure**
+10 to 0	PM2
-1 to –10	PM4
-11 to –20	PM5
Less than –20	PM5
Maximum Allowable Drop in Concrete Temperature/24 h	15°C
PM2 - Protective Measure - Cover concrete with insulation having an R-Value of 0.67 (Note 1). PM3 - Protective Measure - Cover concrete with insulation having an R-Value of 1.33 (Note 1). PM4 - Protective Measure - Cover concrete with insulation having an R-Value of 2.00 (Note 1). PM5 - Protective Measure - House and heat as specified in “Housing and Heating” of OPSS 904.	
Note 1: All R-Values are metric. The conversion factor from metric to imperial unit is: Metric “R” value x 5.678 = Imperial “R” value	