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—Concrete Craftsman Series—
SHOTCRETE FOR THE CRAFTSMAN
CCS-4(08)

SHOTCRETE FOR THE CRAFTSMAN (CCS-4)

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CHAPTER 4—WHAT IS SHOTCRETE?

Shotcrete is concrete conveyed through a hose and pneumatically projected at high velocity onto a surface to achieve compaction, thus a method of placing concrete used primarily in the construction of vertical and overhead surfaces. Shotcrete allows construction of walls and other structures using only a one-sided form. In many situations, it is more economical than conventionally-cast concrete because of its versatility. Tanks, swimming pools, tunnels, mines, sculptured rocks, structural walls, erosion control embankments, retaining walls, and shear-walls are all structures commonly built using shotcrete. In addition, a wide variety of repairs also use shotcrete.

It is placed at various thicknesses against one-sided forms (or existing concrete or masonry structures and rock, earth, or other surfaces). Its build-up nature varies depending on various parameters, which will be described in Chapter 8, Shotcrete Placement. The shotcrete process creates rebound and overspray. Overspray is fine particles with just enough cement to stick to all nearby surfaces and rebound is defined as mainly large aggregate with some sand and cement that bounces or ricochets off the receiving surface and falls on to lower surfaces. The parameters that affects rebound are described in Chapter 8.

The nozzleman is the craftsman that physically directs the placement of the shotcrete. The nozzleman is responsible for the quality of the placed shotcrete and is an important member of a shotcrete crew. The nozzleman must have an understanding of the equipment's operation, safety procedures, and the material being placed.

Although this booklet is directed to nozzlemen, they are not the only important people involved in a shotcrete project. The owner, engineer, contractor, job superintendent, foreman, and shotcrete crew are all important. Only with the cooperation and dedication by everyone involved will a project be successful.

4.1—Introduction

ACI defines shotcrete as "mortar or concrete pneumatically projected at high velocity onto a surface." There are two shotcrete processes: dry-mix and wet-mix.

4.1.1—Dry-Mix Shotcrete

Dry-mix shotcrete is the process illustrated in Fig. 4.1 in which a dry mixture is conveyed pneumatically through a delivery hose at the end of which water is added at a nozzle.

More specifically, all ingredients, except water, are thoroughly mixed together. The cementitious-aggregate

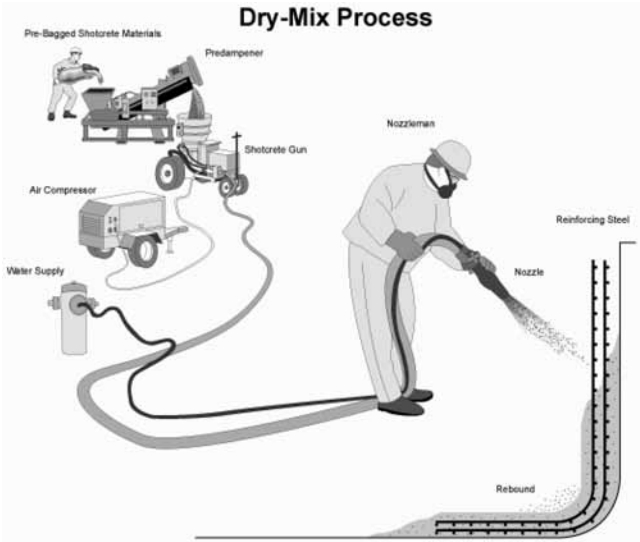

Fig. 4.1—Dry-mix shotcrete. Dry mixture conveyed pneumatically through delivery hose at end of which water is added at nozzle.

mixture is fed into a special mechanical feeder or gun called the delivery equipment. The material is then carried by compressed air through the delivery hose to a nozzle body. The nozzle body is fitted inside with a water ring through which water is introduced under pressure and thoroughly mixed with the other ingredients. The material is shot from the nozzle at high velocity onto the receiving surface. Mixing occurs in the nozzle and as the material impacts the surface.

