out. Dropouts may also occur in overhead work where too much material is gunned or hung in one location at one time. Too little water leaves a dry, dark, sandy surface with no gloss. This condition increases rebound, increases the likelihood of sand pockets, makes finishing difficult, and can produce weak and laminated shotcrete. For effective water control, the water pressure at the nozzle should be substantially greater than the air pressure.

The wet-mix nozzle operator has no control over the water content. The slump of the concrete mixture should be maintained between 1-1/2 and 3 in. (40 to 75 mm). Below a 1-1/2 in. (40 mm) slump, rebound becomes more pronounced, and shotcrete will not readily flow around reinforcement, whereas shotcrete at slumps above 3 in. (75 mm) may develop sagging, puddling, or dropouts in vertical and overhead applications. Higher-slump material may be appropriate for horizontal surfaces.

8.5.4 *Impact velocity*—The velocity of the material at impact is an important factor in determining the ultimate properties of the shotcrete and to adequately encase reinforcement. For most applications where standard nozzle distances of 2 to 6 ft (0.6 to 1.8 m) are used, the impact velocity is a little less than the material velocity at the nozzle. At greater nozzle distances, the impact velocity is considerably less, and it may be necessary to increase the nozzle velocity so that the impact velocity will suit the requirements of the application. Greater distances are sometimes allowed with remote-controlled manipulator arms.

With dry-mix shotcrete, the factors that determine material velocity at the nozzle are volume and pressure of available air, hose diameter and length, size of nozzle tip, type of material, and the application rate it is being gunned at. These factors allow for great flexibility and versatility because large, intermediate, or small volumes of material can be gunned at low, medium, and high velocities according to the immediate needs of the application. Small or large variations in flow, water content, and velocity can be made on order from the nozzle operator.

The type of application and the limitations of workability required for pumping predetermine the water content in wet-mix shotcrete. This usually limits the use of this method to applications with low and medium velocities and large volume, although smaller-volume wet-mix pumps are now available.

8.5.5 *Nozzle technique and manipulation*—Proper nozzle operation is physically demanding. Nozzle technique for wet-mix and dry-mix processes is generally similar, both requiring considerable attention to detail. Because the capabilities of wet-mix and dry-mix procedures and equipment are different, each requires a somewhat different expertise from the nozzle operator, and he or she should not assume that the nozzle techniques are exactly interchangeable, especially the finer details of the skill (Crom 1978).

8.5.6 *Thickness and work position*—Shotcrete may be applied in layers or a single thickness, depending on the position of the work. Overhead work is typically gunned in layers just thick enough to prevent sagging or dropouts, usually 1 to 2 in. (25 to 50 mm). Vertical surfaces may be applied in layers or as a single thickness, while horizontal or flat surfaces are usually gunned in a single thickness. In any case, the thickness of a layer is governed mainly by the requirement that the shotcrete should not sag. Sags or sloughs that go undetected and not removed can hide internal cracks and hollows that make the shotcrete vulnerable to water penetration, freezing-and-thawing action, and reduction or loss of bond between layers.

8.5.7 *Shooting*—Each layer of shotcrete is built up by making several passes of the nozzle over a section of the work area. Whenever possible, sections should be gunned to their full design thickness in one layer, thereby reducing the possibility of cold joints and laminations. The shotcrete should emerge from the nozzle in a steady, uninterrupted flow. Should the flow become intermittent for any reason, the nozzle operator should direct the stream away from the work until it becomes constant. The distance of the nozzle from the work, usually between 2 and 6 ft (0.6 to 1.8 m), should be such as to give best results for work requirements. As a general rule, the nozzle should be held perpendicular to the receiving surface but never oriented at more than 45 degrees to the surface (Fig. 8.1(a) and (b)).

When the nozzle is held at too great an angle from perpendicular, the shotcrete rolls or folds over, creating an uneven, wavy-textured surface that can trap greater amounts of rebound, and overspray. This process, known as rolling, is not a recommended nozzle technique, wastes material, and may create porous and non-uniform shotcrete.

