Modelling of Visco-Plasticity Using Neural Networks

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Abstract

Neural networks can be used to replace complicated functional expressions. In the present work, neural networks are employed to model material hardening and rate-dependence of materials. The material model consists of an Eulerian framework (i.e. all state variables are defined in the current state of the material), and neural networks are added to this framework. The theoretical framework guarantees that such requirements as frame-indifference and thermodynamical consistency are fulfilled by definition. The framework as such has been developed in previous works, and in the present work, neural networks are used to model the rate-dependence and hardening of the material. Both isotropic and directional hardening is considered. No functional expression for these behaviours need to be defined in advance.
The neural network model is implemented in Python and the library Pytorch is used for modelling the neural networks. Simple feed-forward neural networks are used in the present study, and in most cases a single hidden layer is used. The number of neurons in this layer is varied. Poisson's ratio is assumed to be 0.3 or 0.4, depending on which material is considered (steel or polymer). During the training procedure, the shear modulus is estimated along with the network parameters associated with the inelasticity. The error function is defined as the average mean square difference between the reference stress response and the trained stress response.

The neural network-based model is applied to both theoretical reference data as well as actual experimental data in the form of stress–strain data. Different optimisation methods are explored for optimising and training the neural networks. The model was able to reproduce both the theoretical reference solutions as well as the experimental data very well.
An implicit FE formulation is also provided in the form of a subroutine (UMAT) in Abaqus. The implementation was applied to two 3D examples, and the implementation seems to be robust and shows nice convergence properties. Overall, the present neural network-enhanced framework seems to be promising and there is potential for further development.

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