SHOTCRETE SPECIFICATIONS

An Introduction to the Shotcrete Process

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American Shotcrete Association

The American Shotcrete Association is a non-profit organization of contractors, manufacturers, engineers, owners, and others with a common interest in promoting the use of shotcrete. Formed in March, 1998, the first Board of Directors was elected in October of that year.

The **Vision** of the American Shotcrete Association is *"that the shotcrete process be understood and used in every beneficial application"*.

The **Mission** of the ASA is *"to encourage and promote the safe and beneficial use of the shotcrete process"*.

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Seminar Content

- Definition of Shotcrete
- Shotcrete Processes
- Shotcrete Applications
- The Shotcrete Specification
  - *Environmental conditions*
  - *Surface Preparation*
  - *Reinforcement*
  - *Shotcrete Mix Components*
  - *Quality Assurance*
  - *Shotcrete Application*
  - *Finishing and Curing*
  - *ACI Nozzleman Certification*
- Useful Tools and Resources

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Shotcrete - Definition

"Concrete placed by a high velocity pneumatic projection from a nozzle."

As defined in ACI CT-13 *Concrete Terminology*

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Shotcrete is not a product…

…It is simply a method of placing concrete

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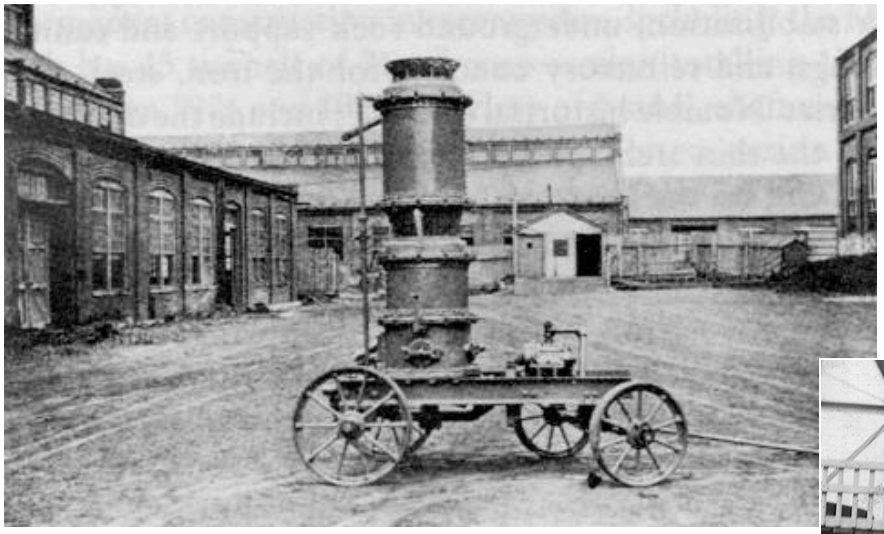
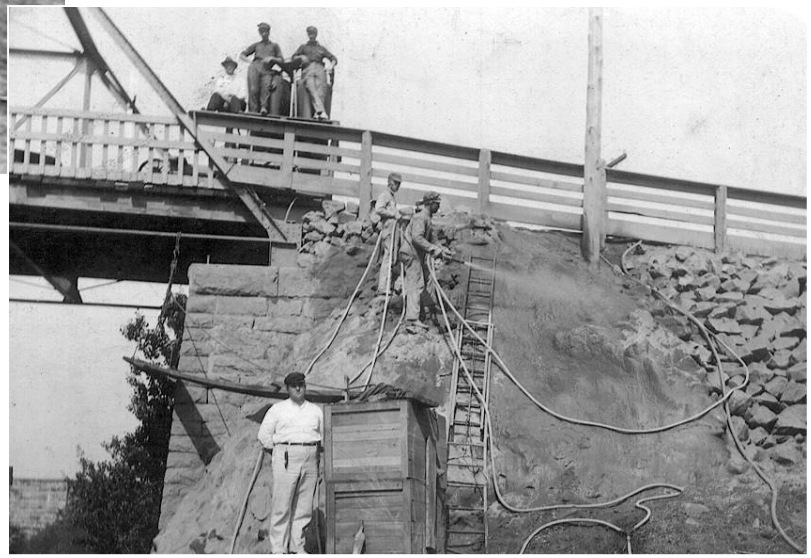
History of Shotcrete



Carl Akeley
Original Shotcrete Gun
1907



Dry-Mix Shotcrete
1920's

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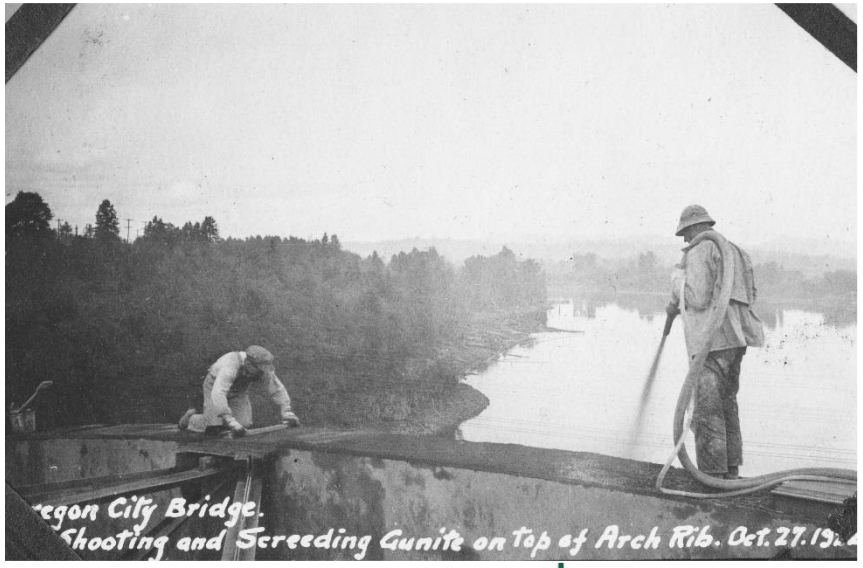
History of Shotcrete

Dual chamber
Shotcrete gun 1922



Dry-mix shotcrete
1922

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History of Shotcrete

Dry-mix shotcrete
Today

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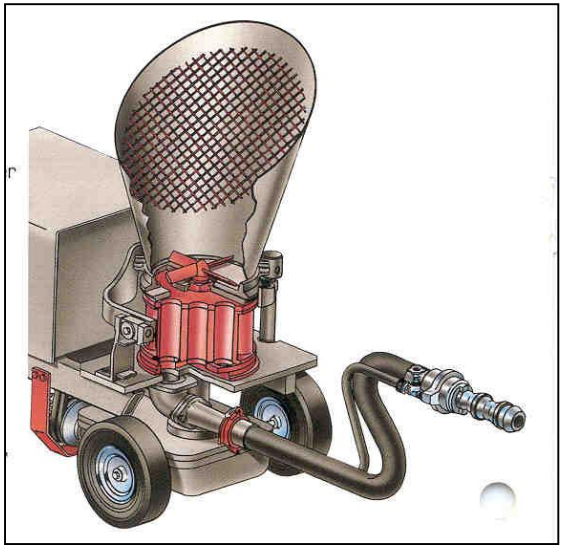
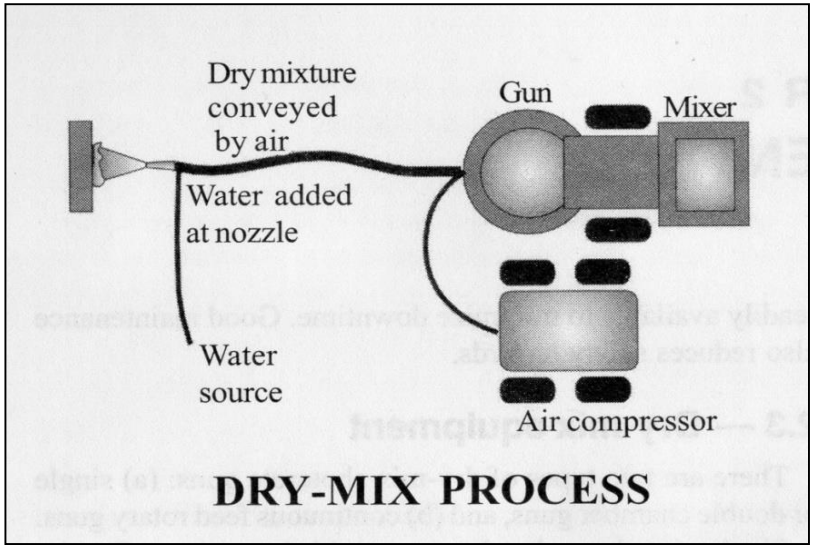
Processes

Dry-mix shotcrete process

The dry concrete mixture is conveyed through a hose in an air stream at high velocity. Water is added at the nozzle to produce plastic material on impact. Mixing of water and the dry material occurs at the nozzle and on the receiving surface.





