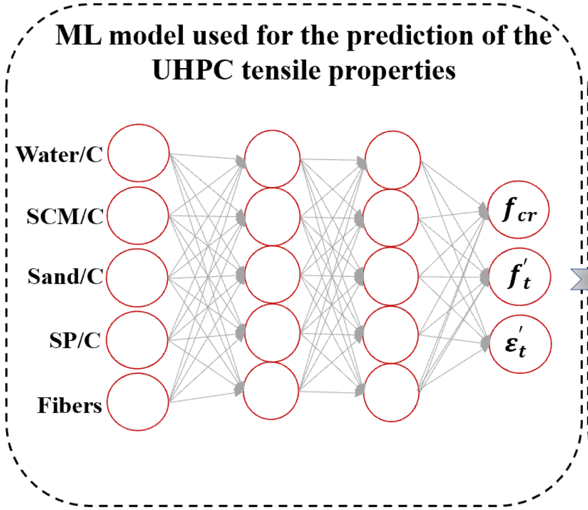
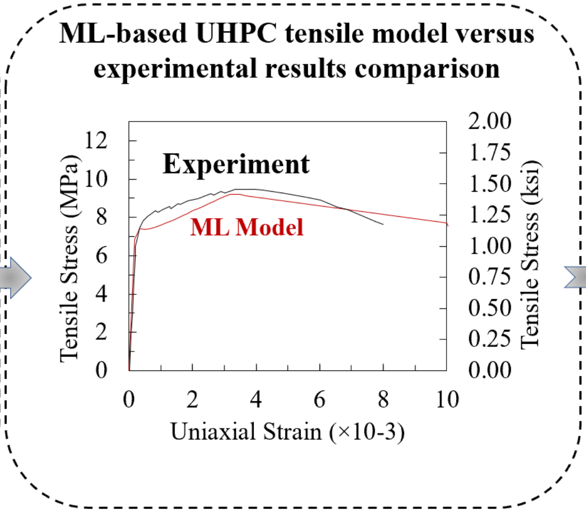
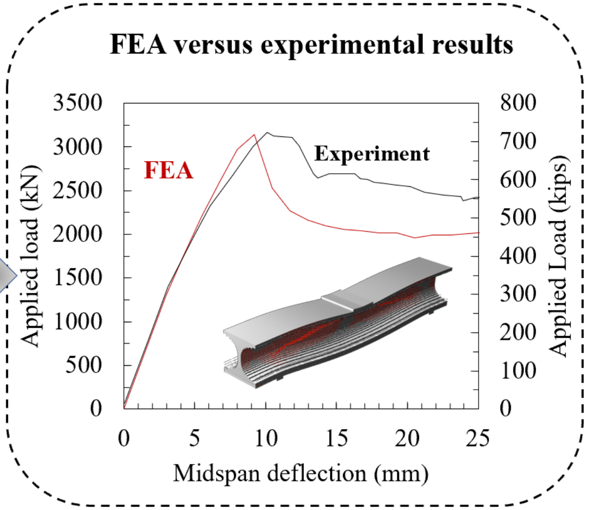
Study on the Behavior of Shear-Critical UHPC Beams Using Machine Learning and Finite Element Analysis

Amjad Diab
Anca Ferche







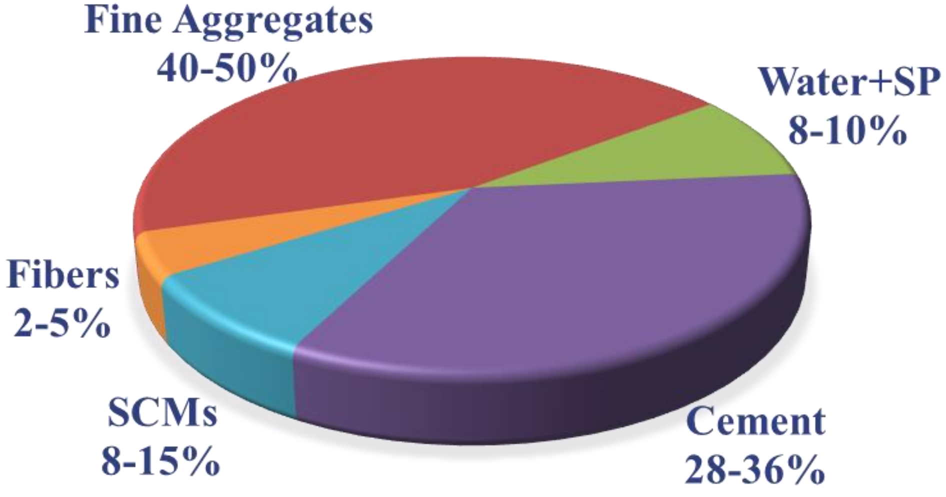
aci CONCRETE CONVENTION

THE UNIVERSITY OF TEXAS AT AUSTIN

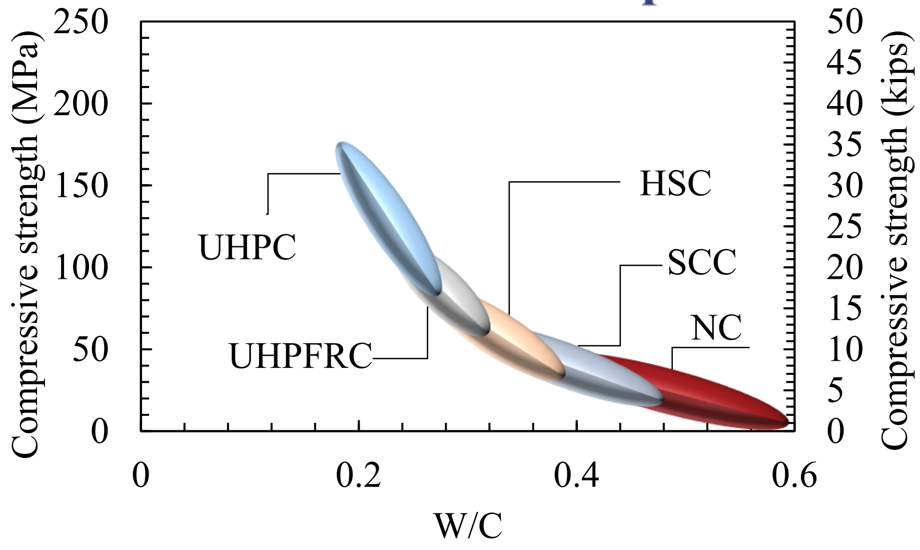
OUTLINE

1. Introduction
2. UHPC Tensile Response
3. Machine Learning Application
4. Modeling UHPC beams Using ML and FEA
5. Conclusions