(The term gunite was once proprietary but became a generic term in 1967, according to the Gunite Contractors Association. Because the American Concrete Institute ceased using the term gunite for the dry-mix method, this manual will refer to it as dry-mix shotcrete.)

4.1.2—Wet-Mix Shotcrete

The wet-mix process is illustrated in Fig. 4.2 and has all the ingredients—including cement, chemical and mineral admixtures, aggregate, and mixing water—thoroughly mixed together before being pumped into a delivery hose or pipeline. Compressed air is added at the nozzle to increase the material velocity. The mortar or concrete is then shot from the nozzle at high velocity onto the receiving surface.

4.1.3—Comparison of Shotcrete Processes

Either process can produce shotcrete suitable for normal construction requirements. Different factors will determine the appropriate process for a particular application (experience of shotcrete crew, volume of shotcrete to be applied, job-site access, availability of materials, etc.).

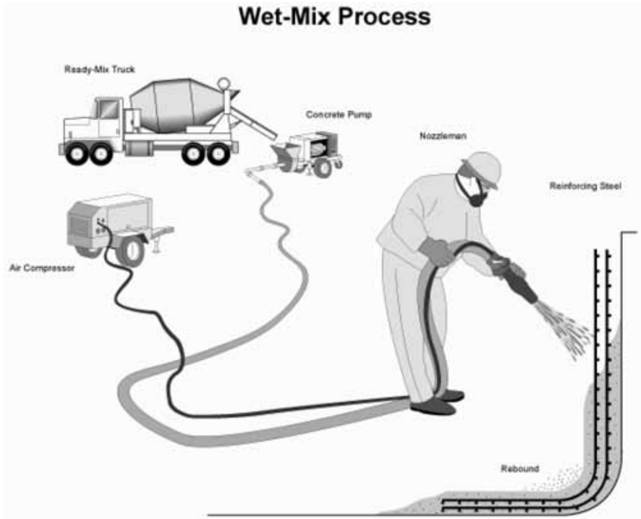

Fig. 4.2—Wet-mix shotcrete. Has all ingredients thoroughly mixed together before being pumped into delivery hose. Compressed air is added at nozzle.

Table 4.1 gives differences in operational features and other properties between the dry-mix and wet-mix shotcrete processes that may merit consideration.

Shotcrete is inherently high-quality concrete. It typically has a low *w/cm* and a high cementitious material content. Shotcrete acquires some of its unique properties from the placement process as the concrete is compacted when it strikes a surface. Therefore, it is important that shotcrete be projected at high velocity to achieve compaction. The nozzleman is responsible for ensuring that shotcrete is properly placed. The quality of shotcrete is largely dependent on the skill and knowledge of the nozzleman.

Shotcrete nozzling is complex and physically demanding. It should not be undertaken by anyone with physical limitations.

Table 4.1—Comparison of shotcrete processes

Dry-mix process	Wet-mix process
1. Instantaneous control over mixing water and consistency of mixture at nozzle to meet variable field conditions	1. Mixing water is controlled at mixing equipment and can be accurately measured
2. Better suited for placing mixtures for smaller concrete repair applications	2. Better assurance that mixing water is thoroughly mixed with other ingredients
3. Capable of being transported longer distances	3. Less dust and cementitious materials lost during shooting operation
4. Delivery hoses are lighter and easier to move	4. Normally has lower rebound, resulting in less waste
5. Lower volume per hose size	5. Higher volume per hose size

Considering that shotcrete is a method of placing concrete, it requires nozzleman skill and experience, adapted delivery equipment, and properly proportioned shotcrete mixtures.

As such, the following chapters provide additional pertinent information on Shotcrete Materials (Chapter 5), Shotcrete Equipment (Chapter 6), Preparation before Shooting, Shotcrete Placement Principles and Techniques, Communication, and Environmental Conditions and Precautions (Chapters 7 to 10). Chapters on Finishing and Tolerance Controls, Safety, and Testing/Quality are also presented (Chapters 11 to 13).