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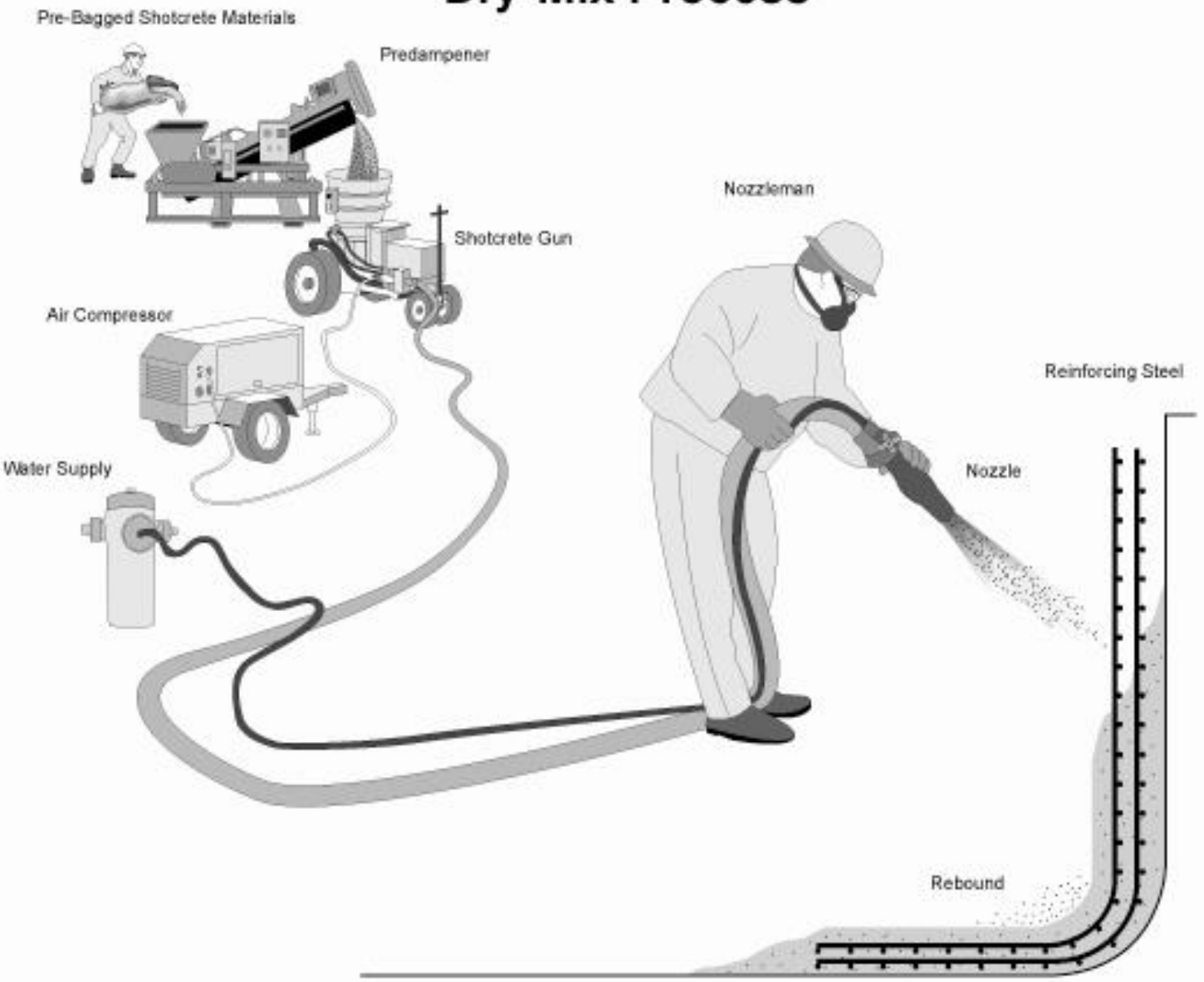
Dry-Mix Process



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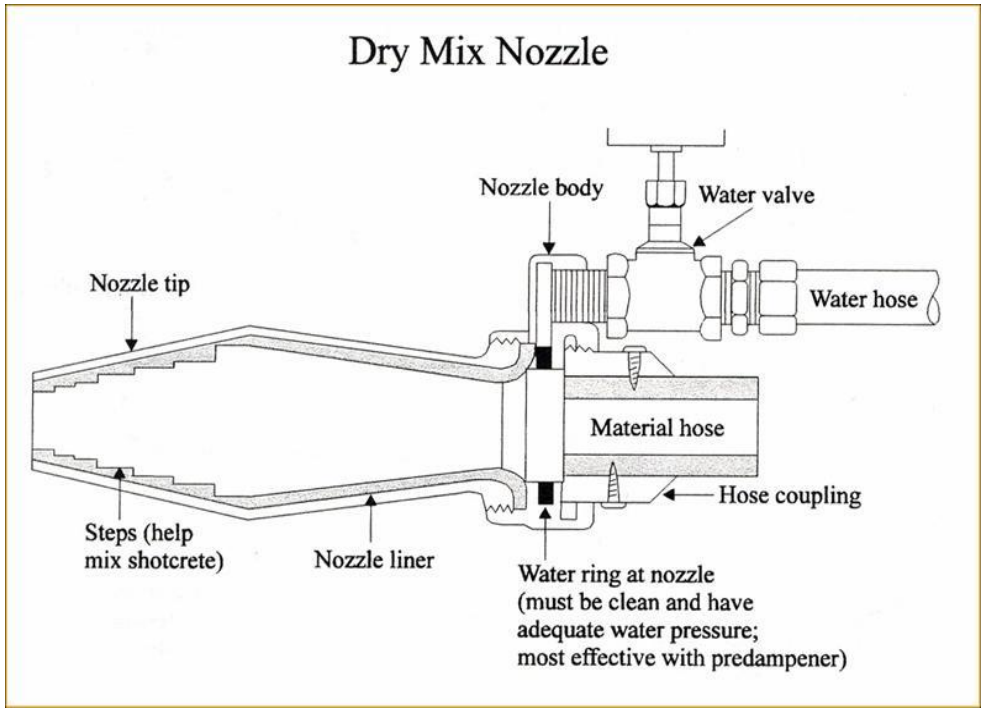
Dry-Mix Nozzle Cross Section



Dry Mix Nozzle tips help with the material mixing.

Removable tips increase the material velocity.

Tip lengths and shapes will change the material spray pattern.

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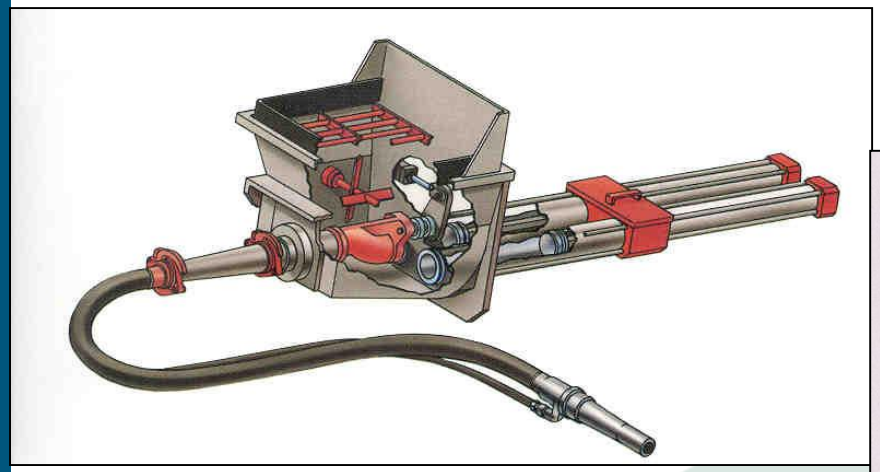
Processes

Wet-mix shotcrete process

The concrete is pumped through a hose and air is added at the nozzle to accelerate the mixture to a high velocity.



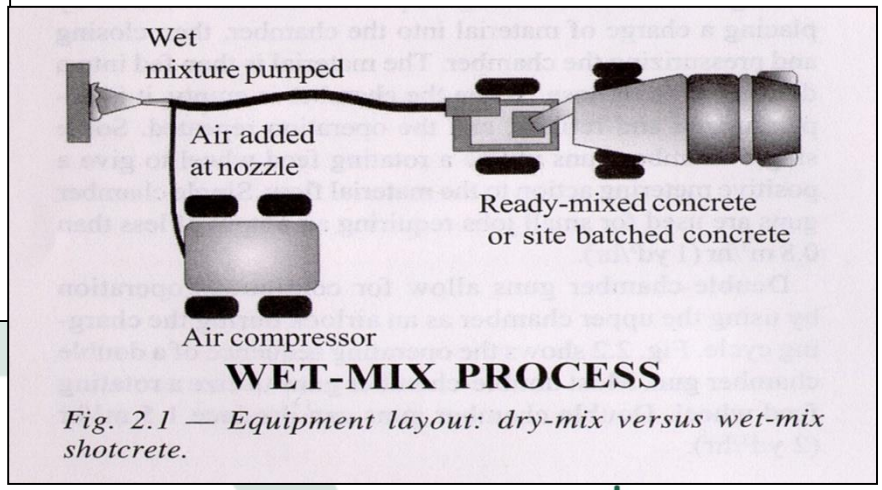


Fig. 2.1 — Equipment layout: dry-mix versus wet-mix shotcrete.

