Concrete Micromanagement

DRP, a Twining Company, employs a growing array of high-tech instruments and advanced analytics to help extend the service lives of bridges.

by Craig A. Shutt

The field of concrete petrography, the microscopic study of concrete's composition and the related quality and durability issues, has grown in significance for the design, construction, and maintenance of concrete bridges. Concrete petrographers analyze new and existing concrete infrastructure to provide information that engineers can use to formulate repair and maintenance options to extend the service life of structures.

DRP, a Twining Company based in Boulder, Colo., has been at the forefront of advances in concrete petrography. "Bridge owners have limited funds to address an overall aging infrastructure, and they must fully understand the condition of the materials in their bridges to know how best to address repairs," explains David Rothstein, DRP's president and founder.

"Advanced expertise is required to understand what investigative methods will work most effectively to get engineers the information they need to repair or rehabilitate a structure," he states. "The only thing worse than not repairing a weakened bridge is to spend time and money on a repair without recognizing the real problem and having the repair fail."

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Rothstein began his consulting work in 1996 and has seen the field become more analytical, precise, and valuable (for more on DRP's history, see the sidebar to this article). "Our strength is that we take a very close look at a small part of the elephant to help owners and engineers understand what is really happening," he says. "We understand we're one piece in the bigger picture—but it's an important piece."

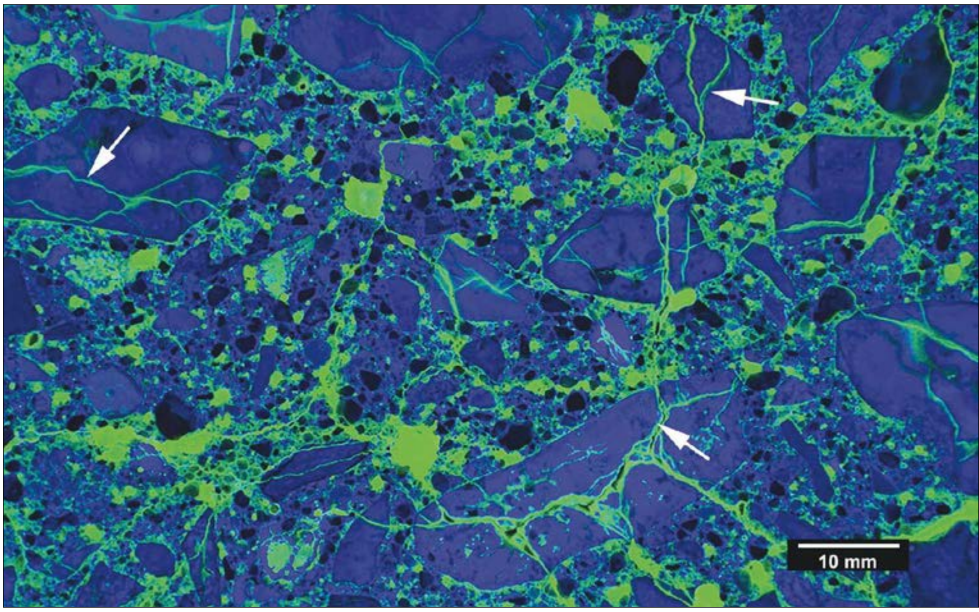
Quantifying Observations

DRP's goal is to quantify evaluative observations with more precision. "The trend is definitely toward providing more quantitative measurements," says Rothstein. "A lot of work in this field has been based on descriptions, and engineers are not wild about descriptions. They prefer numbers."

A recent innovation is fluorescence microscopy, which the firm has been actively using since 2018. DRP's concrete petrographers are now able to use thin sections containing epoxy with fluorescent dye to view the cement paste's microstructure. This technique produces objective measurements of the capillary porosity of the paste, which generally shows a strong correlation with water-to-cement ratio. The brightness of the green fluorescent tone in an area is proportional to the amount of epoxy infiltrating the material. A void (essentially 100% porosity) will be bright green, and a dense aggregate such as quartz (0% porosity) will be black.

