

THE DEVELOPMENT OF IMPROVED SHOTCRETE MATERIALS AND METHODS

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INTRODUCTION

Before the introduction of the more controlled shotcrete specifications that are currently being practiced by the M.T.O., M.T.Q. and other specifying authorities, shotcrete or guniting specifications were often written simply by listing the process and a specified 28 day compressive strength. The quality of shotcrete applications was ensured simply by limiting the eligibility of contractors who could bid the job to those with a pre-determined number of years experience. Mix proportions were often specified by volume and batched using full bags of cement and shovels of bulk sand. The components were then mixed using a mortar mixer and shot into place through a shotcrete machine. Random cores could be taken from the repaired structure to determine if the shotcrete would meet the specified compressive strength. However, few other pro-active measures were taken to ensure an installation of good quality.

Shotcrete specifications have evolved considerably since this time and the introduction of factory controlled pre-blended materials, pozzolins such as silica fume and fly ash, admixtures such as accelerators and powdered air entraining agents, fibre reinforcement of shotcrete mixes and certification of shotcrete nozzlemen have improved the quality of shotcrete applications and reduced the occurrence of poor quality shotcrete.

THE DEVELOPMENT OF THE M.T.O. SHOTCRETE SPECIFICATION

From the early 1980's until February 1988, shotcrete repairs were carried out on M.T.O. and other structures using latex modified, site mixed shotcrete. They included specifications for equipment, materials, procedure and payment. Shotcrete procedures as outlined in the specifications are listed below.

Shotcrete Mix Proportions

These specifications allowed for both wet and dry application methods. Dry mix applications were mostly used as this method was better suited to patching small areas. Dry mix shotcrete was usually "site mixed". Aggregates were obtained from suitable local sources, delivered to site in bulk and stockpiled for later use. These aggregates complied with the fine aggregate gradation given in O.P.S.S 1002. The maximum particle size was 9.5 mm with a nominal particle size of about 2.3mm.

To decrease the permeability of the matrix latex was added at the nozzle. A typical mix proportion (by weight) for the latex modified shotcrete was as follows:

- 1 part cement
- 3.5 parts fine aggregate
- 1/3 parts latex (47.5% solids by weight)
- Water cement ratio of 0.35

Shotcrete Application

The minimum thickness of a single layer of shotcrete was 25mm and the maximum allowed thickness was 50mm. Greater thickness would have to be applied using multiple layers built up without sagging or separation. The shotcrete material would have to reach

its final set and previous layers were to be cleaned of all rebound and/or accumulated material prior to placing an additional layer.

Finishing

Hand finishing using latex modified shotcrete was minimized. Once the shotcrete had reached its final set, excess material was removed from around the perimeter of the repair area using a sharp edged cutting tool. In most cases the shotcrete surface was left with a "rough gun finish",

Curing

Curing requirements included a 24 hour moist cure followed by 72 hours of air drying at temperatures above 10°C. Typical moist curing was accomplished by placing wet burlap over the repaired surface within 1 1/2 hours of shotcrete application. This curing procedure was very difficult to carry out in overhead applications.

Quality Assurance

Original specifications required the contractor to shoot test panels using the nozzlemen and equipment that would be used on the contract. Preconstruction testing included shooting two test panels, one in the vertical position and one in the overhead position.

Cores were taken from the test panels after 4 days and tested at 7 and 28 days. The 7 day strength requirements were a minimum of 25MPa and 28 day strength requirements were a minimum of 30MPa. The cores were also checked for air pockets and trapped rebound material.

Inspection of finished shotcrete was undertaken after the mix had reached its final set. The surface was then sounded with a hammer to detect any hollow areas or areas with inadequate bond. Hollow sounding areas were removed and replaced.

Four cores were also taken from patched areas after 28 days and tested for permeability using the Rapid Chloride Permeability Test procedure. This test was intended to determine the insitu permeability of the shotcrete. A minimum test value of 1,500 coulombs was specified.

GOLDER ASSOCIATES LTD. REPORT TO M.T.O.: "IMPROVED SHOTCRETING METHODS AND MATERIALS"

In early 1988, Golder Associates were retained by the M.T.O. to undertake a study to examine alternative shotcrete mix compositions and to establish procedures for application and surface preparation to be used in a full scale field test.

The primary objective was to "develop a more effective shotcrete mix for repair of corrosion damaged structures". The improved mix would reduce maintenance costs and extend the service life of repairs.

Field Evaluation of Existing Shotcrete Repairs

Several local bridges that had been repaired with site mixed latex modified shotcrete were visited and inspected. Conclusions of the examinations included the identification of several types of problems. A summary of some of these problems were as follows:

1. Moisture migration into the patch causing delamination. There were two entry points for moisture; edges and surface. Placement of shotcrete as tight to the edge of the patch as possible would reduce this problem. Surface roughness provided by the "rough gun finish" and microcracking also promoted the absorption of water into the patch.
2. Delamination of shotcrete at the edges - Sufficient thickness of shotcrete must be applied at the edges to avoid the practice of feather edging. (minimum 25mm) Overshot material debonded from areas where it should have been removed.
3. Poor Surface Preparation - Some areas showed signs of delamination due to poor surface preparation.
4. Curing - Improper curing practices would lead to the development of microcracks. Over time, the size of the cracks could increase and lead to greater water absorption through the surface.
5. Finishing - Latex modified shotcrete was extremely difficult to finish and in most cases a rough gun finish was used. A material that could provide a smooth, homogeneous surface would reduce water related absorption problems.
6. Mix Variability - It was difficult to ensure adequate uniformity with site mixed materials. Volume batching using shovels of bulk sand, varying moisture contents of bulk sand, and variability of cement contents between batches made it difficult to obtain a consistent uniform mix.

Testing of Trial Shotcrete Mixes

A thorough Literature Review was conducted and discussions were held with other specifying authorities and King Packaged Materials Company to determine which shotcrete mixes would be tested and compared with the current M.T.O. standard. Various mixes were bench tested for Compressive Strength, Shrinkage, and Setting Time. These results were used to determine which ones would undergo an actual full scale field trial.

