ENNStressNet - An Unsupervised Equilibrium-Based Neural Network for End-to-End Stress Mapping in Elastoplastic Solids

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Abstract

Determining internal stress and strain fields in solid structures under external loads has been a central focus of continuum mechanics, playing a critical role in characterizing the mechanical behaviors and properties of both engineering and biological systems. With advancements in modern optical and electron microscopy techniques, strain fields can now be directly measured using sophisticated methods such as digital image correlation and digital volume correlation. However, direct measurement of stress fields remains limited to simple cases, such as photoelastic tests and standard uniaxial or shear tests. For elastoplastic solids, which exhibit complex irreversible and history-dependent deformations, stress fields are typically inferred through numerical calculations based on empirical constitutive models that are not always reliable or even available. Here, we introduce an unsupervised equilibrium-based neural network (ENN) that is trained using readily measurable strain fields and forces from a single specimen to directly predict the internal stress field. The ENN's structure aligns with the general framework of the incremental theory of elastoplasticity, without requiring prior knowledge of its detailed mathematical form. Once trained, the ENN, referred to as ENNStressNet, serves as an end-to-end stress mapper, enabling the direct determination of stress fields from measured strain fields in elastoplastic solids with arbitrary geometries and under various external loads. This approach thus bypasses the need for constitutive modeling and numerical simulations in conventional engineering analysis.

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