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Mass Concrete Specifications – Two States' Perspectives

Drilled Shafts as Mass Concrete?

Evaluation of Performance Based Concrete for Bridge Decks in Washington State

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Fig. 1. Cooling pipes (white PVC) in a 12-ft diameter drilled shaft prior to placement of the concrete.

Drilled Shafts as Mass Concrete?

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We are often asked, "Should drilled shafts be considered mass concrete?" Historically, drilled shafts and caissons have not been considered mass concrete, except for particular projects with unique considerations or owner requirements. However, concretes for drilled shafts often have a high cementitious materials content and a correspondingly high maximum temperature. Little can be done to control the environment surrounding the shaft, which means the temperature difference within the placement can be quite high. The choice to treat an element of a structure as mass concrete is meant to prevent damage from an excessive maximum temperature, and to minimize/prevent thermal cracking which occurs due to an excessive temperature difference within the placement.

The 2010 FHWA publication "Drilled Shafts: Construction Procedures and LRFD Design Methods"[1] states that drilled shafts "larger than about 5 ft diameter have characteristics of mass concrete". This publication also extensively discusses self-consolidating concrete (SCC), which implies that drilled shafts should only be constructed with SCC. Based on the benefits of SCC, some owners and engineers require SCC to be used in drilled shafts, and also use industry-standard limits of 160°F (70°C) for the maximum temperature and 35°F (20°C) for the temperature difference. SCC typically requires a high cementitious materials content to achieve the desired rheology. The use of concretes

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with a higher cementitious materials content are commonly used in "wet hole" shaft placements to help ensure the concrete does not segregate or washout.

In many cases, these requirements appear to conflict, especially when high levels of cement replacement with supplementary cementing materials (SCMs) are not permitted. Desired SCM replacement levels for thermal control are typically 50 percent by weight for ASTM C618 class F fly ash or 75 percent by weight of ASTM C989 slag cement. Furthermore, concrete producers who have little to no experience with SCC are asked to develop and produce SCC which is very different from concrete which they are typically accustom to working with or set up to produce (this is a separate issue which has unfortunately resulted in too many litigations due to segregated or poorly performing concrete).

The maximum temperature of concrete in a drilled shaft can be conservatively estimated as the sum of the concrete temperature at placement and the temperature rise of concrete based on the published Equation 1[2] below:

Rise (°F) = 0.16 * (Cement + 0.5*FAsh + 0.8*CAsh + 1.2*SFMK + Factor*Slag) **Eq. 1**

Where: All units for the cementitious materials are in lbs/CY,
Cement = Type I/II portland cement,
FAsh = Class F fly ash,
CAsh = Class C fly ash (no distinction is made for the calcium oxide content of the fly ash, which is the main heat generating portion),
SFMK = Silica fume or metakaolin,
Slag = Slag cement (no distinction is made for grade 100 or grade 120),
Factor = a variable which depends on the percentage of portland cement that is replaced. The factor is:
= 1.0 to 1.1 for 0 to 20% portland cement replacement,
= 1.0 for 20 to 45% portland cement replacement,
= 0.9 for 45 to 65% cement replacement, and
= 0.8 for 65 to 80% cement replacement.

Equation 1 was developed based on project experiences from 6+ ft. thick above-grade mass concrete placements. Equation 1 is also generally applicable to 6+ ft. diameter drilled shafts that are surrounded by subsurface material with typical drilled shaft concretes.

Thermal modeling of the drilled shaft with the specific boundary conditions and with information on the specific concrete mixture to be used is needed to fully evaluate whether or not to treat a smaller-diameter drilled shaft, or shafts that are surrounded by water (lake, river, bay, or ocean), as mass concrete. Table 1 shows an estimate of the temperature rise at the centerline of the drilled shaft, based on 2D thermal modeling, of the effect of the "rise" as determined by Equation 1 above as a function of the shaft diameter, concrete, temperature conditions, and the surrounding conditions. The modeling results shown in Table 1 do not consider admixtures such as corrosion inhibitor or accelerator which accelerate temperature rise and make smaller-diameter shafts behave as if they are larger diameter (the opposite is generally not true when a retarder or hydration stabilizer is used).