CHAPTER 8—SHOTCRETE PLACEMENT PRINCIPLES AND TECHNIQUES

Proper placement of shotcrete is the most important element in achieving good quality shotcrete. Most defects and problems that occur in shotcrete are due to poor placement. Shotcrete is dependent on the skill and actions of the nozzleman. The nozzleman's goal is to achieve adequate compaction free of overspray and rebound and, if reinforcement is present, good encasement.

8.1—General

Shooting techniques vary depending on the shotcrete system (dry-mix or wet-mix), location, thickness, type of surface, and whether or not steel must be encased.

It is important to understand the shotcrete process as a method of placing concrete. As the shotcrete mixture exits the nozzle, the mixture stream fans out. The material in the center of the stream travels the shortest distance and hits the receiving surface with the highest impact velocity. At first, the aggregates ricochet off the receiving surface until sufficient paste builds up to provide a bed into which the aggregate can stick (Fig. 8.1). The impact of the shotcrete stream compacts the shotcrete. The indirect stream, that part of the stream that fans out, hits the receiving surface slower and at an angle. Some of the indirect stream ricochets away, creating overspray and rebound.

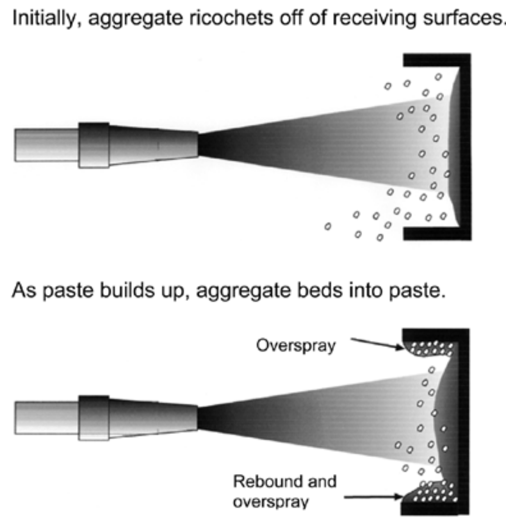

Fig. 8.1—Behavior of shotcrete after exiting nozzle.

Overspray attaches to nearby ledges and reinforcement.

Initially, aggregate ricochets off of receiving surfaces. Figure 8.2 illustrates the constituents and behavior of overspray and rebound. Overspray is made up of fine

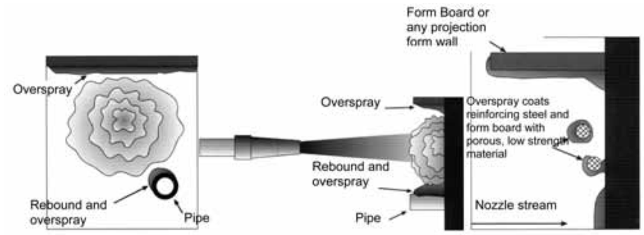

Fig. 8.2—Constituents and behavior of overspray and rebound.

and coarse aggregates with a small amount of cement. Rebound is aggregate that ricochets off the receiving surface and falls onto lower surfaces. Rebound and overspray have just enough cementitious material to be sticky. There is not enough paste in either rebound or overspray to fill the voids between the aggregate particles. Consequently, both rebound and overspray are porous and weak, and therefore should not be incorporated into the work. Wet-mix shotcrete typically does not create as much overspray as dry-mix shotcrete. Both processes create rebound. Controlling overspray and rebound is important to achieving good shotcrete. Overspray accumulation is controlled by shooting perpendicular and first shooting any area that accumulates overspray, such as corners. Rebound is controlled by shooting perpendicular to the surface and by using an air lance.

The basic principles of placement are the same for applying both dry-mix and wet-mix shotcrete. Ideally, the hose should be straddled between the legs and the nozzle should be held waist to shoulder height. To balance the thrust of the shotcrete nozzle stream, the nozzleman typically braces himself by placing one leg to the rear. The nozzle is held so that the shotcrete is placed perpendicular to the receiving surface (Fig. 8.3(a) and (c)) to maximize impact velocity. Shooting at an angle other than 90 degrees to the receiving surface increases both rebound and overspray and reduces the compaction of the in-place shotcrete (Fig. 8.3(b) and (c) and Fig. 8.4).

