A New Way to Predict Creep and Shrinkage

An ACI Foundation-funded research project

by Victoria K. Sicaras, on behalf of the ACI Foundation

Having creep and shrinkage modeling tools to accurately predict concrete behavior over time is essential for designing and maintaining serviceable, safe structures. Knowing how long a structure's useful service life should be, and how concrete performs under sustained loads, is instrumental in determining when retrofits are needed or whether structural issues are materializing. This is particularly important for creep-sensitive structures, such as high-rise buildings, concrete box-girder bridges, and prestressed beams. However, many time-dependent models are outdated with respect to today's growing database of experimental evidence. A new research study funded by the ACI Foundation aims to rectify this issue.

Emerging from the research is a time-dependent design model that captures the complex reality of how creep and shrinkage phenomena are interconnected. Using solidification theory, the researchers calibrated the new model to meet the twin objectives of simplicity in application and theoretical rigor. It is poised for adoption into ACI design guidelines regarding creep and shrinkage, prestress losses, and deflections of concrete structures.

The Need for New Models

ACI Committee 209, Creep and Shrinkage in Concrete, reports information on creep and shrinkage of concrete and concrete structures. Documents published by the committee include ACI PRC-209.2-08, Guide for Modeling and Calculating Shrinkage and Creep in Hardened Concrete[1]; ACI PRC-209.1-05, Report on Factors Affecting Shrinkage and Creep of Hardened Concrete[2]; and ACI PRC-209-92, Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures (Reapproved 2008).[3]

Since their initial publication in the 1990s through the early 2000s, the guides have relied on a creep and shrinkage model developed in 1982 to calculate time-dependent deformations. In 2019, however, ACI Committee 209 determined that the model no longer reflected the current understanding of time-dependent behavior and discontinued support for that model. Experimental evidence collected over the past few decades indicated the model may no longer perform well for long-term (multi-decade) creep and shrinkage predictions, and especially for large or complex structures.

"At the time when the provisions were developed, that model reflected the best knowledge that we had about creep and shrinkage. But when you start to apply it to modern design practices with modern mixtures, beyond how it was originally intended, it breaks down and doesn't work properly," explained Brock Hedegaard, Principal Investigator of the research project and Secretary of ACI Committee 209.

To ensure ACI Committee 209 guidelines align with modern practices and structures, a new model was needed to reflect advances in knowledge about creep and shrinkage mechanisms. In 2019, Hedegaard began working with committee member—and now committee Chair—Mija Hubler on a research proposal with the goal of bringing to life such a model. They found a champion for their work in the ACI Foundation's Concrete Research Council (CRC).

Each year, CRC hosts a request for proposals (RFP) program that awards funding to several concrete research projects. Hedegaard and Hubler's RFP was selected to receive funding in 2020.

Getting Funded

The proposal involved calibrating a creep and shrinkage model that uniquely facilitates both traditional integral-type and modern rate-type analyses (refer to textbox). To create and calibrate the model, researchers needed to curate and vet a comprehensive database, which was a challenging task in itself, Hedegaard said. They also had to identify the appropriate input parameters and perform statistical comparisons to select the final model.

"This sort of undertaking would have been extremely difficult to get off the ground without the ACI Foundation and CRC," Hedegaard stated. "What we were doing did not really qualify as basic research, because we were working with already established databases and not adding new data, and there aren't a lot of funding entities interested in that. But bringing things up to date and making design documents applicable to the state of practice is incredibly valuable."

ACI Foundation Executive Director Ann Masek agreed: "ACI technical committees regularly need updates to their technical work product, and we were pleased with the opportunity to support this critical research need of ACI 209."

CRC's open RFP program allows researchers to submit unsolicited research projects. A major requirement is that the research must be endorsed by at least one ACI technical committee. Thanks to funding from ACI and donations to research from the ACI community, the number of grants awarded has grown significantly over the last several years. The funding is awarded based on relevancy and potential impact of the research, overall proposal quality, researcher capability, supplemental support for the project (such as collaboration with other funders and organizations), and ACI technical committee engagement. In the case of the time-dependent model project, it had unanimous endorsement by ACI Committee 209, as well as commitments from several of the industry's leading design and engineering companies to serve on an advisory panel.