Field Trials

The selected test mixes were supplied by King Packaged Materials Company and produced at their production facility in Onaping Falls. The dry components of each mix were blended in a high shear, counter current Skako pan mixer, and were packaged and labeled before being delivered to an indoor parking garage site in Scarborough, Ontario. This indoor location was chosen for the field trials because it provided ambient temperatures during the trial. (Outdoor temperatures during the testing period were below freezing).

Underground Services (1983) Limited of Bolton, Ontario provided experienced nozzle men and the equipment necessary to undertake the field trials.

Test panels were prepared with a concrete backing in order to conduct bond testing between the shotcrete mix and the concrete surface. Each panel was sandblasted to expose the coarse aggregate of the concrete base in the same manner used for a typical concrete repair.

The equipment used to shoot the test panels was conventional dry mix shotcrete equipment consisting of a pre-dampening unit which was used to "pre-moisten" the dry, pre-bagged materials before they were dropped into the hopper of the shotcrete machine. This pre-moistening process ensured a uniform moisture condition to the mix arriving at the nozzle. In addition, it reduced wear to the shotcrete gun and hoses and reduced the amount of airborne dust.

The shotcrete machine used was an Allentown rotating barrel type machine.

Shooting Procedures

The different mixes were not shot in any order with the exception of the latex modified mixes, which were grouped together to reduce the clean-up time. Between each mix, the material supply hose, pre-dampener and shotcrete machine were cleaned out and allowed to run without material. After shooting latex mixes, the water supply hose was flushed with water and run clean.

The test panels were shot in pairs; one in the vertical position and one in the overhead position. Vertical panels were leaned up against the wall and overhead panels were held against the soffit with jacks.

All panels were shot with consistent air pressure, water/cement ratio and material feed rate and the same nozzle man was used to provide consistently, comparative results.

Each test panel was shot in layers and each layer was allowed to cure until the superintendent felt that another layer could be placed. In most cases additional layers could be placed within 3 to 4 hours. In some cases however, particularly with latex modified mixes, the material had not set enough by the end of the day to allow an additional layer of shotcrete to be placed.

Curing Procedures

Curing conditions were similar for all test panels. The air temperature during the shooting and curing varied between 10°C and 22°C. The relative humidity varied between 65% and 85%. The test panels were moist cured for at least seven days by spraying the panels at regular intervals. The first spraying was usually applied about 4 to 8 hours after the panel had been shot.

Sampling of Hardened Material

After curing for 7 days, the panels were carefully laid flat on the floor of the parking garage for coring. The coring operations were started about 10 days after the first panel was shot. Cores for laboratory testing were obtained in three sizes; 75mm, 100mm and 150mm. The cores were returned to Golder's laboratory in Mississauga and were kept in the moist curing room (relative humidity of 100% at 23°C) until they were tested. The laboratory tests performed on the core samples were as follows:

- Compressive Strength
- Unit Weight
- Absorption
- Rapid Chloride Permeability
- Boiled Absorption
- Bond Strength

In addition to the core samples, a full depth section about 125mm in width was saw cut perpendicular to the reinforcing steel to assess the voids behind the reinforcing steel for each mix. These samples were also returned to the Golder laboratory for examination.

Field Trial Observations

The nozzleman reported that the silica fume mixes had the best "flowing" ability and were the easiest to shoot. In particular, the nozzleman reported that the fine aggregate mix with 8% silica fume by weight of cement was, "the best mix I ever shot".

Portions of the plain shotcrete mixes collapsed within several hours of shooting the second layer. All other mixes remained intact.

The polypropylene fibre mixes produced a large volume of fibre in the air while shooting. The nozzleman compared this to "shooting in a snow storm".

The finished surface of the mixes shot with steel fibre showed some fibres protruding from the surface. The moisture content of the shotcrete was critical in the control of the amount of protruding fibres. If the mix that was shot was too dry, the percentage of protruding fibres was greater. The drier mixes did not seem to have enough plasticity to allow the fibres to roll over to lay flat during shooting.

Both latex mixes encountered blockage of the water delivery lines on many occasions. The contractor changed supply pumps several times with little effect on solving the problem. The blockage was most evident after a pause in shooting for as little as 20 minutes while the mix was changed. As a result, many litres of latex material was wasted in washing out the hose and recharging it before the next panel.

Both latex mixes also required the most number of lifts to complete the required 150mm thickness for the test panels. The laboratory bench test results indicated that the latex modified mixes have longer set times. This was obvious in the field trials as the contractor could not apply the second lift of shotcrete until late in the day. As a result, all the latex panels had cold joints formed when the contractor could not complete a panel on a single day.

Results of the field trials indicated that the mixes modified with silica fume were easiest to shoot and could be shot in thicker lifts effectively. As reported in the literature, the silica fume did enhance the application performance of the steel fibre mixes. The mixes that were the most difficult to place were the latex modified mixes.

Examination of the saw cut samples revealed that the addition of fibre to the mix results in voids behind the reinforcing steel. This effect is not reported in the literature, however, in most of these studies the shotcrete was not applied through a mesh.

The use of pre-bagged mixes and a pre-moistener was essential for this study in order to reduce the effects of changes in the consistency of the mix on the properties of the shotcrete. It was felt that adequate control of consistency could not be achieved with site mixing techniques.

Field Trial Laboratory Test Results

The results of laboratory testing are listed in Appendix A.

Table 1 - Lists the Mix Designation and Description of the mixes that were shot during the Field trials.

Table 2 - Lists the results of Compressive Strength and Density Testing for fine aggregate Mixes.

Table 3 - Lists the results of Bond Strength Testing on fine aggregate mixes.

Table 4 - Lists the results of Rapid Chloride Permeability Testing for fine aggregate mixes.

Table 5 - Lists the results of Boiled Absorption Testing for fine aggregate mixes.

Conclusions

The report concluded that pre-bagging shotcrete mixes under a controlled environment offered the greatest control over aggregate gradation and cement content of the shotcrete mix. Proper finishing is also vital to the long term durability of the shotcrete repair. Hand trowelling densifies the surface layer of the shotcrete and improves durability.

Proper treatment of the edges of the patches is also critical. Sufficient thickness at the edge of the patch (25mm minimum) is required to prevent debonding and cracking of the patch due to "feather edging".

