
AASHTO-AGC-ARTBA Joint Committee

Task Force 37 Report

Guide Specifications for Shotcrete Repair of Highway Bridges

February 1998



**AASHTO-AGC-ARTBA Joint Committee
Subcommittee on Materials
Task Force 37 Report**

**Guide Specifications for Shotcrete
Repair of Highway Bridges**

February 1998



Documents
Document Sharing Hub

© 1998 by the American Association of State Highway and Transportation Officials.
All rights reserved. Duplication is a violation of applicable law.

Introduction

This document is disseminated upon the sponsorship of the Joint Committee of the American Association of State Highway and Transportation Officials, the Associated General Contractors of America and the American Road and Transportation Builders Association (the Joint AASHTO-AGC-ARTBA Committee) in the interest of information exchange, based on the combined technical expertise of the authors. As such, the opinions and conclusions implied or expressed herein do not necessarily reflect the official views or policies of the Joint Committee or its member organizations.

This report was approved for publication by the three member organizations comprising the Joint Committee and was published on behalf of the Joint Committee by AASHTO.

All rights to this report are reserved to the Joint Committee. However, permission to make copies thereof can be obtained with the understanding that credit will be given to the Joint Committee. For permission to make copies, write to AASHTO at the following address:

American Association of State Highway
and Transportation Officials
444 North Capitol St., N.W., Suite 249
Washington, D.C. 20001

Fax (202) 624-5806

February 1998



Documents

Document Sharing Hub

Preface

This Guide Specification is adapted from the Recommended Practice for Shotcrete Repair of Highway Bridges which was prepared by Dr. D. R. Morgan, Professional Engineer of HBT AGRA Limited, Vancouver, B.C., Canada, under the auspices of the Canadian Strategic Highway Research Program (C-SHRP) study titled *Durability of Shotcrete Rehabilitation Treatments of Bridges*. C-SHRP is a program of the Transportation Association of Canada (TAC). The guidance, review and critical comment of the following C-SHRP Project Committee on Shotcrete Repair of Bridges' members in preparation of the original document is gratefully acknowledged:

Dr. David Manning, Professional Engineer, Ministry of Transportation, Ontario

Mr. Paul Carter, Professional Engineer, Alberta Transportation and Utilities

Mr. Daniel Vizina, Ing., Transports Québec

Mr. Greg Williams, Professional Engineer, C-SHRP National Coordinator

The contributions of Mr. W. S. Langley, Professional Engineer, of W. S. Langley and Associates Limited and Dr. Doug Hooton, Professional Engineer, of John Emery Geotechnical Engineering Limited to the initial C-SHRP study are also gratefully acknowledged.

Permission to adapt the document was provided under Cooperative Agreement DTFH61-95-X-00005 between the Federal Highway Administration and the Transportation Association of Canada. The original document was revised and adapted for use in the U.S. by Joint Task Force 37, Shotcrete Repair of Highway Bridges.

**Joint Task Force 37
Shotcrete Repair of Highway Bridges**

Chairman: Gerald White, North Carolina DOT, Raleigh, NC

Secretary: Bruce Johnson, Federal Highway Administration, Salem, OR

Members:

Jim Asher, Fibermesh Company, San Antonio, TX

Ken Boedecker, W. R. Grace and Company, Charleston, SC

Jim Dikeou, ACI, Detroit, MI

Mahmoud Elnahal, Virginia DOT, Richmond, VA

Steven H. Gebler, Construction Technology Laboratories, Inc., Skokie, IL

George Yoggy, Master Builders Technologies, Cleveland, OH

Leon Glassgold, Masonry Resurfacing and Construction Company, Baltimore, MD

Frank Nelson, Oregon DOT, Salem, OR

Christy Philipp, California DOT, Sacramento, CA

Dan Thomas, California DOT, Sacramento, CA

John Simmons, Pneumatic Concrete Inc., Birmingham, AL

Peter C. Tatnall, Bekaert Corporation, Marietta, GA

Larry Totten, Johnson Western Gunite Company, San Leandro, CA

Curt White, Coastal Gunite Construction Company, Cambridge, MD





Documents
Document Sharing Hub

© 1998 by the American Association of State Highway and Transportation Officials.
All rights reserved. Duplication is a violation of applicable law.

Guide Specifications for Shotcrete Repair of Highway Bridges

Table of Contents

Introduction	1
1.0 Background	1
2.0 Specifier's Guide	3
3.0 Definitions	4
4.0 Design Considerations	6
5.0 Checklist	9
Dry-Mix Shotcrete Repair of Highway Bridges	1
1.0 General Description and Requirements	1
2.0 Submittals	3
3.0 Reference Documents	4
4.0 Materials	6
5.0 Shotcrete Proportioning	8
6.0 Supply and Equipment	10
7.0 Preparation for Shotcreting	13
8.0 Quality Assurance and Quality Control Testing	17
9.0 Safety and Clean-Up	21
10.0 Shotcrete Application and Finishing	22
11.0 Curing and Protection	26
12.0 Shotcrete Acceptance and Repair	27
13.0 Measurement	29
Wet-Mix Shotcrete Repair of Highway Bridges	1
1.0 General Description and Requirements	1
2.0 Submittals	3
3.0 Reference Documents	4



4.0	Materials	6
5.0	Shotcrete Proportioning	9
6.0	Supply and Equipment	11
7.0	Preparation for Shotcreting	14
8.0	Quality Assurance and Quality Control Testing	18
9.0	Safety and Clean-Up	22
10.0	Shotcrete Application and Finishing	23
11.0	Curing and Protection	27
12.0	Shotcrete Acceptance and Repair	28
13.0	Measurement	30
Commentary		1
1.0	General Description and Requirements	1
2.0	Submittals	3
3.0	Reference Documents	4
4.0	Materials	4
5.0	Shotcrete Proportioning	12
6.0	Supply and Equipment	17
7.0	Preparation for Shotcreting	21
8.0	Quality Assurance and Quality Control Testing	26
9.0	Safety and Clean-Up	30
10.0	Shotcrete Application and Finishing	30
11.0	Curing and Protection	32
12.0	Shotcrete Acceptance and Repair	33
References		34