To uniformly distribute the shotcrete and minimize the effect of slugging, the operator should direct the nozzle perpendicular to the surface and rotate it steadily in a series of small oval or circular patterns (Fig. 8.2).

Waving the nozzle quickly back and forth changes the angle of impact, wastes material, increases overspray, and unnecessarily increases the texture roughness of the surface.

8.5.8 *Encasing reinforcement*—Reinforcing bars interrupt the material stream, so the area behind the bar is not compacted by the following stream of shotcrete material. This area behind reinforcement needs to be filled either by material that flows around the bar or by having the stream directed behind the bar. A shotcrete mixture that has good impact and sufficient plasticity will flow around and completely encase the reinforcement. High impact velocity will also force stiffer material around the reinforcement. The nozzle operator can increase the impact velocity by moving closer to the work. Sufficient plasticity is more important than high impact velocity when encasing reinforcement. Observing the face of the reinforcement during application of shotcrete will provide an indication of the quality of encasement. When deformations (ridges) on the face of the reinforcement are clearly visible, it is a good indication that material is flowing around the reinforcement, and the reinforcement should become adequately encased.

Larger reinforcement requires a more plastic mixture for good encasement, and the angle of the material stream should be adjusted to ensure the area behind the reinforcement is compacted. For even larger or congested reinforcement, the nozzle operator may have to reduce the air volume and insert

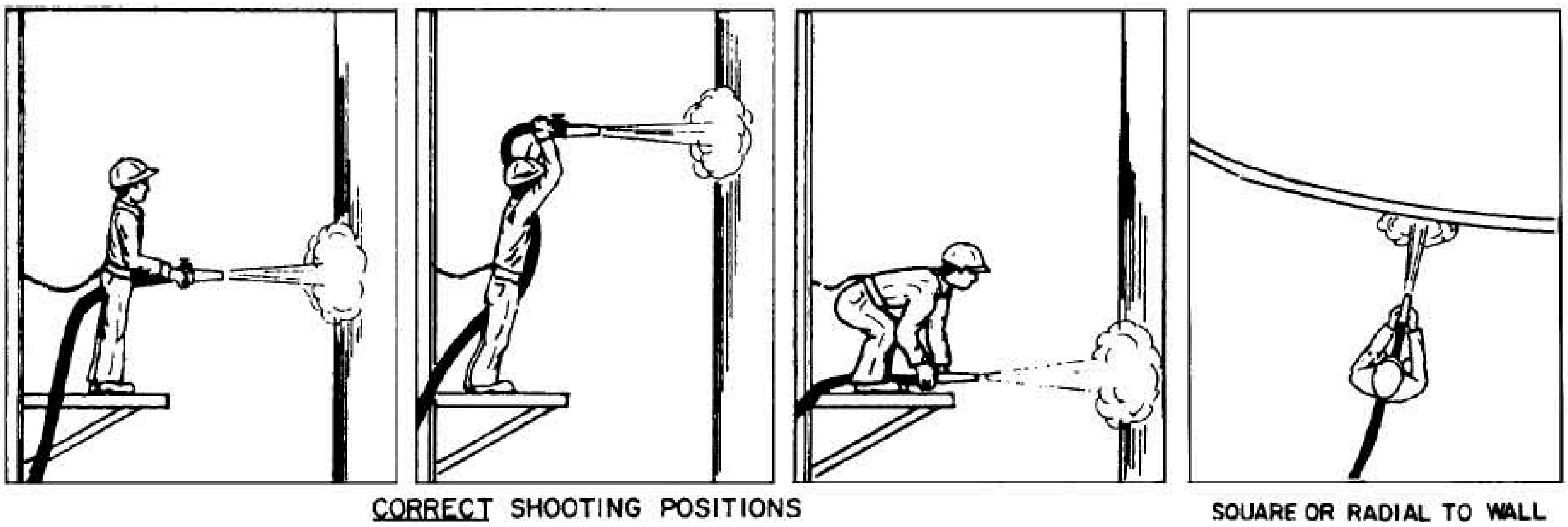

Fig. 8.1(a)—Shooting positions.