The use of silica fume in the shotcrete mix improves shootability of the mix, increases the thickness of material that can be shot in one lift and provides excellent Rapid Chloride Permeability Results.

The report also recommended a full scale field trial be undertaken to further evaluate the performance of a pre-bagged shotcrete mix enhanced with 8% silica fume by weight of cement. It was also recommended that both standard wet curing and M.T.O. approved curing compounds be evaluated during the full scale field trials.

The importance of quality assurance was critical to a successful shotcrete repair. Using qualified nozzle men was the most important factor in achieving a high level of quality. The system used by the M.T.O. to "qualify" shotcrete nozzle men was modified in recent years to allow nozzle men that have been M.T.O. approved to apply shotcrete on any M.T.O. contract in the same calendar year that the approval was granted. A copy of this approval process has been included in Appendix 'B'.

The full scale project field trial was completed in the fall of 1990, on the M.T.O. rehabilitation of the Magnetawan River Bridge. The success of this project led to the evolution of the current M.T.O. shotcrete specification. This specification is currently practiced in a slightly modified form today for all M.T.O. shotcrete projects.

The use of pre-bagged silica fume shotcrete and the prequalification of nozzle men has also been expanded to include shotcrete specifications for the Ministry of Transportation of Quebec, Municipalities such as Metropolitan Toronto and several other private projects such as tunnel repairs, parking garage repairs, marine structures, etc... A copy of the current OPSS 931 shotcrete specification (May 1994) is located in Appendix 'C'.

Proper curing procedures as outlined in current M.T.O. specifications is critical to a durable shotcrete repair. The enforcement of proper curing procedures by quality assurance personnel is necessary. Surface preparation (including pre-wetting of the surface) was not addressed in this report, however, proper surface preparation as outlined in the M.T.O. specification is critical to ensure adequate bond of the shotcrete repair material.

References

A.W. Brown, P.Eng., Dr. C.M.K. Yuen P.Eng., "Improved Shotcreting Methods and Materials".

American Concrete Institute, Committee 506, "Guide to Shotcrete".

Simon Austin & Peter Roberts, "Sprayed Concrete, Properties, Design and Application".

APPENDIX `A'

TABLE 1

MIX PROPORTIONS FOR BENCH MIX TESTING

Mix Designation	Mix Description	Ratios	
		Aggregate/Cement	Water/Cement
P	Standard Mix	3.5	0.35
LS	Low Strength	4.2	0.35
LM	Latex Modified (@0.22 parts latex to 1.0 part cement)	3.5	0.35
S8D	8% Silica Fume*	3.5	0.35
S8W	8% Silica Fume*	3.5	0.40
S12	12% Silica Fume*	3.5	0.35
A1	1% Accelerator	3.5	0.35
A3	3% Accelerator	3.5	0.35
S8A	8% Silica Fume* plus 1 % Accelerator	3.5	0.35
S12A	12% Silica Fume* plus 1 % Accelerator	3.5	0.35

***Expressed in terms of total cementitious material.**

TABLE 2

RESULTS OF THE COMPRESSIVE STRENGTH AND DENSITY TESTING

Fine Aggregate Mixes

Mix Designation	Density (Mg/m ³)	Compressive Strength	
		28 Day (MPa)	56 Day (MPa)
Vertical Panels			
P	2.360	56.7	59.1
L	2.353	44.0	49.2
LD	2.360	57.6	67.6
P/S60	2.401	45.7	53.8
P/S75	2.392	40.7	50.1
S8	2.386	65.5	65.0
S12	2.373	47.3	58.0
S12/S60	2.411	76.1	75.0
S12/S75	2.405	61.3	80.3
P/P	2.404	71.0	79.6
S12/P	2.372	55.7	70.8

Overhead Panels			
P	No Sample		
L	2.363	41.6	39.9
LD	2.376	48.0	52.0
P/S60	2.405	40.1	55.2
P/S75	2.402	56.8	61.2
S8	2.384	57.1	58.6
S12	2.384	47.2	57.9
S12/S60	2.400	70.5	74.0
S12/S75	2.395	58.5	76.1
P/P	2.390	47.5	52.2
S12/P	2.382	67.6	70.7

Note: All compressive strength test results have been corrected for length to diameter ratio according to CAN3-A23.2-14C-M77.

TABLE 3
RESULTS OF LABORATORY BOND TESTING ON FINE AGGREGATE MIXES

Mix Designation	56 Day Compressive Strength (MPa)	Slurry Pre-Treatment		No Pre-Treatment	
		Bond Strength (MPa)	Failure Type	Bond Strength (MPa)	Failure Type
<u>Vertical Panels</u>					
P	59.1	1.43	2	2.00	1
L	49.2	2.00	1	2.14	4
LD	67.6	1.85	1	1.85	4
P/S60	53.8	1.85	1	1.85	1
P/S75	50.1	1.64	1	1.64	1
S8	65.0	1.57	2	1.93	2
S12	58.0	1.43	2	2.28	4
S12/S60	75.0	1.43	4	1.71	4
S12/S75	80.3	2.22	1	2.14	1
P/P	79.6	1.71	1	2.14	1
S12/P	70.8	1.93	1	1.71	1
<u>Overhead Panels</u>					
P	No Sample				
L	39.9	1.43	3	2.14	4
LD	52.0	2.00	4	2.07	1
PS60	55.2	1.85	1	1.70	1
P/S75	61.2	2.00	1	1.93	1
S8	58.6	1.85	2	2.00	2
S12	57.9	1.71	4	2.42	1
S12/S60	74.0	1.71	1	2.14	2
S12/S75	76.1	1.78	1	1.43	1
P/P	52.2	1.43	1	1.00	2
S12/P	70.7	2.00	1	1.85	1

Failure Type 1- at glued surface 3- at bond between shotcrete & substrate
 2- in shotcrete 4- in substrate concrete

