Report on Thermal and Volume Change Effects on Cracking of Mass Concrete

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This report presents a discussion of the effects of heat generation and volume change on the design and behavior of mass concrete elements and structures. Emphasis is placed on the effects of restraint on cracking and the effects of controlled placing temperatures, concrete strength requirements, and material properties on volume change.

Keywords: adiabatic; cement; concrete cracking; creep; drying shrinkage; foundation; heat of hydration; mass concrete; modulus of elasticity; placing; portland cement; pozzolan; restraint; stress; temperature; tensile strength; thermal expansion; volume change.

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CHAPTER 1—INTRODUCTION

1.1—Scope

This report is primarily concerned with evaluating the thermal behavior of mass concrete structures to control the cracking in members that occurs principally from thermal contraction with restraint. This report presents a detailed discussion of the effects of heat generation and volume changes on the design and behavior of mass concrete elements and structures, a variety of methods to compute heat dissipation and volume changes, and an approach to determine mass and surface gradient stresses. It is written primarily to provide guidance for the selection of concrete materials, mixture requirements, and construction procedures necessary to control the size and spacing of cracks. The quality of concrete for resistance to weathering is not emphasized in recommending reduced cement contents; however, it should be understood that the concrete should be sufficiently durable to resist expected service conditions. This report can be applied to most concrete structures with a potential for unacceptable cracking. Its general application has been to massive concrete members 18 in. (460 mm) or more in thickness; it is also relevant for less massive concrete members.

1.2—Mass concrete versus structural concrete

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 most important characteristic of mass concrete that differentiates its behavior from that of structural concrete is its thermal behavior. The generally large size of mass concrete structures creates the potential for large temperature changes in the structure and significant temperature differentials between the interior and the outside surface of the structure. The accompanying volume-change differentials and restraint result in tensile strains and stresses that may cause cracking detrimental to the structural design, the serviceability, or the appearance.

In most structural concrete construction, most of the heat generated by the hydrating cement is rapidly dissipated, and only slight temperature differences develop. For example, a concrete wall 6 in. (150 mm) thick can become thermally stable in approximately 1-1/2 hours. A 5 ft (1.5 m) thick wall would require a week to reach a comparable condition. A 50 ft (15 m) thick wall, which could represent the thickness of an arch dam, would require 2 years. A 500 ft (152 m) thick dam, such as Hoover, Shasta, or Grand Coulee, would take approximately 200 years to achieve the same degree of thermal stability. Temperature differentials never become large in typical structural building elements and, therefore, typical structural building elements are relatively free from thermal cracking. In contrast, as thickness increases, the uncontrolled interior temperature rise in mass concrete becomes almost adiabatic, and this creates the potential for large temperature differentials that, if not accommodated, can impair structural integrity.

There are many concrete placements considered to be structural concrete that could be significantly improved if some of the mass concrete measures presented in this report were implemented. Measures include consideration of issues such as required concrete strengths, age when strength is required, cement contents, supplemental cementitious materials, temperature controls, and jointing.

1.3—Approaches for crack control

If cementitious materials did not generate heat as the concrete hardens, if the concrete did not undergo volume changes with changes in temperature, and if the concrete did not develop stiffness (high modulus of elasticity), there would be little need for temperature control. In the majority of instances, this heat generation and accompanying temperature rise will occur rapidly before the development of elastic properties and, consequently, little or no stress development during this phase. A continuing rise in temperature for many more days is concurrent with the increase in elastic modulus (rigidity). Even these circumstances would be of little concern if the entire mass of the placement could:

1. Be limited in maximum temperature to a value close to its final, cooled, stable temperature;
2. Be maintained at the same temperature throughout its volume, including exposed surfaces;
3. Be supported without restraint (or supported on foundations expanding and contracting in the same manner as the concrete);
4. Relieve its stress through creep; and
5. Have no stiffness or rigidity.

None of these conditions, of course, can be achieved completely. The first and second conditions (such as temperature controls) can be realized to some extent in most construction. The third condition (such as limited restraint) is the most difficult to obtain, but has been accomplished on a limited scale for extremely critical structures by preheating the previously placed concrete to limit the differential between older concrete and the maximum temperature expected in the covering concrete. The fourth and fifth conditions can be somewhat influenced if there is an option to use lower-strength concrete and aggregates with lower coefficients of thermal expansion and lower modulus. This report provides discussion and explanation about these issues and other issues related to controlling thermal volume changes and subsequent cracking.

All concrete elements and structures are subject to volume change in varying degrees dependent upon the makeup, configuration, and environment of the concrete. Uniform volume change will not produce cracking if the element or structure is relatively free to change volume in all directions. This is rarely the case for massive concrete members because size alone usually causes nonuniform change, and there is often sufficient restraint either internally or externally to produce cracking.

The measures used to control cracking depend, to a large extent, on the economics of the situation and the seriousness of cracking if not controlled. Cracks are objectionable where their size and spacing compromise the strength, stability, serviceability, function, or appearance of the structure.

While cracks should be controlled to the minimum practicable width in all structures, the economics of achieving this goal