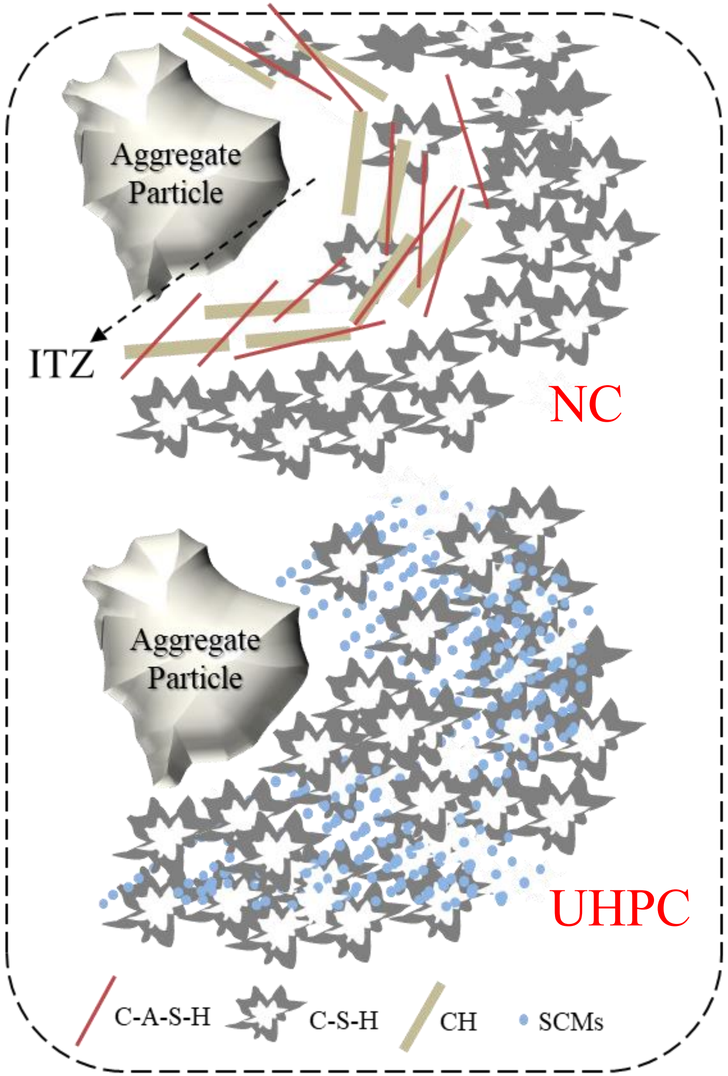
INTRODUCTION



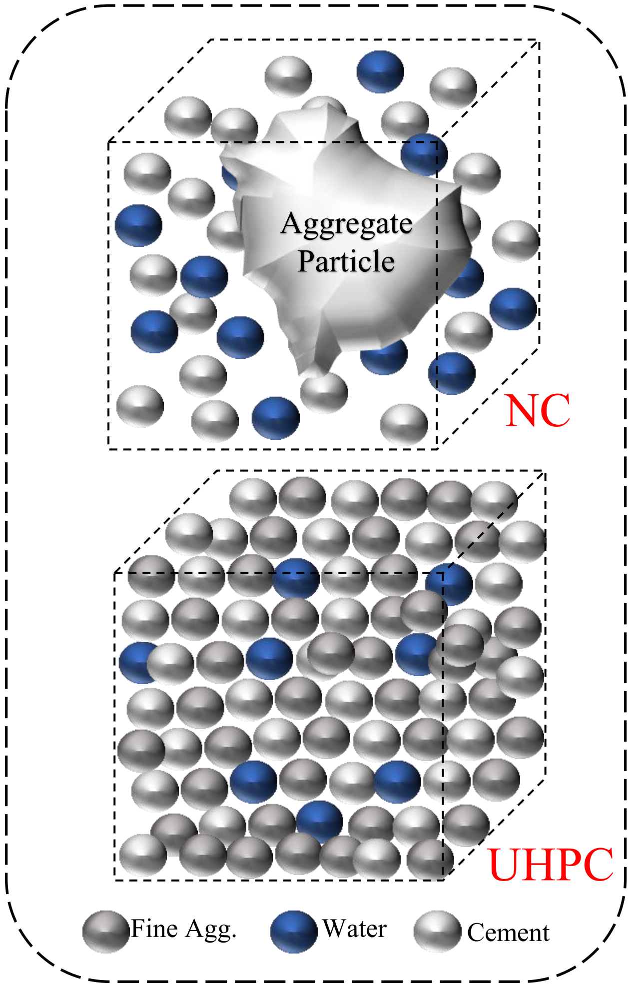
UHPC material composition



Compressive strength vs W/C ratio

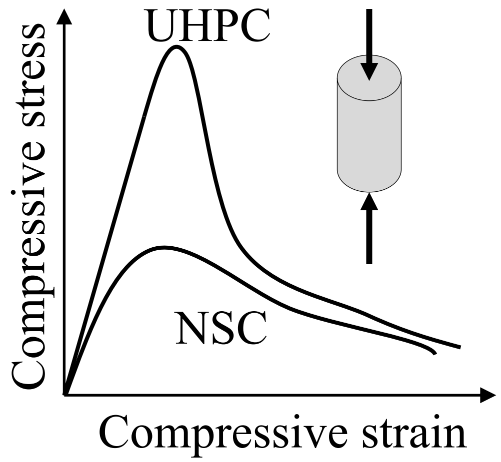


Interfacial transition zone comparison



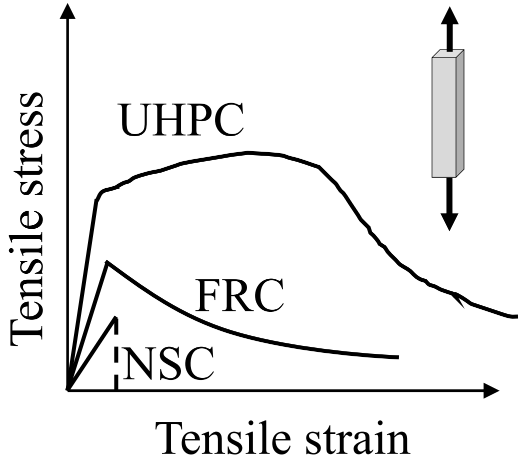
Particle packing comparison

UHPC Mechanical Properties



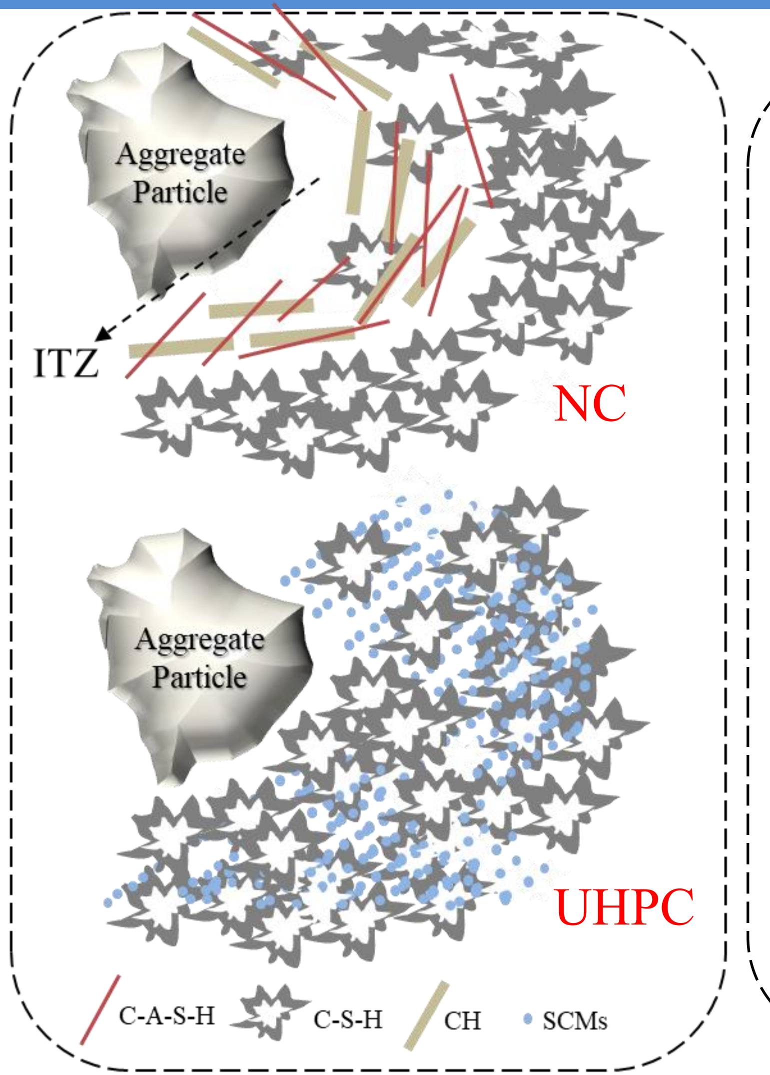
Young's modulus ↑
Prestressing loss ↓

Early compressive strength ↑
Prestressing force ↑



Tensile strength ↑
Post-cracking ductility ↑

Cracking at critical regions ↓



