Chapter 4
Equipment and Crew

4-1. General Equipment

There are two basic types of shotcrete delivery equipment known as guns: dry-mix guns and wet-mix guns. Although either type may be used for most shotcrete work, each has its limitations. It is important to select equipment which is capable of placing the job mixture and maintaining an adequate production rate.

4-2. Dry-Mix Process

Cement and damp aggregate are thoroughly mixed, or premixed, and prebagged cement and aggregate are fed through a premoisturizer. The cement-aggregate mixture is then fed into the gun. The mixture is introduced into the delivery hose via a metering device such as a feed wheel. Compressed air is added at the gun and the mixture is carried through the delivery hose to the nozzle. The nozzle is fitted inside with a perforated water ring through which water and admixtures are introduced under pressure and intimately mixed with the other ingredients as they go through the nozzle. The concrete is propelled from the nozzle at high velocity onto the receiving surface.

a. Description of guns. Dry-mix guns are divided into two classifications, the double chamber gun and the continuous feed gun, each of which is capable of delivering mixtures in a wide range of consistencies.

(1) Double chamber. The first gun developed was the double chamber or pot type, introduced in the early 1900's, shown in Figure 4-1. Although the material enters the upper chamber in batches, the valve arrangement is such that the discharge from the lower chamber is continuous. Until recent years, this gun had been used only for mortar mixtures and the production rate was low, but larger, high-production units which will handle coarse aggregate up to about 3/4 inch are now available.

(2) Continuous feed. The continuous-feed gun was introduced about 1960 and is shown in Figure 4-2. Most of these guns will handle mortar or concrete mixtures with aggregate up to about 3/4-inch and will produce shotcrete at production rates up to 2 cubic yards per hour.

b. Plant layout. A typical plant layout for a dry-mix shotcreting operation, including air and water supplies, gun, delivery hose, and nozzle, is shown in Figure 4-3.

4-3. Wet-Mix Process

Cement, aggregates, and admixtures (except accelerators) are thoroughly mixed. The mixture is fed into the gun and propelled through the delivery hose to the nozzle by compressed air or pneumatic or mechanical pumping. Air is injected at the nozzle to disperse the stream of concrete and generate the velocity for shotcrete placement.

a. Description of guns.

(1) Pneumatic-feed. In the pneumatic-feed equipment shown in Figure 4-4, the premixed mortar or concrete is conveyed from the gun through the delivery hose to the nozzle by slugs of compressed air. At the nozzle additional air may be added if needed to increase the velocity and improve the gunning pattern. This equipment can handle mixtures of a consistency suitable for general shotcrete construction, using mixtures containing up to 3/4-inch aggregate. Guns with a dual mixing chamber and a two-way valve allow mixing of materials and a continuous flow operation.

(2) Positive displacement. In the positive displacement equipment shown in Figure 4-5, the concrete is pumped or otherwise forced through the delivery hose without the use of compressed air. Air is injected at the nozzle to disperse the stream of concrete and impart the velocity necessary for shotcrete placement. Positive displacement delivery equipment requires a wetter mixture than pneumatic-feed equipment, and the velocity of the shotcrete being applied is lower. It is difficult to apply shotcrete to vertical and overhead surfaces by this method unless a suitable accelerator is used. This equipment can also satisfactorily shoot material containing 3/4-inch aggregate.

b. Plant layout. A typical plant layout for each of the wet-mix processes is given in Figures 4-6 and 4-7.

4-4. Auxiliary Equipment

a. Batching and mixing equipment. Most shotcrete is batched and mixed in the field using portable mixing equipment or delivered in mixer trucks from a local ready-mixed concrete plant. Mixing equipment for

