Towards a Hybrid Digital Twin: Fusing Sensor Information and Physics in Surrogate Modeling of a Reinforced Concrete Beam

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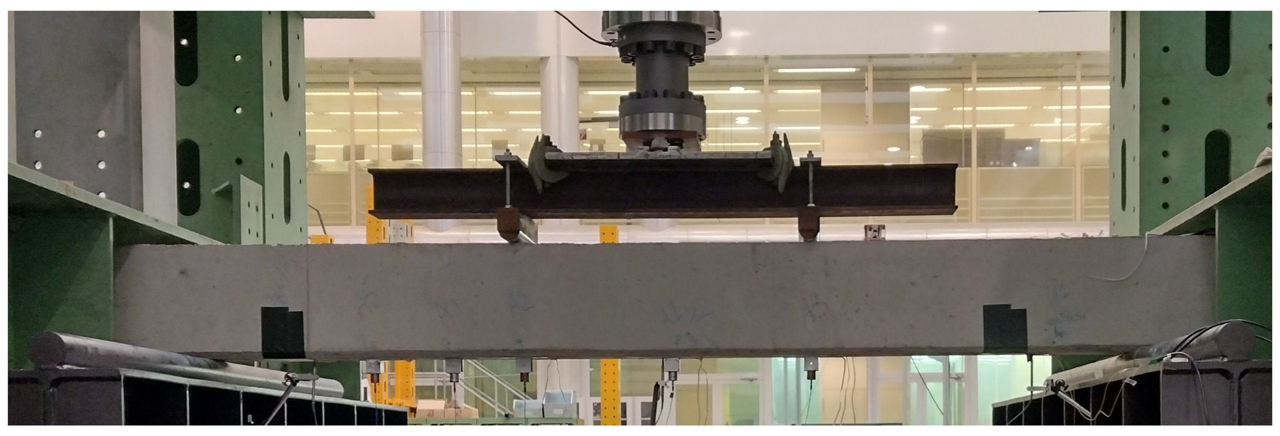
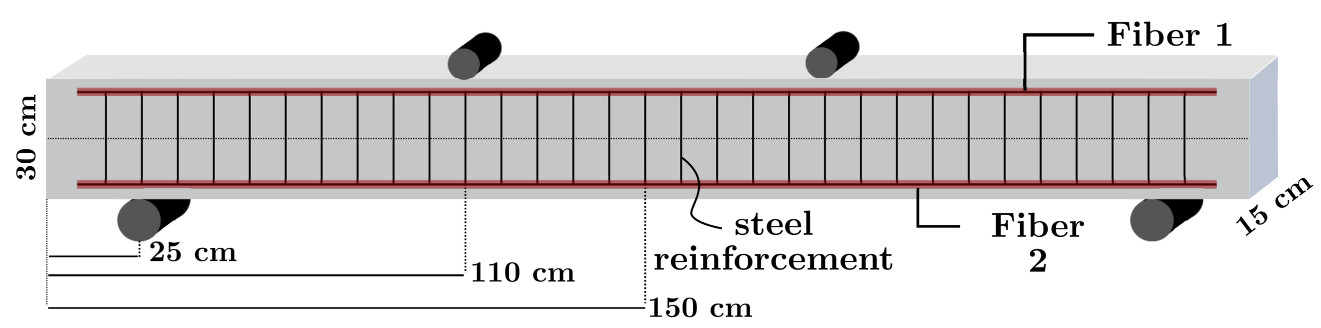
Motivation

Digital twins are increasingly used to support **structural assessment** and **predictive maintenance**. However, purely simulation-based twins often fall short when simplified models cannot capture the full physical complexity. **Hybrid digital twins** address this limitation by combining **physics**-based formulations with **data**-driven corrections derived from measurements. The resulting surrogates remain physically interpretable while improving predictive accuracy and reliability. In this work, we demonstrate this concept for a **reinforced concrete beam**, where a simplified mechanical model is enhanced by **sensor information** within a **physics-informed neural network (PINN)** framework—yielding a **reliable and explainable hybrid surrogate**.