"There was a learning curve with the equipment; it's not just a plug-and-play system," Rothstein says. "We

A concrete slab polished and impregnated with fluorescent epoxy and photographed under ultraviolet light. The bright-green areas show cracks and voids; the cracking is due to a combination of alkali-silica reaction and freezing-and-thawing damage. All Figures and Photos: DRP, a Twining Company.



can combine this technique with image analysis to provide more robust, quantitative measurements of capillary porosity," he explains. "It allows us to measure on a pixel-by-pixel basis the capillary porosity of the concrete. That allows us to evaluate quantitatively how various aspects of the construction process, ranging from consolidation to finishing to curing, affect the microstructure of concrete."

Understanding ASR and DEF

DRP's petrography services can evaluate alkali-silica reaction (ASR) and delayed ettringite formation (DEF), chemical reactions that produce secondary deposits within concrete long after it is put into service. DRP uses a high-resolution scanning electron microscope to determine whether concrete has DEF or ASR. The deposits that fill microcracks resemble gel in both cases, and both mechanisms can occur together.

The presence of ASR may indicate that the concrete is distressed. However, the significance of ASR is not necessarily as great as many engineers think.

"ASR is pretty straightforward to recognize and can be common, but the key is to know what it means when you find it," Rothstein explains. "Cracks are often noticed when grime accumulates in them or something else attracts attention. It's very common to have ASR in a 25-year-old structure without having any structural problems. Our forte is looking beyond the mere presence of ASR to determine whether performance is being affected. That's really what matters."

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With DEF, the reactive components are in the cement paste, rather than the aggregate. The reactions lead to the formation of secondary deposits that consist of ettringite. This mineral contains water, which lies at the root of any deterioration mechanism. "Although we have worked with concrete affected by DEF, it is a rare phenomenon and is encountered much less frequently than ASR," Rothstein says.

Thorough analysis of ASR and DEF helps engineers choose a course of action (see articles in the Summer 2018 and Spring 2019 issues of *ASPIRE*®). Often, monitoring a structure and using sealers are the best responses to ASR, Rothstein says. "They're cheap ways to extend the service life of the bridge without overreacting to the existence of ASR. They're low-tech options, but they can have a big impact."

"Most elements that are isolated from sources of moisture can be repaired," Rothstein says. The goal with any repair is to control water, usually through proper drainage and protection of porosity. Fiber wraps, waterproofing, and other options can provide sufficient protection. "If you can cut off the water's penetration, you stop any durability issue and life cycles can be extended."