Note that Table 1 does not address temperature differences within the shaft concrete. This is intentional as the temperature difference within a drilled shaft within a permanent steel casing that extends through open water will be very close to the difference between the maximum temperature of the concrete and water temperature. For a shaft where the perimeter is surrounded by rock or subsurface material, the temperature difference will be lower, but may not be less than the commonly specified limit of 35°F (20°C) depending on the temperature rise and diameter of the shaft (larger diameters and higher "rise" values give a higher temperature difference).

Regarding the temperature difference, as noted above, limiting the temperature difference is intended to minimize/prevent thermal cracking. When the shaft is within a permanent steel casing, it is our experience that thermal cracking does not occur because the steel casing heats and cools with the surface concrete. Also, the casing significantly confines the placement, which restrains cracks from forming and opening in the concrete. The steel shell will have a high stress when the maximum temperature of the shaft concrete occurs. However, in the cases we have analyzed, the stress has not been above the yield stress of the steel or the compressive strength of the concrete. For this reason, the temperature difference within a steel cased shaft is typically ignored. Rock sockets may provide similar restraint, depending on the properties and fracturing of the rock.

For uncased shafts, when a higher temperature difference limit is not appropriate or feasible, and when precooling of the concrete and/or concrete mixture design changes are not feasible or practical, cooling pipes (such as shown in Figure 1) are often used in the concrete to reduce the effective temperature rise of the in-place concrete and associated temperature difference.

So what is the answer to the question, “should drilled shafts be considered mass concrete?” The answer is yes and for the same reasons that above-grade placements are treated as mass concrete. The concrete mixture, shaft diameter, and temperatures of the concrete and surroundings all determine if mass concrete treatment is warranted.

Temp. Rise of Concrete from Eq. 1, °F	Dia. of Drilled Shaft, ft.	Drilled Shaft Surrounded by Subsurface Material with a 55°F Initial Temperature			Drilled Shaft Surrounded by 55°F Water (in a creek, river, lake, bay, or ocean)		
		Concrete Temperature at Placement			Concrete Temperature at Placement		
		50°F	70°F	90°F	50°F	70°F	90°F
64	4	60%	60%	70%	55%	55%	60%
	5	75%	75%	80%	70%	70%	75%
	6	85%	85%	90%	75%	80%	85%
	7	90%	90%	95%	85%	85%	90%
	8	90%	95%	100%	90%	90%	95%
	9	95%	95%	100%	95%	95%	100%
	10	95%	100%	100%	95%	100%	100%
	12	100%	100%	100%	100%	100%	100%
80	4	70%	70%	75%	60%	55%	65%
	5	80%	80%	85%	70%	75%	80%
	6	85%	90%	95%	80%	85%	90%
	7	90%	95%	95%	90%	90%	95%
	8	95%	95%	100%	90%	95%	100%
	9	95%	100%	100%	95%	100%	100%
	10	100%	100%	100%	100%	100%	100%
	12	100%	100%	100%	100%	100%	100%
96	4	70%	75%	80%	60%	65%	70%
	5	80%	85%	90%	75%	80%	85%
	6	90%	90%	95%	85%	90%	95%
	7	95%	95%	100%	90%	95%	100%
	8	95%	100%	100%	95%	100%	100%
	9	100%	100%	100%	100%	100%	100%
	10	100%	100%	100%	100%	100%	100%
	12	100%	100%	100%	100%	100%	100%
112	4	75%	75%	85%	65%	70%	75%
	5	85%	90%	95%	80%	85%	90%
	6	90%	95%	100%	90%	90%	95%
	7	95%	100%	100%	95%	95%	100%
	8	100%	100%	100%	95%	100%	100%
	9	100%	100%	100%	100%	100%	100%
	10	100%	100%	100%	100%	100%	100%
	12	100%	100%	100%	100%	100%	100%

Table 1 – Percentage of the temperature rise at the centerline of the drilled shaft from equation 1 based on shaft diameter, concrete mixture, surroundings, and temperature

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1. https://www.fhwa.dot.gov/engineering/geotech/foundations/nhi10016/nhi10016.pdf
2. Gajda, J., et al, “A Low Temperature Rise Concrete for Mass Concrete”, Concrete International, American Concrete Institute, August 2014.