TABLE 4

RESULTS OF THE RAPID CHLORIDE PERMEABILITY TESTS

Mix Designation Bond	<u>Vertical Panels</u>		<u>Overhead Panels</u>	
	Coulombs	Permeability Rating	Coulombs	Permeability Rating
<u>Fine Aggregate Mixes</u>				
P	2592	Moderate	No Sample	
L	450 & 564	Very Low	1084	Low
LD	891	Very Low	726	Very Low
P/S60	1366	Low	1065	Low
P/S75	1180	Low	1488	Low
S8	176 & 237	Very Low	194	Very Low
S12	198	Very Low	108	Very Low
S12/S60	125	Very Low	109	Very Low
S12/S75	150	Very Low	130	Low
P/P	855	Very Low	781	Very Low
S12/P	114	Very Low	65	Negligible

> 4000 High

2000 to 4000 Moderate

1000 to 2000 Low

100 to 1000 Very Low

< 100 Negligible

TABLE 5

RESULTS OF THE BOILED ABSORPTION TESTS ON VERTICAL PANELS

Mix Designation	Chloride Permeability (Coulombs)	Initial Absorption (%)	Boiled Absorption (%)	Permeable Void Space (%)
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Fine Aggregate Mixes

P	2592	3.99	4.10	9.35
L	507	2.68	3.53	8.15
LD	891	2.17	2.37	5.54
S8	207	3.75	3.91	9.00
S12	198	3.64	3.76	8.65

APPENDIX `B'

1997 PROCESS FOR
APPROVAL OF
SHOTCRETE NOZZLEMEN

MINISTRY OF TRANSPORTATION
CONCRETE SECTION
ENGINEERING MATERIALS OFFICE

INTRODUCTION

The Ministry of Transportation, Ontario, and (M.T.O.) requires that shotcrete nozzlemen be approved through a testing program prior to placing shotcrete on any M.T.O. work. Nozzleman approval will be based on acceptable construction of both a vertical and an overhead test panel using equipment meeting current specifications and pre-bagged shotcrete mix. Applicants failing to meet the acceptance requirements on the first attempt will be permitted one additional attempt in the same calendar year.

Nozzlemen approved through this process will be permitted to apply shotcrete on any M.T.O. contract in the same calendar year that the approval was granted. A new approval is required for each calendar year. Nozzleman approval may be withdrawn at any time if sub-standard quality of work is observed.

APPLICATION FOR APPROVAL

Experience

Applicants must have previous experience as a shotcrete nozzleman.

Costs

The applicant is responsible for all costs associated with the construction of the test panels and coring of the test panels, as described herein, and delivery of the cores to the M.T.O. laboratory at Downsview. The Ministry will monitor the construction of the test panels, the coring of the test panels, and will examine and test the cores at no cost to the applicant.

Location

The applicant shall provide a site acceptable to the Ministry for the construction of the test panels.

Letter of Application

Applicants seeking approval, shall send a letter of application to:

Ministry of Transportation, Ontario, Engineering
Materials Office, Concrete Section,
Room 110, Central Building, 1201 Wilson
Ave., Downsview, Ontario.
M3M 1J8

at least three weeks prior to the anticipated day of shooting the test panels. The letter shall contain the following information:

Name of applicant(s)
Applicant's birth date,
Applicant's social insurance number,
Applicant's previous experience,
Desired location for construction of the test panels and the time and date the applicant wished to shoot the panels,
Source of pre-bagged mix and mix design to be used in the panels.

The M.T.O. will confirm the acceptability of the applicant, the mix design, location, date and time before the applicant proceeds.

APPROVALPROCEDURE

Test Panels

Two test panels shall be constructed by each applicant, one to be shot in the vertical position and one to be shot in the overhead position. Construction of the test panels shall conform to the current Ministry specification for the applicable shotcrete type. They shall be fabricated as follows:

- The form shall be made of minimum 17mm thick plywood, 1 m x 1 m in size, on suitable stiffeners to prevent vibration of the form. Alternatively, the form may consist of a 1 m x 1 m bed of pre-cast shotcrete or pre-cast concrete slab,
- Size 15 bars shall be placed 40mm from the form at 150mm centres,
- Size 15 bars shall be placed on and perpendicular to the first bars at 300mm centres,
- If the form is constructed of pre-cast shotcrete or concrete, it shall be abrasive blast cleaned within 36 hours and maintained in a wet condition for one hour prior to shooting the test panel,
- Welded galvanized steel wire fabric of 51 mm x 51 mm (MW 5.6 x MW 5.6) mesh size shall be placed against and tied to the outer layer of #15 bars. The wire fabric shall be in two pieces with an overlap of one square near the centre of the panel.

The applicant shall fabricate the test panels in readiness for shooting prior to the day of shooting. Both the shooting and the coring of the test panels must be performed in the presence of an M.T.O. representative. The Ministry representative will photograph the candidate nozzleman for photo identification purposes at the time of shooting.

A shotcrete crew consisting of a minimum of a gunman, labourer and a nozzleman helper shall be provided to assist the applicant nozzleman.

The applicant shall place shotcrete on the test panels to a minimum thickness of 120mm.

Curing of the test panels shall conform to the current Ministry specification for the applicable shotcrete type.

The test panels shall remain in the position in which they were shot until the designated Ministry representative is on site to witness the coring. Moving the test panels except under Ministry supervision will result in rejection of the panel(s).

Coring

The presence of an M.T.O. representative, the applicant shall remove twelve full depth cores from each test panel. Six cores shall contain reinforcing bars and at least one of these shall contain the intersection of two bars and one shall contain the overlap of the mesh. Six cores shall contain no reinforcing bars. If in the process of satisfying the aforementioned requirements, more than twelve cores are cut, all of the cores will be used by the Ministry in the evaluation of the test panel.

The cores shall be cut from the test panels when the shotcrete is four or five days old. The cores shall be placed the same day in suitable containers, covered with water and transported to the Ministry laboratory at Downsview within six days of shooting the test panels.

EVALUATION

General

The evaluation of the applicant will be based on three criteria:

- Application,
- Visual examination of cores,
- Testing of cores for compressive strength.

Application

The applicant will be evaluated on his/her ability to apply the shotcrete to the test panels. The applicant will be permitted to wash out and start over a test panel which he/she considers to be unsatisfactory. This will be permitted only once per panel.