8.2—Dry-Mix Shotcrete

In some respects, dry-mix nozzling is more difficult than wet-mix. In addition to directing the nozzle, the dry-mix nozzleman must also adjust the amount of water that is injected at the nozzle. To judge what is the right amount of water, the nozzleman must carefully watch the shotcrete during shooting. A good mixture with the right consistency produces a slight sheen with no dry spots. A mixture that is too dry has a dark, sandy appearance (dry consistency). A mixture that is too wet has a runny, wet appearance and sags easily (wet consistency). The shotcrete should have a steady flow. If the flow becomes intermittent or stops, the nozzleman must direct the nozzle away from the work.

Fig. 8.3(a)—Correct gunning positions. Correct shooting position is to hold nozzle at 90 degrees (perpendicular) to surface.

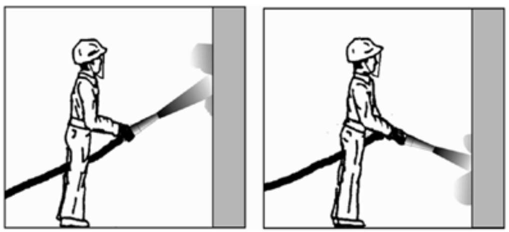

Fig. 8.3(b)—Incorrect gunning positions. Not perpendicular to surface.

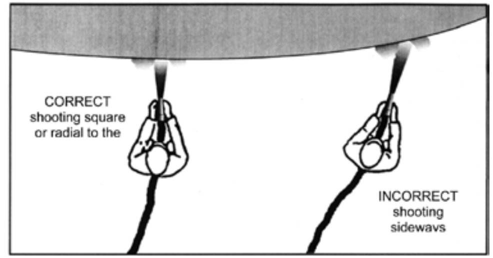

Fig. 8.3(c)—Correct and incorrect gunning positions. View from overhead.

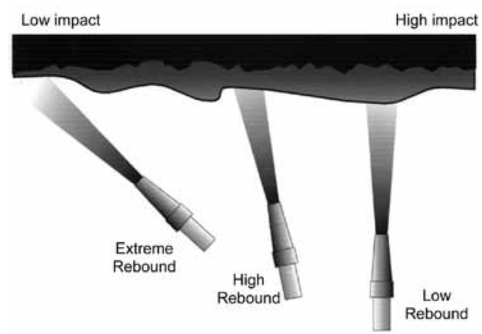

Fig. 8.4—Effects of nozzle angle on degree of material impact and amount of rebound produced.

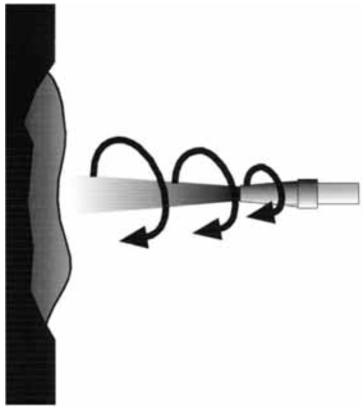

Fig. 8.5—Manipulating nozzle to produce quality shotcrete application.

To achieve a smooth, flat surface, the nozzleman must rotate the nozzle in small circles (Fig. 8.5). Shooting overlapping circles helps mix the material and produces a smooth surface that requires minimum cutting and finishing and improves mixing and consolidation.

