IN-LB	Inch-Pound Units
SI	International System of Units

Mass Concrete—Guide

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American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

www.concrete.org

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Stephen B. Tatro

This guide contains a history of the development of mass concrete practice and discussion of materials and concrete mixture proportioning, properties, construction methods, and equipment. It covers traditionally placed and consolidated mass concrete for massive structures such as dams and provides information applicable to mass structural heavily reinforced concrete and for thermally controlled concrete such as bridge elements and building foundations. This guide does not cover roller-compacted concrete.

Keywords: cement; cracking; fly ash; heat of hydration; mass concrete; mixture proportioning; supplementary cementitious materials; temperature rise; thermal control plan; thermal expansion; volume change.

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CHAPTER 1—INTRODUCTION AND HISTORICAL DEVELOPMENTS

1.1—Scope

Mass concrete covered by this guide generally falls into two classifications, or types. The first type is the traditional mass concrete of structures such as dams, where most of the structure is mass concrete and is constructed of intertwined placements. The second type consists of individual or distinct placements such as high-rise building foundations or bridges, and is increasingly referred to as thermally controlled concrete. Both types of mass concrete have similar principles and basic considerations; however, thermally controlled concrete is often constructed with commercial ready mixed concrete. Thus, it may be designed to be pumpable and can consist of self-consolidating, high-strength, or high-performance concrete, which typically results in concrete containing much higher cementitious materials content than traditional mass concrete. Although this guide mainly focuses on guidance for traditional mass concrete, much of the information can also be applicable to thermally controlled concrete.

The design of traditional mass concrete structures, such as dams, is generally based on durability, economy, and thermal requirements. Strength performance is often a secondary requirement, rather than a primary concern, and is sometimes specified to be achieved at an age of 56 or 90 days instead of 28 days.

The one characteristic that distinguishes mass concrete from other concrete work is thermal behavior. Because the reaction between water and cement is exothermic by nature, the temperature rise within a large concrete mass, where the heat is not quickly dissipated, can be quite high. Significant tensile stresses and strains may result from a decline in temperature as heat from hydration is dissipated at the volume extremities but not at the mass core. Measures should be taken where cracking due to thermal behavior may adversely affect structural integrity, durability, or aesthetics.

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Mass concreting practices were developed largely from concrete dam construction, where temperature-related cracking was first identified. Temperature-related cracking has also been experienced in other concrete structures, including mat foundations, pile caps, bridge piers, superstructure elements, roadway patches, and tunnel linings.

High compressive strengths are not typically required in traditional mass concrete structures; however, there are some cases, such as thin arch dams, where high-strength concrete may be specified. Massive structures, such as gravity dams, resist loads primarily by their shape and mass; strength is of secondary importance. Of more importance are durability and properties connected with temperature behavior and the tendency for cracking.

The effects of heat generation, restraint, and volume changes on the design and behavior of massive reinforced elements and structures are discussed in ACI 207.2R. Cooling and insulating systems for mass concrete are addressed in ACI 207.4R.

1.2—History

Historically, mass concrete considerations evolved out of the use of concrete in dams. The first concrete dams were relatively small, and the concrete was mixed by hand. The portland cement usually had to be aged to comply with a boiling soundness test, the aggregate was bank-run sand and gravel, and proportioning was by the shovelful (Davis 1963). Tremendous progress has been made since the early 1900s, and the art and science of dam building practiced today has reached a highly advanced state. Presently, the selection and proportioning of concrete materials to produce suitable strength, durability, and impermeability of the finished product can now be predicted and controlled with accuracy.

Covered herein are the principal steps from those very small beginnings to the present. In large dam construction, there is now exact and automatic proportioning and mixing of materials. Concrete in 12 yd^3 (9 m^3) buckets can be placed by conventional methods at the rate of 10,000 yd^3/day (7650 m^3/day) at a temperature of less than 50°F (10°C) as placed, even during extremely hot weather. Grand Coulee Dam still holds the record monthly placing rate of 536,250 yd^3 (410,020 m^3), followed by the Itaipu Dam on the Brazil-Paraguay border with 440,550 yd^3 (336,840 m^3) (Itaipu Binacional 1981).

1.2.1 *Before 1900*—Before the beginning of the twentieth century, much of the portland cement used in the United States was imported from Europe. All cements were very coarse by present standards, and quite commonly they were underburned and had a high free lime content. For dams of that period, bank-run sand and gravel were used without the benefit of washing to remove objectionable dirt and fines. Concrete mixtures varied widely in cement content and fine-to-coarse aggregate ratio. Mixing was usually done by hand and proportioning by shovel, wheelbarrow, box, or cart. The effect of the water-cement ratio (*w*/*c*) was unknown, and generally no attempt was made to control the volume of mixing water. There was no measure of consistency except by visual observation of the newly mixed concrete.