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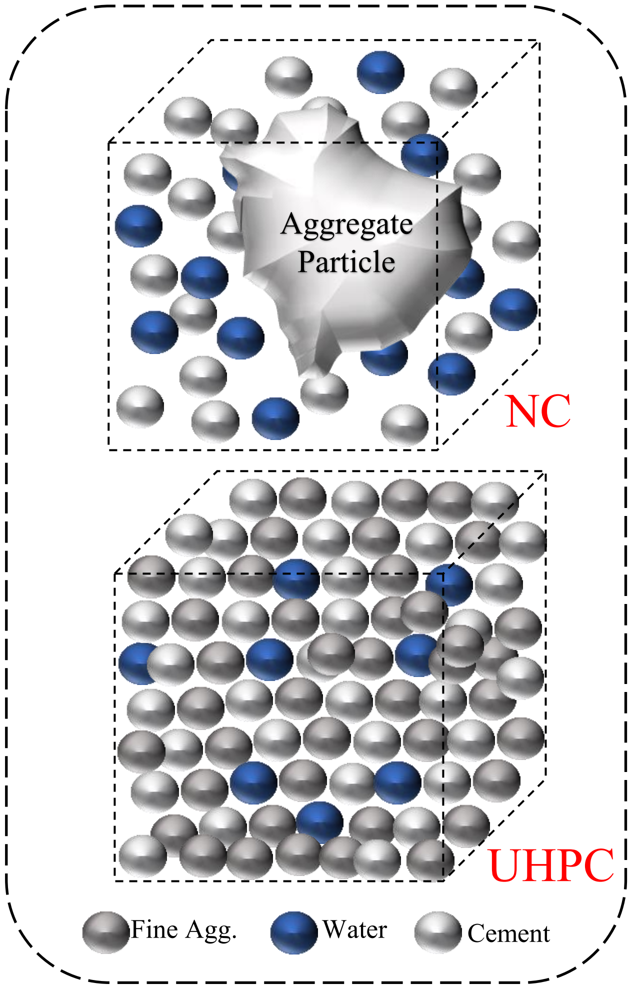
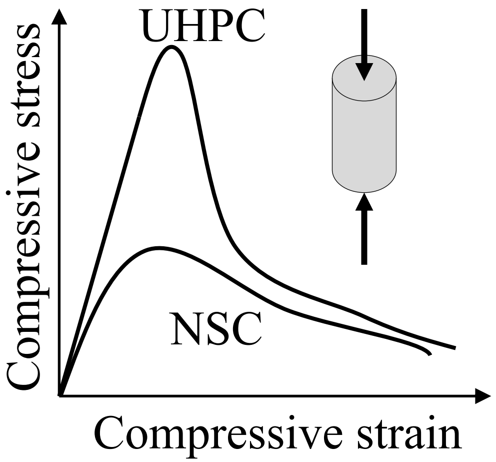


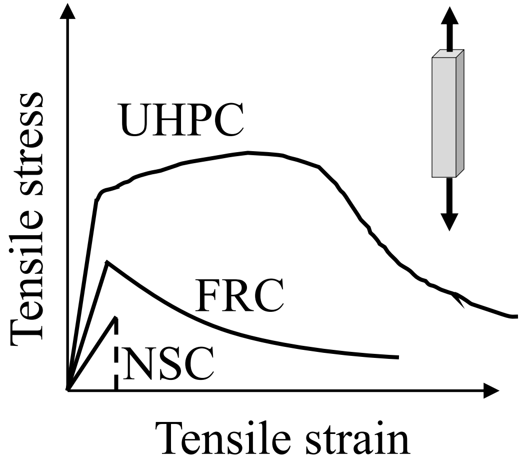
Particle packing comparison

UHPC Mechanical Properties



Young's modulus ⬆
Prestressing loss ⬇

Early compressive strength ⬆
Prestressing force ⬆

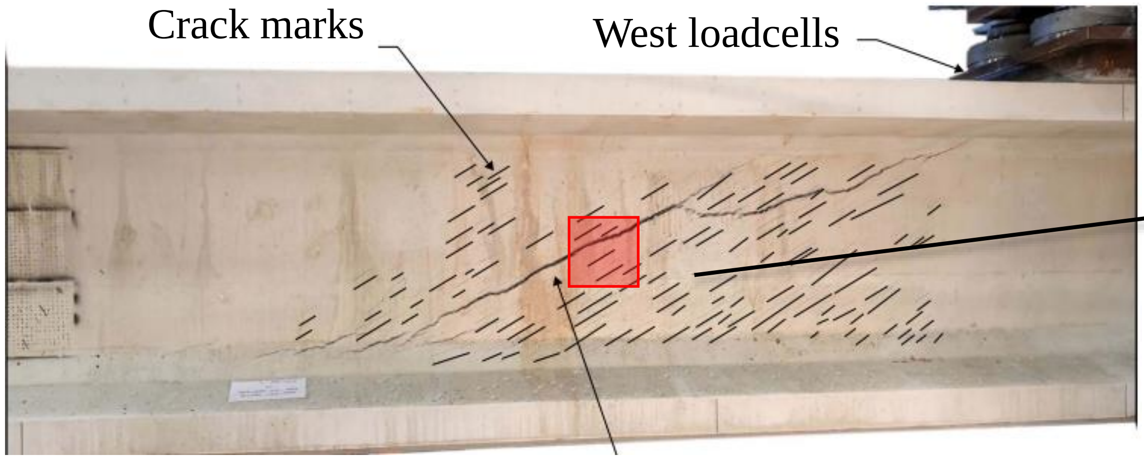


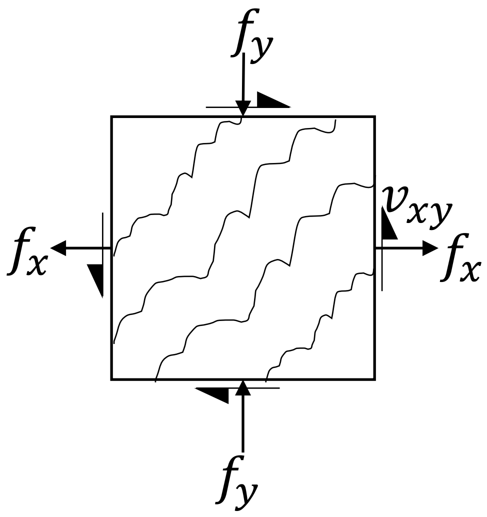
Tensile strength ⬆
Post-cracking ductility ⬆

Cracking at critical regions ⬇

Graybeal, B. (2011). UHPC in the US Highway Infrastructure. *Designing and Building with UHPFRC*, 221-234.