Introduction to the Joint AASHTO-AGC-ARTBA Guide Specifications for

Shotcrete Repair of Highway Bridges

1.0 BACKGROUND This Guide Specification is adapted from the Recommended Practice for Shotcrete Repair of Highway Bridges which was prepared by Dr. D. R. Morgan, Professional Engineer of HBT AGRA Limited, Vancouver, B.C., Canada, under the auspices of the Canadian Strategic Highway Research Program (C-SHRP) study titled *Durability of Shotcrete Rehabilitation Treatments of Bridges*. C-SHRP is a program of the Transportation Association of Canada (TAC). The guidance, review and critical comment of the following C-SHRP Project Committee on Shotcrete Repair of Bridges' members in preparation of the original document is gratefully acknowledged:

Dr. David Manning, Professional Engineer,
Ministry of Transportation, Ontario

Mr. Paul Carter, Professional Engineer, Alberta
Transportation and Utilities

Mr. Daniel Vizina, Ing., Transports Québec

Mr. Greg Williams, Professional Engineer,
C-SHRP National Coordinator

The contributions of Mr. W. S. Langley, Professional Engineer, of W. S. Langley and Associates Limited and Dr. Doug Hooton, Professional Engineer, of John Emery Geotechnical Engineering Limited to the initial C-SHRP study are also gratefully acknowledged.

This document represents the best current practice for the durable shotcrete repair of bridges and is based on the professional experience of the prime author and persons acknowledged above in the implementation of many shotcrete repair projects.

Permission to adapt the document was provided under Cooperative Agreement DTFH61-95-X-00005 between the Federal Highway Administration and the Transportation Association of Canada. The original document was revised and adapted for use in the U.S. by Joint Task Force 37, Shotcrete Repair of Highway Bridges, comprised of the following members:

Jim Asher, Fibermesh Company, San Antonio, TX

Ken Boedecker, W. R. Grace and Company,
Charleston, SC

Jim Dikeou, ACI, Detroit, MI

Mahmoud Elnahal, Virginia DOT, Richmond, VA

Steven H. Gebler, Construction Technology
Laboratories, Inc., Skokie, IL

George Yoggy, Master Builders Technologies,
Cleveland, OH

Leon Glassgold, Masonry Resurfacing and
Construction Company, Baltimore, MD

Frank Nelson, Oregon DOT, Salem, OR

Christy Philipp, California DOT, Sacramento, CA

Dan Thomas, California DOT, Sacramento, CA

John Simmons, Pneumatic Concrete Inc., Birmingham,
AL

Peter C. Tatnall, Bekaert Corporation, Marietta, GA

Larry Totten, Johnson Western Gunit Company, San
Leandro, CA

Curt White, Coastal Gunit Construction Company,
Cambridge, MD

Gerald White, Chairman, North Carolina DOT, Raleigh, NC

Bruce Johnson, Secretary, Federal Highway Administration, Salem, OR

It is believed that if remedial works are conducted rigorously in accordance with the procedures outlined in this Guide Specification, the Owner will be provided with durable shotcrete repairs and greater service life than the surrounding non-repaired concrete.

2.0 SPECIFIER'S GUIDE

This document has been prepared in a three-part format:

- (a) Guide Specifications for Dry-Mix Shotcrete Repair of Highway Bridges,
- (b) Guide Specifications for Wet-Mix Shotcrete Repair of Highway Bridges, and
- (c) Commentary on Guide Specifications for Shotcrete Repair of Highway Bridges.

There is a considerable amount of repetition of content between the Dry-Mix and Wet-Mix Specifications, but it was considered that there were sufficient differences between the dry-mix and wet-mix shotcrete processes that they warranted separate treatment. The Guide Specifications are followed by a Commentary, which applies to both the dry- and wet-mix shotcrete processes. This Commentary draws distinctions between the two processes, and provides the Specifier with guidance to assist in selection of the appropriate shotcrete process for a given project. The Commentary also provides additional guidance to the Specifier and Contractor regarding the practical repair of bridges with shotcrete.

The Joint Task Force recognized that a National Specification cannot be written which would be directly applicable to each State or even each region of the country. Nevertheless, the Specifier should be able to readily adopt material from the document in preparation of project-specific specifications, including combining the two Guide Specifications to allow the contractor to select the most efficient process for a given project.

The Specifier will be required to make certain design selections and choices in preparing a specification. **The Commentary**

section of the document must be used in conjunction with the Guide Specifications section to aid the Specifier in preparation of contract documents. The same numbering system has been used in the Guide Specifications and Commentary section of the document to aid the Specifier in this process. As a further aid to the specifier, a CHECKLIST is provided in Section 5 of this Introduction. This CHECKLIST summarizes items requiring action by the Engineer.

The Payment section was based on a consensus of the Joint Task Force. Nevertheless, it is recognized that agencies may change to other methods of measurement and payment depending on local preferences. These documents concentrate on technical requirements for the remedial work.

