What's Happening in There?

Part 1: Critical elements that dramatically affect shotcrete's hardened properties occur hidden from sight within the nozzle stream

By Oscar Duckworth

Can the skill of the nozzleman be a factor in diminishing or even eliminating rebound? The answer may surprise you

Is this much rebound normal? Bet you've heard that comment before. How much rebound is normal? Rebound and its effects can be a hot topic for not only nozzlemen and crews but also engineers and inspectors, all whose goal is to produce a quality job.

Can the skill of the nozzleman diminish rebound? Rebound is aggregate that, due to impact at high velocity, ricochets off the receiving surface or other hard objects and falls onto lower surfaces. Its control during shotcrete placement will strongly influence both the amount of costly wasted material, and the quality and durability of the in-place work. Unfortunately, rebound is an unavoidable by-product of high-velocity shotcrete placement. Therefore, rebound can never be eliminated. Because rebound will always occur, obtaining a quality product is reliant on the nozzleman and shotcrete crew controlling it during placement.

There are two distinct steps to the control of rebound:

1. Use placement methods to diminish the formation of rebound; and
2. Prevent rebound from being trapped within the in-place material.

Concrete Mixtures + High-Velocity Impact = Separation

Specifications for typical form-and-pour concrete placement have prohibited plastic concrete materials from being dropped excessively for decades, and for good reason. Does concrete bruise easily? Probably not. However, because concrete is a mixture of many individual components, if materials exiting the delivery chute or placement equipment can free fall more than a few feet (meters), the mixture will gain significant velocity. Separation of the aggregates and other particles is likely to occur as the fast-moving material collides with the reinforcing steel or other surfaces at the bottom of the form. This classic problem is easily mitigated by using well-established placement methods. A pipe, belt, or hose depositing materials at or near the bottom of the form slows the materials' downward velocity; therefore, the potential for separation is eliminated.

Clearly, with shotcrete placement, rebound is a form of concrete separation caused by the concrete's velocity upon impact. Because shotcrete is placed with a high-velocity nozzle stream, the fast-moving, larger particles tend to bounce off all hard surfaces. This is the cause of rebound. Diminishing shotcrete's velocity to stop rebound is not practical because all of shotcrete's compaction and consolidation properties are derived from high-velocity impact.

WHY REBOUND MATTERS

Rebound is mainly larger aggregates with little or no encapsulating paste. It is porous and does not possess structural properties. Essentially, it is just a pile of rocks and sand. Rebound that does not fall clear of the concrete section can become unintentionally trapped by the deposition of additional shotcrete material (refer to Fig. 1). Trapped rebound results in loose, unconsolidated aggregate lenses within the in-place concrete section. Loose aggregates, rather than well-consolidated concrete encapsulating the embedded reinforcement, reduce the structural strength. If embedded areas of rebound are widespread, the concrete sections may become structurally deficient and unable to carry the design loads. Loose, entrapped rebound will also provide internal moisture paths that can reduce water tightness and accelerate corrosion of the embedded steel. Over time, with moisture flow through the trapped rebound, unsightly efflorescence deposits can build up on the surface. With poor nozzling techniques, trapped rebound can occur anywhere within shotcrete work, but corners, joints, and areas of congested steel reinforcement are especially susceptible.

Because rebound is continuously generated during shotcrete placement, rebound must be continuously controlled. Because the methods used by the placement crew to control rebound will strongly influence the structural integrity of the completed concrete section, it is the responsibility of the nozzleman and crew to use established techniques that both diminish the formation of rebound and continuously keep the receiving surfaces free of rebound during placement.

Fig. 1: Test specimen displays loose aggregates that did not fall clear of the work and became trapped behind reinforcements

Fig. 2(a)—This freshly applied surface glistening with paste is evidence that the slump is ideal. Reinforcement bars are clean, without buildup. Fast-moving aggregates within the nozzle stream have become deeply embedded within the shotcrete surface, leaving a smooth, shiny paste layer

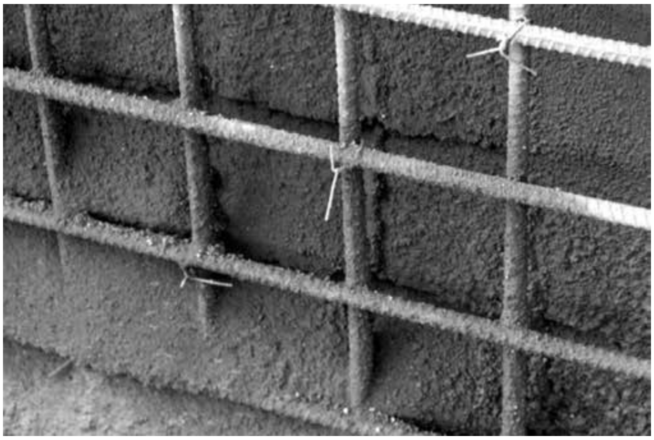


Fig. 2(b)—Buildup on reinforcement and a dull, sandy, or rocky surface is evidence that the material is likely too stiff. The mixture lacks fluidity and is sticking to the reinforcement. Aggregates are not embedding and have either bounced off or remain at the surface, leaving a dull, sandy, or rocky layer