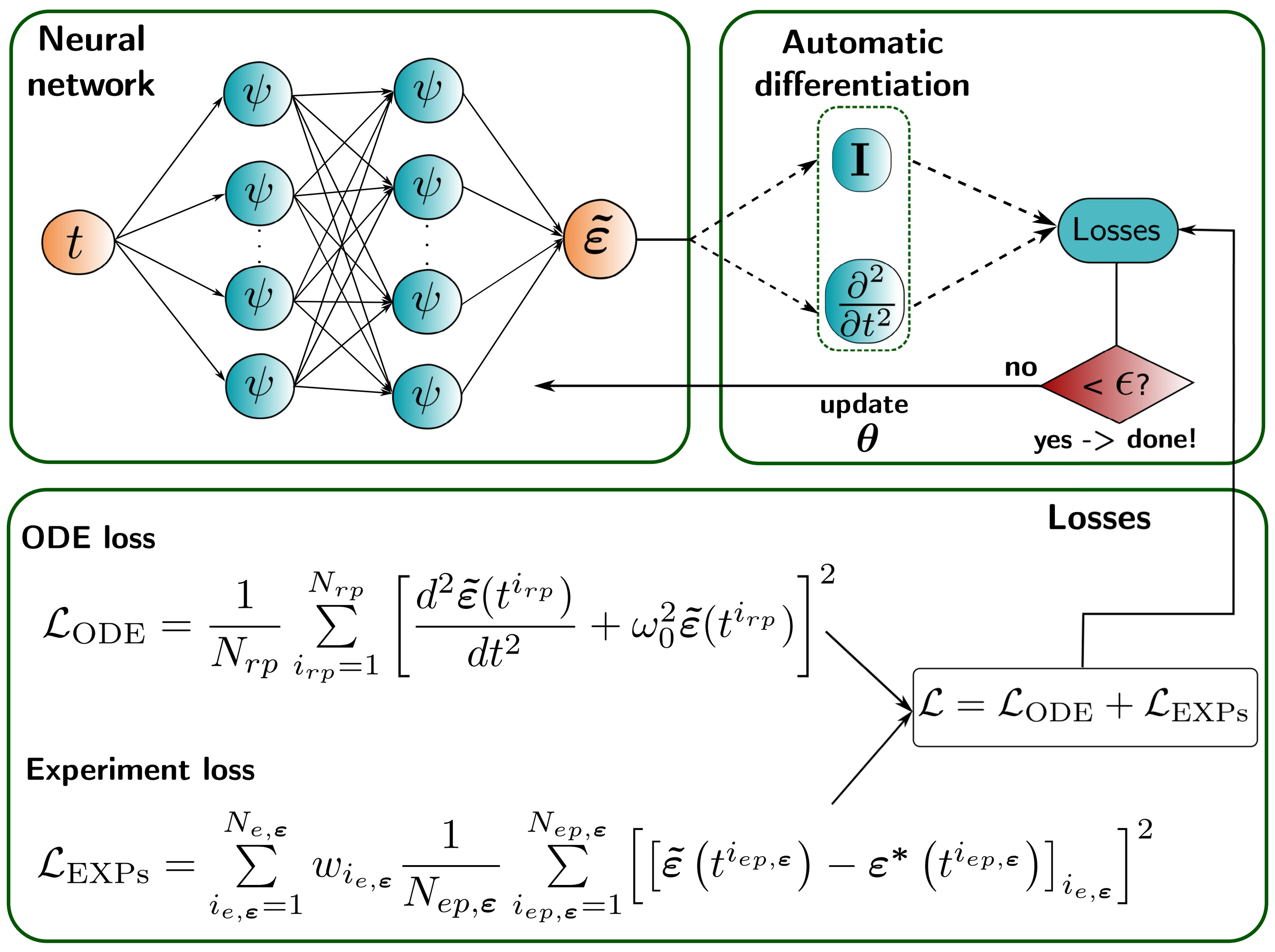
Physical asset: A reinforced concrete beam

Data for our ROMs are collected from a **four-point bending test**. **Fiber-optical sensors** are embedded into the concrete beam to **measure longitudinal strains** (microstrains) along the beam axis, with two sensors positioned on the compression side (fiber 1) and four sensors located on the tension side (fiber 2).