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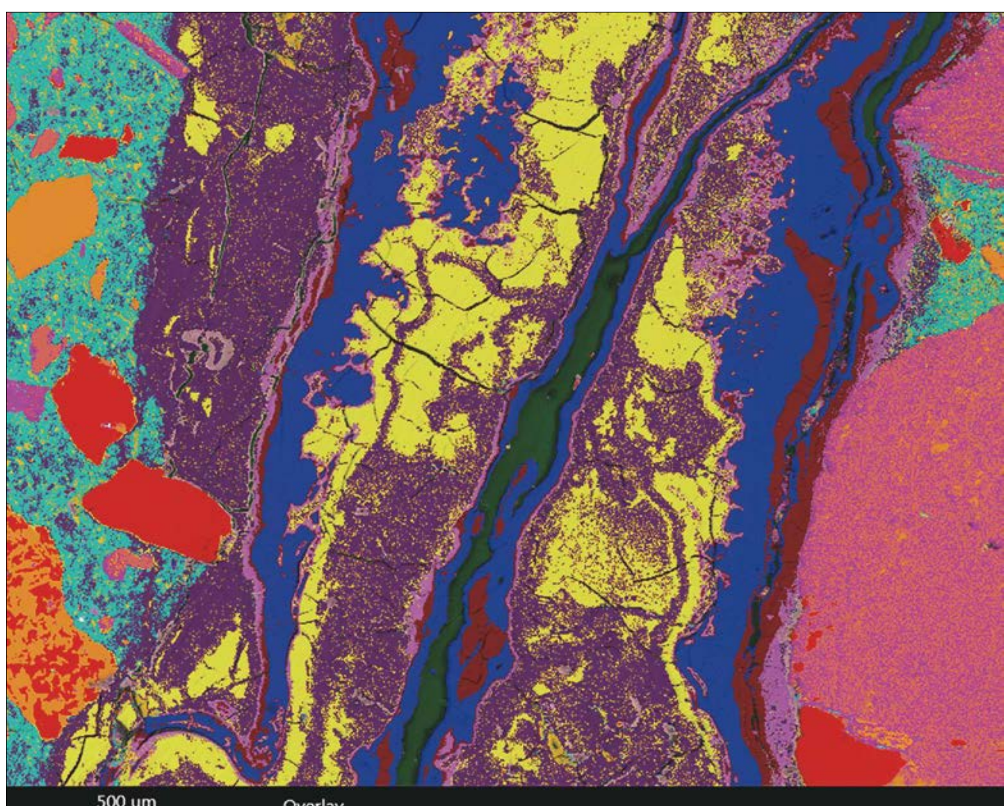
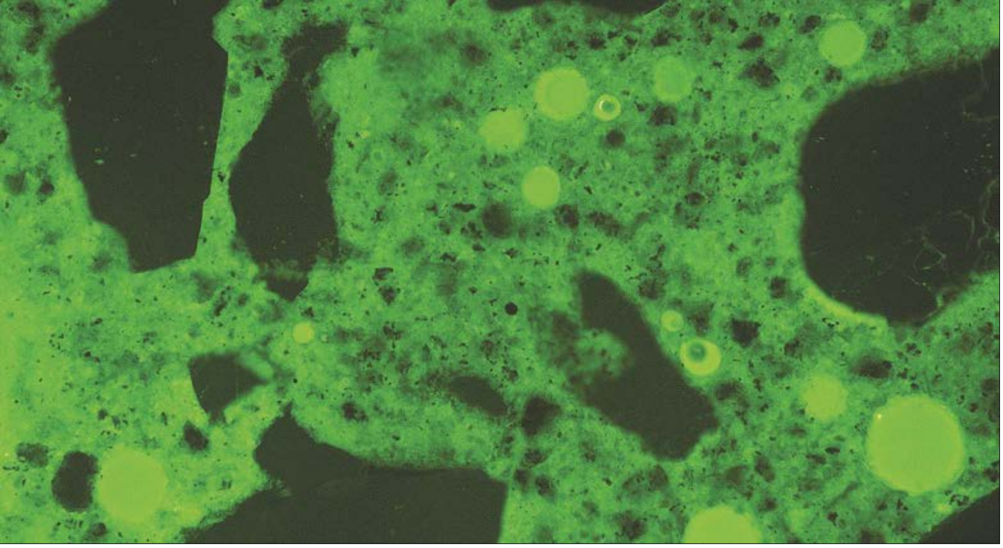
Combatting Deicer Damage

DRP is also doing research on methods to limit the damage caused by chloride-based deicing chemicals, which can cause premature deterioration around joints. "The damage manifests as both cracks that form parallel to joint walls and as microcracking along the joint walls that causes raveling," explains Chunyu (Joe) Qiao, a senior petrographer with DRP.

Qiao has been part of a research team exploring the formation of calcium oxychloride, a secondary compound



An energy dispersive spectroscopy phase map of a sample taken from a concrete seawall in southern California. Petrographic analysis showed that cracking due to alkali-silica reaction (ASR) was present in the distressed section but not in other areas, even though similar aggregates were used. ASR gel (purple and yellow), along with brucite (blue) and magnesium-silicate-hydrate (reddish brown), indicated marine-water infiltration. The analysis showed seawater had elevated the alkali content only in one area, allowing repairs to be made to retain the entire seawall's integrity.



A transmitted fluorescent-light photomicrograph showing detail of the cement paste in a thin section. The bright-green circles are air voids that have 100% porosity, and the black areas are aggregate particles with essentially 0% porosity. The variations between these colors represent variations in the paste's capillary porosity.

that can form just above the freezing point of water and damage concrete. "The infiltration of chlorides is not only a problem for spurring joint rot and concrete deterioration but also a concern for steel reinforcement and corrosion," he says. The group is currently evaluating solutions to protect concrete from these salts.

