Chapter 2
Types of Shotcrete and Applications

2-1. Why Shotcrete

a. Importance of proper application. Properly applied shotcrete is a structurally sound and durable construction material which exhibits excellent bonding characteristics to existing concrete, rock, steel, and many other materials. It can have high strength, low absorption, good resistance to weathering, and resistance to some forms of chemical attack. Many of the physical properties of sound shotcrete are comparable or superior to those of conventional concrete or mortar having the same composition. Improperly applied shotcrete may create conditions much worse than the untreated condition.

b. Advantages of shotcrete. Shotcrete is used in lieu of conventional concrete, in most instances, for reasons of cost or convenience. Shotcrete is advantageous in situations when formwork is cost prohibitive or impractical and where forms can be reduced or eliminated, access to the work area is difficult, thin layers or variable thicknesses are required, or normal casting techniques cannot be employed. Additional savings are possible because shotcrete requires only a small, portable plant for manufacture and placement. Shotcreting operations can often be accomplished in areas of limited access to make repairs to structures.

c. Strength of bonding. The excellent bonding of shotcrete to other materials is often an important design consideration. The force of the impact of this pneumatically propelled material on the surface causes compaction of the shotcrete paste matrix into the fine surface irregularities and results in good adhesion to the surface. Within limits, the material is capable of supporting itself in vertical or overhead applications.

2-2. Applications

The selection of shotcrete for a particular application should be based on knowledge, experience, and a careful study of required and achievable material performance. The success of the shotcrete for that application is contingent upon proper planning and supervision, plus the skill and continuous attention provided by the shotcrete applicator. The following paragraphs discuss the use of shotcrete in several of the more common applications. A number of shotcrete applications by the Corps of Engineers are listed in Appendix C.

a. Repair. Shotcrete can be used to repair the damaged surface of concrete, wood, or steel structures provided there is access to the surface needing repair. The following examples indicate a few ways in which shotcrete can be used in repairs:

(1) Bridges. Shotcrete repair can be used for bridge deck rehabilitation, but it has generally been uneconomical for major full-thickness repairs. It is very useful, however, for beam repairs of variable depths, caps, columns, abutments, wingwalls, and underdecks from the standpoint of technique and cost.

(2) Buildings. In building repairs, shotcrete is commonly used for repair of fire and earthquake damage and deterioration, strengthening walls, and encasing structural steel for fireproofing. The repair of structural members such as beams, columns, and connections is common for structures damaged by an earthquake.

(3) Marine structures. Damage to marine structures can result from deterioration of the concrete and of the reinforcement. Damaging conditions are corrosion of the steel, freezing and thawing action, impact loading, structural distress, physical abrasion from the action of waves, sand, gravel, and floating ice, and chemical attack due to sulfates. These problems can occur in most marine structures such as bridge decks, piles, pile caps, beams, piers, navigation locks, guide walls, dams, powerhouses, and discharge tunnels. In many cases, shotcrete can be used to repair the deteriorated surfaces of these structures.

(4) Spillway surfaces. Surfaces subject to high-velocity flows may be damaged by cavitation erosion or abrasion erosion. Shotcrete repairs are advantageous because of the relatively short outage necessary to complete the repairs.

b. Underground excavations. For the most part, shotcrete is used in underground excavations in rock; but on occasion, it has been successfully used in the advancement of tunnels through altered, cohesionless, and loose soils. Typical underground shotcrete applications range from supplementing or replacing conventional support materials such as lagging and steel sets, sealing rock surfaces, channeling water flows, and installing temporary support and permanent linings.

c. Slope and surface protection. Shotcrete is often used for temporary protection of exposed rock surfaces that will deteriorate when exposed to air. Shotcrete is also used to permanently cover slopes or cuts that may erode in time or otherwise deteriorate. Slope protection should be properly drained to prevent damage from excessive uplift pressure. Application of shotcrete to the surface of landfills and other waste areas is beneficial to prevent surface water infiltration.

d. New structures. Shotcrete is not necessarily the fastest method of placing concrete on all jobs, but where thin sections and large areas are involved, shotcreting can be used effectively to save time. The following paragraphs describe some of the applications involved with construction of new structures.

(1) Pools and tanks. Shotcrete has been used extensively to construct concrete swimming pools. More recently, large aquariums have been constructed using shotcrete.

(2) Shotcrete floors and walls. Shotcrete floors in tanks and pools on well compacted subbase or on undisturbed earth have generally given excellent service. Vertical and overhead construction for walls, slabs, columns, and other structural members has been frequently shotcreted.