"Not only will the research results advance industry practice, with its updated model prediction of time-dependent deflections and stresses in concrete structures, but we also got a chance to support the work of early career professors like Brock [Hedegaard] and Mija [Hubler]," Masek said.

Project Details

Name: Calibration of Simplified Creep and Shrinkage Models Developed Using Solidification Theory

Principal Investigator: Brock Hedegaard, Associate Professor of civil engineering at the University of Minnesota, Duluth, MN

Co-Principal Investigator: Mija Hubler, Associate Professor and the Co-Director of the Center for Infrastructure, Energy and Space Testing at the University of Colorado, Boulder, CO

ACI Technical Committee endorsement: ACI Committee 209, Creep and Shrinkage in Concrete

Funder: ACI Foundation

About the Research: Traditional time-dependent analysis has relied on definition of a compliance function or creep coefficient. For time-varying stresses, the strain may be approximated (for example, through the age-adjusted modulus method) or computed using integral-type analysis. Rate-type analysis does not require computation of an integral over the entire stress history; thus, it is more efficient and accurate for more complex structural analysis. Previously, no existing time-dependent model other than the B3/B4 basic creep expression had a convenient form for performing rate-type analysis.

The model developed over the course of this research project changes this reality. The new model has closed-form expressions for the compliance function and compliance rate, uniquely supporting both analysis approaches. These features place the model on the cutting edge of time-dependent structural analysis.

The calibration was conducted in three steps:

1. Database management and preparation;
2. Identification of appropriate input parameters and calibration by nonlinear optimization; and
3. Statistical comparison and final model selection per information theory.

Supporting Early Career Faculty

At the time of funding, Hedegaard was an Assistant Professor of civil engineering at the University of Minnesota, Duluth, MN, USA. Hubler, who served as Co-Principal Investigator on the project, was an Assistant Professor of civil, environmental, and architectural engineering at the University of Colorado, Boulder, CO, USA. One graduate research assistant contributed to the research.

The ACI Foundation shares ACI's vision of a future where everyone has the knowledge needed to use concrete effectively to meet the demands of a changing world. To support this shared vision, the Foundation's mission is to make strategic investments in ideas, research, and people to create the future of the concrete industry.

"Investing in 'people' is a critical component of the mission, and it drives CRC's efforts to award at least two grants annually to projects led by an associate or assistant professor or other type of early career faculty," according to CRC Chair Sulapha Peethamparan. "This helps us make sure we are aiding the promotion and development of future generations of concrete researchers."

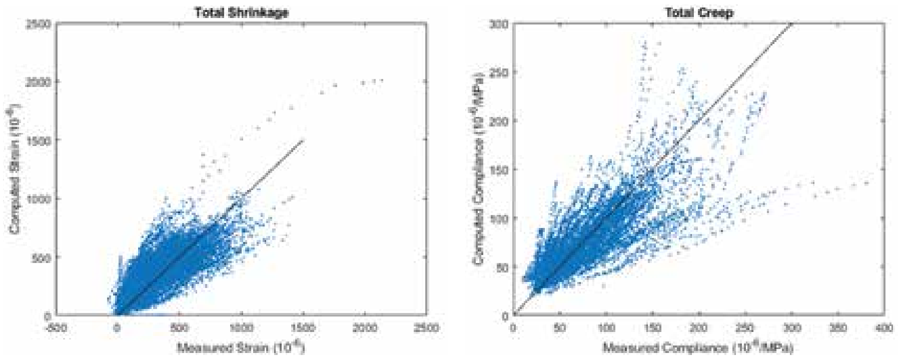
The grants also limit funding of research organizations' indirect costs to 15%. This ensures the funds are directed to the people and activities involved in a project and not the organization's overhead.

"Receiving the funding needed to conduct research helps young professionals like us contribute to academia and industry, and those research projects are great bullet points to have when seeking tenure," Hedegaard said. "But also, most of the CRC grant money we received was used to fund our student's tuition and other project-related needs. Our student was important to the project because he helped develop the model, plus he was doing all the number crunching and MATLAB work."