Estimating Service Life Using Formation Factors

Another area of innovation for DRP involves the use of formation factors to estimate the service life left in an existing bridge. "In the concrete construction industry, formation factor is a relatively new and fresh topic, and it's growing in popularity and understanding," Qiao says. "It's becoming an important evaluation tool for us."

Determining a formation factor is a process that was developed by the petroleum industry in the 1940s and is now being adapted to evaluate both new and in-service concrete mixtures. The factor is a result of measuring the resistivity of a porous material and quantitatively relating it to the material's transport properties. "The concrete industry has struggled to find methods that provide a simple way to measure the transport properties relevant to the durability and service life of hardened concrete," Qiao explains. "Direct measurements of concrete permeability and chloride transport are difficult, requiring extended periods of time and complex testing apparatus." Also, ASTM International doesn't offer a method to measure chloride transport directly, and most current methods, such as the rapid chloride penetrability test (ASTM C1202), are subject to experimental artifacts, such as unintended heating.

The formation factor is solely related to the microstructure and transport properties of the concrete specimen. Therefore, a "formation factor provides a simple and quantitative way to obtain more robust information regarding transport properties, and the industry is moving—albeit slowly—toward adopting the formation factor," Qiao says. "Its key benefit is that it provides an easily measured but robust parameter that can be plugged into various service-life models."

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Best of all, the formation factor can be determined by a simple procedure known as the "bucket test," which has been introduced to the American Association of State Highway and Transportation Officials and some departments of transportation for review. In essence, a concrete cylinder is placed in a saltwater bath with a known composition. The cylinder is left in the bath for a period (typically 14 to 28 days) so that the composition of the pore solution of the concrete cylinder equilibrates with that of the bath. After this conditioning, the concrete's electrical resistivity is measured periodically. The resistivity reflects the transport properties of the material. "The formation factor tells us how well the pores are connected, which influences the rate of penetration of aggressive agents like chloride," Rothstein says.

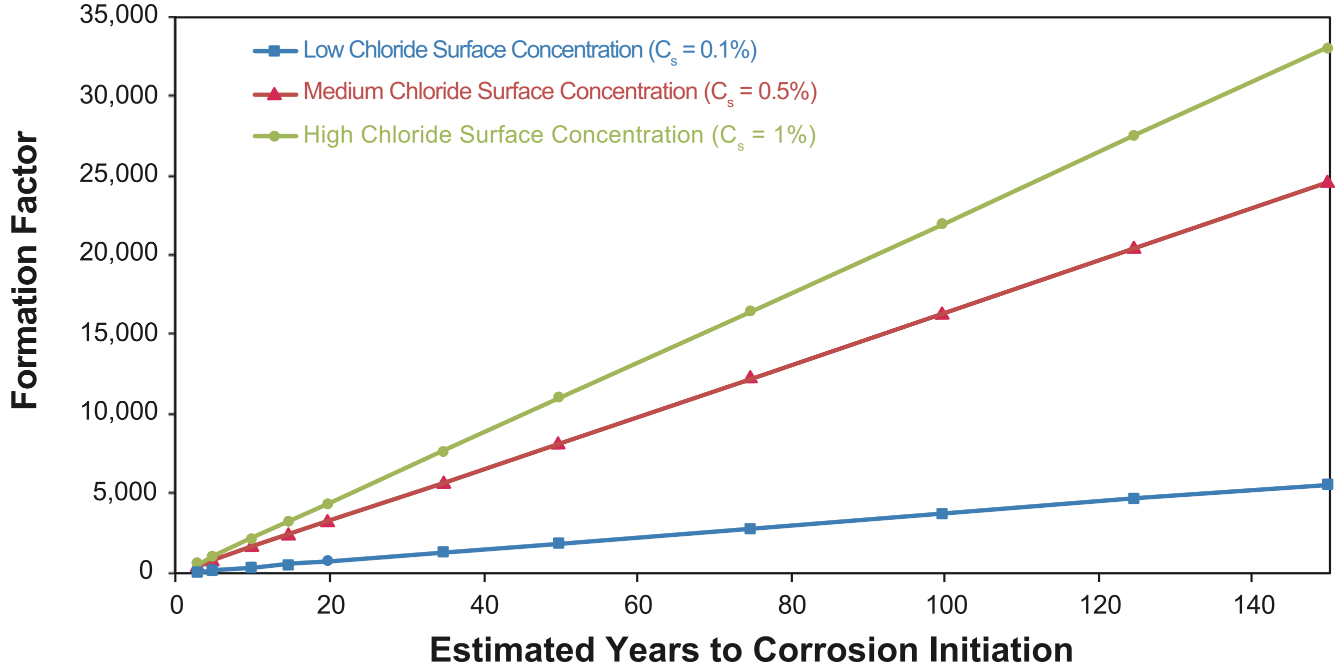
"We need more measurements to confirm that the results are as promising as they appear," Qiao says. "The potential is great. Concrete compositions vary so much that we need to find a way to standardize the results when we measure them."

