Durability of Shotcrete Rehabilitation Treatments of Bridges in Canada

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DURABILITY OF SHOTCRETE REHABILITATION TREATMENTS OF BRIDGES IN CANADA

by

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ABSTRACT

The Canadian Strategic Highway Research Program (C-SHRP) commissioned a study to evaluate the durability of shotcrete rehabilitation treatments of bridges in Canada. This study was undertaken in view of the recognition that a wide range of shotcrete methodologies are being used for repair of bridge structures in different parts of Canada, but relatively little is known about the durability of such repairs. In the preliminary phase of the study reported in this paper, 61 bridges distributed throughout the provinces of Alberta, British Columbia, Ontario and Nova Scotia, were examined. This paper summarizes the results of this investigation and qualitatively rates the performance of the various shotcrete repairs using descriptions such as excellent, good, fair, poor and failed. Photographic documentation is provided illustrating the field performance of a wide range of different types of shotcrete repair and rehabilitation practices.

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LA DURABILITÉ DES TRAVAUX DE REMISE NEUF
AU BÉTON PROJETÉ POUR LES PONTS AU CANADA

par

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ABSTRACT

Le programme stratégique de recherche routière (C-SHRP) a entrepris une étude pour évaluer la durabilité des traitements de réhabilitation au béton projeté pour des ponts au Canada. De nombreuses méthodologies de béton projeté sont présentement employées pour la réparation de la structure de ponts à plusieurs endroits au Canada, mais des renseignements précis concernant la durabilité de ces réparations sont minimes. Dans la section préliminaire de l'étude présentée dans ce rapport, 61 ponts distribués à travers les provinces de l’Alberta, la Colombie Britannique, l’Ontario et la Nouvelle-Écosse, ont été examinés. Ce rapport résume les résultats de cette investigation et classe qualitativement la performance de divers réparations au béton projeté en utilisant un barème tel “excellent”, “good”, “fair”, “poor” et “failed”. La documentation photographique est fournie afin d’illustrer la performance sur chantier des divers types de procédures de réparations et réhabilitations au béton projeté.
INTRODUCTION

In May 1990 the Canadian Strategic Highway Research Program (C-SHRP) commissioned a study to evaluate the "Durability of Shotcrete Rehabilitation Treatments of Bridges". In the preamble to the work statement, C-SHRP noted that:

"Very limited data is available on the long term performance of shotcrete structures in the field. Most durability data for shotcrete is the result of physical performance in laboratory freeze-thaw testing. Most case history data available provides only qualitative visual data with little physical quantification of the properties of layered concrete in the field. There is a wide variety of material being used for shotcrete in Canada and application procedures vary greatly between different areas. There is a need to develop information concerning the relative performance and long term durability of these different shotcrete treatments".

The stated goal of the project is to evaluate the durability of shotcrete rehabilitation for bridge components and to develop recommended practice defining the production of durable shotcrete in the field. The specific project objectives are:

- To identify construction and application factors which contribute to the quality of the rehabilitation repairs and to quantify their effect on performance.
- To determine those materials factors which have the most significant effect on service life and to quantify their effect.
- To develop service life predictions of shotcrete repairs for various combinations of material and application methods.

Scope of Work

The scope of work defined by the C-SHRP Technical Steering Committee is divided into 12 distinct tasks, with this paper covering the first four as follows:

Task 1: Determine the extent of shotcrete rehabilitation repairs for bridge components in Canada.

Task 2: Evaluate the physical condition of shotcrete repairs by visual means, for a range of structures displaying good and poor performance.

Task 3: Select a range of structures for a more detailed evaluation using non destructive testing. The variety of repairs should include both wet and dry shotcrete processes, and shotcretes modified by the addition of latex, silica fume, fibres etc.

Task 4: Prepare an interim report documenting the use of shotcrete for bridge rehabilitation in Canada and a preliminary evaluation of shotcrete performance. Based upon the preliminary field investigations, present a detailed work plan for the quantitative evaluation of the selected structures.
The required study products are:

- Quantification of the material factors which produce durable shotcrete repairs.
- Quantification of the construction variables which contribute to service life of the repairs.
- A manual of recommended practice for the construction of durable shotcrete repairs of the rehabilitation of highway bridge structures in Canada.
- A quantitative service life prediction methodology for shotcrete repairs.

EXTENT OF SHOTCRETE REPAIRS OF BRIDGES

Literature Search

The first work undertaken to determine the extent of shotcrete rehabilitation treatments of bridges was a computer search of the technical literature, using the National Research Council of Canada CAN/OLE and the U.S. Transportation Research Board TRIS data bases. The key words "shotcrete/gunite and bridge", and "shotcrete/gunite and durability", were used in this search. A bibliography of pertinent references from this computer search is appended. This compilation is supplemented by additional references (not retrieved from the computer search) which had been compiled by the American Concrete Institute, ACI 506, Shotcrete Durability Subcommittee.

It was found that very little quantitative information is available in the literature concerning the durability of shotcrete rehabilitation treatments of bridges. Most references are concerned with the design and construction of the actual shotcrete repair. While this information is useful, there is a dearth of information in the published literature regarding the durability of such repairs. This demonstrates and reaffirms the need for this study.

Questionnaire

In order to assist in determining the extent of shotcrete rehabilitation treatments of bridges in Canada a Questionnaire was compiled and mailed to 29 bridge owning authorities across Canada. A total of 14 questionnaires were returned. A list of all respondents is given in Table 1, together with a summary of the number of shotcrete repaired bridges in each jurisdiction.

The completed Questionnaires provide only a partial statement of the extent of shotcrete rehabilitation treatments of bridges in Canada. Nevertheless, the responses were useful, as not only did they provide a good broad overview of the use of shotcrete for bridge rehabilitation in Canada, but they also provided the basis for selection of structures for the field evaluation. The completed questionnaires have been compiled and included in a 300 page report titled "Durability of Shotcrete Rehabilitation Treatments of Bridges" submitted to C-SHRP by Hardy BBT Limited.
SELECTION OF STRUCTURES FOR EVALUATION

The selection of bridge structures for evaluation was based on the following criteria:

- The bridge structures should be geographically distributed across Canada, so as to encompass as wide a range of climatic exposure conditions as possible.

- The structures should be reasonably accessible to the laboratories of the participant researchers in order to maximize the number of structures which could be examined for a given budget.

- The repaired bridges examined should include as wide a range of shotcrete processes and types as possible; e.g. wet-mix shotcrete and dry-mix shotcrete processes; conventional shotcrete, latex-modified shotcrete, silica fume shotcrete; mesh and steel fibre reinforced shotcrete; shotcretes made with and without accelerators.

- The shotcrete repairs should be of varying ages and include a range of different environmental exposure conditions; e.g. dry environment, exposure to wetting from precipitation, deicing chemicals, tidal action in a marine environment, freeze-thaw exposure.

- The reasons for shotcrete repair of the original concrete structures should be as wide-ranging as possible; e.g. repair of concrete delaminating or spalling from corroded embedded reinforcing steel; repair of concrete deteriorated from aggressive exposure conditions such as: freeze-thaw attack, exposure to deicing chemicals, alkali aggregate reactivity.

- The availability of construction records detailing the condition of the structure prior to repair, materials and methodology of repair.

