

TASK 2&3: HYPERELASTICITY

Fabian Roth

SECTIONS



2.1 Data preparation

2.2 Naive model

2.3 Physics-augmented model

2.4 Concentric sampled deformation gradients

3.1 Invariant-based model

3.2 Deformation-gradient based model

3.3 Data augmentation

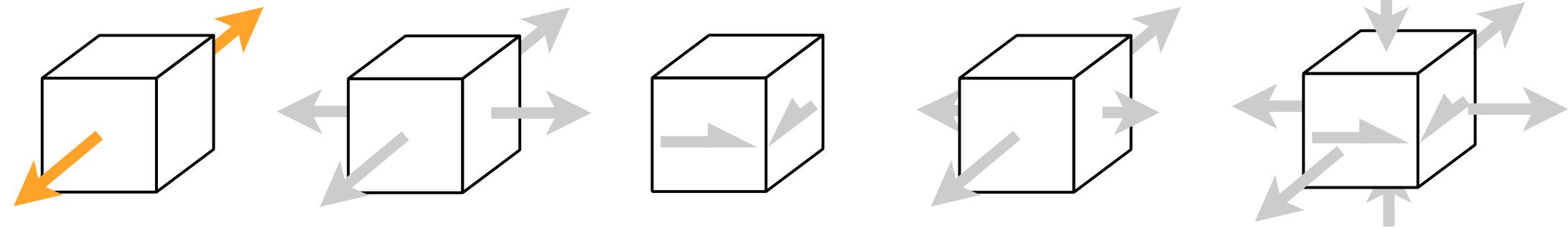


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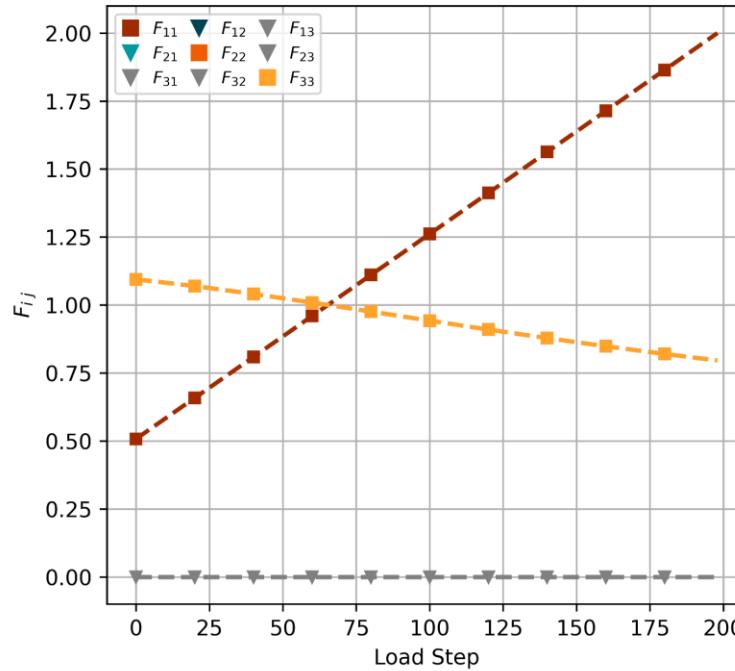
TASK 2

HYPERELASTICITY I

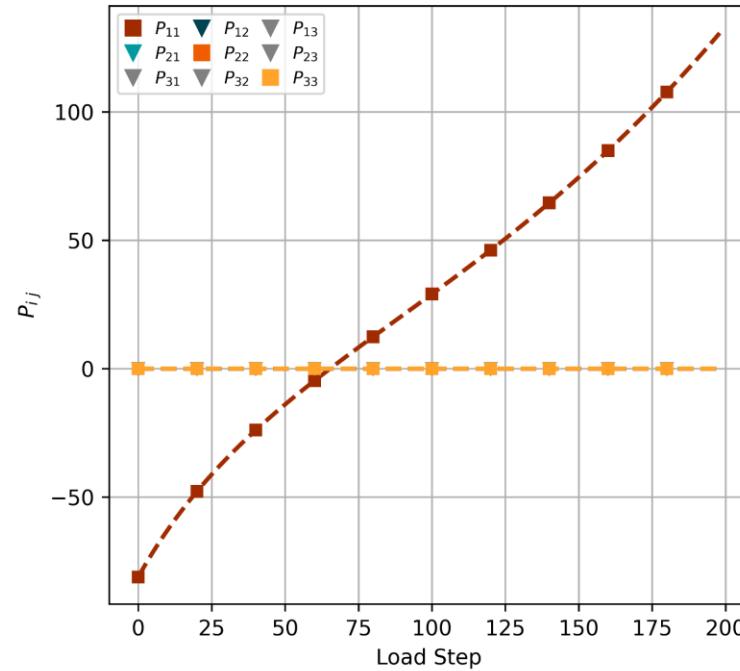
DATA - UNIAXIAL



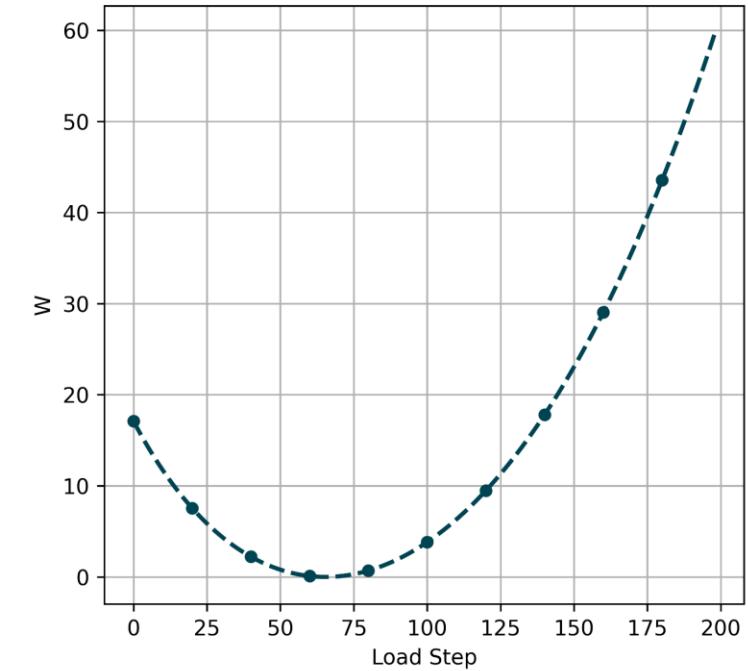
Deformation Gradient F



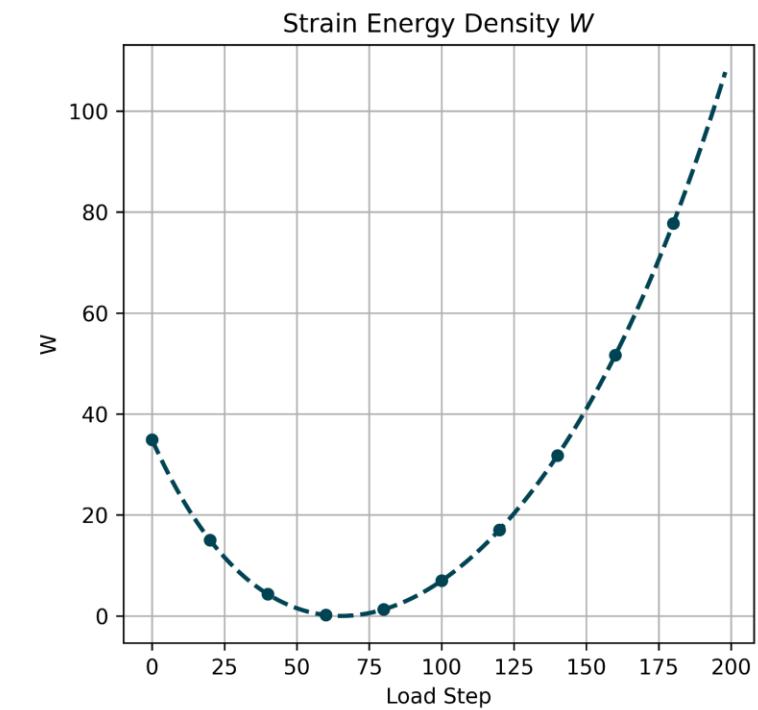
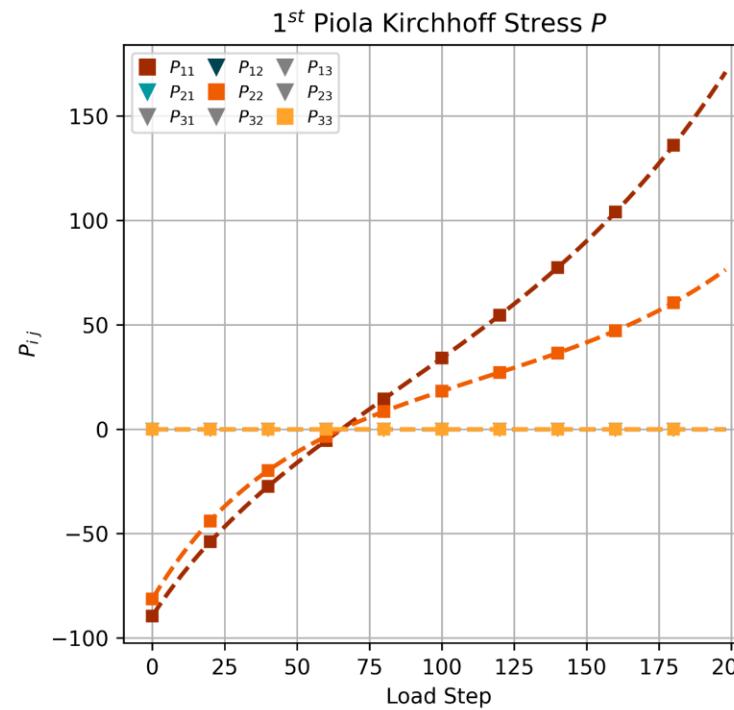
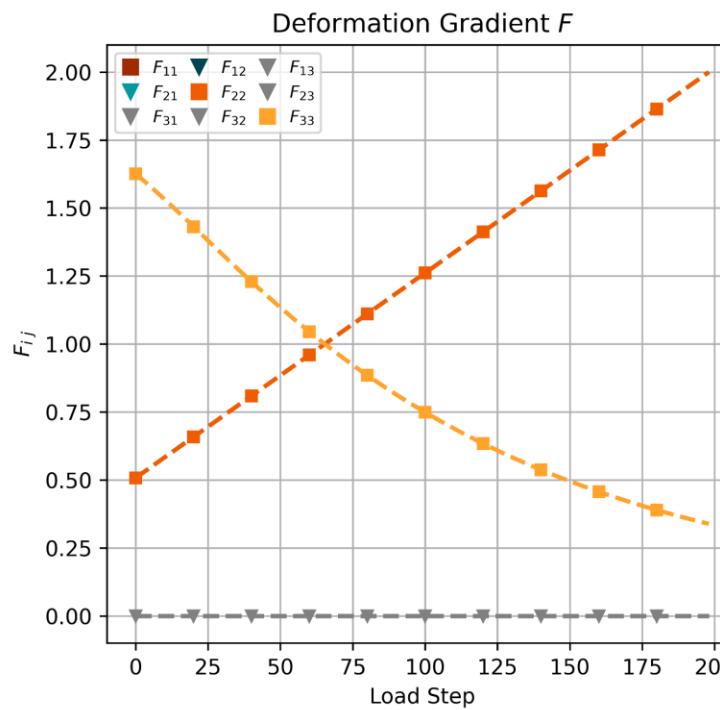
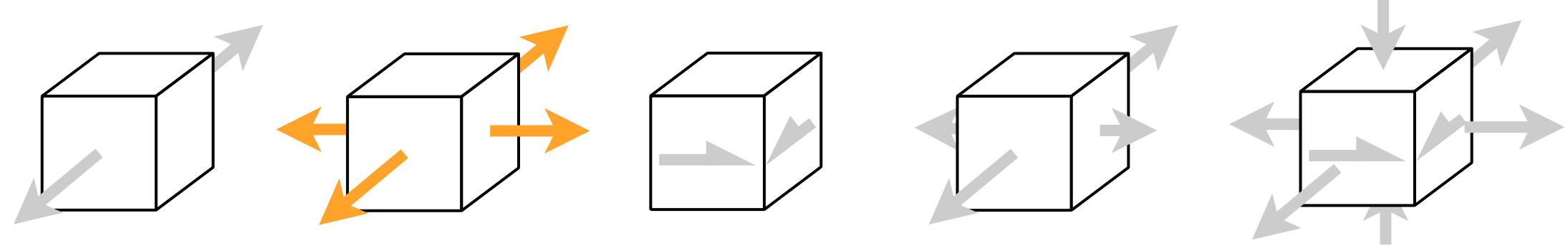
1st Piola Kirchhoff Stress P



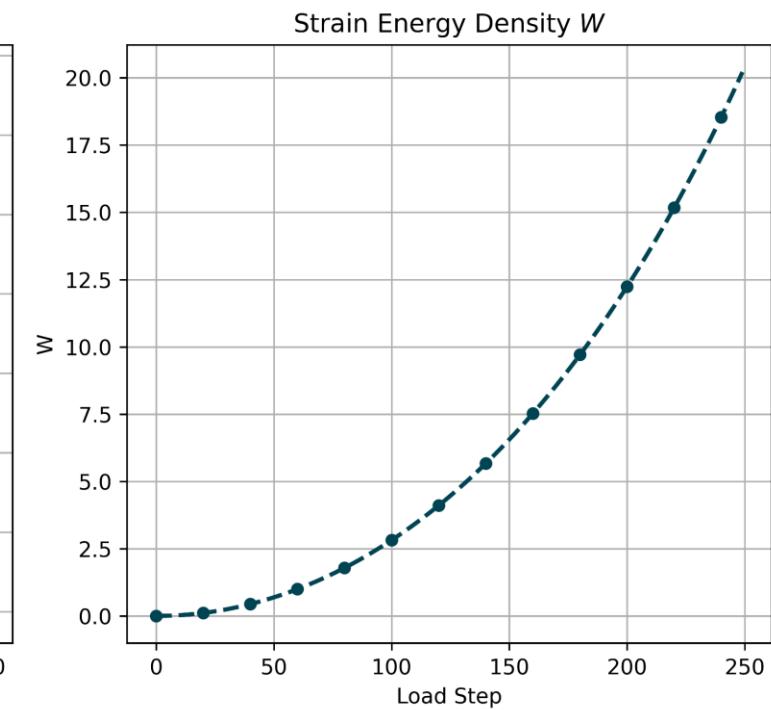
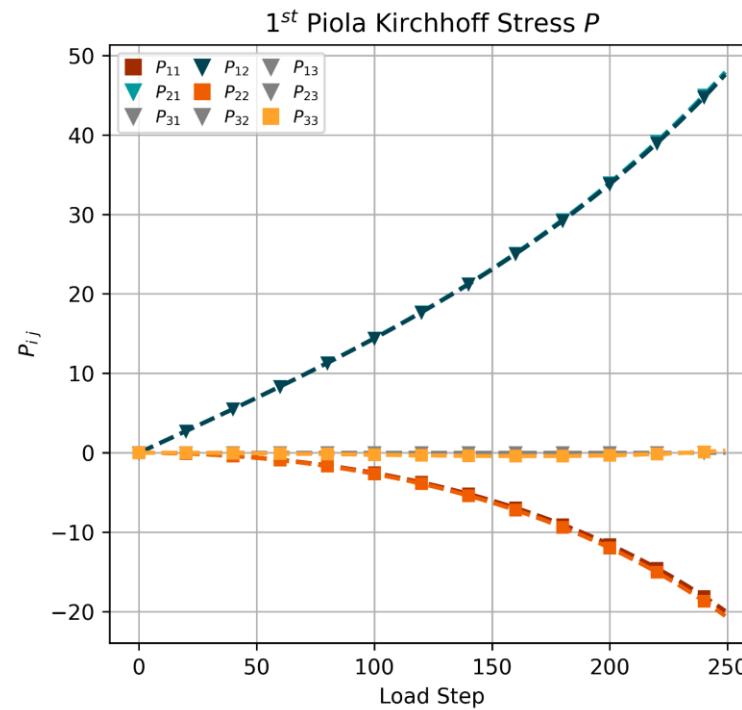
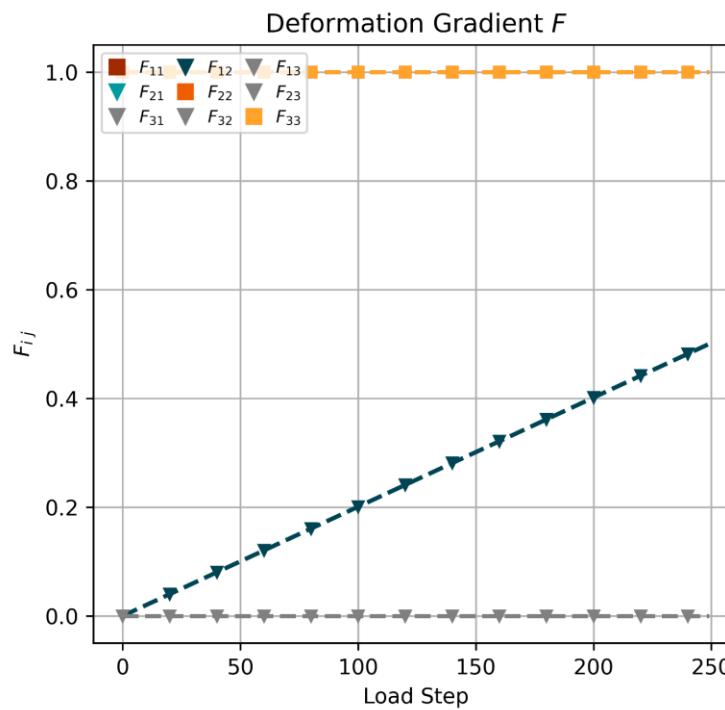
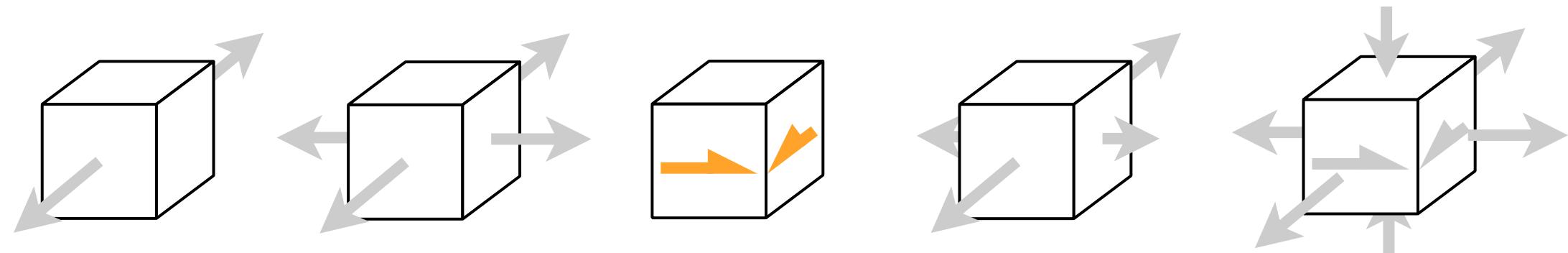
Strain Energy Density W



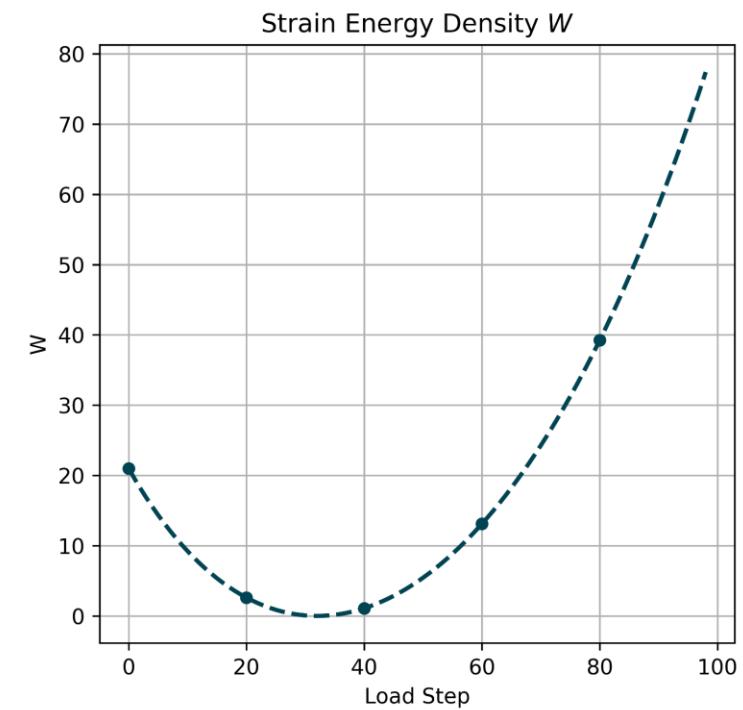
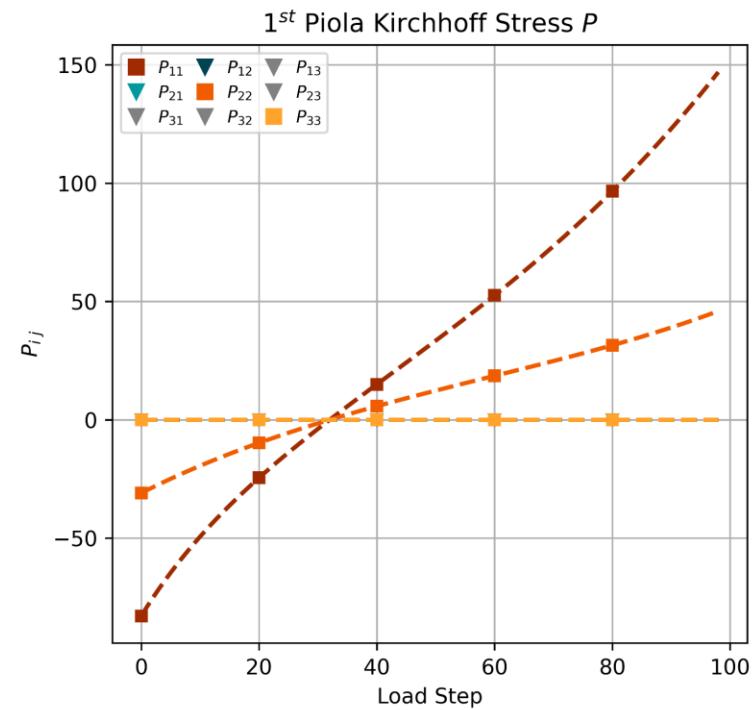
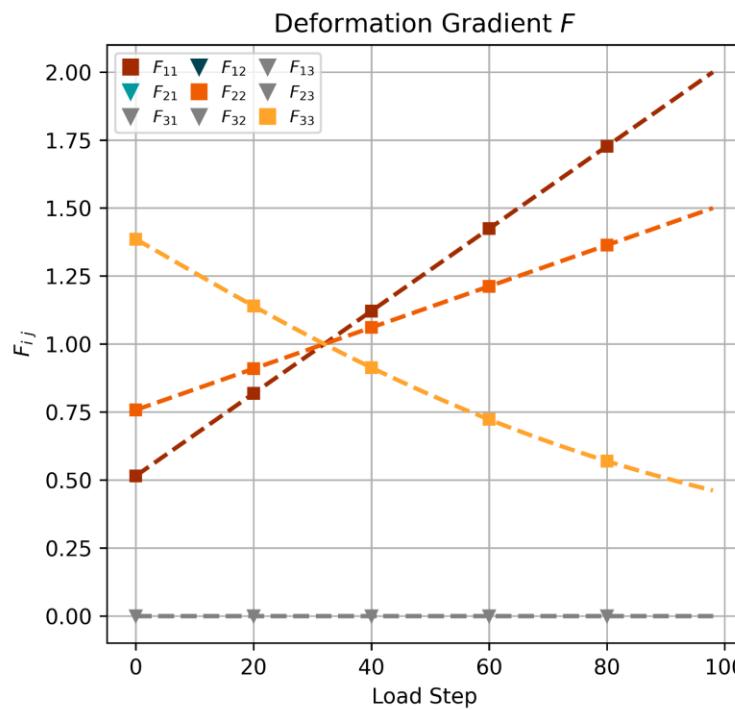
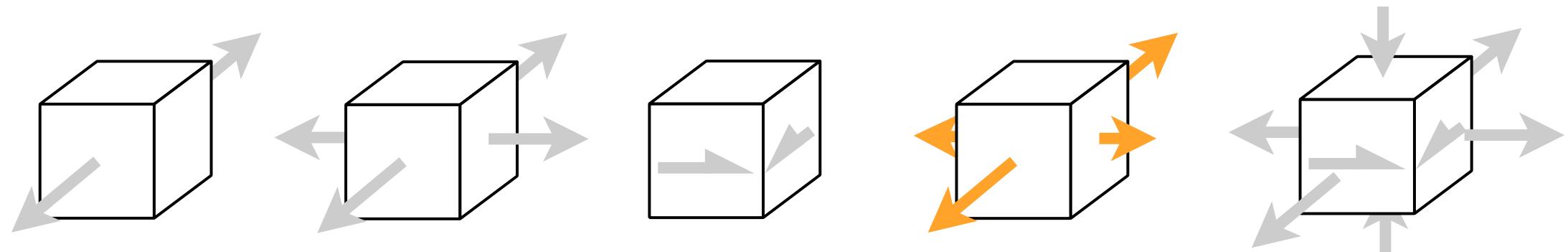
DATA - BIAXIAL



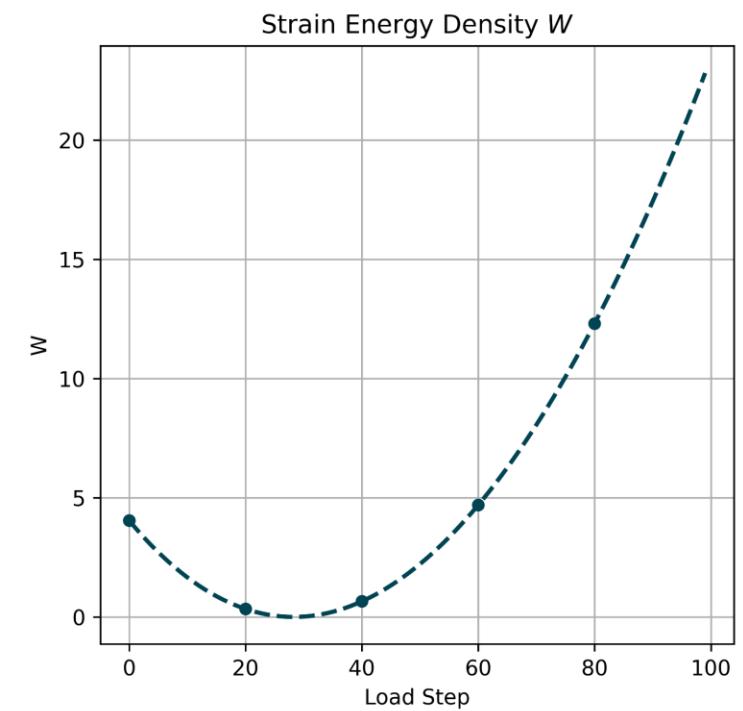
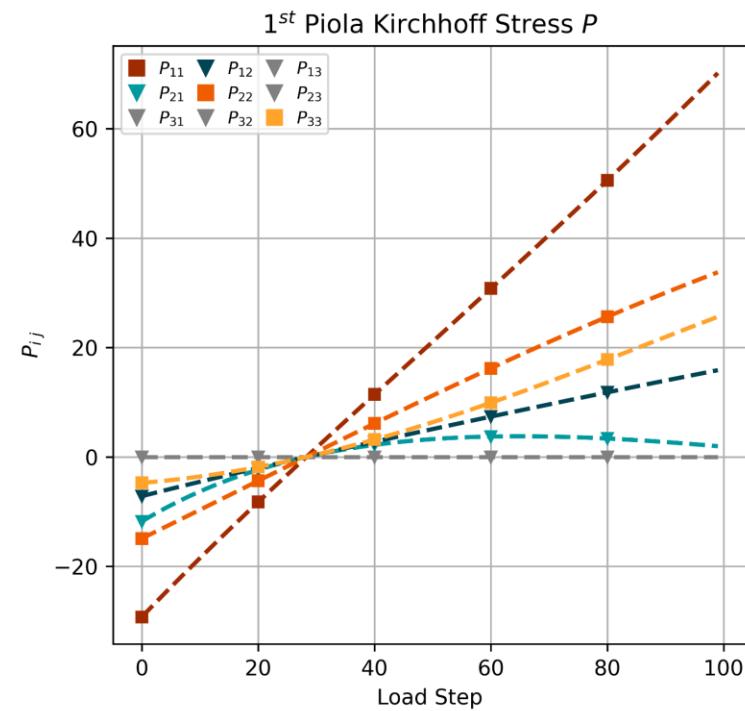
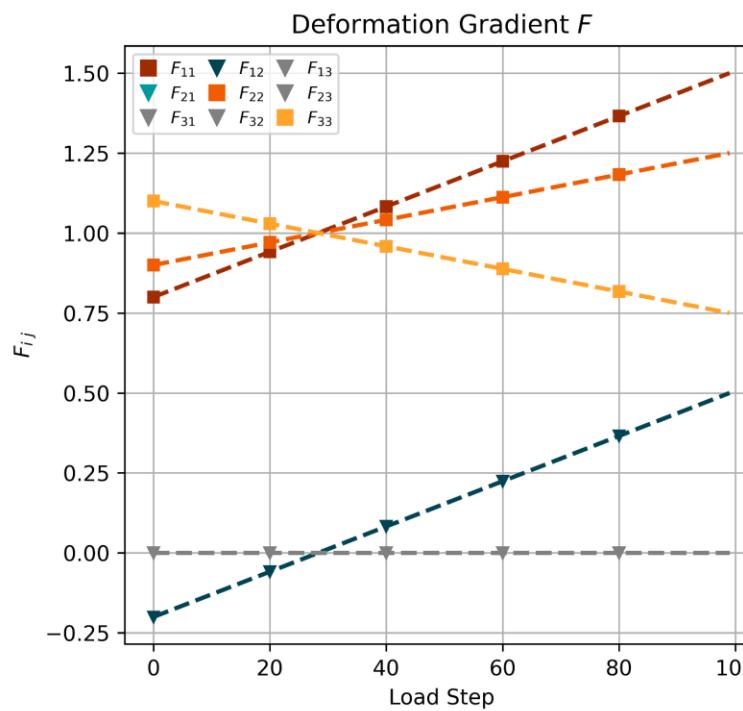
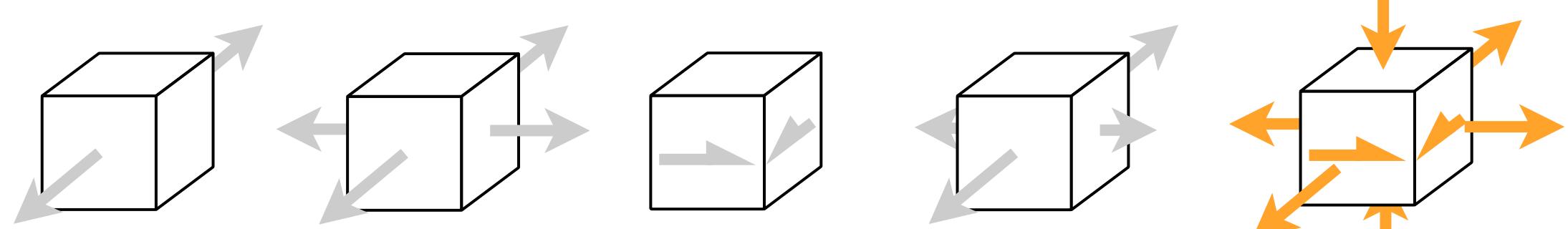
DATA - SHEAR