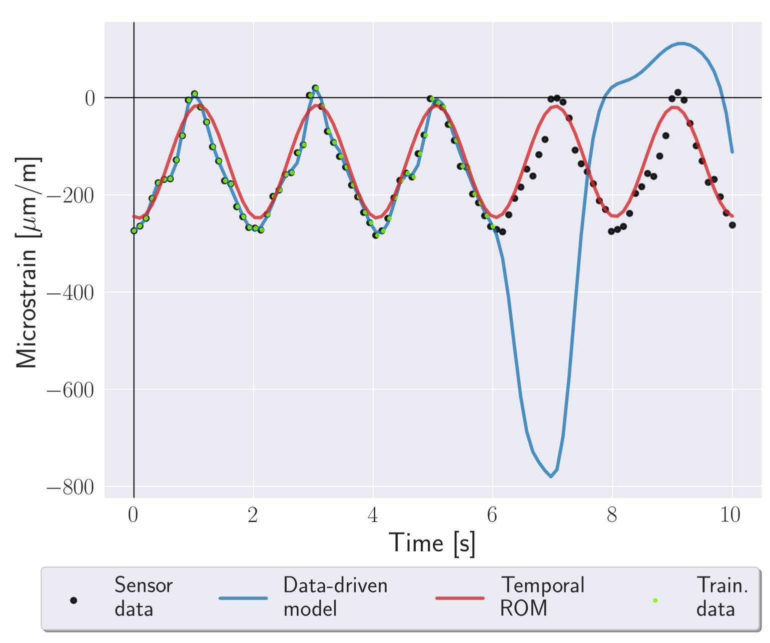




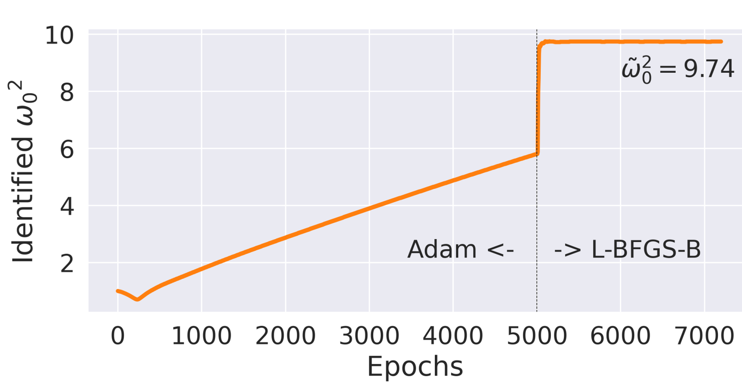
A PINN-based Temporal ROM



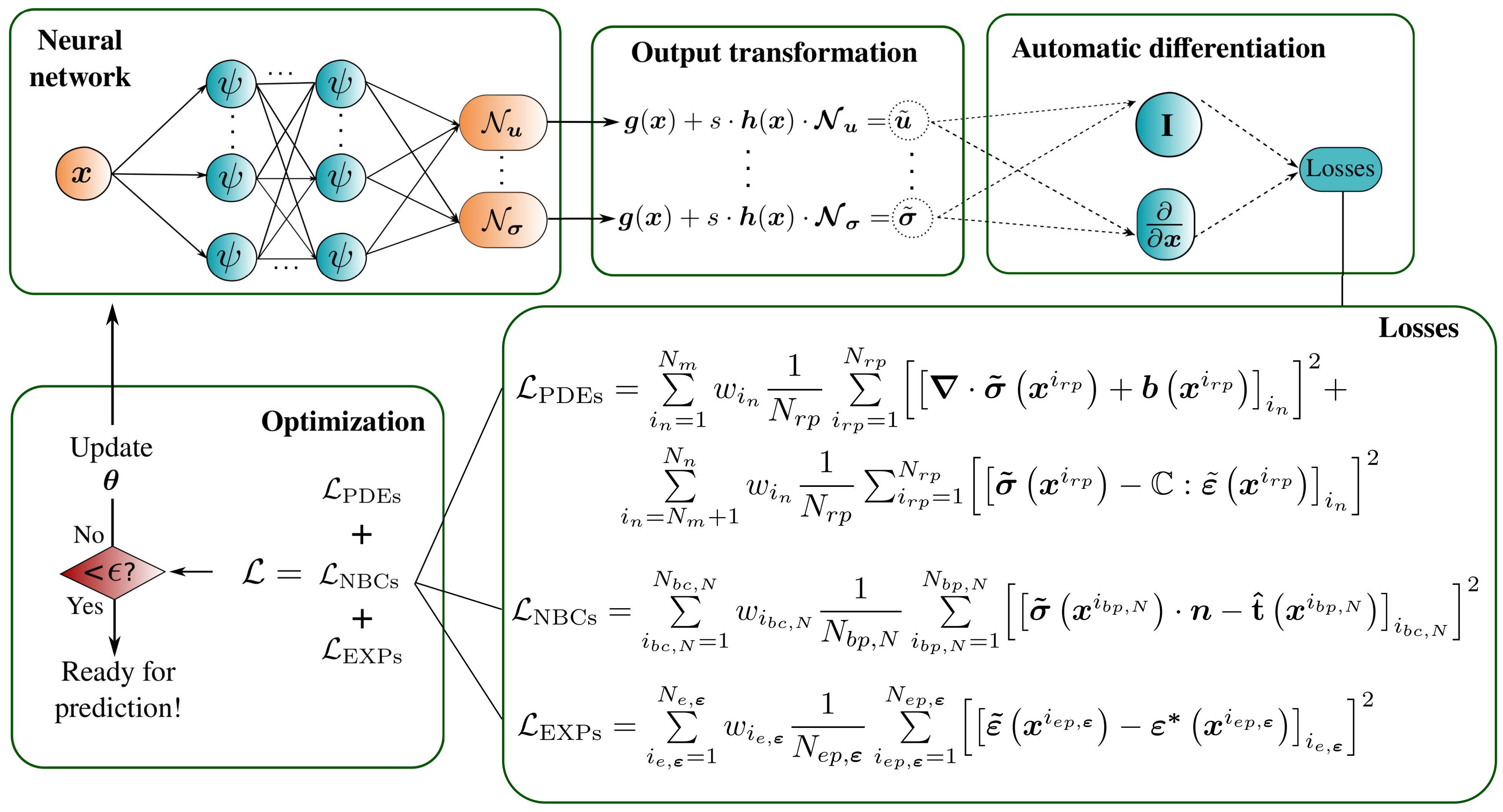
In the left figure, we compare a purely data-driven model and the temporal ROM and indicate training and measurement data points.