Pertinent American Concrete Institute (ACI) and American Society for Testing and Materials (ASTM) documents are invaluable for providing background and details of common practice when making decisions about a specific project. However, they are not normally referenced in Specification documents since they are not written in specification format. Of these documents, the most useful is the ACI 506R-90, *Guide to Shotcrete*. While this document does not specifically address the use of shotcrete for repair of bridges, it contains much useful information which will be of assistance to the Specifier in preparing contract documents. The Guide Specifications cite specific chapters in ACI 506R with the intent that the specifier, using the Commentary, will choose the requirements which apply to the project and insert those requirements in the project specifications using appropriate imperative language.

3.0 DEFINITIONS

The following definitions refer to words and terms used in this specification. For definitions not covered in this document, refer to ACI 506R and ACI 506.2.

- 3.1 **Acceptable, approved or permitted:** Acceptable to, approved or permitted by the Engineer.
- 3.2 **Bench gunning:** The practice of shooting thick members of full section by building from the bottom up.
- 3.3 **Blowpipe:** Air jet operated by nozzleman's helper in shotcrete gunning to assist in keeping rebound and overspray out of the work.

- 3.4 Contractor:** The person, firm or corporation with whom the Owner enters into agreement for construction of the work.
- 3.5 Dry-Mix Shotcrete:** Shotcrete in which most of the mix water is added at the nozzle.
- 3.6 Engineer:** The accepting authority responsible for issuing the project specifications and administering work under the contract documents.
- 3.7 Ground Wire (also called screed wire or shooting wire):** Small gauge, high strength wire used to establish line and grade to guide shotcrete work.
- 3.8 Gunning (also called shooting):** The act of applying shotcrete.
- 3.9 Nozzleman:** Worker on the shotcrete crew who manipulates the nozzle, controls air or water addition at the nozzle and controls final deposition of the material.
- 3.10 Overspray:** Shotcrete material deposited away from the intended receiving surface.
- 3.11 Predampener (also known as premoisturizer):** An apparatus used to predampen dry-mix shotcrete materials prior to discharge into the shotcrete gun.
- 3.12 Rebound:** Shotcrete material leaner than the original mixture which ricochets off the receiving surface and falls to accumulate on the ground or other surfaces.
- 3.13 Rod:** Sharp-edged cutting screed used to trim shotcrete to forms or ground wires.
- 3.14 Shotcrete:** Mortar or concrete pneumatically projected at high velocity onto a receiving surface.
- 3.15 Sloughing (also called sagging):** Subsistence of shotcrete, due generally to excessive water in the mix or placing too great a thickness of shotcrete in a single pass.
- 3.16 Specifier:** The authority issuing the project specifications, normally the Engineer.

- 3.17 Wet-Mix Shotcrete:** Shotcrete in which all the shotcrete ingredients, including mix water, are mixed prior to introduction into the shotcrete delivery system, and compressed air is introduced to the material flow at the nozzle.

4.0 DESIGN CONSIDERATIONS

- 4.1** Review of the performance of some 60 shotcrete repaired bridges in Canada (Reference 1, Commentary) has revealed that there are certain basic considerations which should be applied in the design of shotcrete repairs for bridges in order to provide durable, long service-life repairs.
- 4.2** Most deterioration in bridge structures, which has given rise to the need for shotcrete repair, has resulted from the combined actions of deicing chemicals and frost action on saturated concrete. In the remedial design, every attempt should be made, wherever possible, to protect the existing concrete and new shotcrete repairs from continuing exposure to deicing chemicals and saturation. Such measures may include sealing, repair or replacement of bridge decks and/or expansion joints; redesign of deck and abutment drainage systems; re-profiling substructure elements such as pier caps and abutments to prevent ponding and facilitate drainage. If this is not done, the original concrete can continue to deteriorate around the shotcrete repair, ultimately compromising the repair.
- 4.3** In many bridges it may be necessary to maintain either full or partial traffic on the bridge deck during the period of shotcrete remedial work. It should be noted that it may be difficult to effect quality repairs on elements which are subjected to continuous vibration or deflections from traffic during shotcreting operations. Careful consideration should be given at the design stage as to whether traffic control measures or restrictions need to be placed on the bridge during the repair program. Questions which need to be considered include the following:
- Will live loads be allowed on the bridge during repairs?
 - Will temporary shoring or strengthening of the structure be required?
 - How long must the repairs be allowed to cure before the bridge is returned to full service?

- 4.4** Some shotcrete repair of bridges has been required because of general deterioration of the concrete matrix, attributable to alkali-aggregate reactivity, or the use of inherently non-freeze/thaw durable, non-air-entrained concrete in the original construction. In shotcrete repair of such structures, reliance should not be placed solely on the quality of bond of the shotcrete to the original concrete for long-term performance of the repair. Concrete could continue to deteriorate behind the shotcrete repair and thus it becomes important to tie back the repair shotcrete into the existing concrete, using appropriately designed anchors or the existing reinforcement. If this is not done, there is a danger of long-term "slabbing" failure of the repair, the failure being initiated in the original concrete with the shotcrete still adhered to it.
- 4.5** Corrosion of embedded reinforcing steel and subsequent spalling in the original concrete has been the cause of the need for shotcrete repair of many bridges. In many instances, corrosion has resulted from a lack of adequate cover to reinforcing steel (sometimes caused by cage movement during original construction). In such repair, it is important that all spalled, deteriorated and delaminated concrete be removed. Also, concrete should be removed and replaced in areas displaying high reinforcing steel corrosion activity as indicated by half-cell potential measurements or other suitable procedures. In such repairs, concrete should be removed from around corroded reinforcing steel to provide a minimum of 20 mm clearance behind the steel, to facilitate full encapsulation with shotcrete. Tests have shown (Reference 2, Commentary) that only partial removal of concrete to the front face of the reinforcing steel will compromise the longevity of the repair, particularly in elements subjected to repetitive dynamic loading. Reinforcing bars should be bent back or surface contours adjusted to provide adequate cover.
- 4.6** In many severely corroded bridge elements, it may be necessary to remove and replace, or supplement existing reinforcing steel with additional reinforcement. Some older bridges may be inadequately reinforced by current design standards. Additional reinforcement can be included as part of the designed repair. Fiber reinforcement can be effectively used in some structures, in lieu of reinforcing mesh, but not in lieu of primary reinforcing steel. Fiber reinforcement can be very effective in minimizing thermal and shrinkage-induced cracking in the shotcrete repair. It also provides increased toughness and impact resistance to the shotcrete repair.