Based on the preceding criteria and the responses to the Questionnaire complemented by communications with bridge-owning authorities, shotcrete consultants, shotcrete materials suppliers and contractors, a total of 61 bridges in four different provinces were selected for evaluation. Table 1 summarizes the geographical distribution of the selected structures. Table 2 provides a list of the 61 bridges evaluated.

EVALUATION METHODOLOGY

The principal investigators, aided in many cases by engineers from the bridge-owning authorities familiar with the details of the shotcrete repairs on their particular structures, carried out field examinations of 61 bridges during the spring to fall of 1990. The following basic methodology was used:

- Detailed field notes concerning each bridge or bridge component examined were recorded on a dictaphone. The field notes were transcribed into a written record, and filed with the project records.

- Extensive photographs were taken and photographic documentation is retained in the project files for each bridge examined.
• Visual examination and photographic documentation was supplemented by sounding with a 
geological hammer to detect the presence of delamination (if any). Crack widths were 
recorded using a crack comparator. Any areas of obviously defective shotcrete were further 
investigated by removing small quantities of material with a geological hammer.

• The overall condition of the repair of the bridge was rated as:

   excellent, good, fair, poor or failed

In some instances more than one of these ratings was assigned to a bridge, because of variable quality 
of the condition of repairs within or between components of a bridge (e.g. a particular bridge 
abutment might be in a good state of repair, but adjacent columns might be in a poor state of repair). 
While there was a high degree of variability in the aesthetics of shotcrete repairs on different 
structures, aesthetics per se was not a factor in rating the condition of the repairs, as it was not 
considered a factor influencing durability.

SURVEY OF STRUCTURES

ALBERTA

A total of 10 Alberta Transportation & Utilities (ATU) bridges, 4 City of Calgary bridges and 5 City 
of Edmonton bridges were examined. Some useful data concerning the ATU bridges is available in 
the prime references 3 and 10. Additional useful documentation (including photographic records) 
of the shotcrete remedial works on the ATU bridges was made available by the ATU and is on file.

Prior to 1984 ATU used latex modified wire mesh reinforced dry-mix shotcrete for bridge repair. 
Bridges #1,#2,#5,#6 and #8 (see Table 2) were repaired with this system. The shotcrete repairs 
generally displayed fair to good performance. The same can, however, not be said for all the original 
concrete adjacent to repair areas. Original concrete in some of the bridges (which was presumably 
ot sufficiently deteriorated at the time repairs were conducted to warrant repair) had continued to 
deteriorate in areas subjected to deicing chemicals, saturation and freeze-thaw exposure. This 
deterioration took two major forms:

• Continuing corrosion induced deterioration of original reinforced concrete elements, resulting 
in cracking, delamination and spalling of the original concrete. An example of such 
deterioration in the Happy Valley Grade Separation (bridge #1) is shown in Figure 1.

• Deicing chemical and freeze-thaw scaling induced deterioration. An example of such 
deterioration in the sidewalk of the Canmore Grade Separation (bridge #5) is shown in Fig. 
2. Similar Deterioration in original concrete in the sidewalk of the Bow River Bridge at 
Canmore (bridge #6) is shown in Fig. 3.

In the case of the Happy Valley Grade Separation (bridge #1), the continuing deterioration of the 
original concrete occurred because water and salt continue to seep through the deck onto sub-
structural elements. The shotcrete repairs looked unsightly because of accumulations of 
efflorescence, leachates and staining, but close examination revealed that the shotcrete itself was still 
well bonded to the original concrete and had suffered no deterioration from the aggressive salt 
exposure condition. Any delaminations observed had occurred in the original concrete.
By contrast, after shotcrete repairs on the Morley Grade Separation (bridge #3) were completed, the deck was overlaid with steel fibre reinforced concrete. This was effective in preventing continuing seepage of water and salts through to the sub-structural elements. This structure was repaired with dry-mix steel fibre reinforced, silica fume shotcrete and the repair was observed to be in good condition.

The latex modified shotcrete repairs on bridges #1, #2, #5, #6 and #8 all displayed varying amounts of cracking. These cracks varied from restrained shrinkage cracks in repairs to legs of precast girders to general pattern cracking. ATU reported that some of the pattern cracking on these structures appeared within the first few days of application of repair shotcrete. The observed pattern cracking appears to be attributable to a combination of early plastic shrinkage and longer term restrained drying shrinkage, possibly aggravated by thermal effects.

In 1984 ATU (Ref. 3, 10) changed to the use of steel fibre reinforced dry-mix shotcrete, giving the following reasons:

- less surface cracking
- easier to finish
- elimination of most meshing
- improved mechanical properties
- greater number of qualified contractors able to bid the work
- better mix quality control
- more economical repair method (60 to 70% cost of latex modified shotcrete).

ATU reported (Ref. 3, 10) that a total of 7 bridges were repaired with dry-mix, steel fibre reinforced shotcrete during 1984. A prebagged shotcrete mix with a 4:1 aggregate:cement ratio by volume, 8 mm maximum size aggregate, and 25 mm long crimped steel fibre added at an addition rate of 60 kg/m³, was specified. Reported average compressive strengths at 7 and 28 days were 54.8 and 67.8 MPa respectively for the seven bridges.

Pier tops of one of the bridges repaired in 1984 (bridge #10), over the North Saskatchewan River at Drayton Valley, were examined during this C-SHRP study. These pier tops were observed to be in excellent condition, with no delamination or freeze-thaw deterioration and only very minor fine (<0.1 mm) hairline pattern cracks on one of the pier caps.

From 1985, ATU started to incorporate silica fume in the dry-mix steel fibre reinforced shotcrete. Silica fume was incorporated in the shotcrete because of:

- reduced rebound
- greater thickness of build-up achievable in a single pass; particularly on overhead surfaces
- enhanced resistance to chloride ion intrusion.

As a caution, ATU (Ref. 3, 10) noted the importance of proper moist curing if plastic and early restrained drying shrinkage cracking is to be avoided with silica fume shotcrete.

Between 1985 and 1987, twelve ATU bridges were repaired with steel fibre reinforced, silica fume, dry-mix shotcrete. Four of these bridges (bridges #3, 4, 9 and 10) were examined in this C-SHRP study. Three of the bridges were in good to excellent condition. Apart from some fine (generally
<0.15 mm wide) restrained drying shrinkage cracks; and some minor delamination at featheredging on one of these structures (bridge #4), the shotcrete repairs were all performing well. There was no evidence of any freeze-thaw deterioration in any of these structures.

By contrast, the repair on the fourth bridge, (bridge #9) over the North Saskatchewan River at Rocky Mountain House, was in only fair condition. The repair shotcrete on this structure differed from the other three bridges in that an accelerator was incorporated in the mixture. It is now well-known that most accelerators increase the drying shrinkage and hence cracking potential of shotcrete. In this case the use of an accelerator has resulted in extensive pattern and restrained drying shrinkage cracking. Some of the restrained shrinkage cracks were as much as 1.25 mm wide; pattern cracks averaged 0.5 mm wide. While there was no significant delamination, or evidence of freeze-thaw deterioration in the shotcrete repairs, this is not considered a good-quality repair. ATU has since discontinued using accelerators in rehabilitation shotcrete mixes.