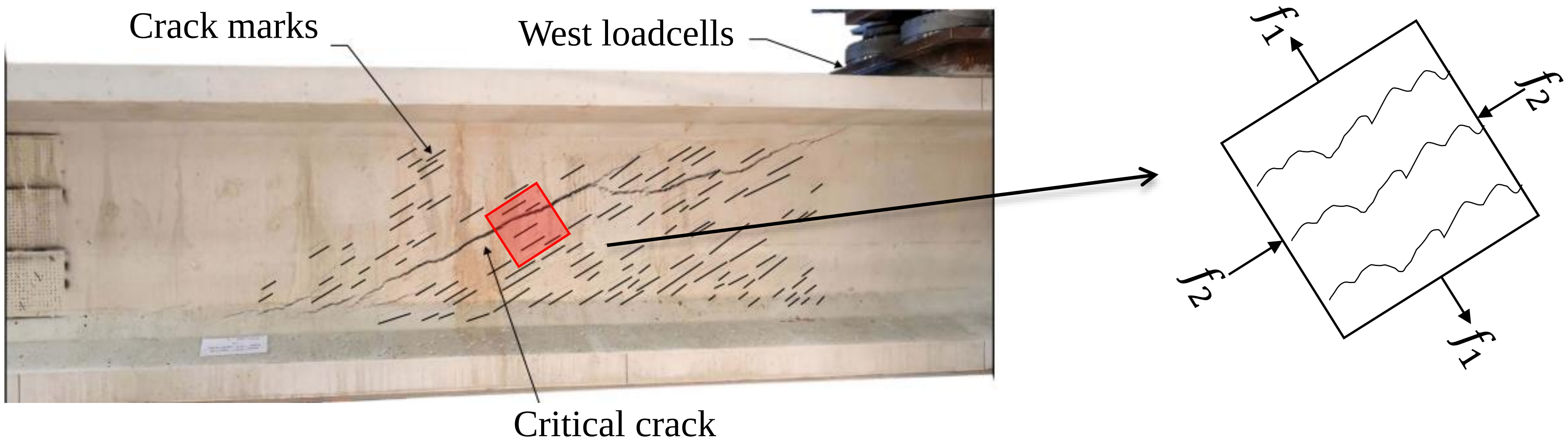
COMPLICATIONS





El-Helou, R. G., & Graybeal, B. A. (2022). Shear behavior of ultrahigh-performance concrete pretensioned bridge girders. *Journal of Structural Engineering*, *148*(4), 04022017.

COMPLICATIONS



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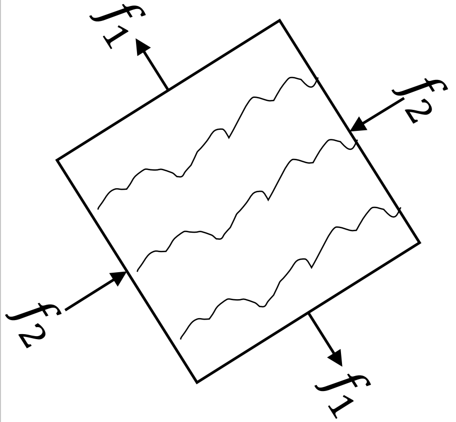
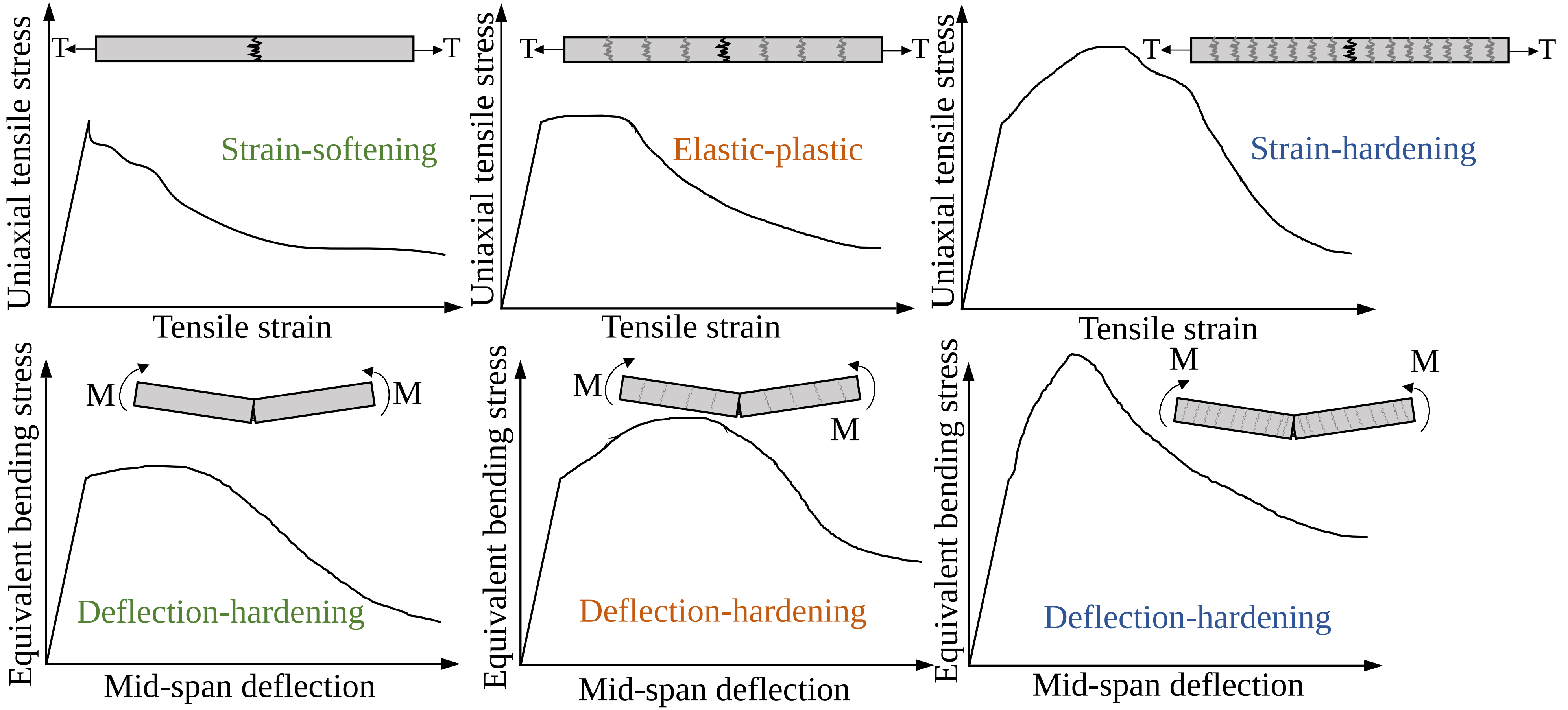
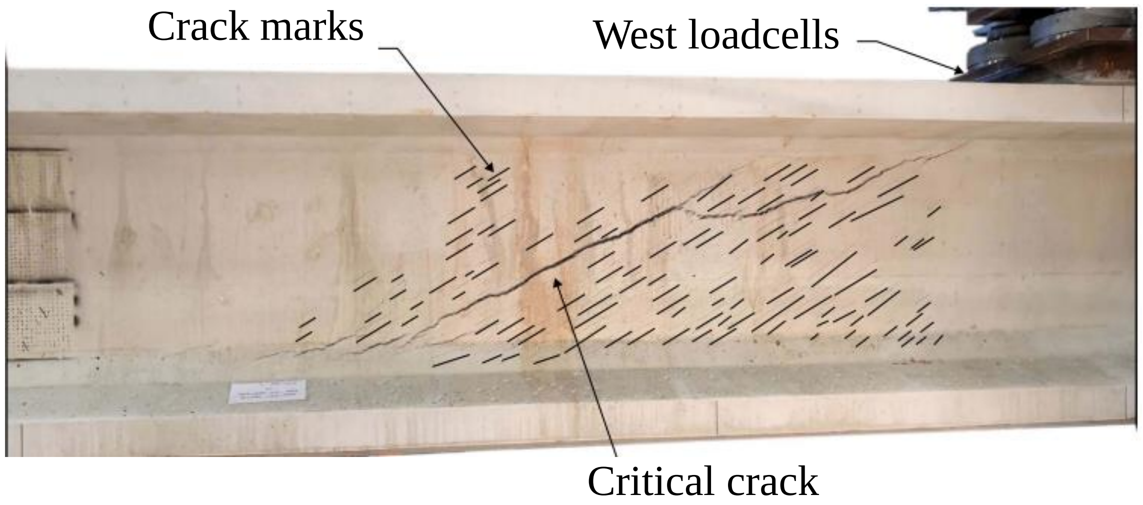
COMPLICATIONS