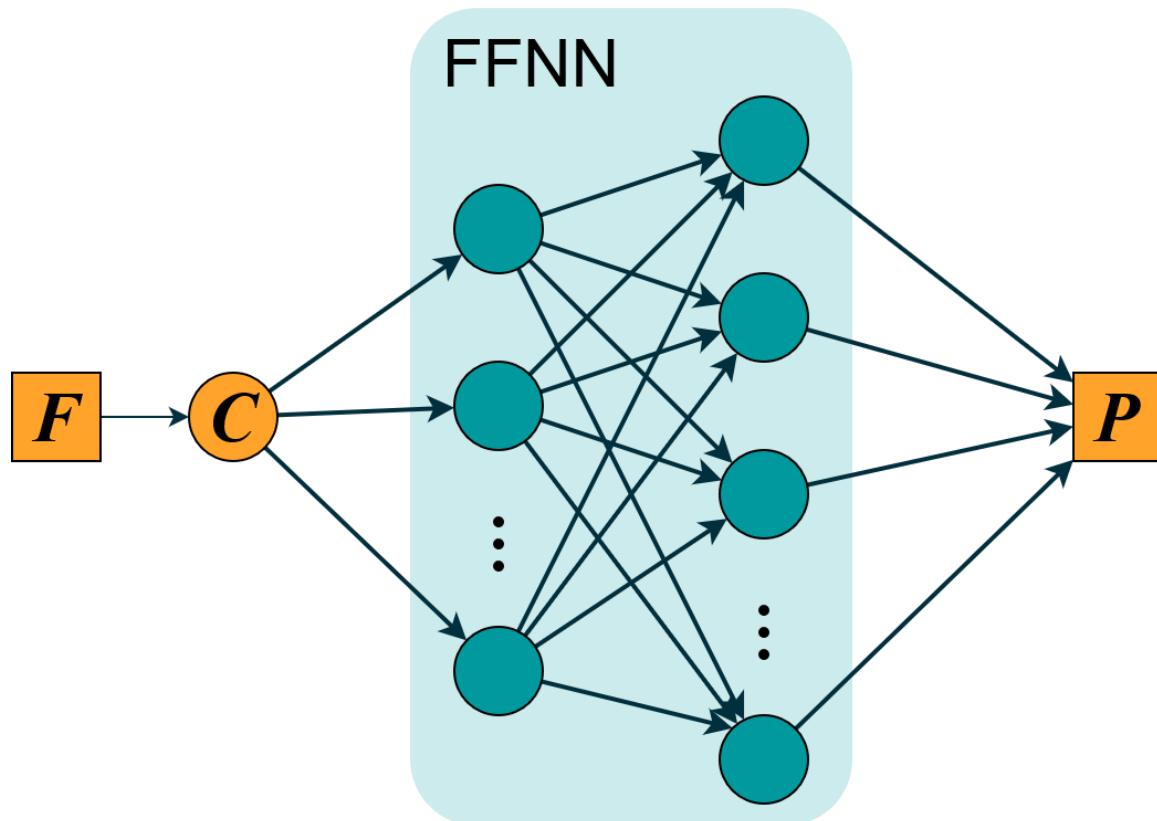
DATA - BIAXIAL TEST



DATA - MIXED TEST

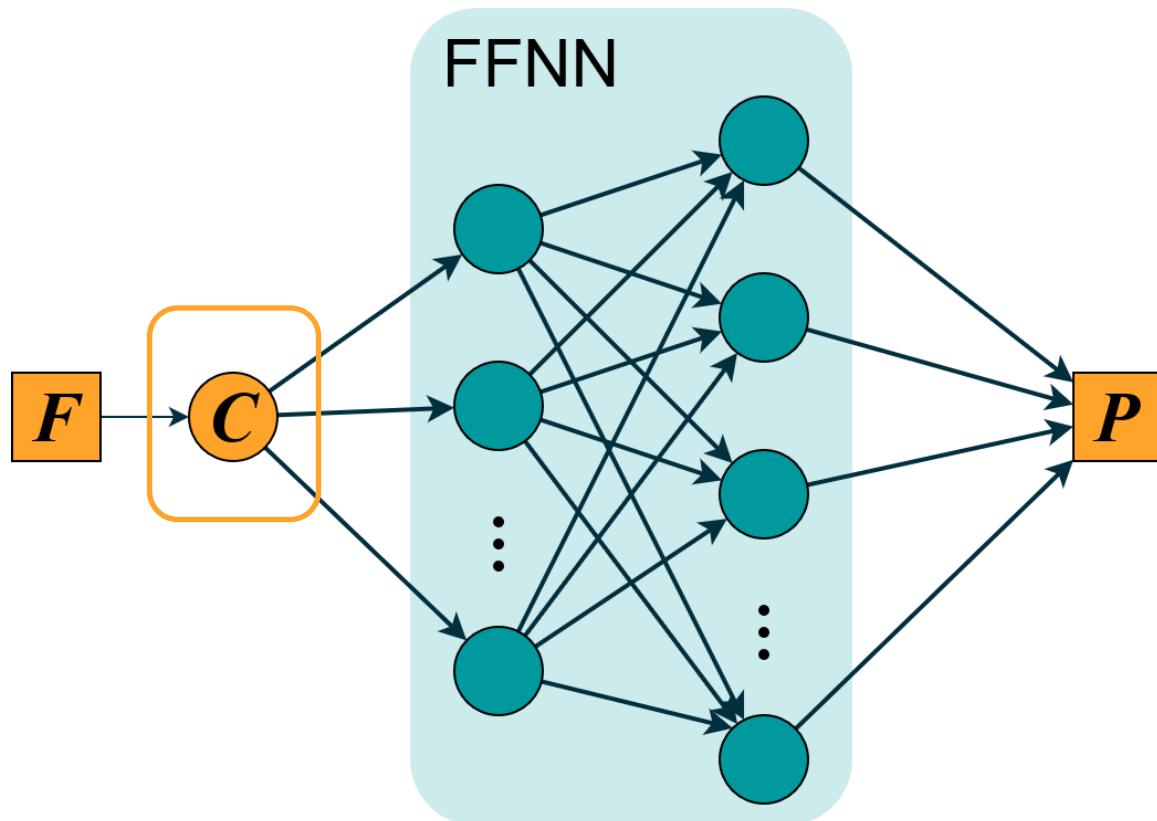


NAIVE MODEL



Physical conditions:

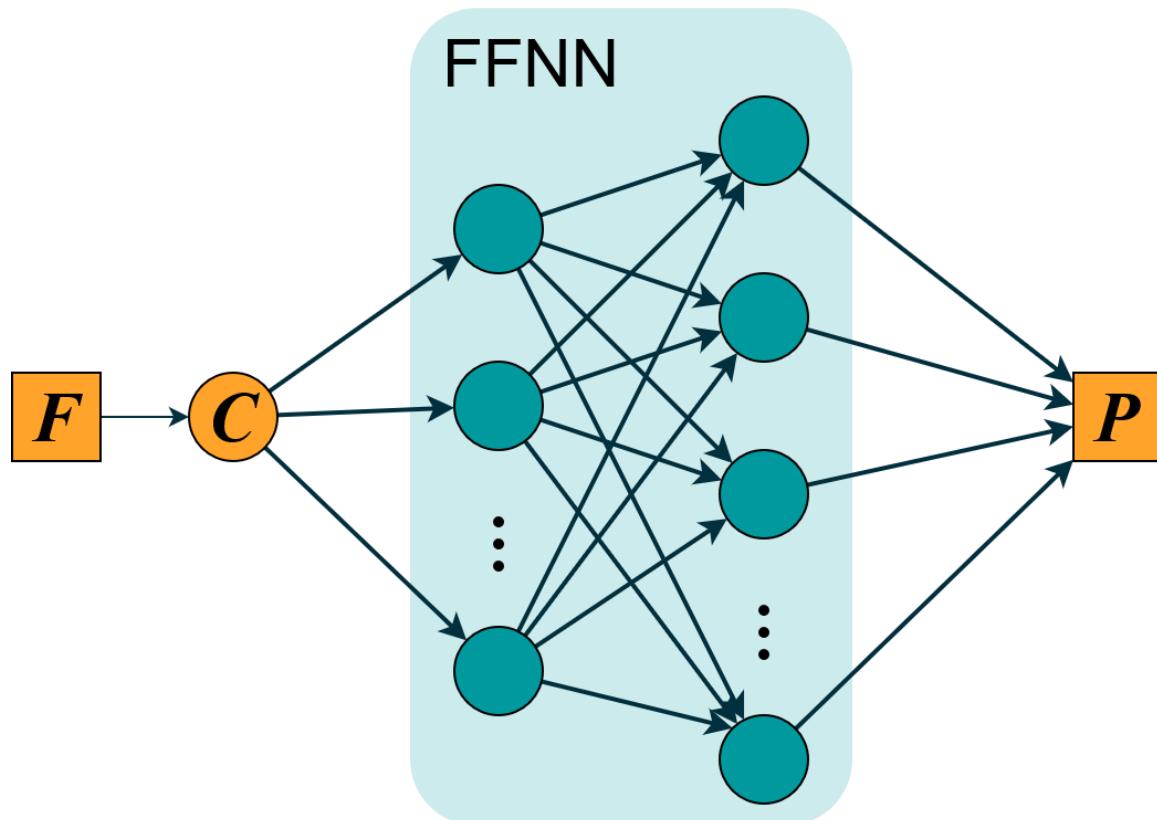
NAIVE MODEL



Physical conditions:

- ✓ Objectivity

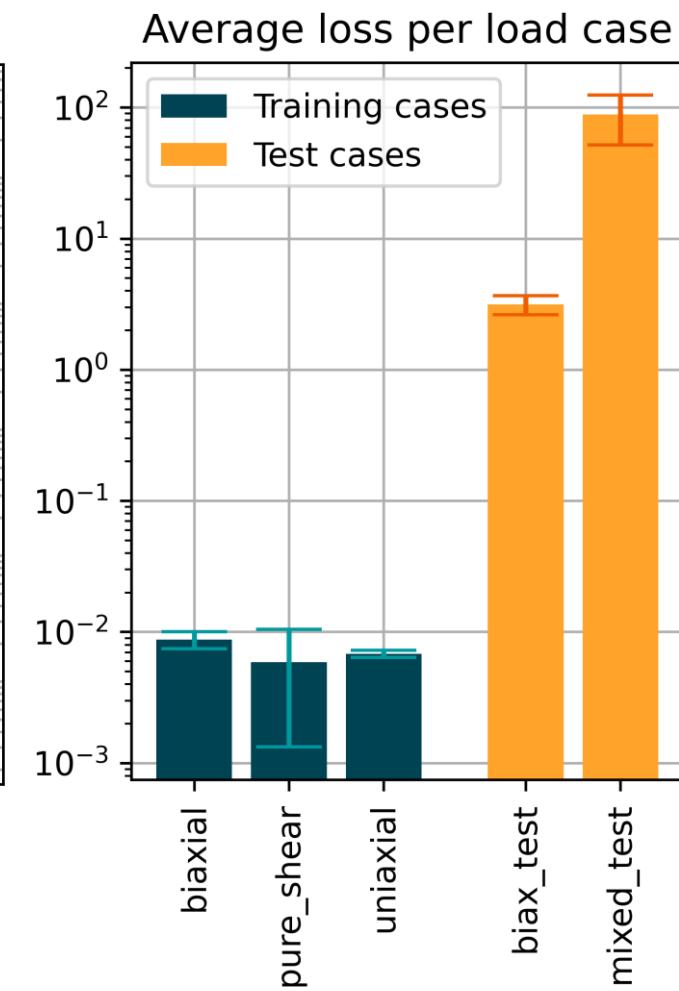
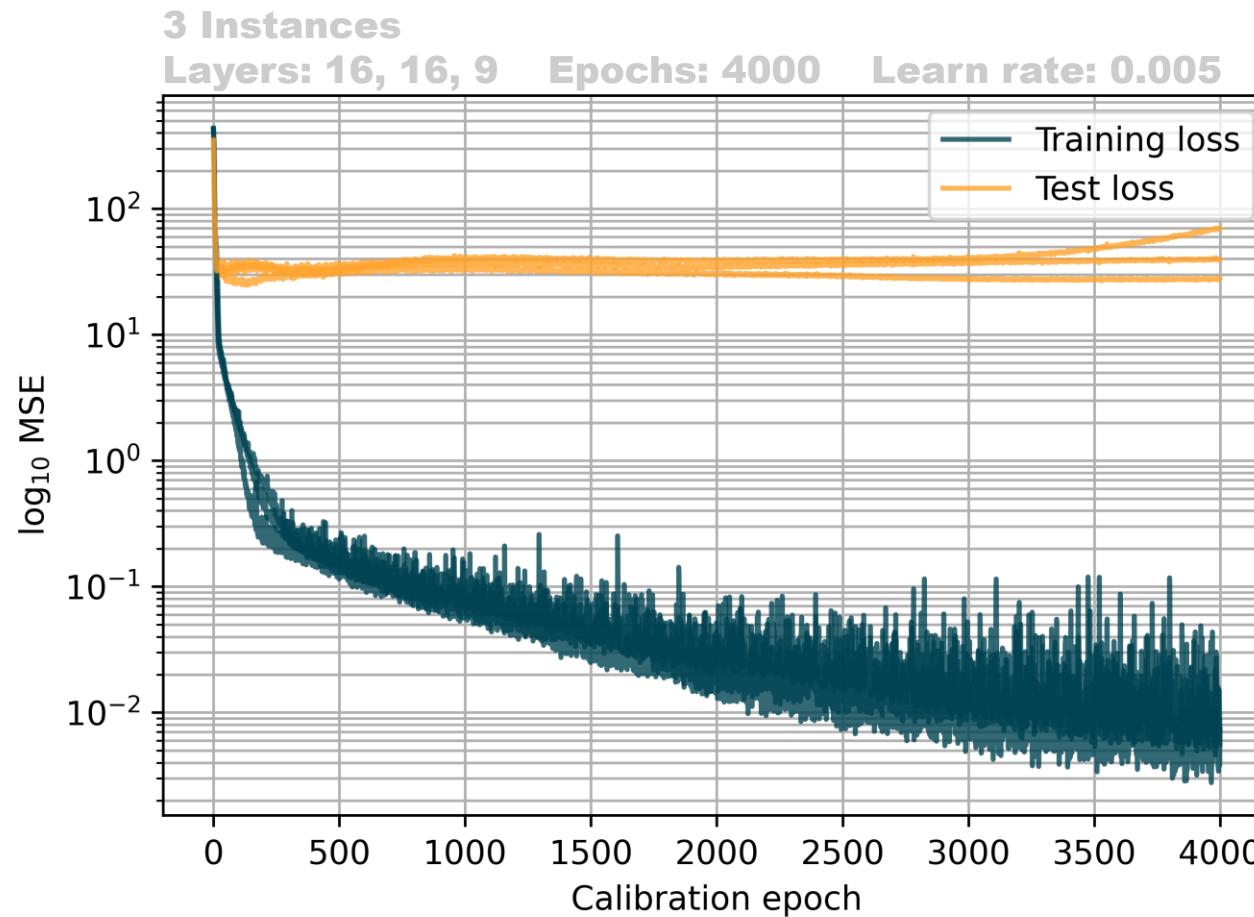
NAIVE MODEL



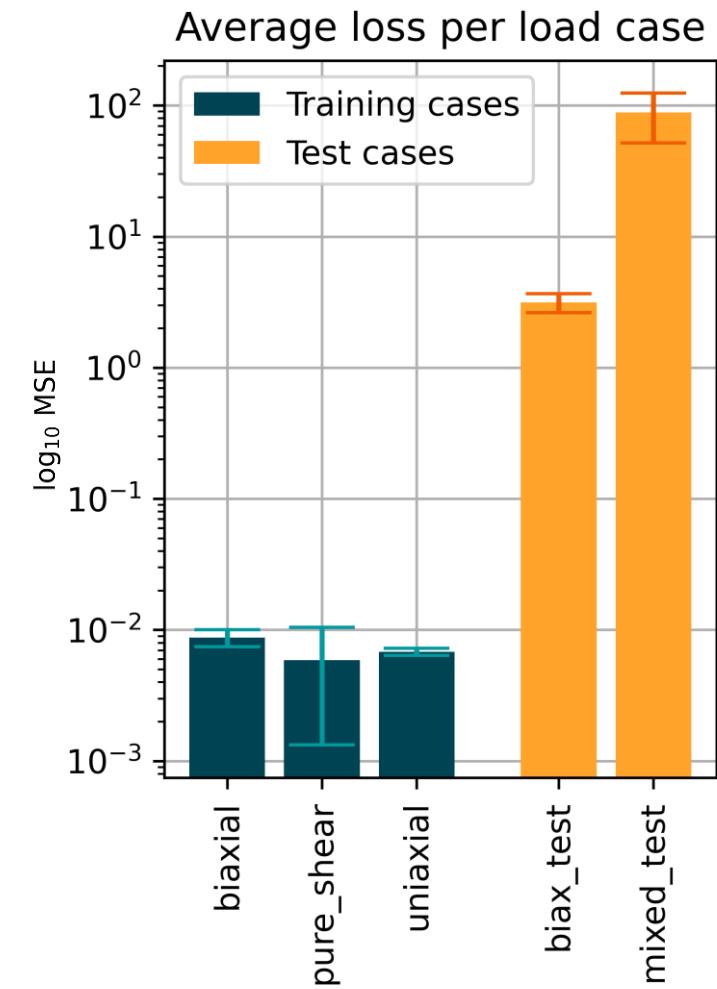
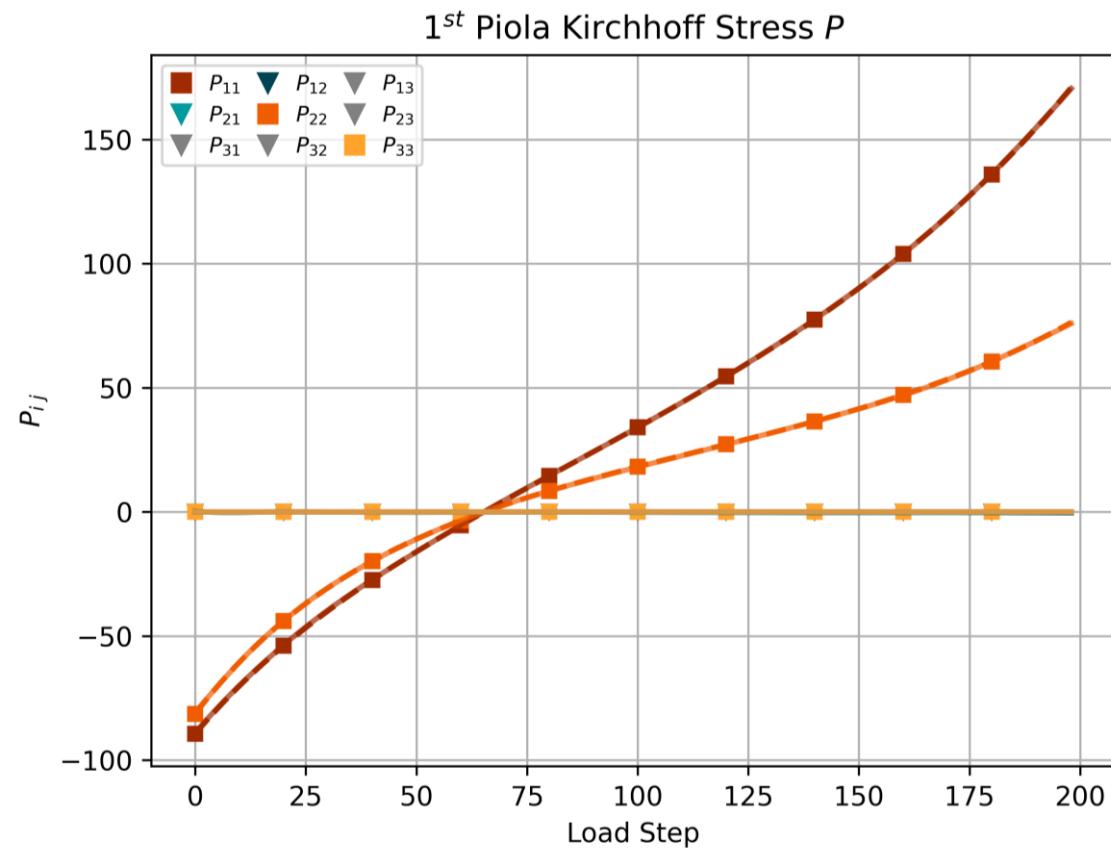
Physical conditions:

- ✓ Objectivity
- ✗ Material Symmetry
- ✗ Thermodynamics
- ✗ Polyconvexity/Ellipticity
- ✗ Normalization
- ✗ Growth Condition

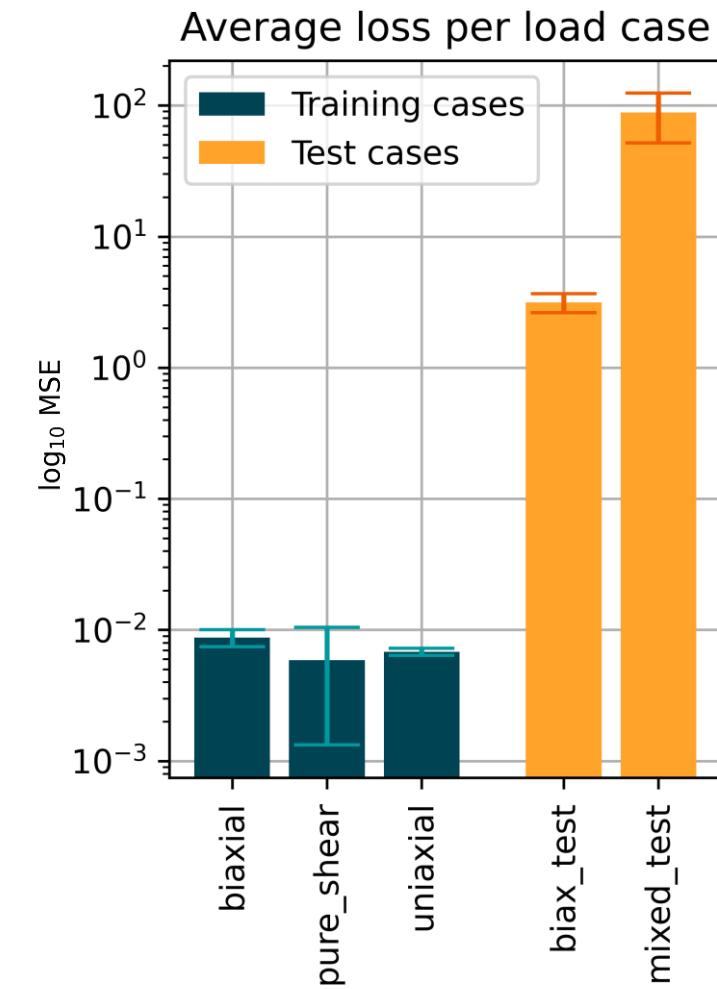
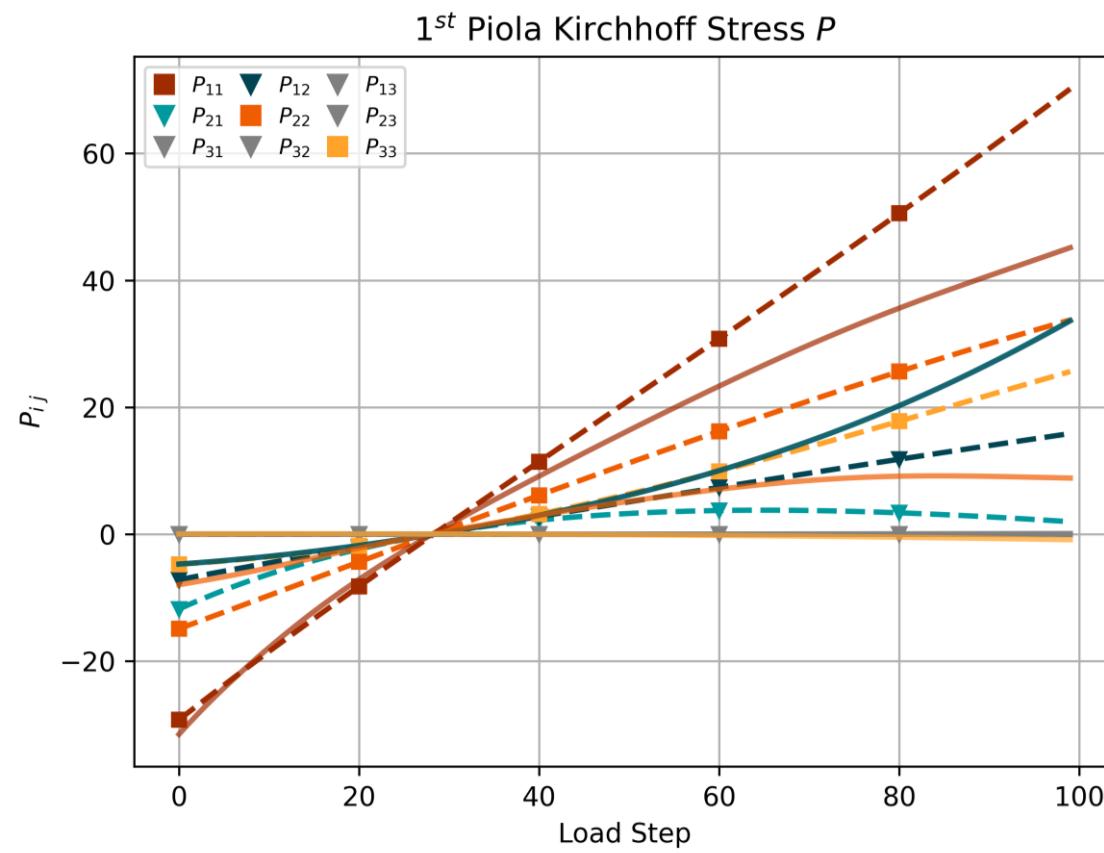
NAIVE MODEL



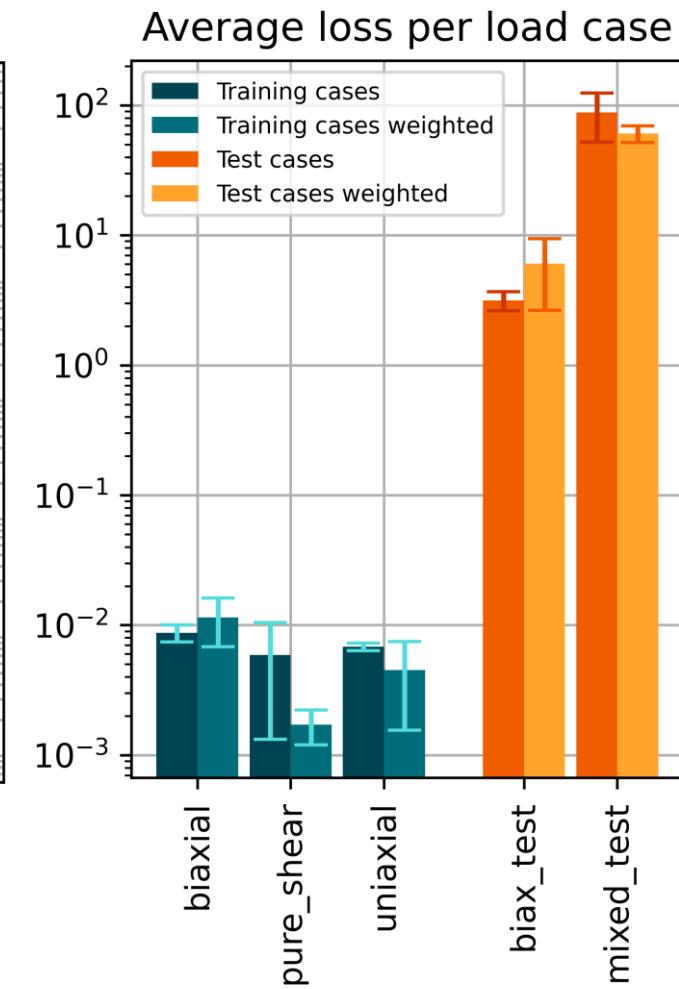
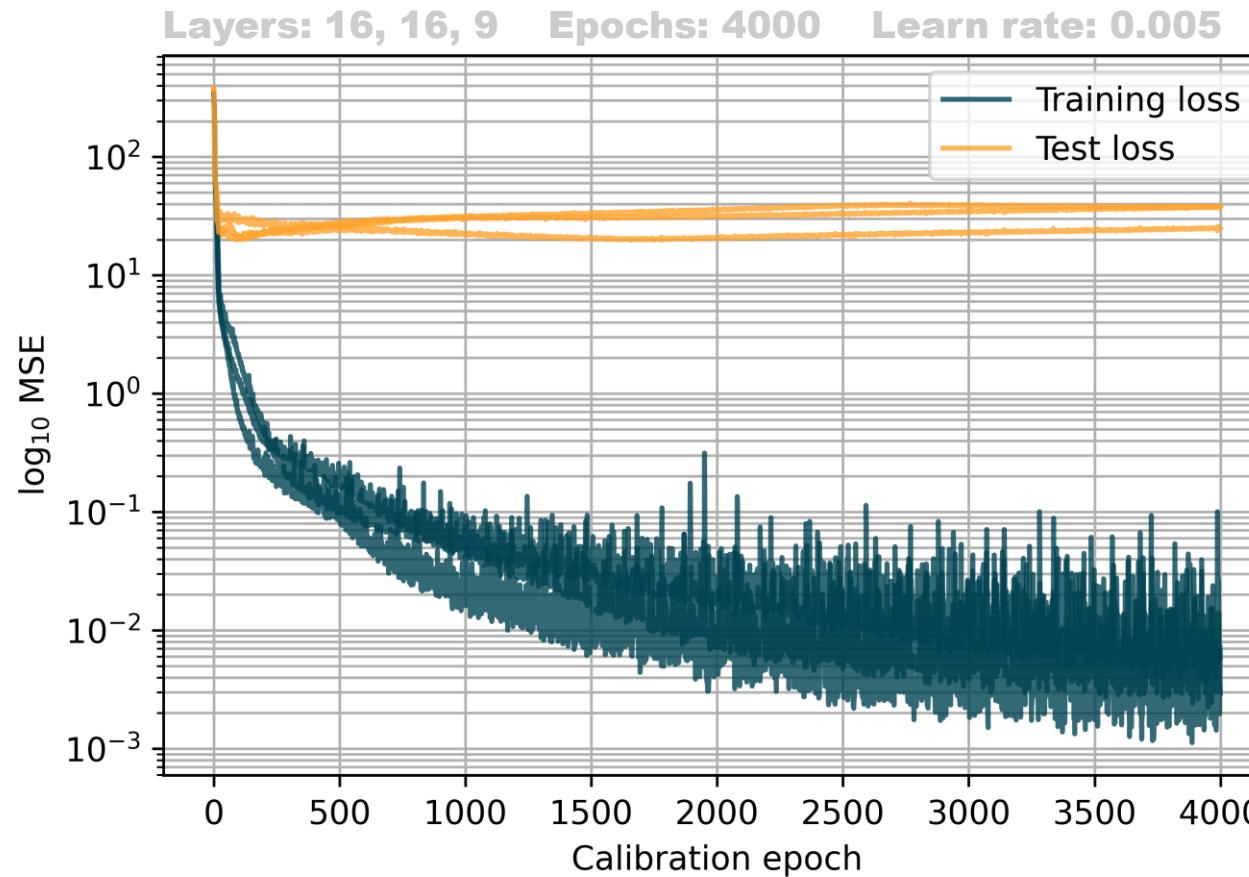
NAIVE MODEL - BIAXIAL