The shotcrete repairs in 1986 of the jacketed piers at bridge #10 over the North Saskatchewan River at Drayton Valley were some of the best examples of an excellent quality shotcrete repair observed in the 61 bridges examined in this C-SHRP study. There was no evidence of delamination or freeze-thaw deterioration in any of the repairs on these large exposed piers. Most of the repairs were crack-free. Fig. 4 shows one of the shotcrete repaired piers.

Four City of Calgary bridge structures were examined. Repair of the Centre Street Bridge over the Bow River (#11) was superficial; a flash coat of shotcrete over abutment, deck soffit and spandrel elements. The Crowchild bridge over the Bow River (#13) was undergoing repair. The vertical retaining walls under the Eighth Street/9th Avenue Subway (bridge #12) were repaired with dry-mix, steel fibre reinforced shotcrete. The repair was given a trowelled finish. Some fine vertical hairline drying shrinkage and reflection cracks were observed on these long retaining walls, but otherwise the repair was performing well. The most substantial shotcrete repair of a bridge in Calgary was the complete jacketing of the John Hexall bridge over the Bow River (bridge #14). A dry-mix steel fibre reinforced shotcrete was used. Some pattern and restrained shrinkage cracks were observed. Some light rust staining was observed at some crack locations, but this rust appears to emanate from corrosion of the steel truss bridge and bearing components. Overall the repair was considered to be in good condition.

Four City of Edmonton bridge structures were examined. The 132nd Street bridge (bridge #15) was repaired with a conventional dry-mix shotcrete and displayed pattern cracking in beam soffit repairs as shown in Fig. 5. Cracking and deterioration was continuing in concrete adjacent to the repaired areas. The repairs were considered to be in fair to good condition, but further remedial work in adjacent deteriorating concrete will likely be required soon. The repairs to the H.C. girders on the 18th Avenue bridge over Blackmud Creek (bridge #16) were done with a dry-mix shotcrete with a small amount of polypropylene fibre addition. The open joints in this unsealed deck permitted continuous seepage onto the H.C. girders. There were some vertical restrained drying shrinkage cracks. Some efflorescence was observed at cracks, but no delamination was detected. Overall the repairs were considered to be in good condition in spite of the severe exposure condition.

The arches and transverse beams in the Campbell Street bridge (bridge #17) were recently (1989) repaired with a dry-mix steel fibre reinforced shotcrete. The repair was finished to approximate the original concrete finish and a white pigmented coating applied to the entire structure. The repair was of excellent quality. Visually this was one of the best examples of shotcrete repair observed in all the
bridges examined in this C-SHRP study; it was in fact difficult to even find repair areas. The repaired
structure is shown in Fig. 6.

The 105th Street Railroad Overpass (bridge #18) piers and pier caps were repaired with steel fibre
reinforced dry-mix shotcrete. These repairs were in generally good condition, with the following
exceptions: some pattern cracking was noted in parts of the structures more exposed to sun and the
prevailing wind; in some locations a thin flash-coat between adjacent deeper repair areas was
delaminated. This type of thin flash-coat repair should be avoided.

The shotcrete jacketing of the piers of the CNR High Level bridge over the North Saskatchewan
River (bridge #19) was completed in 1960 using conventional gunite (sanded, dry-mix shotcrete). Access
to these piers, to enable a detailed examination, was not available. This repair has virtually
completely failed as shown in Fig. 7. Much of the shotcrete has already been removed; the shotcrete
which remains displays massive regularly spaced pattern cracking and has slabbled off the original
concrete. There was no evidence of any form of mechanical anchorage of the shotcrete to the
original concrete. It appears that the shotcrete has slabbled off, with the original concrete still
adhered to it. This was one of only two shotcrete repairs given a failed rating in this C-SHRP study.
This was also the oldest shotcrete repair examined in this study and while rated as failed in 1990, it
is worth noting that it survived nearly 30 years despite lack of anchorage and modern shotcrete
techniques.

BRITISH COLUMBIA

There has been limited use of shotcrete for repair of bridge structures in British Columbia. Two
bridge structures owned by the B.C. Ministry of Transportation & Highways (MTH) and two marine
bridge structures were examined. Abutments and piers at the MTH Lytton Bridge over the
Thompson River (bridge #21) were jacketed with dry-mix steel fibre reinforced shotcrete (prebagged
supply) in 1982. This was likely the first bridge structure repaired with steel fibre reinforced shotcrete
in Canada. After 8 years in service this repair is in excellent condition. There were a few short,
discrete restrained drying shrinkage cracks but no evidence of any delamination or other forms of
deterioration. Uncapped original abutment concrete has, however, continued to deteriorate from
freeze-thaw action. This demonstrates of the importance of "capping" piers and abutments during
jacketed shotcrete repairs.

Between 1983 and 1985 the Canada Place Trade and Convention Centre was constructed on the old
(circa 1923) Pier B.C. in Vancouver harbour. The pier (bridge #22) consists of a central berm,
contained by a sea-wall and a surrounding suspended concrete apron supported on some 6000 precast
concrete piles. The original apron carried both road and rail traffic but now carries only road traffic.
Some $1 million was spent in shotcrete rehabilitation of the corrosion and new construction damaged
pier substructure in 1983 - 84. The initial work was done using prebagged and ready mix supplied
dry-mix shotcrete. In 1984 the project was completed using prebagged silica fume dry-mix shotcrete.
This was the first reported use of silica fume in dry-mix shotcrete in Canada. Many parts of the
structure are exposed to daily tidal cycling. Other than for a few minor restrained drying shrinkage
cracks (mostly at the edges of repaired areas) and occasional minor efflorescence at locations, where
water has continued to seep through the deck, the repairs were found to be in excellent condition.
Similarly the adjacent South Approach Road to Canada Place (bridge #23), which was repaired with
dry-mix, steel fibre reinforced silica fume shotcrete in 1987, was found to be in excellent condition.
NOVA SCOTIA

The Nova Scotia Department of Transportation & Communications (NSDTC) submitted a list of some 77 bridges which were repaired with shotcrete between 1976 and 1989. The Department has considerable experience with both wet and dry-mix shotcrete, but the dry-mix process predominates. Shotcrete repairs are typically given a nozzle finish. To date no latex, silica fume or fibre reinforcement are reported to have been used in repair of bridges in Nova Scotia. Shotcrete repair areas are generally reinforced with wire mesh or reinforcing steel and the repair areas are normally anchored back to the original concrete. NSDTC report that they have found shotcrete to be less expensive than forming and casting and with a few exceptions are generally satisfied with the workmanship, appearance and performance of the shotcrete repairs conducted to date.

One area of freeze-thaw deterioration was noted in the shotcrete in the abutment repair of the Pleasant Valley Bridge (bridge #29). Very poorly consolidated wet-mix shotcrete was found at the top of an abutment as shown in the photo in Fig. 8. The jacketed repair acted as a dam for water seeping into this area from a defective bridge deck/abutment joint. The shotcrete in this area had deteriorated into rubble from freeze-thaw action and wire mesh fabric was exposed and corroding. The shotcrete in this localized area was considered to have failed.