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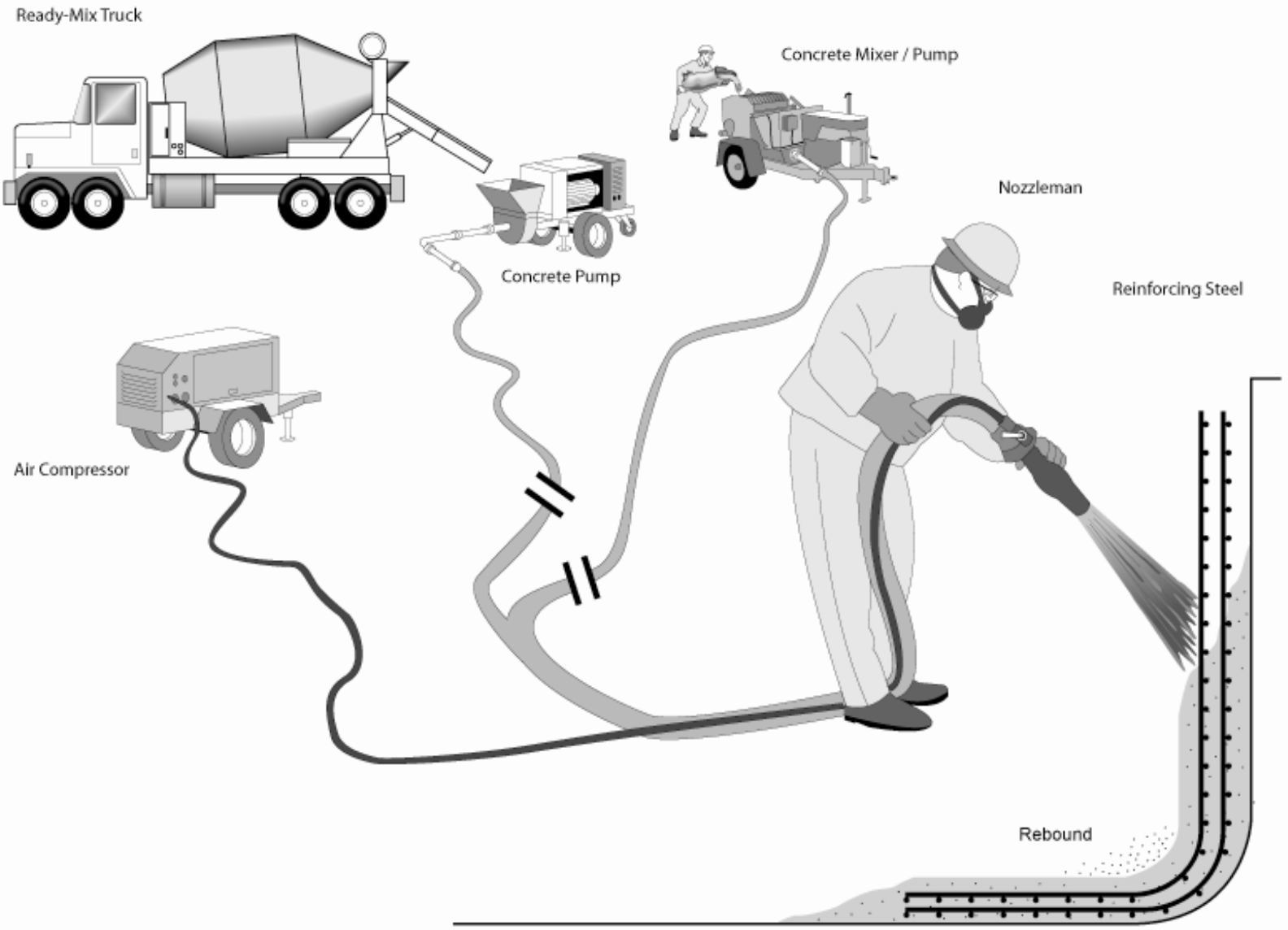
Wet-Mix Process



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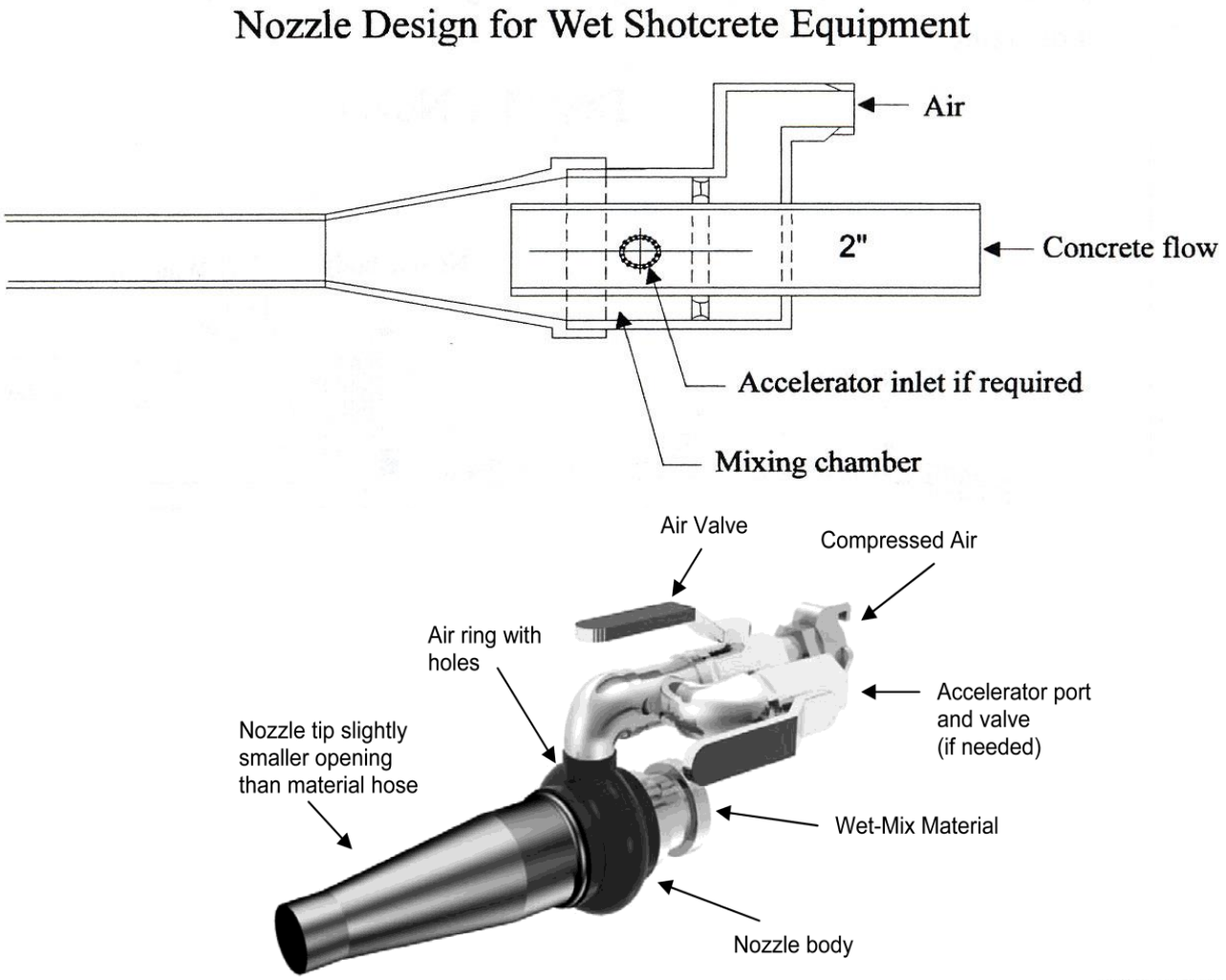
Wet-Mix Shotcrete Nozzle



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Dry vs Wet Process?

Specifications should be performance based and left to the choice of the contractor

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Uses of Shotcrete

Structural rehabilitation

- Buildings, parking structures, historic

Uses of Shotcrete

Infrastructure rehabilitation

- Bridges, tunnels, underground etc.

Uses of Shotcrete

Infrastructure rehabilitation

- Dams and hydraulic structures (water reservoirs, canals, spillways, locks, creek stabilization, etc.)

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Uses of Shotcrete

Infrastructure rehabilitation

- Marine structures (piers, wharves, sea walls, light stations, berth faces, dry docks, etc.)

Uses of Shotcrete

Infrastructure rehabilitation

- Strengthening and seismic retrofit

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Tunnel Enlargement

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Underground Subway Stations

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Slope Stabilization

- Rock Slope Stabilization
- Earth Embankments
- Creek Channelization
- Containment Beams

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Tunnel Portal

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Soil Nailed Slope

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Bridge Repair

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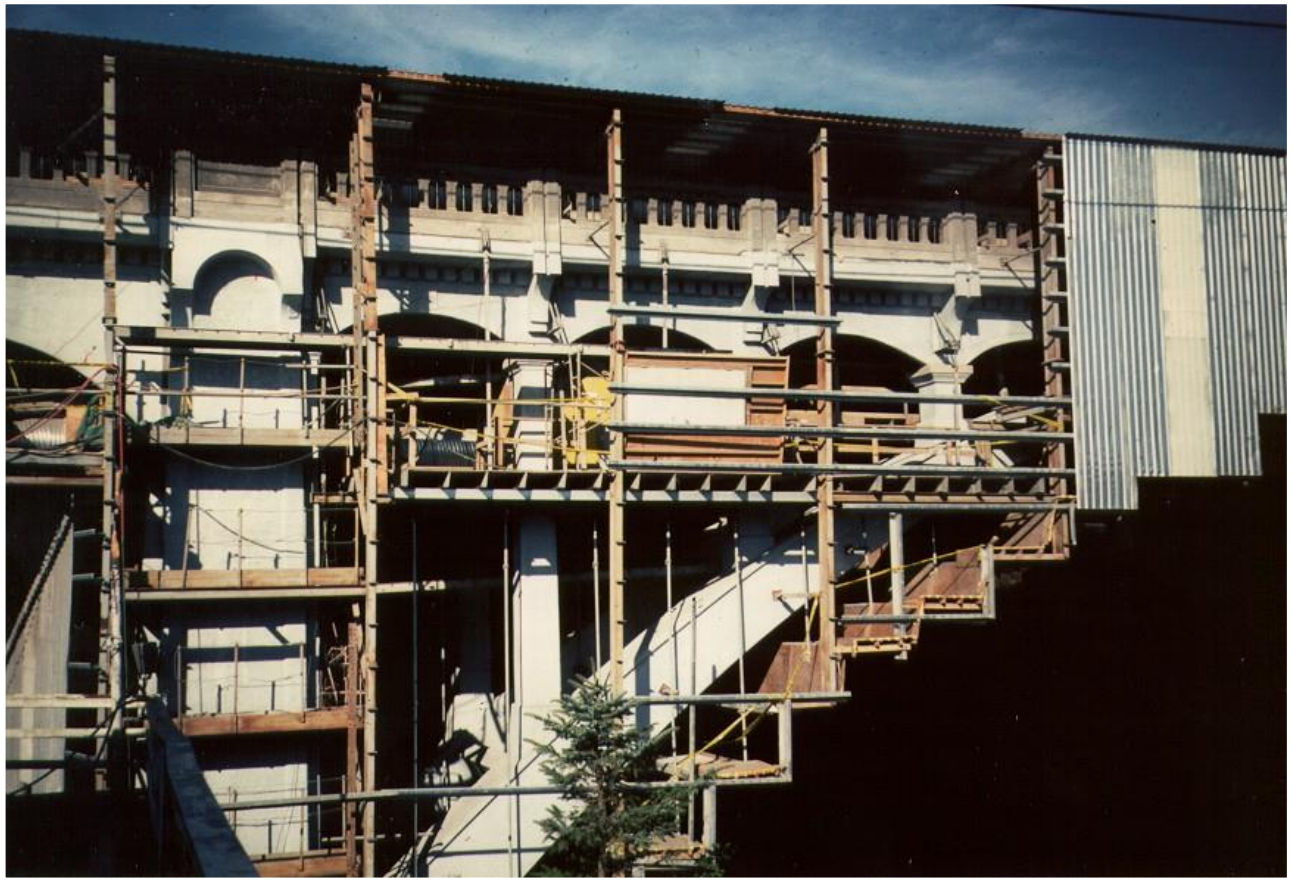
Bridge Reconstruction