THE NOZZLEMAN'S ROLE IN DIMINISHING THE FORMATION OF REBOUND

The role of the nozzleman in preventing the detrimental effects of rebound cannot be overemphasized. It is the nozzleman's responsibility to use appropriate techniques and continuously maintain the correct slump for the project at hand. Nozzleman skill and the proper choice of slump during placement is one of the primary factors affecting the formation of rebound. Slump is a numerical value indirectly corresponding to the flow characteristics or workability of a mixture at a given moment. The nozzleman must constantly use visual indicators rather than a specific slump range to determine whether the flow characteristics of material are correct, or need to be adjusted. Although recognizing the appropriate workability for a given project through its slump value is important, it is not exact. With experience, the nozzleman should be able to more accurately maintain proper workability by visually monitoring the surface and the freshly applied materials behavior as it is applied. The nozzle stream should flow easily but not excessively around reinforcements, and produce a surface that displays a glossy and smooth outer layer, rather than a sandy or rocky surface.

A relatively smooth surface, glistening with paste, indicates that the mixture is sufficiently workable (refer to Fig. 2(a)). This surface is evidence that fast-moving aggregates within the nozzle stream have become deeply embedded within the shotcrete surface, leaving a glistening, glossy paste layer. Buildup on reinforcement or a dull, sandy, or rocky surface is a red-flag indicator that the material is too stiff (refer to Fig. 2(b)). The mixture lacks fluidity and some of the aggregates are not embedding. Aggregates that have either bounced off or remain slightly embedded at the surface leave a dull, sandy, or rocky layer.

Rebound increases dramatically if aggregates cannot embed at impact. Do not increase the slump excessively; too high of slump will certainly create other placement problems. Nozzlemen must control rebound by using important visual indicators at the surface of the freshly applied material to continuously maintain a sufficiently workable mixture.

MIXTURE RHEOLOGY

Mixture rheology is a term used to define the physical properties of a concrete mixture in its fluid or plastic state. Mixture choices that affect rheology have a powerful effect on the rebound rate. Mixture choices such as the use of silica fume, fibers, or certain admixtures can be used to significantly reduce the rebound rate through the paste layer's ability to retain, rather than ricochet materials as impact occurs at the receiving surface.

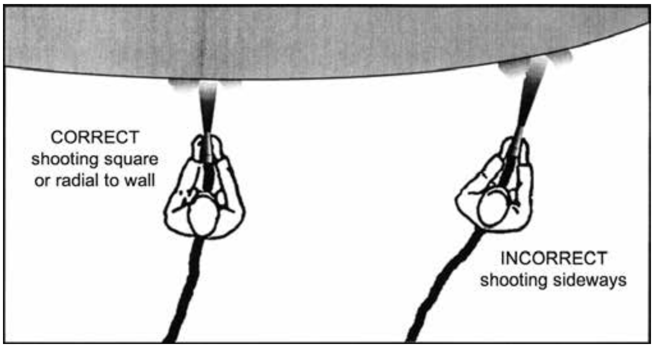


Fig. 3—Correct and incorrect gunning positions from view from overhead (ACI CP-60(15), p. 58)

Fig. 4—Blow pipe operator continuously maintains a clean receiving surface by working ahead of nozzle stream

NOZZLE DISTANCE AND ANGLE

The nozzleman must maintain a position that orients the nozzle stream perpendicular to the work's receiving surface. Shooting at an angle other than perpendicular causes excessive rebound and should be avoided (refer to Fig. 3).

Use nozzle technique, distance, and angle to focus the nozzle stream primarily into a developing puddle of material at the receiving surface rather than directing the nozzle onto a hard-receiving surface. Shooting into a puddle of material dramatically reduces rebound.

Keep the nozzle close to the receiving surface, especially when working within congested reinforcement patterns. Nozzle velocity diminishes quickly as distance increases. Insufficient velocity cannot properly embed aggregates and will create excessive rebound. Use bench shooting techniques when working within congested reinforcement patterns and, when possible, direct the nozzle stream mainly through openings and around obstacles within the reinforcement pattern.

PREVENT REBOUND FROM BEING TRAPPED WITHIN THE IN-PLACE MATERIAL

Techniques used to control rebound created can substantially reduce the amount of rebound; however, they cannot eliminate it entirely—some rebound will always occur.

Because rebound is continuously generated during shotcrete placement, the continuous use of proper nozzle techniques, in conjunction with the proper use of a blow pipe when needed, are necessary requirements to prevent trapped rebound. The continuous use of a blow pipe or other suitable device is a required placement step in the current ACI 506.2-13, "Specification for Shotcrete":

"3.4.3.4 Shotcrete crew shall continuously remove accumulations of rebound and overspray using a compressed air blowpipe, or other suitable device, in advance of deposition of new shotcrete."