*Good to excellent* quality repair was evident in the Tusket River Bridge (bridge #31). These repairs on abutments and piers displayed generally excellent profile and finish. A few reflection and restrained drying shrinkage cracks were observed but no delamination was evident in areas accessible to sounding. There was no evidence of freeze-thaw deterioration in the shotcrete repairs. However, the shotcrete jacket had not completely encapsulated the top horizontal surface of the central bridge pier and the exposed original concrete in this area was freeze-thaw damaged. The concrete had turned to rubble to a depth of about 20 mm from the exposed surface. This demonstrates the importance of completely encapsulating old (likely non-air entrained concrete) when doing jacketed repairs with shotcrete. This problem of freeze-thaw deterioration of uncapped original concrete on a shotcrete jacketed pier repair is also evident in the central pier on the East Kempville Bridge (bridge #28). The original concrete had deteriorated to rubble to a depth of 50 mm.

The final structure examined in Nova Scotia was the rock slope abutment encapsulation under the Prospect Connector Bridge (bridge #25) in Halifax. This work was completed in 1978 with a sanded dry-mix shotcrete and displayed fairly extensive pattern and drying shrinkage cracking. This cracking was most pronounced in areas not protected by the bridge deck. There was no provision for relief of groundwater in these rock abutments and substantial efflorescence and seepage was evident in areas not protected by the bridge deck. In some localized areas of pronounced water seepage there was evidence of localized freeze-thaw deterioration; shotcrete had been eroded and turned to rubble. Underneath the bridge, the relatively protected shotcrete was in generally good condition.

The NSDTC advised that the repairs to the Tusket River bridge (bridge #31) are more representative of typical shotcrete bridge repairs in Nova Scotia than the other NSDTC bridges examined in this study. Although the remaining seven bridges examined may not be representative of typical bridge repairs in Nova Scotia they provided valuable information to the overall Canada wide survey. Bridges #29 and #25 were the only bridges, out of the 61 inspected, which exhibited any freeze/thaw deterioration of the shotcrete itself.
ONTARIO

A total of 30 bridges were examined. Nineteen of these structures are owned by the Ontario Ministry of Transportation & Communications (OMTC); 8 were in the Toronto (Southern Ontario) region and 11 in the Ottawa (Eastern Ontario) region. Seven of the structures examined are owned by the Municipality of Metropolitan Toronto and two by the Regional Municipality of Ottawa/Carleton. Nearly all these Ontario structures have been repaired with mesh reinforced latex-modified dry-mix shotcrete.

Most of the shotcrete work appears to be based on the OMTC Specifications for "Latex Modified Shotcrete", Special Provision No. 9999FO8. The basic shotcrete specification requires the use of 1 part latex modifier to 3 parts Portland cement by mass and a water to cement ratio, by mass not greater than 0.35. A 51 mm x 51 mm MW5.6 x MW5.6 welded, galvanized steel wire fabric is typically specified. Some specifications permit the use of the wet-mix shotcrete process, but it is understood from discussions with OMTC personnel that nearly all the work has been completed using the dry-mix shotcrete process.

The eight OMTC Southern Region bridges examined were all repaired with latex modified shotcrete during the years 1981 to 1990. The majority of the repairs were in good to excellent condition, although some examples of fair and poor repairs were found. The majority of repairs were on structural elements such as deck soffits, piers, pier caps, diaphragms, beams and abutments.

One of the earlier repairs was done in 1982 on the Bronte Creek Bridge (bridge #34). Some poor quality remedial work was evident on this structure. Many of the repaired areas on piers exhibited extensive pattern cracking and delamination at the edge of repairs, where the shotcrete had been featheredged over the inadequately prepared original pier surface as illustrated in Fig. 9. Similar delamination of featheredged shotcrete was evident in repairs on the Hoggs Hollow South Collector (bridge #36) repaired in 1981. OMTC clearly recognized that featheredging of shotcrete repairs was an undesirable practice, as in later repairs on the Leslie Street Bridge (bridge #32) completed in 1985/86, the Credit River Bridge (bridge #33) completed in 1987/88, and the Sixteen Mile Creek Bridge (bridge #39) completed in 1989/90, featheredged shotcrete was trimmed back to the edge of repair areas and no delaminations were detected. See for example the photos in Fig. 10 of repairs to the Sixteen Mile Creek bridge (bridge #39). The current MTO Specification Special Provision No. 999FO8 requires excess shotcrete around the edges of the repair area to be "sliced off with a sharp edged cutting tool". This is considered good practice.

The incidence of cracking in the latex modified shotcrete repairs on OMTC Southern Region bridges was highly variable. In some bridges, such as the Leslie Street Bridge (bridge #32) there was some very minor (likely plastic shrinkage) cracking in repairs on the edges of outer beams and parapets, which were exposed to the sun and wind. Repairs in shaded and more protected areas under the deck of the deck soffit, piers and pier cross-heads, displayed negligible cracking. Similarly repairs of piers, arches, beams and slab soffits of the Credit River Bridge (bridge #33) displayed only occasional (plastic shrinkage) cracks and no pattern cracking. This was also true of the repairs to the Sixteen Mile Creek Bridge (bridge #39).

By contrast many of the bridges repaired prior to 1984 displayed widespread pattern cracking. For example the Bronte Creek Bridge (bridge #34), Hoggs Hollow North and South Collectors (bridges #35 and #36), Highway 88 over Highway 400 Overpass (bridge #37) and Humber River Bridge
(bridge #38) all displayed widespread pattern cracking. It is believed that much of this cracking was likely initiated by early age plastic shrinkage strains, aggravated by longer term restrained drying shrinkage. Pattern cracks were typically about 0.1 mm wide at the surface, but in places cracks as wide as 0.6 mm were recorded. In addition to the classic pattern cracking, in some structures reflection cracking was evident where cracks extended from the adjacent concrete through into the shotcrete repair.

Dry-mix latex modified shotcrete repairs carried out on the Gardiner Expressway in Toronto during the period 1981 to 1983 were examined. Work completed under five different contracts was examined. Most of these repairs were completed on pier bents and pier caps and beams, with some repairs on precast deck beam soffits. Most repair was to corrosion damaged reinforced concrete elements. Corrosion was primarily caused by deicing chemical salt spray and water and deicing salt solutions leaking through expansion joints and saturating substructural elements. Fig. 11 gives a good illustration of the type of deterioration which had to be repaired on bent piers and caps.

The condition of repairs on these various contracts was highly variable. The repairs at bent #46, (bridge #46) completed in 1980 were judged to be in good to excellent condition with no significant delamination and negligible cracking. Repairs to bent #114 (bridge #41), bent DT18 (bridge #43) and the ramp at bent #178 (bridge #45) were judged to be in generally fair to good condition. Pattern cracking typically varying from 300 to 600 mm on centre and from 0.1 mm to as much as 0.8 mm wide was observed in these structures. Pattern cracking tended to be most pronounced in repairs exposed to the sun and wind. Pattern cracking was generally much less pronounced in shaded areas. Some delamination of featheredged shotcrete applied over the original (non-chipped) concrete was noted in the two bents repaired in 1981 (bridges #41 and #43).

By contrast the repairs to bent #180 (bridge #44) were judged to be in generally poor condition. This shotcrete exhibited extensive pattern cracking at spacing varying from about 100 to 300 mm on centres as shown in Fig. 12. Crack widths varied from hairline to 0.4 mm wide. Aesthetically the repair was very unattractive. In summary the condition of the shotcrete repairs on the Gardiner Expressway was of varying quality, ranging from excellent to poor. Overall the repairs displayed significantly more pronounced pattern cracking than was observed in the OMTC Southern Region latex-modified shotcrete repairs. The reason for this is not clear, but is possibly related to ambient conditions and curing practice during shotcrete repair.