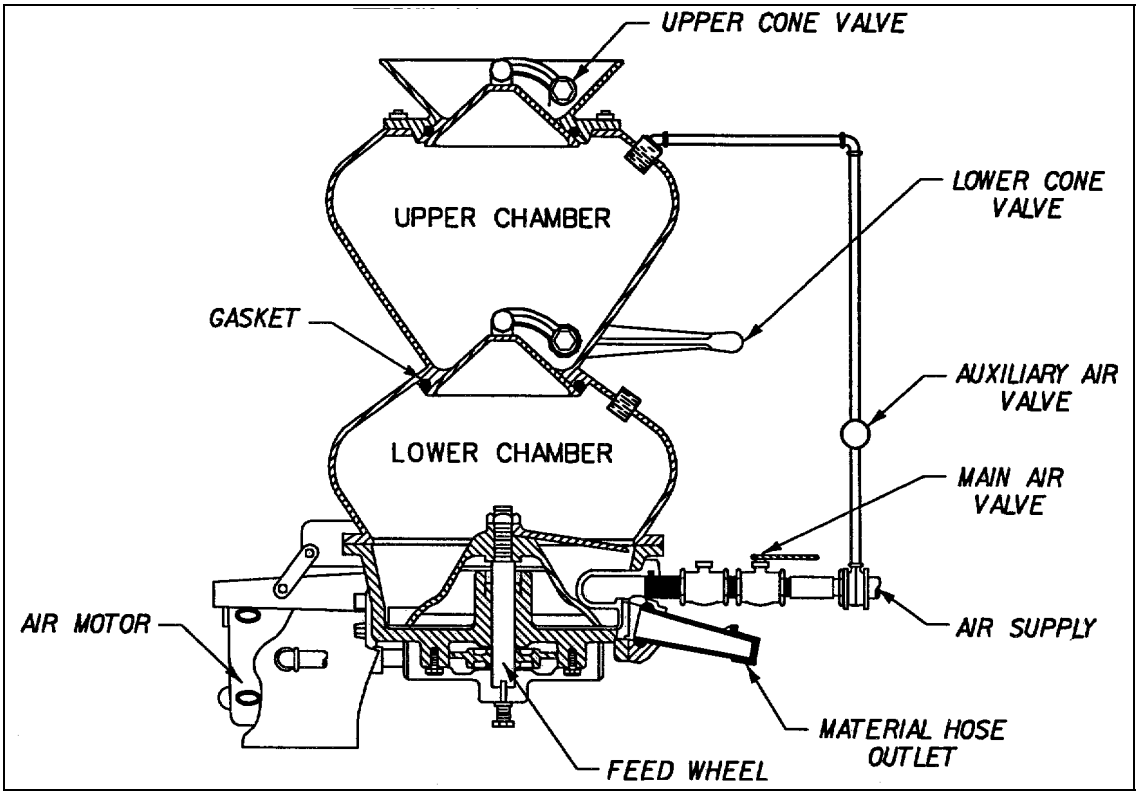

Figure 4-1. Cross section of typical double-chamber dry-mix gun (Crom 1966; copyright permission granted by ACI)

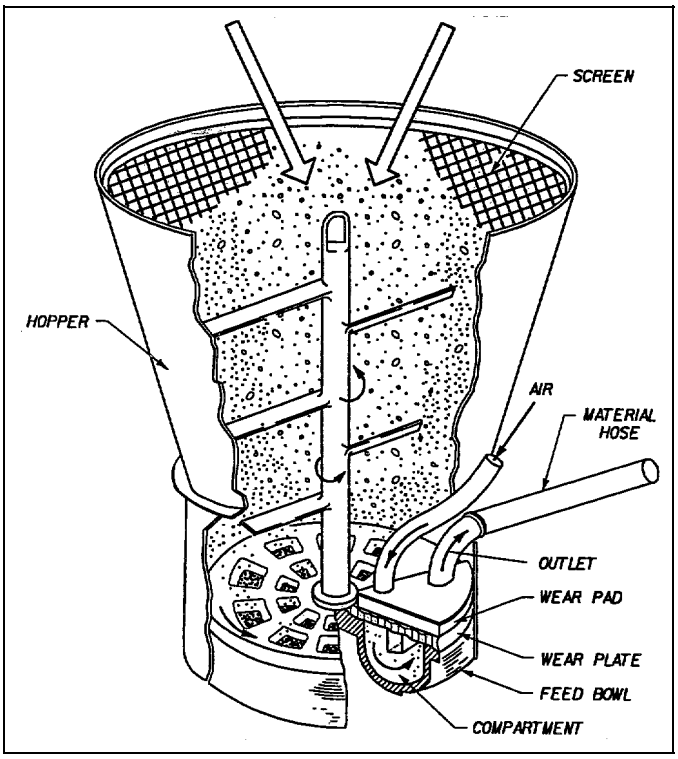

Figure 4-2. Cross section of typical continuous-feed dry-mix gun (Mahar, Parker, and Wuellner 1975)