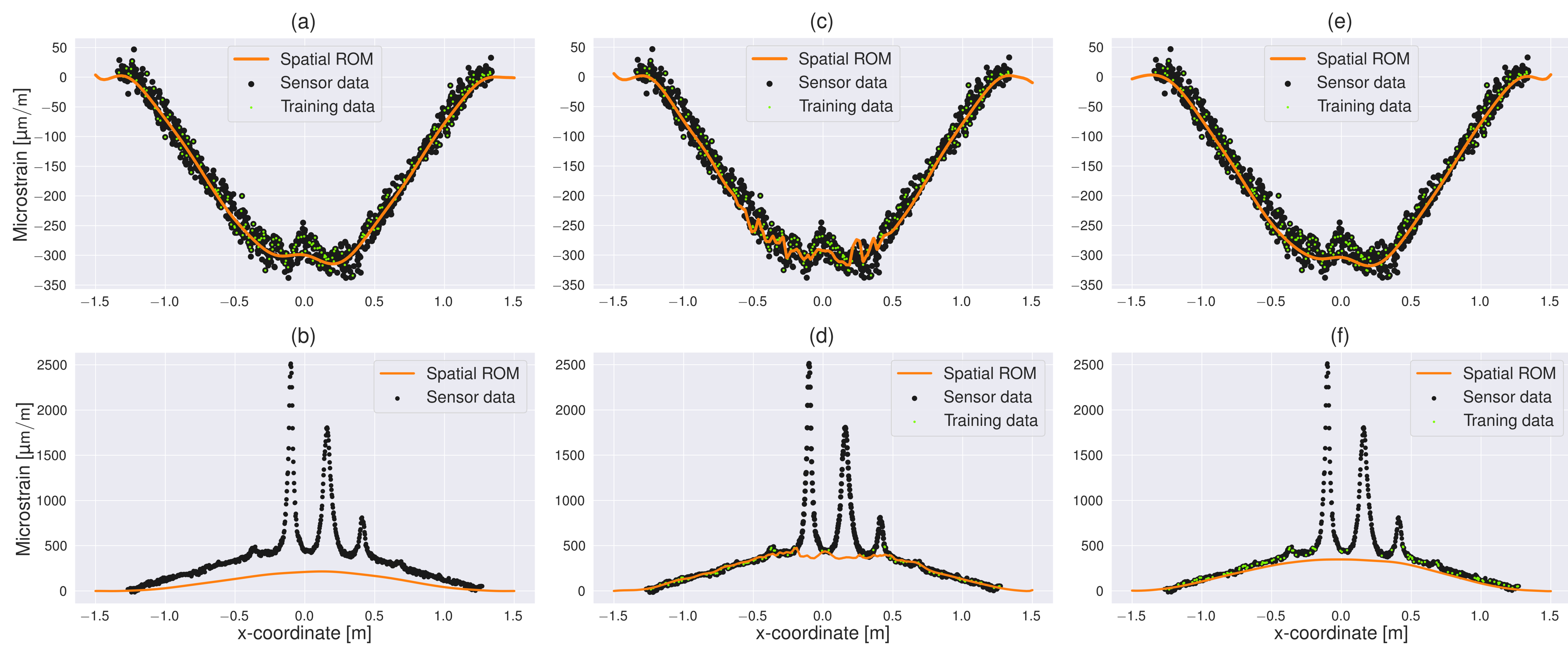
The natural frequency of the system is identified as $\tilde{\omega}_0^2 \approx$ 9.74 rad^2 Hz^2, which closely approximates the true value of $\omega_0^2 \approx$ 9.87 rad^2 Hz^2.