Other Municipality of Metropolitan Toronto bridges examined included the Dundas Street Overpass (bridge #47) and Saint Clair Street Rail Bridge Underpass (bridge #48). The Dundas Street Overpass was repaired with latex modified shotcrete and was in generally good condition, with the exception of some fair to poor quality repairs on the soffit of beams adjacent to the railway track. The usual fine pattern cracking was evident on exterior piers exposed to the sun; interior piers were relatively crack free. Some corrosion induced deterioration of existing concrete, adjacent to shotcrete repairs, was evident where moisture and salts continued to leak out over edge girders. Repairs to the Saint Clair Rail Bridge Underpass (#48) were completed in 1988 using conventional (no latex) dry-mix shotcrete. These repairs were in generally excellent condition, with only a few very minor pattern cracks, mainly on west walls exposed to the sun. Unlike the other OMTC and Municipality of Metropolitan Toronto bridges examined, this shotcrete was finished to straight edges, to give a cast concrete appearance as shown in Fig. 13.
Eleven OMTC bridges in the Ottawa region which had been repaired with latex modified dry-mix shotcrete between 1983 and 1988, were examined. Quite extensive repair was conducted on the Rideau Canal Bridge (bridge #49) on Highway 417 in 1985. Elements repaired included pier bents, piers, fascia, diaphragms and abutment walls. Access to the piers in the river was not available, but visually the piers appeared to be in good condition, with the exception of the usual pattern cracking on exterior piers exposed to the sun, and some minor corrosion induced staining where there appeared to be insufficient shotcrete cover to reinforcing mesh.

Eight of the bridges examined were overpasses of Highway 417 over city streets (bridges #50 to 57). These bridges were repaired with latex-modified dry-mix shotcrete in 1983 and 1985. There was variable quality in the condition of these repairs, with the quality being generally better in the repairs completed in 1985 compared to the repairs completed in 1983. The bridges repaired in 1985 (bridges #51, #52 and #53) were in generally good to excellent condition, with negligible pattern cracking and only a few minor delaminations where shotcrete applied over the original finished concrete surface had not been sufficiently cut-back with a trowel.

By contrast the bridges repaired in 1983 (bridges #54, #55, #56 and #57), displayed major pattern cracking. This pattern cracking was visually most pronounced in areas of repairs exposed to the sun and weather. See for example the photo in Fig. 14. Pattern cracks varied from 0.05 to 0.4 mm wide. An interesting phenomenon was observed; the latex-modified shotcrete tends to become darkened on either side of cracks exposed to moisture. This has had the effect of grossly exaggerating the visual appearance of the cracks as shown in Fig. 14. Close examination of these abutment repairs revealed essentially the same pattern cracking in both sheltered and exposed areas. The pattern cracks in exposed areas are highly visible whereas the pattern cracks in sheltered areas are barely visible. No significant delaminations were detected in any of these areas.

The Montreal Road Bridge (bridge #58) was repaired in 1983 by the same contractor who repaired the Highway 417 bridges in 1983. These repairs were generally in excellent condition; probably attributable to much of the repair being in sheltered areas. Large repaired areas, up to 24 m long, displayed only very minor (0.05 mm wide) pattern cracks and no delaminations. The Kemptville Creek Bridge (bridge #59) on Highway 43 near Ottawa was also examined. Some polypropylene fibre was used in the latex-modified dry-mix shotcrete used to repair the deck soffit and abutments on this project. There was limited access for close-up examination of these repairs, but visually, with the exception of some efflorescence and seepage at the perimeter of some deck soffit repairs, the shotcrete appeared to be in good condition. Pattern cracking was not evident from examination with binoculars.

Two bridges under the jurisdiction of the Regional Municipality of Ottawa/Carlton, which had been repaired with latex-modified dry-mix shotcrete, were examined. The first was the O'Connor Street Bridge (bridge #60) over an arm of the Rideau Canal. This historic bridge had been rehabilitated with a total shotcrete lining of the deck soffit, abutments and wing walls. With the exception of a few minor cracks at one corner of the arch where some efflorescence was still occurring, the repair appeared to be in excellent condition and had pleasingly reinstated the aesthetic appearance of the bridge. Prior to rehabilitation the bridge was in an advanced state of deterioration from the combined effects of freeze-thaw cycling and alkali-aggregate reactivity. Good photographic documentation is available from the owners depicting the condition of the bridge before and during repair.
QUEBEC

Only a limited Questionnaire return was received from Quebec. Bridge structures in Quebec were not included in the Phase I field survey of bridges. The writer did, however, make a tour of shotcrete repaired bridge and highway structures in Montreal in October 1990. It was readily apparent from this tour that extensive shotcrete bridge repairs have and are being undertaken in Montreal. It appears that the majority of this work has been completed with either conventional or latex modified dry-mix shotcrete. Current repair work on the Metropolitan Boulevard (one of the largest highway structure shotcrete repairs ever undertaken in North America) is being undertaken with dry-mix silica fume shotcrete. Air entraining admixture is reportedly being added to the mix water supplied to the nozzle and a small amount of polypropylene fibre is being added at the shotcrete gun. A blended Portland-silica fume cement (about 8 percent silica fume by mass of cement) is being used. Shotcrete is being supplied either from mobile batcher units or dry-bagged premix supply. Aesthetics of repairs on columns were generally very good. The shotcrete repairs were finished to straight sitelines and a rigorous curing regime, involving wrapping newly shot columns with wet burlap and polyethylene sheets, was being implemented. Cured structures appeared largely crack-free.

SUMMARY OF OBSERVATIONS

A total of 61 bridges in the provinces of British Columbia, Alberta, Ontario and Nova Scotia were examined in the first phase (Tasks 1 to 4) of this C-SHRP study. In order to provide an overall picture of the durability of shotcrete rehabilitation treatments of bridge structures in Canada, repairs to each bridge were rated as excellent, good, fair, poor or failed. In some instances a bridge was assigned more than one rating because of variable quality of performance of repairs within or between components of a bridge. Ratings for individual bridges examined are summarized in Table 2.

The graph in Fig. 15 provides an overall summary of the condition of shotcrete rehabilitation treatments of the bridges examined. Some 25 percent of repairs were judged to be in excellent condition, 37 percent in good condition, 25 percent in fair condition, 10 percent in poor condition and 3 percent of repairs were considered to have failed. It is realized that this is a preliminary analysis, based primarily on visual and sounding evaluations, and as such is somewhat subjective. Also, this survey does not cover all provinces in Canada. Nevertheless this study is believed to provide a reasonable overview of the performance of shotcrete rehabilitation treatments of bridge structures in Canada.