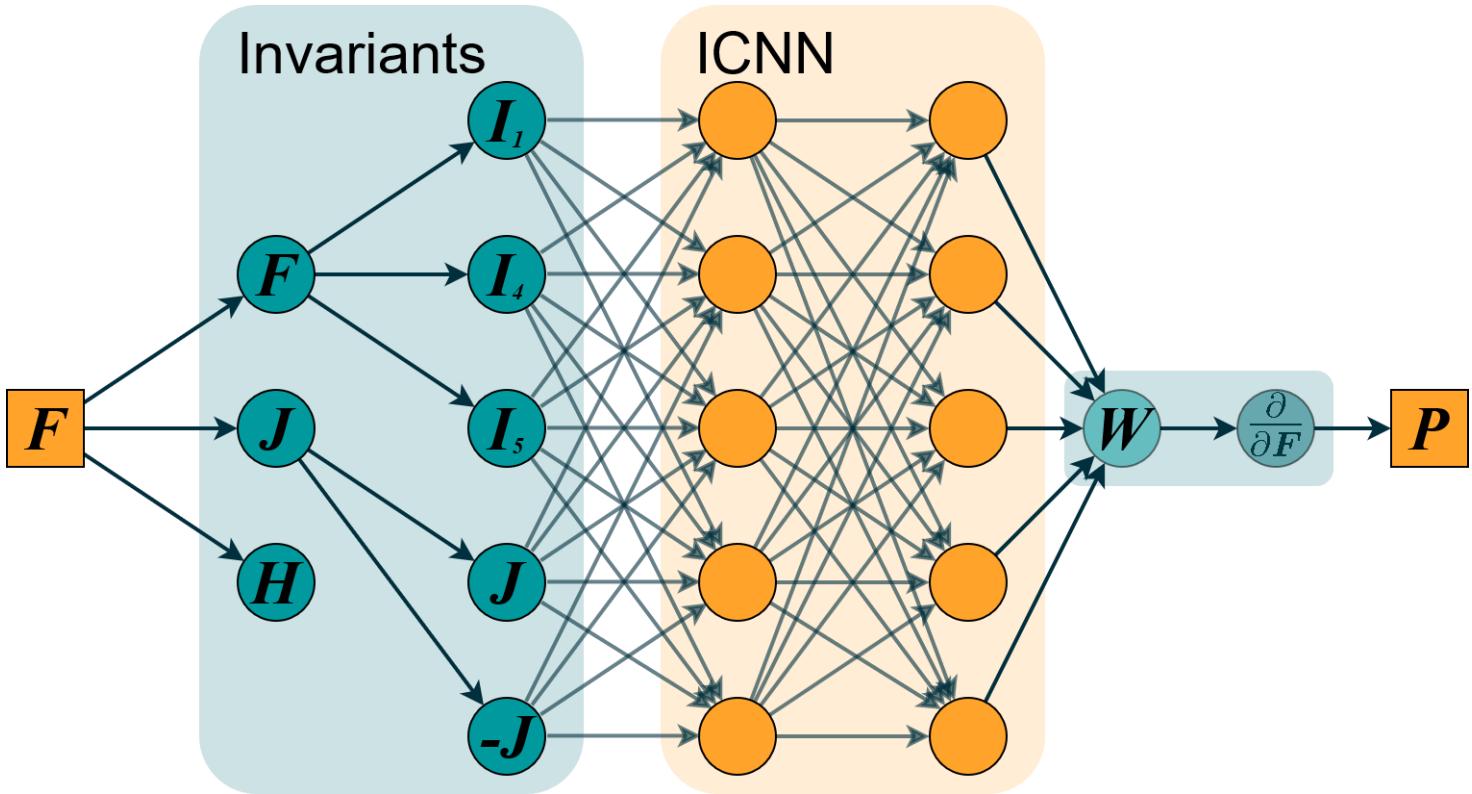
NAIVE MODEL - MIXED TEST



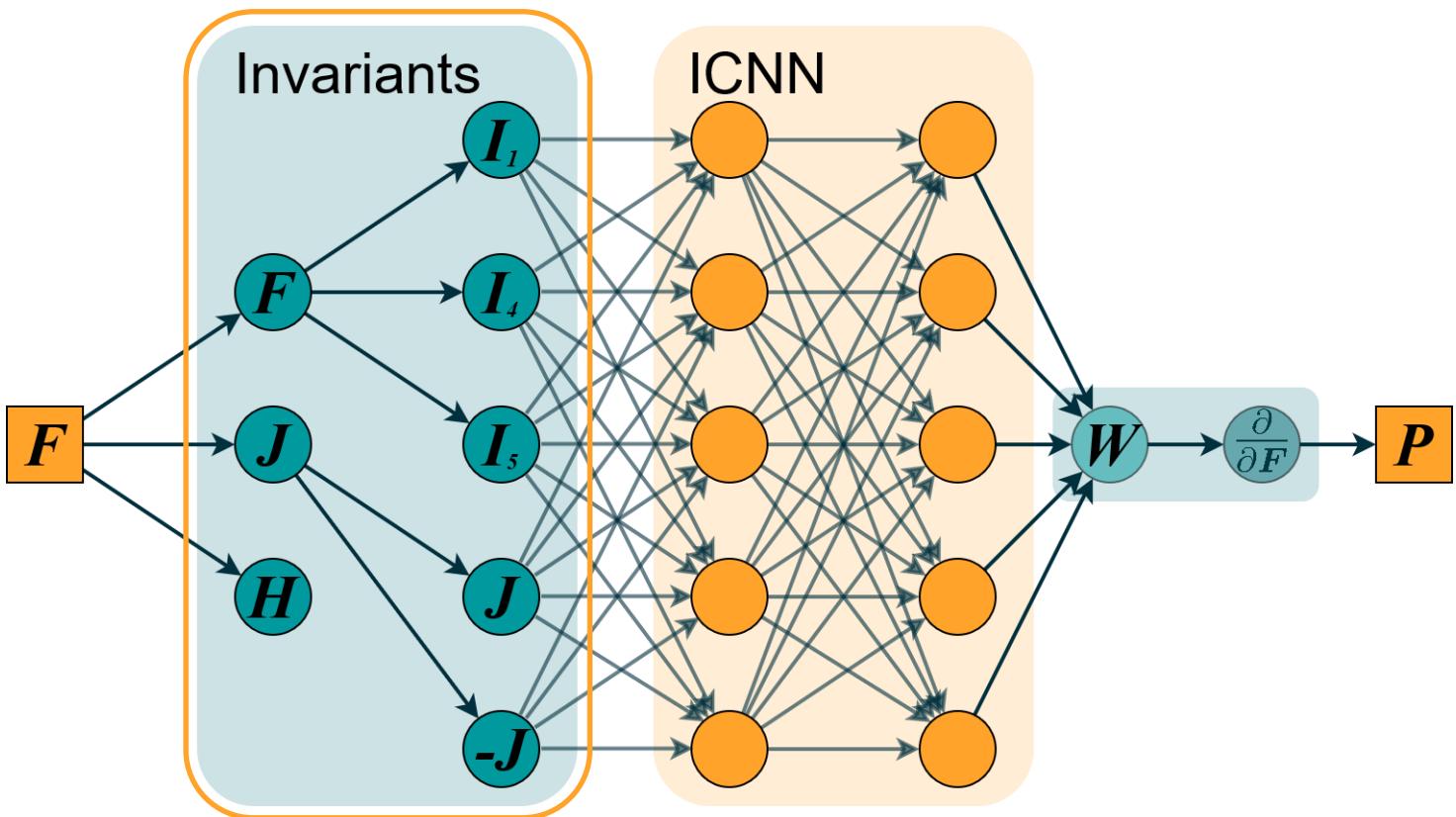
NAIVE MODEL - LOSS WEIGHTING STRATEGY



PHYSICS-AUGMENTED MODEL



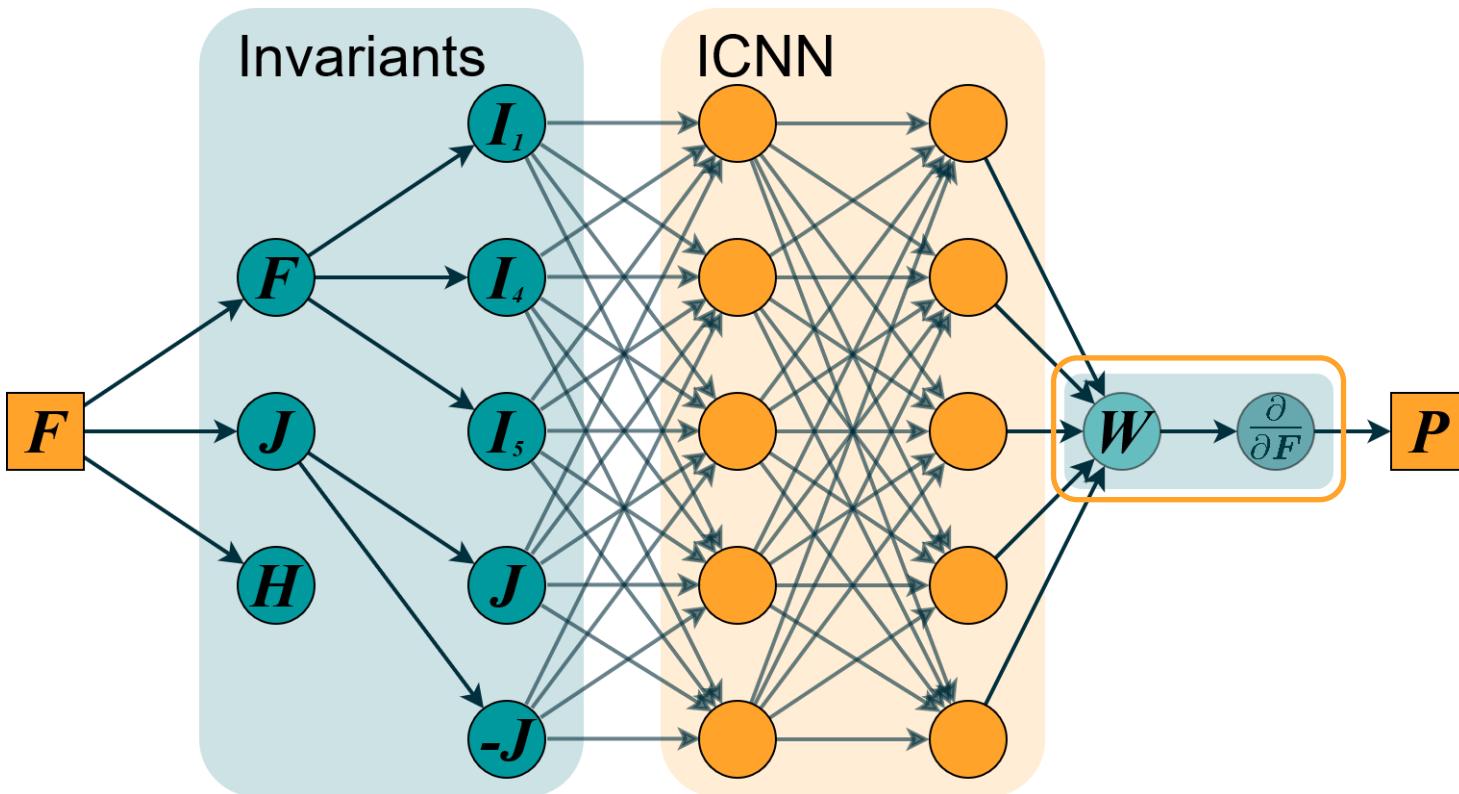
PHYSICS-AUGMENTED MODEL



Physical conditions:

- ✓ Objectivity
- ✓ Material Symmetry

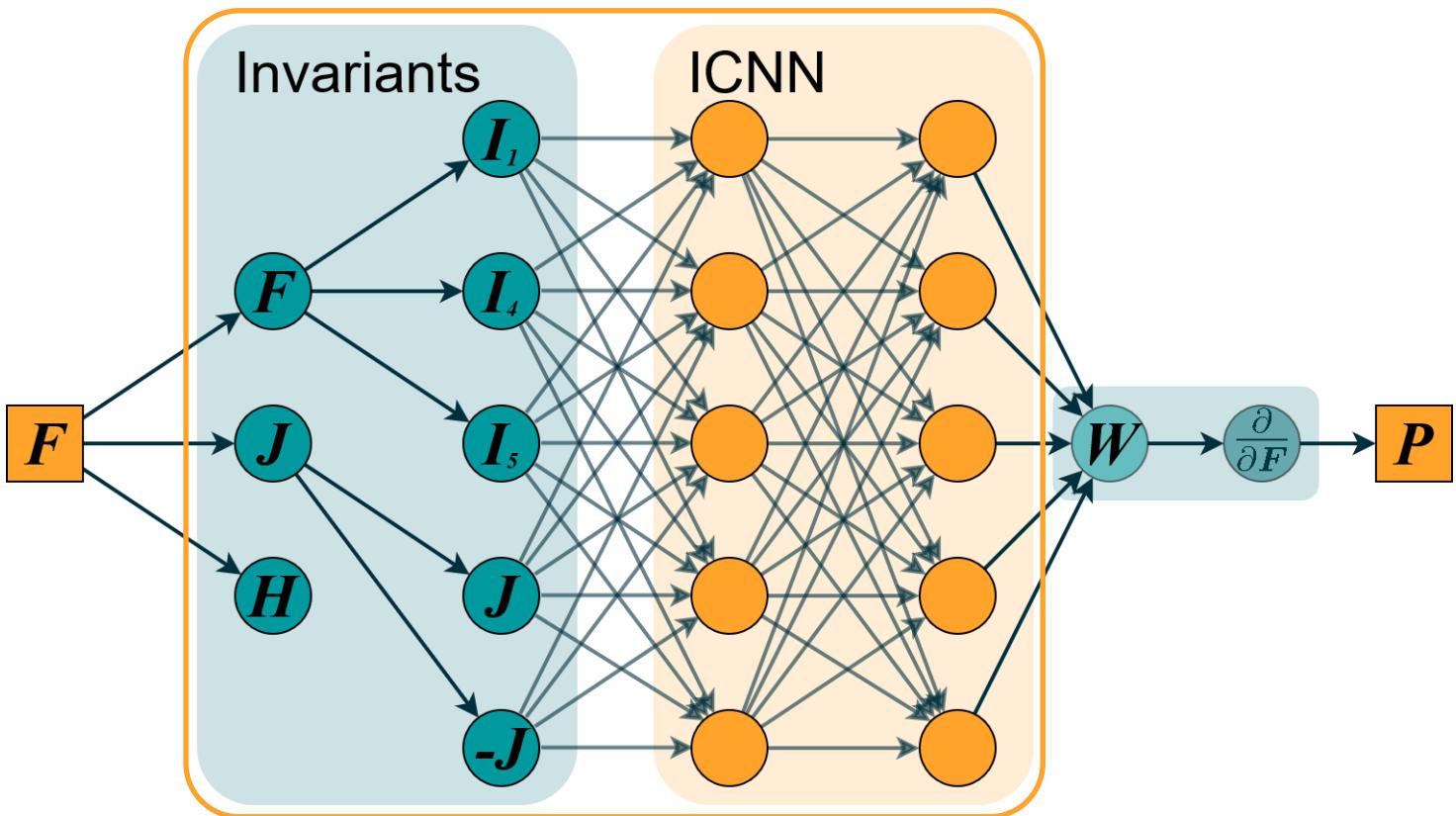
PHYSICS-AUGMENTED MODEL



Physical conditions:

- ✓ Objectivity
- ✓ Material Symmetry
- ✓ Thermodynamics

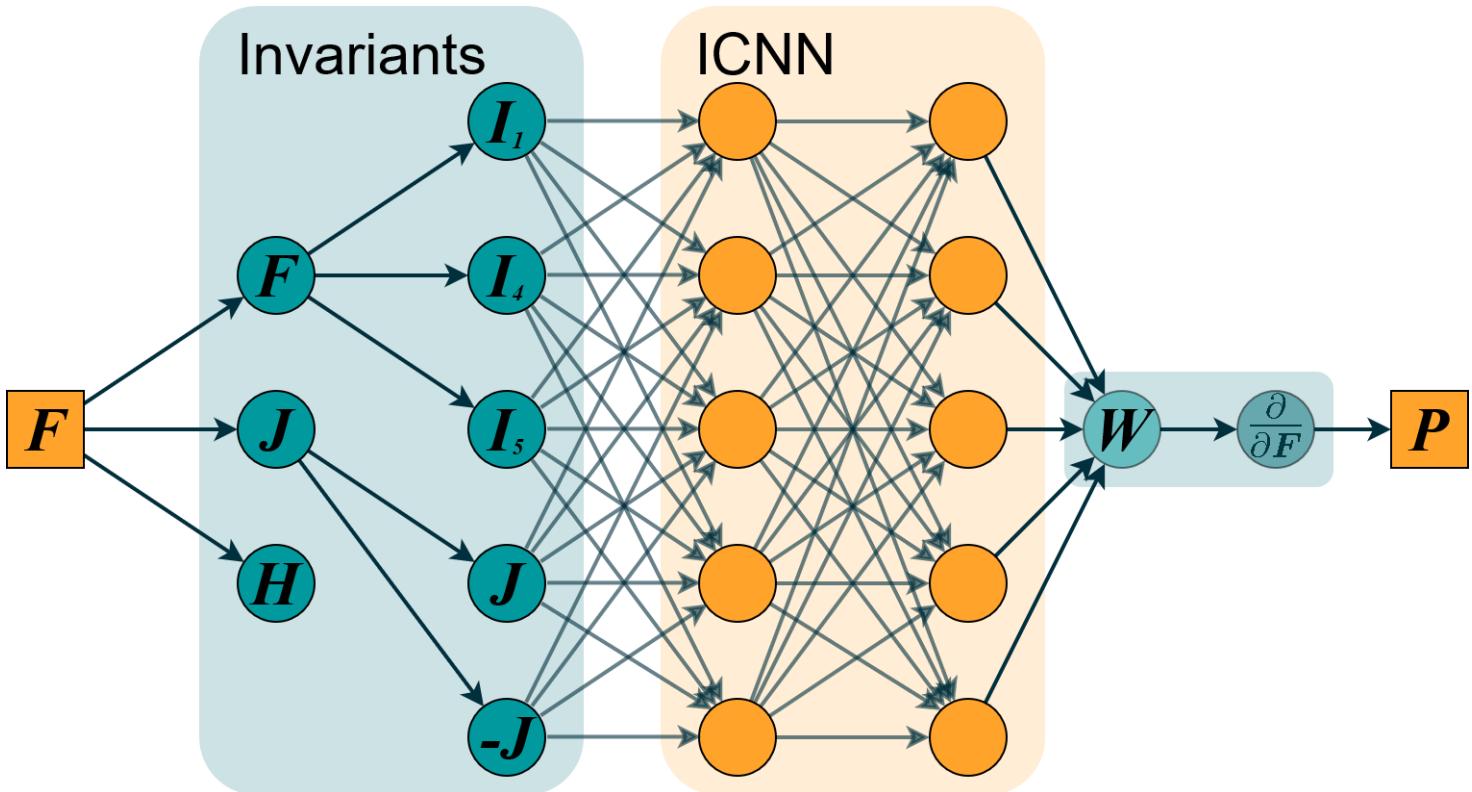
PHYSICS-AUGMENTED MODEL



Physical conditions:

- ✓ Objectivity
- ✓ Material Symmetry
- ✓ Thermodynamics
- ✓ Polyconvexity/Ellipticity

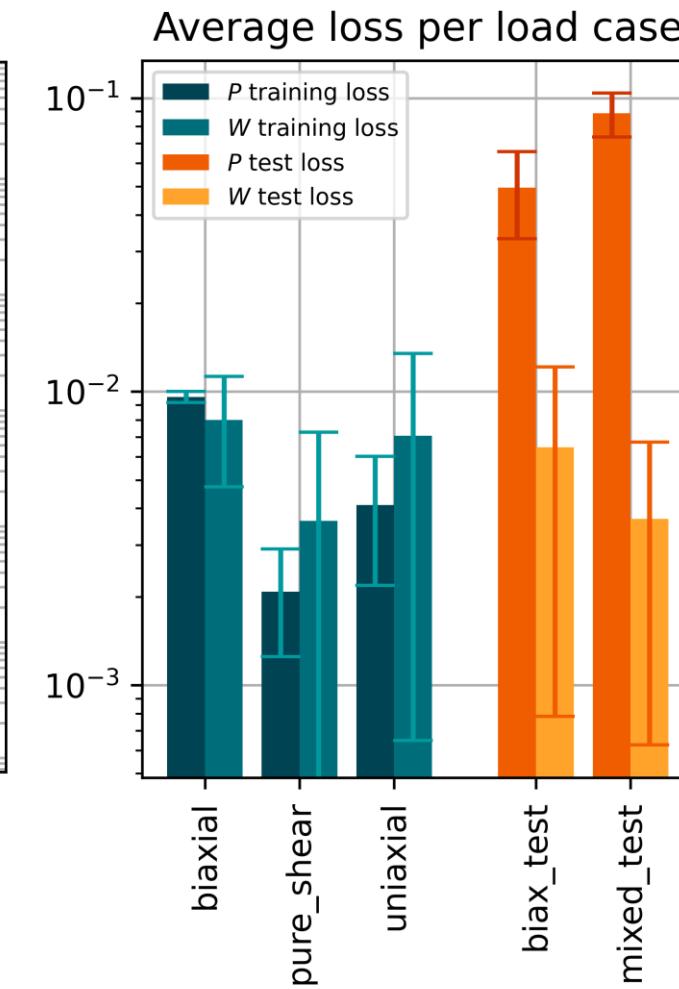
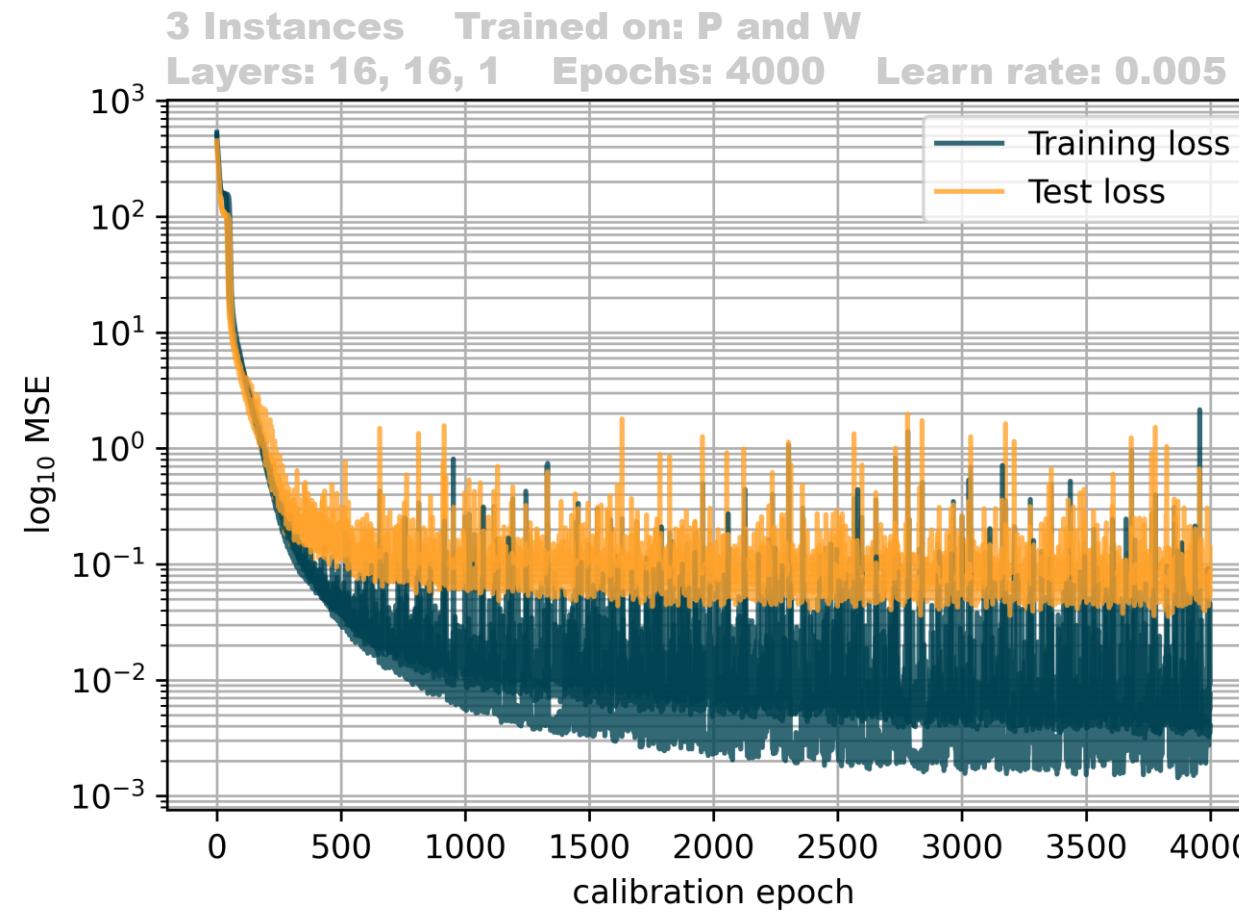
PHYSICS-AUGMENTED MODEL



Physical conditions:

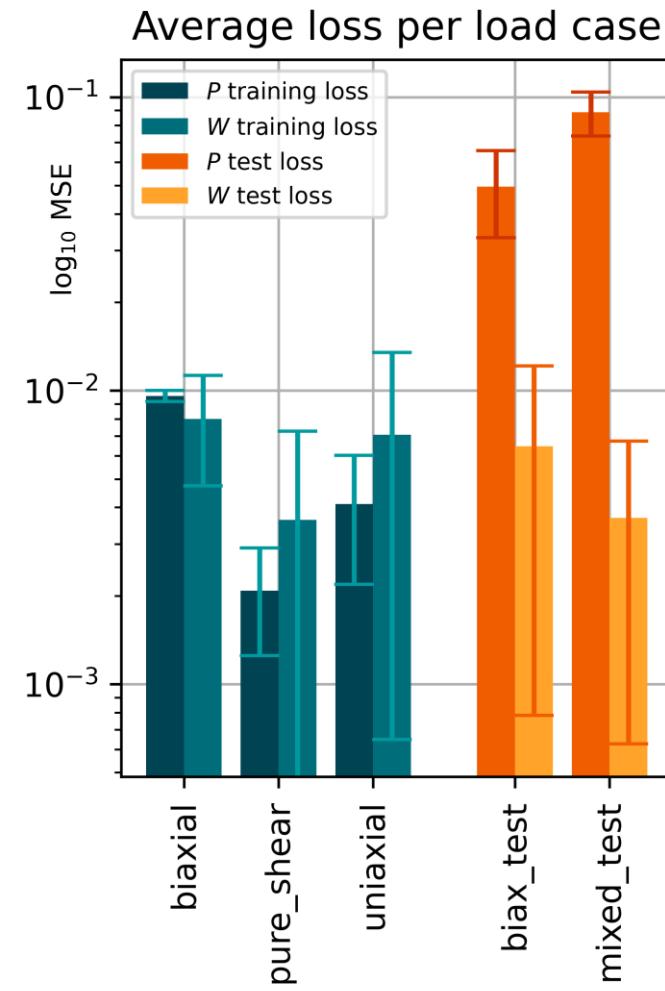
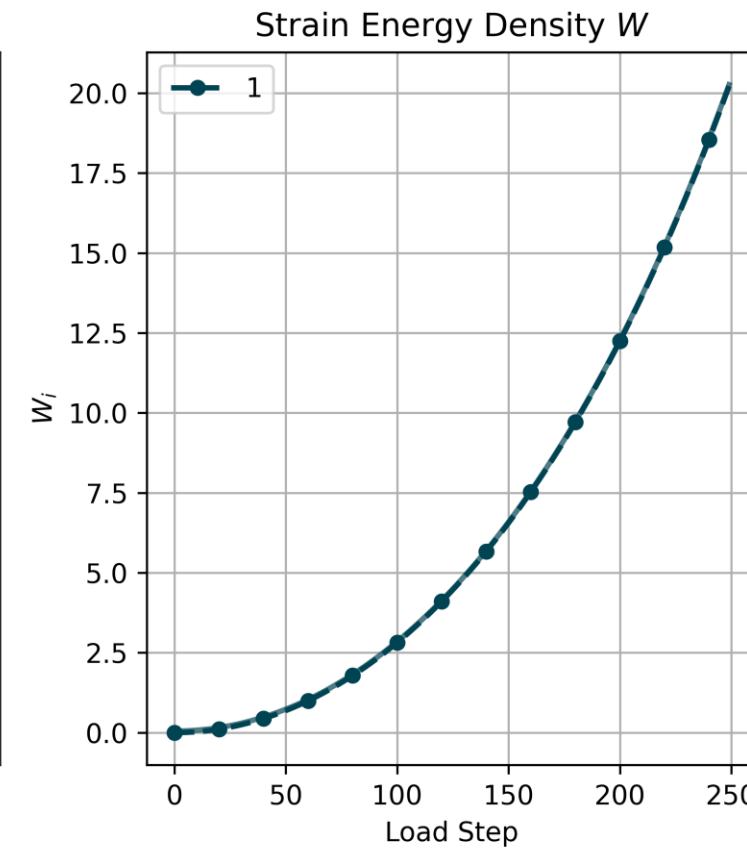
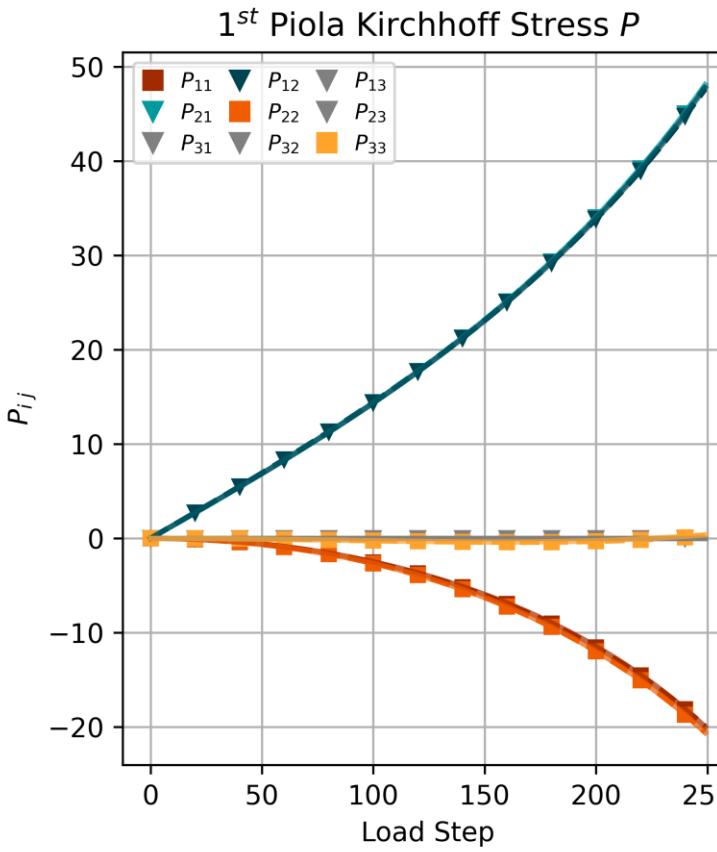
- ✓ Objectivity
- ✓ Material Symmetry
- ✓ Thermodynamics
- ✓ Polyconvexity/Ellipticity
- ?
- ?
- Normalization
- Growth Condition

