

PROCEEDINGS

Experimental and Numerical Characterization of Dynamic Tri-Axial Mechanical Behavior Under Coupled Freezing and High Strain-Rate Conditions

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ABSTRACT

Concrete infrastructure in cold regions often faces coupled threats from sub-zero temperatures and sudden dynamic loads such as impact or blast events, yet few studies have addressed the mechanical response of frozen concrete beyond uniaxial conditions. This work bridges that gap through a tri-axial Split Hopkinson Pressure Bar (SHPB) testing program combined with finite element modeling. A series of experiments are conducted on frozen concrete specimens at various confining pressures and strain rate to characterize the coupled effects of strain rate, freezing, and three-dimensional stress state on the compressive strength, deformation capacity, and failure modes of the material. The tri-axial SHPB data show that freezing stiffens the pore-water phase and markedly raises peak strength, while confinement restricts lateral dilation and shifts the failure mode from brittle splitting toward distributed crushing. A notable coupling between temperature and confinement was observed: the strain rate sensitivity measured under confining pressure at -15 °C differs substantially from that at room temperature under the same confinement, indicating that treating these effects independently leads to non-conservative predictions. Based on the experimental observations, a modified Drucker-Prager (DP) strength model and constitutive model is proposed that incorporates strain rate dependence and freezing effects within a three-dimensional stress framework. The model parameters are calibrated against the tri-axial SHPB test data across the investigated range of confinement levels. The proposed constitutive model is then implemented into a finite element method (FEM) code, and numerical simulations of the tri-axial SHPB tests are performed to validate the modeling framework. The simulation results demonstrate good agreement with the experimental data in terms of stress-strain response, peak strength, and failure patterns, confirming the capability of the proposed framework to capture the essential features of frozen concrete under dynamic tri-axial loading. This integrated experimental-numerical approach provides a reliable tool for predicting the dynamic behavior of concrete structures in cold environments under complex loading scenarios.

KEYWORDS

Tri-axial SHPB; frozen concrete; strain rate effect; 3D stress state; DP model; constitutive modeling; FEM

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