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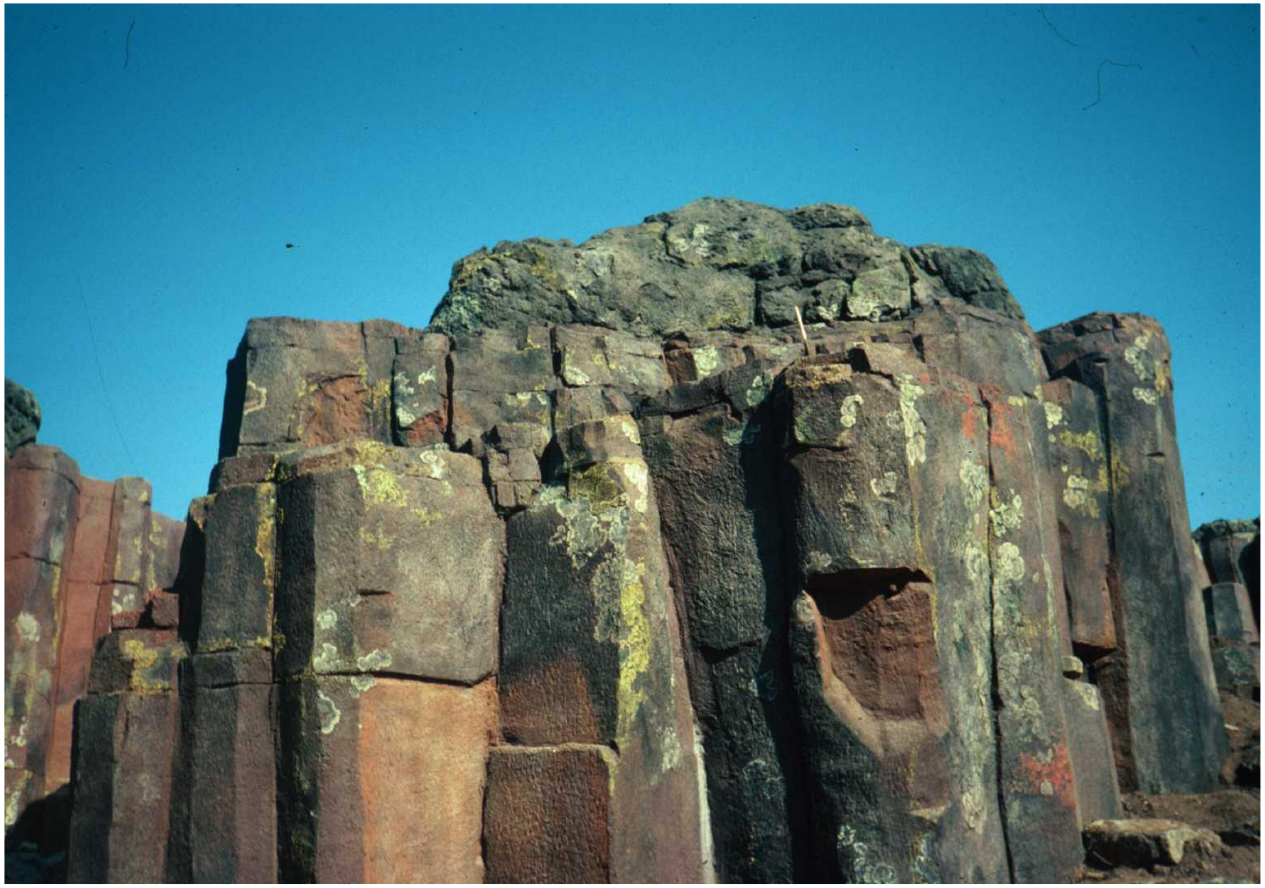
Zoo Exhibit – Simulated Rock



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The Shotcrete Specification

The Key to a Successful Project

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Environmental Conditions

Cold weather – Follow ACI 306R (Cold Weather Concreting)

- Do not apply shotcrete if air temperature is 40°F (5°C) and falling unless protective measures taken
- Do not apply shotcrete on frozen surfaces
- Keep mix temperature above 50°F (10°C)
- Protect shotcrete from freezing until it has reached at least 500 psi (4 MPa) in compressive strength
- Use warm mix water

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Environmental Conditions

Hot weather (Follow ACI 305R Hot Weather Concreting)

- Keep shotcrete mix temperature as low as possible
- Do not apply shotcrete when ambient temperature above 100°F (38°C) unless precautions taken
- Use cool water in mixture
- Use shades where possible
- Use fogging / misting for cooling and controlling evaporation

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Environmental Conditions

Wind

- Do not apply shotcrete during high wind conditions
- Provide protective barriers
- Causes separation of fines in nozzle stream
- Causes high rates of evaporation
- Can cause plastic shrinkage cracking

Environmental Conditions

- Rain
  - Do not apply shotcrete if during heavy rain or if heavy rain is forecast
  - Do not apply shotcrete onto surfaces with ponded or running water
  - Use tarpaulins / tents to protect from rain

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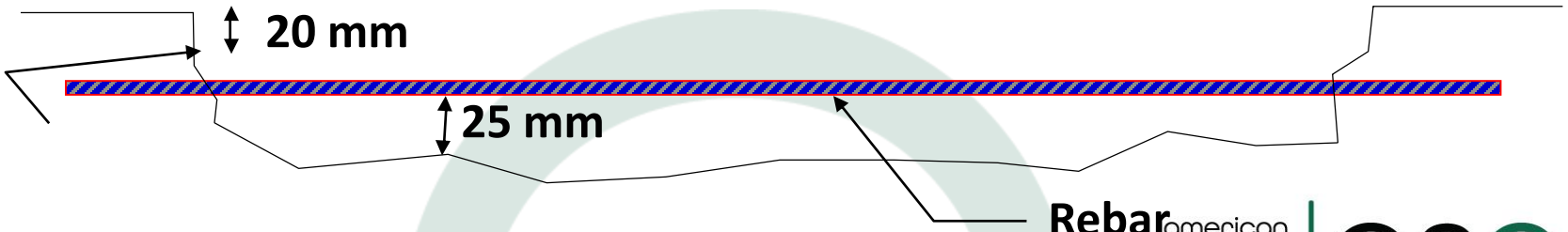
Preparation of Existing Structure

- Concrete Removal
- Saw cut the edge of the repair area at a minimum depth of ¾” (20 mm)
- Avoid feather-edging!
- Remove any loose or unsound concrete
- Maintain a minimum clearance of 1” (25 mm) behind exposed reinforcing steel.



Preparation of Existing Structure

- Immediately before shotcrete application:
- Pressure wash concrete surface
- Ensure all loose debris, dust etc is removed
- Bring surface to saturated, surface dry condition (SSD)

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Preparation of Existing Structure

- Bonding agents are ***never*** recommended for wet or dry mix shotcrete applications
- The nature of the shotcrete process ensures excellent bond to properly prepared SSD substrate
- Bonding agents ***will*** create a “bond breaker” at the interface between the shotcrete and the substrate and ***will*** lead to bond failure

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Formwork

- One-sided forms may be used to provide gunning surface
- Ensure formwork is stable and properly braced
- Apply form release agents to strippable formwork
- Ensure formwork is clean and free of debris (overspray/rebound)

Reinforcement

- Ensure that bars are properly anchored to prevent movement or vibration during shooting
- Wire mesh may be used to minimize cracking due to drying shrinkage

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Alignment Control

- Use alignment control devices to establish line and grade. Devices include:
  - *Ground wires (piano wire)*
  - *Pencil rods (1/4” high tension pre-stressing steel) for curved profiles*
  - *Depth gages*
  - *Guide strips/formwork*

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Alignment Control

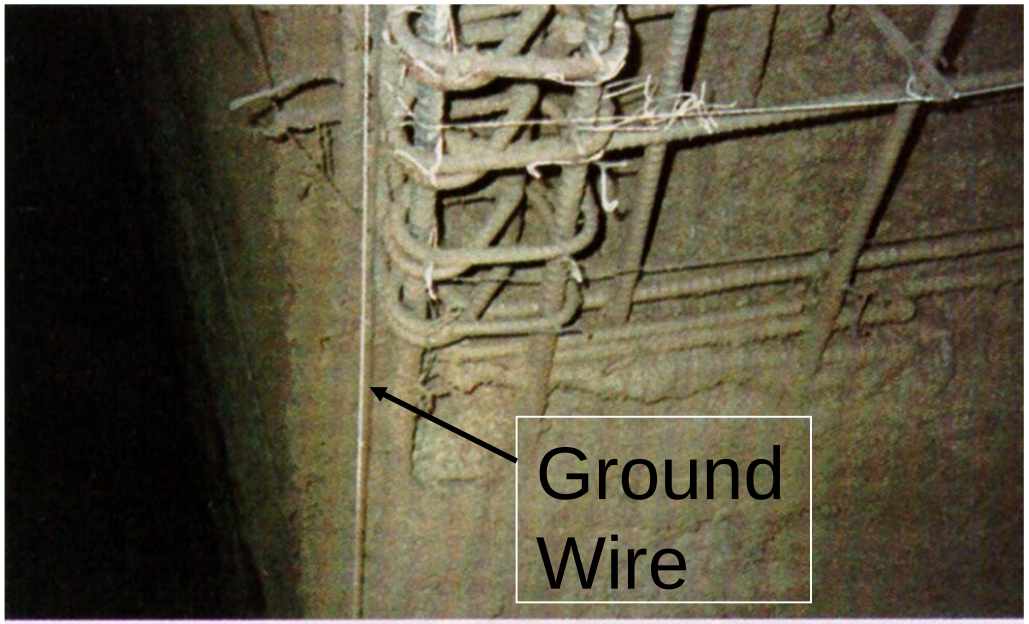

Figure 2: Ground wire delineates finish of a corner without restriction of nozzle trajectory.