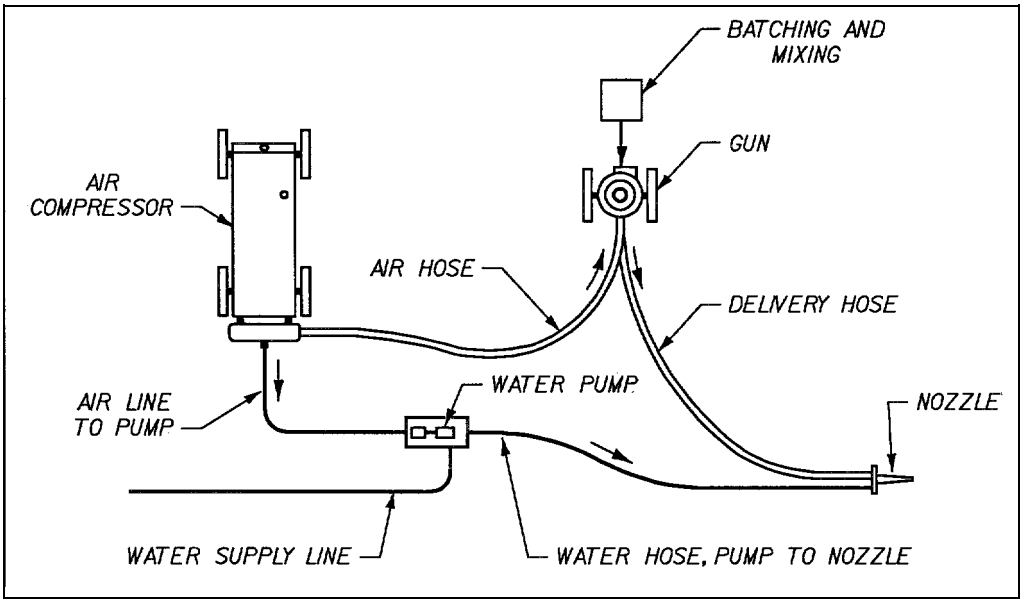

Figure 4-3. Typical plant layout for dry-mix shotcreting (Crom 1966; copyright permission granted by ACI)

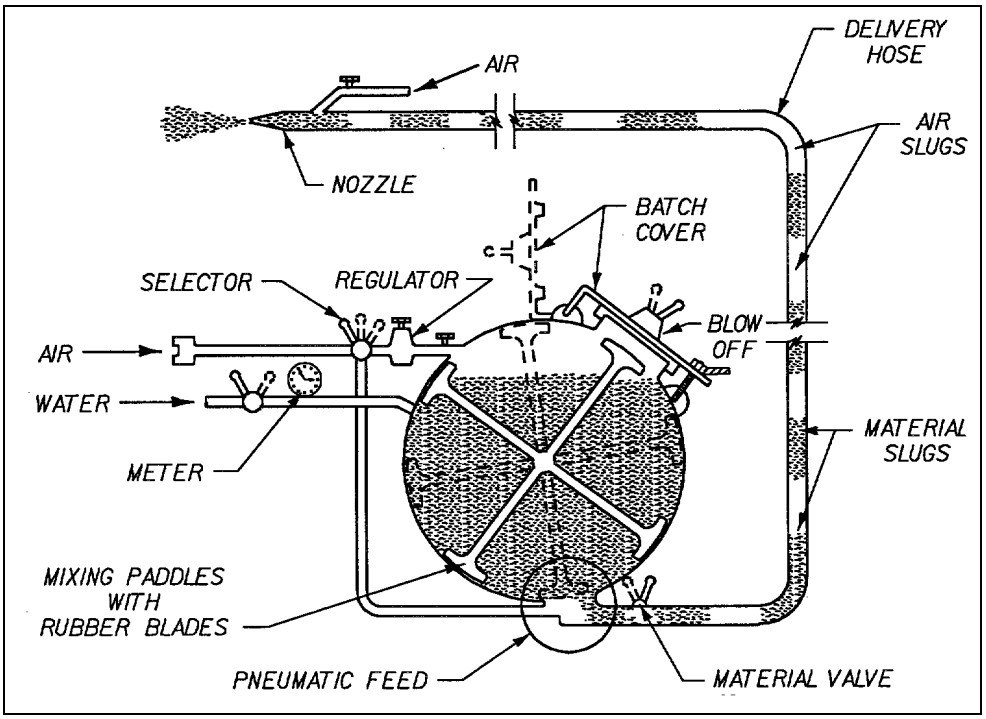

Figure 4-4. Cross section of pneumatic-feed shotcrete gun (Hoffmeyer 1966; copyright permission granted by ACI)