Visual Examination of Cores

All cores extracted from a test panel will be used in the evaluation of the panel. The cores will be examined for defects and the magnitude of defects such as:

- Delaminations,
- Sand pockets or lenses,
- Voids,
- Shadows or voids behind reinforcing bars.

Each core will be rated on a scale of 1 - 5 with 1 being a core with no defects and 5 being a core with one or more serious defects. Visual standards (cores) will be maintained in the Ministry's Concrete Section for reference. To pass, the average rating for all cores in a panel must be 1.5 or less. If the panel fails the visual examination, none of the cores from the panel will be tested for compressive strength and the applicant will be considered to have failed to meet acceptance requirements.

Testing of Cores for Compressive Strength

The cores without reinforcing steel will be tested for compressive strength, two at seven days of age and four at twenty eight days.

The minimum average strengths required are:

- 25 MPa at seven days, (average of two cores)
- 30 MPa at twenty eight days. (average of four cores)

If any set of cores fail to meet the above strength requirements, the panel will be considered to have failed.

List of Approved Nozzlemen

Applicants having successfully completed the requirements of this approval process will be considered by the Ministry of Transportation to be approved for shotcrete application on any

Ministry project within the same calendar year the approval was granted. However, the approval may be revoked at any time due to unsatisfactory work.

A list of approved nozzlemen will be maintained by the Engineering Materials Office, Concrete Section, and copies of the list provided to the Contract Management Office and the Regional Construction Offices.

The list will contain the nozzleman's name, date of birth and social insurance number. This list will also be supplemented with photo identification.

APPENDIX `C'