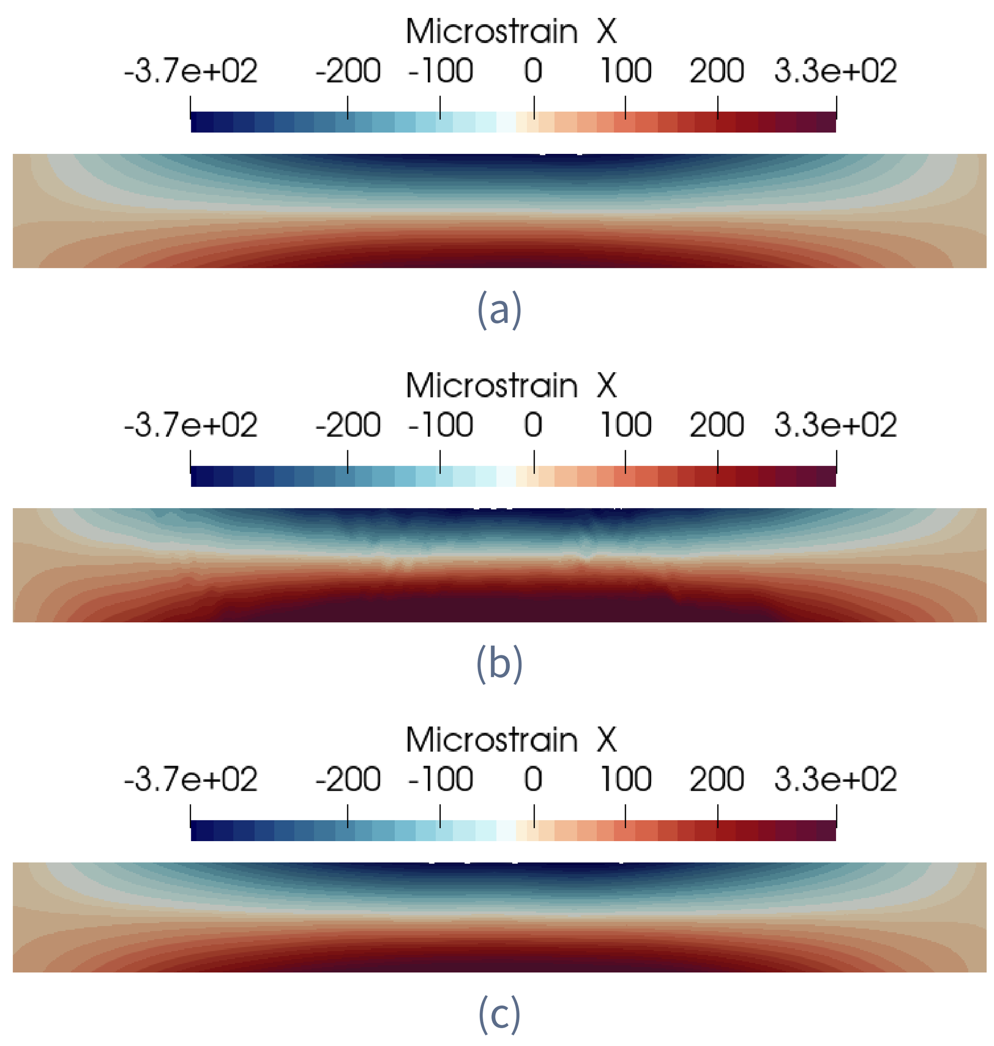
A PINN-based Spatial ROM



Strain predictions using the spatial ROM along compression and tension sides. Plots in the upper row represent the compression side, while plots in the lower row represent the tension side. Different scenarios are shown as (a,b) **Scenario 1**: only compression data is involved, (c,d) **Scenario 2**: both compression and tension data are involved, and (e,f) **Scenario 3**: both compression and tension data are involved, but the weight for the sensor loss is set to $w_{\text{EXPs,T}} = 0.01$.



Strain predictions using the spatial ROM within the beam domain for three scenarios: (a) Scenario 1, (b) Scenario 2, (c) Scenario 3.



References

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