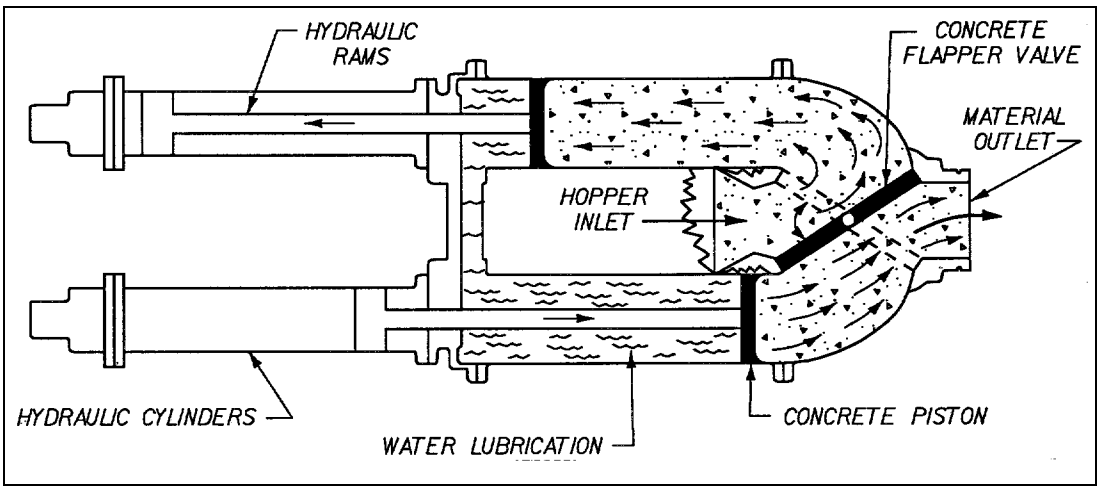

Figure 4-5. Schematic of positive displacement pump (Fredricks, Saunders, and Broadfoot 1966; copyright permission granted by ACI)

