Post-doctoral project

Physics-informed neural networks for the analysis of nonlinear structures

A post-doctoral position is open at Navier Laboratory (Univ Gustave Eiffel, Ecole des Ponts, CNRS).

In the recent years, applications of machine learning (ML) techniques have experienced an upsurge like no other numerical technique, to the point that ML is now being applied in most scientific disciplines. This trend is also supported by the fact that a number of high-quality, accessible, computational frameworks are freely available as open source projects[1].

ML techniques can be seen as "super-interpolation techniques" that thrive in the realm of high-dimensionality problems. Within the framework of solid mechanics, upscaling of heterogeneous, non-linear materials is a typical example of such high-dimensional problems, with arguably an *infinite* number of internal variables. In the recent years, ML techniques (in particular, Artificial Neural Networks, ANN) have therefore become a *de facto* modeling tool for the mechanics of *materials*[2], less so for the mechanics of *structures*.

In order to provide efficient predictions, ANN need to be trained with a large dataset (e.g. pairs of stress- and strain-increments), which can be prohibitively expensive. Besides, blind training might omit essential prior knowledge that ought to *constrain* the resulting ANN. This widely acknowledged objection to ML techniques has recently been sidestepped with the introduction of more advanced, so-called *physics-informed*, neural networks[3] (PINN). For example, thermodynamics-based Artificial Neural Networks[4,5] (TANN) were recently introduced by Masi, Stefanou and coauthors to ensure that the predictions of the constitutive behavior of an inelastic material were consistent with the fundamental laws of thermodynamics.

We propose in this project to extend the ideas underlying PINN and TANN to nonlinear *structures*. As a first step, the TANN technique will be applied to the constitutive modeling of a non-linear beam (at

1 For example: scikit-learn, PyTorch, TensorFlow.
2 Peng et al., Multiscale Modeling Meets Machine Learning: What Can We Learn? DOI:10.1007/s11831-020-09405-5
3 Raissi et al., Physics-informed neural networks: A deep learning framework for solving forward and inverse problems involving nonlinear partial differential equations. DOI:10.1016/j.jcp.2018.10.045
4 Masi et al., Thermodynamics-based Artificial Neural Networks for constitutive modeling. DOI:10.1016/j.jmps.2020.104277
5 Masi et Stefanou, Multiscale modeling of inelastic materials with Thermodynamics-based Artificial Neural Networks (TANN). DOI:10.1016/j.cma.2022.115190

6 et 8 avenue Blaise Pascal – Cité Descartes – Champs-sur-Marne-F-77455 MARNE-LA-VALLÉE CEDEX 2
Tél. : +33 (0) 1 64 15 37 51 – Courriel : sebastien.brisard@univ-eiffel.fr – https://navier-lab.fr/

the level of the “integration point”). The objective is to train such a network to learn the cross-section non-linear response in terms of axial and bending strains. In the context of elastoplastic materials, the number of plastic internal state variables describing the plastic state within the cross-section can be very large. A specific model reduction strategy will therefore be investigated in order to represent such a plastic state with a limited number of state variables. The computational efficiency of the resulting nonlinear beam model will be tested against classical multi-fiber beam models. In a second stage, we will consider the extension of the proposed methodology to a fully 3D beam model including shear effects and torsional behaviour.

This project will be supervised by J. Bleyer (jeremy.bleyer@enpc.fr), S. Brisard (sebastien.brisard@univ-eiffel.fr) and K. Sab (karam.sab@enpc.fr). The candidate is expected to have basic knowledge of the mechanics of beams and of material nonlinearities in solid mechanics. He should be comfortable with scientific programming (preferred language: Python). Background in data science would be appreciated.

This 12 month position is available from january, 1st 2023 ; gross salary is 2748€ per month. Applications should be sent to all three supervisors and should include: cover letter, electronic copy of the PhD thesis and all publications, as well as two referees.