Guide for Consolidation of Concrete

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Consolidation is the process of removing entrapped air from freshly placed concrete. Several methods and techniques are available, the choice depending mainly on the workability of the mixture, placing conditions, and degree of air removal desired. Some form of vibration is usually employed.

This guide includes information on the mechanism of consolidation and gives recommendations on equipment, characteristics, and procedures for various classes of construction.

The paired values stated in inch-pound units and hard SI units are usually not exact equivalents. Therefore, each system is to be used independently of the other. Combining values from the two systems may result in nonconformance with this guide.

Keywords: box out; compaction; consistency; consolidation; placing; rheology; rodding; segregation; spading; tamping; vibration; vibrator; workability.

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CHAPTER 1—GENERAL

Freshly placed unconsolidated concrete contains excessive and detrimental entrapped air. If allowed to harden in this condition, the concrete will be porous and poorly bonded to the reinforcement. It will have low strength, high permeability, and poor resistance to deterioration. It may also have a poor appearance. The mixture should be consolidated if it is to have the properties desired and expected of concrete.

Consolidation is the process of inducing a closer arrangement of the solid particles in freshly mixed concrete or mortar during placement by the reduction of voids, usually by vibration, centrifugation (spinning), rodding, spading, tamping, or some combination of these actions.

Stiffer mixtures require greater effort to achieve proper consolidation. By using certain chemical admixtures (ACI 212.3R), consistencies requiring reduced consolidation effort can be achieved at lower water content. As the water content of the concrete is reduced, concrete strength, permeability, and other desirable properties improve, provided that the concrete is properly consolidated. Alternatively, the

Fig. 1.1(a)—Pleasing appearance of concrete in church construction.

Fig. 1.1(b)—Pleasing appearance of concrete in utility building construction.

Fig. 1.1(c)—Close-ups of surfaces resulting from good consolidation.

cementitious materials content can be lowered, reducing the cost while maintaining the same strength. If adequate consolidation is not provided for these stiffer mixtures, the strength of the in-place concrete decreases rapidly.

Equipment and methods are now available for fast and efficient consolidation of concrete over a wide range of placing conditions. Concrete with a relatively low water content can be readily molded into an unlimited variety of shapes, making it a highly versatile and economical construction material. When good consolidation practices are combined with good formwork and good form release agents, concrete surfaces have a highly pleasing appearance (Fig. 1.1(a) through (c)).

CHAPTER 2—EFFECT OF MIXTURE PROPORTIONS ON CONSOLIDATION

2.1—Mixture proportions

Concrete mixtures are proportioned to provide the workability needed during construction and the required properties in the hardened concrete. Mixture proportioning is described in ACI 211.1, 211.2, and 211.3R.

2.2—Workability and consistency

Workability of freshly mixed concrete determines the ease and homogeneity with which concrete can be mixed, placed,

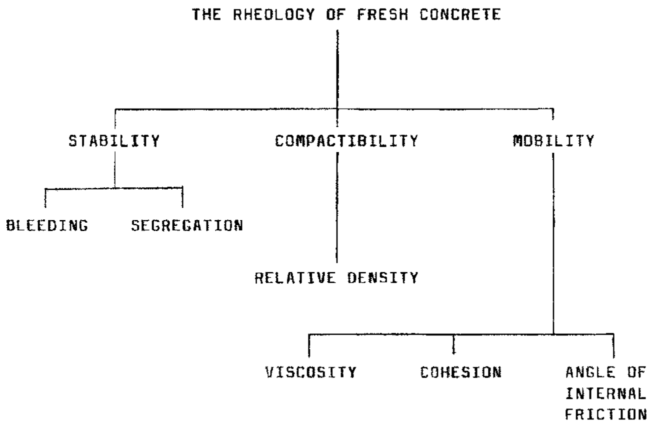

Fig. 2.1—Parameters of rheology of fresh concrete.