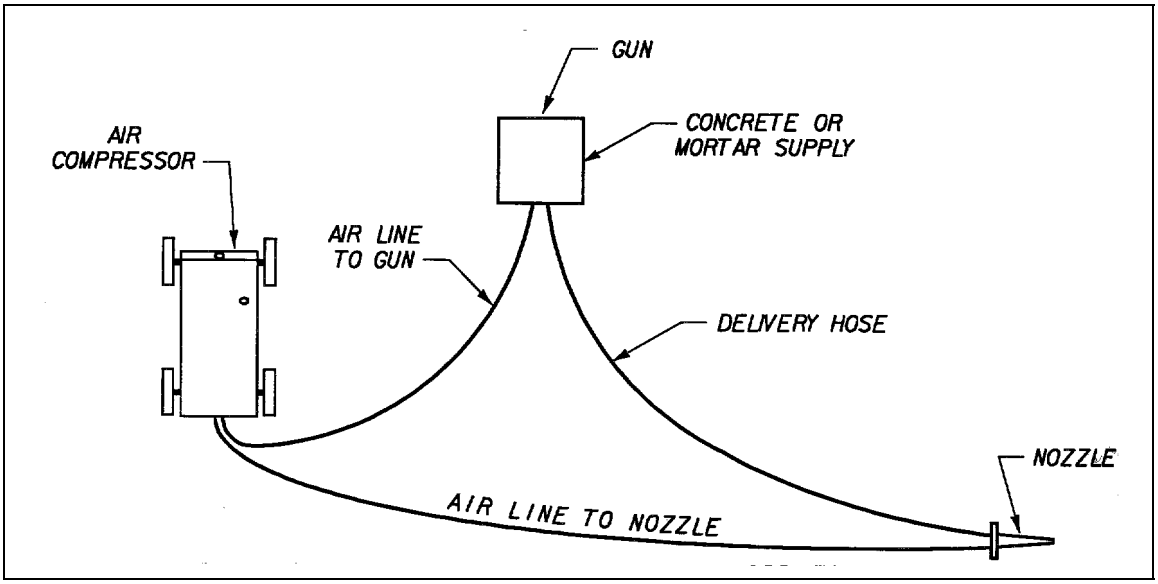

Figure 4-6. Typical plant layout for wet-mix pneumatic-feed equipment

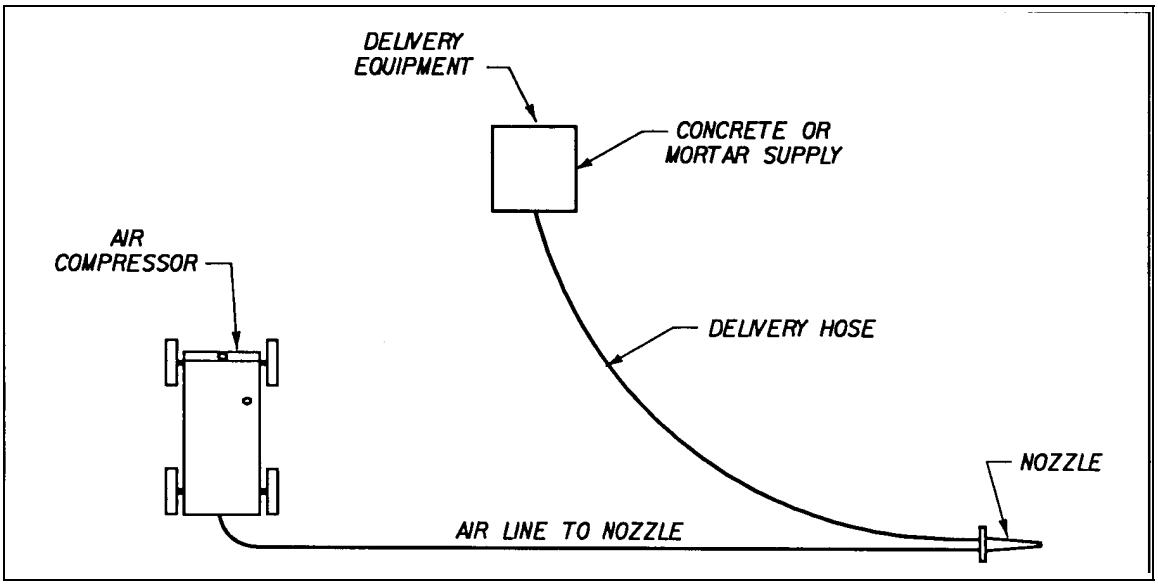

Figure 4-7. Typical plant layout for wet-mix positive displacement equipment

shotcrete is of the batch or the continuous type. Where ready-mixed concrete is used, it should conform to CRD-C 31 (ASTM C 94). Equipment for the batch type should conform to CRD-C 31 (ASTM C 94). In the continuous type, individual ingredients are fed to a mixer screw by means of variable speed augers, belt-feed systems, or a combination of both. This equipment should conform with CRD-C 98 (ASTM C 685). A hopper is sometimes used in high production units of both these types to collect and feed the mixture as required. Water-metering systems are also available to redampen the mixture. Batching and mixing equipment must be capable of maintaining an adequate and continuous flow of homogeneous material. Batching by mass is preferred and will normally be required. Water may be batched by mass or volume. For small jobs, approval may be given to batching by a volumetric container, provided periodic weight checks are made. Since many shotcrete jobs have a low production rate and are in isolated locations, mixing is often done by a small drum mixer at the jobsite.

b. Admixture dispensers. Admixtures may be added when needed during mixing or at the nozzle, depending on their properties and the type of shotcrete process (dry or wet).

(1) In the dry-mix process, dry (powder) admixtures are usually introduced into the mixture during batching. If a continuous feed gun is being used, they may also be added directly into the gun hopper by a special dispenser, usually an auger-type dry dispenser driven by and calibrated to the gear train of the shotcrete machine. The dispenser should be capable of metering a precise quantity of admixture, usually 1 to 4 percent by mass of the cement, into the mixture, and must be capable of accurately varying the ratio of accelerator to cement.

(2) In the dry-mix process, liquid admixtures must be introduced at the nozzle through the mixing water. The admixture may be premixed with water and pumped to the nozzle or added directly to the mixing water at the nozzle.

(3) In the wet-mix process, dry or liquid admixtures may be added to the mixture when batching provided the pumping properties are not adversely altered. As an example, an accelerator would create problems if added during batching, while a high-range water reducing admixture (HRWR) might have beneficial effects. In wet-mix applications, only liquid admixtures may be added to the air supply at the nozzle. They are proportioned to the delivery rate of the mixture through the material hose.

c. Air compressor. A properly operating air compressor of ample capacity is essential to a satisfactory shotcreting operation. The compressor should maintain a supply of clean, dry, oil-free air adequate for maintaining sufficient nozzle velocity for all parts of the work while simultaneously operating all air-driven equipment and a blowpipe for cleaning away rebound.