How can we predict the behavior?
Which test has consistent results?

UHPC Tensile Response Characteristics



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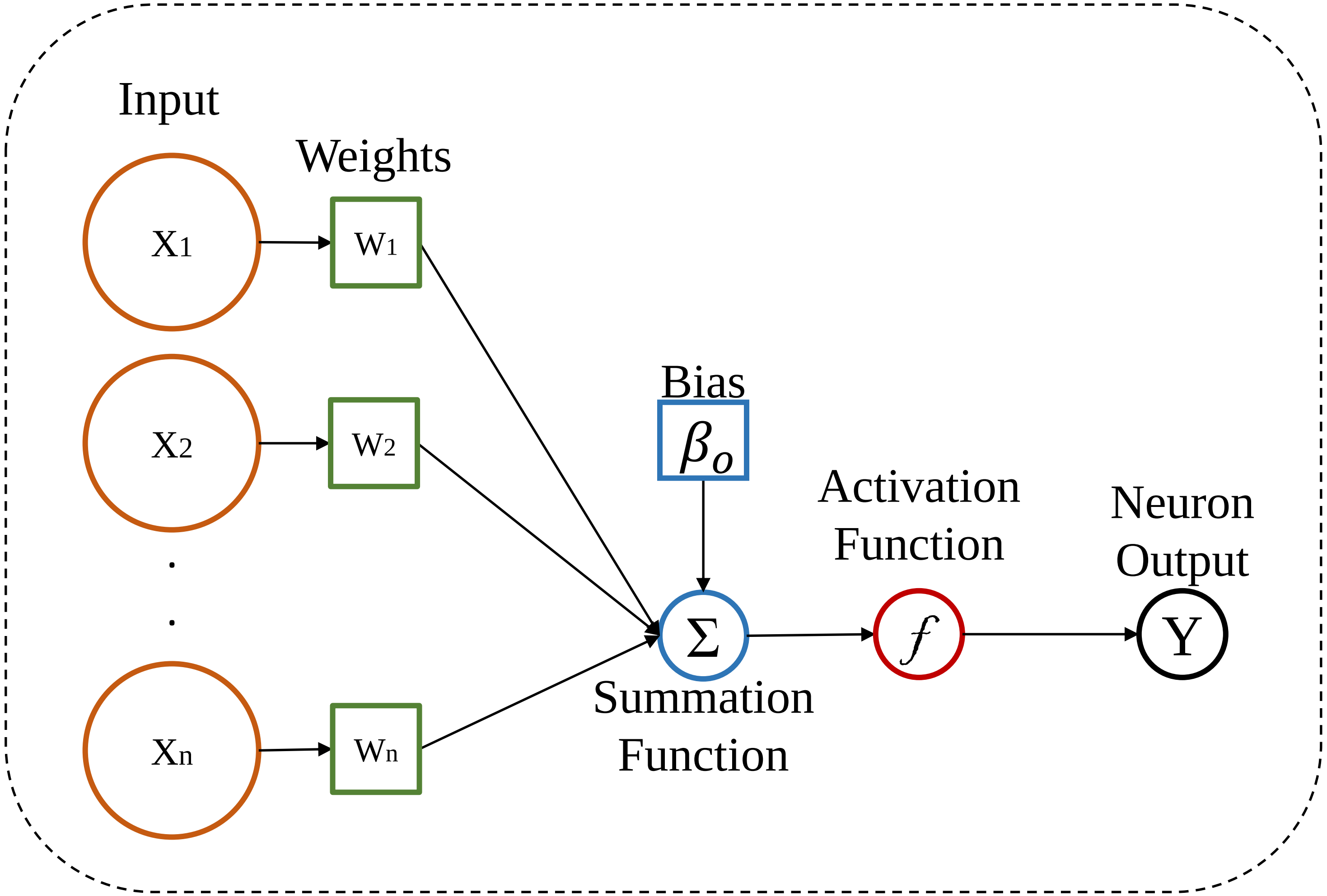
Evaluating the tensile strength of UHPC:

- Equation based on the compressive strength (Not applicable)!
- Equation based on fiber reinforcement content (Not applicable)!
- Interrelationship between UHPC constituents
- Emergence of new fiber types and alternative SCMs

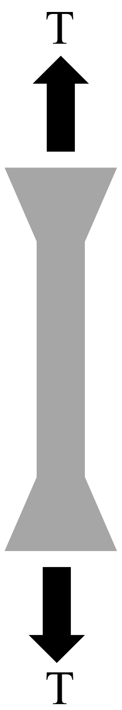
New technique to predict the tensile behavior of UHPC that can be updatable to keep up with emerging UHPC mixes

Machine Learning

- ✓ Analyze complex relationships
- ✓ Map interrelationships between input parameters
- ✓ Updatable based on the training datapoints



