TENDER DOCUMENTS

SUBSECTION 6.34
SHOTCRETE

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SUBSECTION 6.34 SHOTCRETE

6.34.1 GENERAL

6.34.1.1 This subsection sets out the requirements for the repair of surfaces using shotcrete as part of the rehabilitation of existing roadway infrastructures provided for in this Contract.

6.34.1.2 The requirements related to concrete demolition are set out in subsection 6.21 *Demolition and Removal.*

6.34.1.3 The requirements related to reinforcing steel and anchors are set out in subsection 6.31 *Reinforcing Steel for Concrete.*

6.34.2 REFERENCE STANDARDS

6.34.2.1 The **Contractor** shall perform all shotcrete work in accordance with the requirements of the following standards and documents, to which the provisions of the Contract are added:

6.34.2.1.1 (AASHTO) American Association of State Highway and Transportation Officials:

- AASHTO M182-05-UL *Standard Specification for Burlap Cloth Made from Jute or Kenaf and Cotton Mats*;
- AASHTO T026-79-UL *Standard Method of Test for Quality of Water to be used in Concrete*.

6.34.2.1.2 (ACI) American Concrete Institute:

- ACI 304.2R-96 *Placing Concrete by Pumping Methods*;
- ACI 306R-88 *Cold Weather Concreting (Reapproved 2002)*
- ACI 506R-05 – *Guide to Shotcrete*;
- ACI 506-3R-91 – *Guide to Certification of Shotcrete Nozzelman*;
- ACI 506.2-95 – *Specification for Shotcrete*;

6.34.2.1.3 (ASTM) ASTM International :

- ASTM C109/C109M-07e1 *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)*;
- ASTM C157/C157M-06 *Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete*;
- ASTM C171-07 *Standard Specification for Sheet Materials for Curing Concrete*;

- ASTM C260-06 *Standard Specification for Air-Entraining Admixtures for Concrete*;
- ASTM C295-03 *Standard Guide for Petrographic Examination of Aggregates for Concrete*;
- ASTM C309-07 *Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete*;
- ASTM C348-02 *Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars;*
- ASTM C387/C387M-06a - *Standard Specification for Packaged, Dry, Combined Materials for Mortar and Concrete*;
- ASTM C457-08b *Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete*;
- ASTM C494/C494M-08a *Standard Specification for Chemical Admixtures for Concrete*;
- ASTM C642-06 *Standard Test Method for Density, Absorption, and Voids in Hardened Concrete*;
- ASTM C666/C666M-03(2008) *Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing*;
- ASTM C672/C672M-03 *Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals*;
- ASTM C685/C685M-07 *Standard Specification for Concrete Made By Volumetric Batching and Continuous Mixing*;
- ASTM C881/C881M-02 *Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete*;
- ASTM C882/C882M-05e1 *Standard Test Method for Bond Strength of Epoxy-Resin Systems Used With Concrete by Slant Shear*;
- ASTM C1017/C1017M-07 *Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete*;
- ASTM C1064/C1064M-08 *Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete*;
- ASTM C1116/C1116M-08 - *Standard Specification for Fiber-Reinforced Concrete*;
- ASTM C1140-03a - *Standard Practice for Preparing and Testing Specimens from Shotcrete Test Panels*;
- ASTM C1152/C1152M-04e1 *Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete*;
- ASTM C1202-07 *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*;

- ASTM D512-04 *Standard Test Methods for Chloride Ion In Water*;
- ASTM D516-07 *Standard Test Method for Sulfate Ion in Water*;
- ASTM D4191-03 *Standard Test Method for Sodium in Water by Atomic Absorption Spectrophotometry*;
- ASTM D4192-03 *Standard Test Method for Potassium in Water by Atomic Absorption Spectrophotometry*;
- ASTM D5095-91(2007) *Standard Test Method for Determination of the Nonvolatile Content in Silanes, Siloxanes and Silane-Siloxane Blends Used in Masonry Water Repellent Treatments*;
- ASTM D5167-03 *Standard Practice for Melting of Hot-Applied Joint and Crack Sealant and Filler for Evaluation*;
- ASTM D5329-07 *Standard Test Methods for Sealants and Fillers, Hot-Applied, for Joints and Cracks in Asphaltic and Portland Cement Concrete Pavements*.

6.34.2.1.4 (CSA) Canadian Standards Association:

- CAN/CSA-A23.1-04/A23.2-04 *Concrete Materials and Methods of Concrete Construction/Methods of Test and Standard Practices for Concrete;*
- CAN/CSA-A23.3-04 *Design of Concrete Structures*;
- CAN/CSA-A3000-03 *Cementitious Materials Compendium (Consists of A3001, A3002, A3003, A3004 and A3005)*;
- CAN/CSA S6-06 *Canadian Highway Bridge Design Code*.

6.34.2.1.5 (BNQ) Bureau de normalisation du Québec:

- BNQ 2501-025 *Sols – Analyse granulométrique des sols inorganiques;*
- BNQ 2560-114/2007 *Travaux de génie civil – Granulats,* Partie IV *Béton de masse volumique normale*;
- BNQ 2621-900/2005 *Béton de masse volumique normale et constituants*.

6.34.2.1.6 (MTQ) Ministère des Transports du Québec (MTQ):

- MTQ – *Cahier des charges et devis généraux* (CCDG);
- MTQ – *Normes – Ouvrages routiers* – Tome VII *Matériaux*, Chapitre 3 *Béton de ciment et produits connexes,*
    - *Norme 3201 Béton projeté par procédé à sec;*
    - *Norme 3301 Béton projeté par procédé humide;*

6.34.3 MATERIALS

6.34.3.1 CEMENT AND ADMIXTURE MATERIALS

6.34.3.1.1 Hydraulic cement shall conform to standards CAN/CSA-A23.1 and CAN/CSA -A3000.

6.34.3.1.2 The cementitious material used shall be a general use GU Portland hydraulic cement or a GUb-SF, GUb-S/SF or GUb-F/SF hydraulic cement.

6.34.3.1.3 The total mass of supplementary cementing materials (fly ash, ground granulated blast-furnace slag and silica fume) shall not exceed 30% of the total mass of the binder.