Fig. 8.1(b)—Correct shooting position.

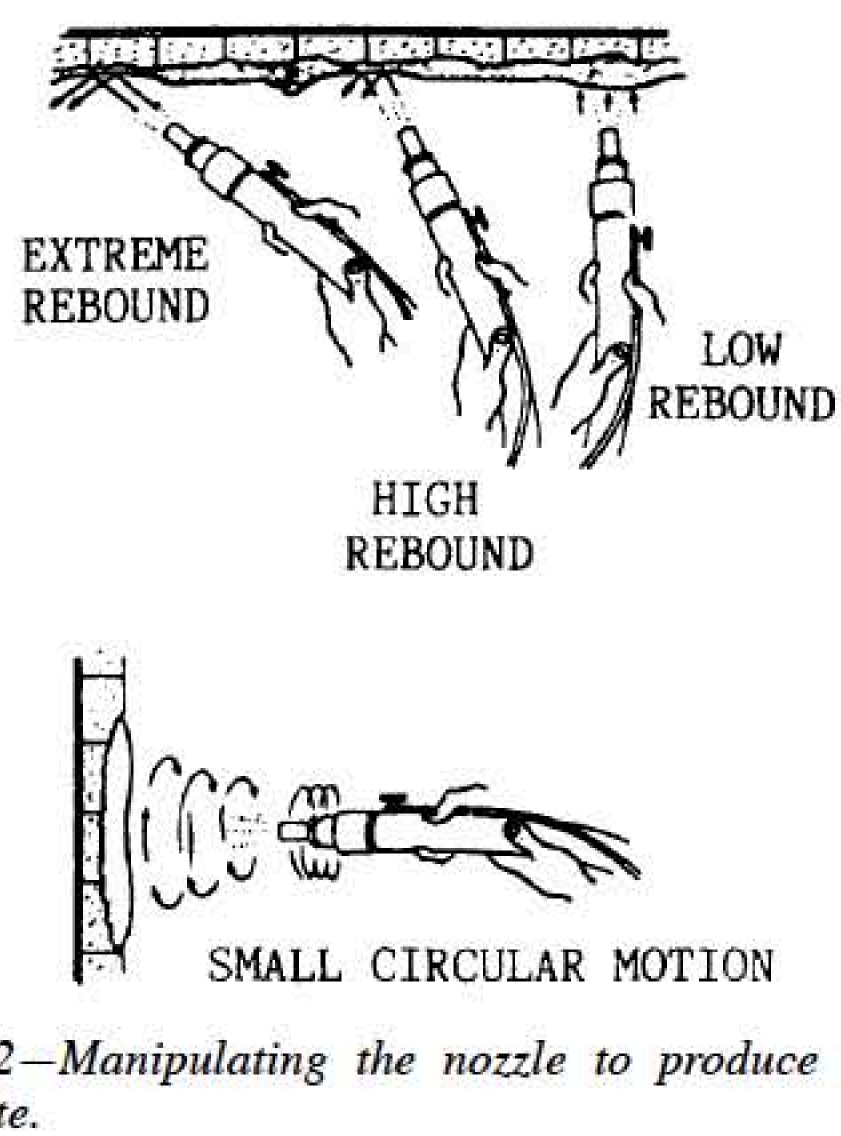

Fig. 8.2—Manipulating the nozzle to produce the best shotcrete.

the nozzle tip behind the bars. When working in close, the volume and velocity of the shotcrete should be reduced to prevent a blowback of air that will create voids. Voids will develop if sloughing occurs behind the bars.

When shooting walls in vertical layers, the application should begin at the bottom and fill corners. The first layer should, if possible, completely encase the reinforcement adjacent to the form. Subsequent layers should be thin enough so that sloughing and sagging does not occur. The allowable thickness is dependent primarily on the plasticity of the shotcrete and the texture of the receiving surface.