- 4.7** In repair of deteriorated load-bearing elements, it may be necessary to carry out the repair work in a sequential manner, with partial concrete removal, preparation and shotcreting being completed in repair of a bridge component, prior to removal of more material. This is particularly important in repair of pier caps and abutments in areas adjacent to bearings. Careful consideration should be given by the Engineer and Contractor to the needs for shoring and sequential repair so that the safety of the structure is not compromised.
- 4.8** The design should prohibit “featheredging” of shotcrete repairs or the application of “skim-coats” of shotcrete to unprepared original concrete surface. Such types of repairs have a high occurrence of failure in the field. The perimeter of all prepared areas for shotcrete repairs should be chipped on a 45-degree angle (to facilitate escape of rebound) except that the outer edges of prepared repair areas should be saw cut to a square edge, to a minimum depth of 15 mm, to neatly define the extremity of the repair and eliminate shotcrete “featheredging”.
- 4.9** Where considerable thicknesses of shotcrete are required to be applied (particularly in overhead applications), consideration should be given to the use of dry-mix silica fume shotcrete. Wherever possible, shotcrete should be applied in a single lift, rather than in multiple-layer construction; dry-mix silica fume shotcrete is better suited to single lift construction than any of the other shotcrete types.
- 4.10** In repair of structural elements such as piers, abutments and parapets, the designer should attempt to completely cap the element with repair shotcrete. If the shotcrete repair does not cap the element, there is a potential for the shotcrete to act as a “dam” and promote the saturation of the original concrete with water and salt solution. This can accelerate deterioration of the original concrete. Caps should be designed with a minimum 3 percent grade to facilitate drainage.
- 4.11** Superstructure elements, such as deck soffits, girders, beams and arches, should be designed with grooves or drip strips, to prevent wetting and staining of the soffits of such elements with water and salts.
- 4.12** Finally, the designer should consider the aesthetic requirements for the shotcrete repairs. The particular type of shotcrete used, and type of finish selected, will affect aesthetics. The most economical finish is the as-shot, gun finish. This may suffice for

many structures with low visibility or on secondary highways, but may not be satisfactory for bridges in city areas, or on primary highways, where visual aesthetics and public perception are important. In such structures, the requirements for finishing of shotcrete repairs and possibly even the application of pigmented coatings should be considered at the design stage.

5.0 CHECKLIST

This CHECKLIST summarizes items requiring action by the Engineer. The reference numbers in the checklist refer to numbers in the clauses in the Guide Specifications which follow.

1.2 Qualifications

1.2.1 Specify contractor and nozzlemen qualifications.

1.3 Requirements

1.3.1 Provide details in the contract documents and in the field regarding areas of spalled, deteriorated and damaged concrete requiring removal.

1.3.1 Provide details regarding replacement of excessively corroded reinforcing steel.

1.3.1 Provide details for all new reinforcing steel, mesh and anchors.

1.3.2 Provide criteria and guidelines or details for temporary support of portions of the bridge, if needed.

2.0 Submittals

2.0 Review submittal and approve contractor qualification test reports, mix design, preconstruction trial results, quality control program, curing details and temporary support.

4.0 Materials

4.1.1 Specify required cement type.

4.2.1 Specify which supplementary cementing materials, if any, to be used.

4.4.1 Specify nominal maximum aggregate size and gradation.

4.5.1 Specify whether air-entraining admixture is required and the amount or rate of addition at the nozzle, if appropriate.

4.5.2 Specify which chemical admixtures are required or allowed.

4.6.2 Provide details for all replacement reinforcing steel.

4.6.4 Specify whether fiber is to be used, and if so, type, length, diameter, if appropriate, and addition rate (kg/m^3).

5.0 Shotcrete Proportioning

5.1.1 Review and approve shotcrete mixture proportions proposed for use by Contractor.

5.1.4 Review shotcrete mix performance test data from previous experience, if available.

5.2.1 Specify silica fume content, if appropriate.

5.3 Performance Requirements

5.3.1 Specify shotcrete performance requirements.

(Note: Make any project-specific changes to Table 1 that may be required.)

5.3.2 (Optional) Establish maximum permissible rapid chloride permeability coulomb limits for shotcrete which does not contain silica fume.

6.0 Supply and Equipment

6.1.1 Provide written approval for site batching using either the volume or mass batching method.

6.1.5 Specify frequency for mass batch checks on volumetrically proportioned shotcrete mixtures.

7.0 Preparation for Shotcreting

7.1.1 Provide direction for removal of unsound concrete and for removal depths greater than 150 mm, if appropriate.

7.1.7 Specify whether requirement for abrasive blast cleaning of prepared surfaces may be waived (e.g., in case of surface preparation with high-pressure water blasting).

7.1.8 Approve the method of disposal of debris.

7.2 Reinforcement

7.2.2 Direct Contractor as to which corroded reinforcing steel to remove and replace. Specify the percent of loss of cross section for which bars must be augmented or replaced.

7.2.4 Specify the minimum lap length for replacement reinforcement.

7.2.6 Specify whether welding of replacement reinforcement is permitted.

7.2.11 Specify whether fiber reinforcement is permitted as an alternative to mesh reinforcement; provide details for anchor and tie-back systems.