Some of the dams were of cyclopean masonry in which plums (large stones) were partially embedded in a very wet concrete. The spaces between plums were then filled with concrete. Some of the early dams were built without contraction joints and without regular lifts. There were, however, notable exceptions where concrete was cast in blocks, the height of lift was regulated, and concrete of very dry consistency was placed in thin layers and consolidated by rigorous hand tamping.

Generally, mixed concrete was transported to the forms by wheelbarrow. Where plums were employed in cyclopean masonry, stiff-leg derricks operating inside the work area moved the wet concrete and plums. The rate of placement was, at most, a few hundred cubic yards (cubic meters) a day. Generally, there was no attempt to moist cure the concrete.

An exception to these general practices was the Lower Crystal Springs Dam, completed in 1890. This dam is located near San Mateo, CA, approximately 20 miles (30 km) south of San Francisco. According to available information, it was the first dam in the United States in which the maximum permissible quantity of mixing water was specified. The concrete for this 154 ft (47 m) high structure was cast in a system of interlocking blocks of specified shape and dimensions. An old photograph indicates that hand tampers were employed to consolidate the dry concrete (concrete with a low water content and presumably very low workability). Fresh concrete was covered with planks as a protection from the sun, and the concrete was kept wet until hardening occurred.

1.2.2 *1900 to 1930*—After the turn of the century, construction of all types of concrete dams greatly accelerated. More and higher dams for irrigation, power, and water supply were built. Concrete placement by means of towers and chutes became common. In the United States, the portland cement industry became well established, and cement was rarely imported from Europe. ASTM specifications for portland cement underwent little change during the first 30 years of the century, aside from a modest increase in fineness requirement determined by sieve analysis. Except for the limits on magnesia and loss on ignition, there were no chemical requirements. Character and grading of aggregates were given more attention during this period. Very substantial progress was made in the development of methods of proportioning concrete. The water-cement strength relationship was established by Abrams (1918) from investigations before 1918. Nevertheless, little attention was paid to the quantity of mixing water. Placing methods using towers and flat-sloped chutes dominated, resulting in the use of excessively wet mixtures for at least 12 years after the importance of the *w*/*c* had been established.

Generally, portland cements were employed without admixtures. There were exceptions, such as the sand-cements used by the U.S. Reclamation Service (now the U.S. Bureau of Reclamation [USBR]) in the construction of the Elephant Butte Dam in New Mexico and the Arrowrock Dam in Idaho. At the time of its completion in 1915, the Arrowrock Dam, a gravity-arch dam, was the highest dam in the world at 350 ft (107 m). The dam was constructed with lean interior concrete and a richer exterior face concrete. The mixture for interior concrete contained approximately 376 lb/yd^3 (223 kg/m^3) of a blended, pulverized granite-cement combination. The cement mixture was produced at the site by intergrinding approximately equal parts of portland cement and pulverized granite so that no less than 90% passed the No. 200 (75 mm) mesh sieve. The interground combination was considerably finer than the cement being produced at that time.

Another exception occurred in the concrete for one of the abutments of Big Dalton Dam, a multiple-arch dam built by the Los Angeles County Flood Control District during the late 1920s. Pumicite (a pozzolan) from Friant, CA, was used as a 20% replacement by mass for portland cement.

In the early part of the twentieth century, cyclopean concrete went out of style. For dams of thick section, the maximum size of aggregate for mass concrete increased to 10 in. (250 mm). The slump test had come into use as a means of measuring consistency. The testing of 6 x 12 in. (150 x 300 mm) and 8 x 16 in. (200 x 400 mm) job cylinders became common practice in the United States. European countries generally adopted the 8 x 8 in. (200 x 200 mm) cube for testing the strength at various ages. By the end of the 1920s, mixers of 3 yd^3 (2.3 m^3) capacity were commonly used, and there were some of 4 yd^3 (3 m^3) capacity. Only Type I cement (portland cement) was available during this period. In areas where freezing-and-thawing conditions were severe, it was common practice to use a concrete mixture containing 564 lb/yd^3 (335 kg/m^3) of cement for the entire concrete mass. The construction practice of using an interior mixture containing 376 lb/yd^3 (223 kg/m^3) and an exterior face mixture containing 564 lb/yd^3 (335 kg/m^3) was developed to make the dam's face resistant to the severe climate and yet minimize the overall use of cement. In areas of mild climate, one class of concrete that contained amounts of cement as low as 376 lb/yd^3 (223 kg/m^3) was used in some dams (TVA 1940).

An exception was the Theodore Roosevelt Dam built during the years of 1905 to 1911 in Arizona. This dam consists of a rubble masonry structure faced with rough stone blocks laid in portland-cement mortar made with a cement manufactured in a plant near the dam site. For this structure, the average cement content has been calculated to be approximately 282 lb/yd^3 (167 kg/m^3). For the interior of the mass, rough quarried stones were embedded in a 1:2.5 mortar containing approximately 846 lb/yd^3 (502 kg/m^3) of cement. In each layer, the voids between the closely spaced stones were filled with a concrete containing 564 lb/