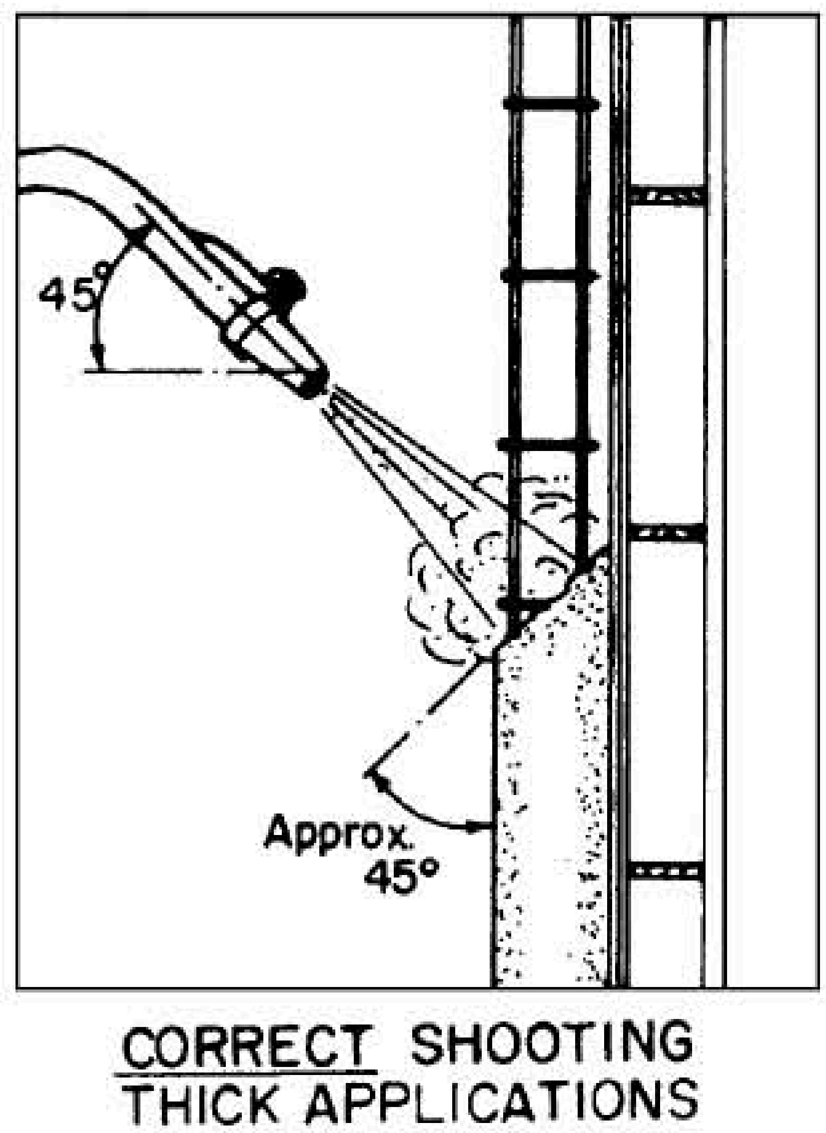

Fig. 8.3—Bench or shelf shooting of concrete.

The other method of constructing a vertical wall (over 6 in. [150 mm]) is to shelf or bench shoot. Instead of shooting directly against the vertical surface, a thick layer of material is built up at the bottom. The nozzle stream is directed into the top surface that is maintained at an approximately 45-degree slope (Fig. 8.3). The lift height is dependent on the slump of the shotcrete, reinforcement spacing, receiving surface texture, weather, and other factors. Shotcrete lift height should be limited to prevent sloughing and sagging. The timing between lifts is also dependent on many variables. Successive lifts can be placed when the previous lift is sufficiently stiff to support the weight of the next lift (Fig. 8.4).

When shooting horizontal slabs, the operator should hold the nozzle at a slight angle from the perpendicular so that the rebound is blown onto the completed portion where it can be removed.