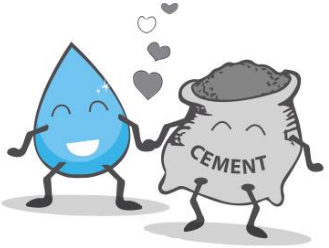
MACHINE LEARNING

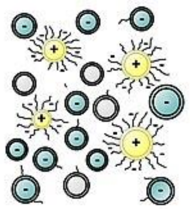


SCMs

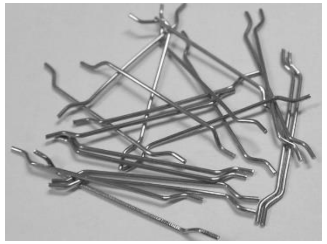
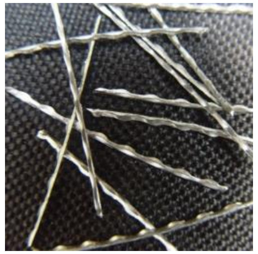


W/C & SP





Steel fibers

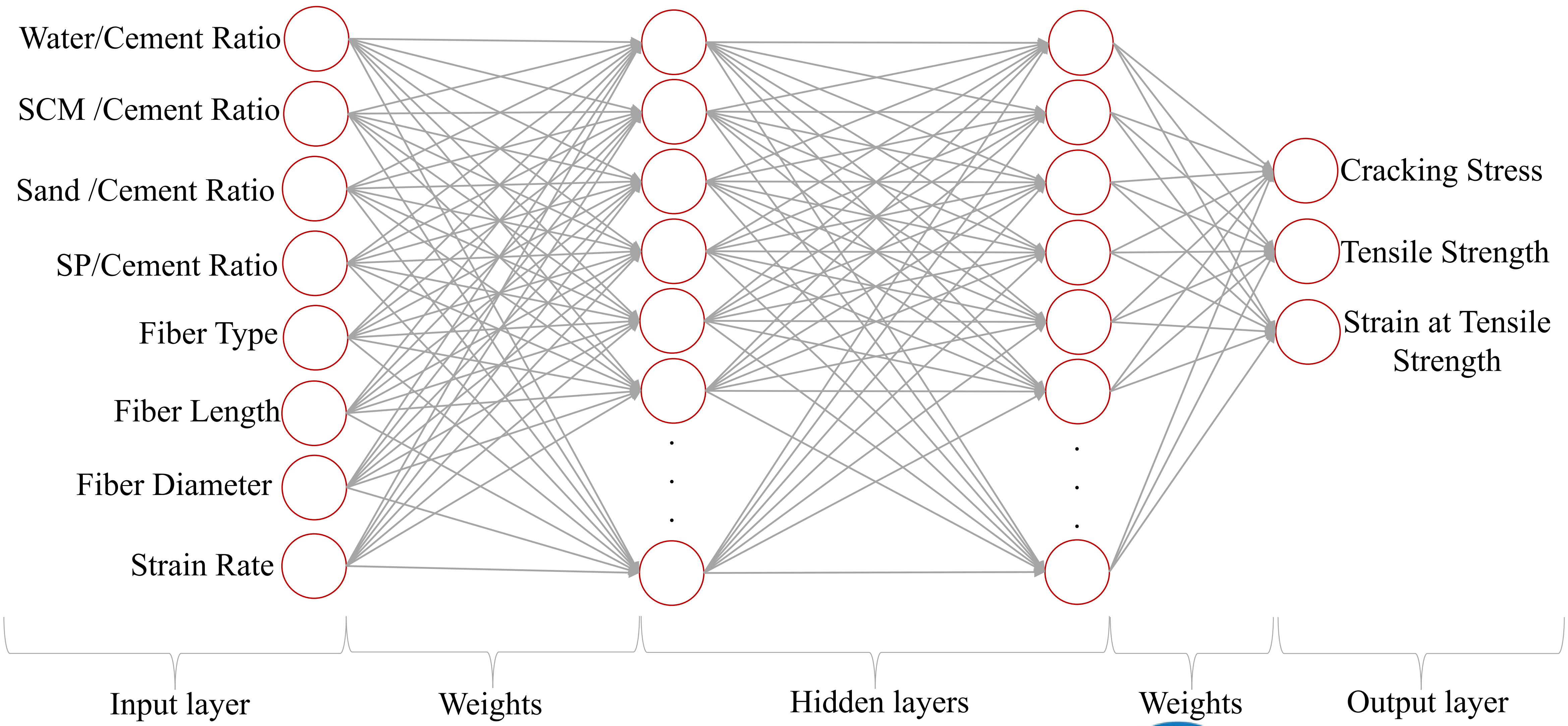




PE fibers

575 Datapoints

Train | Test

ARTIFICIAL NEURAL NETWORK