PHYSICS-AUGMENTED MODEL



PHYSICS-AUGMENTED MODEL

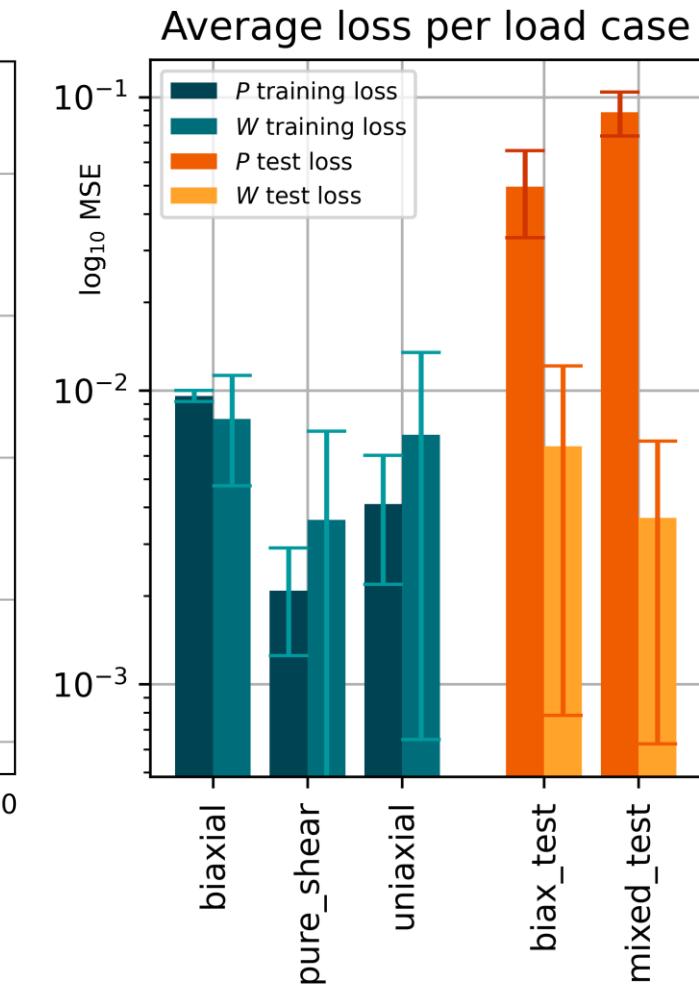
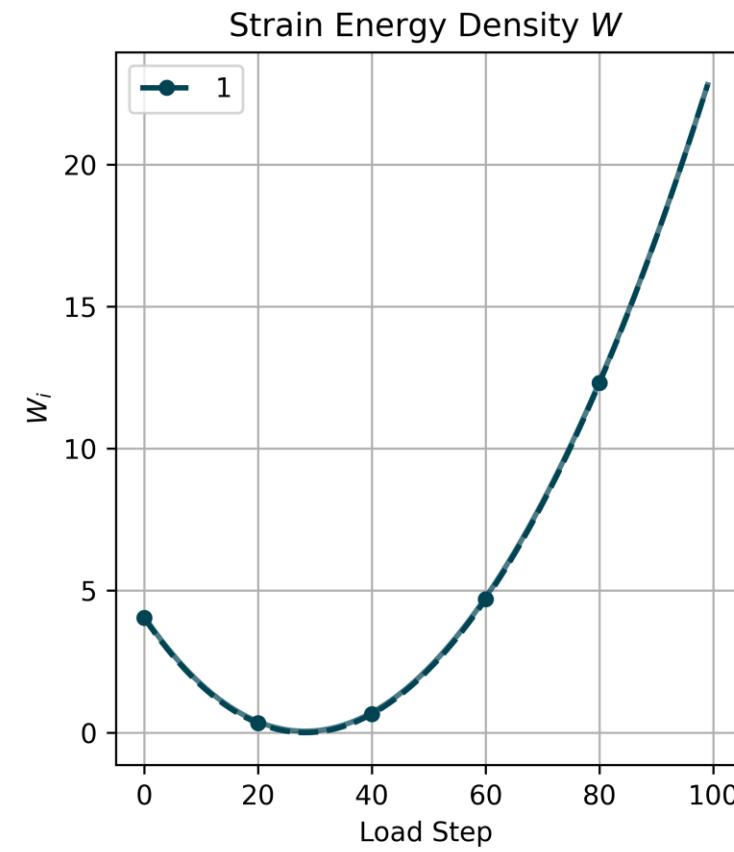
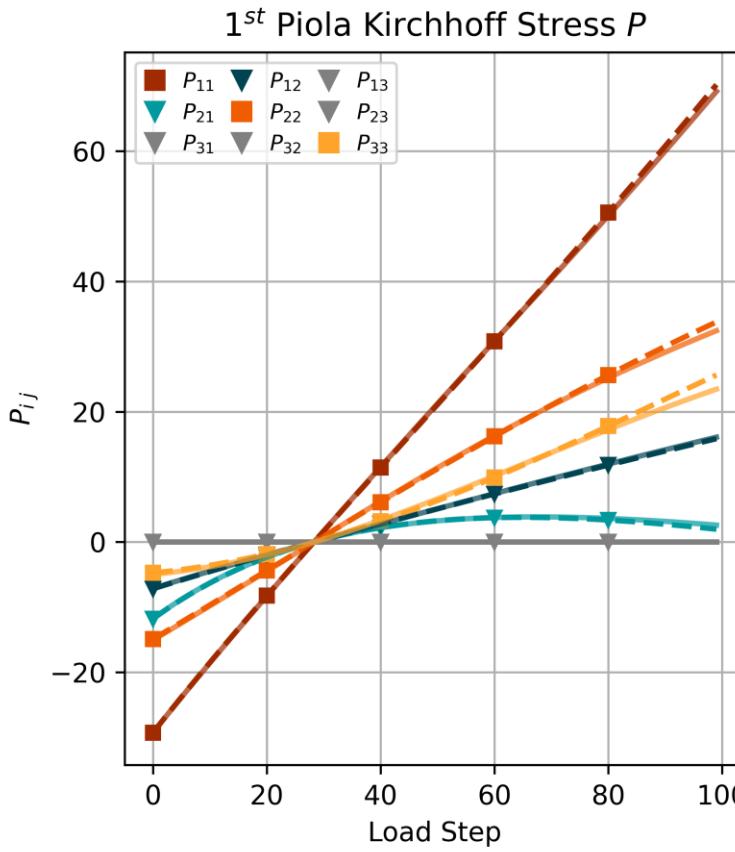
Load Case: pure_shear



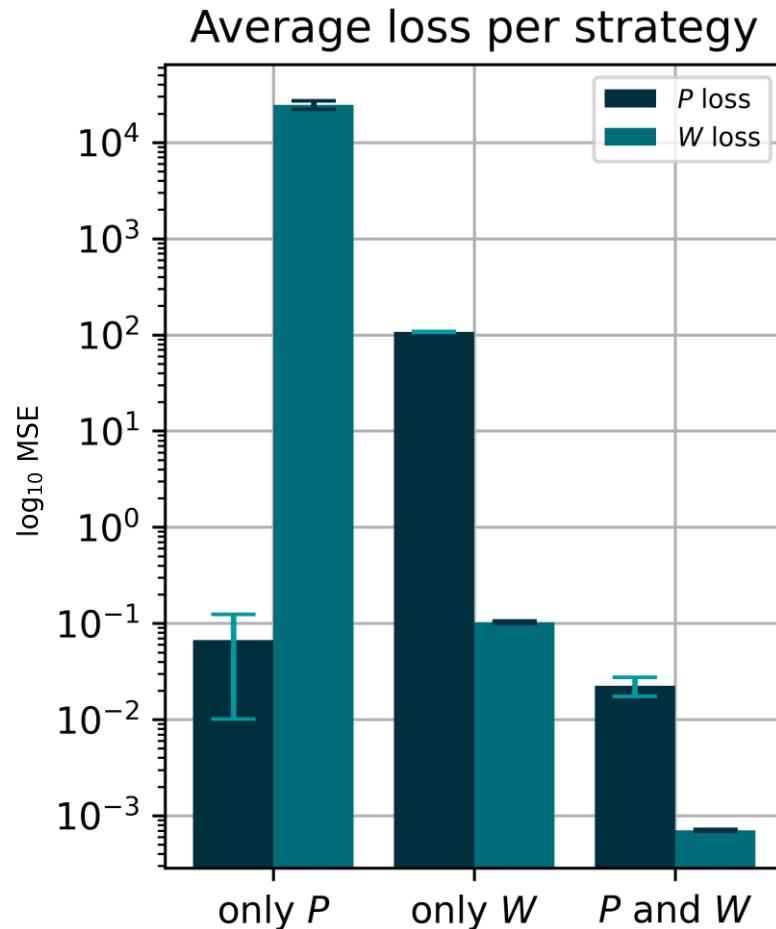
PHYSICS-AUGMENTED MODEL



Load Case: mixed_test

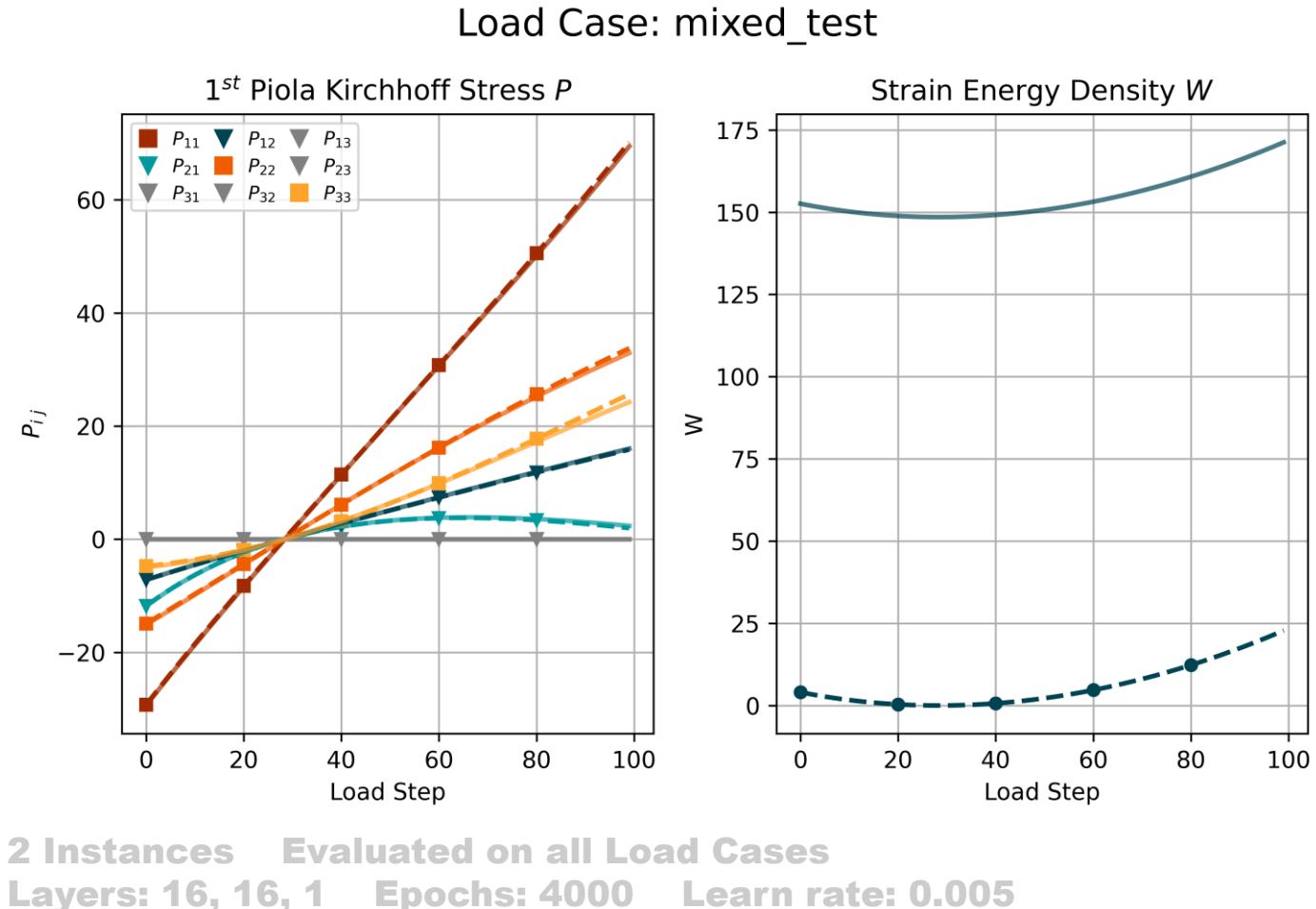
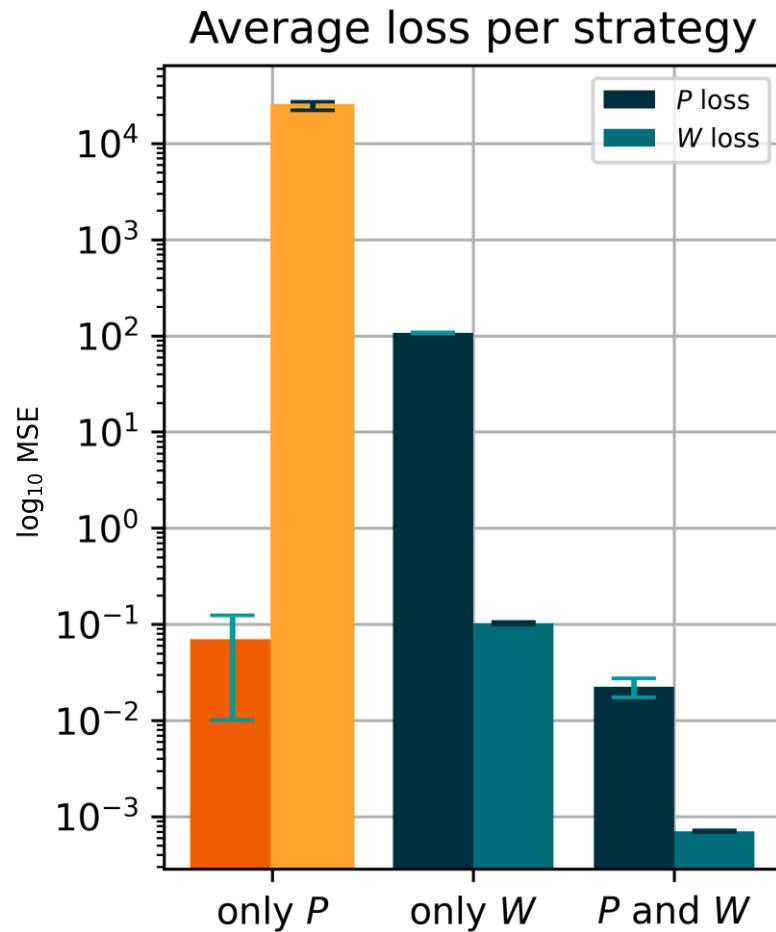


TRAINING STRATEGIES

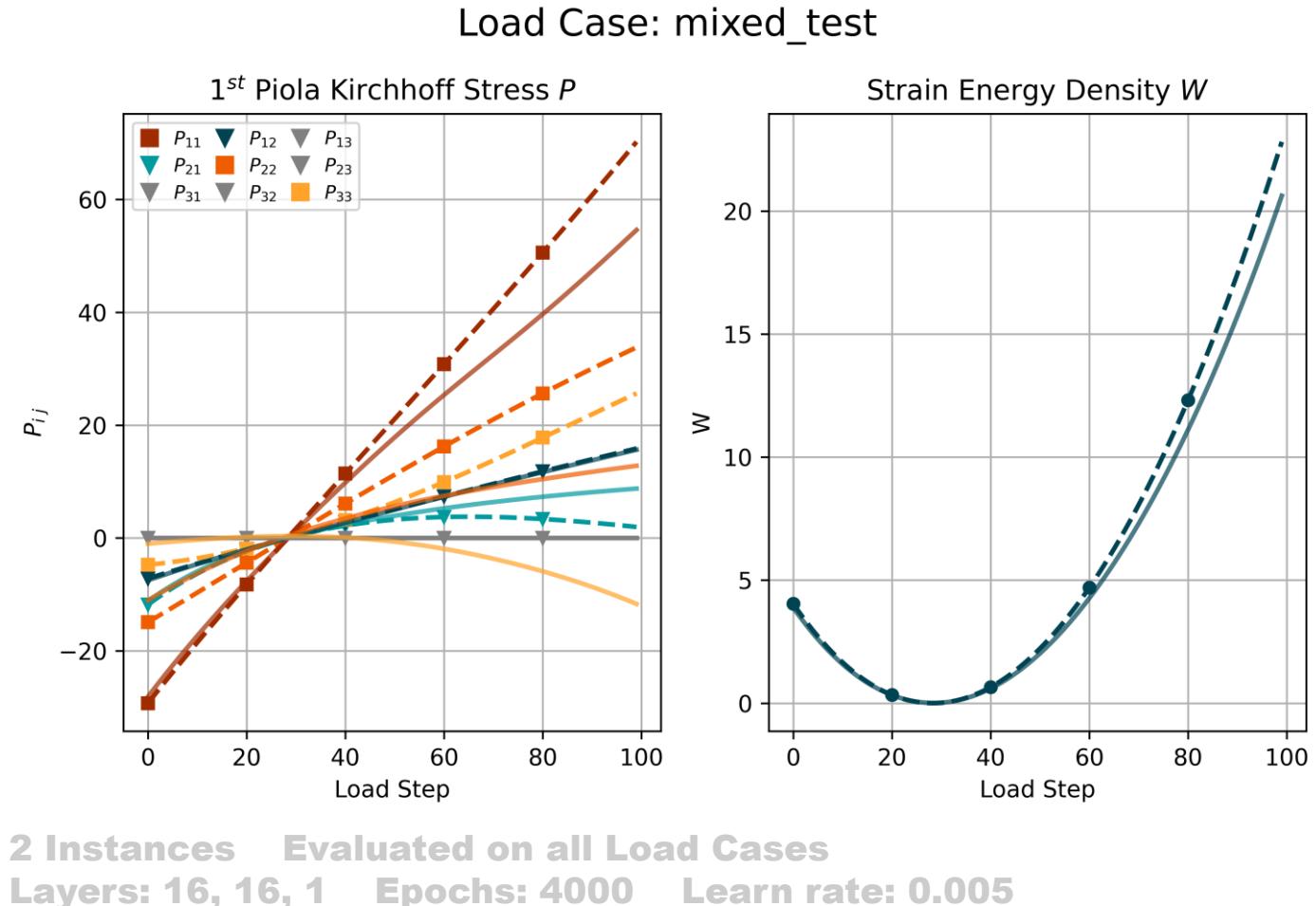
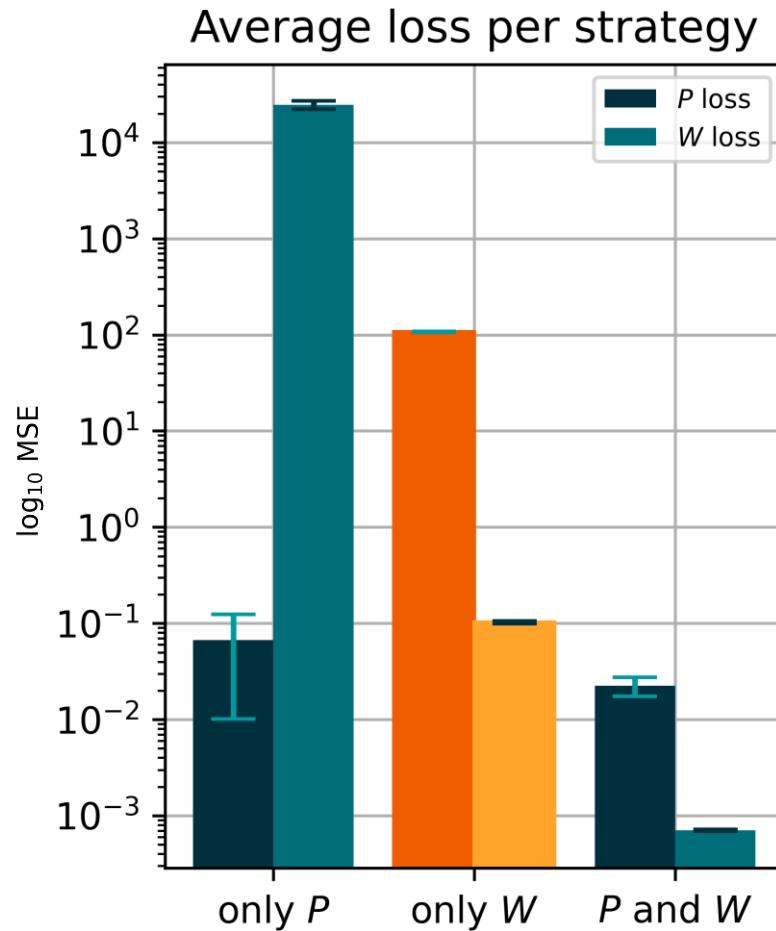


2 Instances Evaluated on all Load Cases
Layers: 16, 16, 1 Epochs: 4000 Learn rate: 0.005

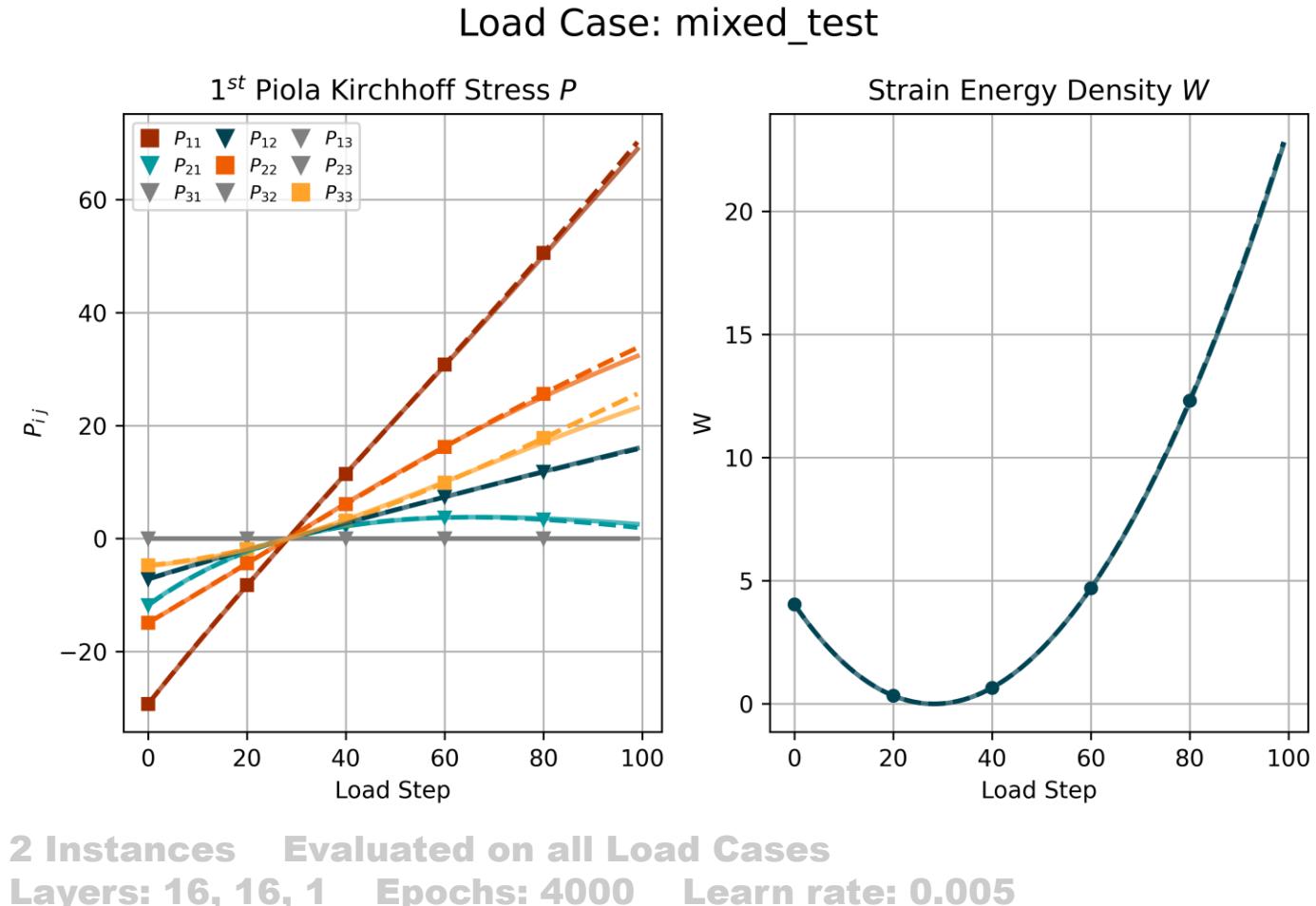
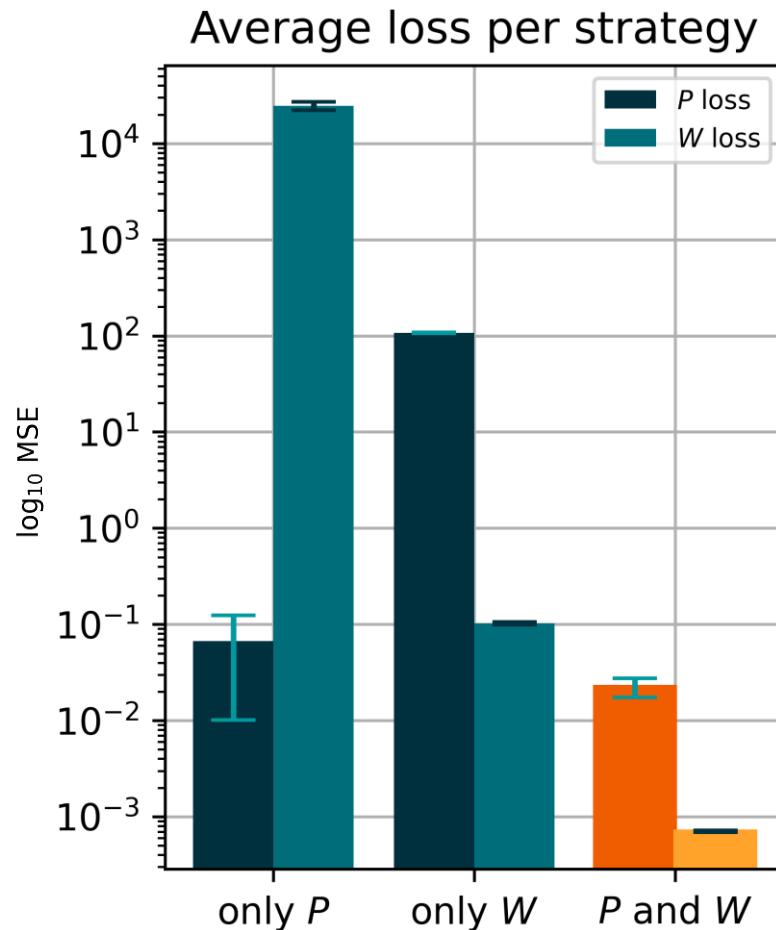
TRAINING STRATEGIES