The large majority of shotcrete repairs examined were completed during the years 1981 to 1986; only three of the repairs examined were more than 10 years old; three bridges were under active repair at the time of examination. It had been hoped that more 10 to 20 year old shotcrete repairs would have been available for investigation, in order to enhance development of the service life prediction model required in the second phase of this C-SHRP study. Unfortunately bridge owning authorities and other industry sources contacted were unable to provide significant numbers of readily accessible sites of older bridge repairs. It appears that either shotcrete was little used as a repair medium for bridge structures prior to the 1980's and/or the persons involved in shotcrete repairs prior to the 1980's have now retired or left the bridge owning authorities and the pertinent information is no longer readily available.
CONCLUSIONS

The following is a summary of the key observations and conclusions reached in this Phase I evaluation:

- A wide range of shotcrete materials have been used for rehabilitation of bridge elements, with strong regional preferences being evident. For example:
  - nearly all shotcrete repair in Ontario has been performed with latex modified dry-mix shotcrete;
  - most shotcrete repair in Nova Scotia has been completed with conventional dry-mix shotcrete;
  - prior to 1984 most shotcrete repair in Alberta was completed with latex modified dry-mix shotcrete; after 1984 steel fibre reinforced dry-mix shotcrete, either with or without silica fume, became the preferred repair material;
  - there has been hardly any repair of bridges with shotcrete in the Prairie provinces of Saskatchewan and Manitoba;
  - a variety of repair materials have been used in British Columbia, but since 1984, dry-mix silica fume shotcrete both with and without steel fibre reinforcement has been the preferred repair material; latex modified shotcrete has not been used in British Columbia.

- The large majority of shotcrete repairs have been to vertical or overhead surfaces of bridge components such as: piers, pier caps, girders, beams, diaphragms, arches, deck soffits, fascia, abutments and wing walls. Curb and gutter and parapet elements have been repaired with shotcrete in a few bridges, mainly in Alberta.

- Most repairs have been required because of deterioration of the original concrete caused by:
  - concrete cracking and spalling, because of chloride induced corrosion of reinforcing steel and embedded metals;
  - freeze-thaw deterioration, often aggravated by the presence of deicing chemicals, of either non air-entrained or likely inadequately air-entrained concrete;
  - cracking and deterioration of concrete caused by alkali-aggregate reactivity.

- Armed with the benefits of hindsight it is apparent that the need for shotcrete repair could have been avoided in many of the bridges examined if the bridge decks had been adequately drained and waterproofed and, in particular, if expansion joint details and maintenance had prevented water and deicing chemical solutions from leaking down onto substructural elements.
62 percent of the shotcrete repairs examined were rated as being in *good* to *excellent* condition. The main factors which caused a downgrading of a repair rating from *excellent* to *good* were:

- cracking; generally in the form of pattern cracking, restrained shrinkage cracking and occasionally reflection cracking;
- delamination of featheredged shotcrete applied outside of chipped, prepared areas, directly over the original concrete surface.

25 percent of shotcrete repairs examined were rated as being in only *fair* condition. The main factors which gave rise to this rating included:

- cracking and delaminations similar to those observed in repairs rated as *good*, but more pronounced; i.e. generally wider and more widespread cracks and larger areas of delamination;
- poor workmanship, in the form of trapped rebound and overspray; less than adequately consolidated shotcrete (caused by poor shooting technique) and very rough surface texture;
- continued deterioration of original concrete around or within the repaired areas, caused by either a failure to eliminate the original cause of deterioration (usually leaking deicing chemical solutions), or a failure to protect original non-air entrained or inadequately air entrained concrete with a sloped shotcrete cap.

10 percent of the shotcrete repairs were rated as being in *poor* condition. The main factors which gave rise to this rating were:

- extremely poor shotcrete workmanship, resulting in incorporation of layers of entrapped rebound and/or overspray in the completed work;
- gross pattern cracking in latex modified shotcrete repairs; likely attributable to placing shotcrete during unfavourable ambient conditions and/or inadequate curing;

Only 3 percent of shotcrete repairs (or parts of repairs) were considered to have *failed*. These included:

- the High Level Bridge in Edmonton, where the original dry-mix shotcrete jacket applied in 1960 had slabbled off the bridge piers in massive sheets. Close access to these piers for detailed examination was not available, but it appears that the failure had occurred in the non-air entrained concrete in behind the shotcrete jacket; the shotcrete was not mechanically anchored with reinforcement or dowels and became detached, with the original concrete still adhered to it. (The writer has observed this type of failure on several shotcrete jacketed hydraulic structures such as dams, locks and dry docks);
freeze-thaw deterioration of shotcrete repairs was observed in only two structures, both in Nova Scotia. Localized areas of freeze-thaw deterioration were found in areas of seepage coming through a regular dry-mix shotcrete applied to a rock bridge abutment in Halifax. Provision of drainage behind the shotcrete and/or weep holes could have helped prevent this condition. In another Nova Scotia bridge, poor consolidation of conventional wet-mix shotcrete at the top of an abutment beam seat, which was subjected to critical saturation from a leaking deck/pavement abutment joint, resulted in an area of shotcrete turning to rubble after 5 years of freeze/thaw exposure.

- With the exception of the above examples, the shotcrete repairs examined appeared remarkably unaffected by freeze-thaw exposure conditions, in spite of some repairs being subjected to as many as 10 years of exposure to leaking deicing chemical solutions (e.g. some repairs in Alberta and on the Gardiner Expressway); i.e. it does not appear that freeze-thaw exposure and deicing salt scaling is a significant mechanism of deterioration of shotcrete repairs provided the repair is properly designed and shotcrete mixtures are properly designed, applied and cured.

- Latex modified shotcrete was observed to be much more vulnerable to pattern cracking than conventional wet or dry-mix shotcretes, or steel fibre reinforced shotcretes. From discussions with contractors carrying out latex modified shotcrete repairs, it appears that such shotcrete is very susceptible to plastic shrinkage induced pattern cracking if the temperature rises above 25°C and if there is even a light wind, particularly for repairs exposed to direct sunlight. Further, with time any moisture able to penetrate cracks causes a darkening of the latex-modified shotcrete around the cracks. This gives the visual appearance of much wider cracks than actually exist and is aesthetically displeasing. These are major impediments to the use of latex modified shotcretes for bridge repair, particularly if the cracks become wide enough to allow chloride ion intrusion to the level of the reinforcing steel. This issue will be studied in the second phase of this C-SHRP study.

- The large majority of shotcrete repairs examined have been left in the natural as-shot surface finish. Technically this is often desirable, as the shotcrete is not vulnerable to damage from improperly timed or performed finishing operations, which could introduce tears or delaminations into the plastic shotcrete. Aesthetically, however, such repairs leave much to be desired. For many highway and rural bridges, aesthetics is not a major concern. In rehabilitation of city bridges and elevated freeways, aesthetics is often important. Some very good examples of finished shotcrete repairs were observed in bridges in Alberta and Nova Scotia and bridge abutment protection in British Columbia. There are, of course, higher costs associated with finished surfaces, but as a general comment it is suggested that more consideration should be given to finishing shotcrete repairs in city environments, in order to improve public perception of the quality of the repair.

- Finally, for patch-type shotcrete repairs, it is apparent from this preliminary evaluation of bridge structures across Canada that for most applications the longevity of the shotcrete repair will be largely dictated by the rate of continuing deterioration in the surrounding original reinforced concrete. Very little deterioration of properly designed, applied and cured shotcrete was found; it appears that for most structures, additional repairs will be required.
to surrounding original concrete, long before any remedial work is required on existing shotcrete repairs.