(1) Table 4-1 gives recommendations for compressor capacity, diameter of delivery hose, and maximum production rate for the dry-mix process. The operating air pressure is the pressure driving the material from the delivery equipment into the hose and is measured by a gage near the material outlet of the gun. The air pressure should be steady (nonpulsating). A compressor of adequate capacity will ensure that the operating air pressure is sufficient.

(2) The values shown in Table 4-1 are based on a hose length of 150 feet, with the nozzle not more than 25 feet above the delivery equipment. Operating pressures should generally not be less than 40 psi, when 100 feet or less of shotcrete hose is used. Operating pressures are generally increased about 5 psi for each additional 50 feet of hose and about 5 psi for each 25 feet that the nozzle is raised above the gun.

(3) Air requirements for the wet-mix process have not been thoroughly studied. In general, however, the values for the pneumatic-feed type are a little lower than those shown, but back pressures are higher. Positive displacement equipment requires at least 105 ft^3/min. at 100 psi at the air ring for proper operation.

(4) Certain moisture conditions will cause an increase of water vapor in the compressed air stream which will adversely affect the shotcrete operation. A moisture trap or filter should always be installed in the supply line from the compressor.

d. Water supply for dry-mix equipment. Water supply booster pumps should be capable of supplying at least a 10-gallon/minute flow at 60 psi at the nozzle for standard nozzles. The water pressure must be constant and must be 15 to 30 psi or more greater than the operating air pressure.

e. Aggregate premoisturizer. It is common practice in large volume dry-mix shotcrete projects to prebag all

the shotcrete materials together in a dry condition at the site. It is advantageous to premoisturize this material to 3-6 percent, by dry mass, prior to entering the shotcrete gun. A premoisturizer is a piece of equipment staged just before the shotcrete gun that uniformly distributes and mixes water to a continuous feed of dry materials.

4-5. Special Equipment

a. Steel fiber-reinforced shotcrete. It is critical that fibers be uniformly distributed throughout the mixture. Proper batching procedures and equipment can prevent the possible problems of fibers tangling together into fiber balls. For small projects, no special equipment is necessary. Fibers can be manually added to the mixture at an appropriate rate to prevent balling of fibers. Larger dry-mix shotcrete projects use prebagged material, including predistributed fibers. Specialized fiber feeder equipment, consisting of a drum and screen mechanism that uniformly screens the individual fibers into the shotcrete mixture, is available for continuous production of shotcrete. As with other continuous-feed systems, calibration of the system is mandatory to achieve proper proportions.

b. Silica-fume shotcrete. No special equipment is necessary for batching and mixing silica-fume shotcrete. Densified or slurried packaging eases manual batching methods common for low production-rate projects. Higher production-rate projects use bin systems similar to flash-feed systems, liquid pumping systems similar to liquid admixture systems, or prebagged materials.

c. Nozzles. A dry-mix nozzle typically consists of a tip, water ring, control valve, and nozzle body arranged in a wide variety of nozzle tips, nozzle sizes, and configurations. Figure 4-8 shows a section of a dry-mix nozzle. A wet-mix nozzle usually consists of a rubber nozzle tip, an air injection ring, a control valve, and nozzle body. Figure 4-9 shows an example of a wet-mix nozzle section. Some investigations have shown improved mixing action and less rebound for dry-mix shotcrete when a special prewetting nozzle is used and the water ring is placed in the hose 1 to 8 feet before of the nozzle. This has been particularly effective for silica-fume shotcrete.

d. Remote-controlled nozzles. During recent years, the use of remote-controlled nozzles has become increasingly popular, particularly for underground work. These machines are truck-mounted and include a boom-mounted nozzle, a gun, and an air compressor. The remote controls allow the nozzleman to rotate the nozzle in an 18-inch-diameter circle to allow proper application technique. The nozzleman can also swing the nozzle around 360 degrees and maneuver it closer to or farther from the surface being shot. Significant economy is realized because of higher placement rates and reduced crew size. Because of the remote location of the operator, some safety benefits can be realized from avoiding rebound of aggregates and fibers.