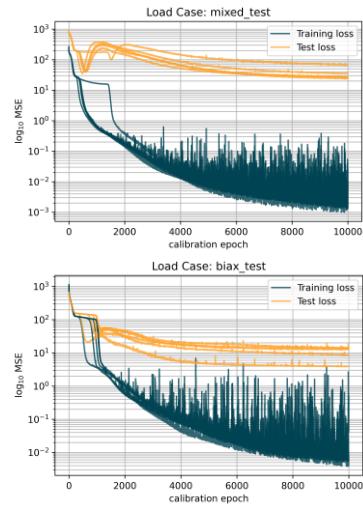
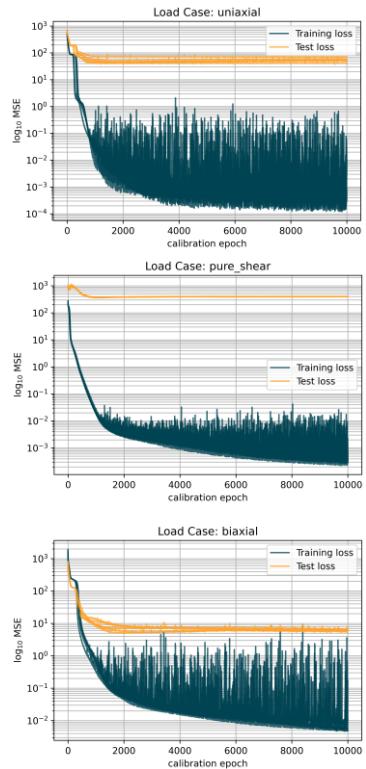
TRAINING STRATEGIES



TRAINING STRATEGIES

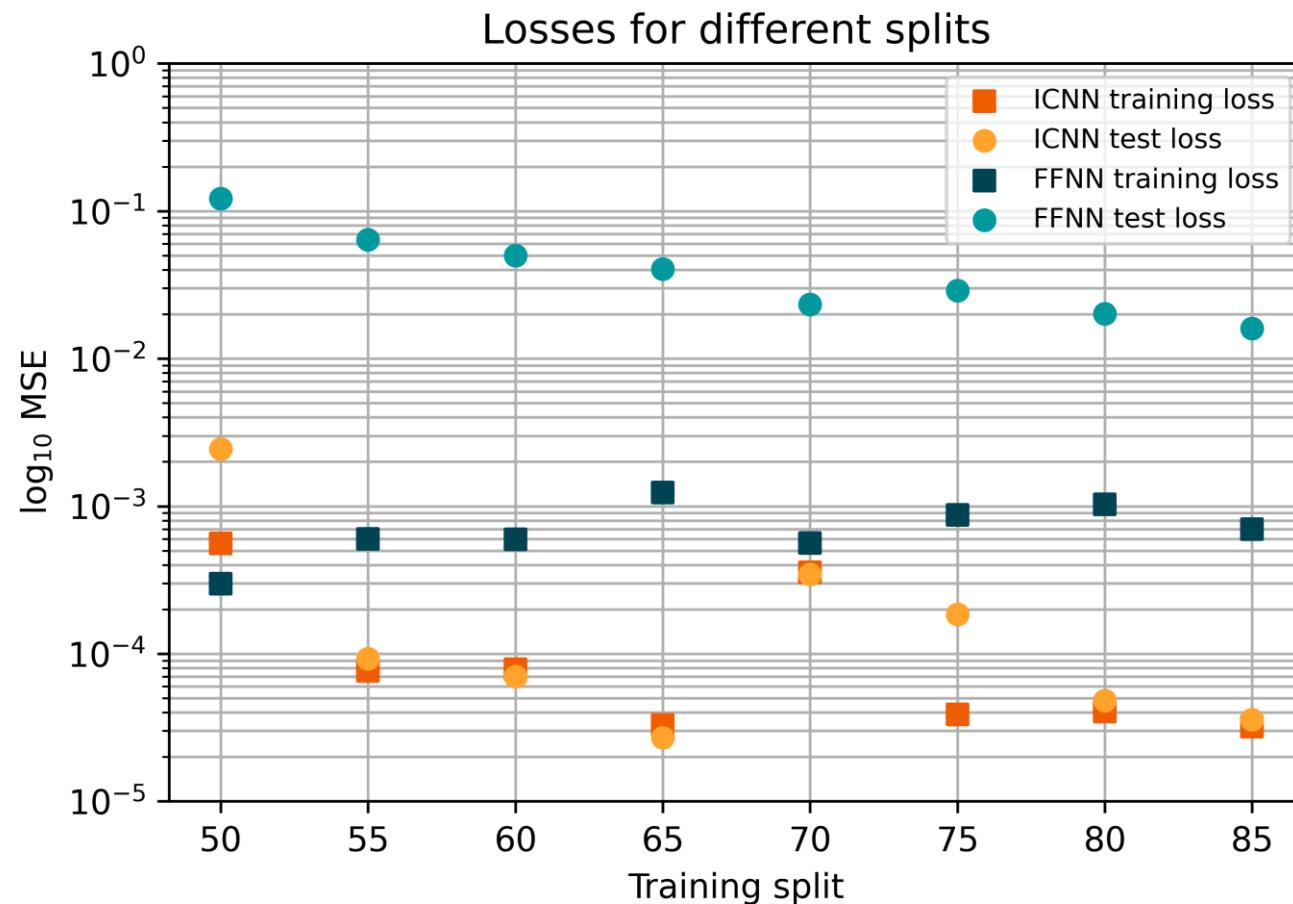


SINGLE LOAD CASE TRAINING



5 Instances each
Layers 16, 16, 1 Epochs: 10,000
Learning rate: 0.003
Trained on: P and W

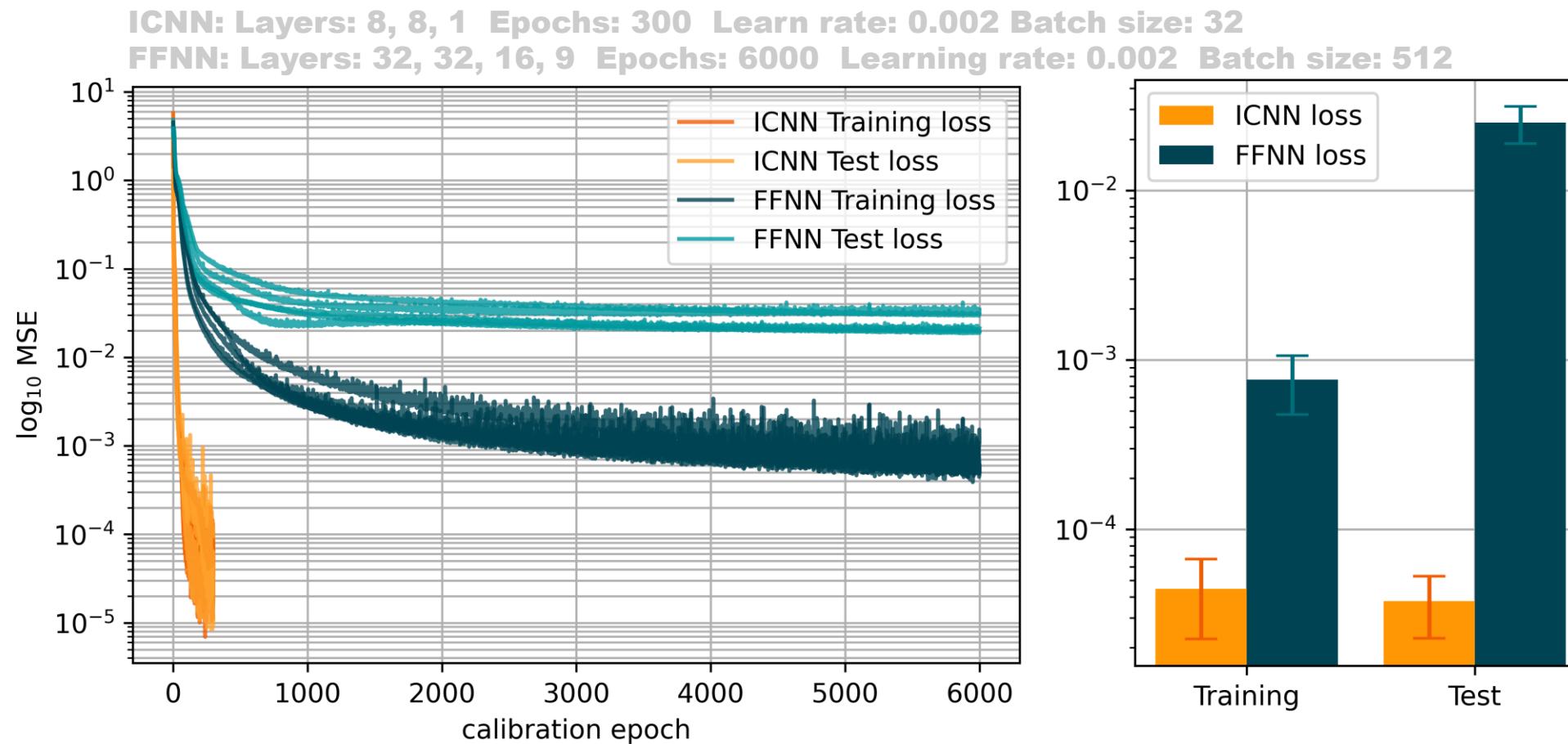
CONCENTRIC SAMPLED DEFORMATION GRADIENTS



ICNN: Layers: 8, 8, 1 Epochs: 300
Learn rate: 0.002 Batch size: 32
FFNN: Layers: 32, 32, 16, 9
Epochs: 6000 Learning rate: 0.002
Batch size: 512

CONCENTRIC SAMPLED DEFORMATION GRADIENTS

**80/20
Split**

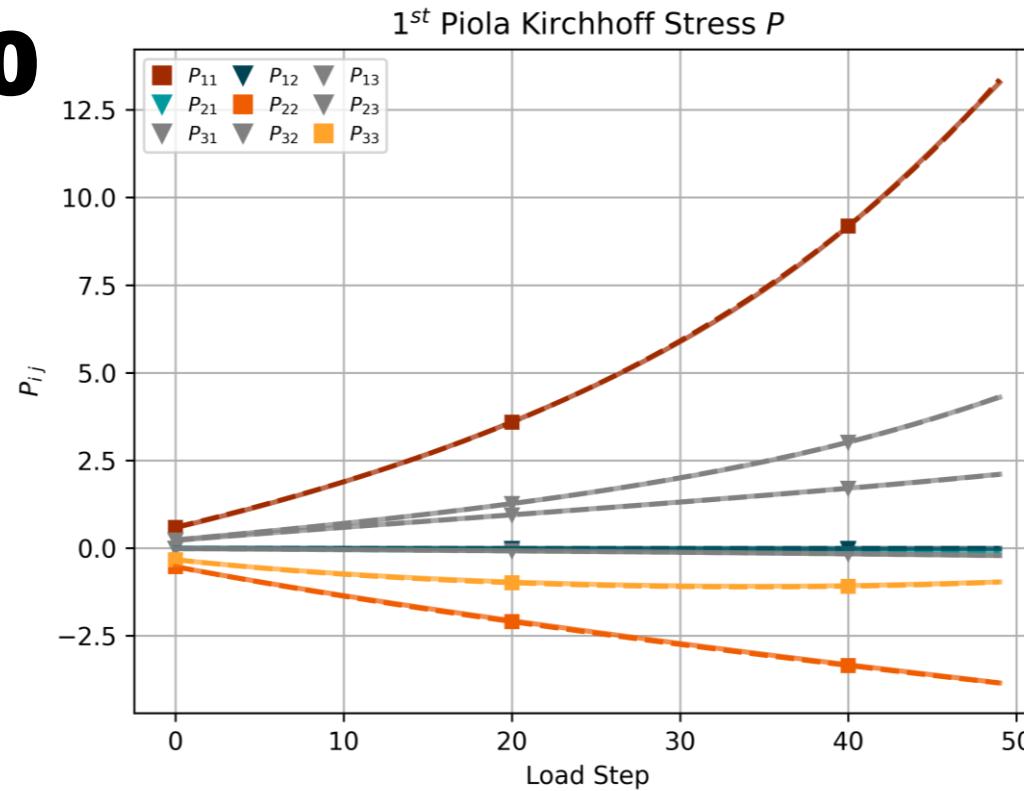


TRAINING LOAD CASE

ICNN

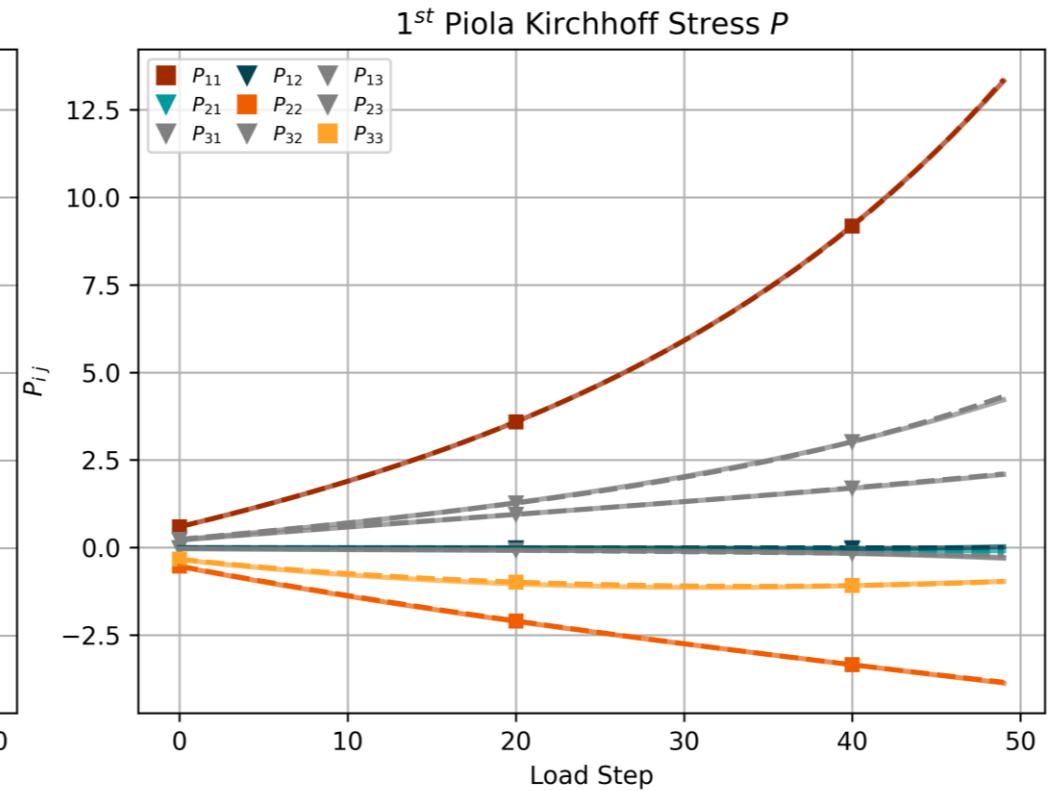
ICNN prediction for train load case 32

**80/20
Split**



FFNN

FFNN prediction for train load case 32

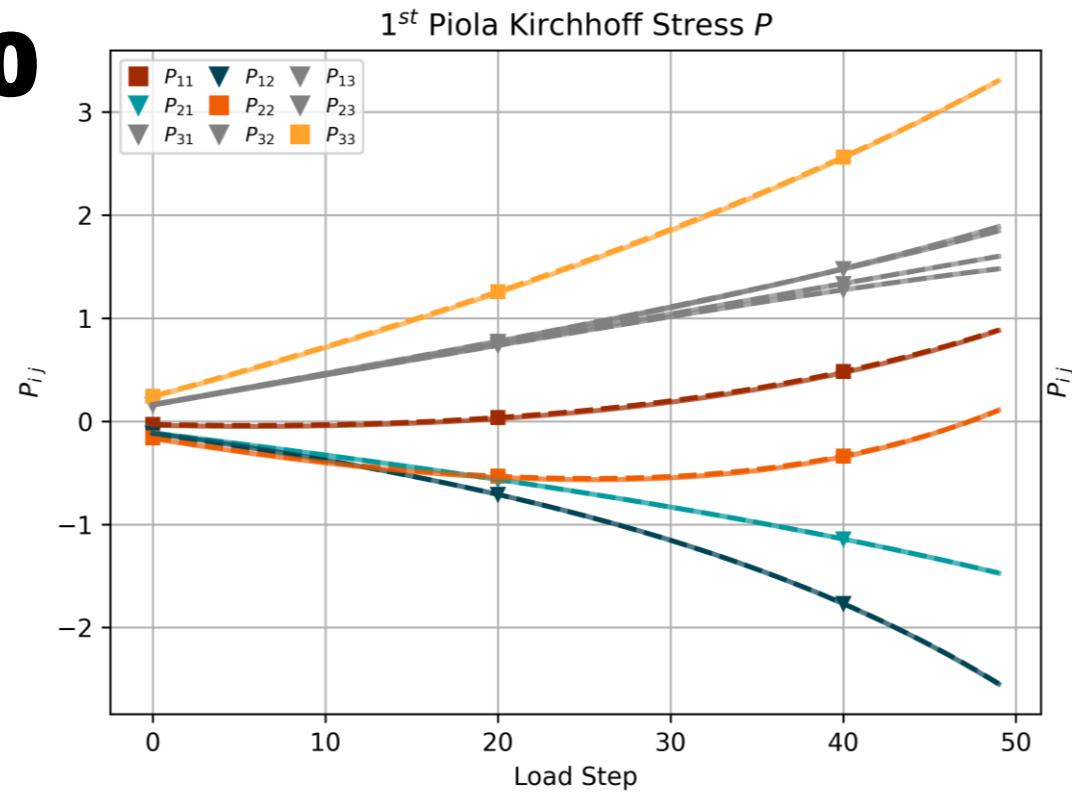


TEST LOAD CASE

ICNN

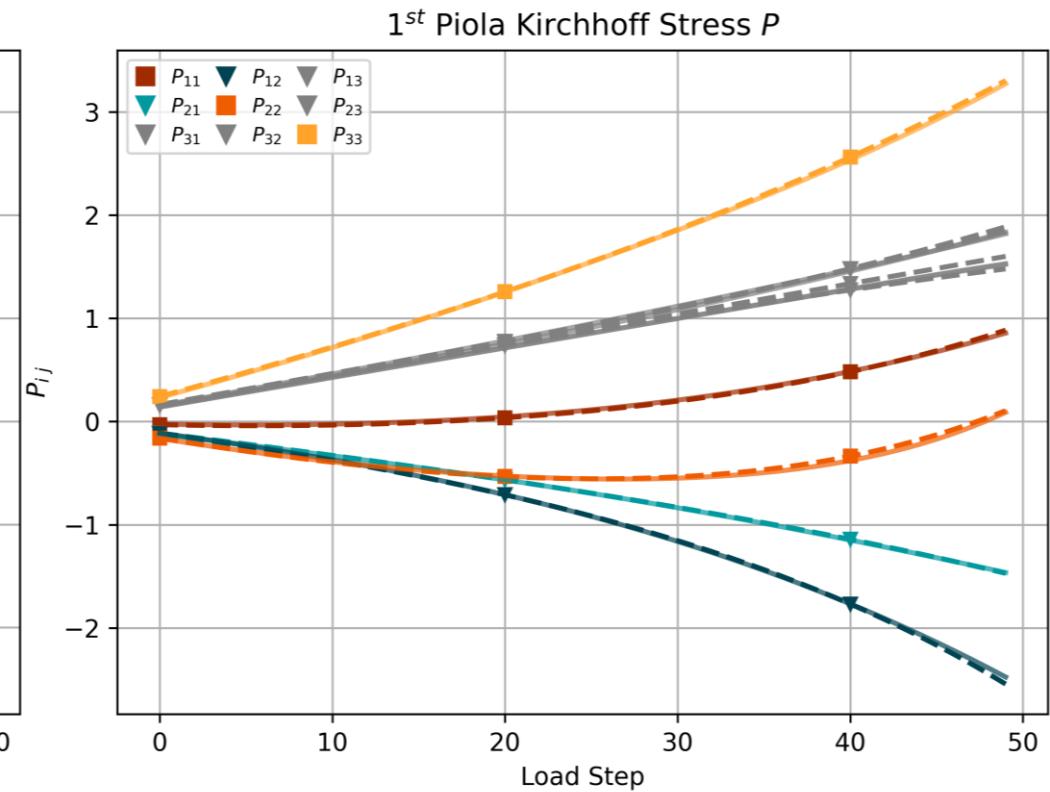
ICNN prediction for test load case 11

**80/20
Split**



FFNN

FFNN prediction for test load case 11



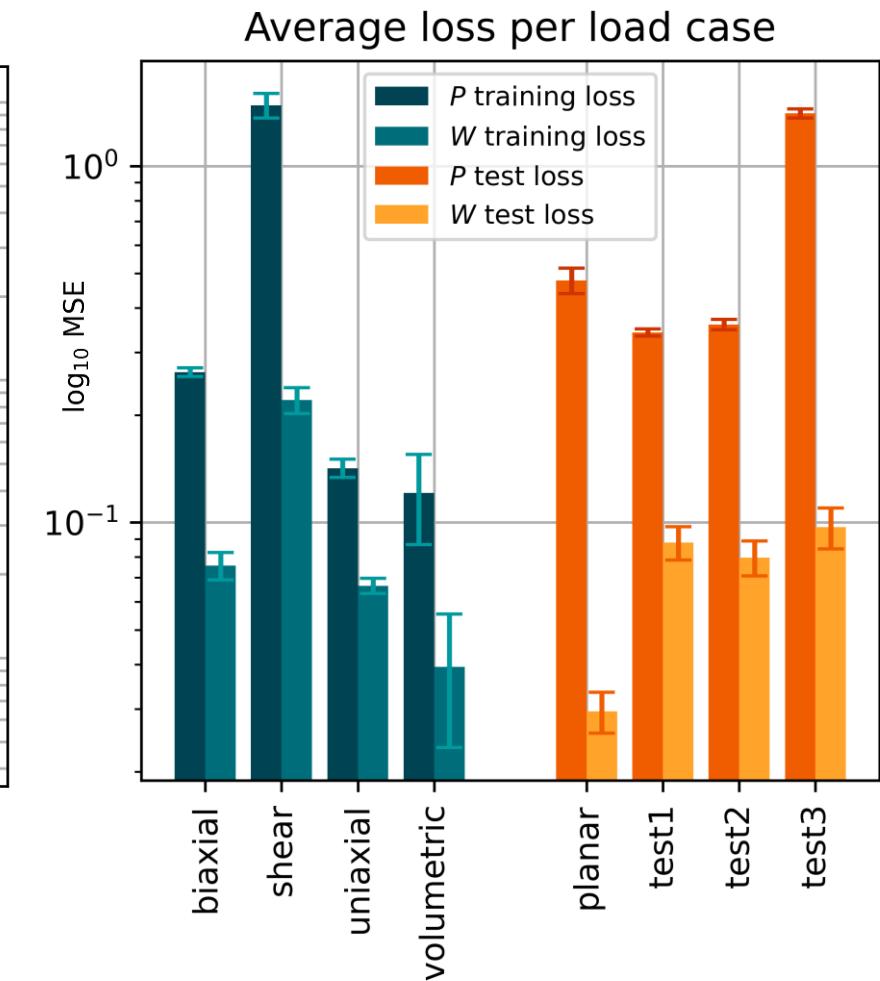
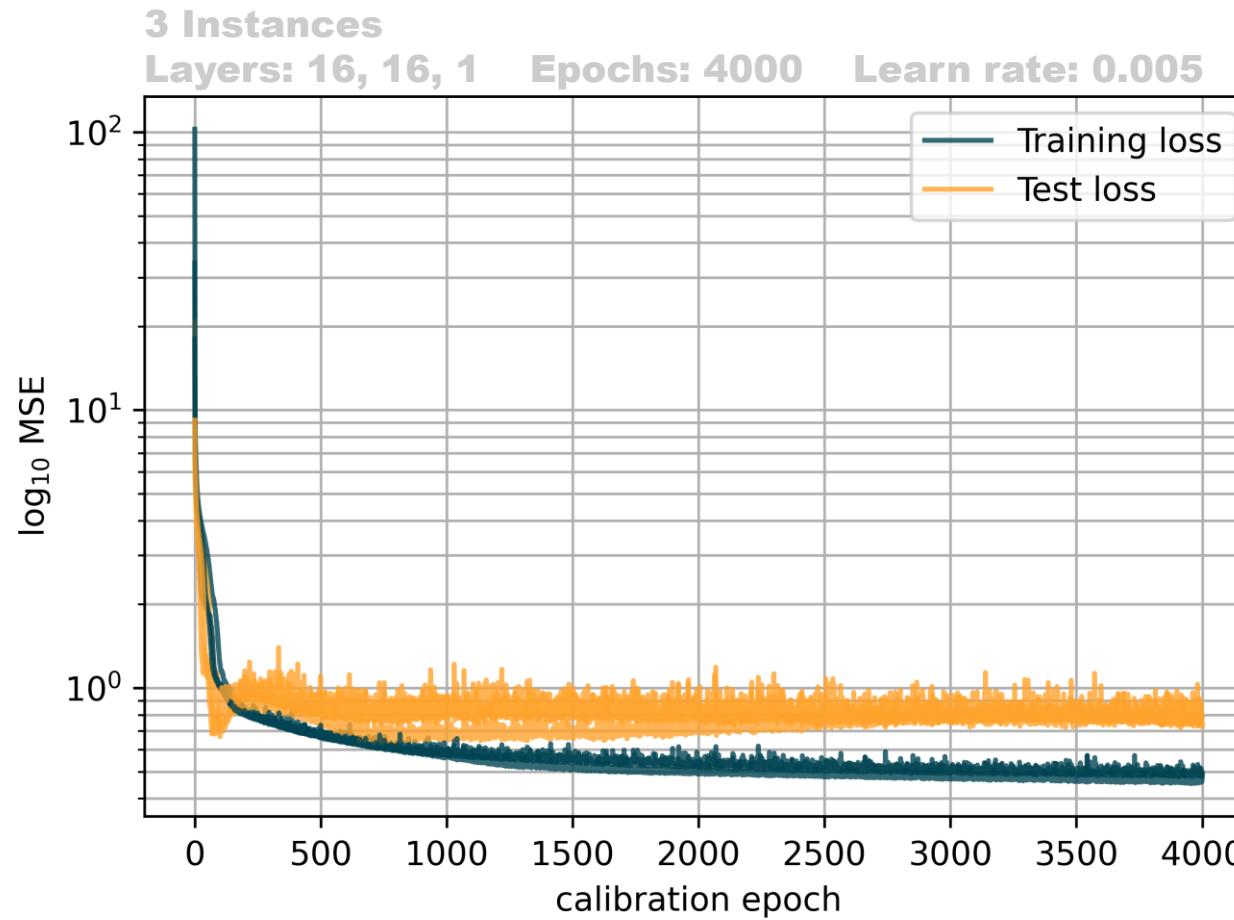


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TASK 3

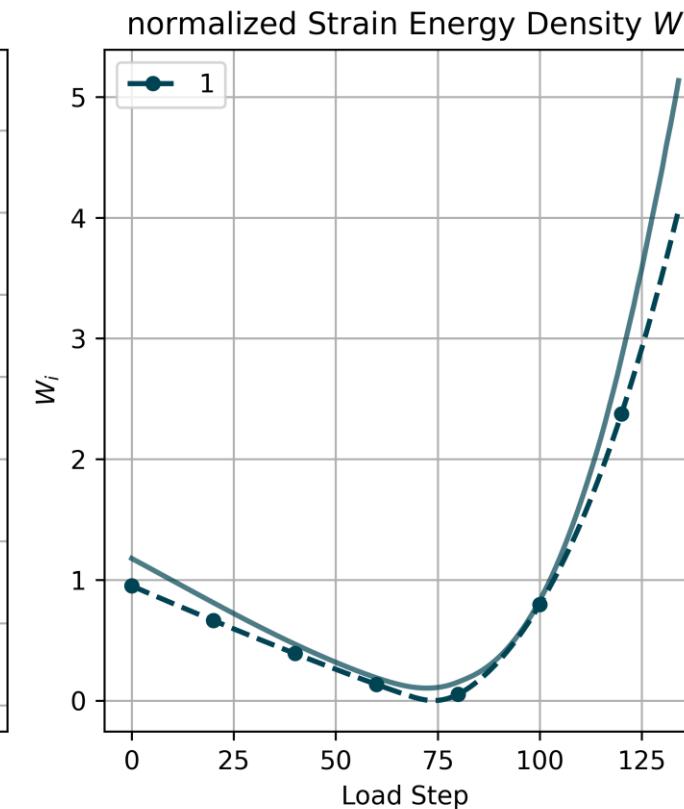
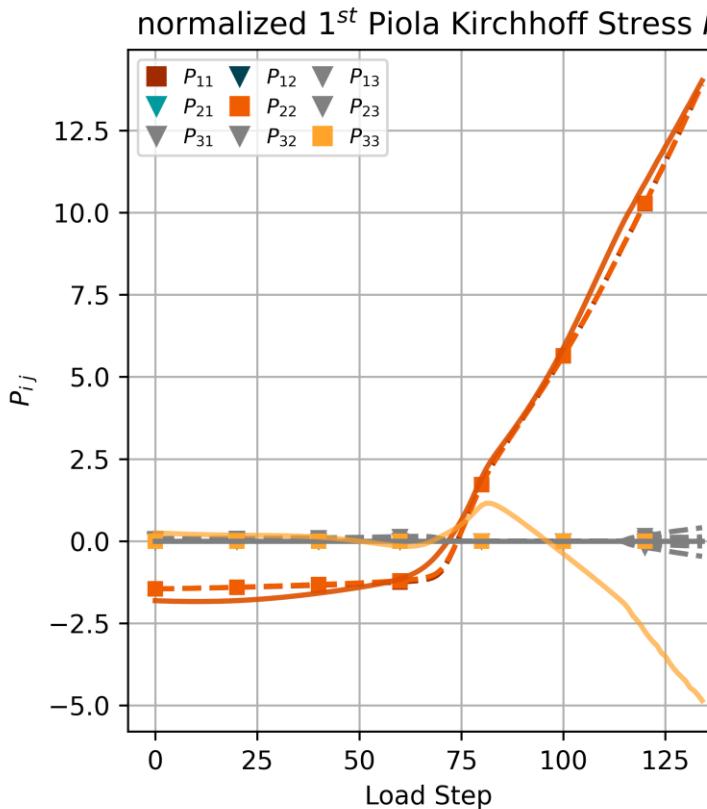
HYPERELASTICITY II