8.3—Wet-Mix Shotcrete

Wet-mix techniques are similar to dry-mix techniques. Because the wet-mix process delivery hose is full of concrete, the wet-mix process produces nearly four times as much material per hour as the dry-mix process using the same size hose. Although the wet-mix nozzleman does not have to adjust the water, he must control the greater volume of material. Because the wet-mix material hose is full of concrete, it is heavier than a dry-mix hose and therefore more difficult to maneuver. Wet-mix is usually pushed through the material hose by a pump that strokes, which makes the material come out in surges. The wet-mix nozzleman must plan nozzle movements to coincide with the surges in the material flow. Should the line plug or if the air is cut off, reducing the velocity of the shotcrete, the nozzleman should direct the nozzle away from the work. When beginning, the nozzleman should also direct the nozzle away from the work because material used to slick the material line is not suitable for incorporation in the work.

8.4—Horizontal Surfaces

Horizontal surfaces are usually cast rather than shot. It is difficult to shoot a horizontal surface and prevent the incorporation of rebound into the work. Dry-mix and wet-mix techniques are a little different for shooting horizontal surfaces.

8.4.1—Dry-Mix Shotcrete

As with all shotcreting, the nozzle stream should be directed perpendicular to the receiving surface. To shoot perpendicular to a floor, the dry-mix nozzleman must loop the material hose overhead and direct the nozzle at his toes. Aggregate will bounce off the floor until a bed of paste builds up, which can absorb the impact of the aggregate. Rebound (bouncing aggregate) will quickly collect around the nozzleman. To control the build-up of rebound, the nozzleman must move quickly, covering the entire area with a light coating of cement paste and continually repeat the process. In addition to the rebound accumulating, overspray becomes attached to the surrounding vertical surfaces. Overspray is also controlled by continually coating the edges and corners with fresh paste to absorb future overspray. The nozzleman works from the edge and builds towards the center (Fig. 8.6). Vertical surfaces need to be repeatedly recoated. If left uncoated, overspray will accumulate on the vertical surfaces, forming a porous lens. Continually shooting thin layers provides a paste bed that can absorb overspray. During shooting, rebound and overspray may look like good shotcrete, so the nozzleman must keep moving in a regular pattern, continually freshening all surfaces. The final job is eventually made up of many thin layers. Only work an area small enough so that it can be quickly recoated.

8.4.2—Wet-Mix Shotcrete

The wet-mix nozzleman also starts shooting in the

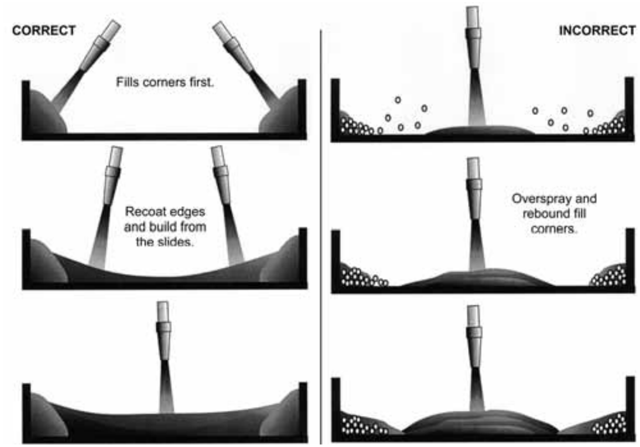

Fig. 8.6—Proper and improper sequencing of shooting horizontal surface.

corners but will bring the slab to full thickness by shooting down at a 45-degree angle. Wet-mix is continually applied at a 45-degree angle to the floor and 90 degrees to the receiving surface edge into the just previously placed shotcrete. Shooting into the thick bed of fresh paste will absorb most of the aggregate and minimize rebound.

8.5—Corners

Shotcrete placed into the corner formed by two vertical

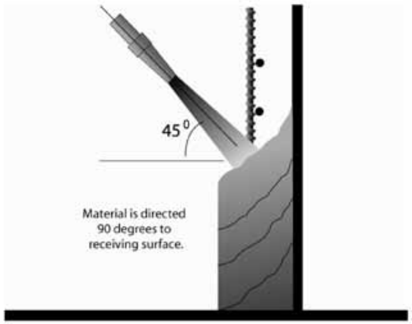

Fig. 8.7—Bench shooting for thick, heavily-reinforced wall.

surfaces should be shot at a 45-degree angle into the corner so the corner will fill out and provide a surface of approximately 45 degrees to a wall intersection. Rebound is controlled by directing the nozzle so the shotcrete stream hits the previously placed material at a 90-degree angle. Corners and cavities are shot first, otherwise rebound and overspray will accumulate. When shooting along a wall, the nozzleman must move ahead to obstacles and encase them to prevent them from accumulating rebound and overspray.