Mutual Benefits of Industry Involvement

"Our industry advisory panel was very helpful in terms of brainstorming model candidates," Hedegaard said. "We had building engineers, bridge engineers, and a distribution of people who had performed creep and shrinkage testing."

The project's advisory panel included representatives from FIGG Bridge Group; Meyer Borgman Johnson (MBJ); MJ2 Consulting; Skidmore, Owings & Merrill (SOM); Wiss, Janney, Elstner Associates (WJE); and WSP USA. Ongoing dialogue



The research project's calibrated model predictions compared to measurements from the Northwestern University creep and shrinkage database (based on Fig. 8 in Reference 4)

between the researchers and panel members guided the concept of a model that incorporates the interconnectedness of creep and shrinkage.

"MJ2 Consulting's Matt D'Ambrosia brought up the fact that different types of creep and shrinkage don't occur separately. They are connected in some way because it all comes down to what happens to water in concrete. Factoring in these relationships between creep and shrinkage phenomena is one of the reasons why the model does very well in comparison with the databases. It's a big leap forward for our industry, I hope," Hedegaard explained.

Panel members also provided input on what they would want to see in a design document, which was beneficial for both the researchers and the companies involved, Hedegaard said. Because the model aligns with industry best practices where it makes sense to do so, it is both useful for theoretical predictions and as a practical tool in real-world applications.

Brock Hedegaard checks out a double-ring concrete shrinkage test at the Turner-Fairbank Highway Research Center laboratory in McLean, VA, USA *(photo courtesy of Brock Hedegaard)*

Advancing the Concrete Industry

During the project duration, results were presented at ACI convention Open Topic technical sessions and regular meetings of ACI Committee 209. Roman Wan-Wendner, ACI Subcommittee 209-D Chair and ACI Committee 209 Vice Chair, served as committee liaison between the project team, the advisory panel, and Committee 209.

"The project was a positive and fun process," Hedegaard said. "There was a lot of back and forth as we bounced ideas around, and a lot of creative thinking from multiple angles and parties. What we ended up with was a model that is a very good fit to the database, but it's also a tool that you can take to your design office and use."

A manuscript documenting the calibrated model was published in the May 2023 issue of *ACI Materials Journal*.[4] The model also will be presented to ACI Committee 209 for incorporation into ACI PRC-209.2. In addition, it will be featured in two planned reports from Committee 209 documenting time-dependent structural analysis by either traditional integral methods or modern rate-type methods. The model, which facilitates both, is expected to form the basis for robust design guidance in both documents.

The ACI Foundation looks forward to funding future research and innovations that provide needed solutions for industry needs, Masek said. Organizations can aid the Foundation's efforts and support concrete-related research and technology advancements by contributing their expertise, experience, and donations. Visit **www.acifoundation.org/giving** for more details.

References

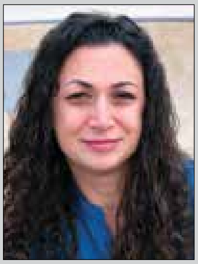
1. ACI Committee 209, "Guide for Modeling and Calculating Shrinkage and Creep in Hardened Concrete (ACI PRC-209.2-08)," American Concrete Institute, Farmington Hills, MI, 2008, 45 pp.

2. ACI Committee 209, "Report on Factors Affecting Shrinkage and Creep of Hardened Concrete (ACI PRC-209.1-05)," American Concrete Institute, Farmington Hills, MI, 2005, 12 pp.

3. ACI Committee 209, "Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures (ACI PRC-209-92) (Reapproved 2008)," American Concrete Institute, Farmington Hills, MI, 1992, 47 pp.

4. Hedegaard, B.D.; Clement, T.J.; and Hubler, M.H., "Coupled Pore Relative Humidity Model for Concrete Shrinkage and Creep," *ACI Materials Journal*, V. 120, No. 3, May 2023, pp. 103-116.

Selected for reader interest by the editors.



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