ACKNOWLEDGEMENTS

This paper summarizes the results of the first phase of a study conducted for C-SHRP by Hardy BBT Limited in association with John Emery Geotechnical Engineering Limited and W.S. Langley and Associates Limited. The principal investigators were Dr. D.R. Morgan and Mr. J. Neill assisted by Dr. D. Hooton and Mr. W.S. Langley. The guidance and review provided by the C-SHRP Project Committee, particularly Dr. D. Manning of the Ontario Ministry of Transportation & Communications and Mr. P. Carter of Alberta Transportation and Utilities is greatfully acknowledged. The assistance provided by various bridge-owning authorities during the field surveys and in responding to the mailed Questionnaire is likewise greatfully acknowledged.
PRIME REFERENCES

Keywords: "shotcrete/gunite and bridge" and "shotcrete/gunite and durability"


5. Eloniemi, P.; Moijanen, K, "Improvement of Construction Repair and Maintenance Methods of Bridges", Roads and Waterways Administration, Opatinsilta 12 Helsinki 52 Finland.


SUPPLEMENTARY REFERENCES

1. ACI 506R-90, "Guide to Shotcrete", American Concrete Institute, Detroit, 41 pp.

2. ACI 506.2-90, "Specifications for Materials, Proportioning and Application of Shotcrete", American Concrete Institute, Detroit, 7 pp.

3. ACI 506.3R-82, "Guide to Certification of Shotcrete Nozzleman", American Concrete Institute, Detroit, 11 pp.


16. Hoff, G.C., "Durability of Fiber Reinforced Concrete in a Severe Marine Environment", American Concrete Institute, Detroit, ACI SP 100, 1987, pp. 997-1041.


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TABLE 2: SUMMARY OF BRIDGES EVALUATED
<p>| Bridge # | Province    | Owner                                            | Bridge Location                  | Shotcrete Process | Shotcrete Type            | Year Repaired | Rated Condition   |
|---------|-------------|                                                 |                                 |                  |                          |              |                  |
| 30      | Nova Scotia | Nova Scotia Department of Transportation and     | Gardeners Mill Bridge, Yarmouth  | Wet              | No Latex or Silica Fume  | 85           | Fair/Poor        |
|         |             | Communication                                    | County                           |                   |                           |              |                  |
| 31      | Nova Scotia | Nova Scotia Department of Transportation and     | Tusket River Bridge, Yarmouth     |                  |                          |              | Excell/Good      |
|         |             | Communication                                    | County                           |                   |                           |              |                  |
| 32      | Ontario     | Ontario Ministry of Transportation &amp; Communications | Leslie Street, Toronto           | Dry              | Latex                    | 85/86        | Excellent        |
| 33      | Ontario     | Ontario Ministry of Transportation &amp; Communications | Credit River, Toronto            | Dry              | Latex                    | 87/88        | Excellent        |
| 34      | Ontario     | Ontario Ministry of Transportation &amp; Communications | Bronte Creek Bridge, Toronto     | Dry              | Latex                    | 82           | Good/Fair/Poor   |
| 35      | Ontario     | Ontario Ministry of Transportation &amp; Communications | Hoggs Hollow, North Collector,   | Dry              | Latex                    | 82           | Good             |
|         |             |                                                 | Toronto                          |                   |                           |              |                  |
| 36      | Ontario     | Ontario Ministry of Transportation &amp; Communications | Hoggs Hollow, South Collector,   | Dry              | Latex                    | 81           | Good             |
|         |             |                                                 | Toronto                          |                   |                           |              |                  |</p>
<table>
<thead>
<tr>
<th>Bridge #</th>
<th>Province</th>
<th>Owner</th>
<th>Bridge Location</th>
<th>Shotcrete Process</th>
<th>Shotcrete Type</th>
<th>Year Repaired</th>
<th>Rated Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>Ontario</td>
<td>Ontario Ministry of Transportation &amp; Communications</td>
<td>Highway 88, over Highway 400, Toronto</td>
<td>Dry</td>
<td>Latex</td>
<td>83</td>
<td>Fair/Poor</td>
</tr>
<tr>
<td>38</td>
<td>Ontario</td>
<td>Ontario Ministry of Transportation &amp; Communications</td>
<td>Humber River Bridge, Toronto</td>
<td>Wet</td>
<td>Latex</td>
<td>82</td>
<td>Excell/Good</td>
</tr>
<tr>
<td>39</td>
<td>Ontario</td>
<td>Ontario Ministry of Transportation &amp; Communications</td>
<td>Sixteen Mile Creek, Toronto</td>
<td>Dry</td>
<td>Latex</td>
<td>89/90</td>
<td>Excell/Good</td>
</tr>
<tr>
<td>40</td>
<td>Ontario</td>
<td>Municipality of Metropolitan Toronto</td>
<td>Gardiner Expressway, Bent #115, Toronto</td>
<td>Dry</td>
<td>Latex</td>
<td>81</td>
<td>Fair</td>
</tr>
<tr>
<td>41</td>
<td>Ontario</td>
<td>Municipality of Metropolitan Toronto</td>
<td>Gardiner Expressway, Bent #114, Toronto</td>
<td>Dry</td>
<td>Latex</td>
<td>81</td>
<td>Good/Fair</td>
</tr>
<tr>
<td>42</td>
<td>Ontario</td>
<td>Municipality of Metropolitan Toronto</td>
<td>Gardiner Expressway, Bent A97, Toronto</td>
<td>Dry</td>
<td>No Latex or Silica Fume</td>
<td>85</td>
<td>Excellent</td>
</tr>
<tr>
<td>43</td>
<td>Ontario</td>
<td>Municipality of Metropolitan Toronto</td>
<td>Gardiner Expressway, Bay Street/Lakeshore, Bent DT18, Toronto</td>
<td>Dry</td>
<td>Latex</td>
<td>81/82</td>
<td>Good/Fair</td>
</tr>
<tr>
<td>44</td>
<td>Ontario</td>
<td>Municipality of Metropolitan Toronto</td>
<td>Gardiner Expressway, York to Rees, Bent 180, Toronto</td>
<td>Dry</td>
<td>Latex</td>
<td>83</td>
<td>Poor</td>
</tr>
</tbody>
</table>
### TABLE 2: SUMMARY OF BRIDGES EVALUATED