7.3 Anchors

7.3.1 Specify anchor spacing.

7.3.2 Specify anchor type.

7.3.3 Specify minimum pull-out force required for anchors; specify frequency of anchor testing to verify pull-out force.

7.4 Alignment Control and Cover

7.4.2 Review and approve Contractor's proposed means of alignment and cover control.

7.4.7 Specify required tolerances on finished work.

8.0 Quality Assurance and Quality Control Testing

8.1.1 Administer quality assurance program, as detailed in Section 8.1.1.

8.2.1 Specify the hardened shotcrete properties to be tested in the contractor's quality control program and the frequency of the tests.

8.3.1 Evaluate Contractor performance in preconstruction trial.

8.3.3 Direct the contractor to core preconstruction trial panels at reinforcement intersections and in unreinforced areas.

8.3.7 Evaluate quality of cores extracted from prequalification test panel.

10.0 Shotcrete Application and Finishing

10.1.1 Review and approve prepared areas prior to application of shotcrete.

10.1.6 Specify whether use of curing compound is permitted in multiple-layer shotcrete construction.

10.1.8 Approve areas not requiring temporary support.

10.1.9 Verify whether sufficient lighting and ventilation is being provided to enable safe application of quality shotcrete.

10.1.12 Specify the tolerance for line and grade of shotcrete repair surfaces.

10.2.1 Specify type of finish required.

11.0 Curing and Protection

11.1.1 Specify whether use of curing compound permitted.

11.1.3 Specify minimum period of moist curing.

11.2.3 Review and approve Contractor's proposed hot weather shotcreting procedures.

11.2.5 Review and approve Contractor's proposed heating procedures for cold weather shotcreting.

12.0 Shotcrete Acceptance and Repair

12.1.1 Reject shotcrete work which does not conform to the project specifications.

12.1.4 Examine the completed shotcrete work for any deficiencies.

12.1.5 Implement a program of testing for in-place shotcrete if compliance testing on shotcrete test panels, or assessment of plastic or hardened shotcrete indicates non-conformance with project specifications; provide details for locations of cores to evaluate in-place shotcrete. Specify core hole patching details.

12.2.3 Inspect and approve prepared repair areas prior to application of repair shotcrete.

Part II of the Joint AASHTO-AGC-ARTBA Guide Specifications for

Dry-Mix Shotcrete Repair of Highway Bridges

1.0 GENERAL DESCRIPTION AND REQUIREMENTS

1.1 Scope

1.1.1 This document provides a guide specification for the repair of highway bridges using the dry-mix shotcrete process. It provides guide specifications for: selection of materials; shotcrete mixture proportioning; selection of shotcrete equipment; preparation for shotcreting; quality assurance and quality control testing; safety measures; shotcrete application, finishing and curing procedures; and shotcrete acceptance. If incorporated into the Contract Documents, this document shall become a part of the Contract Documents and the Contractor shall comply with all provisions in this document unless otherwise specified by the Contract Documents or modified in writing by the Engineer.

1.2 Qualifications

1.2.1 The shotcrete contractor's crew foreman and nozzlemen shall meet the following requirements unless otherwise specified in the Contract Documents:

- (a) Furnish proof that the shotcrete crew foreman has at least 5 years experience in shotcrete repair work on projects of similar size and character along with 5 references who were responsible for supervision of similar projects. Include name, address and

telephone number of references who will testify to the successful completion of these projects by the shotcrete crew foreman.

- (b) Furnish proof that the nozzle men have successfully completed 3 projects of similar size and character along with 3 references of those responsible for supervision of these projects. The nozzle men shall also pass a test, described in Section 8.3, demonstrating their competence.

1.3 Requirements

1.3.1 The Contractor shall furnish all labor, materials and equipment for the following:

- (a) Removal of all spalled, deteriorated and damaged concrete as detailed in the Contract Documents and directed by the Engineer;
- (b) Cleaning corrosion product from corroded in-place reinforcing steel and *where specified* removing and replacing excessively corroded reinforcing steel with new reinforcement;
- (c) Preparing concrete surfaces to receive shotcrete by either high-pressure water blasting or abrasive grit blasting;
- (d) Installing all new reinforcing steel, mesh and anchors as detailed in the Contract Documents;
- (e) Supply, application, finishing, curing and protection of shotcrete; and
- (f) Provision of a quality control program to ensure compliance of completed shotcrete remedial work with contract documents.

1.3.2 The Contractor shall implement a safety program which shall include but not necessarily be limited to the following:

- (a) Ensuring that the structural integrity of all bridge elements is protected during the repairs by shoring or other suitable means *as specified in the Contract Documents*;

- (b) Protecting all personnel and the traveling public from falling debris, blasting grits and high-pressure water jets during concrete removal processes;
- (c) Protecting all personnel and the traveling public from pneumatically applied shotcrete and rebound materials during the shotcrete application process;
- (d) Ensuring that all employees have training for materials being handled on site and that Material Safety Data Sheets for all materials being used are available on site for inspection and use; and
- (e) Ensuring compliance with all state and Federal OSHA regulations.

2.0 SUBMITTALS

The Contractor shall submit to the Engineer 10 working days before the commencement of production shotcreting work written documentation which provides:

- 2.1** The qualifications of the work crew, including the supervisor, shotcrete nozzlemen, gunmen and blowpipe operators, and the references for the supervisor and nozzlemen required in 1.2.1 (a) and (b).
- 2.2** Test records, showing source and proof of conformance to project specifications of all shotcrete materials, including:
 - (a) Portland cement,
 - (b) Supplementary cementing materials (silica fume, fly ash, ground blast furnace slag),
 - (c) Aggregates,
 - (d) Mix water,
 - (e) Chemical admixtures, and
 - (f) Reinforcement, including welded wire mesh fabric, reinforcing steel, fibers.
- 2.3** Details of proposed shotcrete mixture(s) including shotcrete proportions and means of shotcrete supply.

