Concrete vibration

The why and how of consolidating concrete

By Bruce A. Suprenant
Department of Civil Engineering & Mechanics
University of South Florida
Tampa, Florida

What factor has a greater effect on concrete compressive strength than any other? Most engineers would say water-cement ratio . . . as water-cement ratio increases strength decreases. Duff Abrams showed this in 1919, and Abrams' law is the principle behind most concreting proportioning methods used today. But Abrams ran his tests on fully consolidated concrete. Unless concrete is properly consolidated, voids reduce strength regardless of the water-cement ratio. And, as shown in Figure 1, the effect is significant.

Right after it's placed, concrete contains as much as 20% entrapped air. The amount varies with mix type and slump, form size and shape, the amount of reinforcing steel, and the concrete placement method. At a constant water-cement ratio, each percent of air decreases compressive strength by about 3% to 5%. Consolidating the concrete, usually by vibration, increases concrete strength by driving out entrapped air. It also improves bond strength and decreases concrete permeability.

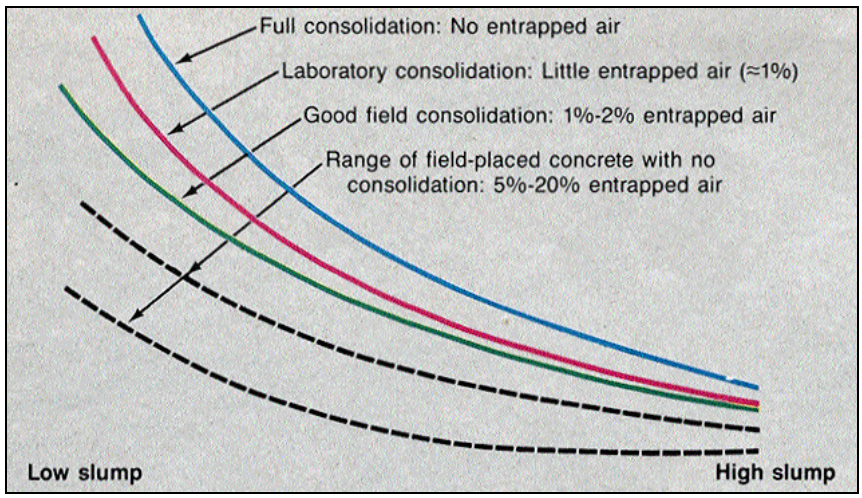


Figure 1. **Degree of consolidation can have as much effect on compressive strength as water-cement ratio. Low-slump concrete may contain up to 20% entrapped air when placed.**

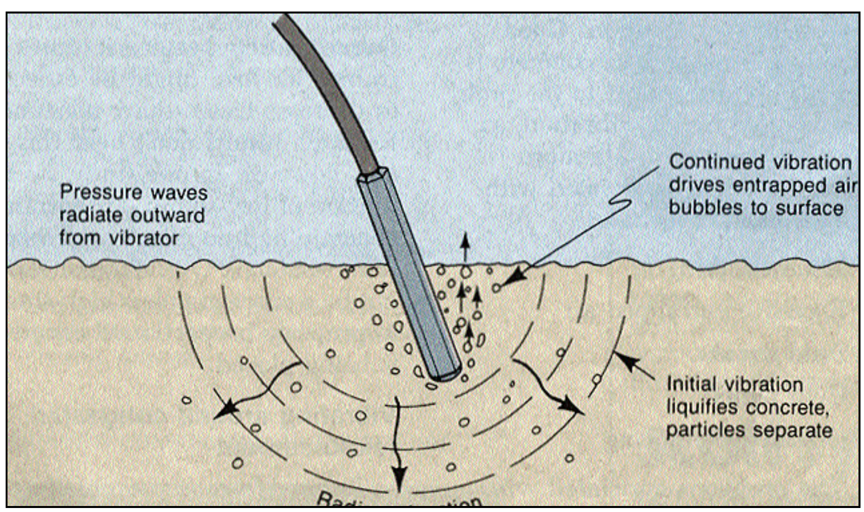


Figure 2. **A vibrator consolidates concrete in a two-part process. The first waves liquify the concrete so it flows better and the continuing waves knock out air bubbles.**

Vibration is a two-part process

How does vibration consolidate concrete? Figure 2 shows it to be a two-part process. A vibrator creates pressure waves that separate aggregate particles, reducing friction between them. Piles of concrete flat-

Figure 3. **The vibrator head must fit between the rebars and have a high enough frequency to quickly consolidate the concrete.**