6.34.3.1.4 Silica fume shall be U type conforming to standard CAN/CSA-A3000, in a ratio of 6% to 8% of the mass of the cement.

6.34.3.1.5 Fly ash, where required, shall conform to the requirements for type F in standard CAN/CSA-A3000 and, more specifically, the section of the standard entitled A3001 – *Binders used in Concrete*.

6.34.3.1.6 Unless otherwise indicated, the use of ternary cement is prohibited between October 15 and March 31.

6.34.3.2 WATER

6.34.3.2.1 Water used to make concrete, including water added to the predampener and the shotcrete nozzle and water used for curing, shall be fresh, clean, potable and free of oil and chemical or organic impurities and shall conform to standard CAN/CSA-A23.1.

6.34.3.2.2 Untreated water used as mix water shall meet the following characteristics (from standard CAN/CSA-A23.1, clause 4.2.2):

Parameter	Maximum Concentration in Mix Water (mg/l)	Standard
Chlorine	500 (for pre-stressed concrete) 1,000 (for other reinforced concrete)	ASTM D512
Sulphate (SO_4)	3,000	ASTM D516
Alkali ($Na_2O + 0{,}658\ K_2O$)	500 600	ASTM D4191 ASTM D4192
Total solids	50,000	AASHTO T026

6.34.3.3 AGGREGATE

6.34.3.3.1 All aggregate shall be clean, strong and free of adverse substances and shall meet the requirements of standard CAN/CSA-A23.1 applicable to the appropriate exposure class.

6.34.3.3.2 The **Contractor** shall submit to the Engineer for review a statement signed by the qualified person who conducted the petrographic examination of the fine and coarse aggregate (in accordance with standard ASTM C295) certifying that the aggregate used in the concrete will not lead to excessive expansion or cracks in the concrete caused by the alkali-aggregate reaction or any other adverse reaction, as prescribed in standard CAN/CSA-A23.1.

6.34.3.3.3 Aggregate shall be made of natural sand, gravel or crushed stone conforming to the requirements of standard CAN/CSA-A23.1 applicable to particle size, strength and durability.

6.34.3.3.4 Aggregate used to mix the shotcrete shall be stockpiled and handled so as to prevent segregation and shall be maintained in a 3% to 7% moisture content range. The **Contractor** shall use shelters or tarpaulins to protect the aggregate stockpiles from damp weather, rain or other adverse conditions.

6.34.3.3.5 Normal-density fine aggregate

6.34.3.3.5.1 Normal-density fine aggregate shall be made of natural sand, manufactured sand or a mixture of the two.

6.34.3.3.5.2 The maximum particle size of the fine aggregate shall be:

Sieve size (mm)	**Percentage of total mass passing through each sieve**							
	10 mm	**5 mm**	**2.5 mm**	**1.25 mm**	630 μm	315 μm	160 μm	80 μm
10 to 2.5	100	95 to 100	80 to 100	50 to 90	25 to 65	10 to 35	2 to 10	0 to 3

6.34.3.3.6 Normal-density coarse aggregate

6.34.3.3.6.1 Coarse aggregate 10 to 2.5 mm shall be stockpiled and added separately from the fine aggregate (maximum nominal size 5 mm) during mixing operations. The particle size of the 10 to 2.5 mm coarse aggregate used shall meet the requirements set out in Table 2 of standard CAN/CSA-A23.1.

6.34.3.3.6.2 The particle size requirements for coarse aggregate are:

Sieve size (mm)	Percentage of total mass passing through each sieve						
	28 mm	20 mm	14 mm	10 mm	5 mm	2.5 mm	1.25 mm
10 to 2,5	-	-	100	85 to 100	10 to 30	0 to 10	0 to 5

6.34.3.3.7 Alkali-aggregate reactivity

6.34.3.3.7.1 The aggregate used for the concrete shall not react on contact with the alkali in the concrete so as to cause excessive expansion of the concrete, cracking or both.

6.34.3.3.7.2 The reactivity potential of aggregate shall be tested in accordance with standard CAN/CSA-A23.2-14A.

6.34.3.3.7.3 The classification of the reactivity of aggregate is based on Table 2 in standard CAN/CSA-A23.2-27A. Results obtained using the quick test will not be considered.

6.34.3.3.7.4 Aggregate classified as “highly reactive” shall not be used. Aggregate classified as “moderately reactive” may be used in combination with the following preventive measure:

6.34.3.3.7.4.1 Limit the amount of alkali in the Portland cement to a maximum of 2.4 kg/m^3 Na_2O equivalent as prescribed in Table 5 *Preventive Measures* in standard CAN/CSA-A23.2-27A;

6.34.3.3.7.5 Aggregate presenting alkali-carbonate reactivity shall not be used.

6.34.3.4 ADMIXTURES

6.34.3.4.1 Air-entraining agent

6.34.3.4.1.1 The **Contractor** shall add a mixture of air-entraining agents to the water. The air-entraining agents shall conform to standard ASTM C260. The **Contractor** may use a powder air-entraining agent for prepackaged mixtures with prior approval from the Engineer.

6.34.3.4.1.2 The **Contractor** shall not add any other admixtures to the concrete mix without prior authorization from the Engineer. The **Contractor** shall not use any admixture containing chlorine.

6.34.3.4.1.3 Characteristics of air void system in hardened concrete:

Shotcrete method	Minimum air content, %	Spacing factor μm	
		Maximum individual result	Maximum average result
Dry	--	320	300
Wet	≥ 3.0	260	230

6.34.3.4.2 Chemical admixtures

6.34.3.4.2.1 Chemical admixtures shall conform to standard ASTM C494/C494M or ASTM C1017/C1017M.

6.34.3.4.2.2 Aluminate-based accelerators are permitted.

6.34.3.4.2.3 Chemical admixtures shall not contain any chlorides. Further, type C or E admixtures (accelerators) are prohibited unless specifically authorized by the Engineer.

6.34.3.4.2.4 Unless otherwise indicated, only type A water reducers shall be used. They shall produce a water reduction of more than 5% compared with the control mix also containing entrained air.