8.6—Vertical Surfaces

Benching and vertical layering are the two different methods used to shoot vertical walls.

Fig. 8.8—Bench shooting thick preconstruction panel.

8.6.1—Bench Shooting

Bench shooting is the most common method used to shoot thick, heavily-reinforced walls. Benching requires adequate support of the freshly applied shotcrete from below. Shooting begins at the base. The nozzle is directed at a 45-degree angle into the floor-wall corner (Fig. 8.7 and 8.8). Material will develop a 45-degree slope into which the nozzleman continually directs the nozzle stream. The slope allows rebound to roll off. The nozzle stream is kept perpendicular to the surface of the previously placed material to reduce rebound and ricocheting. Nozzlemen usually work along the length of the wall, shooting the bottom 1/2 or 1 m (1-1/2 or 3 ft), and then going back to build up another 1/2 m (1 to 2 ft) after initial set has occurred. If plastic shotcrete is stacked too high, sags and voids will occur under horizontal bars. In the extreme, the entire wall can sag or slough. The height the nozzlemen builds the wall depends on the stiffness of the mixture (which is affected mostly by the mixture proportions and temperature) and the roughness of the substrate. An air lance (blow pipe) is sometimes operated by another crew member to remove rebound.

8.6.2—Vertical Layers

Vertical layering is another method used to build a wall. A wall built using vertical layering is made up of multiple thin vertical layers of shotcrete each placed on the previous layer (Fig. 8.9). Support is by adhesion to the previous layer. The nozzle stream should be directed perpendicular to the work surface and slightly upward, particularly if encasing steel. Shotcrete should be placed from the bottom working up, but can sometimes be placed from the top down, provided the material will stay in place and rebound can be removed. The thickness of a vertical layer depends on the stiffness of the mixture and the roughness of the substrate. A smooth substrate surface may only hold a 12 to 25 mm (1/2 to 1 in.) thick layer while a rough surface may hold a 50 mm (2 in.) thick layer. At the bottom, like bench shooting, the nozzle should be directed at a 45-degree angle into the floor-wall corner and back against the just-placed shotcrete. To achieve a smooth surface, rotate the nozzle tip to create overlapping circles. The overlapping circles give the nozzleman the opportunity to fill in low areas in a smooth sweeping motion.

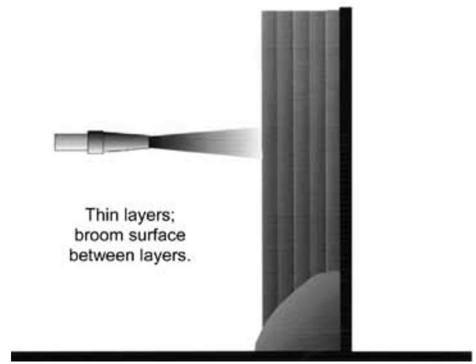

Fig. 8.9—Vertical layering for building a wall.

8.7—Overhead Surfaces

Placing material overhead is difficult. Until a thick enough bed of material is developed to absorb the aggregate, nearly everything shot up comes right back down onto the nozzleman. Overhead work is most commonly placed in thin layers to prevent sagging or dropouts. When

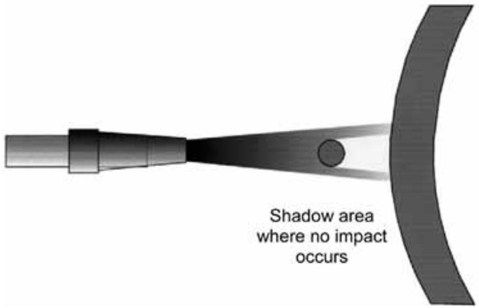

Fig. 8.10—Resulting shadow behind reinforcing bars where no impact occurs.

shooting overhead surfaces, accelerators are sometimes added to the mixture to allow shooting thicker layers. As in shooting vertical and horizontal surfaces, the nozzle should always be held perpendicular to the receiving surface. Rebound is usually not a problem other than severely obstructing the nozzleman's visibility. Overspray still occurs but can be controlled by continually moving and covering the area with thin coats of shotcrete. Higher air pressure can assist in placing the material overhead.