INVARIANT-BASED MODEL

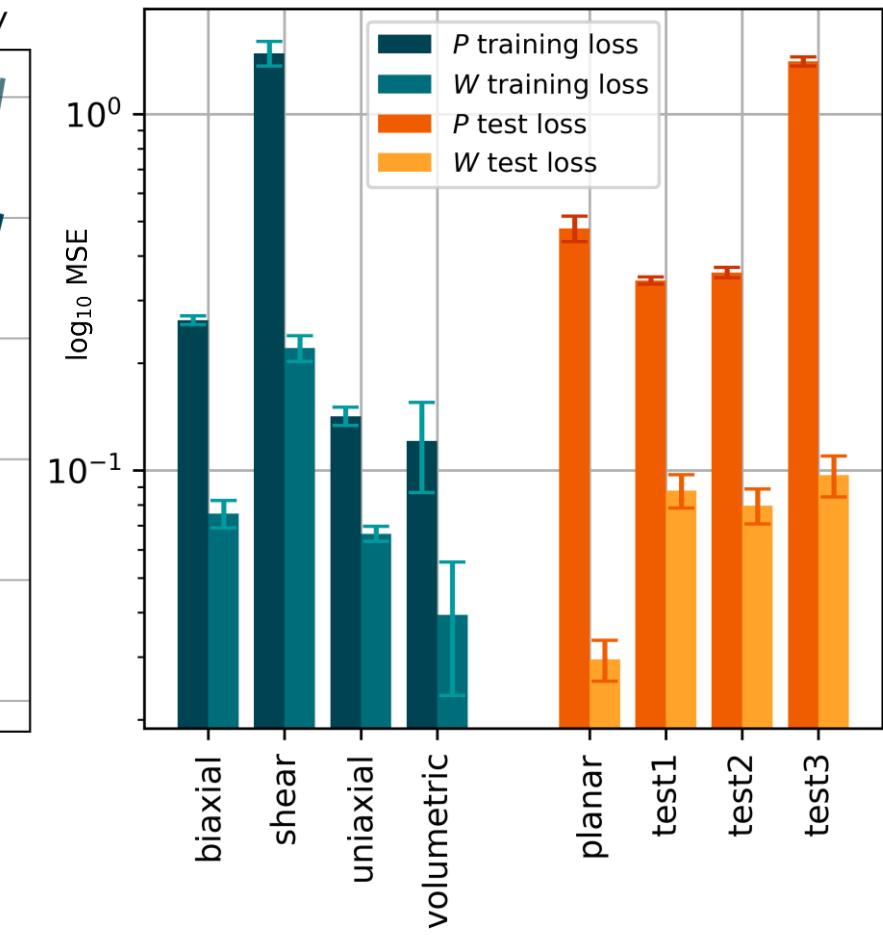


INVARIANT-BASED MODEL

Load Case: biaxial



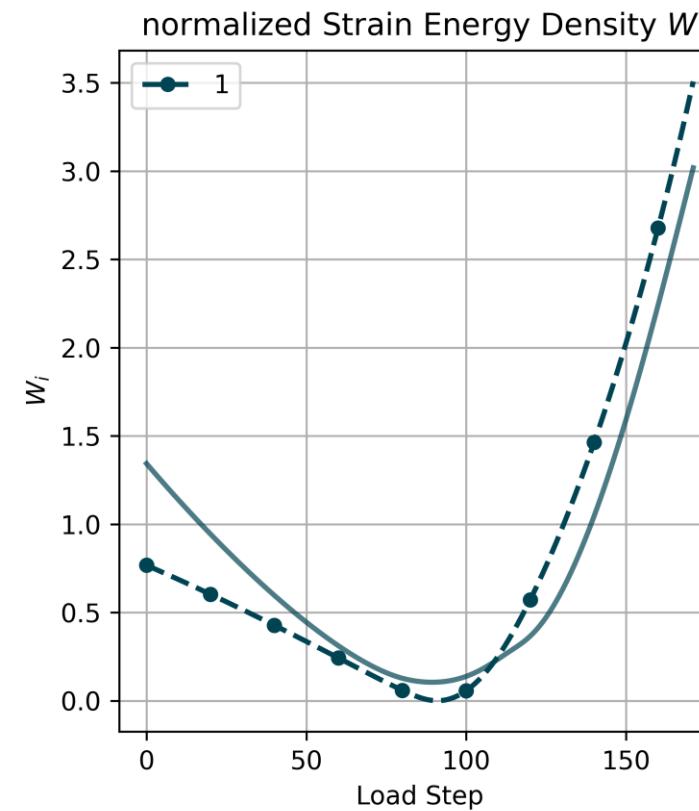
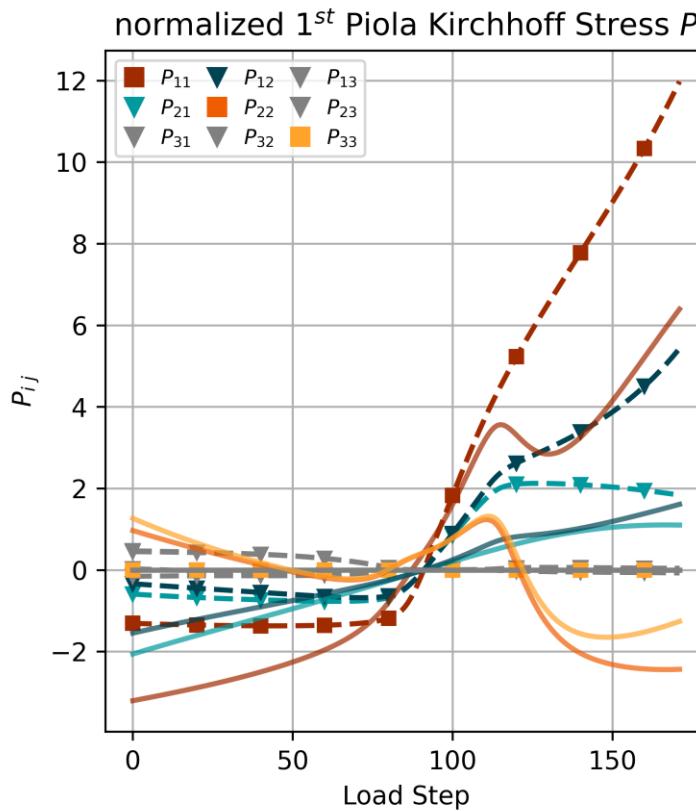
Average loss per load case



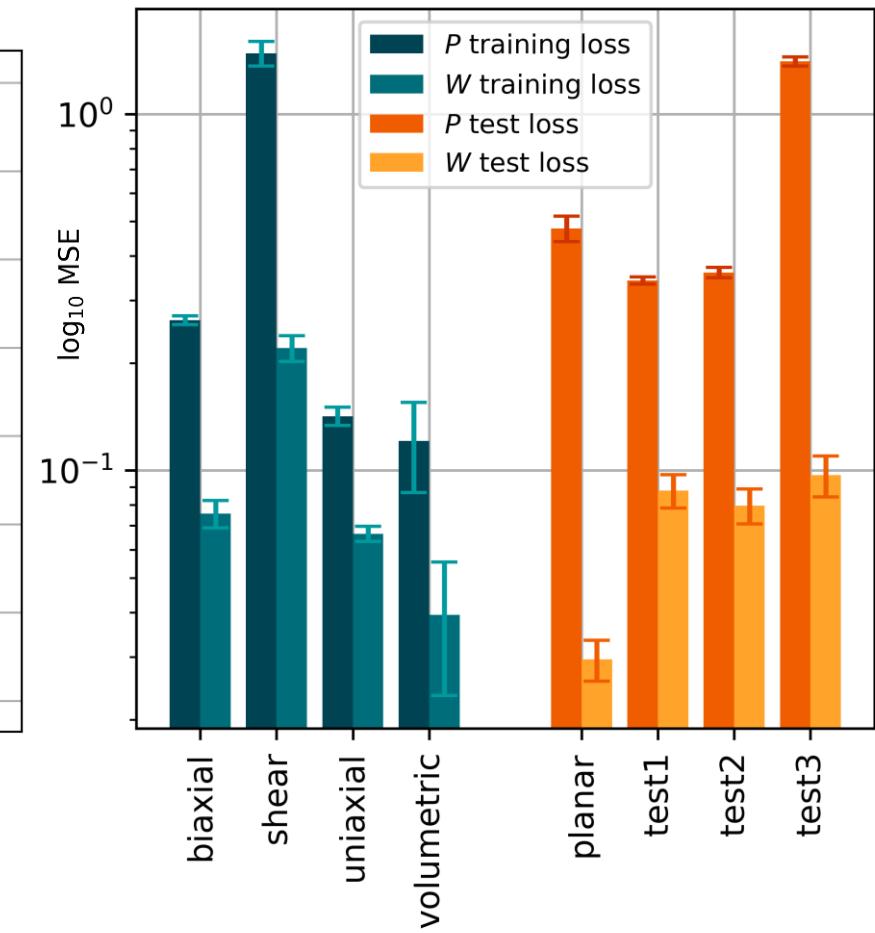
INVARIANT-BASED MODEL



Load Case: test3



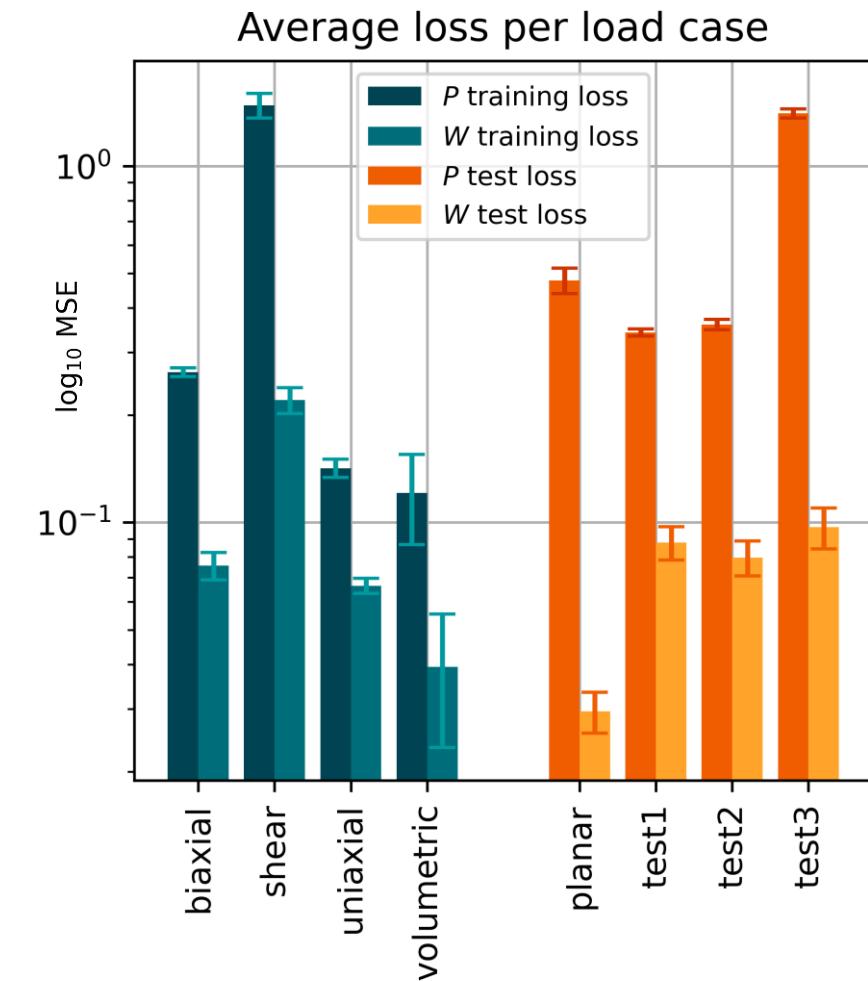
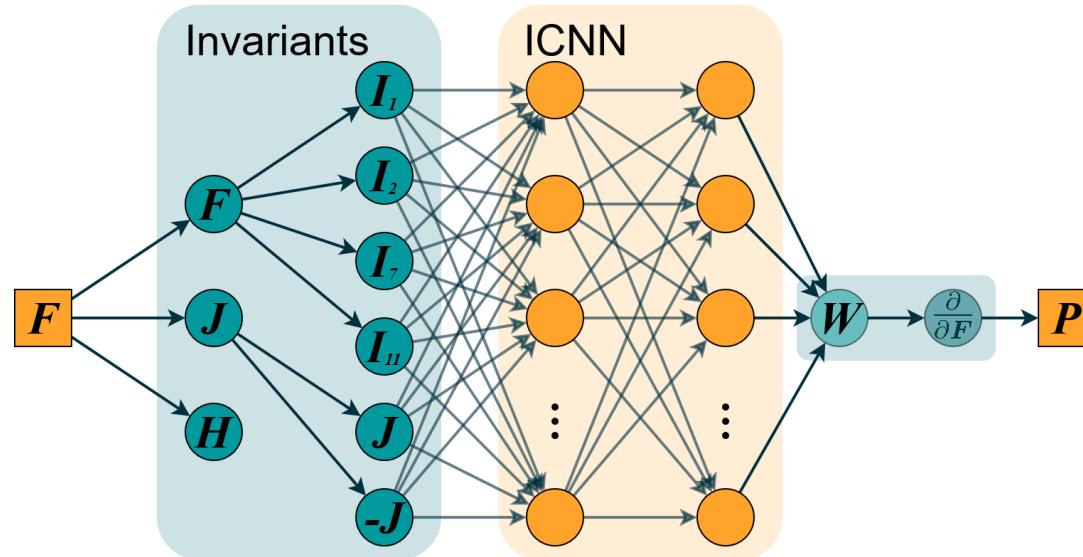
Average loss per load case



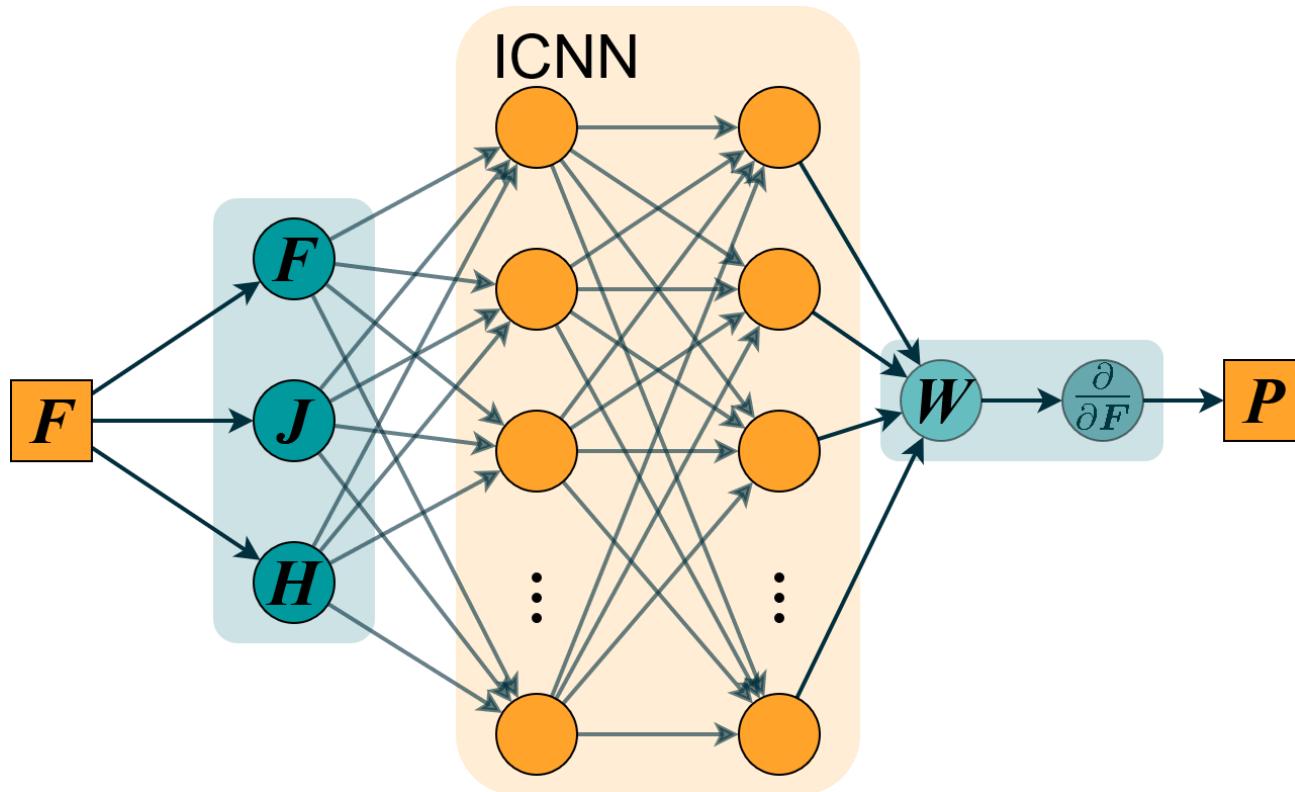
INVARIANT-BASED MODEL

Possible reasons for bad fit:

- To little information in Invariants
- Model not flexible enough



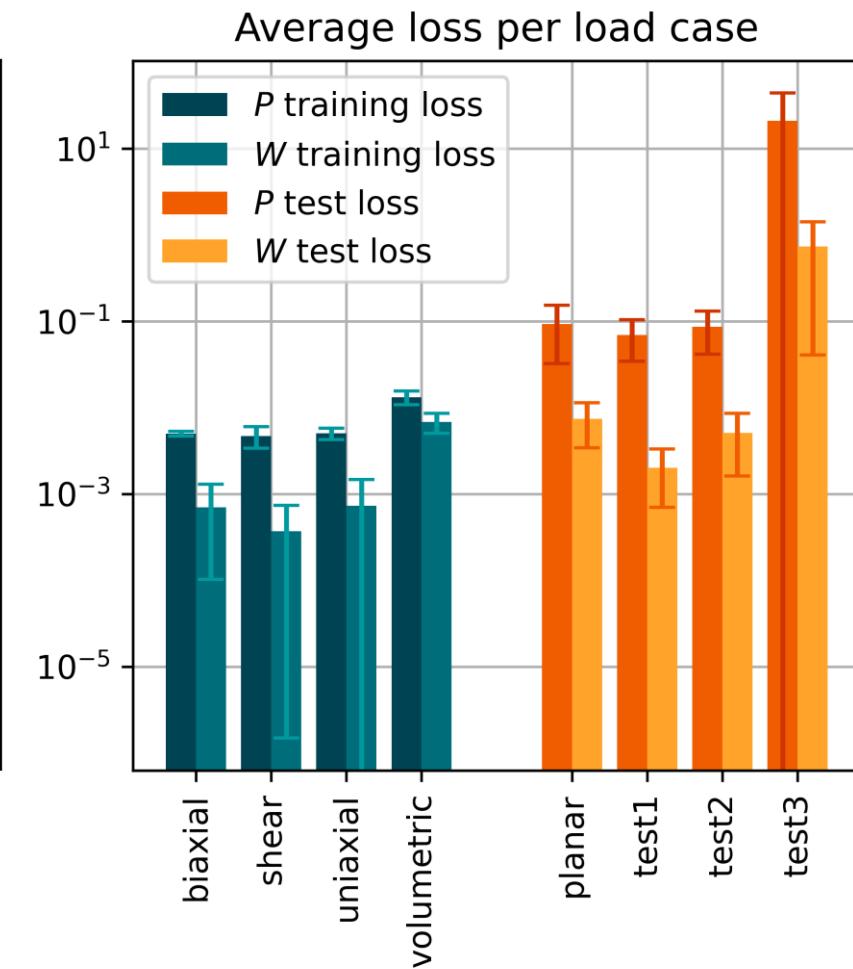
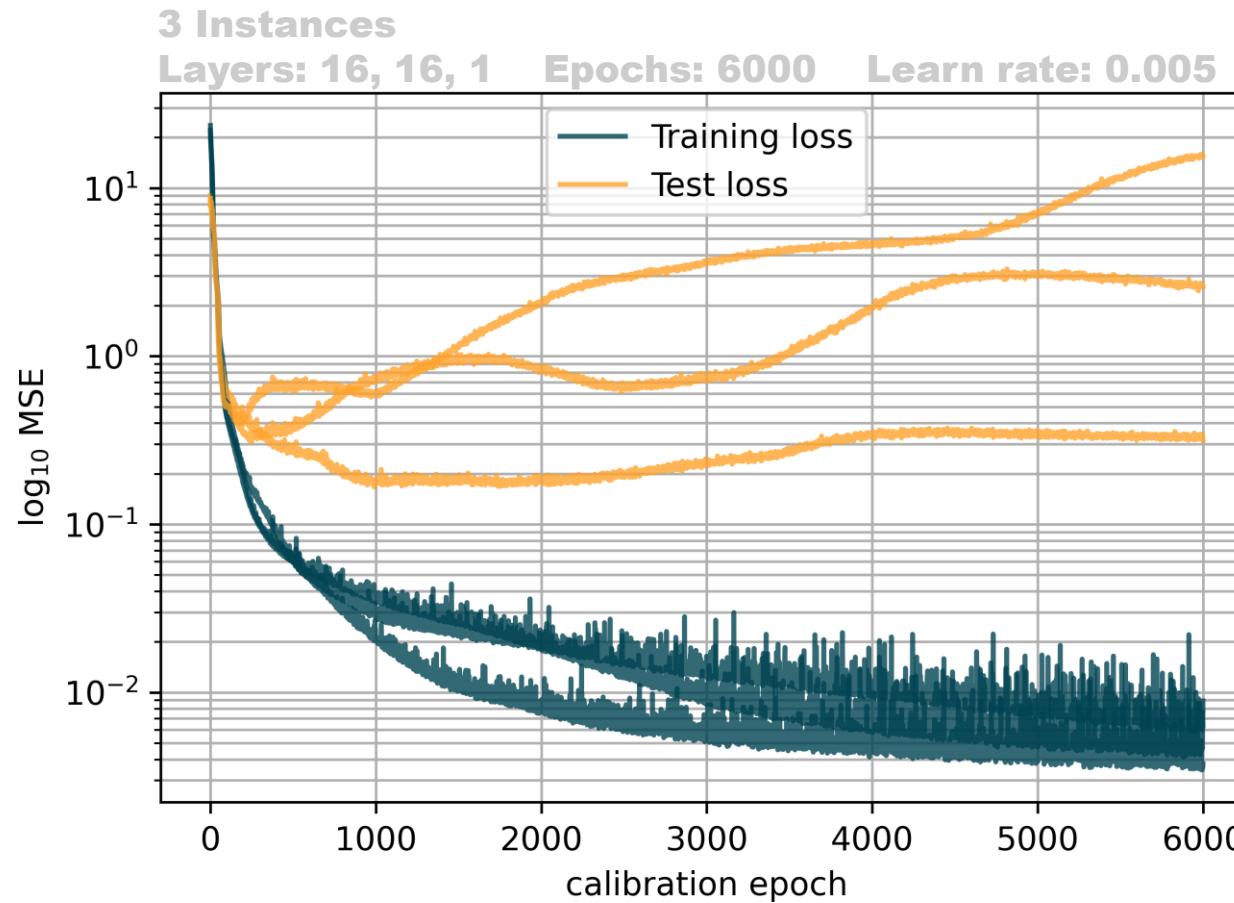
DEFORMATION-GRADIENT BASED MODEL (DGBM)



Physical conditions:

- ? Objectivity
- ? Material Symmetry
- ✓ Thermodynamics
- ✓ Polyconvexity/Ellipticity
- ? Normalization
- ? Growth Condition

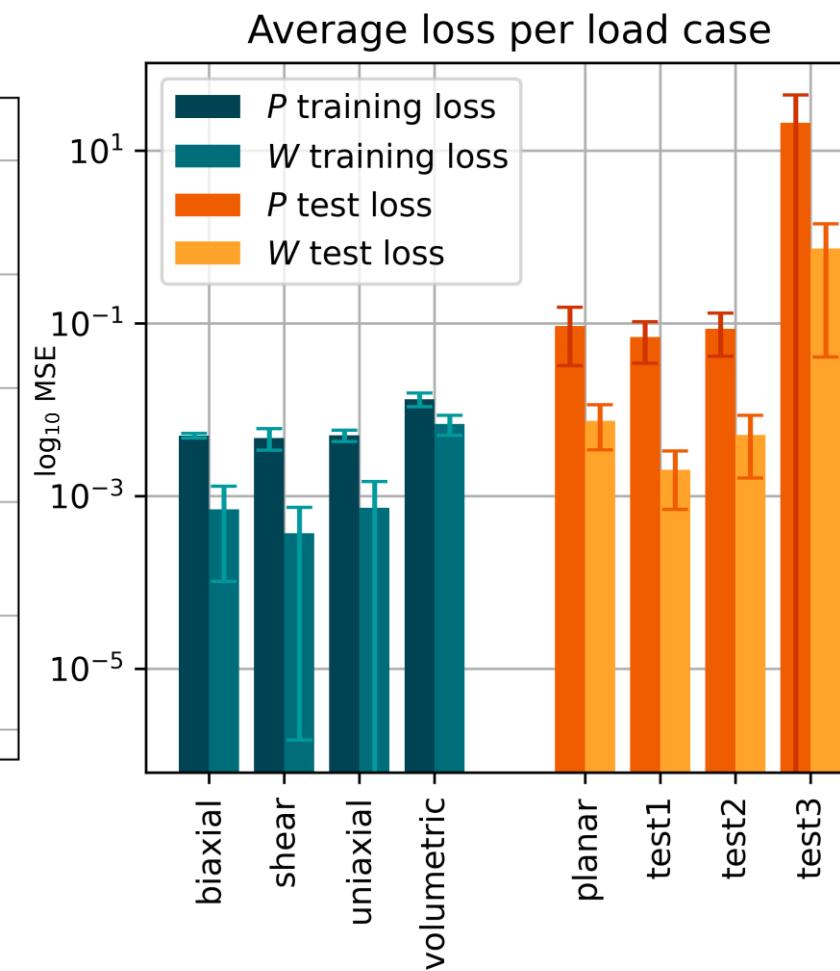
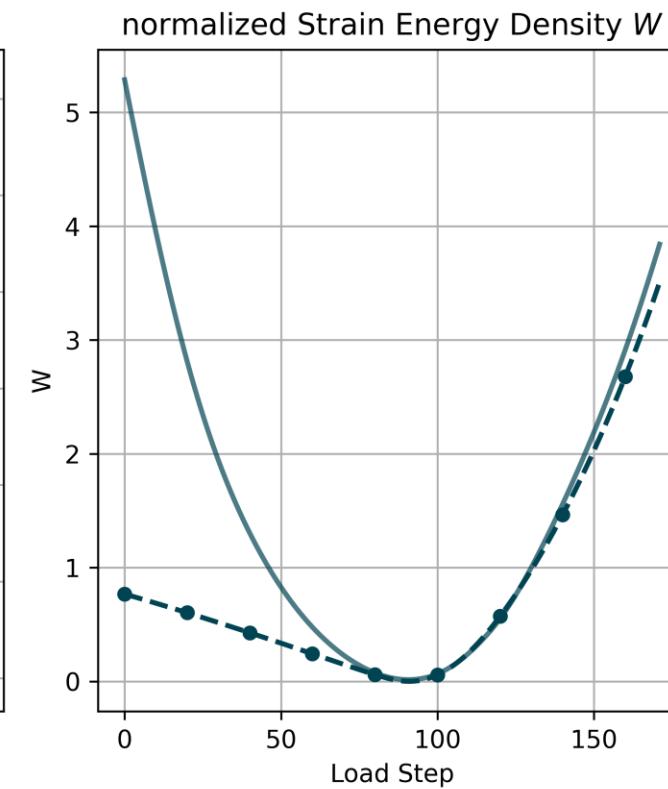
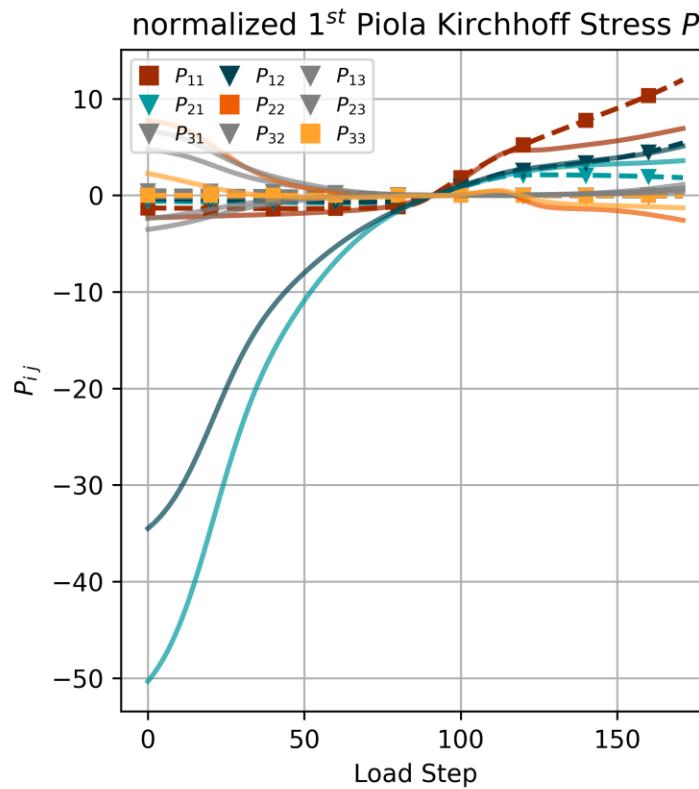
DEFORMATION-GRADIENT BASED MODEL (DGBM)