- 2.4 Results of the preconstruction testing program and a description of the proposed construction quality control testing program, including the frequency of specific tests.
- 2.5 Proposed curing procedures and protection to be provided to shotcrete.
- 2.6 Proposed scaffolding or other temporary support system for workers and inspectors.
- 2.7 Proposed falsework or temporary support system for all bridge elements which undergo loss of strength or support during concrete removal operations. Design criteria for temporary structural support systems shall be as listed in the Contract Documents.

3.0 REFERENCE DOCUMENTS

- 3.1 The documents referenced below form a part of this document only to the extent referenced. In case of conflicts between the referenced portions of these documents and this specification, the requirements of this specification take precedence.

3.1.1 American Concrete Institute (ACI)

ACI 305R	Hot Weather Concreting
ACI 306R	Cold Weather Concreting
ACI 506R	Guide to Shotcrete
ACI 506R.3	Guide to Certification of Shotcrete Nozzlemen
ACI 506.2	Specifications for Materials Proportioning and Application of Shotcrete

3.1.2 American Society for Testing and Materials (ASTM)

ASTM A 185	Specification for Steel Welded Wire Fabric, Plain, for Concrete Reinforcement
ASTM A 385	Practice for Providing High-Quality Zinc Coating (Hot Dip)

ASTM A 615	Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
ASTM A 641	Specification for Zinc-Coated (Galvanized) Carbon Steel Wire
ASTM A 706	Specification for Low-Alloy Steel Deformed Bars for Concrete Reinforcement
ASTM A 767	Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement
ASTM A 775	Specification for Epoxy-Coated Reinforcing Steel Bars
ASTM A 820	Specification for Steel Fibers for Fiber Reinforced Concrete
ASTM C 33	Specification for Concrete Aggregates
ASTM C 39	Test Method for Compressive Strength of Cylindrical Concrete Specimens
ASTM C 42	Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
ASTM C 150	Specification for Portland Cement
ASTM C 260	Specification for Air-Entraining Admixtures for Concrete
ASTM C 387	Standard Specification for Packaged, Dry, Combined Materials for Mortar and Concrete
ASTM C 494	Specification for Chemical Admixtures for Concrete
ASTM C 595M	Specification for Blended Hydraulic Cements
ASTM C 618	Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete

ASTM C 642	Standard Test Method for Specific Gravity, Absorption and Voids in Hardened Concrete
ASTM C 685	Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing
ASTM C 989	Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
ASTM C 1017	Specification for Chemical Admixtures for Use in Producing Flowing Concrete
ASTM C 1116	Standard Specification for Fiber Reinforced Concrete and Shotcrete
ASTM C 1140	Standard Practice for Preparing and Testing Specimens from Shotcrete Test Panels
ASTM C 1202	Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
ASTM C 1240	Specification for Silica Fume for Use in Hydraulic-Cement Concrete and Mortar

3.1.3 American Association of State Highway and Transportation Officials (AASHTO)

AASHTO M 6	Standard Specification for Fine Aggregate for Portland Cement Concrete
AASHTO M 80	Standard Specification for Coarse Aggregate for Portland Cement Concrete
AASHTO M 157	Ready-Mixed Concrete

4.0 MATERIALS

4.1 Cement

4.1.1 Cement shall conform to the requirements of ASTM C 150 or C 595M. Engineer shall select appropriate cement type.

4.2 Supplementary Cementing Materials

4.2.1 *Engineer shall specify* which supplementary cementing materials, if any, are permitted or required for use on project.

4.2.2 Fly ash shall conform to the requirements of ASTM C 618.

4.2.3 Granulated slag shall conform to the requirements of ASTM C 989, Grade 100 or 120, ground granulated blast furnace slag.

4.2.4 Silica fume shall conform to the requirements of ASTM C 1240.

4.3 Water

4.3.1 All water used in shotcrete production, including water added in premoisturizer and at the shotcrete nozzle, shall be of drinking water standard and free of oil and chemical or organic impurities.

4.3.2 Similarly, all water used for high-pressure water blasting, predampening of concrete surfaces prior to application of shotcrete, in blowpipes for removal of rebound and overspray, and for shotcrete curing shall be of drinking water standards and free of oil and chemical or organic impurities.

4.4 Aggregates

4.4.1 Aggregates shall be normal weight aggregates conforming to the requirements of AASHTO M 6 for fine aggregate and AASHTO M 80 for coarse aggregate. Gradation of aggregates shall be as required in the Contract Documents or as approved by the Engineer.

4.5 Admixtures

4.5.1 No admixtures shall be added to the shotcrete *without approval of the Engineer*. In particular any admixtures containing chlorides shall not be used. Shotcrete accelerators shall not be used *without written authorization by the Engineer*.

4.5.2 Air-entraining admixtures shall be added to the mix water *if specified in the Contract Documents*. Air-entraining admixtures shall conform to the requirements of ASTM C 260.

4.6 Reinforcement

4.6.1 Welded wire mesh fabric shall be welded galvanized steel of dimensions and mass specified in drawings and shall conform to ASTM A 185.

4.6.2 New or replacement reinforcing bars shall be installed as detailed in the Contract Documents. Reinforcing bars shall conform to ASTM A 615, A 706, A 767, or A 775.

4.6.3 Inserts for attachment of welded wire mesh fabric to existing concrete shall be galvanized in accordance with ASTM A 385 and A 641, and be of adequate length and strength to resist a 10-kN pull-out force.