4-6. Crew Composition

a. The quality of shotcrete depends largely on the skill of the application crew. The shotcrete crew may consist of four to eight individuals, depending on the size of the operation and the type and setup of equipment. A typical crew may include the foreman, nozzleman, delivery equipment operator, and nozzleman's helpers. Additional personnel such as a delivery equipment operator helper and operator for haulage of materials may also be necessary. By far, the most important member of the crew is the nozzleman.

Table 4-1
Compressed Air Required for Dry-Mix Guns

Compressor Capacity at 100 psi ft^3/min	Inside Diameter of Delivery Hose inches	Maximum Production Rate yd^3/hr
365	1	4
425	1-1/4	6
500	1-1/2	9
700	1-3/4	10
900	2	12
1,000	2-1/2	15

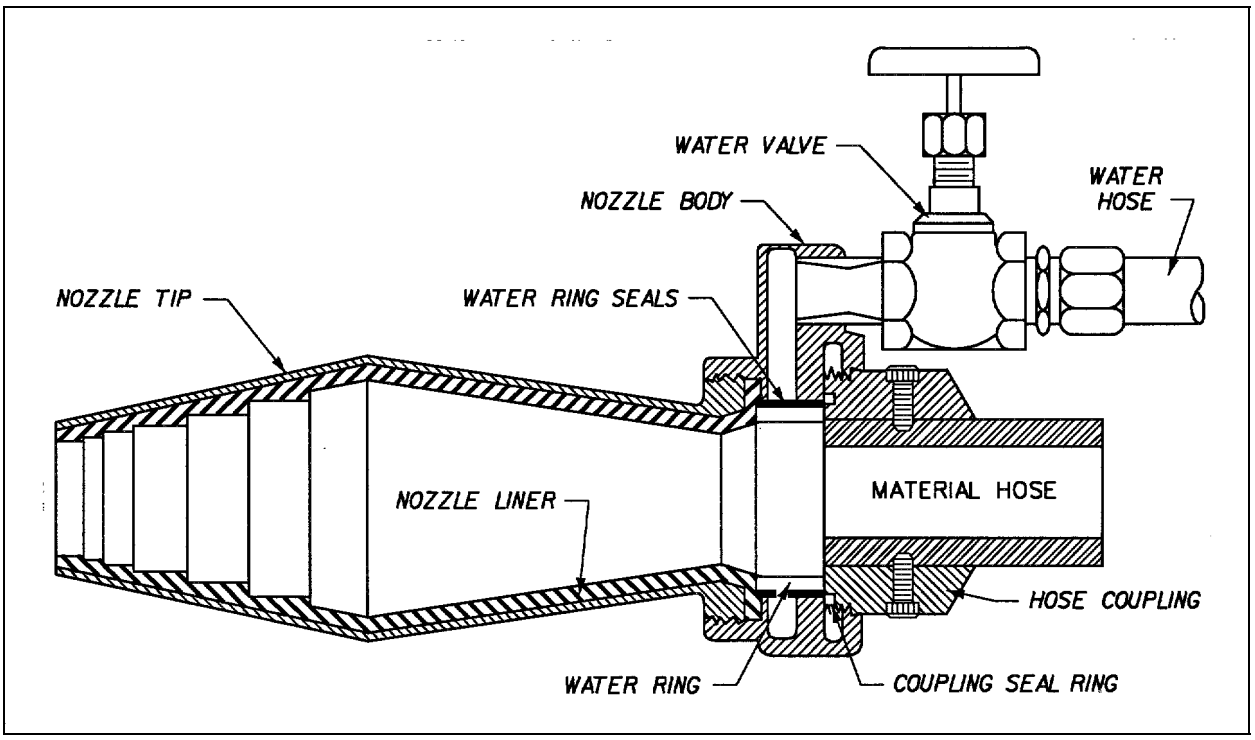

Figure 4-8. Typical dry-mix nozzle (paragraph A-2, ACI 1991c; copyright permission granted by ACI)