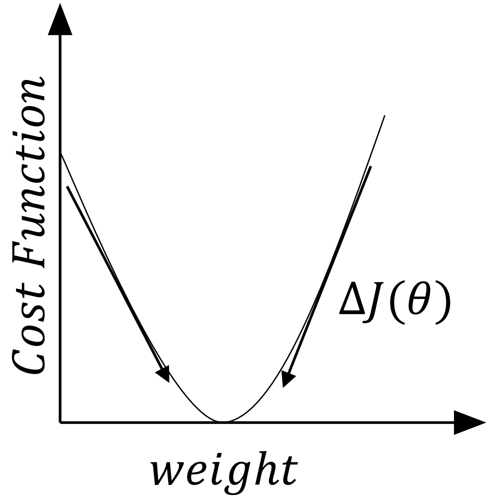


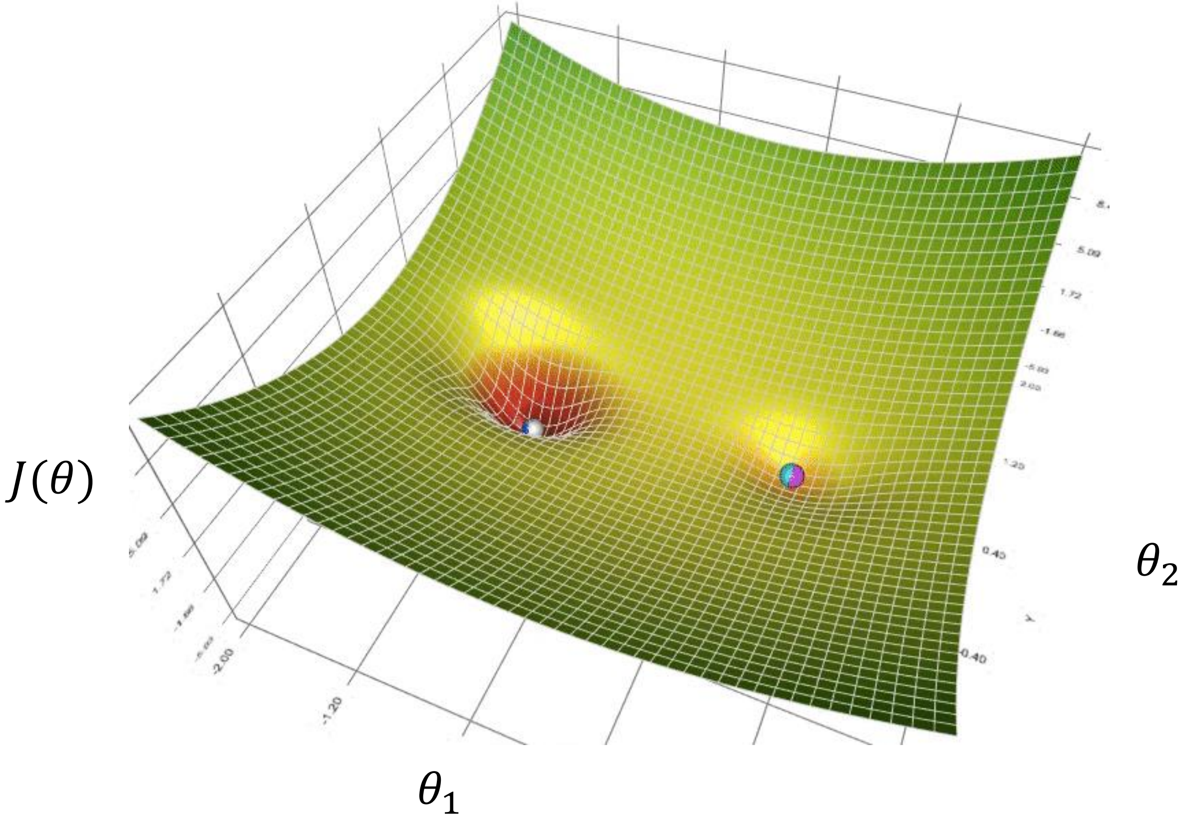
Gradient Descent

$$RMSE = \frac{1}{n}\sum_{1}^{n}(y - y^i)^2$$

$$Cost\ Function = \frac{1}{2n}\sum_{1}^{n}(y - y^i)^2$$

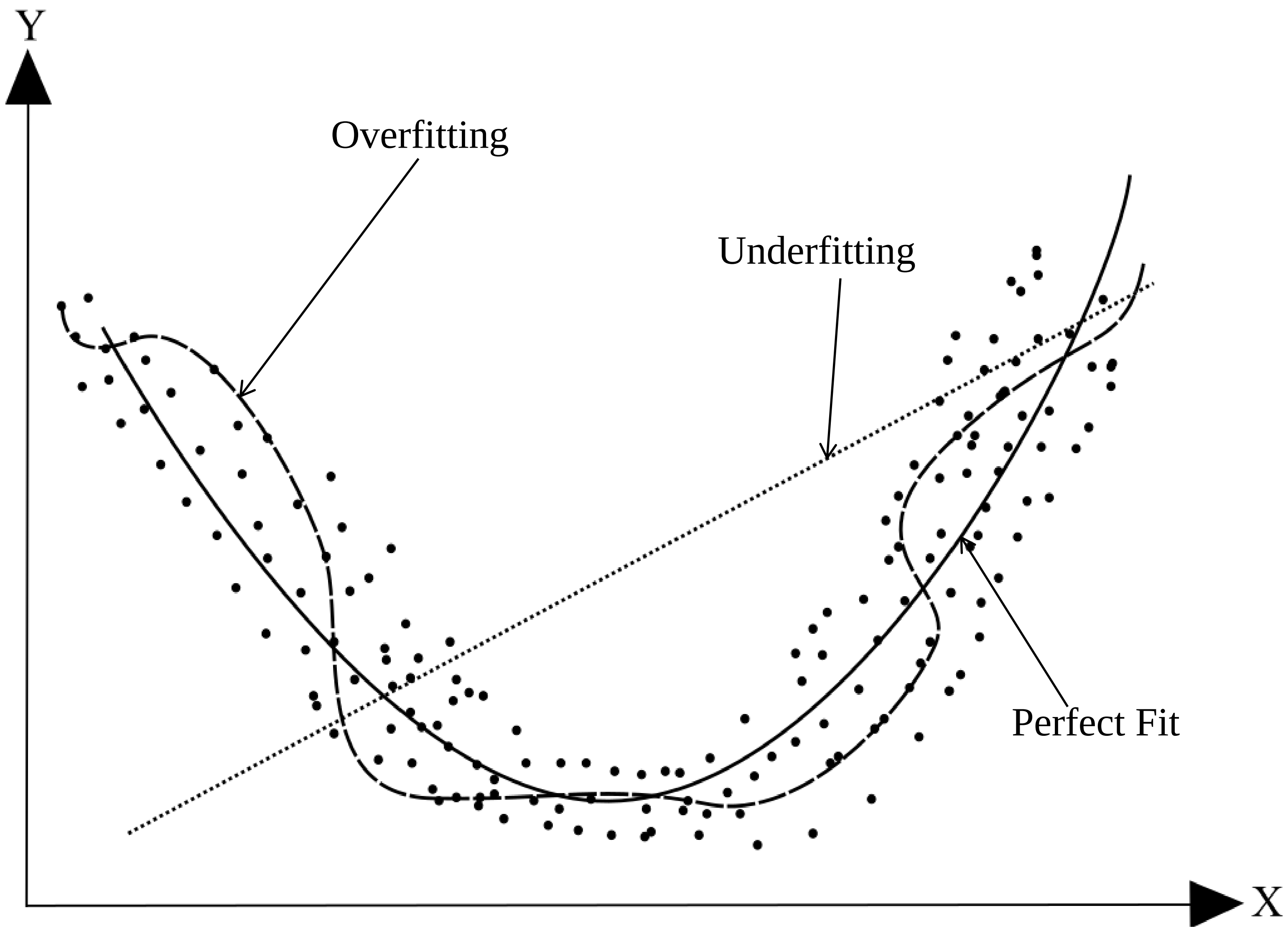
$Goal: Minimize\ cost\ function$





$$\theta_n = \theta_n - J(\theta_n)$$