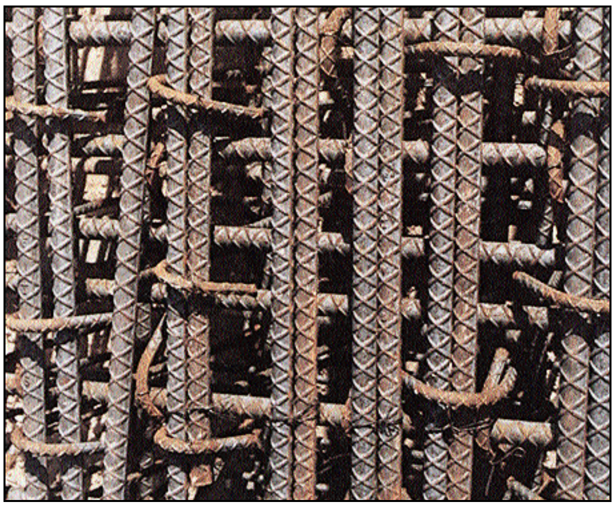


Figure 4. **Vibration alone won't consolidate concrete adequately when reinforcing is congested. To ensure adequate consolidation it may be necessary to use superplasticizers, reduce aggregate maximum size, or adjust rebar spacing.**

ten as the concrete flows around reinforcing steel and up to the form face. Large voids (honeycomb) disappear.

But making the concrete flowable doesn't finish the compaction process. Almost simultaneously, a second stage starts to occur as entrapped air bubbles rise to the surface. This deaeration process continues after the concrete has flattened out.

Until both vibration stages are complete, the concrete isn't fully consolidated. If the vibrator is removed too soon, some of the smaller bubbles won't have time to rise to the surface. Vibration must continue until most of the air entrapped during placement is removed. It's usually not practical, though, to remove all the entrapped air with standard vibrating equipment.

Different vibrators for different jobs

The earliest form of equipment used as a vibrator was a rod stuck into the concrete, pushed down and pulled up. Rodding works for concretes with slumps greater than 3 inches, but it's rarely used because of the costly labor required. Because rodding doesn't put extra pressure on forms, however, it has helped more than one contractor complete a concrete pour when forms were bulging.

The most common vibrator used is the electric, flexible shaft type. Other types include electric motor-in-head, pneumatic, and hydraulic. Vibrator output, usually expressed as a frequency, is controlled in a different way for each type of vibrator:

- An electric vibrator uses voltage.
- A pneumatic vibrator uses air pressure.
- A hydraulic vibrator uses pressure and flow rate of hydraulic fluid.

On the jobsite the contractor can check the operating performance of his equipment by measuring frequency. If it's low he should check for voltage fluctuations, air pressure losses, or hydraulic pressure drops.

The type of vibrator must match the requirements of the concrete and the jobsite (Figure 3). Frequency rates determine the amount of vibration time required to complete the two-stage consolidation process.

In the 1960s, vibration frequencies were much lower. To compact a ½-inch-slump concrete took 90 seconds at 4,000 vibrations per minute (vpm), 45 seconds at 5,000 vpm, and 25 seconds at 6,000 vpm. Today's typical frequency of 15,000 vpm requires only 5 to 15 seconds of vibration time.

Internal vibrators chosen for most jobs have a frequency of 12,000 to 17,000 vpm in air. The common flexible shaft-type vibrator reduces its frequency by about 20% when immersed in concrete. Motor-in-head types provide a constant frequency when in air or concrete.

How to use an internal vibrator

Producing a dense concrete without segregation requires an experienced vibrator operator. Inexperienced operators tend to merely flatten the concrete because they don't vibrate long enough to deaerate the concrete. Undervibration is more common than overvibration because of a worker's effort to keep up with the concrete or to increase productivity.

The operator can judge whether

or not vibration is complete by watching the concrete surface. When no more large air bubbles escape, consolidation is adequate. Skilled operators also listen to the pitch or tone of the vibrator motor. When an immersion vibrator is inserted in concrete, the frequency usually drops off, then increases, becoming constant when the concrete is free of entrapped air.

Never use a vibrator to move concrete laterally. Concrete should be carefully deposited in layers as close as possible to its final position in the form. As each layer is placed, insert the vibrator vertically. The distance between insertions should be about 1½ times the radius of action (usually 12 to 24 inches). Radius of action is a distance from the vibrator head within which consolidation occurs. It varies with equipment and concrete mix.

Walls and columns. Special techniques are necessary to blend layers of concrete in walls and columns. Let the vibrator penetrate quickly to the bottom of the layer and at least 6 inches into the preceding layer. Then move the vibrator up and down, generally for 5 to 15 seconds, to blend the layers. Withdraw the vibrator gradually with a series of rapid up and down motions.