6.34.3.4.2.5 If a superplasticizer (high-range water reducer) is required by the *Special Technical Conditions*, the following special measures must be taken by the **Contractor** when mixing the concrete:

6.34.3.4.2.5.1 before the superplasticizer is added, the concrete shall have a slump within the prescribed limits;

6.34.3.4.2.5.2 at the time it is placed, the concrete shall have an air content within the prescribed limits.

6.34.3.4.2.6 Where a superplasticizer is used, the slump measured after placement shall be maintained at a maximum of 130 mm unless otherwise indicated by the Engineer.

6.34.3.5 FIBRES

6.34.3.5.1 Shotcrete shall contain only polypropylene fibres with the following characteristics:

- homopolymer-based virgin polypropylene;
- tensile strength: 275 to 425 MPa;
- water absorption: zero;
- density: 0.90 to 0.92;

- length: 12 to 20 mm;
- moisture resistant and resistant to alkali in concrete.

6.34.3.5.2 If a mobile volumetric batcher unit is used to make the dry shotcrete, the polypropylene fibres must first be mixed with the fine aggregate at the plant and the air-entraining agent must be added to the water in the tank of the mobile unit, which must have an agitator.

6.34.3.6 CURING AGENTS

6.34.3.6.1 The materials used to cure the concrete shall meet the requirements set out in the following standards: ASTM C171, ASTM C309 and AASHTO M182-UL.

6.34.3.6.2 Membrane-forming curing agent

6.34.3.6.2.1 A chemical curing agent may not be used unless specifically permitted in the *Special Technical Conditions* or authorized by the Engineer as a temporary curing measure where the Engineer determines that wet curing is difficult to achieve.

6.34.3.6.2.2 The membrane-forming curing agent used shall conform to standard ASTM C309, clear with a fugitive dye (type 1-D).

6.34.3.6.3 Absorbent fabric

6.34.3.6.3.1 Absorbent fabric made of unwoven needle-punched synthetic polyester or polypropylene fibres shall have a minimum surface mass of 300 g/m^2 and shall be white.

6.34.3.6.3.2 The absorbent fabric shall be at least 1 m wide and shall not contain any substances that might be adverse to the concrete. New fabric shall be rinsed in running water to make it more absorbent and to remove any soluble materials.

6.34.3.6.4 Waterproof sheet

6.34.3.6.4.1 The waterproof sheet shall conform to standard ASTM C171.

6.34.3.6.4.2 The waterproof sheet may be:

6.34.3.6.4.2.1 a clear or opaque white polyester film at least 0.1 mm thick or

6.34.3.6.4.2.2 a sheet with a minimum surface mass of 305 g/m^2 covered on one side with an opaque white polyethylene film at least 0.1 mm thick.

6.34.3.6.4.3 The waterproof sheet shall be at least 1 m wide, have no tears and be free of any substances that might be adverse to the concrete.

6.34.3.7 CALCIUM CHLORIDE

6.34.3.7.1 Calcium chloride is not to be used at any time.

6.34.3.8 SHOTCRETE

6.34.3.8.1 The shotcrete shall meet the following characteristics:

Specified shotcrete method	Minimum compressive strength at 28 days (MPa)	Type and quantity of cement (kg/m^3)		Max. w/cm ratio	Coarse aggregate (min. %)	Air content of fresh concrete (%)	Slump (mm)	Min. fibre mass (kg/m^3)
		Composite cement(1)	HE (2)					
Dry	35	450	460	0.40	10	3.5 – 7(3)	---	0.9
Wet	35	410	---	0.40	25	10 – 15(4)	100±30(4)	0.9

Notes: (1) GUb-SF, GUb-F/SF or GUb-S/SF composite hydraulic cement.
(2) Overhang application.
(3) Air content measured after loading into air meter.
(4) Slump and air content measured at mixer truck discharge following addition of superplasticizer, if applicable.

6.34.3.8.2 The work shall be carried out using dry or wet shotcrete. Overhead repairs to surfaces shall be done using dry shotcrete.

6.34.4 EQUIPMENT AND TOOLS

6.34.4.1 MOBILE VOLUMETRIC BATCHER UNIT

6.34.4.1.1 For small quantities of shotcrete, the concrete can be measured and mixed on site in a mobile volumetric batcher units in accordance with standard ASTM C685/C685M, unless otherwise indicated by the Engineer.

6.34.4.1.2 If the **Contractor** opts to supply the concrete from floating facilities, a mobile plant on the barge is permitted if the plant meets all the requirements set out in standard ASTM C685/C685M. Mix tests shall then be conducted by the **Contractor**, as well as tests to determine the mixing sequence and the mixing time for each ingredient.

6.34.4.1.3 The mobile volumetric batcher units and operator shall be identified and only they will be authorized to supply concrete during the work. The results of the tests shall be recorded in writing and a copy given to the Engineer before concrete placement begins. The storage areas for the materials shall conform to standard CAN/CSA-A23.1 and shall be set up so as to protect the materials from moisture and weather.

6.34.4.1.4 The first 0.25 m³ of concrete used to prepare and calibrate the equipment may not be used and shall be discarded.

6.34.4.2 MIXER OR PREDAMPENER (DRY MIX SHOTCRETE)

6.34.4.2.1 The mixer or predampener used for pre-humidifying the pre-mixed ingredients shall have sufficient capacity to constantly produce a consistent mixture with a water content of 3% to 6% of the total mass of the mix and shall have sufficient capacity to ensure that there are no delays in performing the work. The materials shall be discharged without separating. Discharge of completely dry materials into the shotcrete gun shall not be permitted.

6.34.4.2.2 For site mixed materials, if the moisture content in the sand is too low to provide a moisture content of the mixed shotcrete materials in the range of 3% to 6%, than the shotcrete shall be predampened in a predampener prior to discharge into the shotcrete gun.

6.34.4.3 PUMP (DRY MIX SHOTCRETE)

6.34.4.3.1 The pump is a tank into which the contents from the mixer are transferred. An air pressure is established inside the tank so that the hose and the nozzle are fed continuously at the required velocity in order to provide a smooth stream of uniformly mixed material.