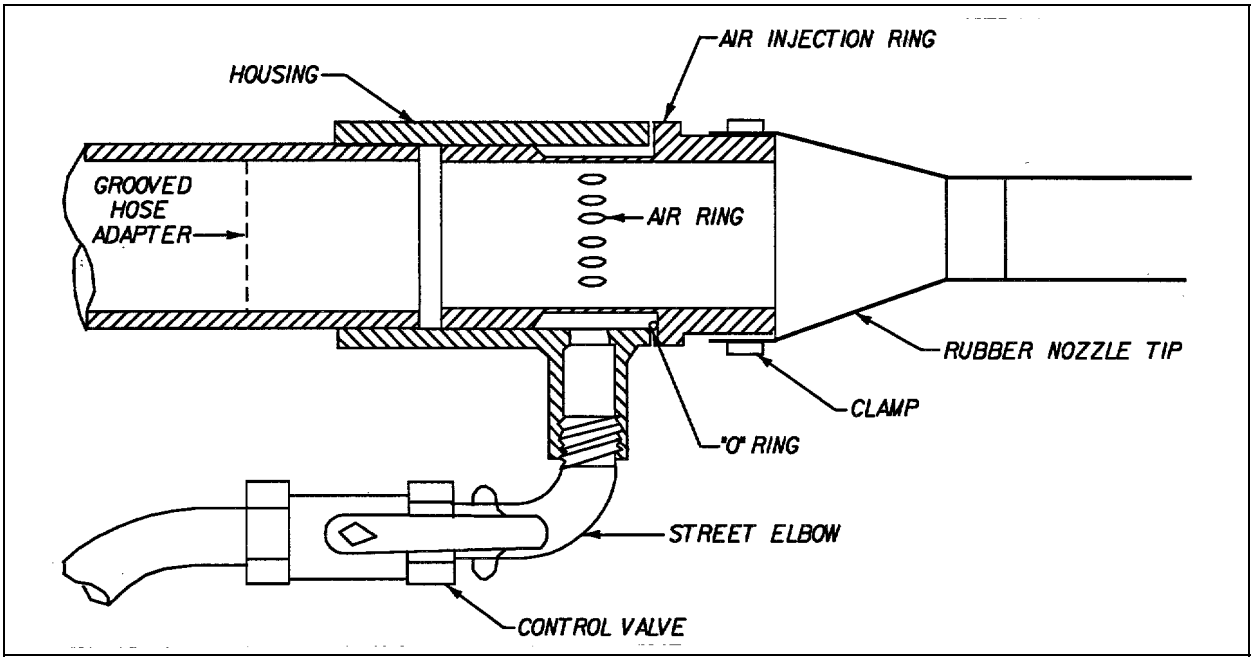

Figure 4-9. Typical wet-mix nozzle (paragraph A-2, ACI 1991c; copyright permission granted by ACI)

b. The success of the shotcrete crew depends largely on the ability of the nozzleman since he controls the surface preparation, the material delivery rate, the impingement of the shotcrete particles on the surface, the thickness, and, in the dry-mix process, the water-cement ratio. The nozzleman should have served an apprenticeship on similar applications and should be certified, as discussed in Chapter 5, for his ability to satisfactorily perform his duties and to gun shotcrete of the required quality. During production he will perform the following duties:

(1) Ensure that all surfaces to be shot are clean and free of laitance or loose material, using air and air-and-water blast from the nozzle as required.

(2) Ensure that the operating air pressure is uniform and provides proper nozzle velocity for good compaction.

(3) Regulate the water content so that the mixture will be plastic enough to give good compaction and a low percentage of rebound, but stiff enough not to sag. (In the dry-mix process the nozzleman actually controls the mixing water, while in the wet-mix process he directs changes in consistency as required.)

(4) Hold the nozzle at the proper distance and as nearly normal to the surface as the type of work will permit to secure maximum compaction with minimum rebound.

(5) Follow a sequence that will fill corners with sound shotcrete and encase reinforcement without voids behind the steel, using the maximum practicable layer thickness.

(6) Determine necessary operating procedures for placement in close quarters, at extended distances, or around unusual obstructions where placement velocities and mixture consistency must be adjusted.

(7) Direct the crew to start and stop the flow of material and stop the work when material is not arriving uniformly at the nozzle.

(8) Ensure that sand lenses, slough pockets, or laminations are cut out for replacement.

(9) Bring the shotcrete to finished lines in a neat and workmanlike manner.

(10) Assume responsibility for safety in the area where shotcrete is applied. He must be aware of other people in his immediate vicinity and take care not to direct the shotcrete stream irresponsibly. He should always maintain a firm grip on the nozzle and plan his movements so that he does not lose control of the material hose.

c. The nozzleman's apprentice or helper operates an air blowpipe at least 3/4 inch in diameter to assist the nozzleman in keeping all rebound and other loose or porous material out of the new construction (except in classes of work where the trapped rebound can readily be removed by the nozzleman). He also assists the nozzleman in moving hoses and in other assignments as required.