Addressing Concrete Issues for Drilled-Shaft Foundations

by Silas C. Nichols, Federal Highway Administration

The Federal Highway Administration's (FHWA's) National Geotechnical Team has been working with industry partners to better understand factors contributing to the performance of concrete when used in underground mass placements such as drilled shafts. Innovations in drilled-shaft construction equipment over the last two decades, combined with increased load-carrying demands for foundation elements, have resulted in significantly larger and deeper shaft excavations that have tested the ability of conventional concrete mixtures to meet necessary performance requirements.

The construction conditions for drilled-shaft foundation projects are more complex than those for other reinforced concrete structures. Therefore, the concrete mixtures used for shaft excavations must be designed to address specific application requirements.

The most important requirements are those that contribute to the workability of fresh concrete during transport and placement operations. Concrete may be transported long distances to remote sites and pumped long distances. It may be required to flow readily through a tremie and through congested reinforcement under slurry. Additionally, concrete may have to remain workable for 4 to 8 hours, or longer, in wide-ranging ambient temperature conditions.

Fresh concrete placed in drilled-shaft operations must also consolidate under its own weight without the assistance of vibration, and it must remain stable without segregation, excessive bleeding, or excessive heat of hydration. These requirements for workability are now relatively common in drilled-shaft construction, and balancing them has become a significant challenge to engineers.

To address some of these issues, FHWA is currently leading a research effort to study factors that contribute to the performance of concrete placed for geotechnical applications, and specifically drilled-shaft foundations. The primary objective of the research is to develop performance standards that correlate to basic demands for drilled shafts and allow for better concrete mixture designs.

Tremie being used for concrete placement for a drilled shaft. All Photos: Federal Highway Administration.

FHWA Guidance for Drilled-Shaft Concrete

The basic demands for concrete in drilled-shaft applications are currently summarized in FHWA's *Geotechnical Engineering Circular No. 10* as follows:[1]

- *Workability*: The concrete must have the ability to flow readily and fill the shaft excavation completely. The concrete must readily pass through the reinforcement without blocking to achieve thorough contact with the surrounding soil or rock. The concrete must be self-leveling within the excavation and consolidate under self weight; vibration of concrete in a borehole is not possible or practical.
- *Workability retention*: With underwater tremie placement, or when the casing must be withdrawn after completion of concrete placement, the drilled-shaft concrete must retain workability and have controlled setting times suitable for completion of placement operations.
- *Stability*: While providing the high degree of workability required, the fresh concrete must still have robust stability and resist any tendency to segregate or bleed. The paste within the concrete should have a high degree of cohesion so that coarse aggregate particles are evenly distributed, and water within the mixture should remain distributed without a tendency to bleed and result in nonuniform properties or bleed-water channels.
- *Durability*: The concrete cover on the reinforcement must provide low permeability so as to minimize the potential for corrosion of the reinforcement. If the subsurface environment is aggressive or may become aggressive during the life of the foundation, the concrete should be designed to have high density and

low permeability so that the concrete is able to resist the negative effects of the environment.
- *Appropriate strength and stiffness*: The concrete must provide the strength and stiffness necessary to meet structural performance requirements.

In most cases, drilled shafts are not subject to large structural stresses, so strength demands are relatively ordinary compared with the extreme workability requirements cited above.

Research Priorities

Ongoing FHWA-led research is focusing on several uncertainties related to workability, durability, and thermal issues related to concrete used for deep foundations. The current research areas prioritized for investigation are:

- *Evaluate or develop practical tests to assess and rate the potential for concrete mixtures to segregate or bleed excessively*. Researchers are attempting to clarify how much bleed is acceptable. This effort is being leveraged by ongoing research by the European Federation of Foundation Contractors and the Deep Foundations Institute.
- *Address concerns about thermal issues in large-diameter drilled shafts*. Investigators are working to quantify risks for drilled-shaft concrete damage resulting from high temperatures, especially because there are no documented cases of such damage. The research effort seeks to establish clear threshold temperatures and temperature differentials beyond which damage can be expected.

FHWA believes that a better understanding of these issues may reduce some of the most critical uncertainties and provide the basis for the development of industry guidelines regarding concrete for use in deep foundations.

Concluding Remarks

The FHWA research is focused on drilled shafts because they are one of the primary below-ground concrete applications considered by transportation agencies. However, the findings of this study will also be applicable to other below-ground structural elements, including secant and tangent pile walls, slurry (concrete diaphragm) walls, tremie seals (pedestal foundations), building mat foundations, and cast-in-place tunnel and shaft structures.

The research is being performed in three phases. The first phase, which was completed in 2016, included a comprehensive literature review, a survey of transportation agencies, and the identification of topics that should be prioritized for additional research. The second phase is ongoing and is focused on modeling and testing for thermal issues in concrete. The third phase will begin in fall 2018 and will be focused on field and laboratory testing to better understand bleed and segregation. The expectation is that the efforts will be completed by late 2019.

Concrete placed by free falling from a chute for a drilled shaft, which is a common practice in dry shaft excavations. Field studies have shown that concrete mixtures designed for dry placement in drilled shafts can be dropped freely for distances up to about 80 ft without issues related to segregation.

For additional information, please contact Silas Nichols, Principal Bridge Engineer—Geotechnical, Federal Highway Administration Office of Bridge Technology; silas.nichols@dot.gov.

Reference

1. Federal Highway Administration (FHWA). 2010. *Drilled Shafts: Construction Procedures and LRFD Design Methods. Geotechnical Engineering Circular No. 10*. Washington, DC: FHWA. https://www.fhwa.dot.gov/engineering/geotech/foundations/nhi10016/nhi10016.pdf.