6.34.4.4 HOSES AND NOZZLE

6.34.4.4.1 The hoses shall be flexible, be at least 38 mm in diameter, be capable of withstanding the required pressure and have sealed connectors between the sections of hose.

6.34.4.4.2 For dry mix shotcrete, the nozzle must be equipped with a branch connection with an adjustable valve for water feeding hose. When it reaches the nozzle, the water has to pass through a perforated ring that ensures that the mix is uniformly hydrated as it exits the nozzle. The interior gasket of the nozzle shall be replaced as needed. The water valve shall be adjustable in order to control the flow of water as needed.

6.34.4.4.2.1 The water supply ring shall be carefully monitored during shooting to see if any holes are blocked. If, in the Engineer's opinion, the shotcrete is not consistently wet, the **Contractor** shall stop work and clean the water supply ring or take any other corrective measures.

6.34.4.5 WATER PUMP (DRY MIX SCHOTCRETE)

6.34.4.5.1 The water pump shall be capable of supplying water pressures in excess of 105 kPa with respect to the air pressures so that the water is intimately mixed with the predampended shotcrete materials. If the water pressure is inadequate, the **Contractor** shall install a water booster pump to provide a steady water pressure.

6.34.4.6 COMPRESSOR

6.34.4.6.1 The compressor shall have sufficient capacity to provide sufficient quantity of clean, dry air at the required pressure (at least 310 kPa) for 45 m of hose in order to prevent any fluctuation in pressure and maintain sufficient nozzle velocity.

6.34.4.6.2 The minimum pressure must be increased by 35 kPa for every additional 15 m of hose. In addition, the working pressure must be increased by 35 kPa for every additional 8 m of difference in height between the compressor and the nozzle.

6.34.4.6.3 The minimum pressures must be observed, taking into account the use of auxiliary devices such as a blow pipe and/or a predampening hose.

6.34.4.6.4 The air supply system shall contain a moisture and oil trap to prevent contamination of the shotcrete.

6.34.4.7 AUXILIARY EQUIPMENT

6.34.4.7.1 Auxiliary shotcrete equipment such as the delivery hose, the water hose, the water booster pumps, the blow pipes, the couplings, the admixture dispensers and the fibre feeders shall conform to standard ACI 506R.

6.34.4.8 CONCRETE PUMP (WET MIX PROCESS)

6.34.4.8.1 The pumping equipment shall conform to standard CAN/CSA-A23.1.

6.34.4.8.2 The concrete pump used shall be capable of pumping concrete through the hose at the required rate of flow without any changes to the mixture.

6.34.4.8.3 No adjustment to the mixture to obtain a product with a higher concrete element, a high sand-stone ratio or slump higher than required by the specifications is permitted to meet the requirements of specific models.

6.34.5 EXECUTION OF WORK

6.34.5.1 PRE-WORK MEETING

6.34.5.1.1 The **Contractor** shall hold a pre-work meeting at least fourteen (14) calendar days prior to the start of the shotcreting work. The **Contractor** shall at that time have the following items verified by the Engineer:

6.34.5.1.1.1 the proposed method of placement for each type of repair according to the drawings and specifications;

6.34.5.1.1.2 the proposed repair materials based on the requirements of these specifications, including any adjustments made during conformity tests;

6.34.5.1.1.3 the **Contractor**'s quality control program.

6.34.5.2 SHOTCRETE MIX

6.34.5.2.1 The **Contractor** is responsible for the proposed shotcrete mix and shall provide the Engineer fourteen (14) calendar days prior to shotcreting operations with the mix formulas and the proposed placement methods.

6.34.5.2.2 The **Contractor** shall provide a description of the concrete mix dated and signed by the manufacturer's quality control officer. The description shall not be more than one year old.

6.34.5.2.3 Concrete mix – wet mix process

6.34.5.2.3.1 The data sheet of the concrete mix shall include the following information:

- a name, number or code;
- the density of the fresh concrete in kg/m³ of the mixture for the specified air content and slump;
- the mass of cement in kg/m³ of the mixture;
- the quantity of water in l/m³ of the mixture;
- the mass of the fine aggregate and coarse aggregate in kg/m³ of the mixture (saturated, dry surface);
- the water/binder ratio with aggregate saturated, dry surface;
- the specified compressive strength;
- the air content and slump limits;
- the types of admixture, the names and manufacturers of the products and the proposed quantities;
- the type of cement, the source and the identification of the cement plant;
- a report from a recognized laboratory issued within the previous three (3) years establishing for the mixture provided the characteristics of the entrained air void, namely the air content, the air void spacing factor and the specific surface;
- the inherent manufacturing and complementary characteristics of the fine and coarse aggregate and the source of aggregate for each calendar year;

- the particle size distribution, the dry crushed density, the gross relative density (saturated surface dry), the percentage absorption of the fine and coarse aggregate and the fineness modulus and colour indicator of the fine aggregate;

- a report from a recognized laboratory issued within the previous three (3) years establishing the potential alkali-aggregate reactivity;

- the results of performance and conformity tests if required by the *Special Technical Conditions*.

6.34.5.2.4 Concrete mix – Dry mix process

6.34.5.2.4.1 The data sheet of the bagged concrete mix shall include, in addition to the information required in paragraph 6.34.5.2.3.1:

- the recommended use;

- precautions and limitations.

6.34.5.2.5 The mix formulas shall be reviewed and verified by the **Owner**'s laboratory. The **Owner** reserves the right to request changes to the formula so that it meets the specifications.

6.34.5.2.6 The Engineer may request that the **Contractor** submit samples of the admixtures it plans to use.

6.34.5.2.7 A manufacturer's certificate must accompany all samples of admixtures confirming that they are the same mixture as those that will be supplied by the **Contractor**.

6.34.5.3 MIXTURE AND MANUFACTURE OF CONCRETE

6.34.5.3.1 The **Contractor** shall obtain its supply from a manufacturer capable of guaranteeing that the facilities, equipment and materials used to manufacture the concrete and all operations related to concrete manufacture conform to standard CAN/CSA-A23.1.