During placement, the blow pipe operator should work immediately ahead of the nozzle stream, continuously sweeping the receiving surface as material is being applied (refer to Fig. 4).

The blow pipe valve should be adjusted to supply enough air to easily displace rebound, but not displace freshly applied concrete materials. Rebound tends to accumulate in corners, ledges, joints, and behind reinforcement, where the nozzle stream cannot effectively embed the aggregates or blow them free of the work. The blow pipe operator must be especially vigilant in these areas to maintain a clean receiving surface. Placement should always begin in bottom corners or other areas that may trap rebound. Filling these areas first prevents accumulation of rebound. If possible, avoid aiming the stream directly toward, but rather on either side of reinforcement or other obstacles. Materials striking hard objects will rebound excessively. Use bench shooting techniques when working within congested reinforcement

Fig. 5(a)—Maintain a relatively sharp angle and completely cover reinforcements to encourage rebound to fall free of the work

Fig. 5(b)—Close-up reveals what can occur when reinforcement is not properly covered by the nozzleman. Rebound will become trapped by the deposition of additional material if it is not blown free of the work. This is the likely cause of the flaws within the test specimen in Fig. 1

patterns. Maintain a fairly sharp angle along the top of the bench to encourage rebound to fall free rather than become trapped and fill around reinforcements completely to diminish potential accumulations behind bars (refer to Fig. 5(a) and (b)).

HOW TO MAKE A USEFUL BLOW PIPE

Want to make a blow pipe? What could be easier? A fitting, a valve, and a few feet of pipe, and we have the perfect blow pipe. Or do we? An effective blow pipe must be capable of continuously keeping a receiving surface free of rebound as material is being applied. Although this task seems simple, the compressed air stream from a blow pipe can easily disrupt the nozzle stream's compaction and consolidation or disturb in-place material if the blow pipe air stream is too powerful. The blow pipe tip's shape plays a role in its usefulness. A blow pipe with an open tip can consume a LOT of air and thus a large portion of the air compressor's total output, potentially leaving insufficient air to accelerate concrete from the nozzle. Even with a relatively low air volume, an open tip will create a narrow, powerful stream that can displace or even blow a hole into freshly placed material during use. The design in Fig. 6 requires far less air flow. It creates a wide fan pattern that is powerful enough to clear rebound, but cannot easily displace material. A blow pipe 3 ft (0.9 m) in length sweeping a foot or two (0.3 to 0.6 m) from the receiving surface yields effective cleaning and excellent range of motion while giving the nozzleman sufficient working room for placing concrete.

An air compressor should be properly sized to adequately provide air flow to both the nozzle and blow pipe. If operation of the blow pipe causes a noticeable loss of air to the nozzle, the compressor is too small and must be upsized.

Fig. 6—This blow pipe is constructed from 0.75 in. (19 mm) steel pipe, approximately 3 ft (0.9 m) long. The tip has been shaped to a width of 0.25 in. (6 mm) with common tools to provide a wide fan pattern. It is efficient, durable, and requires very little air

It is important to remember that the control of rebound is the responsibility of the nozzleman and crew (refer to Fig. 7). Because rebound is continuously generated during shotcrete placement, the continuous use of proper nozzle techniques, in conjunction with the proper use of a blow pipe when needed, are necessary requirements to a quality job.

Fig. 7—The nozzleman and blow pipe operator working side by side

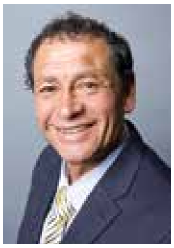
Safety Tip

The blow pipe is a dangerous tool. A high-powered compressed air stream can cause serious injuries. Never direct the stream towards someone. Exercise caution when handling a blow pipe.

NOZZLEMAN'S CHECKLIST

There are two distinct steps to the control of rebound. The nozzleman must use placement methods to diminish the formation of rebound and prevent rebound from being trapped within the in-place material, such as:

- Using visual cues to continuously maintain the correct slump for the project at hand;
- Considering recommended mixture design choices such as the use of silica fume, admixtures, or fibers to diminish the formation of rebound;
- Focusing the nozzle stream primarily into the developing puddle of material rather than directing the nozzle onto a hard receiving surface;
- Positioning the nozzle stream perpendicular to the receiving surface—shooting from an angle causes excessive rebound;
- Starting in corners or other areas that may trap rebound;
- Directing the blow pipe operator to work immediately ahead of the nozzle stream by continuously sweeping the receiving surface as material is being applied; and
- Using a blow pipe that uses a fan pattern that is powerful enough to clear rebound, but cannot easily displace material.



*ACI Certified Nozzleman **Oscar Duckworth** is an ASA and American Concrete Institute (ACI) member with over 25,000 hours of nozzle time. He has worked as a nozzleman on over 2500 projects. Duckworth is currently an ACI Examiner for the wet- and dry-mix processes. He serves on the ASA Board of Direction and as Chair of ASA's Education Committee. He continues to work as a shotcrete consultant and certified nozzleman.*