4.6.4 Fibers shall conform to the requirements of ASTM C 1116. Fiber type, length and addition rate shall be as *specified in the Contract Documents*.

4.7 Materials Handling and Storage

4.7.1 Portland cement and supplementary cementing materials shall be stored so as to be protected from exposure to moisture and temperatures below 5 degrees C and above 30 degrees C.

4.7.2 All admixtures shall be maintained at temperatures above 5 degrees C and below 30 degrees C at all times.

4.7.3 Aggregates used in site batching of shotcrete shall be stockpiled and handled so as to prevent segregation, and shall be maintained in a 3 to 7 percent moisture content range. Shelters or tarpaulins shall be used to protect the aggregate stockpiles during periods of wet weather.

4.7.4 Fiber shall be stored in dry, sealed containers until ready for batching and shall be free from corrosion, oil, grease or other contaminants.

5.0 SHOTCRETE PROPORTIONING

5.1 Mixture Design

5.1.1 The Contractor shall be responsible for shotcrete mixture proportioning and shall submit the proposed shotcrete mixture proportions *to the Engineer for review and approval* 10 working days prior to application of production shotcrete. As a minimum,

for each shotcrete mixture design the following information shall be submitted:

- (a) An easily identifiable mix designation, number or code;
- (b) Batch quantities of fine aggregate, coarse aggregate, cement, supplementary cementing material, expected water demand (to include all water from moisture in aggregates, and water added in premoisturizer and at nozzle) and all other shotcrete ingredients, in kg/m^3 , based on saturated surface dry aggregates; and
- (c) Aggregate source, gradation, relative bulk density (specific gravity) and absorption.

5.1.2 Allowance shall be made for the shooting orientation and rebound in shotcrete mixture proportioning.

5.1.3 Shotcrete shall be proportioned to meet the performance requirements detailed in the project drawings and Section 5.3.

5.1.4 The Contractor shall submit performance test data from previous experience, if available, along with the shotcrete mixture proportions *for review by the Engineer*.

5.1.5 In the absence of suitable shotcrete mixture proportioning experience, the Contractor shall use the nominal trial mixture proportions detailed in Section 5 of the Commentary section of this Guide Specification. Adoption of these nominal trial mixture proportions shall not relieve the Contractor of responsibility for meeting the performance requirements detailed in the Contract Documents.

5.2 Silica Fume Shotcrete

5.2.1 The silica fume content of silica fume shotcrete shall be between 5 and 15 percent by mass of cement content or as *specified in the Contract Documents*.

5.2.2 Silica fume shall be supplied and added to the mixture in either a slurry; loose, uncompacted; or partially compacted form. Densely compacted silica fume shall not be used.

5.3 Performance Requirements

5.3.1 Shotcrete shall conform to the performance requirements in Table 1.

TABLE 1
Dry-Mix Shotcrete Performance Requirements

Test Description	Test Method	Age (Days)	Specified Requirement
Min. Compressive Strength, MPa (f'_c)	ASTM C 39 ASTM C 42	7 28	28 35
Max. Boiled Absorption, % Max. Vol. of Permeable Voids, %	ASTM C 642	7 7	8 17
Max. Rapid Chloride Permeability, Silica-Fume Shotcrete, Coulombs	ASTM C 1202	7	1500

5.3.2 For dry-mix shotcretes other than silica-fume shotcrete, *the Contract Documents shall establish* maximum permissible rapid chloride permeability coulomb limits.

6.0 SUPPLY AND EQUIPMENT

6.1 Batching, Mixing and Supply

6.1.1 Dry-mix shotcrete shall be batched, mixed and supplied by one of the following methods:

- (a) Dry-bagged premix material supplied in either small bags (30 kg typical) or large synthetic cloth bulk bin bags (1600 kg typical),
- (b) Site batching, using either volume or mass batching subject to *written approval by the Engineer* of the proposed batching equipment.

6.1.2 The use of mobile volumetric batcher units shall be permitted, provided such units are properly calibrated in accordance with ASTM C 685.

6.1.3 The use of central or transit mix batched and transit mix supplied dry-mix shotcrete shall not be permitted unless the Contractor can demonstrate satisfactory conformance to all the project performance requirements.

6.1.4 All dry-mix shotcrete shall be shot within 45 minutes of the time that moisture (either from damp sand or the premoisturizer) comes into contact with the cementitious materials.

6.1.5 When using volume batching, proportions shall be verified *at the frequency specified in the Contract Documents*, using a mass batching check. The minimum checking frequency shall be at the beginning of the work and at least once a week thereafter.

6.1.6 Dry-bagged premixed shotcrete materials shall be produced in conformance with the pertinent requirements of ASTM C 387. In particular, all aggregates shall be dried to a moisture content of less than 0.1 percent by mass, based on oven drying at 105 to 110 degrees C.

6.1.7 Dry-bagged premixed shotcrete materials shall be protected from moisture during handling, transport and storage. Any bags which display lumps of pre-hydrated shotcrete shall not be used on the project.

6.1.8 Dry-bagged premixed shotcrete materials shall be maintained in a temperature range of 5 to 30 degrees C during storage and application. Frozen material shall not be used.

6.2 Shotcrete Placing Equipment

6.2.1 Shotcrete batching, mixing and supply equipment shall be capable of combining the dry-mix shotcrete materials into a uniform mixture and discharging it without segregation.

6.2.2 Dry-bagged premixed shotcrete materials shall be predampened to provide a consistent moisture content in the range of 3 to 5 percent by mass in a predampener, prior to discharge into the shotcrete gun. Discharge of completely dry materials into the shotcrete gun shall not be permitted, unless satisfactory performance is demonstrated in the test panel.