M.T.O.
CONSTRUCTION
SPECIFICATION
FOR STRUCTURE
REHABILITATION
SHOTCRETE

ONTARIO PROVINCIAL STANDARD SPECIFICATION
METRIC OPSS 931 MAY 1994

CONSTRUCTION SPECIFICATION FOR STRUCTURE REHABILITATION – SHOTCRETE

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931.06	Equipment	931.08.01	Inspection After Curing
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<p>931.04.02 - Submissions</p> <p>931.04.02.01 - Cement Certifications</p> <p>Prior to using the cement in the shotcrete mix, the Contractor shall submit one copy of the cement supplier's certificate to the Contract Administrator slating that the cement is candied free from early stiffening tendencies.</p> <p>931.04.02.02 - Mix Design</p> <p>The mix proportions and the name of the supplier of the prebagged Shotcrete mix Shall be forwarded to tile Contract Administrator for approval at least two weeks prior to commencement of the shotcrete operation.</p> <p>931.04.02.03 - Silica Fume</p> <p>The name of the supplier of the silica fume shall be forwarded to the Contract Administrator for approval at least two week prior to commencement of the shotcrete operation.</p> <p>931.04.02.04 - Continuous Feed Predampener</p> <p>Details of the continuous teed predampener shall be submitted to the Contract Administrator at least two weeks prior to the application of the shotcrete by the dry mix process.</p> <p>931.04.02 05 - Nozzle Operator</p> <p>The names of the nozzle operators and proof of their qualification shall be submitted to the Contract Administrator at least two weeks prior to the commencement of the application of the shotcrete.</p> <p>931.04.02 06 - Curing</p> <p>The plan for curing including equipment and procedures to he used shall be submitted to me Contract Administrator at least two weeks prior to commencement of trio application of the shotcrete.</p> <p>931.05 - Materials</p> <p>931.05.01 - Cement</p> <p>The cement shall conform to OPSS 1301</p> <p>931.05.02 - Shotcrete Mixes</p> <p>931.05.02 - General</p> <p>The shotcrete shall have a nominal minimum 28</p>	<p>day strength of 30 MPa.</p> <p>The shotcrere shall have a maximum value of 1000 coulombs Silica fume shotcrete and 1500 coulombs for latex Modified Shotcrete when tested for chloride permeability at 28 days.</p> <p>The term shotcrete shall include mortar, where substitution is permitted. The mortar shall be the same mix proportions as the shotcrete.</p> <p>The shotcrete mix shall be supplied prebagged. The mix shall be maintained in a dry condition up to the time of its use, and shall be used within three months of packaging.</p> <p>Each bag shall be stamped with the name of the manufacturer, mix identification and date of packaging</p> <p>931.05.02.02 - Normal Shotcrete</p> <p>The water to cement ratio, by mass, shall not be greater than 0.35.</p> <p>931.05.02.03 - Latex Modified Shotcrete</p> <p>The water to cement ratio by mass, shall not be greater than 0.35 and this shall include the water in the latex modifier. The latex modifier to cement ratio, by mass shall be one part latex modifier to three parts cement.</p> <p>The latex modifier shall not be diluted by more than 10% by volume prior to shotcreting</p> <p>931.05.02.04 - Silica Fume Shotcrete</p> <p>The shotcrere mix shall contain 8% silica fume by mass or total cement-silica fume mixture. The ratio of water to cement-silica fume mixture by Mass shall not be greater than 0.35.</p> <p>931.05.03 - Latex Modifier</p> <p>The latex modifier shall conform to OPSS 1312 and shall be delivered to the jobsite in sealed containers with the trade name and date of manufacture affixed to the containers by the manufacturer.</p> <p>The latex modifier shall be maintained above 5°C and below 30°C at all times.</p> <p>The latex modifier shall be agitated immediately prior to use in conformance with (no manufacturers recommendations.</p> <p>Sufficient latex modifier to complete the work shall be</p>
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<p>931.05.04 - Burlap Burlap shall conform to OPSS 1306.</p> <p>931.05.05 - Water Water shall conform to OPSS 1302.</p> <p>931.05.06 - Reinforcement 931.05.06.01- Welded Steel Wire Fabric The welded wire fabric shall be welded galvanized steel of 51 mm x 51 mm, MW 5.5 x MW 5.5, and shall conform to CSA G 30.5. Each insert for the attachment of the welded steel wire fabric to the concrete surface shall be of adequate length and strength to resist a pull-out force of 1.0 kN and be galvanized in conformance with CAN/CSA G 164.</p> <p>931.05.06.02 - Tie Wire Tie wire shall conform to clause 905.05 of OPSS 905.</p> <p>931.05.07 - Silica Fume Silica fume shall Conform to CAN3-A23.5.</p> <p>931.05.08 - Curing Compound Curing compound shall conform to OPSS 1315</p> <p>931.05.09 - Aggregate Curing compound shall conform to OPSS 1002</p> <p>931.06 - Equipment 931.06.01 - Mixers 931.06.01.01 - Dry Mix Process A continuous feed predampener shall be used. 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 nose at a rate sufficient to ensure a continuous smooth stream of uniformly mixed shotcrete mixture being delivered to the nozzle, at the velocity required</p>	<p>delivered to the jobsite at least seven days prior to commencement of the latex Modified shotcrete work</p> <p>The discharge nozzle shall be equipped with a manually operated liquid injection system, water ring, for directing an even distribution of liquid through the mixture. The liquid valve shall be capable of ready adjustment to vary the quantity of liquid, and shall be convenient to the nozzle operator.</p> <p>The nozzle shall be capable of delivering a Conical discharge stream with uniform appearance throughout.</p> <p>The delivery equipment shall be thoroughly cleaned at the end of each day's production.</p> <p>The air compressor shall provide a non-pulsating supply of oil-free clean air adequate to maintain the required nozzle velocity for application of the shotcrete.</p> <p>The liquid pressure at the discharge nozzle shall be sufficiently greater than the operating air pressure to assure that the liquid is thoroughly mixed with the other materials. The liquid pressure shall be uniform and non-pulsating.</p> <p>931.06.01.02 - Wet Mix Process The wet mix process shall only apply to normal shotcrete and latex modified shotcrete.</p> <p>The mixing equipment shall be capable of thoroughly mixing the specified materials in sufficient quantity to maintain continuous placing.</p> <p>The delivery equipment shall be capable of delivering the pre-mixed materials accurately, uniformly and continuously through the delivery hose.</p> <p>The delivery and mixing equipment shall be capable of discharging all mixed material with no carryover from one batch to the next.</p> <p>The mixing equipment shall be thoroughly cleaned at the end of each day's production and inspected.</p> <p>The air compressor shall provide a non-pulsating supply of clean air adequate to maintain the required nozzle velocity for application of the shotcrete</p>
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<p>931.06.03 - Compressor – Air Blasting</p> <p>The compressor for air blasting shall have a minimum capacity of 3.5 m³/min. The compressed air shall be free from oil when tested in conformance with ASTM D4285.</p> <p>971.06.04 - Hand Finishing Equipment</p> <p>Only magnesium, wood or sponge rubber floats shall be used.</p> <p>931.07 - Construction</p> <p>931.07.01 - Management of Excess Materials</p> <p>Excess materials resulting from the performance of the work under this specification shall be removed and managed as specified in the contract.</p> <p>931.07.02 - Normal Shotcrete Latex Modified Shotcrete Silica Fume Shotcrete</p> <p>931.07.02.01 - Operational Constraints</p> <p>Shotcreting shall not be carried out when the air or concrete surface temperature is below 10°C or is likely to fall below 10°C within 24 hours of shotcreting. Shotcreting shall not be carried out when the air or concrete surface temperature is above 30°C or is likely to rise above 30°C within 24 hours of shotcreting. Shotcreting operations shall be suspended during weather conditions which may adversely affect the quality of the work or cause excessive waste.</p> <p>Scheduling of the shotcreting operations shall be such as to ensure that shotcreting is completed in all areas where concrete removal has commenced prior to seasonal shutdown.</p> <p>931.07.02.02 – Access to Work, area Work platform and Scaffolding</p> <p>Safe and adequate access shall be provided to facilitate the performance of the work, and any inspection or measurement of the work by the Contract Administrator.</p> <p>Typical locations and areas of rehabilitation shall be as shown on the contract drawings. The actual locations and extent of rehabilitation will be determined during the layout of the area to be rehabilitated.</p> <p>Where the shotcrete is to extend over the original Concrete surface, that portion of the existing surface shall be roughened by scabbing, chipping or bush hammering to expose coarse aggregate.</p>	<p>937.06.02 - Straight Edge</p> <p>The straight edge shall be 1.0 m long and Commercially made of metal.</p> <p>The area of concrete to be shotcreted shall be abrasive blast cleaned to 50 mm beyond the perimeter of the removal area.</p> <p>Abrasive blast cleaning shall be in conformance with OPSS 929 to an extent conforming to subsection 929.07.04. Abrasive blast cleaned areas shall have the subsequent treatment applied within 36 h or shall be reblasted.</p> <p>Immediately prior to wetting the concrete, all dust and loose material shall be removed from the prepared surface by compressed air. The area to be shotcrete shall be maintained in a wet condition for a period of two hours before the application of the shotcrete. Excess water shall be removed from the surface using compressed air.</p> <p>931.07.02.04 – Placement of Welded Steel Wire Fabric</p> <p>After the abrasive blast cleaning of the area to receive shotcrete, the Contractor shall place a welded steel wire fabric in all areas greater than 0.1 m² that have a minimum dimension of 200 mm. The edges of adjoining welded steel wire sheets shall be overlapped by one wire spacing plus 50 mm. The wires shall be kept clean of any substance which may reduce the bond of the shotcrete and/or mortar to the wire surface.</p> <p>The welded Steel wire fabric shall be securely fastened to the exposed reinforcing steel by ties placed at not more than a 300 mm square grid.</p> <p>Inserts shall be used for fastening the existing reinforcing steel to the existing concrete when the reinforcing steel is not capable of providing rigid support for the wire fabric.</p> <p>Where there is no existing reinforcing steel, the wire fabric shall be anchored to the concrete with inserts placed at not more than a 300 mm square grid. The minimum clearance between the wire fabric and the existing concrete shall be 20 mm.</p> <p>Each installed insert shall resist a pull-out force of at least 1.0 KN</p> <p>931.07.02.05 - Approval of Nozzle Operator</p> <p>A nozzle operator approved by the Owner shall be provided for the application of the shotcrete. Approval may require the evaluation, by the Owner, of test</p>
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panels prepared by the nozzle operator doing the work Notwithstanding this approval, the nozzle operator shall be replaced when, in the opinion of the Contract Administrator, the quality of the work is not maintained.