(3) Shotcrete domes. Construction techniques using inflatable air-forming systems have made the construction of shotcrete shells or domes practical. These large structures have been used for residential housing, warehousing, bridge, and culvert applications.

2-3. Shotcrete Processes

Shotcrete can be applied by two distinct application techniques, the dry-mix process and the wet-mix process.

a. Dry-mix shotcrete. The cementitious material and aggregate are thoroughly mixed and either bagged in a dry condition, or mixed and delivered directly to the gun. The mixture is normally fed to a pneumatically operated gun which delivers a continuous flow of material through the delivery hose to the nozzle. The interior of the nozzle is fitted with a water ring which uniformly injects water into the mixture as it is being discharged from the nozzle and propelled against the receiving surface.

b. Wet-mix shotcrete. The cementitious material, aggregate, water, and admixtures are thoroughly mixed as would be done for conventional concrete. The mixed material is fed to the delivery equipment, such as a concrete pump, which propels the mixture through the delivery hose by positive displacement or by compressed air. Additional air is added at the nozzle to increase the nozzle discharge velocity.

c. Comparison of dry-mix and wet-mix processes. Shotcrete suitable for most requirements can be produced by either the dry-mix or wet-mix process. However, differences in the equipment cost, maintenance requirements, operational features, placement characteristics, and product quality may make one or the other more attractive for a particular application. A comparative summary of the advantages and disadvantages of the processes is given in Table 2-1.

(1) Bond strengths of new shotcrete to existing materials are generally higher with dry-mix shotcrete than with wet-mix shotcrete. Both shotcrete mixtures often provide significantly higher bond strengths to existing materials than does conventional concrete.

(2) Typically, dry-mix shotcrete is applied at a much slower rate than wet-mix shotcrete. Dry-mix shotcrete is often applied at a rate of 1 or 2 cubic yards per hour compared to wet-mix shotcrete applied at a rate of up to 7 or 8 cubic yards per hour. Depending on the application, the in-place production rate may be significantly lower because of obstacles, rebound, and other features which may cause delays.

(3) Rebound is the shotcrete material that "bounces" off the shooting surface. Rebound for conventional dry-mix shotcrete, in the best of conditions, can be expected to be at least 20 percent of the total material passed through the nozzle. Wet-mix shotcrete rebounds somewhat less than dry-mix shotcrete.

(4) The use of air-entraining admixtures (AEA) in shotcrete is practical only in wet-mix shotcrete. When batched properly, AEA forms an air-void system suitable for providing frost resistance to wet-mix shotcrete. The formation of an air-void system in dry-mix shotcrete is not possible. However, dry-mix shotcrete, when properly proportioned and applied, will have a compressive strength exceeding approximately 7,000 pounds per

Table 2-1
Comparison of Features of Dry-Mix and Wet-Mix Shotcrete Processes

Dry-Mix Process	Wet-Mix Process
Mixing water instantaneously controlled at the nozzle by operator to meet variable field conditions.	Mixing water controlled at plant and measured at time of batching.
Longer hose lengths possible, if necessary.	Normal pumping distances necessary.
Limited to accelerators as the only practical admixture.	Compatible with all ordinary admixtures. Special dispensers for addition of accelerators are necessary.
Use of air-entraining admixture not beneficial. Resistance to freezing and thawing is poor.	Air entrainment possible. Acceptable resistance to freezing and thawing.
Intermittent use easily accommodated within prescribed time limits.	Best suited for continuous application of shotcrete.
Exceptional strength performance possible.	Lower strengths, similar to conventional concrete.
Lower production rates.	Higher production rates.
Higher rebound.	Lower rebound.
Equipment maintenance costs tend to be lower.	Equipment maintenance costs tend to be higher.
Higher bond strengths.	Lower bond strengths, yet often higher than conventional concrete.

square inch (psi). It has performed well in moderate exposures to freezing and thawing.

2-4. Fiber-Reinforced Shotcrete

a. Unreinforced shotcrete, like unreinforced conventional concrete, is a brittle material that experiences cracking and displacement when subjected to tensile stresses or strains. The addition of fibers to the shotcrete mixture adds ductility to the material as well as energy absorption capacity and impact resistance. The composite material is capable of sustaining postcrack loadings and often displays increased ultimate strength, particularly tensile strength. Fibers used in shotcrete are available in three general forms: steel fibers, glass fibers, and other synthetic fibers. Natural fiber, a fourth form, is not commonly used in shotcrete and will not be discussed.