6.34.5.3.2 The concrete manufacturer's plant shall have a compliance certificate issued by the BNQ pursuant to certification protocol NQ 2621-905.

6.34.5.4 DELIVERY SLIP

6.34.5.4.1 For the wet mix process, before the concrete is unloaded, the **Contractor** shall give the Engineer a delivery slip containing the following information:

- the business name of the concrete manufacturer and the identification of the mixing facility;

- the date and identification number of the slip;
- the name of the **Contractor** to which the concrete is to be delivered;
- the name of the roadway infrastructure or part thereof;
- the grade of the concrete;
- the number of the formula, including the quantities of cement, water, coarse aggregate, fine aggregate and admixtures actually used in the mixture;
- the admixtures used;
- the temperature limits specified for fresh concrete;
- the air content limits;
- the slump limits;
- the quantity of concrete in cubic metres;
- the number of the truck, the cumulative quantity of the pour and the load number;
- the loading time;
- the site arrival time;
- the unloading start time;
- the quantity of water added after mixing and the signature of the engineer who authorized that addition.

6.34.5.4.2 For the dry process, the following information must appear on the bags:

- the manufacturer's name;
- the name of the product;
- the dry weight;
- the air-entraining agent;
- the accelerator;
- the yield;
- the recommendations for application;
- the storage time;
- the batch number.

6.34.5.5 QUALITY CONTROL

6.34.5.5.1 The **Contractor** shall establish, maintain and cover the cost of a quality control program for the shotcrete work in order to ensure that the work meets the Contract requirements. Such program must include, but it not limited to:

6.34.5.5.1.1 retention of test results for all quality control operations, including:

6.34.5.5.1.1.1 for any materials measured on site, monitoring of the particle size distribution and moisture content of the aggregate; the **Contractor** must check the moisture content at the start of each shotcrete application and whenever the moisture content of the aggregate changes;

6.34.5.5.1.1.2 for pre-mixed and pre-bagged materials, wash out tests at the frequency determined by the Engineer to check the cement content, the particle size distribution for the aggregate and the fibre content in the case of shotcrete reinforced with fibres;

6.34.5.5.1.1.3 for shotcrete measured by volume, verification of the mixture by proportion of moisture and proportions of ingredients at the prescribed frequency.

6.34.5.6 CONFORMITY TEST

6.34.5.6.1 The **Contractor** shall carry out a conformity test in order to enable the Engineer to evaluate the conformity of the proposed materials, shotcrete mixture, equipment and staff with the requirements of the Contract.

6.34.5.6.2 Every nozzleman shall prepare conformity test panels. The test panels shall be produced in conformity with standard ASTM C1140 and be at least 750 X 750 mm X 125 mm deep. The test panels shall be made of plywood or steel plates and have edges cut on a 45 degree angle to limit rebound.

6.34.5.6.3 Half the test panels shall contain reinforcing and anchors representative of the sizes and spacings required for the work. The other half of the panels shall not have any reinforcing (other than reinforcing fibres) so that samples of the shotcrete can be taken for conformity testing.

6.34.5.6.4 The **Contractor** shall prepare one test panel for each nozzleman to be used for this Contract and each mixture used based on the projected direction of spray.

6.34.5.6.5 For dry mix shotcrete, the Engineer establishes the consistency of the concrete using a needle penetrometer to which the **Contractor** must add a nozzle designed specifically for shotcrete. The result of the conformity test will be used as a reference for acceptance of the work.

6.34.5.6.6 The **Owner**'s laboratory will take three (3) samples of the unreinforced shotcrete at each test age in order to check the performance parameters described in these specifications with the exception of the measurement of chloride ion penetration test (ASTM C1202), for which two (2) samples will suffice.

6.34.5.6.7 The **Owner**'s laboratory will take three (3) core samples 100 mm in diameter at the points where the steel reinforcing bars and mesh overlap and another at an anchor point to determine whether the shotcrete is sufficiently consolidated around the reinforcing.

6.34.5.6.8 The Engineer will assess the quality of the core samples and the test panels. If a test panel is rejected, the nozzleman will be allowed to prepare another one. If the second test panel is also rejected, the nozzleman will not be permitted to perform work under this Contract unless otherwise agreed or indicated by the Engineer.

6.34.5.6.9 The conformity test panels shall be wet cured on site with polyethylene sheets at a temperature between 15°C and 30°C for at least twenty-four (24) hours and shall not be moved.

6.34.5.6.10 If the conformity test samples do not meet the performance requirements of these specifications, the **Contractor** shall make the necessary adjustments and prepare new test panels. Shotcrete work may not begin until the performance requirements are met.

6.34.5.7 STAFF QUALIFICATIONS, METHODS AND EQUIPMENT

6.34.5.7.1 Fourteen (14) days prior to the start of shotcrete work, the **Contractor** shall submit to the Engineer a document indicating:

6.34.5.7.1.1 the qualifications and experience of the work crew. Shotcrete work shall be performed only by fully qualified specialists. The shotcrete nozzleman shall have ACI 506.3R certification.

6.34.5.7.1.2 a list of proposed shotcreting equipement, including brand name, model and capacity of shotcrete gun, predampener and air compressor;

6.34.5.7.1.3 proposed curing and protection to be provided to shotcrete.

6.34.5.8 PREPARATION OF EXISTING SURFACES BEFORE SPRAYING

6.34.5.8.1 Existing surfaces (concrete or rock)

6.34.5.8.1.1 All surfaces shall be clean, solid and free of loose fragments, sawdust, ice, snow and any other foreign substances or debris and shall be sufficiently rough to ensure a complete bond with the new concrete.

6.34.5.8.1.2 In the case of hardened concrete surfaces, the laitance shall be removed and the aggregate partially exposed.

6.34.5.8.1.3 Rock surfaces may be cleaned by means of air, water or abrasive blasting or vigorous brushing.

6.34.5.8.1.4 The surfaces shall be rough, and the roughness of a treated surface shall have an amplitude of at least 5 mm.

6.34.5.8.1.5 The **Contractor** shall then remove any excess water from the surface using air blasting only.

6.34.5.8.1.6 The **Contractor** shall monitor and remove any water infiltration and ponding that have formed in hollows, to the satisfaction of the Engineer.

