When Should Mass Concrete Requirements Apply?

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Insulated columns for a bridge project. Photo: John Gajda.

Mass Concrete Mechanism

Temperature builds within a concrete placement when the rate of heat generation by the hydration of cementitious materials exceeds the rate of heat loss through the surfaces of the placement. Concretes with a high cementitious materials content will generate heat quite quickly; quicker than the heat can escape. Thick placements also trap heat such that the cementitious materials at the center cannot readily dissipate the heat. Saying this differently, if one were to use a concrete mixture that contains, for example, 600 lb/yd^3 of cementitious materials (where 75% is Type I/II portland cement and 25% is class F fly ash) in an 8-in.-thick bridge deck, the rate of heat dissipation would be fast enough that the concrete does not get overly hot and therefore does not behave as mass concrete. However, if the same concrete mixture was used in a 6-ft-thick placement, the story would be different; the interior of the placement would get quite hot since the heat cannot dissipate as quickly as it is generated; the concrete placement would behave as mass concrete.

The question of when a placement should be considered to be mass concrete is often debated. From the American Concrete Institute (ACI) definition, mass concrete is "any volume of concrete in which a combination of dimensions of the member being cast, the boundary conditions, the characteristics of the concrete mixture, and the ambient conditions can lead to undesirable thermal stresses, cracking, deleterious chemical reactions, or reduction in the long-term strength as a result of elevated concrete temperature due to heat from hydration." This is an excellent definition, however, it does not provide the simple and measurable guidance that most engineers and contractors are looking for; it does not provide a quantitative definition, such as a thickness-based definition.

ACI 301, *Specifications for Structural Concrete*,[1] attempts to provide simple and measurable guidance in the "notes to the specifier section" at the back of the document, by stating that placements that are 4-ft thick and greater should be considered mass concrete. In placing the guidance in the notes section, rather than the specification section, the actual thickness that is specified is left to the discretion of the specifier.

In this same section, ACI 301 also states that placements with a minimum cementitious materials content of 660 lb/yd^3 should also be considered mass concrete. This latter guidance, although well meaning, has resulted in treatment as mass concrete for placements which probably should not be considered mass concrete. For example, we have written letters demonstrating that a 1-ft-thick wall constructed with a concrete containing 675 lb/yd^3 of cementitious materials will not behave as mass concrete.

So when should a placement be treated as mass concrete? When the maximum temperature in the placement exceeds the typical industry standard limit of 160°F and/or when the temperature difference in the placement exceeds the typical industry standard limit of 35°F between the interior of the placement and a point that is 2 to 3 in. below/inside the center