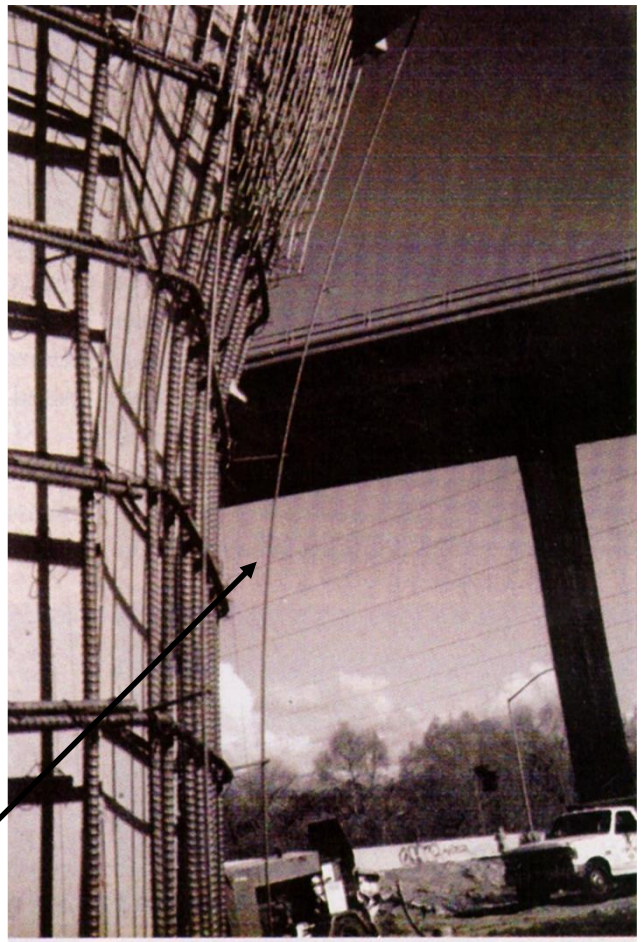

Figure 3: Small diameter steel rod delineates final curvature contour of a bridge pier.

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Typical Shotcrete Mixture

- Cement (Type I II or III) 17 - 20%
- Silica Fume 1.5 - 8%
- Water Reducing Admixtures Wet mix only
- Blended Aggregates 75 – 80% (ACI Gradation No. 1 or 2)
- Air-entraining admixture* To provide maximum spacing factor of 300 µm
- Synthetic Fibers* 1.7-3.4 lbs/yd^3
- Steel Fibers* 65-115 lbs/yd^3
- *Project specific

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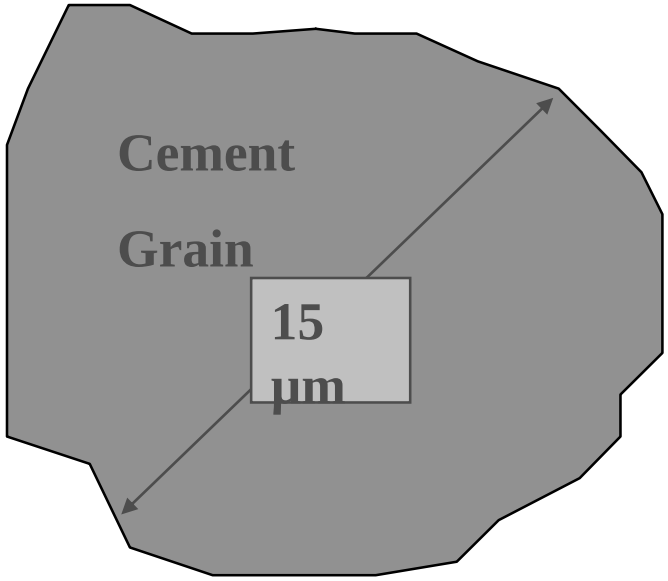
Cementing Materials

- Cement should be type I, II or III and should conform to ASTM C 150
- Cement will vary by geographical region and will affect properties such as set time and water demand.
- Water/Cementitious material ratio should range between 0.30 to 0.45.

Silica Fume

- **Silica fume is a byproduct of producing silicon metal or ferrosilicon alloys.**
- **Round particle (100-200× smaller than Portland cement)**
- **High SiO_2 content**



Silica Fume

0.1 µm

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Benefits of Silica Fume
Plastic Properties

- Improves adhesion
- Increases cohesive properties of shotcrete mixes
- Improves build up before sloughing
- Reduces rebound
- Improves wash-out resistance

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Benefits of Silica Fume

Hardened Properties

- Provides higher compressive & flexural strengths
- Reduces porosity (permeability) - Improves durability
- Improves resistance against alkali aggregate reactivity
- Improves resistance to sulfate & chemical attack
- Reduces chloride ion penetration - Reduces corrosion of embedded reinforcing steel

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Benefits of Fly Ash
Plastic Properties

- Easier to pump
- Slower reaction and set time –
  - good in hot weather
  - Not in cold weather

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Benefits of Fly Ash
Hardened Properties

- Reduces porosity (permeability) - Improves durability
- Improves resistance against alkali silica reactivity (ASR)
- Improves resistance to sulfate & chemical attack
- Higher long-term compressive strength

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Set Accelerators

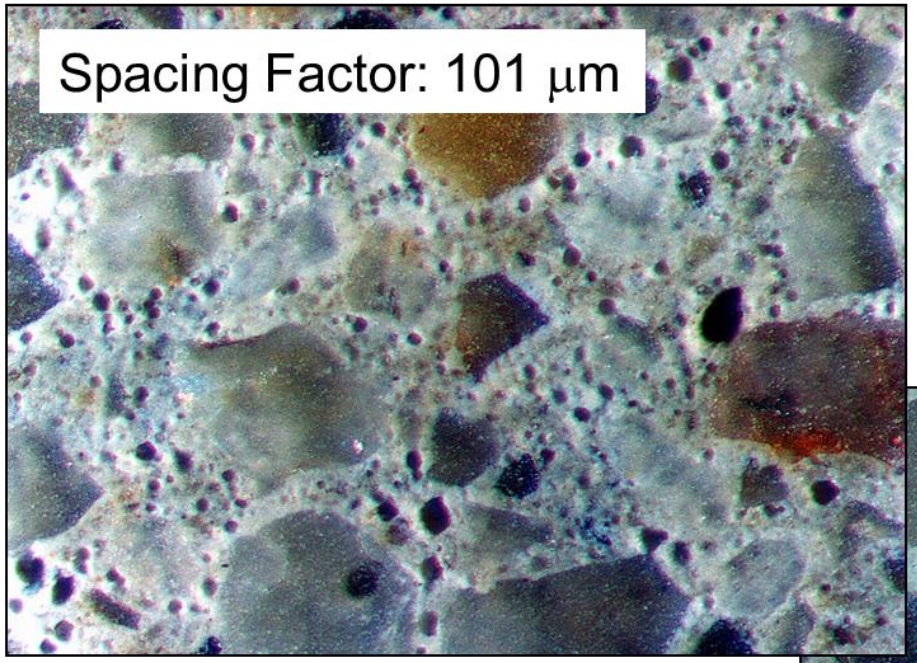
- Improve ability to build thicker applications in a single pass (in wet areas, increases productivity)

- Reduces set time and develops higher, early age compressive strength (Open areas to traffic quicker – bridges, parking decks, subways)

- Accelerator MUST be added using controlled dosing methods. Too much accelerator is detrimental to quality of the concrete!