8.8—Encasing Steel

Properly encasing reinforcing steel with shotcrete is important. As the shotcrete mixture passes by bars or other obstructions, a shadow area behind the bar is not directly impacted by the shotcrete stream (Fig. 8.10). The size of the shadow increases as the distance from the receiving surface increases and as the size of the obstacle increases. Because the material stream does not impact the shadow area, the shotcrete behind the bar is not properly compacted. Voids can develop. To fill in the shadow area behind bars, the dry-mix shotcrete must have good consistency, the wet-mix shotcrete must have good workability and both processes require sufficient impact velocity so that the material will flow easily around the bar (Fig. 8.11) and be spread into the shadow area from compaction. A mixture that is too stiff or is not hitting with sufficient impact velocity will build up on the face of the bars, creating a larger obstacle and forming a void behind the bars. High impact velocity can, to some degree, overcome a stiff mixture and force material to flow around steel. Moving the nozzle closer to the work can increase impact velocity. Typically, 0.6 to 1.2 m (2 to 4 ft) is the proper distance. Adding more air at the nozzle can also increase impact velocity. Another indication of good encasement is the formation of a ridge instead of a valley behind a bar (Fig. 8.11).

The proper material consistency (dry-mix) and workability (wet-mix) is the key to good encasement. To properly encase steel, the shotcrete mixture (wet-mix) should have a 50 to 75 mm (2 to 3 in.) slump. A high-plasticity mixture (75 to 100 mm [3 to 4 in.] slump)

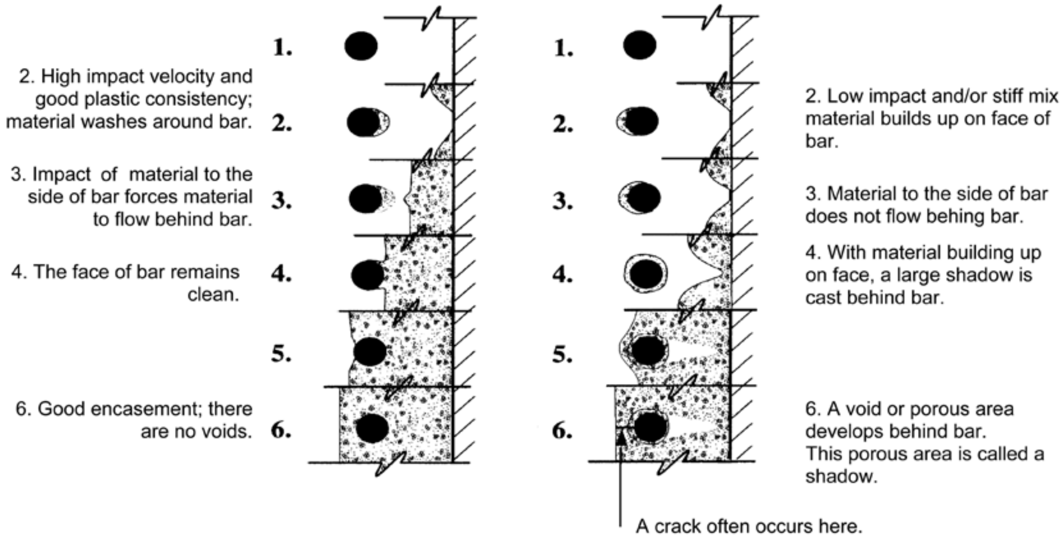

Fig. 8.11—Correct and incorrect way to encase reinforcing steel.

requires less impact velocity to force material to flow around to the backside of an obstacle. It is the nozzleman's job to make sure that there is both sufficient plasticity and impact velocity. When the combination of plasticity and velocity is right, the face of the steel will glisten and remain clean. Deformations on reinforcing bars will be clearly visible. A ridge building up at the back of the bar, rather than a valley, will develop behind the bar. Figures 8.12 to 8.15 illustrate the results of good and poor encapsulation techniques.