6.34.5.8.2 Demolished concrete surfaces

6.34.5.8.2.1 The **Contractor** shall demolish deteriorated concrete and prepare the substrate in accordance with the requirements set out in subsection 6.21 *Demolition and Removal*.

6.34.5.8.2.2 After water blasting, the **Contractor** shall remove any excess water from the surfaces using air blasting only.

6.34.5.8.2.3 Before the concrete is sprayed, the work area shall be checked for water and any pools that have formed in hollows shall be removed to the satisfaction of the Engineer.

6.34.5.8.2.4 At least three (3) hours before the new concrete is sprayed, the **Contractor** shall thoroughly humidify the surfaces to be repaired so that they are saturated surface dry. Excess water shall be removed by means of air blasting fifteen (15) minutes prior to placement of the concrete so that the substrate remains saturated surface dry at the time of placement.

6.34.5.9 APPLICATION OF SHOTCRETE

6.34.5.9.1 Application conditions

6.34.5.9.1.1 All areas prepared for repair by means of shotcrete shall be examined and approved by the Engineer before the shotcrete is applied.

6.34.5.9.1.2 The **Contractor** shall not apply shotcrete where rain or strong wind could adversely affect the shotcrete spray unless it installs appropriate protective covers, enclosures or windscreens. Shotcrete work shall not be started or continued if the surfaces to be covered are exposed to rain or runoff.

6.34.5.9.1.3 Temperature control

6.34.5.9.1.3.1 The temperature of the concrete delivered to the site shall conform to standard CAN/CSA-A23.1 and be measured at the discharge point from the mixing truck in accordance with standard ASTM C1064/C1064M.

6.34.5.9.1.3.2 The temperature of the applied shotcrete shall preferably be between 10°C and 20°C, but shall not be less than 10°C or more than 25°C.

6.34.5.9.1.4 If the site conditions (relative humidity, wind speed, air temperature and direct exposure to sunlight) are such that the shotcrete develops plastic shrinkage or cracking during its initial set period, the **Contractor** shall stop applying the shotcrete until conditions improve or take corrective measures.

6.34.5.9.1.5 Application of shotcrete in hot weather

6.34.5.9.1.5.1 In severely dry conditions, the forms, reinforcing and spraying equipment must be protected from direct sunlight or cooled by means of misting and evaporation.

6.34.5.9.1.5.2 The **Contractor** shall take such measures as are needed to ensure that the evaporation rate is less than 1.0 kg/m²h as prescribed in Appendix D of standard CAN/CSA-A23.1.

6.34.5.9.1.5.3 If the evaporation rate exceeds or is in danger of exceeding the above limit, the **Contractor** shall take the necessary measures, including one (1) of the following:

- erecting windscreens around the concrete surfaces;
- wetting the substrate before placing the concrete;
- placing sun shades over the concrete during finishing;
- lowering the temperature of the concrete;
- covering the surface of the concrete with polyethylene film between finishing stages;
- starting to cure the concrete as soon as it has been towelled;
- placing and finishing the concrete at night.

6.34.5.9.1.5.4 The **Contractor** shall stop applying shotcrete if the air temperature rises above 30°C unless the **Contractor** is using special methods for applying shotcrete in hot weather, which must be approved in advance by the Engineer.

6.34.5.9.1.6 Application of shotcrete in cold weather

6.34.5.9.1.6.1 When the air temperature is 5°C or less or is expected to drop below 5°C within twenty-four (24) hours of application (according to the forecast from the Environment Canada weather office closest to the work), all equipment and materials needed to protect the concrete while it cures must be available and ready for use before application begins.

6.34.5.9.1.6.2 Snow and ice shall be removed before shotcrete is placed on any surface. The **Contractor** shall not use calcium chloride or other de-icing agents to remove ice from formwork or substrate.

6.34.5.9.1.6.3 All surfaces with which fresh concrete comes into contact shall be heated to a minimum temperature of 10°C and kept at that temperature for at twelve (12) consecutive hours before the concrete is placed. Concrete shall not be sprayed onto a surface the temperature of which would help lower the temperature of the concrete.

6.34.5.9.1.6.4 In cold weather, the **Contractor** shall ensure that the concrete is appropriately protected throughout the placement and curing process. Such protection shall be assured by means of heated shelters, covers, insulation or a combination thereof.

6.34.5.9.1.6.4.1 The shelter may be heated by live steam, forced hot air or fixed heaters.

6.34.5.9.1.6.4.2 If devices that release carbon monoxide are used, the **Contractor** shall ensure that the gas is exhausted from the shelter. Under no circumstances shall carbon monoxide be allowed to come into contact with the concrete.

6.34.5.9.1.7 Time between mixing and application

6.34.5.9.1.7.1 At no time shall more than one hundred and twenty (120) minutes elapse between manufacture and unloading. Any departure from this requirement must be approved by the Engineer before the concrete is placed.

6.34.5.9.1.7.2 If more than ninety (90) minutes have elapsed since the concrete was mixed, the air content and temperature of the concrete must be rechecked by the **Contractor**.

6.34.5.9.1.7.3 Concrete that is not placed within the prescribed time cannot be used.

6.34.5.9.2 Application

6.34.5.9.2.1 Shotcrete shall be applied to vertical surfaces starting at the bottom of the repair.

6.34.5.9.2.2 Shotcrete work shall conform to standards ACI 506R and ACI 506.2. Wherever possible, the **Contractor** shall apply shotcrete over the full thickness in a single layer. Otherwise, the **Contractor** must use the minimum number of layers needed to obtain the full thickness of shotcrete without slump, separation or rippling. Application must be completed within 120 minutes after the concrete is mixed.

6.34.5.9.2.3 Shotcrete nozzles shall be used in the proper manner and as prescribed in standard ACI 506R. Specifically:

6.34.5.9.2.3.1 the **Contractor** shall hold the nozzle at a right angle to and approximately 1 m away from the surface to be treated except to fill corners, finish edges or coat large reinforcing bars;

6.34.5.9.2.3.2 the **Contractor** shall cover the reinforcement steel bars and mesh carefully keeping the faces of the steel clean and applying the shotcrete in order for it to accumulate from behind the reinforcing bars as to minimize sand and air pockets;

6.34.5.9.2.3.3 the combination of the air pressure in the nozzle, the moisture content of the shotcrete and the distance between the nozzle and the surface must be optimized in order to achieve maximum consolidation of the shotcrete.

