Experimentally Validated Computational Modeling of Creep and Creep-Cracking for Nuclear Concrete Structures

PI: Zachary Grasley, Texas A&M University
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Collaborators:
Joseph Bracci – Texas A&M University
Christopher Jones – Sandia National Lab
Benjamin Spencer – Idaho National Lab

ABSTRACT:
The Expanded Proactive Materials Degradation Assessment (EMDA) identified creep-creep cracking interaction in nuclear concrete structures as an important area of materials degradation that could adversely impact safe operation of a reactor. The objectives of the proposed research are to develop a full 3D experimentally validated creep and cracking model for nuclear concrete, to incorporate the new model into the Grizzly structural FEM code, and to validate the models via a large-scale mock-up of a nuclear concrete structure. The scope of the proposed research involves a plethora of advances in creep experiments, creep material modeling, large-scale testing, and structural modeling of nuclear containment facilities. The research team has a strong background in each of these aspects of the proposed work, which has led to novel ideas to help mitigate the many challenges associated with the complex problem of concrete creep and creep-cracking. A unique concrete creep test that extracts the full 3D character of the stress and strain state will be utilized to devise a comprehensive 3D constitutive model. The 3D model will be key to implementing full 3D structural simulations of concrete containment structures, in contrast to past approaches that have largely neglected out of plane stresses and deformations – including creep strains induced by the Poisson effect. A full 3D experimental and modeling approach is absolutely necessary to capture creep and creep-cracking effects given the configuration of reinforcement, the structural geometry of nuclear containment facilities, and the shifting of principal normal and shear stresses that may occur during load changes or structural modification. The time-temperature superposition principle will be utilized to help extend the predictive capabilities of the models to creep durations well beyond the project term while simultaneously enabling parametric temperature dependence. A new research paradigm whereby symbiotic physical experiments and virtual experiments are coupled to accelerate the scientific process will be leveraged to enhance the nuclear concrete creep database; this database will further be bolstered by a data-and-knowledge-sharing collaboration with Electricité de France. Large-scale structural tests will be conducted at a unique facility that involves real-world weathering and high temperatures, and allows such experiments to extend for several decades; this opens the possibility to extreme long-term validation of the structural model at some date well beyond the project term. The research team has been carefully assembled to ensure the greatest probability of success of the proposed project. The experienced team includes concrete creep experts (both experiments and modeling), a large-scale concrete testing expert, experts in computational structural modeling, and experts with close ties to the nuclear power industry. The combination of expertise, experience, and a carefully crafted research plan will result in a thorough understanding of nuclear concrete creep, including the effects of load reversals, temperature history, mixture design effects, etc. Such an understanding of the complex creep-creep cracking processes and their parametric dependencies – combined with a fundamentally sound modeling approach – will enable *a priori* optimization of structure modification and rapid assessment of the effects of changes in loading. Annual presentations for the sponsor and a final, written report will detail the findings. Additionally, a 3D structural modeling tool will be produced that leverages the advances in material understanding and modeling to accurately simulate long-term creep and the effects of load changes or structure modifications.