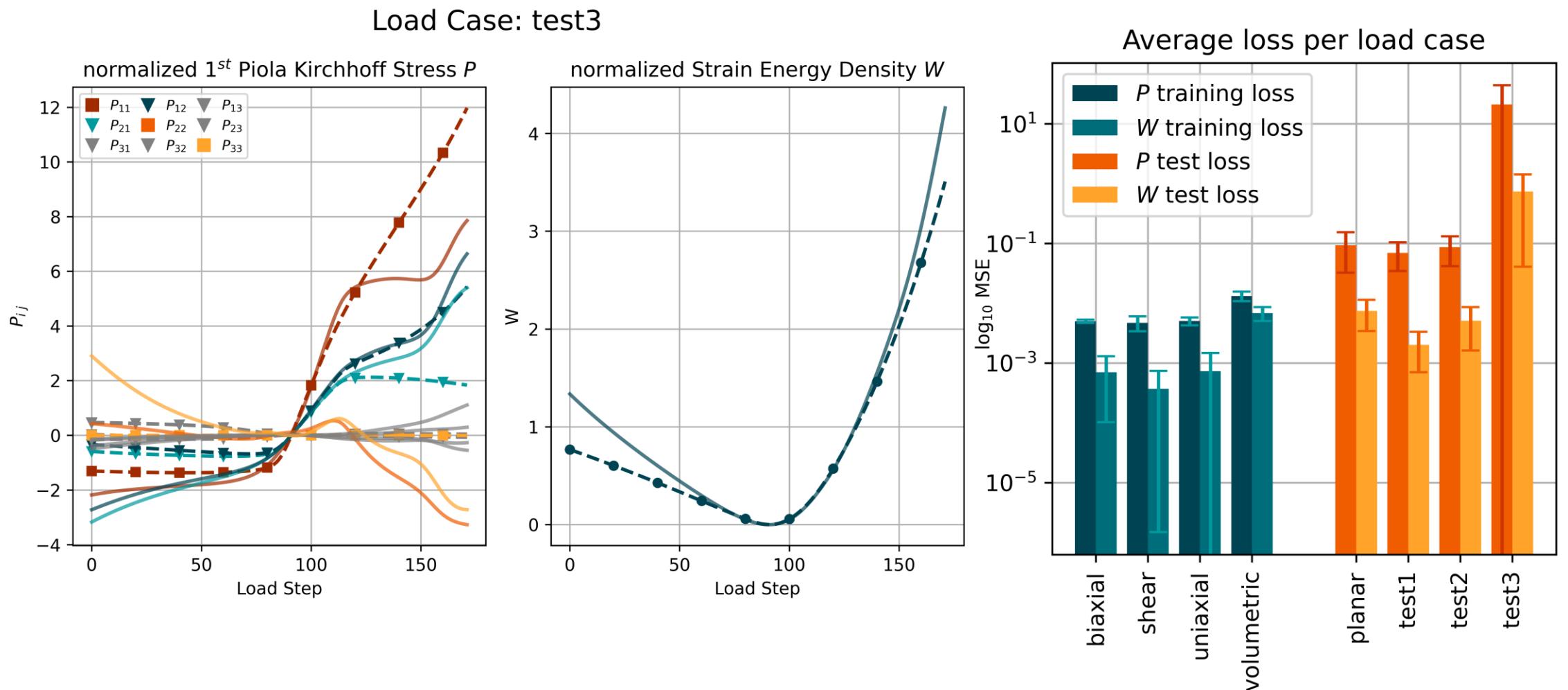
DGBM - PROBLEMS



Load Case: test3

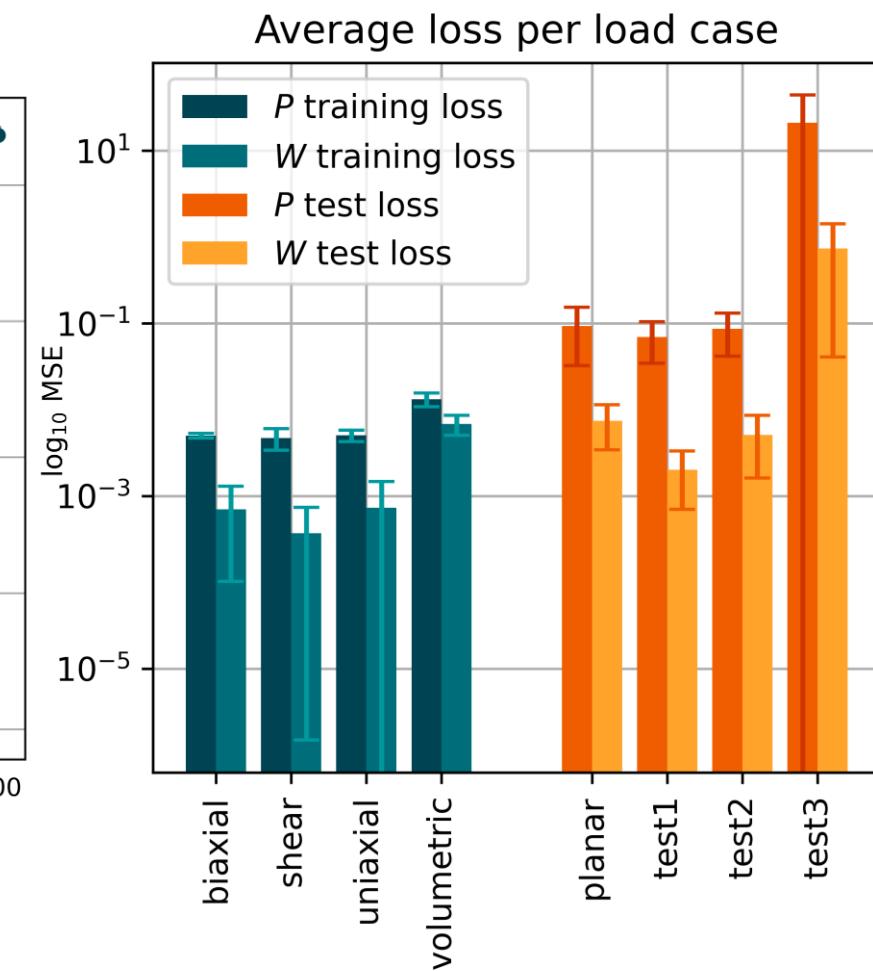
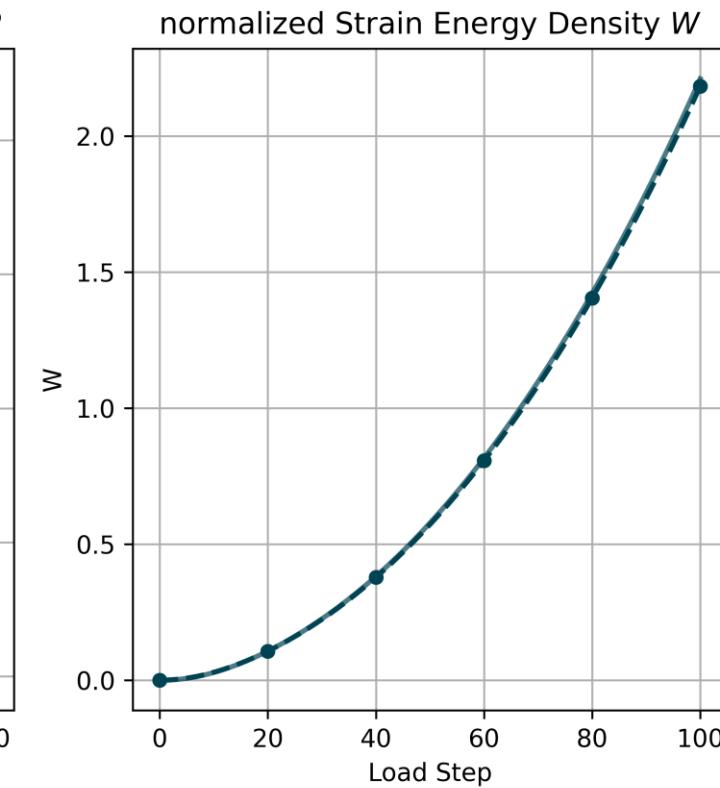
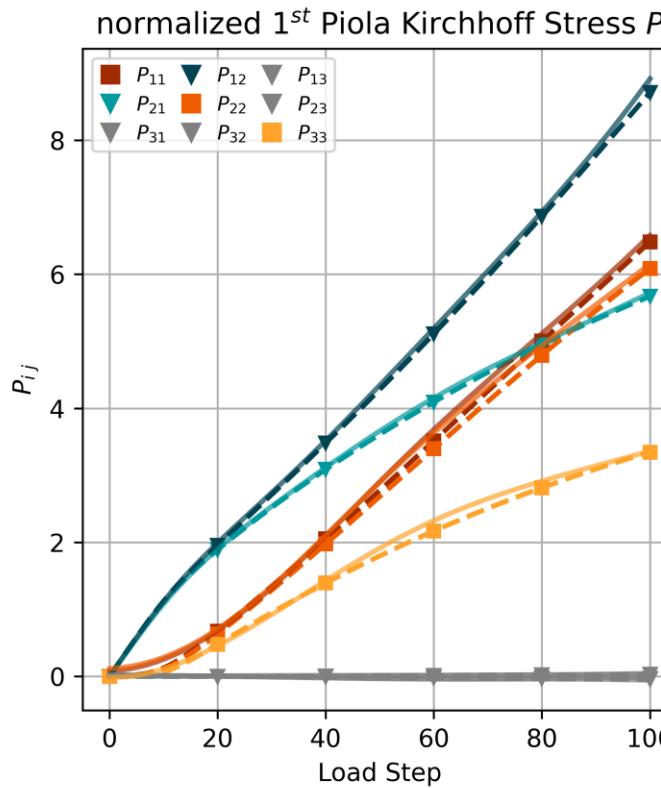


DGBM - PROBLEMS



DEFORMATION-GRADIENT BASED MODEL

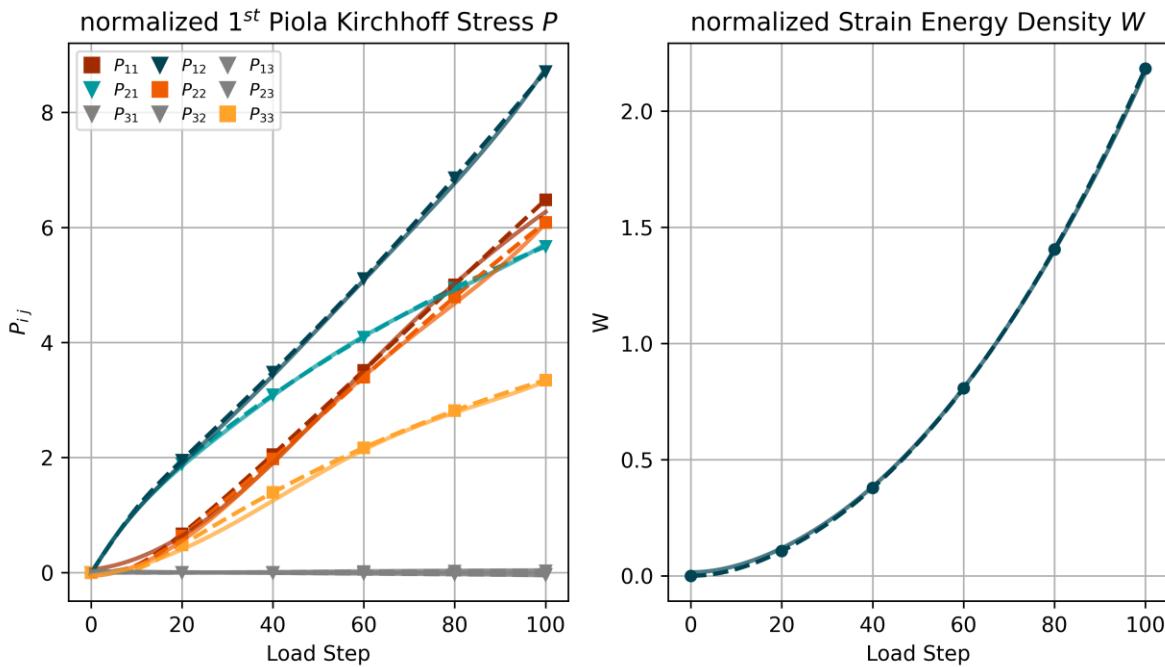
Load Case: shear



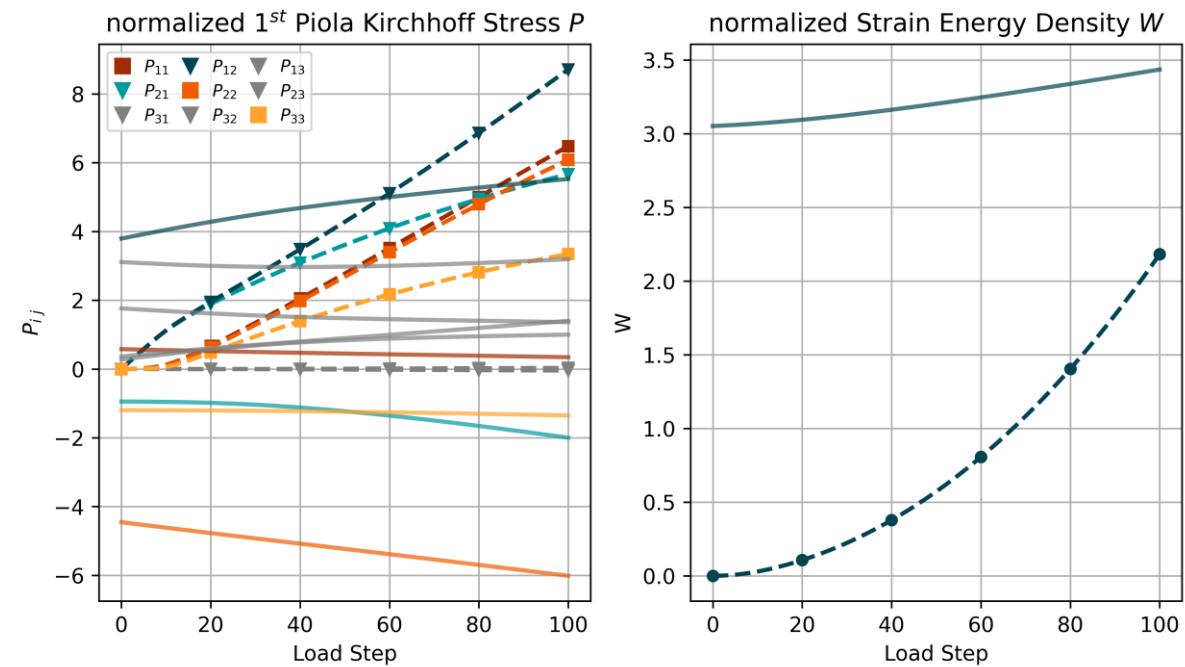
DGBM - MATERIAL SYMMETRY



Original Load Case: shear



Load Case: shear, augmented with Q_{mat}

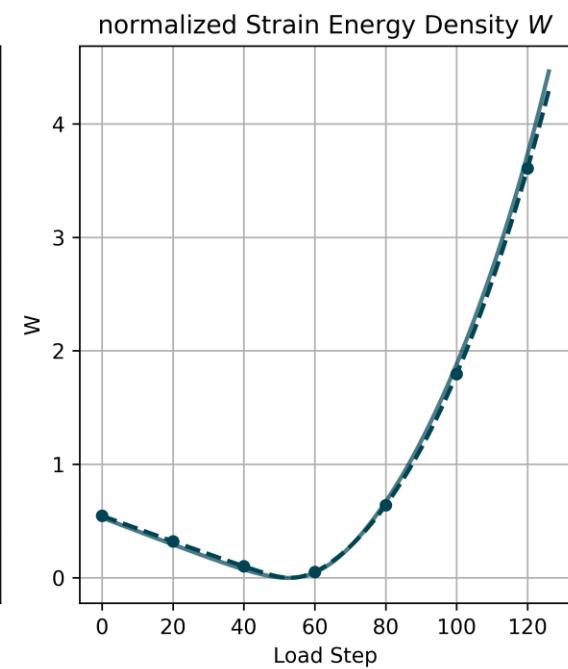
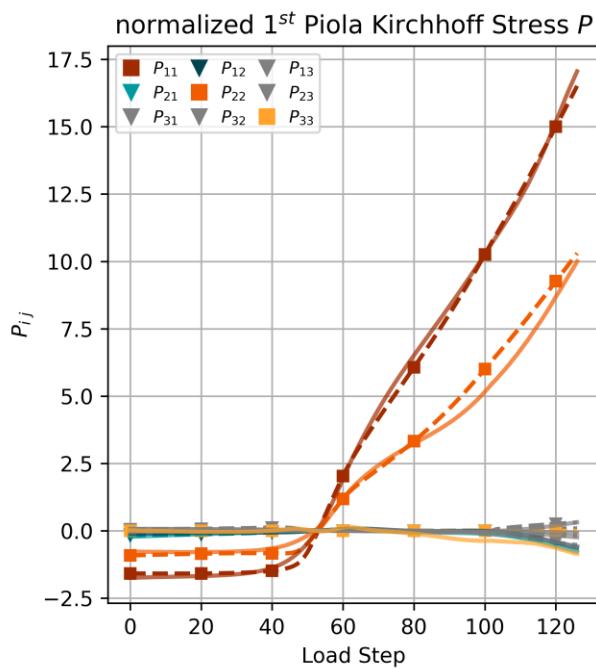


$$\mathbf{P}(\mathbf{F}) \stackrel{!}{=} \mathbf{P}(\mathbf{F}\mathbf{Q}_{mat})\mathbf{Q}_{mat}^T$$

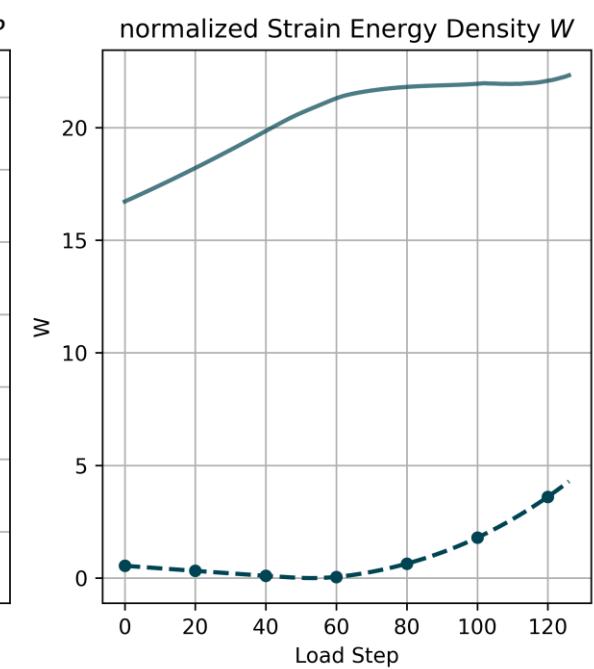
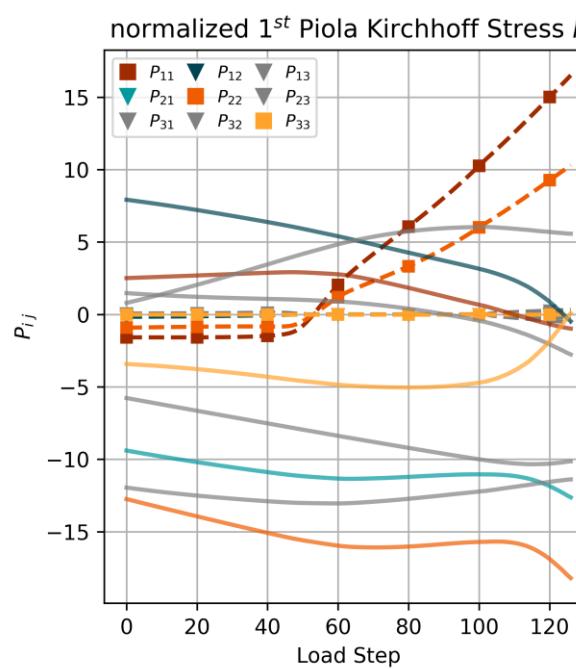
DGBM - OBJECTIVITY



Original Load Case: test2

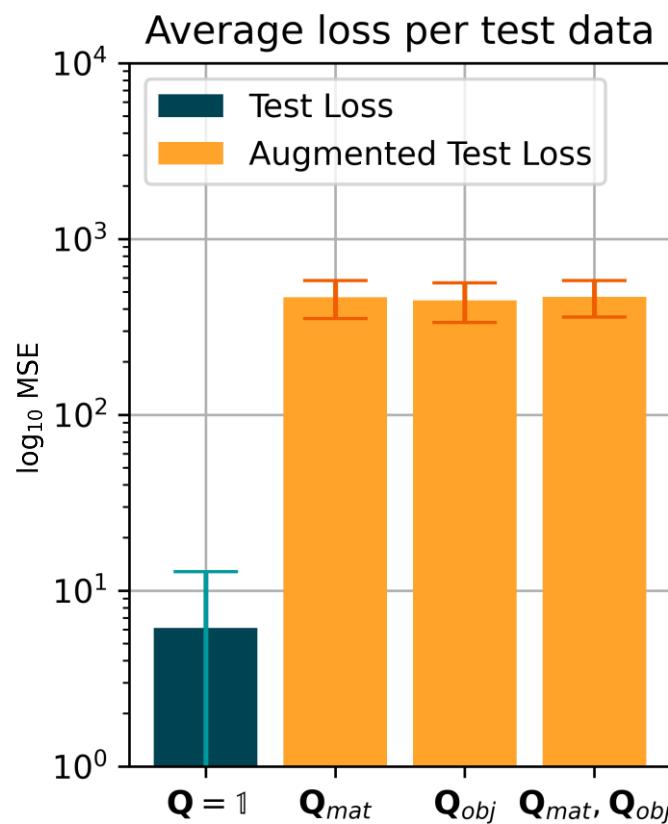


Load Case: test2, augmented with Q_{obj}

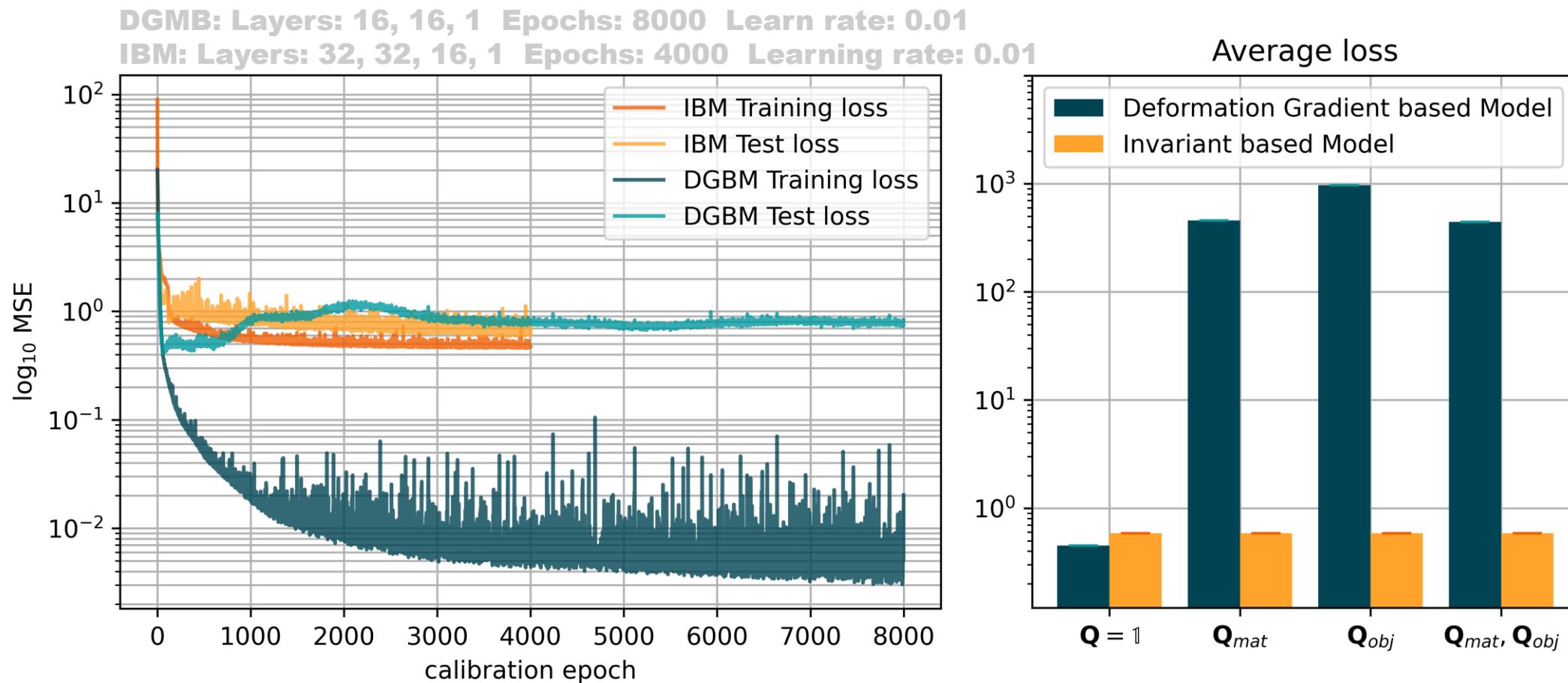


$$\mathbf{P}(\mathbf{F}) \stackrel{!}{=} \mathbf{Q}_{obj}^T \mathbf{P}(\mathbf{Q}_{obj} \mathbf{F})$$

