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Guide to Mass Concrete

Reported by ACI Committee 207

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Mass concrete is any volume of concrete with dimensions large enough to require that measures be taken to cope with the generation of heat from hydration of the cement and attendant volume change to minimize cracking. The design of mass concrete structures is generally based on durability, economy, and thermal action, with strength often being a secondary concern. This document 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 and does not cover roller-compacted concrete.

Keywords: admixture; aggregate; air entrainment; batch; cement; compressive strength; cracking; creep; curing; durability; fly ash; formwork; grading; heat of hydration; mass concrete; mixing; mixture proportion; modulus of elasticity; placing; Poisson's ratio; pozzolan; shrinkage; strain; stress; temperature rise; thermal expansion; vibration; volume change.

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ACI 207.1R-05 supersedes ACI 207.1R-96 and became effective December 1, 2005.

CHAPTER 1—INTRODUCTION AND HISTORICAL DEVELOPMENTS

1.1—Scope

Mass concrete is defined in ACI 116R as “any volume of concrete with dimensions large enough to require that measures be taken to cope with generation of heat from hydration of the cement and attendant volume change to minimize cracking.” The design of mass concrete structures is generally based on durability, economy, and thermal action, with strength often being a secondary, rather than a primary, concern. The one characteristic that distinguishes mass concrete from other concrete work is thermal behavior. Because the cement-water reaction 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 the restrained volume change associated with a decline in temperature as heat of hydration is dissipated. Measures should be taken where cracking due to thermal behavior may cause a loss of structural integrity and monolithic action, excessive seepage and shortening of the service life of the structure, or be aesthetically objectionable. Many of the principles in mass concrete practice can also be applied to general concrete work, whereby economic and other benefits may be realized.

This document contains a history of the development of mass concrete practice and a discussion of materials and concrete mixture proportioning, properties, construction methods, and equipment. This document covers traditionally placed and consolidated mass concrete, and does not cover roller-compacted concrete. Roller-compacted concrete is described in detail in ACI 207.5R.

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 thick-section concrete structures, including mat foundations, pile caps, bridge piers, thick walls, and tunnel linings.

High compressive strengths are usually not required in mass concrete structures; however, thin arch dams are exceptions. Massive structures, such as gravity dams, resist loads primarily by their shape and mass, and only secondarily by their strength. 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. Mixture proportioning for mass concrete is discussed in ACI 211.1.

1.2—History

When concrete was first used in dams, the 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 all-time record monthly placing rate of 536,250 yd^3 (410,020 m^3), followed by the more recent achievement at Itaipu Dam on the Brazil-Paraguay border of 440,550 yd^3 (336,840 m^3) (Itaipu Binacional 1981). The record monthly placing rate of 328,500 yd^3 (250,200 m^3) for roller-compacted concrete was achieved at Tarbela Dam in Pakistan. Lean mixtures are now made workable by means of air entrainment and other chemical admixtures and the use of finely divided pozzolanic materials. Water-reducing, strength-enhancing, and set-controlling chemical admixtures are effective in reducing the required cement content to a minimum and in controlling the time of setting. Placing rates for no-slump concrete, by using large earth-moving equipment for transportation and large vibrating rollers for consolidation, appear to be limited only by the size of the project and its plant’s ability to produce concrete.

1.2.1 *Before 1900*—Before to 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 in sand-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, also very wet. 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.

An exception to these general practices was the Lower Crystal Springs Dam, completed in 1890. This dam is located near San Mateo, California, about 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 was 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 and his associates from investigations before 1918, when Portland Cement Association (PCA) Bulletin 1 appeared (Abrams 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 μm) 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, California, was used as a 20% replacement by mass for portland cement.

During this period, cyclopean concrete went out of style. For dams of thick section, the maximum size of aggregate for mass concrete was increased to as large as 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. Mixers of 3 yd^3 (2.3 m^3) capacity were commonly used near the end of this period, and there were some of 4 yd^3 (3 m^3) capacity. Only Type I cement (normal 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 during this period 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.

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/yd^3 (335 kg/m^3) of cement, into which rock fragments were manually placed. These conditions account for the very low average cement content. Construction was slow, and Roosevelt Dam represents perhaps the last of the large dams built in the United States by this method of construction.

1.2.3 *1930 to 1970*—This was an era of rapid development in mass concrete construction for dams. The use of the tower and chute method declined during this period and was used only on small projects. Concrete was typically placed using large buckets with cranes, cableways, railroad systems, or a combination of these. On the larger and more closely controlled construction projects, the aggregates were carefully processed, ingredients were proportioned by weight, and the mixing water was measured by volume. Improvement in workability was brought about by the introduction of finely divided mineral admixtures (pozzolans), air entrainment, and chemical admixtures. Slumps as low as 3 in. (76 mm) were employed without vibration, although most projects in later years of this era used large spud vibrators for consolidation.

A study of the records and actual inspection of a considerable number of dams shows that there were differences in condition that could not be explained. Of two structures that appeared to