Table 2.1—Consistencies used in construction*

Consistency description	Slump, in. (mm)	Vebe time, s	Compacting factor average	Thaulow drop table revolutions
Extremely dry	—	32 to 18	—	112 to 56
Very stiff	—	18 to 10	0.70	56 to 28
Stiff	0 to 1 (0 to 25)	10 to 5	0.75	28 to 14
Stiff plastic	1 to 3 (25 to 75)	5 to 3	0.85	14 to 7
Plastic	3 to 5 (75 to 125)	3 to 0*	0.90	<7
Highly plastic	5 to 7-1/2 (125 to 190)	—	—	—
Flowing	7-1/2 plus (190 plus)	—	0.95	—

*Test method is of limited value in this range.

consolidated, and finished. Workability is a function of the rheological properties of the concrete.

As shown in Fig. 2.1, workability may be divided into three main aspects:

1. Stability (resistance to bleeding and segregation);
2. Ease of consolidation; and
3. Consistency, affected by the viscosity and cohesion of the concrete and angle of internal friction.

Workability is affected by grading, particle shape, surface texture, proportions of aggregate and cement, use of pozzolan or ground-granulated blast-furnace slag (GGBFS), chemical admixtures, air content, and water content of the mixture. Consistency is the relative mobility or ability of freshly mixed concrete to flow. It also largely determines the ease with which concrete can be consolidated. Once the materials and proportions are selected, the primary control over workability is through variations in the water content or by adding a chemical admixture. The slump test (ASTM C 143) is widely used to indicate consistency of mixtures used in normal construction. The Vebe test (ASTM C 1170) is recommended for stiffer mixtures. Values of slump, compacting factor, drop table spread, and Vebe time for the entire range of consistencies used in construction are given in Table 2.1.

Other measures of consistency, such as the Powers' remolding test and the concrete rheometers recently developed, are available. These methods are infrequently used. The various consistency tests have been discussed by Neville (1981), Vollick (1966), and Ferraris (1999).

2.3—Workability requirements

The concrete should be sufficiently workable so that consolidation equipment, when properly used, will give adequate consolidation. A high degree of ability to flow may be undesirable because it may increase the cost of the mixture and reduce the quality of the hardened concrete. Where such a high degree of ability to flow is the result of too much water in the mixture, the mixture will generally be unstable and will probably segregate during the consolidation process.

In mixtures that are highly plastic to flowing (Table 2.1), small nominal maximum-size aggregate and high content of fine aggregate are frequently used because the high degree of ability to flow means less work in placing. Mixtures such as these may have undesirable characteristics such as high shrinkage, cracking, and stickiness. At the other extreme, it is inadvisable to use mixtures that are too stiff for the intended conditions of consolidation. They will require great consolidation effort and even then may not be adequately consolidated. Direction, guidance, and trail mixtures are often required to achieve the use of mixtures of lower slump or fine aggregate content, or a larger nominal maximum-size aggregate, so as to give a more efficient use of the cement.

Concrete containing certain chemical admixtures may be placed in forms with less consolidation effort. Refer to reports of ACI Committee 212 for additional information. The use of pozzolans or GGBFS may also affect the consolidation effort required to properly consolidate concrete. Refer to ACI 232.2R, 233R, and 234R for more information regarding these materials. The amount of consolidation effort required with or without the use of chemical admixtures and pozzolans or GGBFS should be determined by trial mixtures under field conditions.

The workability of the mixture in the form determines the consolidation requirements. This workability may be considerably less than at the mixer because of slump loss due to high temperature, premature stiffening, delays, or other causes.

CHAPTER 3—METHODS OF CONSOLIDATION

The consolidation method should be compatible with the concrete mixture, placing conditions, form intricacy, and amount of reinforcement. Many manual and mechanical methods are available.

3.1—Manual methods

Plastic, highly plastic, and flowing consistency (Table 2.1) mixtures may be consolidated by rodding. Spading is sometimes used at formed surfaces—a flat tool is repeatedly inserted and withdrawn adjacent to the form. Coarse particles are shoved away from the form and movement of air voids toward the top surface is facilitated, thereby reducing the number and size of bugholes in the formed concrete surface.

Hand tamping may be used to consolidate stiff mixtures. The concrete is placed in thin layers, and each layer is carefully