Encasing bars larger than 15M (No. 5) bars requires a wetter consistency for dry-mix and a higher slump with wet-mix shotcrete. Reducing or eliminating the shadow can be achieved by directing the shotcrete placement at

Fig. 8.12—Proper encapsulation of reinforcing steel. Good compaction and proper velocity. Note glossy appearance, bar deformation, and even build-out of shotcrete.

Fig. 8.13—Another quality application. Note even build-out of material and how ridge has been formed in it.

Fig. 8.14—Example of poor encapsulation. Material is too dry and shadows have formed behind bars. Also note obvious valleys in shotcrete material.

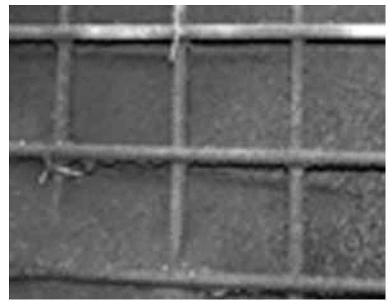

Fig. 8.15—Another poor job. There are shadows behind bars and valleys in material. Note sandy dry surface and lack of any glossy appearance.

a slight angle from both sides to force the material behind the bar (Fig. 8.16). A normal slump of 50 to 75 mm (2 to 3 in.) may be required. The volume should be reduced and the nozzle stream directed so material can hit the area directly behind the reinforcement (thereby reducing the shadow area). In some cases, the air volume must be reduced and the nozzle brought in closer to the work.

8.9—Crew Responsibilities

A shotcrete crew is usually made up of a foreman, nozzleman, air-lance operator, laborers, finishers, and either gun operator or pump operator. The foreman is responsible for planning and organizing the crew and work. The finisher trims and scrapes the shotcrete, bringing it to line and grade, and may also apply a finish to the surface. The gunman and pump operator are responsible for operation and maintenance of the equipment. An air-lance operator is needed to remove rebound and overspray in some situations.

The nozzleman is responsible for the placement of the shotcrete and provides the leadership necessary for a quality shotcrete job. If the mixture is too stiff, if there is insufficient air for velocity, if the wind is blowing too hard, if the forms are vibrating, or if the scaffolding is not safe, the nozzleman should stop shooting and correct the problem before continuing. Many problems with shotcrete are caused by a lack of skill, knowledge, or leadership on the part of the nozzleman. The nozzleman is the only person that sees all the material as it is being placed and is a key person in getting a good quality shotcrete job. Handling a nozzle is difficult. The nozzle and hose are heavy, and shotcrete exiting with a high velocity creates a backpressure that the nozzleman must also counteract. It may take some time for new nozzlemen to develop the instinctive skills needed to both hold the nozzle and properly direct it. Good nozzlemen are craftsmen. A good nozzleman is relaxed, acts instinctively, and plans future movement, which allows for smooth transition from one part of the job to the next.

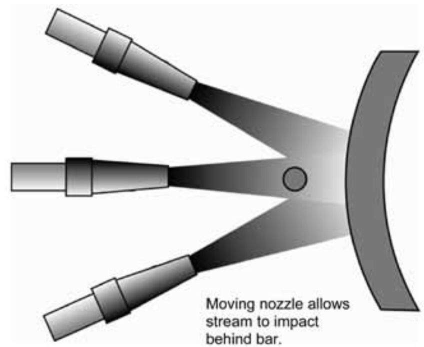

Fig. 8.16—Encasing large diameter bars. Angle nozzle slightly to force material behind bar.