Formation factor is developing into a critical evaluation tool for DRP, Rothstein says. "We think it's the path to helping the industry extend service life, by helping to standardize measurements so we're all on the same page. Owners have different approaches, and they want a numerical result that will indicate the remaining service life. This will work for everyone if we can prove it is robust, consistent, and reliable."

Looking Forward

DRP is a future-oriented company. It plans to continue its work with fluorescence microscopy and formation factor, along with using other tools and techniques to characterize the condition of concrete for clients. "We need to do more outreach to explain techniques and educate clients. We also encourage owners, engineers, contractors, and producers—everyone involved in concrete construction—to get involved with the American Concrete Institute, the Precast/Prestressed Concrete Institute, and other technical societies to learn the latest advancements in concrete properties and techniques."

DRP also plans to more than double its 2000-ft^2 existing facility to 5500 ft^2 and to add more capabilities and services, in part to help evaluate and solidify its work on formation factor. This progression was enhanced in 2017, when DRP was acquired by Twining Inc., a construction engineering, inspection, and testing firm that has been in business more than 100 years. The acquisition gives DRP the capability to develop a wider range of testing



An example of the relationship between formation factor and predicted service life. Note: C_s = the concentration of chlorides in solutions in contact with concrete. Figure developed from an approach described by Spragg.[1,2]

capabilities and expertise, and helps the firm to attain access to potential clients in California, where Twining is based.

"We had been courted in the past as a potential partner, but we never considered such offers seriously until we began a conversation with Twining," Rothstein says. "They continually push at the forefront of the industry, refining existing strengths and services, and developing new capabilities and expertise. This is exactly the kind of organization that we want to align with."

The potential for growth as new challenges arise keeps DRP engaged and looking to the future. "We're always finding new ideas and stumbling upon new anomalies that need to be examined and understood," Rothstein says. "The industry continues to create new aggregates, new mix designs, new admixtures, and new questions we need to answer. That's what keeps it fun."

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References

1. Spragg, R.P. 2017. "Development of Concrete Performance Specifications that Include Formation Factor." PhD dissertation, Purdue University, West Lafayette, IN.
2. Weiss, W.J., R.P. Spragg, O.B. Isgor, M.T. Ley, and T. Van Dam. 2017. "Toward Performance Specifications for Concrete: Linking Resistivity, RCPT and Diffusion Predictions Using the Formation Factor for Use in Specifications," In: *Proceedings*. fib Symposium 2017, International Federation for Structural Concrete, Maastricht, The Netherlands.

DRP Grows, Evolves

DRP Consulting Inc. (David Rothstein Petrographic Consulting) was founded in 1996 by David Rothstein after he earned a PhD in geology at the University of California, Los Angeles, and was asked to analyze the types of aggregate in a client's quarry. In 1999, he began postdoctoral studies at Northwestern University in Evanston, Ill., while continuing his consulting business.

In 2001, Rothstein moved to Boulder, Colo., to work on concrete structures of all types. In 2009, he hired an assistant to handle sample preparation, then an administrative assistant to handle paperwork, and then two more petrographers. Today, the firm employs six people and is a subsidiary of Twining Inc. of Long Beach, Calif.

EDITOR'S NOTE

See the FHWA article on Performance Engineered Mixtures (PEM) in the Fall 2017 issue of ASPIRE *for more discussion of the formation factor and other innovative approaches to ensure a longer service life for concrete structures.*