b. The use of steel fibers has evolved rapidly since its inception in the late 1950's. The present third-generation steel fibers are greatly superior to the earlier fibers. Early mixing and handling problems which hampered uniform distribution of fibers in a mixture have been minimized by the manufacture of fibers with low-aspect ratios (ratio of length to diameter), surface deformations, and improved shape.

c. The use of glass-fiber-reinforced shotcrete (GFRS) is an adaptation of the technology of using chopped glass fibers and a resin binder. The equipment and process to apply glass-fiber shotcrete is not a conventional shotcrete operation, but requires a special gun and delivery system. This process termed "spray-up" is used extensively in the construction of lightweight panels for building cladding and special architectural features and is usually applied in a plant production situation. A common onsite application is the construction of simulated rock structures for animal exhibits at zoos. The fibers are made from a special zirconium alkali-resistant (AR) glass to resist deterioration in the highly alkaline portland-cement environment. Guidelines for the use of glass-fiber spray-up are provided by the Prestressed Concrete Institute (PCI) (1981).

d. Other synthetic fibers are composed of nylon, polypropylene, polyethylene, polyester, and rayon. The predominant fiber used for shotcrete has been of polypropylene produced in a collated fibrillated form. The primary benefit of synthetic fiber additions to shotcrete is to decrease width of shrinkage cracks in the material.

e. Typical applications for fiber-reinforced shotcrete are for tunnel linings, surface coatings on rock and soil, slopes, structures, embankments, or other structures that may be subject to high deformations or where crack control is needed.

2-5. Silica-Fume Shotcrete

a. Silica fume is a very fine noncrystalline pozzolanic material composed mostly of silica. Silica fume is used in concrete and shotcrete to increase strength, decrease permeability, and enhance cohesion and adhesion. Specific advantages of silica fume in shotcrete are the improved bond strength of shotcrete to substrate surfaces, the improved cohesion of the shotcrete, and the resulting ability to apply thicker layers of shotcrete in a single pass to vertical and overhead surfaces. The material is more resistant to "washout," where fresh shotcrete is subject to the action of flowing water, and rebound is significantly reduced. Shotcrete containing silica fume may have improved resistance to aggressive chemicals.

b. In general, silica-fume shotcrete produces unhardened and hardened material properties which, among other uses, make it suitable as a substitute for polymer-modified shotcrete and accelerated shotcrete applications. Use of silica-fume shotcrete should be considered for many applications that presently use conventional shotcrete because of its bond and strength performance.

c. Silica-fume shotcrete has been widely used in tunnel construction often combined with fibers to control shrinkage cracking. Because of inherent improvements in permeability, silica-fume shotcrete has been used to cap landfills and other waste areas to be sealed from surface water infiltration. Performance in high-strength applications is more easily accomplished with silica-fume shotcrete.

2-6. Polymer-Modified Shotcrete

a. Polymers are incorporated into shotcrete in two ways. In one method, the entire binder is composed of a polymer material. This is no longer a hydraulic-cement product but a polymer shotcrete. The more common use of polymers is the addition of a polymer emulsion to the hydraulic-cement mixture, as with a partial replacement of the mixing water, or as total replacement, which disperses throughout the mixture forming a continuous polymer matrix. This is termed polymer-portland-cement shotcrete.

b. The emulsified polymer for use in shotcrete has usually been styrene butadiene. Acrylic polymer latexes and epoxy resins are less frequently used products for portland-cement systems. The advantage of polymer-modified systems are that the polymers improve flexural and tensile strengths, improve bond, and reduce absorption because of lower permeabilities.

2-7. Accelerated Shotcrete

a. Accelerating admixtures are used extensively in shotcrete. Highly effective accelerators have been developed for rapid setting of shotcrete. Often considered "super-accelerators," these are commonly used with dry-mix shotcrete. With the increasing use of silica fume, the use of accelerators may decline somewhat. In the past, these accelerators were exclusively powdered materials added to dry-mix shotcrete materials. Now both powdered and liquid admixtures are used in both dry-mix and wet-mix shotcrete. The use of these accelerators with a wet-mix process requires that the accelerator be added at the nozzle rather than batched with the other materials.

b. Applications include tunnel support and linings, seawalls, portions of dams, roof construction, slope protection, and water-retention structures such as canals, thick concrete sections applied vertically or overhead, rapid repairs, and leaks sealed with flashset shotcrete. Accelerated shotcrete is particularly beneficial in tunnel support because it allows rapid section buildup, early strength development, and seals water leakage. For applications in the splash zone of marine structures, an accelerating admixture may be used to prevent freshly placed shotcrete from being washed away by the incoming tide or by wave action.