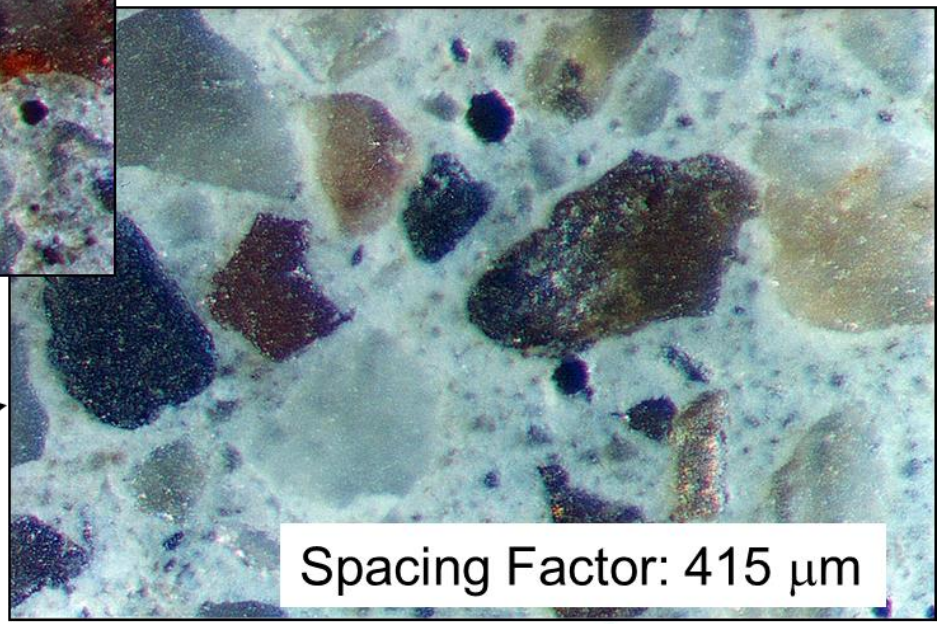
Air Entraining Admixtures

Dry-Mix Shotcrete



Air Entrained

Non-Air Entrained



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Air-entrained (300 cycles)

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Not Air-Entrained (300 cycles)

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Synthetic Fibers

- Micro Fiber
  - *Dosage rate of 1 to 3 lbs/yd^3 (0.6-1.8 kg/m^3) as recommended by manufacturer*
  - *May be added to reduce the possibility of early-age shrinkage cracking (plastic shrinkage)*
- Macro Fiber
  - *Dosage rate of 3 to12 lbs/yd^3 (1.8-7.2 kg/m^3)*
  - *May be added to reduce the possibility of shrinkage cracking (plastic shrinkage)*
  - *May be added to increase toughness and energy absorption*

Steel Fibers

- Steel Fiber
  - *Dosage rate of 60-100 lbs/yd^3 (40-60 kg/m^3) as recommended by manufacturer*
  - *Should not be used in conjunction with wire mesh*
  - *May be added to reduce the possibility of shrinkage cracking*
  - *May be added to increase toughness and energy absorption*

Aggregates

ASTM C 33

All normal weight aggregates used in shotcrete mix designs should comply with ASTM C 33

ACI Gradations

The combined aggregates should meet one of the following gradations specified by ACI.

- Gradation No. 1 - Fine aggregate shotcrete 1/4” maximum aggregate size
- Gradation No. 2 - Fine and coarse aggregate 3/8” maximum aggregate size

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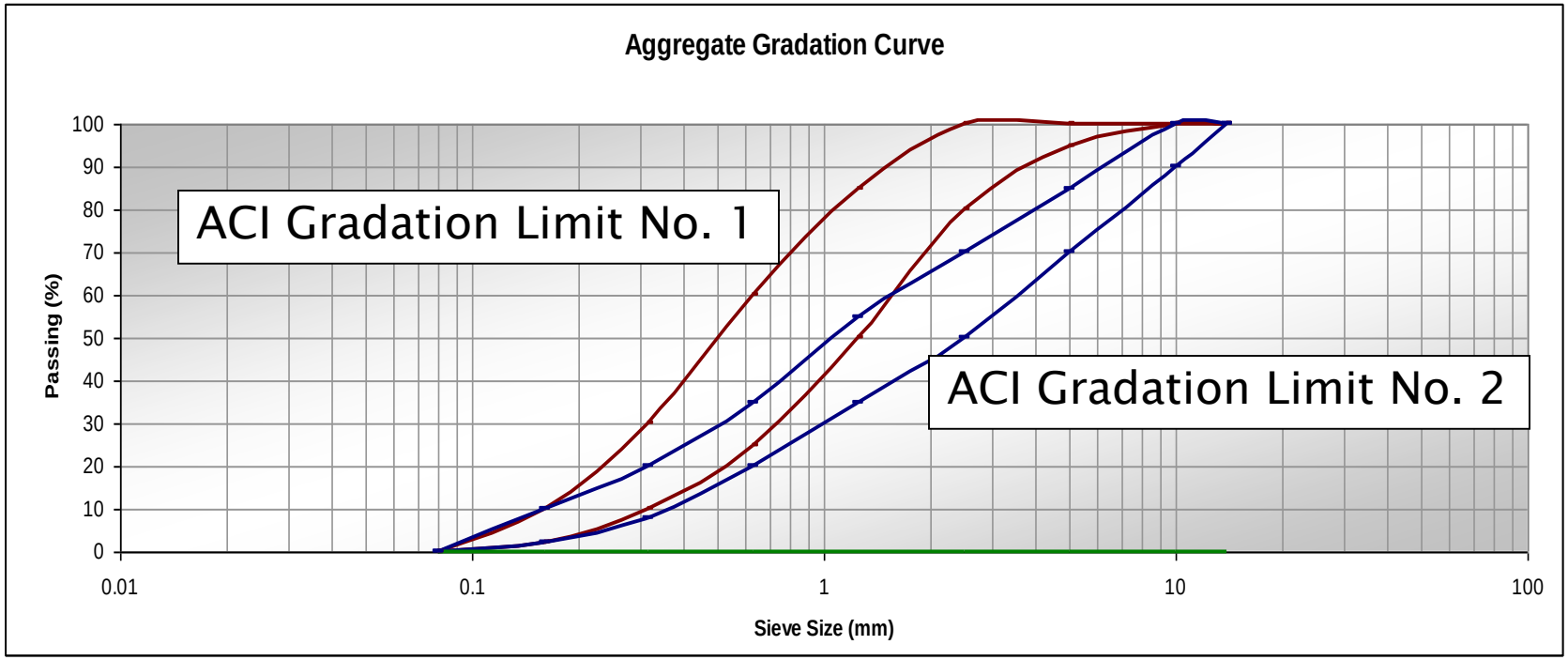
Aggregates

ACI 506R – Guide to Shotcrete - Gradation No. 1 and 2



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Fiber Reinforcement

- Monofilament Micro-Synthetic Fibers – Typically used in repair applications to minimize cracking due to drying shrinkage
- Steel Fibers - Typically used in mining, tunnelling and rock slope stabilization applications to improve flexural toughness, impact resistance and ductility
- Monofilament Macro-Synthetic Fibers - A new generation of fibers that provide the same hardened properties (flexural toughness and energy absorption) as steel fibers.

Quality Assurance (QA)
Quality Control (QC)

- Shotcrete acceptance/rejection criteria
  - Plastic shotcrete
    - Age, temperature and setting time
    - Sags, sloughing, tears
    - Reinforcing encapsulation
    - Line, grade and cover
    - Finish and tolerance

Quality Assurance (QA)
Quality Control (QC)

- Shotcrete acceptance/rejection criteria
  - Hardened shotcrete
    - Compressive strength (cores from panels)
    - Flexural strength (beams)
    - Toughness (circular panls)
    - Premeability (boiled absorption)

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Application of Shotcrete

Guidelines in ACI 506R-05 “Guide to Shotcrete”

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Good Shooting Practices

Shooting edges of the repair area and working towards the center, to prevent trapping rebound in the corners.

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Good Shooting Practices

The shotcrete on this pier was gunned in place in one day. The shotcrete easily conforms to the round contour of the pier where forming would have been extremely expensive.

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Finishing Shotcrete

- Finishing operations are usually done because of Aesthetics or Technical reasons:
  - Smooth surface: flow characteristics, etc
  - Rough surface: bond of further layer, etc
- Finishing operations have an impact on cost depending on the requested flatness and smoothness

Types of Shotcrete Finish

Examples

- Natural or gun finish
- Cut
- Broom or brush finish
- Sponge finish
- Floated or troweled
- Carved
- Textured
- Exposed aggregate
- Painted & Stained

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Typical Float Finish

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Types of Finish

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Sponge Finish

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Completed Shotcrete Piers

Match existing contours
without expensive formwork

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Curing Shotcrete

- Curing is required to fully hydrate cement and increase strength
- Hydration will stop quickly if internal concrete moisture drops below 80%
- Curing ***MUST*** start immediately in hot, dry or windy conditions: use fogging/misting devices

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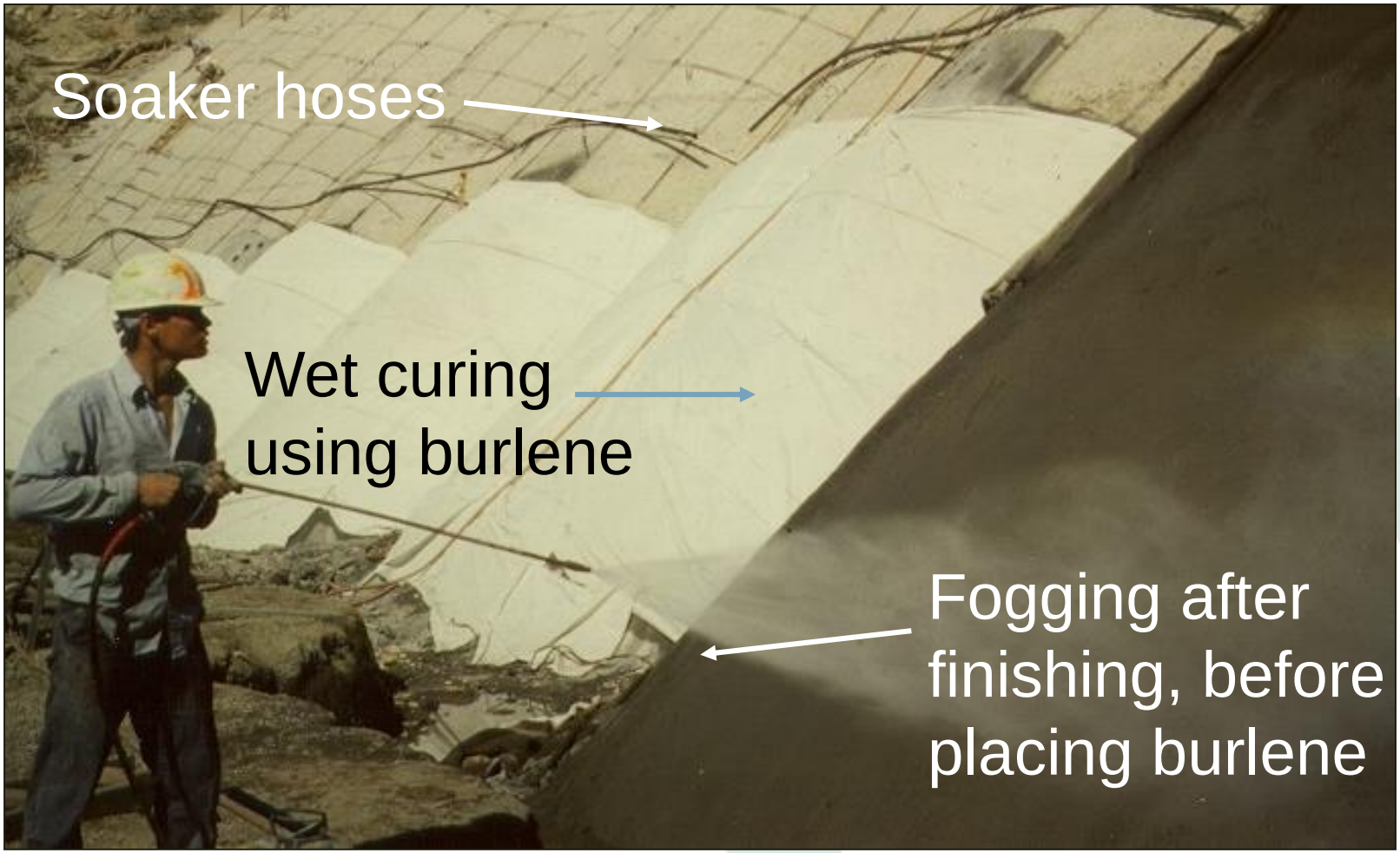
Proper Curing Practices