6.34.5.9.2.4 Where the **Contractor** applies the concrete in multiple layers, the first layer shall be prepared before the next one is applied using one of the following methods:

6.34.5.9.2.4.1 sweeping the previous layer with a stiff straight-bristle broom to remove any loose materials or overspray before the concrete starts to set;

or

6.34.5.9.2.4.2 if the concrete has started to set, the **Contractor** shall wait at least twenty-four (24) hours to prepare the surface, after which the surface shall be prepared by sandblasting or high-pressure water blasting to remove any loose materials hardened overspray or any other materials that will prevent a good bond.

6.34.5.9.2.5 Where successive layers of concrete are needed to attain the full thickness of shotcrete, the **Contractor** shall, by means of misting or watering, prevent the first layer from drying. Curing products may not be used without the prior written authorization of the Engineer. If the **Contractor** uses a curing product, it shall remove it by abrasive blasting or high-pressure water blasting before applying the next layer. The layer underneath shall be free of surface water and shall be saturated surface dry when the next layer is applied.

6.34.5.9.2.6 The **Contractor** shall take care to protect adjacent surfaces from overspray and splatters. The **Contractor** shall remove any overspray and splatters from the surfaces to which shotcrete is to be applied, which is best done when the material is still plastic using compressed air hoses, scrapers, wire brushes or other appropriate tools. Hardened overspray and splatters must be removed by means of abrasive blasting, picks, high-pressure water or other appropriate techniques before more shotcrete is applied.

6.34.5.9.2.7 Overspray and splatters cannot be used for the work and must be removed from the site.

6.34.5.9.2.8 The **Contractor** shall apply shotcrete according to the limits, grades and tolerances specified on the drawings using plumb lines, depth gauges, guide strips, forms or other appropriate devices. The **Contractor** shall apply the shotcrete so as to provide the minimum cover required on the drawings.

6.34.5.9.2.9 The **Contractor** shall cut any metal depth gauges to 5 mm below the surface of the shotcrete in order to prevent surface rust.

6.34.5.9.2.10 In the case of shotcrete with aggregate no bigger than 10 mm or shotcrete reinforced with fibres, application of a final layer of shotcrete 5 mm to 20 mm thick with aggregate no bigger than 5 mm will be permitted.

6.34.5.10 SURFACE FINISHING

6.34.5.10.1 Before finishing, the **Contractor** shall cut the shotcrete to the prescribed limits and grades using cutting tools or other devices. The **Contractor** shall allow the shotcrete to harden sufficiently before cutting and thinning in order to prevent tearing, cracking, delamination and scaling. The **Contractor** shall remove the alignment wires once cutting and thinning are complete. The surface profile shall be verified and corrected using a 3 metre rule. Any hollows deeper than 15 mm over 3 metres shall be corrected.

6.34.5.10.2 Unless otherwise indicated on the drawings or in the *Special Technical Conditions*, the **Contractor** shall provide a textured finish comparable to the existing surfaces by leaving the shotcrete in its natural finished state if the texture is adequate or by using one of the following methods:

- wood float finish: preliminary finish for other surface treatments or granular texture finish;
- rubber float finish: to produce a finer grainy textured finish;
- fine metal brush finish: fine, sandy textured finish;
- steel trowel finish: dense, soft, hard finish.

6.34.5.11 CLEAN-UP

6.34.5.11.1 The **Contractor** shall remove all debris, abrasives and removed splatters and overspray according to the requirements in subsection 6.13 *Environmental Protection*.

6.34.5.12 CONSTRUCTION JOINTS

6.34.5.12.1 Construction joints are stop points and are permitted only where indicated on the drawings or in the *Special Technical Conditions*.

6.34.5.12.2 Construction joints not indicated on the drawings must be authorized by the Engineer and located and designed so as to cause as little harm as possible to the strength of the concrete and the appearance of the roadway infrastructure.

6.34.5.12.3 Where a construction joint has to be made, the set concrete surface must be sufficiently rough, free of any foreign bodies or laitance and saturated with water and kept wet with no excess surface water until the concrete work resumes, in accordance with article 6.33.5.5.1 *Existing surfaces* (*concrete or rock*).

6.34.5.12.4 When formwork is being done, chamfer strips shall be placed along the joints so that the exposed edge will have a uniform finish.

6.34.5.13 SEALING OF CONSTRUCTION JOINTS

6.34.5.13.1 Contraction joint

6.34.5.13.1.1 For contraction joints, the **Contractor**, in addition to the requirements set out in standard CAN/CSA-A23.1, must meet the following requirements:

6.34.5.13.1.1.1 contraction joints shall be made by sawing, hand shaping or insertion of prefabricated strips into the concrete to promote cracking;

6.34.5.13.1.1.2 contraction joints are permitted only where shown on the drawings;

6.34.5.13.1.1.3 unless otherwise indicated on the drawings, joints shall be spaced on a grid no bigger than 4.5 m;

6.34.5.13.1.1.4 shaped joints and prefabricated strips shall be set into the concrete to a depth of at least 25 mm.

6.34.5.13.2 Joint rustication

6.34.5.13.2.1 Unless otherwise indicated on the drawings, all horizontal and vertical construction joints and contraction joints shall be rusticated by the use of 20 mm chamfer strips placed in the forms.

6.34.5.13.2.2 The chamfer strips shall be made of the same material as the forms.

6.34.5.13.2.3 The chamfer strips shall be placed so as to leave a neat regular groove in the concrete at all construction joints, along the vertical showing edge of contraction joints and at all exposed edges and corners of the concrete.

6.34.5.13.2.4 All chamfer strips shall be equal in cross-section and installed true to line and grade.

6.34.5.14 CURING

6.34.5.14.1 Curing method

6.34.5.14.1.1 As soon as finishing is complete, the **Contractor** shall apply a chemical curing product to temporarily prevent the shotcrete from drying. Wet curing must begin within 60 minutes after the surface is finished and the curing product is applied.