Elevated beams and slabs. Beams and joists placed monolithically with slabs should be vibrated separately before slab placement. Place the slab concrete after vibrating the beam, but before the beam concrete is set. Allow the vibrator to penetrate through the slab into the previously placed beam to blend the two structural elements.

Undervibration vs. overvibration

Undervibration is far more common than overvibration. Good quality normal-weight concrete is not readily susceptible to the problems caused by overvibration, so when in doubt, vibrate more.

The problems associated with undervibration include:

- Honeycombing
- Excessive entrapped air
- Sand streaks
- Cold joints
- Subsidence cracking

The problems associated with overvibration include:

- Segregation
- Sand streaks
- Loss of entrained air
- Form deflection
- Form damage or failure

Overvibrating, because it causes entrained air loss, might be expected to decrease freeze-thaw resistance. Research results don't bear this out, however. In one study, overvibration of low-slump, air-entrained concrete had no effect on freeze-thaw resistance. Overvibration should not be a concern unless high-slump, improperly proportioned concrete is being placed.

Vibrating around congested reinforcement

To provide good concrete-to-steel bond, vibration is especially important in areas congested with rebar. Vibration alone doesn't solve the problem. Other actions must be taken to help complete concrete consolidation, such as:

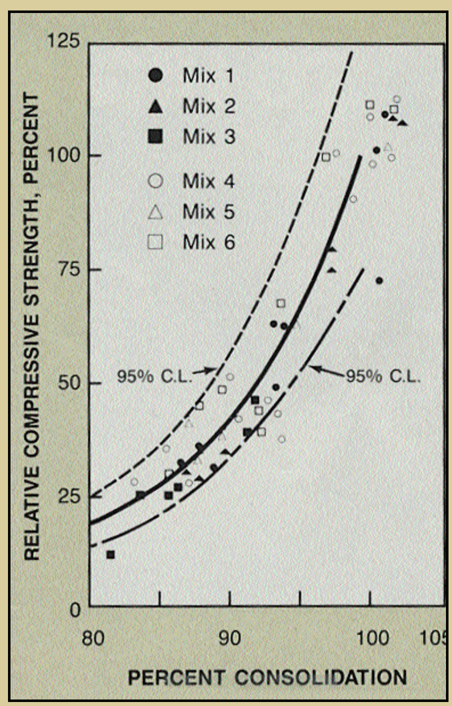
- Using admixtures to increase flowability but limit segregation

TESTS PROVE CONSOLIDATION AFFECTS COMPRESSIVE STRENGTH

A study by Construction Technologies Laboratories, Inc., Skokie, Illinois (Ref. 2), used six different concrete mixes to establish the effect of consolidation on the compressive strength, bond stress, and chloride permeability of concrete. The six mixes included limestone and gravel aggregates, a cement content of either 520 or 610 pounds per cubic yard, an air content from 5% to 10%, and had a slump of 1 to 2 inches.

The results dramatically underscore the need for consolidation. Compressive strength was reduced by about 30% for each 5% decrease in degree of consolidation (see graph). Bond stress suffered a loss of about 50% for a 5% decrease in degree of consolidation. Poorly consolidated concretes also were more permeable to chloride ions.

Before vibration, percent consolidation for field concrete is typically at 80% to 95%. After vibration it's usually between 95% and 100%.



- Changing mix proportions or ingredients to increase flowability

- Designing the reinforcing for ease of concrete placing

To achieve proper consolidation by internal vibration in congested areas, the designer should provide obstruction-free vertical access of 4x6-inch minimum openings to insert the vibrator. Horizontal spacing of these openings should not exceed 24 inches or 1½ times the vibrator's radius of action. Engineers designing congested reinforcement should also design for proper consolidation, otherwise contractors can't always guarantee adequate concrete-to-steel bond (Figure 4).

References

1. "Guide for Consolidation of Concrete," ACI 309R-87, ACI Materials Journal, September-October 1987, American Concrete Institute, Box 19150, Detroit, Michigan 48219.

2. Whiting, D., G. W. Seegebrecht, and S. Tayabji, "Effect of Degree of Consolidation on Some Important Properties of Concrete," SP-96, Consolidation of Concrete, American Concrete Institute.

3. Olsen, Mikael, "Energy Requirements for Consolidation of Concrete During Internal Vibration," SP-96, Consolidation of Concrete, American Concrete Institute.

4. Troxell, Davis, & Kelly, Composition and Properties of Concrete, McGraw-Hill, New York, New York, 1968.

Editor's note

For more information, read "Choosing a Concrete Vibrator," Concrete Construction, September 1982, page 701. To order a photocopy, contact the Book and Reprint Division, Concrete Construction Publications, Inc., 426 South Westgate, Addison, Illinois 60101; telephone 312-543-0870.

PUBLICATION#C880563