DEFORMATION-GRADIENT BASED MODEL

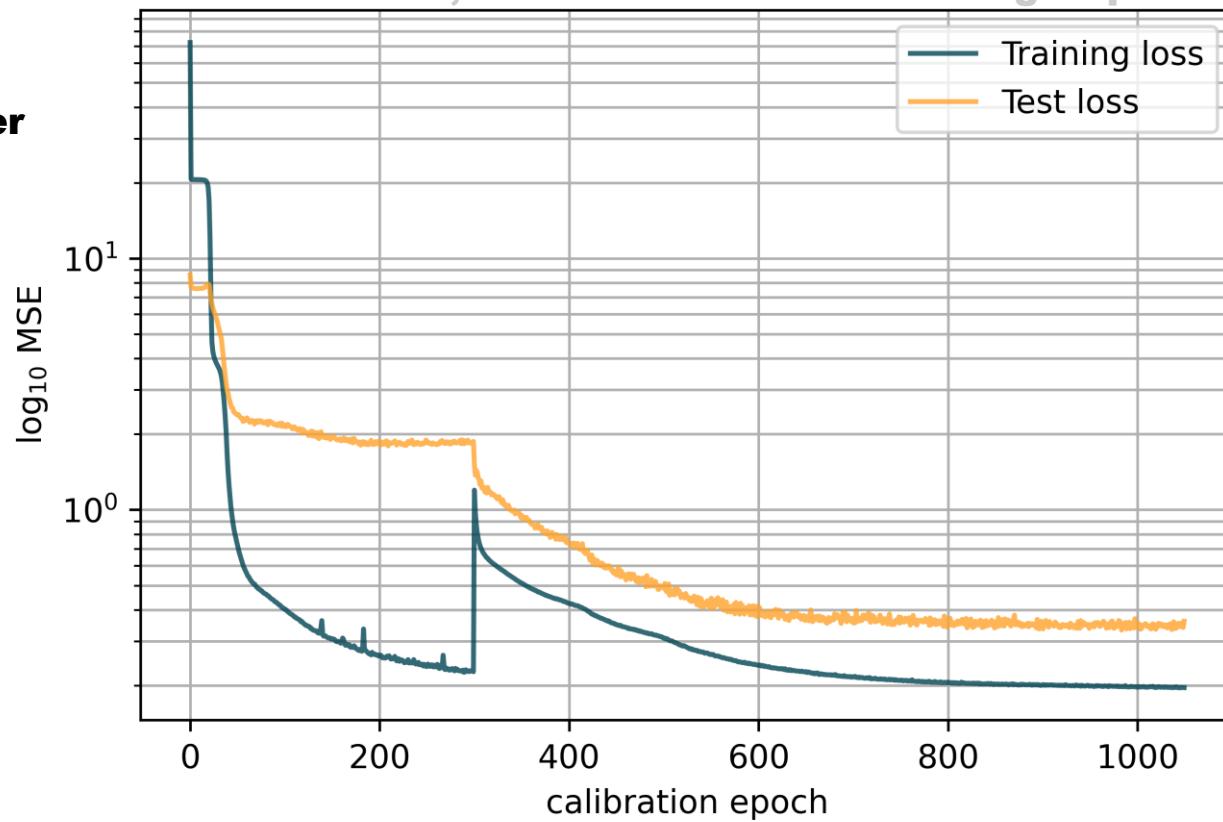


DGBM, IBM COMPARISON

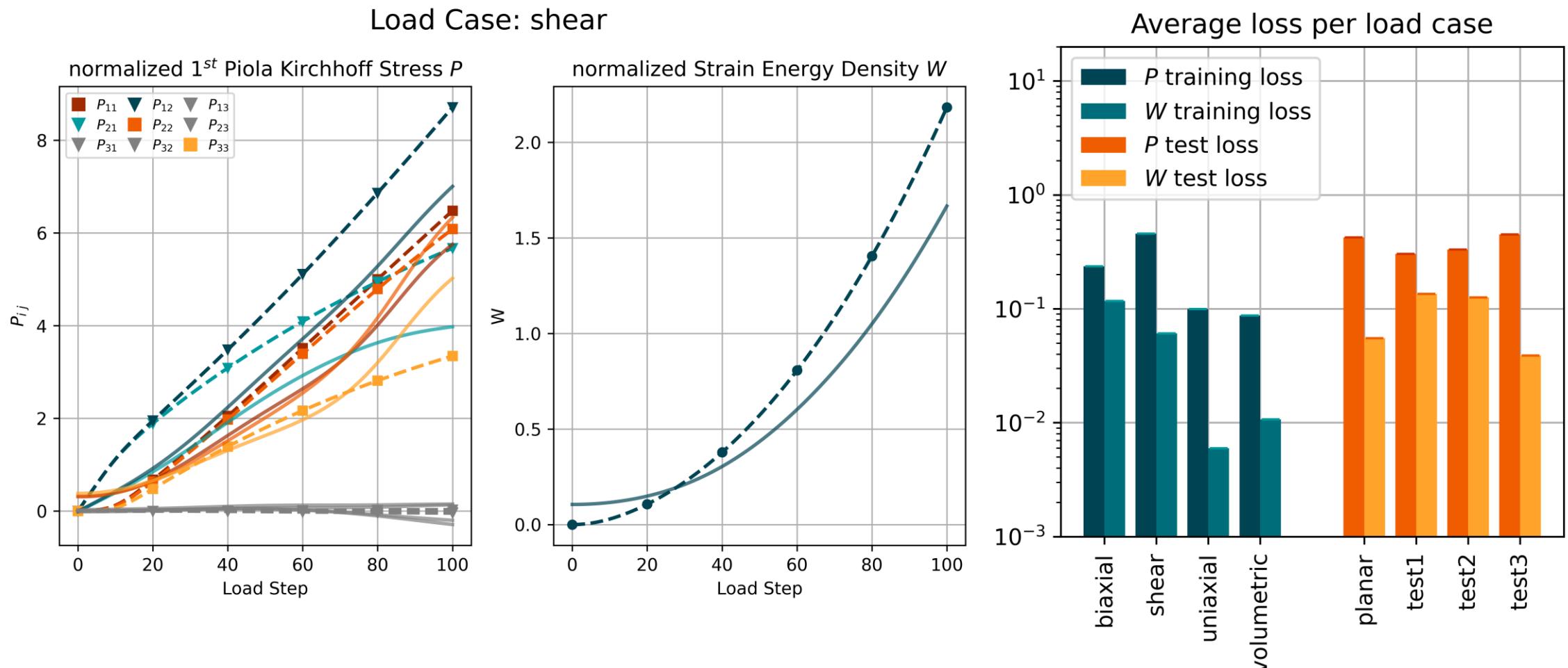


DATA AUGMENTATION

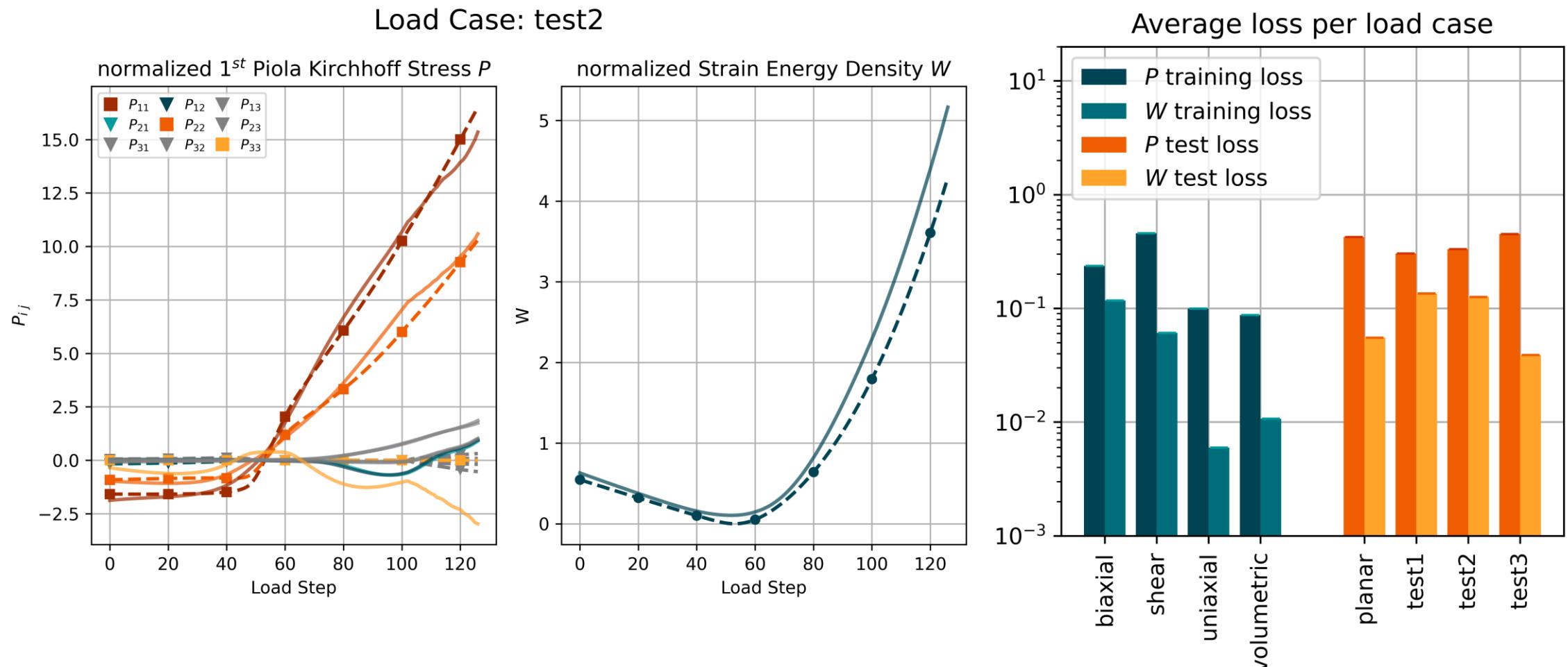
64
Observer



DATA AUGMENTATION

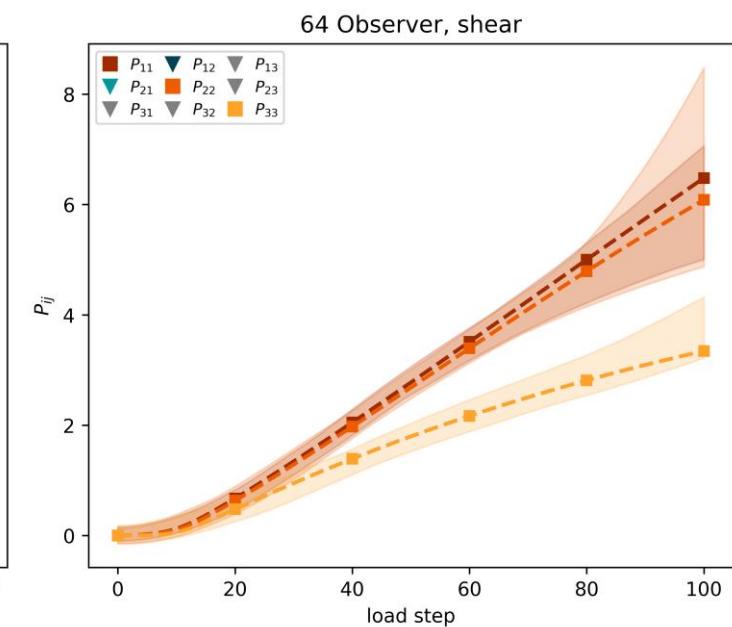
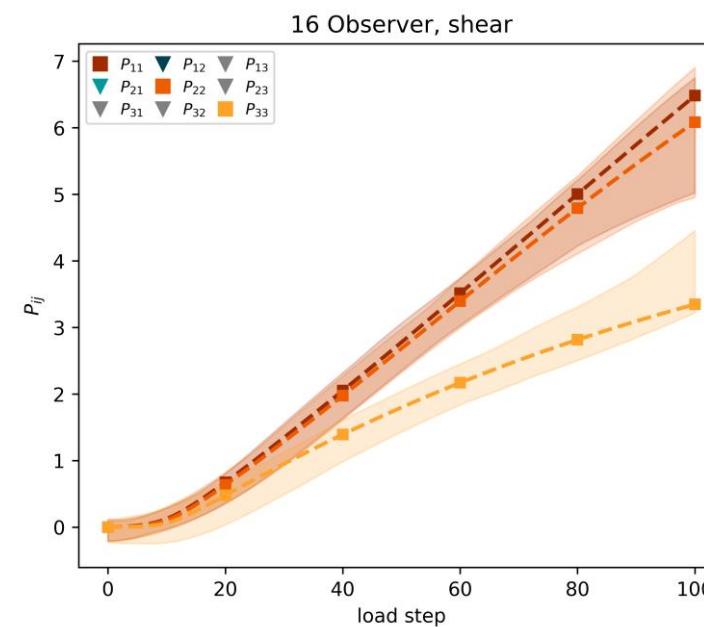
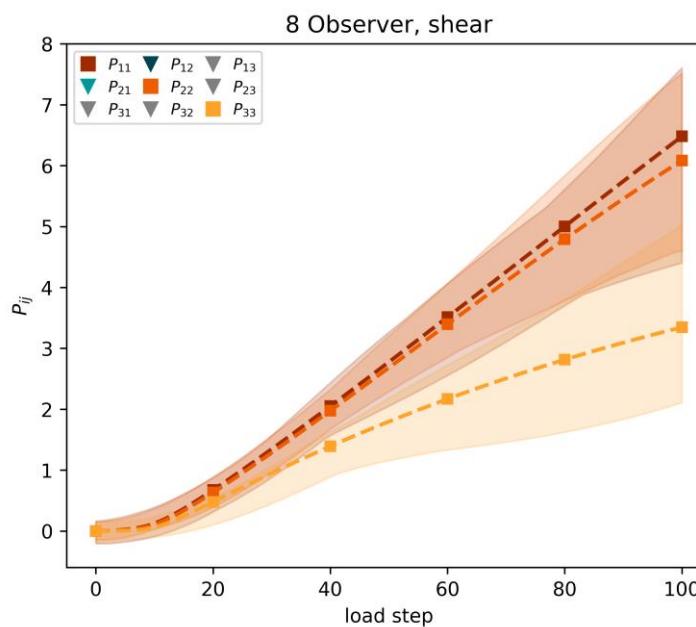


DATA AUGMENTATION



DATA AUGMENTATION OBJECTIVITY

Model trained on shear case only



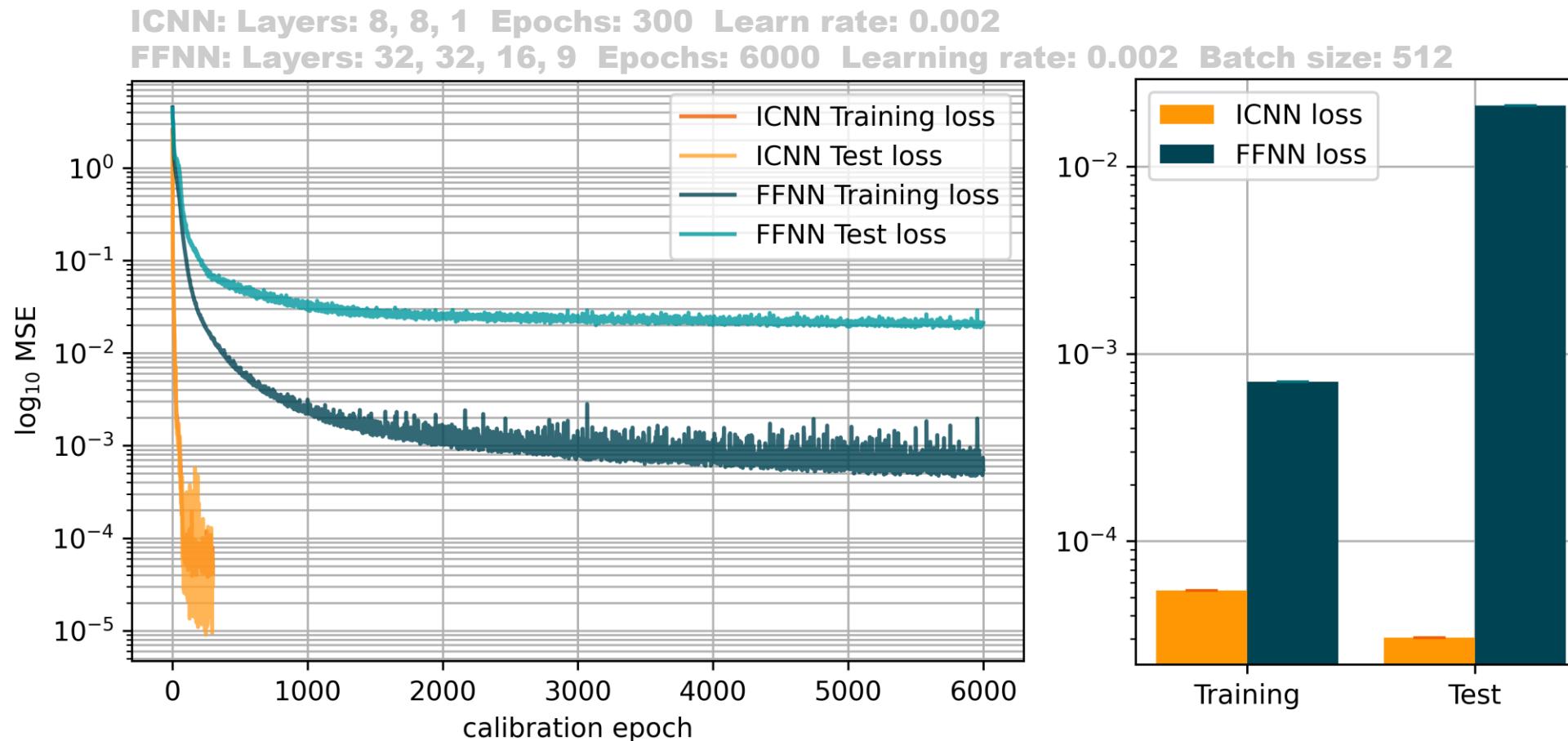
1000 Evaluation Observers



DISCUSSION

CONCENTRIC SAMPLED DEFORMATION GRADIENTS

**95/5
Split**

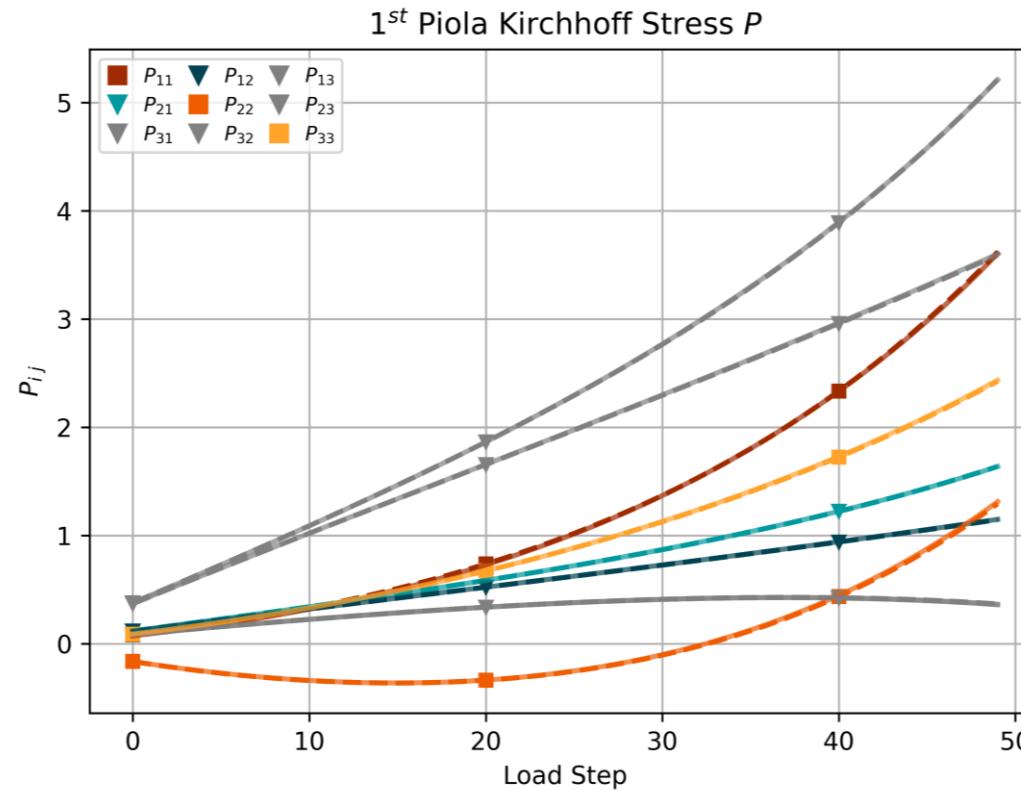


TRAINING LOAD CASE

ICNN

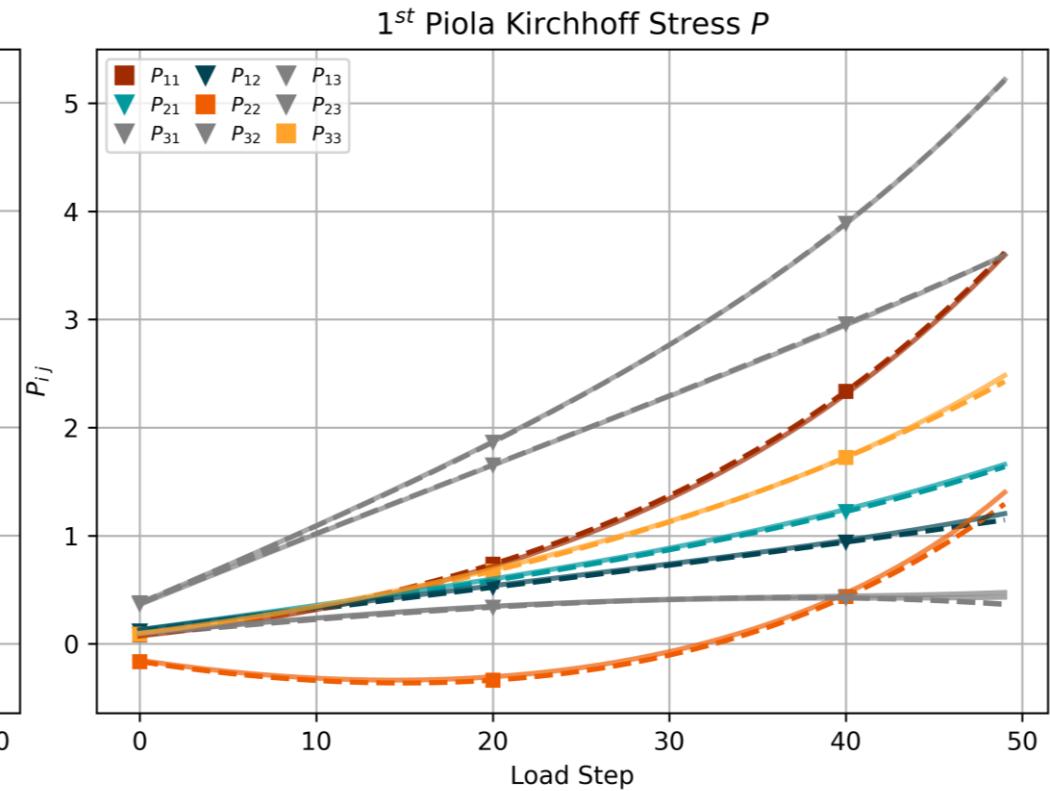
ICNN prediction for train load case 37

**95/5
Split**



FFNN

FFNN prediction for train load case 37

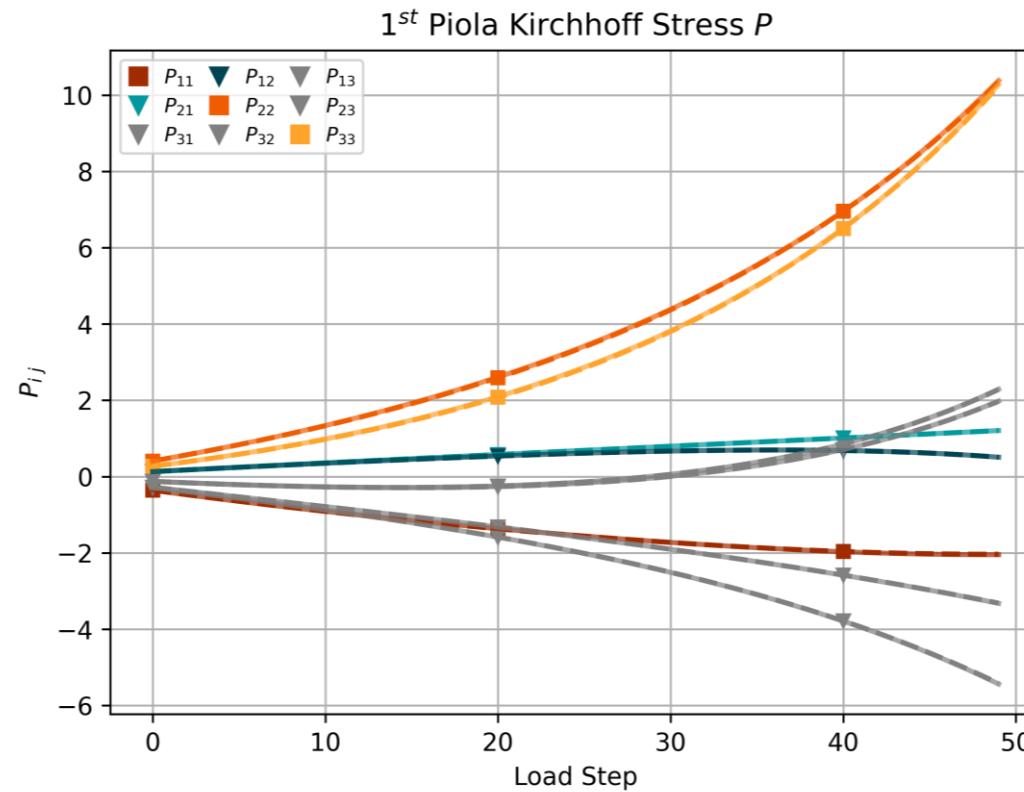


TEST LOAD CASE

ICNN

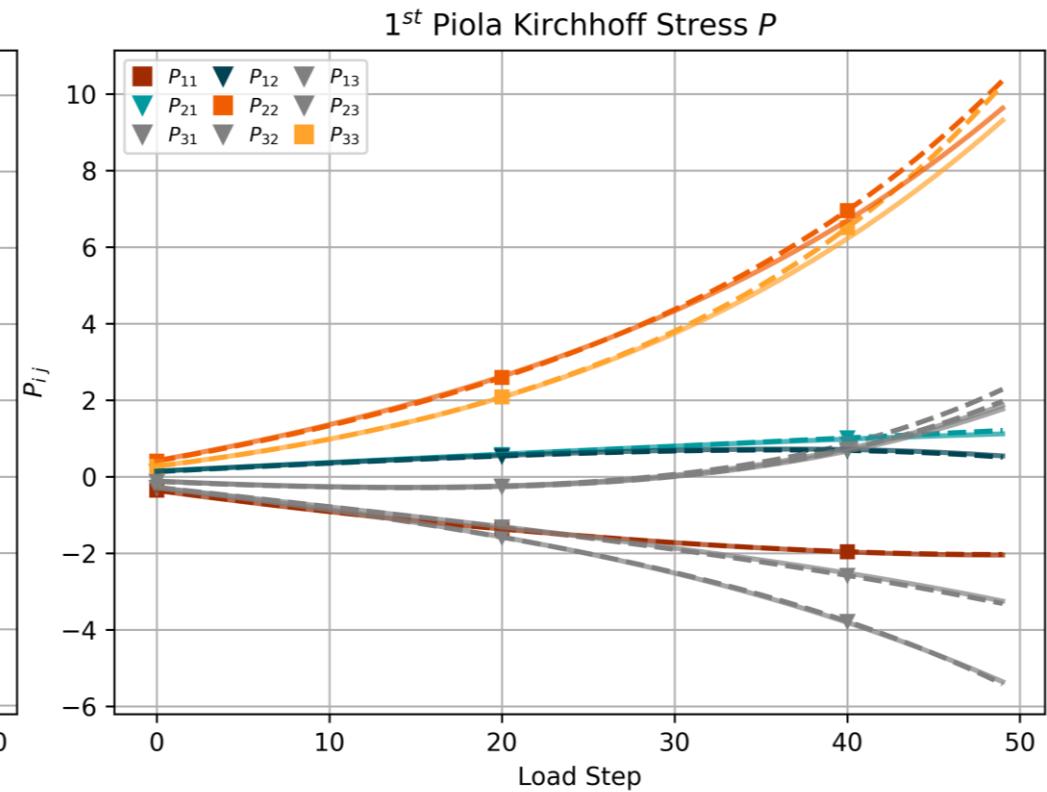
ICNN prediction for test load case 90

**95/5
Split**

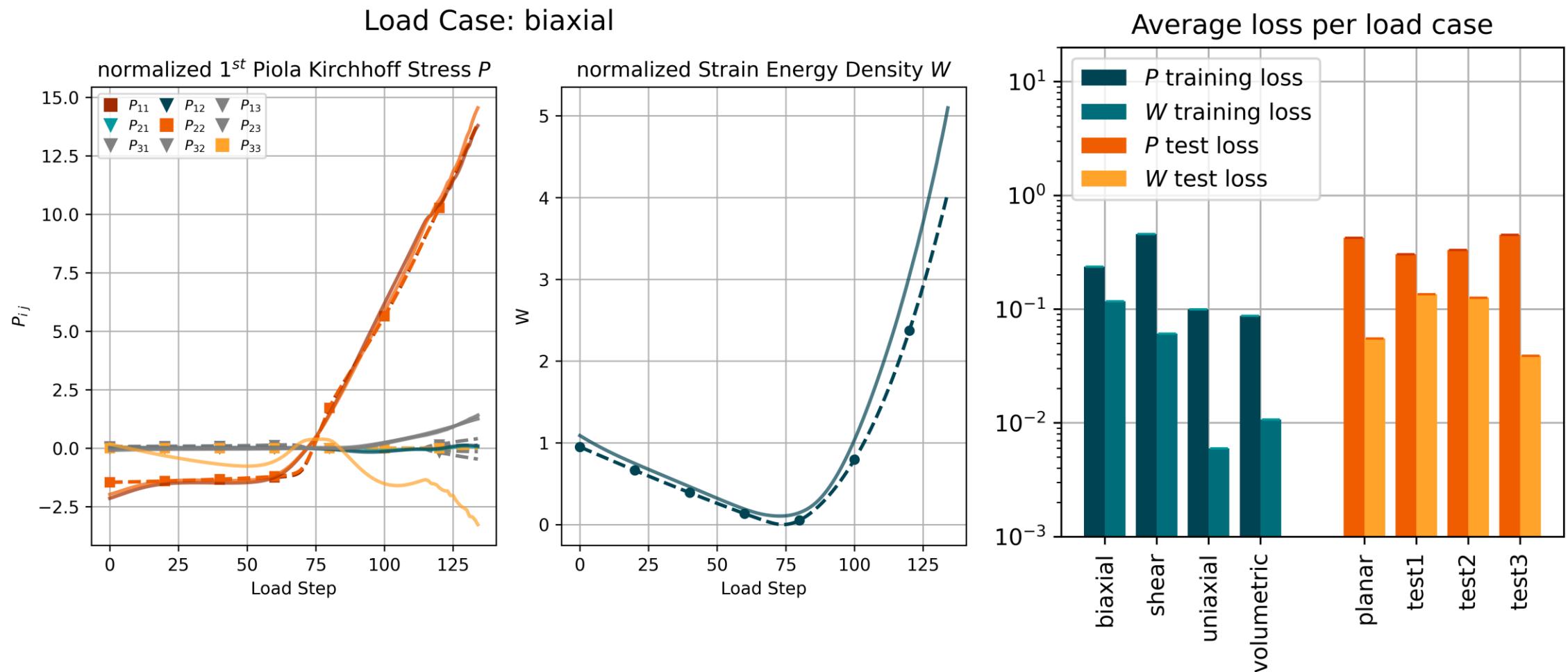


FFNN

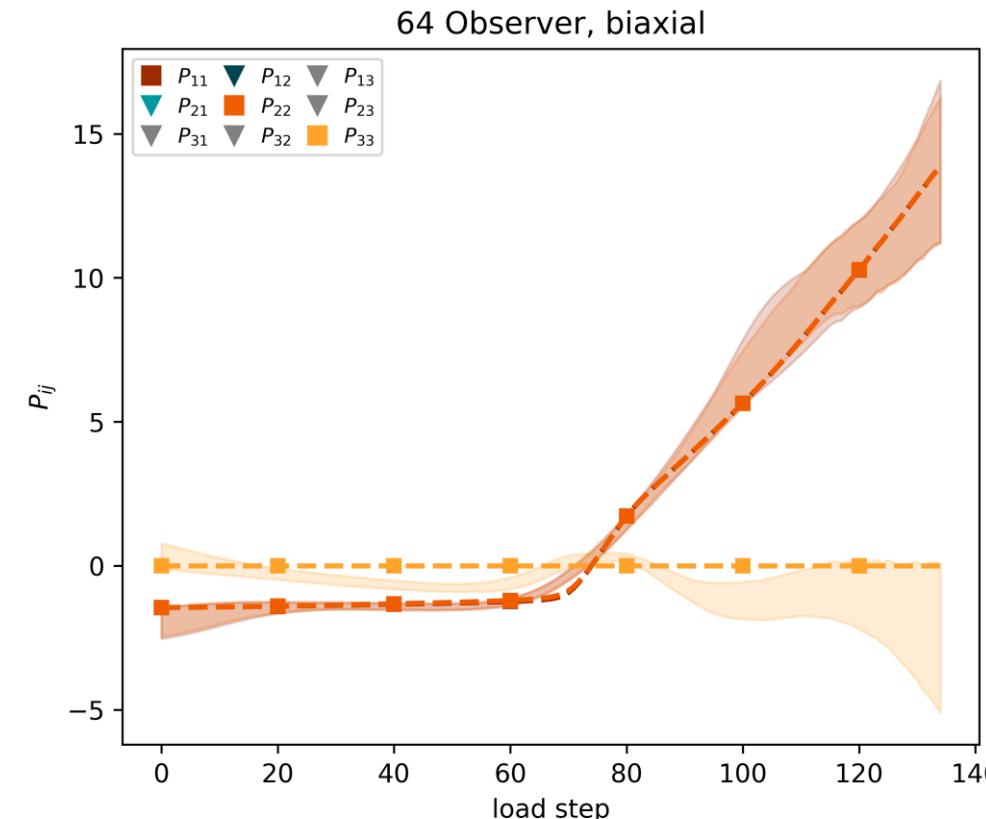
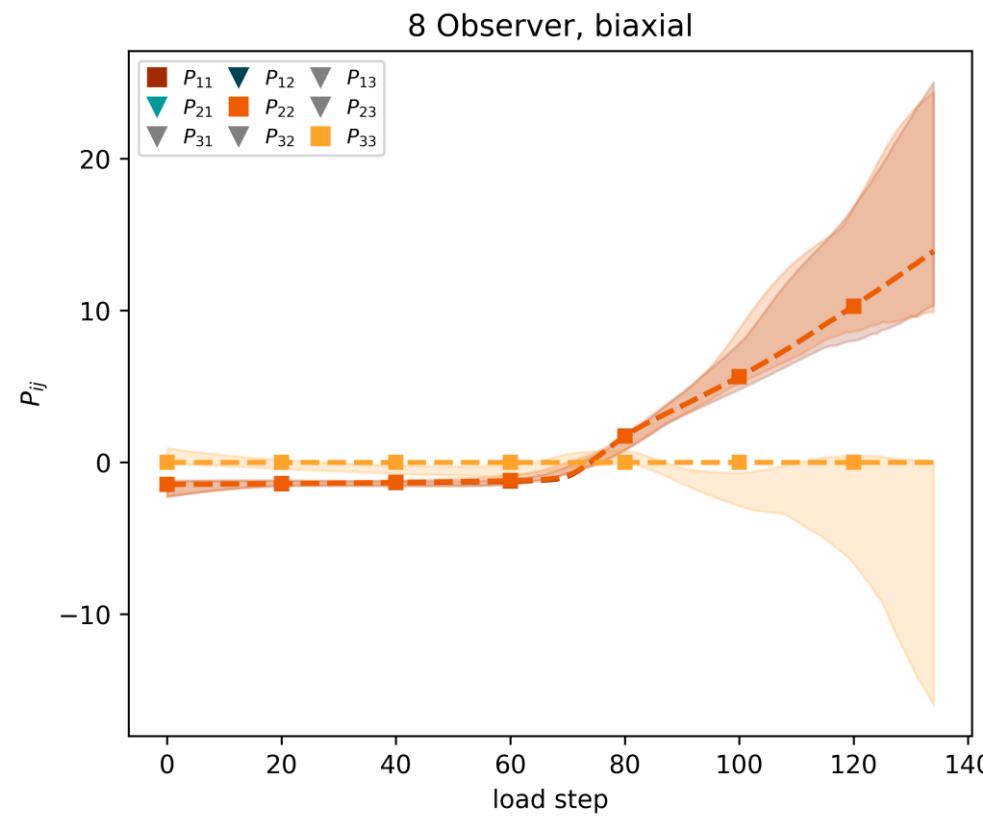
FFNN prediction for test load case 90



DATA AUGMENTATION



DATA AUGMENTATION OBJECTIVITY



DATA AUGMENTATION OBJECTIVITY