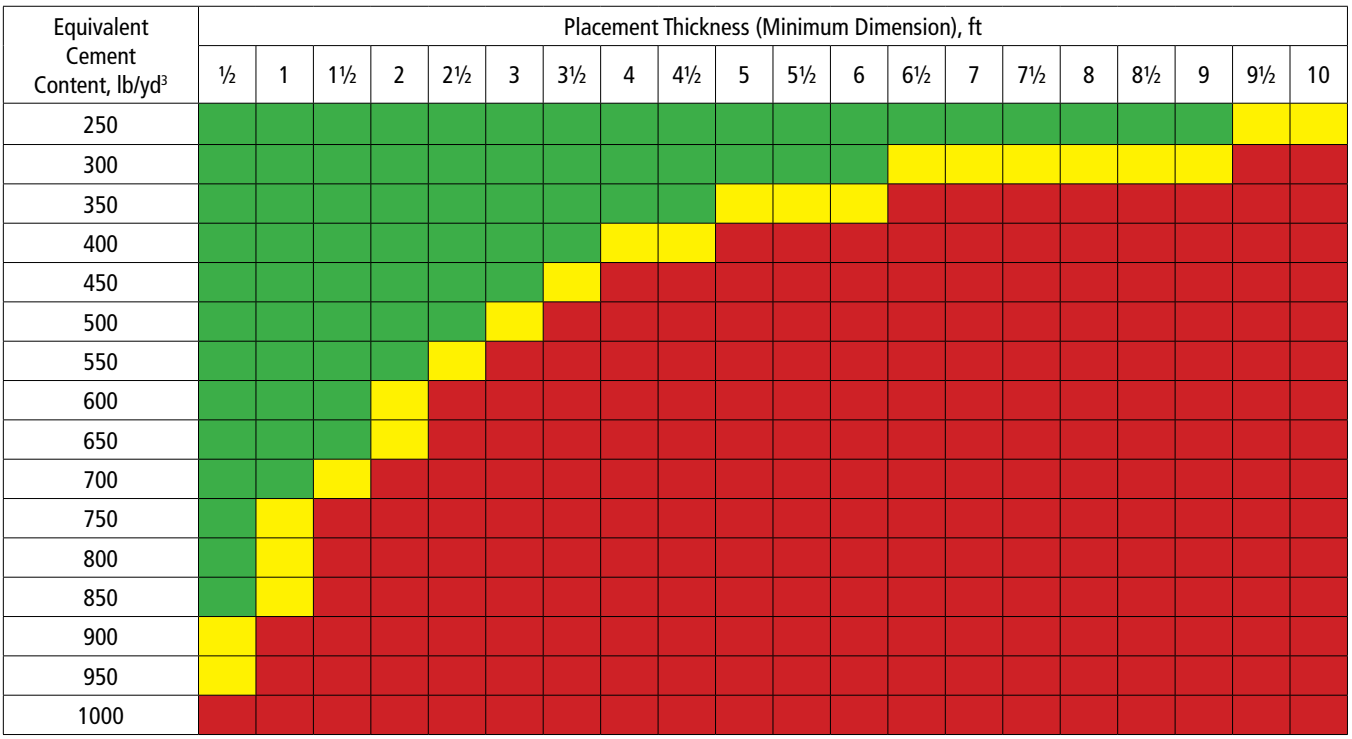

Chart of placement versus equivalent cement content for normal-weight concrete. Red is mass concrete, green is not mass concrete. Yellow is a buffer zone that is left to the discretion of the specifier. Chart: John Gajda.

of a nearby surface. Placements that will not exceed these limits under typical placement conditions do not need to be considered mass concrete. What exceeds these limits is a function of the placement thickness and the concrete mixture proportions, specifically the type and quantities of the cementitious materials that are used.

We have been working to develop a better definition of mass concrete; one that takes into consideration both the placement thickness as well as the concrete mixture design. Thermal modeling was performed using mass concrete software to look at the maximum temperature and temperature difference in a series of different thickness placements with various concrete mixture proportions. In these mixture proportions, the cementitious materials such as portland cement, fly ash, slag cement, silica-fume, and metakaolin were converted to an "equivalent cement" content based on an equation (shown below) from an article in the August 2014 edition of *Concrete International* magazine.[2] Although this equation is not perfect, in that it probably does not adequately cover every combination of cementitious materials, from our experience, it is reasonably accurate as a "ballpark" comparison method for most concretes.

Equivalent Cement Content = (*Cement* + 0.5**FAsh* + 0.8**CAsh* + 1.2**SFMK* + *Factor***Slag*), lb/yd³

where:

Cement is Type I/II portland cement, lb/yd³;

FAsh is Class F fly ash, lb/yd³;

CAsh is Class C fly ash (no distinction is made for the calcium oxide content of the fly ash, which is the main heat generating portion), lb/yd³;

SFMK is silica fume or metakaolin, lb/yd³;

Slag is slag cement (no distinction is made for Grade 100 or Grade 120), lb/yd³; and

Factor is a variable which depends on the total percentage of cement being replaced (1.0 to 1.1 for 0 to 20% cement replacement, 1.0 for 20 to 45% cement replacement, 0.9 for 45 to 65% cement replacement, and 0.8 for 65 to 80% cement replacement).

For the modeling, we assumed that the concrete would not be placed during cold-weather conditions (that is, it would not be insulated), it would not be thermally protected (that is, treated as mass concrete), it would be constructed using steel forms, and it would not be subjected to cold rain or windy conditions. We also assumed that the temperature of the delivered concrete was 10°F above the average air temperature, with the average air temperature being the average of the daily high and the daily low air temperatures on the day of placement, the preceding several days, and the following several days.

We looked at the maximum temperature and maximum temperature difference that were predicted by the thermal modeling. In virtually all cases, the temperature difference was the limiting factor; in other words, without insulation on the surface of the placement, modeling showed that the temperature difference would exceed the industry standard 35°F temperature difference limit before the maximum temperature exceeded the 160°F maximum temperature limit.

From this, a placement thickness-versus-equivalent-cement-content chart was developed and is shown in this article. Again, although not perfect, this chart provides a reasonable definition of when a placement should be considered mass concrete. We believe it is along the lines of what the industry is looking for.

References

1. American Concrete Institute (ACI). 2010. *Specifications for Structural Concrete*. ACI 301-10, Farmington Hills, Mich.: ACI.
2. Gajda, J., M. Weber, and I. Diaz-Loya. 2014. "A Low Temperature Rise Mixture for Mass Concrete." *Concrete International*, ACI, August.

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EDITOR'S NOTE

For more information on mass concrete, see the HPC Bridge Views *article at www.hpcbridgeviews.com/i47/Article1.asp.*