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Curing Compounds

- Alternative when wet curing is not practical
- Reduces evaporation, but does not compensate for moisture loss
- Curing compound must be removed before application of subsequent layers of shotcrete
- 2X the rate

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Benefits of Pre-blended Materials

- Allows homogeneous blending of raw materials of varying densities (silica fume & cement)
- Improved distribution of fibers (when applicable)
- Improved air entrainment properties
  - *Air content, Air Void Distribution, Spacing Factor*

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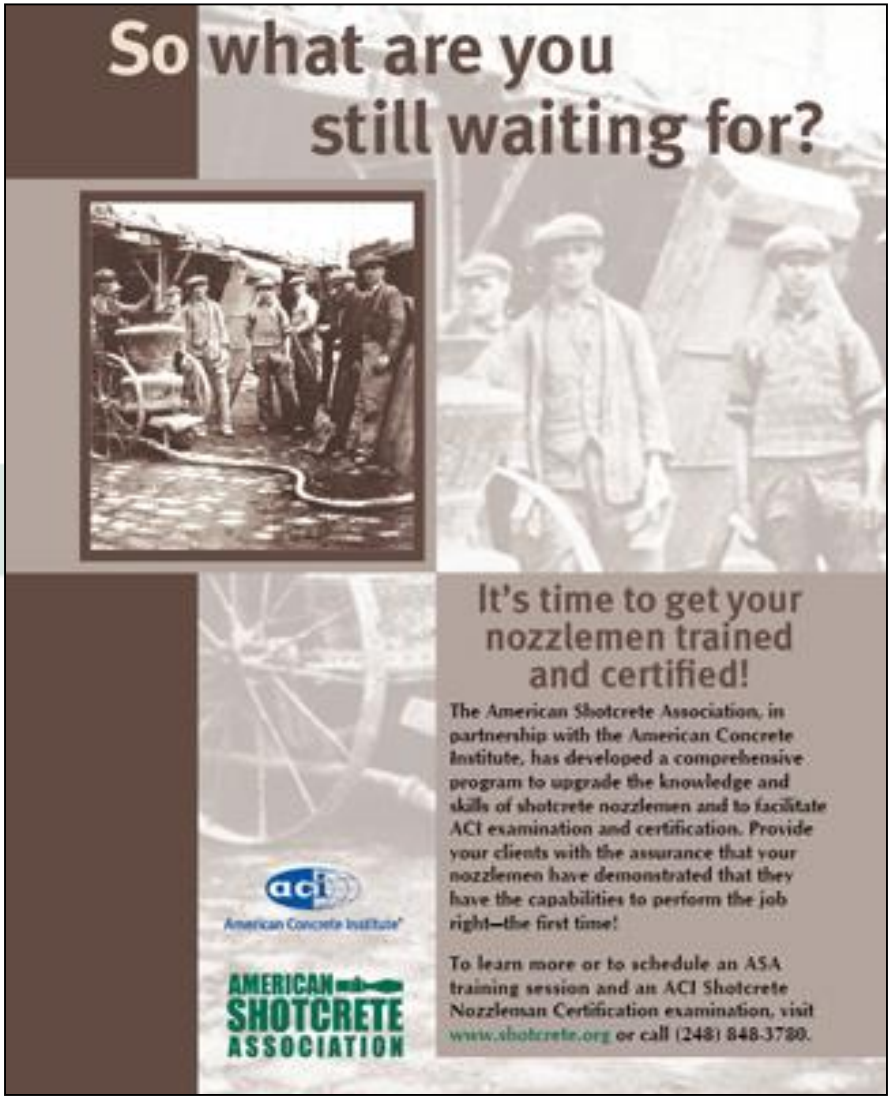
ACI Nozzleman Certification Program



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Requirements for Nozzleman Certification

- Must incorporate ASA mandatory education
- Requires 500 hours of documented experience that can be verified by the examiner
- Written examination, Oral examination, practical examination (test panels are shot and core graded)
- ACI Nozzleman Certification application is processed by ASA

Note: upon passing, will be posted to ACI & ASA websites & receive complimentary 1-yr ASA membership

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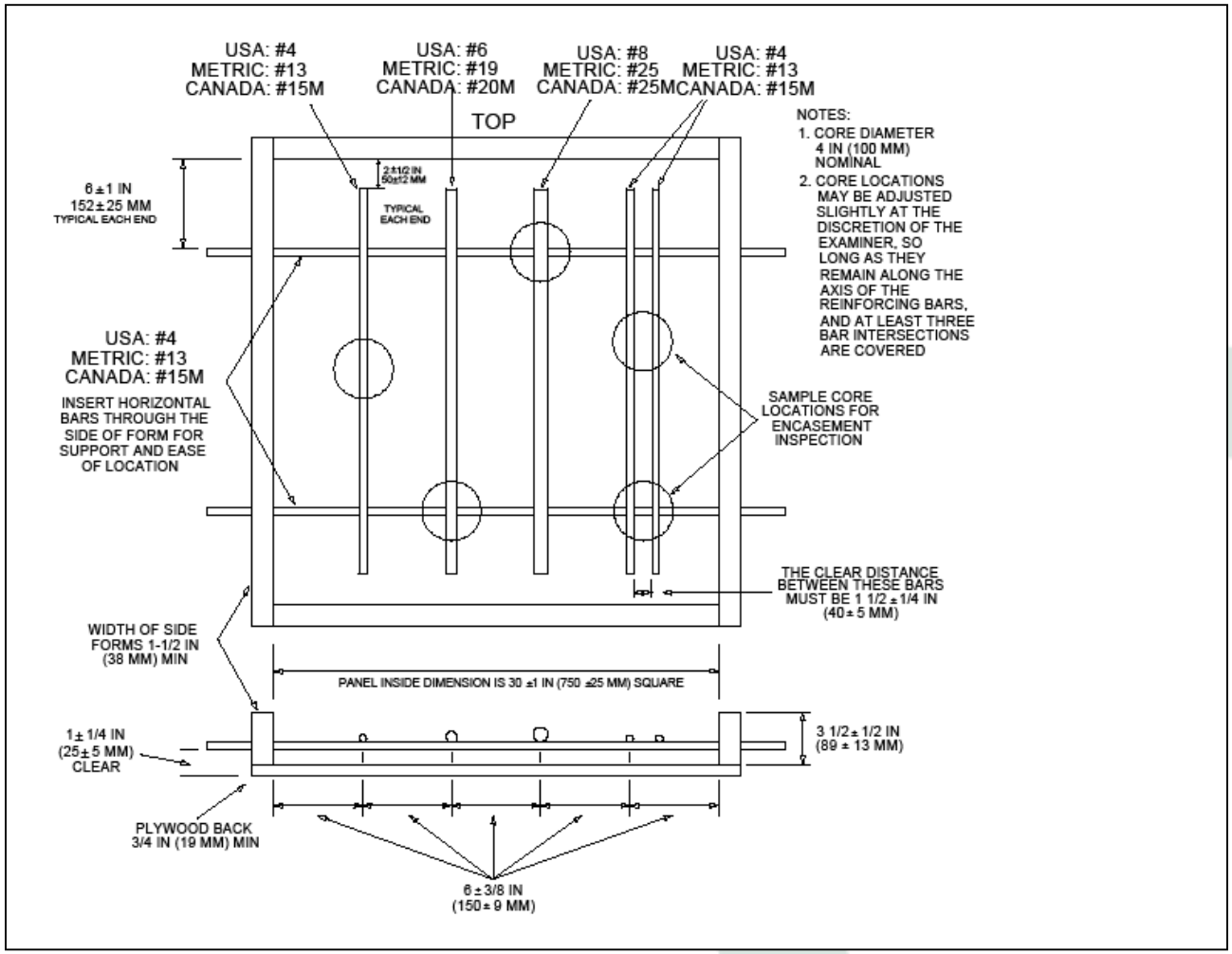
ACI Certification Panel



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Use Qualified Contractors

It is the responsibility of the owner/specifier to ensure that the shotcrete contractor and his crew are qualified to properly complete the project.

This responsibility starts (but does not end) with nozzleman certification!