<table>
<thead>
<tr>
<th>Bridge #</th>
<th>Province</th>
<th>Owner</th>
<th>Bridge Location</th>
<th>Shotcrete Process</th>
<th>Shotcrete Type</th>
<th>Year Repaired</th>
<th>Rated Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>Ontario</td>
<td>Municipality of Metropolitan Toronto</td>
<td>Gardiner Expressway, Ramp Bent 178, Toronto</td>
<td>Dry</td>
<td>Latex</td>
<td>83</td>
<td>Good</td>
</tr>
<tr>
<td>46</td>
<td>Ontario</td>
<td>Municipality of Metropolitan Toronto</td>
<td>Gardiner Expressway, Bent 157, Toronto</td>
<td>Dry</td>
<td>Latex</td>
<td>80</td>
<td>Excell/Good</td>
</tr>
<tr>
<td>47</td>
<td>Ontario</td>
<td>Municipality of Metropolitan Toronto</td>
<td>Dundas Street Overpass, Toronto</td>
<td>Dry</td>
<td>Latex</td>
<td>?</td>
<td>Excell/Poor</td>
</tr>
<tr>
<td>48</td>
<td>Ontario</td>
<td>Municipality of Metropolitan Toronto</td>
<td>Saint Clair Street Rail Bridge, Toronto</td>
<td>Dry</td>
<td>Latex</td>
<td>88</td>
<td>Excellent</td>
</tr>
<tr>
<td>49</td>
<td>Ontario</td>
<td>Ontario Department of Transportation &amp; Communications</td>
<td>Rideau Canal Bridge, Ottawa</td>
<td>Dry</td>
<td>Latex</td>
<td>85</td>
<td>Good</td>
</tr>
<tr>
<td>50</td>
<td>Ontario</td>
<td>Ontario Department of Transportation &amp; Communications</td>
<td>Main Street, Ottawa</td>
<td>Dry</td>
<td>Latex</td>
<td>885</td>
<td>Good</td>
</tr>
<tr>
<td>51</td>
<td>Ontario</td>
<td>Ontario Department of Transportation &amp; Communications</td>
<td>Elgin Street, Ottawa</td>
<td>Dry</td>
<td>Latex</td>
<td>85</td>
<td>Excellent/Good</td>
</tr>
<tr>
<td>52</td>
<td>Ontario</td>
<td>Ontario Department of Transportation &amp; Communications</td>
<td>O’Connor Overpass, Ottawa</td>
<td>Dry</td>
<td>Latex</td>
<td>85</td>
<td>Excellent</td>
</tr>
<tr>
<td>Bridge #</td>
<td>Province</td>
<td>Owner</td>
<td>Bridge Location</td>
<td>Shotcrete Process</td>
<td>Shotcrete Type</td>
<td>Year Repaired</td>
<td>Rated Condition</td>
</tr>
<tr>
<td>---------</td>
<td>------------------</td>
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<td>-------------------------------</td>
<td>-------------------</td>
<td>----------------</td>
<td>---------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>53</td>
<td>Ontario</td>
<td>Ontario Department of Transportation &amp; Communications</td>
<td>Bank Street, Ottawa</td>
<td>Dry</td>
<td>Latex</td>
<td>85</td>
<td>Good</td>
</tr>
<tr>
<td>54</td>
<td>Ontario</td>
<td>Ontario Department of Transportation &amp; Communications</td>
<td>Kirkwood Overpass, Ottawa</td>
<td>Dry</td>
<td>Latex</td>
<td>83</td>
<td>Fair/Poor</td>
</tr>
<tr>
<td>55</td>
<td>Ontario</td>
<td>Ontario Department of Transportation &amp; Communications</td>
<td>Carling Westbound, Ottawa</td>
<td>Dry</td>
<td>Latex</td>
<td>83</td>
<td>Good/Fair</td>
</tr>
<tr>
<td>56</td>
<td>Ontario</td>
<td>Ontario Department of Transportation &amp; Communications</td>
<td>Carling Eastbound, Ottawa</td>
<td>Dry</td>
<td>Latex</td>
<td>83</td>
<td>Good/Fair</td>
</tr>
<tr>
<td>57</td>
<td>Ontario</td>
<td>Ontario Department of Transportation &amp; Communications</td>
<td>Clyde Avenue, Ottawa</td>
<td>Dry</td>
<td>Latex</td>
<td>83</td>
<td>Good/Fair</td>
</tr>
<tr>
<td>58</td>
<td>Ontario</td>
<td>Ontario Department of Transportation &amp; Communications</td>
<td>Montreal Road Bridge, Ottawa</td>
<td>Dry</td>
<td>Latex</td>
<td>83</td>
<td>Excellent</td>
</tr>
<tr>
<td>59</td>
<td>Ontario</td>
<td>Ontario Department of Transportation &amp; Communications</td>
<td>Kempville Creek Bridge, Ottawa</td>
<td>Dry</td>
<td>Latex</td>
<td>88</td>
<td>Good</td>
</tr>
<tr>
<td>60</td>
<td>Ontario</td>
<td>Regional Municipality of Ottawa/Carlton</td>
<td>O’Connor Street Bridge, Ottawa</td>
<td>Dry</td>
<td>Latex</td>
<td>86</td>
<td>Excellent</td>
</tr>
<tr>
<td>61</td>
<td>Ontario</td>
<td>Regional Municipality of Ottawa/Carlton</td>
<td>Rideau River Bridge, Ottawa</td>
<td>Dry</td>
<td>Latex</td>
<td>90</td>
<td>Good</td>
</tr>
</tbody>
</table>
Fig. 1: Corrosion induced staining and cracking in original concrete adjacent to shotcrete repair: Happy Valley Grade Separation (Bridge #1).

Fig. 2: Continuing freeze/thaw deterioration of original concrete adjacent to shotcrete repair in sidewalk of Canmore Grade Separation (Bridge #5). Latex modified shotcrete displayed no freeze/thaw deterioration.
Fig. 3: Continuing freeze/thaw deterioration of original concrete adjacent to shotcrete repair in sidewalk of Bow River bridge at Canmore (Bridge #6). Latex modified shotcrete displayed no freeze/thaw deterioration.

Fig. 4: Close-up view of one of the piers shown in Fig. 7. Steel fibre reinforced silica fume shotcrete jacket varied in thickness from 75 to 450 mm and was largely crack-free.
Fig. 5: Continuing deterioration in original concrete adjacent to shotcrete repairs in 132nd Street bridge (Bridge #15) in Edmonton.

Fig. 6: General view of steel fibre reinforced dry-mix shotcrete repair to Campbell Street bridge (Bridge #17) in Edmonton. Arches were repaired with shotcrete and found to be in excellent condition with no cracking.
Fig. 7: High Level bridge in Edmonton over the North Saskatchewan River (Bridge #19). There has been a massive slabbing failure of the 30 year old dry-mix shotcrete from these piers.

Fig. 8: Shotcrete has turned to rubble from freeze/thaw action and reinforcing mesh is corroded in this area of poorly consolidated wet-mix shotcrete at an abutment beam seat of the Pleasant Valley Bridge (Bridge #29).
Fig. 9: Example of featheredged, latex-modified shotcrete, applied over improperly prepared original concrete, which is now delaminating; Bronte Creek Bridge (Bridge #34) Queen Elizabeth Way.

Fig. 10: Example of well-finished latex modified shotcrete applied to arched beam in Sixteen Mile Creek Bridge, Toronto (Bridge #39); featheredged shotcrete has been trimmed back to edge of deep repair.
Fig. 11: Typical corrosion induced deterioration of a pier on the Gardiner Expressway, Toronto (Bridge #42) prior to repair.

Fig. 12: Example of extensive pattern cracking in latex-modified shotcrete repair to bent #180 on the Gardiner Expressway. Cracks verified from 0.05 to 0.4 mm wide and repair was judged to be of poor quality.
Fig. 13: Conventional dry-mix shotcrete repair to the Saint Clair Rail Bridge Underpass (Bridge #48), in Toronto. Shotcrete finished to give cast-concrete appearance and was in generally excellent condition.

Fig. 14: Latex-modified shotcrete repair to the Carling Street westbound underpass under Highway 417, Ottawa (Bridge #55). Note the pronounced pattern cracking visible in exposed areas of the bridge abutment.
FIG. 15: SUMMARY OF CONDITION RATING OF BRIDGES OR PARTS OF BRIDGE STRUCTURES