6.2.3 Similarly, for site-mixed materials, if the moisture content in the sand is too low to provide a moisture content of the mixed shotcrete materials in the range of 3 to 5 percent, then the shotcrete shall be predampened in a predampener, prior to discharge into the shotcrete gun.

6.2.4 The mixing and predampening units shall be capable of producing a shotcrete mixture with a uniform moisture content,

such that the nozzleman is not required to repeatedly adjust the water content at the nozzle water ring.

6.2.5 The delivery equipment (gun) shall be capable of discharging a continuous, smooth stream of uniformly mixed material into the delivery hose.

6.2.6 The discharge nozzle shall be equipped with a manually operated water injection system (water ring) for directing an even distribution of water through the mixture. The water valve shall be capable of ready adjustment to vary the quantity of water and shall be convenient to the nozzleman.

6.2.7 The water pressure at the discharge nozzle shall be sufficiently greater than the operating air pressure so that the water is intimately mixed with the predampened shotcrete materials. If the line water pressure is inadequate, a water booster pump shall be introduced into the water line to provide a steady, non-pulsating water pressure. Water heaters shall be provided during cold weather if required to produce shotcrete at a suitable temperature.

6.2.8 The water ring shall be carefully monitored for any signs of blockage of individual water spray holes. If non-uniform wetting of discharged shotcrete becomes apparent, shooting shall be stopped, and the water ring cleaned or other appropriate corrective actions taken.

6.2.9 The delivery equipment shall be thoroughly cleaned at the end of each shift. Any build-up of coatings in the delivery hose and nozzle liner shall be removed. The water ring and nozzle shall be regularly inspected and replaced as required.

6.3 Auxiliary Shotcrete Equipment

6.3.1 The Contractor shall supply a clean, dry air supply, capable of maintaining sufficient nozzle velocity for all parts of the work and simultaneous operation of a blowpipe and, if pneumatically operated, the predampener.

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

6.3.3 Auxiliary shotcrete equipment such as delivery hose, water hose, water booster pumps, blowpipes, couplings, admixture dispensers and fiber feeders shall conform to the recommendations in Section 3.8 of ACI 506R.

7.0 PREPARATION FOR SHOTCRETING

7.1 Concrete Removal and Preparation

7.1.1 The Contractor, *at the direction of the Engineer*, shall locate and remove all loose, spalled, deteriorated and delaminated concrete. Sounding shall be used to locate delaminated areas. Care shall be exercised not to damage areas of sound concrete or reinforcing steel during concrete removal operations. Unless specifically *directed by the Engineer*, depth of removal shall not exceed 150 mm. Concrete removal shall be in accordance with a sequence approved by the Engineer.

7.1.2 Concrete removal shall be accomplished using one or more of the following methods:

- a) Chipping with hand picks, chisels or light-duty pneumatic or electric chipping hammers (not to exceed 7 kg mass);
- b) Scarifiers, scabblers or other suitable mechanical means; and/or
- c) High-pressure (100 to 275 MPa) water jetting.

7.1.3 If sound concrete is encountered before existing reinforcing steel is exposed, the surface shall be prepared and repaired without further removal of the concrete. When corroded reinforcing steel is exposed, concrete removal shall continue until there is a minimum 20-mm clearance around the exposed, corroded reinforcing bar. Care shall be taken to not damage bond to adjacent non-exposed reinforcing steel during concrete removal processes.

7.1.4 The perimeter of all areas where concrete is removed shall be tapered at an approximately 45-degree angle, except that the outer edges of all chipped areas shall be sawcut to minimum depth of 15 mm to prevent featheredging unless otherwise approved by the Engineer.

7.1.5 After all deteriorated concrete has been removed, the repair surface to receive shotcrete shall be prepared by abrasive blast cleaning or high-pressure (100 to 275 MPa) water jetting. The repair surface shall have an adequate surface roughness

determined as three peak-to-valley measurements of 5 mm within 150 mm.

7.1.6 Abrasive blast cleaning or high-pressure water jetting shall remove all fractured surface concrete and all traces of any unsound material or contaminants such as oil, grease, dirt, slurry, or any materials which could interfere with the bond of freshly placed shotcrete. Cleaned areas shall have shotcrete applied within 48 hours or shall be reblasted.

7.1.7 The requirement for abrasive blast cleaning or high-pressure water jetting may be waived by *the Engineer* where concrete removal has been performed with high-pressure water blasting and the prepared surface is free of any residual slurry or other material detrimental to adequate shotcrete bond.

7.1.8 Unless otherwise *specified in the Contract Documents*, all material removed shall become the property of the Contractor and shall be disposed of as approved by the Engineer.

7.2 Reinforcement

7.2.1 All corroded reinforcing steel exposed during concrete removal shall have corrosion products removed by abrasive grit blasting. The exposed reinforcing steel surface that is facing away from the sandblast nozzle shall be cleaned to remove all dust and loose particles.

7.2.2 Reinforcing steel displaying deep pitting or loss of more than 20 percent of cross-sectional area or as *specified in the Contract Documents* shall be removed and replaced or augmented with additional reinforcement, as *detailed in the Contract Documents*.

7.2.3 In cases of isolated pitting, the existing reinforcing steel need not be cut, but shall be reinforced by addition of appropriately placed reinforcing bar of suitable length as *detailed in the Contract Documents*.

7.2.4 The minimum lap splice length of all replacement and new reinforcing steel shall be as *detailed in the Contract Documents*. Such bars shall be placed in accordance with the recommendations of ACI 506R, Sections 5.4 and 5.5. In particular, bars shall not be bundled in lapped splices, but shall be placed such that the minimum spacing around each bar is three times the maximum aggregate size or 20 mm, whichever is larger, to allow for proper encapsulation with shotcrete.