931.07.02.06 - Placing

The Contract Administrator shall be notified three working days prior to the time shotcreting is scheduled to commence and the shotcreting shall not proceed until the surface preparatory work has been inspected by the Contract Administrator.

Structural components and appurtenances other than concrete shall be protected from the shotcreting operation. Other areas being prepared for shotcrete shall also be protected. The concrete surface surrounding the repair area shall be cleaned immediately after the application of each layer of shotcrete using suitable hand tools.

The thickness of the layer shall be such that there is no sagging or separation. Unless controlled by the required depth of repair each single layer shall be not less than 25 mm thick. Prior to placing each layer of shotcrete all loose material shall be removed from the surface of the repair area. When a subsequent layer of shotcrete cannot be applied before the previous layer attains its initial set, moist curing by continuous fog mist in conformance with the curing requirements of this specification shall be applied. If the previous layer has hardened the surface of the shotcrete shall be thoroughly cleaned of any laitance by wire brushing and wetted prior to application of an additional layer of Shotcrete.

The total required depth of shotcrete shall be placed within one working day,

At the end of any period of shotcreting, 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 of any laitance and wetted.

The shotcrete Shall be applied only to areas where concrete has been removed or where the existing surface has been roughened by scabbling, chipping, or bush hammering. A 1:1 slope shall be provided to meet the existing concrete surface.

Where practicable, shotcrete shall be placed without the use of formwork.

When the requirements of this Specification, Cannot otherwise be met the formwork may be used and shall conform to OPSS 919.

Formwork shall be adequately braced against excessive vibration, and constructed to permit the escape of air and rebound during the shotcreting operation.

The supply of the materials and the air pressure, at the nozzle, shall be uniform so that there is a steady, continuous flow of shotcrete with no surging or pulsating.

The velocity of the shotcrete as it leaves the nozzle Shall be maintained at a uniform rate determined for the given job conditions which ensures that the shotcrete bonds to the existing surface with proper compaction, with minimum rebound.

The nozzle shall be held in such a position that the let of material will impinge at right angles to the surface. To place shotcrete behind reinforcing bars the shotcrete may be sprayed at a slight angle towards the back of the bar. All rebound shall be removed continuously as the work proceeds. Rebound or waste material shall not be worked back into construction or salvaged and re-used.

The Shotcrete shall be placed level or slightly above the level of the original concrete surface. When required, the shotcrete shall be built up beyond the original concrete surface to provide a minimum of 50 mm of cover to the wire mesh or reinforcing steel.

Where the area of the individual repair does not exceed 300 mm in any direction and the required thickness of the repair does not exceed 50 mm, the Shotcrete may be replaced by mortar when permitted in writing by the Contract Administrator.

Any predampened mixture which is not utilized within one hour shall not be incorporated into the work.

931.07.02.07 - Finishing

When the surface of the shotcrete has attained its initial set, the excess material shall be sliced off with a sharp edged cutting tool, primarily around the perimeters of the repair areas.

When the final layer of shotcrete has attained its initial set, the surface of normal shotcrete and silica fume shotcrete shall be finished with hand finishing equipment.

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

<p>931.07.02.08 - Curing</p> <p>931.07.02.08.01 - General</p> <p>Shotcrete shall be initially moist cured by continuous fog mist for a minimum period of 24 hours. The curing shall commence as soon as the fog mist can be applied without deforming the, surface of the shotcrete.</p> <p>When approved by the Contract Administrator a continuous fog mist may be applied manually to individual areas if the use of the entire fog mist system will adversely affect the finishing of adjacent patches.</p> <p>When an area of fresh shotcrete is exposed to direct sunlight or to wind, the curing shall be applied immediately after the final application of shotcrete in that area.</p> <p>Air in contact with the repaired surfaces shall be maintained at temperatures above 10°C for at least 96 hours after the application of shotcrete The method of maintaining the temperature required shall be approved by the contract Administrator.</p> <p>Mortar Shall be Cured in the same manner as the shotcrete</p> <p>931.07.02.08.02 - Normal end Silica Fume Shotcrete</p> <p>After the initial 24 hour moist curing period, moist curing shall Continue for an additional period of 72 h by means of tog mist or wet burlap.</p> <p>The burlap shall be placed In a manner that will ensure that ft is in full contact with the shotcrete during the curing period. The burlap shall be thoroughly soaked, by immersion in water, for 24 hours before application. and kept continuously moist during the curing period.</p> <p>Immediately after removal of moist curing, the shotcrete surface shall be coated with a membrane curing compound in conformance with OPSS 904.</p> <p>931.07.02.08.03 – Latex Modified Shotcrete</p> <p>After the initial 24 hour moist curing period, moist curing period latex modified shotcrete shall be air dried above 10°C for an additional 72 hours.</p> <p>931.07.02.09 - Coring for Testing</p>	<p>For up to 100 m² of the vertical repair area, to which shotcrete is applied. Two cores are required.</p> <p>For up to 100 m² of the horizontal repair area in the overhead position to which Shotcrete has been applied, two cores are required.</p> <p>For each of the above applications, two additional cores are required for every additional 100 m² of area or portion thereof.</p> <p>931.07.02.09.02 - Core Sampling for Chloride Permeability</p> <p>At locations randomly selected by the Contract Administrator, 100 mm diameter cores, at least 75 mm in length, shall be taken by the Contractor from the shotcrete when it is a minimum of four days old end a maximum Of 14 days old and submitted to the Contract Administrator, Cores may contain mesh but shall not contain reinforcing bars.</p> <p>For up to 100 m² of the vertical repair area, to which shotcrete is applied. two cores are required.</p> <p>For up to 100 m² of the horizontal repair area in the overhead position t0 which Shotcrete has been applied, two cores are required.</p> <p>For each of the above applications, two additional cores are required for every additional 100 rrr² of area or portion thereof.</p> <p>931.07.02.09.03 - Filling of Core Holes</p> <p>Following extraction of the cores the Contractor shall remove all laitance and other debris from the core holes. The holes shall be compressed air blasted, wetted and tilled with a shotcrete mortar mix or a patching material placed in conformance with the manufacturer's recommendations.</p> <p>931.07.03 – Remedial Work</p> <p>Areas with defects as described in clause 931.08.01 a b, and c shall be removed and replaced. Cracks shall be treated in conformance with Table 1 - 1 Treatment of Cracks. The method or removal and repair shall be submitted to the Contract Administrator</p>
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<p>931.07.02.09.01 Core Sampling for Compressive Strength</p> <p>At locations randomly selected by the Contract Administrator, 75 mm diameter cores, at least 100 mm in length, shall be taken by the Contractor from the shotcrete when it is a minimum of four days old and a maximum of 14 days old submitted to the Contract Administrator. Cores may contain mesh but shall not contain reinforcing bars.</p> <p>931.8 - Quality Assurance</p> <p>931.08.01 - Inspection After Curing</p> <p>The Contract Administrator will inspect the work to determine E the completed work contains.</p> <ol style="list-style-type: none"> areas which are debonded or hollow; porous or rebound material; areas which have sagged; cracks <p>931.08.02 - Testing of Cores</p> <p>Cores taken and Submitted to the Contract Administrator for sampling for compressive strength and chloride content will be subject to acceptance testing performed by the Owner or the Owner's agent.</p> <p>The Strength will be tested in conformance with CSA/CAN3-A23.2. The chloride content will be tested in conformance with AASHTO Test Method T277.</p> <p>The evaluation of the test results will be based on the average of the tests on the cores taken In each of the vertical and horizontal repair areas.</p> <p>931.08.02 - Latex Modifier</p> <p>Tests will be performed on the latex modifier prior to commencement of the work.</p>	<p>931.09 - Measurement for Payment</p> <p>931.09.01 - Actual Measurement</p> <p>931.09.01.01 - Normal Shotcrete Latex Modified Shotcrete Silica Fume Shotcrete</p> <p>931.09.01.01.01 - By Area</p> <p>Measurement will be by area of concrete removed in square metres in conformance wall 928.09.</p> <p>931.09.01.01.02 - By Volume</p> <p>Measurement for payment will be of the volume in cubic metres of the concrete removed in conformance with OPSS 928.09 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.</p> <p>931.10 - Basis for Payment</p> <p>931.10.01 - Normal Shotcrete Item</p> <p>931.10.02 - Latex Modified Shotcrete item</p> <p>931.10.03 - Silica Fume Shotcrete Item</p> <p>Payment at the Contract price for the above tender item shall be full compensation for all labour equipment and material to do the work.</p>
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TABLE 1
TREATMENT OF CRACKS
Depth mm