6.34.5.14.1.2 When the concrete has fully set, the **Contractor** must keep it wet for seven (7) days unless otherwise indicated in the *Special Technical Conditions*. The **Contractor** shall carry out wet curing using one or more of the following methods:

6.34.5.14.1.2.1 wrap the concrete in wet burlap covered with a waterproof polyethylene sheet to slow the drying of the burlap and keep the wrapping continuously moist with a watering system;

6.34.5.14.1.2.2 install sprinklers, watering hoses or other devices to keep the shotcrete repairs continuously wet and ensure that no damage is caused to the concrete surface. The use of intermittent moistening methods that allow the shotcrete to cycle through wet and dry periods while curing is not permitted.

6.34.5.14.1.3 Concrete that is not cured in accordance with the specifications or the Engineer's instructions will not be paid for. Furthermore, the **Owner** reserves the right to have concrete work redone at the **Contractor's** expense if, in the Engineer's opinion, the quality of the work was impaired because of a lack of curing.

6.34.5.14.1.4 Cold-weather curing

6.34.5.14.1.4.1 The concrete shall be kept a temperature of at least 10°C for the minimum curing period of seven (7) days.

6.34.5.14.1.4.2 Wet curing shall be completed twelve (12) hours before the end of the protected period.

6.34.5.14.1.4.3 This minimum period for protecting the concrete shall be extended if the concrete has not attained 70% of the required strength at twenty-eight (28) days or according to the strength specified in the *Special Technical Conditions*.

6.34.5.14.1.4.4 Heaters shall be sufficient in capacity and number to keep the concrete at the required temperature.

6.34.5.14.1.4.5 If devices that release carbon monoxide are used, the **Contractor** shall ensure that the gas is exhausted from the shelter. Under no circumstances shall carbon monoxide be allowed to come into contact with the concrete.

6.34.5.14.1.4.6 After the protected period, the temperature of the concrete shall be gradually lowered for the first twenty-four (24) hours. The temperature shall not be lowered faster than 10°C an hour. The concrete shall not be exposed to outdoor air if the difference between the temperature of the concrete surface and the temperature of the outdoor air is more than 20°C.

6.34.5.14.1.4.7 Throughout the protected period, the **Contractor** shall supply and install a sufficient number of thermometers that record the low and high temperatures to check the temperature of the concrete and a thermometer to check the temperature of the outdoor air.

6.34.5.14.1.4.8 Any concrete damaged by freezing, inadequate protection or insufficient curing shall be removed and replaced by the **Contractor** at no additional cost to the **Owner**.

6.34.5.15 ACCEPTANCE OF SHOTCRETE

6.34.5.15.1 The Engineer has the authority to accept or reject shotcrete work under but not limited to paragraph 6.34.5.15.2. The **Contractor** shall provide the Engineer with access to the repaired surfaces at all times for purposes of verification. Shotcrete that does not conform to the Contract provisions will be rejected based on the results of the test panels, during application of the shotcrete or once the work is complete.

6.34.5.15.2 Deficiencies that constitute sufficient grounds for the Engineer to reject plastic shotcrete include, but are not limited to:

6.34.5.15.2.1 failure to control and properly remove build-up of overspray and rebound;

6.34.5.15.2.2 incomplete consolidation around reinforcing bars, mesh and anchors;

6.34.5.15.2.3 excessive shotcrete rebound or excessive fibre rebound in the case of fibre-reinforced shotcrete;

6.34.5.15.2.4 incorporation of sand lenses, excessive voids, delaminations, sags and sloughing;

6.34.5.15.2.5 failure to apply shotcrete within the required limits, grades and tolerances;

6.34.5.15.2.6 discrepancy between consistency measures in conformity test and consistency measures during application.

6.34.5.15.3 Repair of deficiencies

6.34.5.15.3.1 Concrete that is deemed to be defective by the Engineer while it is still plastic shall be removed using picks, scrapers or other appropriate mechanical devices. The **Contractor** may use high-pressure water jets provided the removal and the means used by the **Contractor** to manage the removal of the shotcrete and sludge are acceptable to the Engineer.

6.34.5.15.3.2 Once curing is complete, the **Contractor** and the Engineer shall verify the adhesion of the new concrete using a geologist's hammer.

6.34.5.15.3.3 Hardened concrete that is deemed to be defective shall be removed and redone at no cost to the **Owner**. During this process, the **Contractor** shall be careful not to damage the steel reinforcing bars, mesh or anchors. The **Contractor** shall replace at no cost to the **Owner** any embedded element damaged in the course of removing shotcrete.

6.34.6 PENALTY

6.34.6.1 If the actual strength of the concrete at twenty-eight (28) days is less that the prescribed strength, the following penalties will be applied:

Prescribed Strength 35 Mpa	
Strength at 28 days (MPa)	**Penalty (%)** [(1)]
34.0 to 34.9	2%
33.0 to 33.9	4%
32.0 to 32.9	6%
31.0 to 31.9	8%
30.0 to 30.9	10%
29.0 to 29.9	25%
28.0 to 28.9	40%
27.0 to 27.9	55%
26.0 to 26.9	70%
25.0 to 25.9	85%
< 25.0	See paragraph 6.34.6.2

[(1)]: % of unit price tendered for the pertinent pay item of the Price Table for deficient quantities.

6.34.6.2 If the strength of the concrete at twenty-eight (28) days is less than the lower end of the range indicated in the table in paragraph 6.34.6.1, the **Owner** reserves the right to have the deficient work redone at the **Contractor**'s expense.

6.34.6.3 No penalty applies where the strength is greater than prescribed. However, the **Owner** reserves the right to ask the **Contractor** to change the mix at its expense or modify its quality control measures, particularly with regard to the proportion of cement and the water content of the aggregate if the strength is significantly greater than the strength specified and the strength values are, in the Engineer's opinion, detrimental to the quality of the work, particularly in terms of excessive cracking.

END OF SUBSECTION