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Before Issuing a Contract:

1. Ensure the contractor has a long and successful business history (check references)
2. Ensure the contractor has successful history on similar projects (check references)
3. Ask for work history of the contractor's key personnel (nozzlemen and supervisors)
4. Ensure the nozzleman possesses the experience and skill for the project
5. Ensure that all nozzlemen are currently certified for the method (dry and/or wet) and orientation (vertical and/or overhead) for which they will be shooting

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www.ACIcertification.org/verify

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Useful Tools and Resources

- www.shotcrete.org/buyersguide (source contractors, consultants and suppliers with related project experience) www.ACIcertification.org (for information on nozzlemen certification)
- ASA Staff – 248-848-3780 or info@shotcrete.org
- ACI Certification Staff – 248-848-3790 or john.nehasil@concrete.org

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This concludes The American Institute of Architects
Continuing Education Systems Course

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Abraham Lincoln Memorial Bridge Interstate 39 in LaSalle, Illinois

7,122 ft in length with 2 lanes in each direction

86 piers approximately 70 ft. high above rivers, lakes, wetlands & railroads

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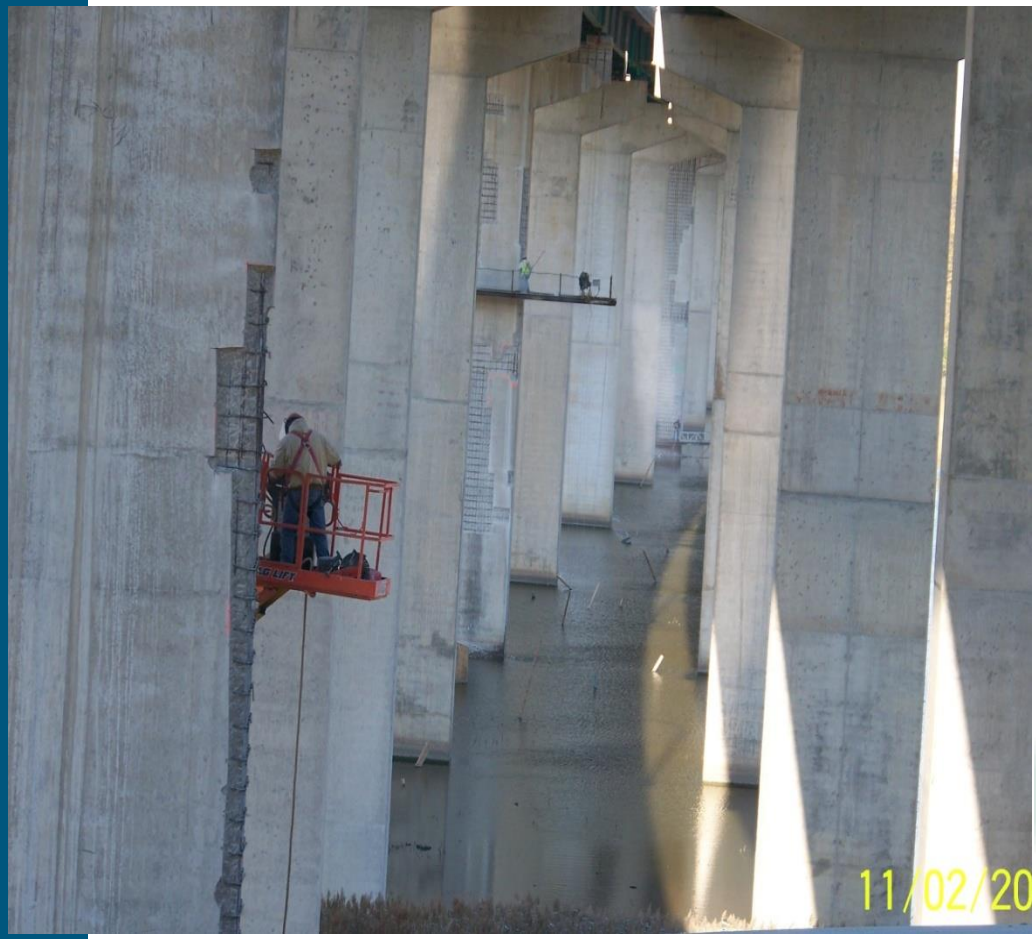
50 ft. by 6 ft. Platforms weighing more than 6,000 lbs.

Over 30,000 lbs. of reinforcement supplemented



All shotcrete work completed by ACI certified nozzlemen

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Cured with wet cotton mats for 7 days

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15,000 CF of removal and replacement

Dan Ryan Expressway
Chicago, Illinois

Elevated structure runs through the heart of the City of Chicago

One of the largest and busiest expressways

120 piers
approximately
60 ft. high above local roads, businesses & railways

60 ft. boom lifts used to access piers

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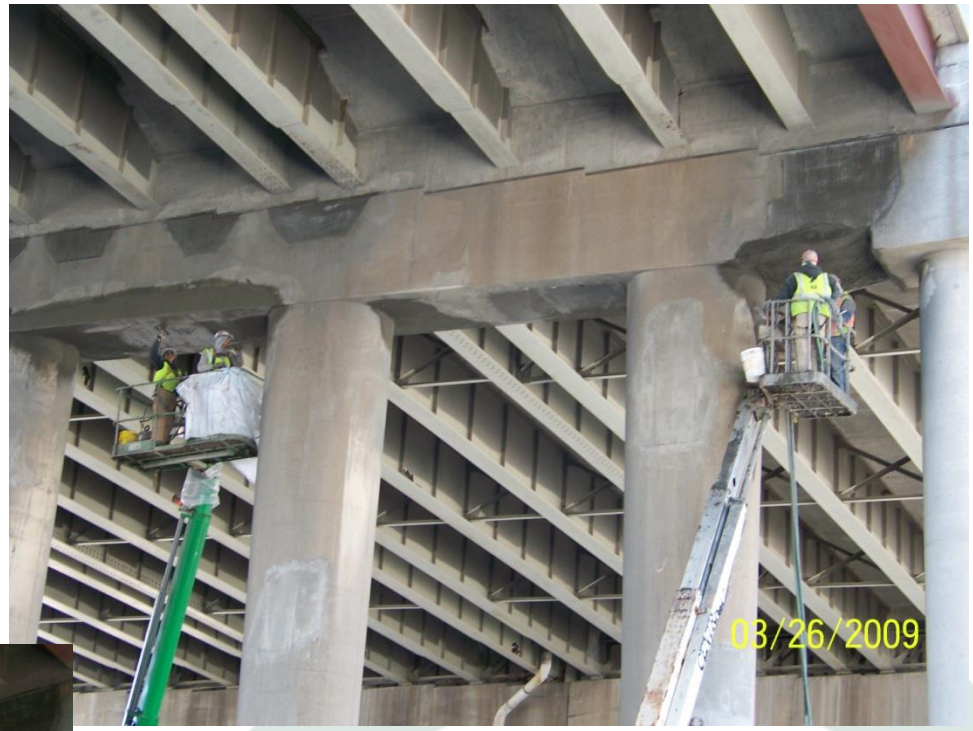
Over 15,000 lbs. of reinforcement supplemented

All shotcrete work was done from the ground and pumped upward to the nozzle



Completed by ACI certified nozzlemen

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Cured with wet cotton mats for 7 days

use of shotcrete over form and pour was chosen for its advantages in scheduling and sustainability

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11,000 cubic feet of removal and replacement

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The Noblestown Road Bridge

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The Deterioration of Piers

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Pier hammerhead, the rusting reinforcing bars caused the entire underside of this pier hammerhead to delaminate and spall from the surface.

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Drainage problems led to the corrosion of the reinforcing bars and the expanding rust scale caused the concrete to spall

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The deterioration on this pier hammerhead vividly illustrates the urgency of this rehabilitation project

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Preparation of Repair Areas

The repair areas were delineated, saw cuts were made and the deteriorated concrete was removed behind the first layer of reinforcing bars. The reinforcing bars were sandblasted to remove the scale, prior to the installation of the wire mesh.

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Preparation of Repair Areas

The concrete was deteriorated from the reinforcing bars outwards, however on this pier even sound concrete was removed to allow the shotcrete to wrap around and encapsulate the reinforcing

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Different Repairs on a Pier

Shotcrete repairs were specified in most areas but conventional form and pour repairs were required on this pier where the right side of this pier hammerhead is set up for forming operations.

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The bridge was supported during removal and repair operations

Shotcrete allows easy overhead placement

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In Place Shotcrete

This freshly gunned pier hammerhead shows the results that can be achieved when shotcrete is placed correctly with an experienced crew.

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Eliminating Difficult Forming Work

The shotcrete easily conformed to the shape of the round piers on this freshly gunned pier, providing an excellent result.

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Prepackaged Materials

Prepackaged materials were used. To the left the shotcrete material is being pre-dampened prior to gunning and to the right are the 3000 lb sacks and holding hopper.

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Supporting the bridge during concrete removal and shotcrete

During construction operations the bridge was supported. Traffic was diverted to the two east or west bound lanes and only one side of a pier could be removed and placed at a time.

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Completed Shotcrete Piers

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Completed Shotcrete Piers

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Completed Shotcrete Repairs

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Tunnel Project

Project Name:
Liberty Tunnels Phase 2

Project Location:
Pittsburgh, PA

Shotcrete Contractor:
Mosites Construction Co.

General Contractor:
Mosites Construction Co.

Architect/Engineer:
Parsons Brinkerhoff

Material Supplier/Manufacturers:
The Quikrete Companies*

Project Owner:
Pennsylvania Department of Transportation

* Corporate Member of the American Shotcrete Association

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Tunnel Project

Where necessary, additional reinforcement was installed.

Prior to material installation the substrate was prepared using hydro-demolition.

Tunnel Project

The 3000 lb bulk bags were predampened as a part of the installation process.

Shotcrete being applied vertically by an ACI certified nozzleman.

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Tunnel Project

Shotcrete being applied overhead by an ACI certified nozzleman.

Finished wall with a white to clear curing agent.

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Tunnel Project

Finished patch on ceiling with white to clear curing agent.

Prepared substrate ready for application of flashcoat.

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Tunnel Project

Finished tunnel

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