Maximum Width mm of a Crack	≤ 150	>15.0 < Full Depth	Full Depth
≤ 0.30	No Treatment	Repair; or, If lineal measurement of crack per m ² is 16 m or greater, remove and replace shotcrete	Repair or, If lineal measurement of crack per m ² is 8 m or greater, remove full depth and replace shotcrete
> 0.30	Repair or, If lineal measurement of crack per m ² is 16 m or greater, remove full depth and	Repair or, If lineal measurement of crack per m ² is 8 m or greater, remove full depth and replace shotcrete	Repair or, If lineal measurement of crack per m ² is 4 m or greater, remove full depth and

<p>931.08.03 - Latex Modifier</p> <p>931.09 - Measurement For Payment</p> <p>931.09.01 - Actual Measurement</p> <p>931.09.01.01.01 Normal Shotcrete Latex Modified Shotcrete Silica Fume Shotcrete</p> <p>931.09.01.01.01 By Area .02 By Volume</p> <p>931.10 Basis of Payment</p> <p>931.10.01 Normal Shotcrete item 931.10.02 Latex Modified Shotcrete item 931.10.03 Silica Fume Shotcrete – item</p> <p>931.01 - Scope</p> <p>This specification covers the requirements for the preparation, placing, finishing, and curing of normal shotcrete, latex modified Shotcrete and Silica fume shotcrete used in structure rehabilitation and repair.</p> <p>931.02 - References</p> <p>This specification refers to the following standards, specifications or publications.</p> <p>Ontario Provincial Standard Specifications, Construction:</p> <p>OPSS 904 Concrete Structures OPSS 905 Steel Reinforcement for Concrete OPSS 919 Formwork and False work OPSS 928 Structure Rehabilitation - Concrete Removal OPSS 929 Abrasive Blast Cleaning Concrete Construction</p> <p>Ontario Provincial Standard Specifications, Material:</p> <p>OPSS 1002 Aggregates - Concrete OPSS 1301 Hydraulic Cementing Materials OPSS 1302 Water OPSS 1306 Burlap OPSS 1312 Latex Modifiers for Use in Concrete OPSS 1315 Pigmented Curing Compounds for Concrete</p>	<p>Canadian Standards Association Standards.</p> <p>CAN3-A23.2-M90 Method of test for concrete</p> <p>CAN3-A23.5-M86 - R1992 - Supplementary Cementing Materials</p> <p>G 30.5 - M 1983 Welded Steel Wire Fabric for Concrete Reinforcement</p> <p>CAN/CSA G 164 - M92 Hot Dip Galvanizing for Irregularly Shaped Articles</p> <p>American Association State Highway Transportation Officials:</p> <p>AASNT0 T277-89 - Rapid Determination of the Chloride Permeability of Concrete</p> <p>American Society for Testing Materials</p> <p>ASTM D4285-83 - 1988 - Method for indicating Oil or water in Compressed air.</p> <p>931.03 - DEFINITIONS</p> <p>For the purpose of this specification the following definitions apply.</p> <p>Proposal: means a Contractor's submission or changes, when engineering design is required, affecting the original design as stipulated in this specification.</p> <p>Rehabilitation; means any modification, alteration. Or improvement to a structure or its components which is designed to correct defects or deficiencies.</p> <p>Structure: means any bridge, culvert, tunnel, retaining wall, wharf, dock, guideway or any part thereof.</p> <p>931.04 – Submission and Design Requirements</p> <p>931.04.01 - Proposals</p> <p>931.04.01.01 - General</p> <p>Proposals by the Contractor shall bear the seal and signature of a Professional Engineer.</p> <p>Three sets of the proposal Shall be submitted to Iris Owner three weeks prior to commencement of the work.</p>
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