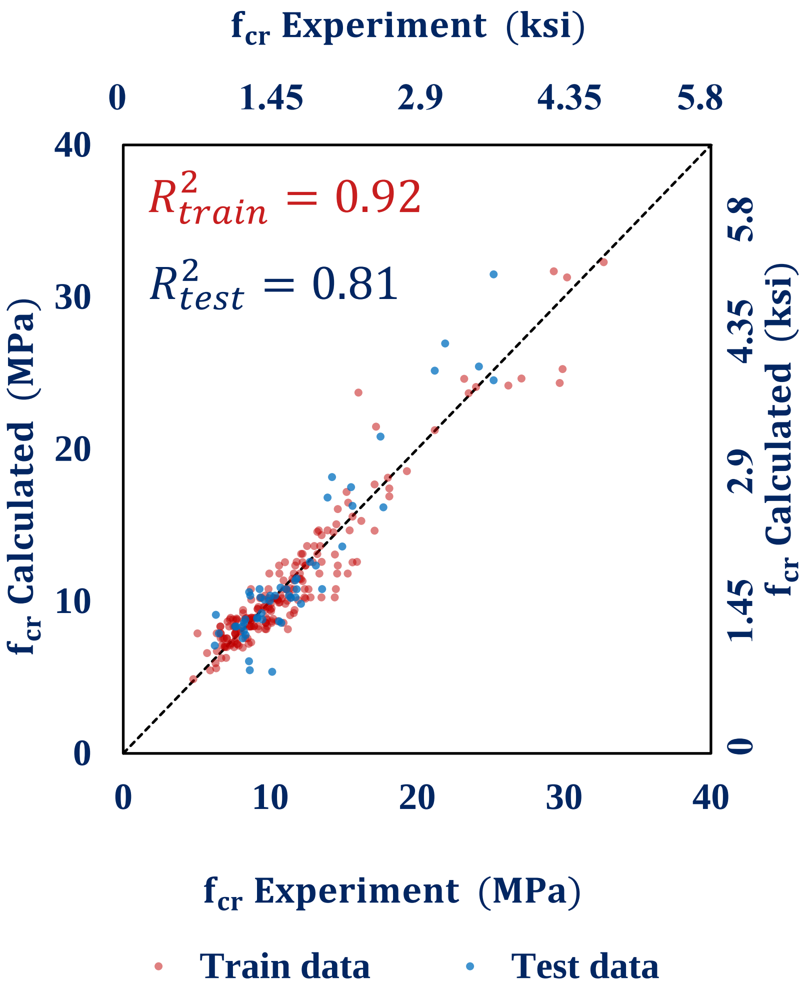
UNDERFITTING & OVERFITTING

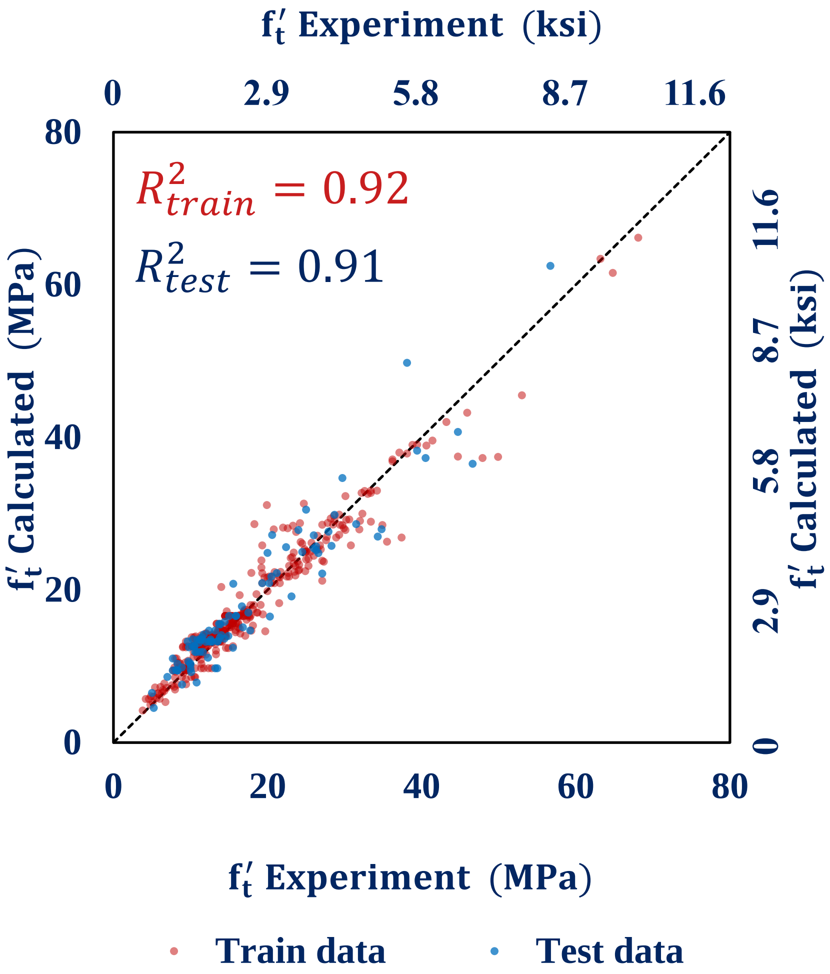


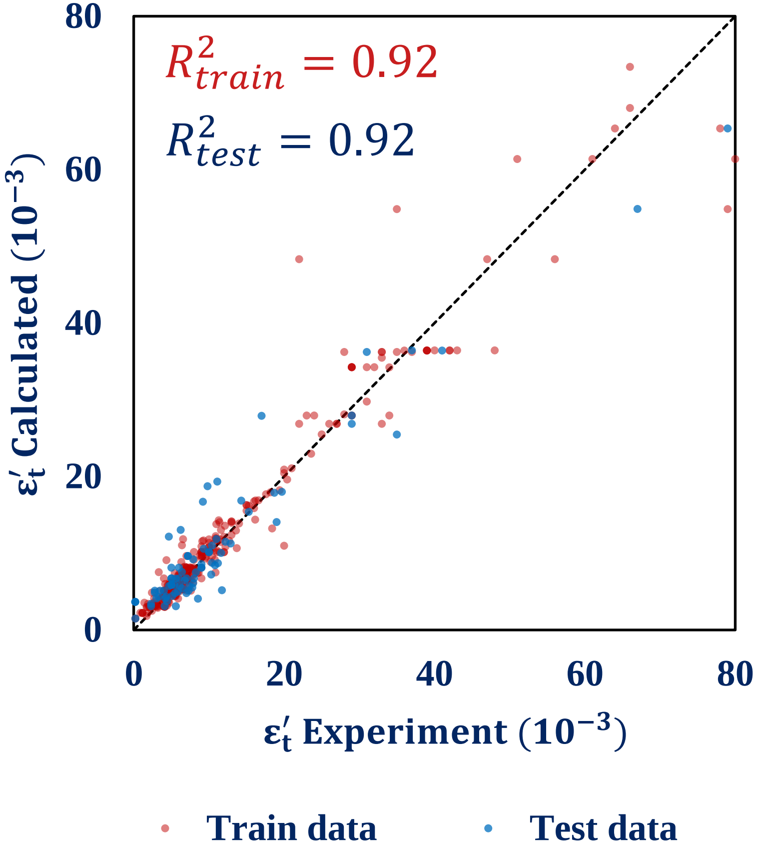
Avoiding overfitting

- ✓ Data segmentation
- ✓ Eliminating random data segmentation

Predicting the Tensile Response of UHPC



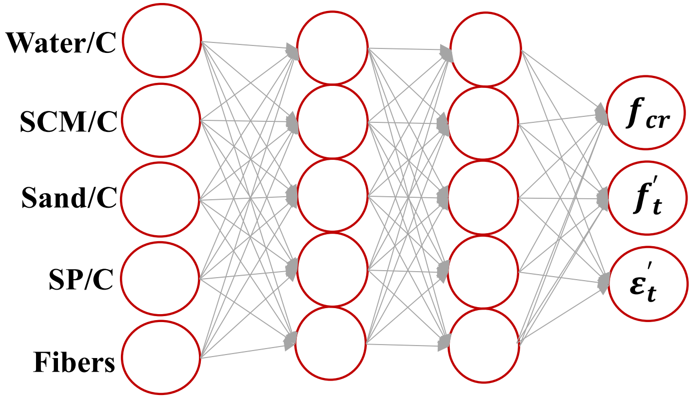




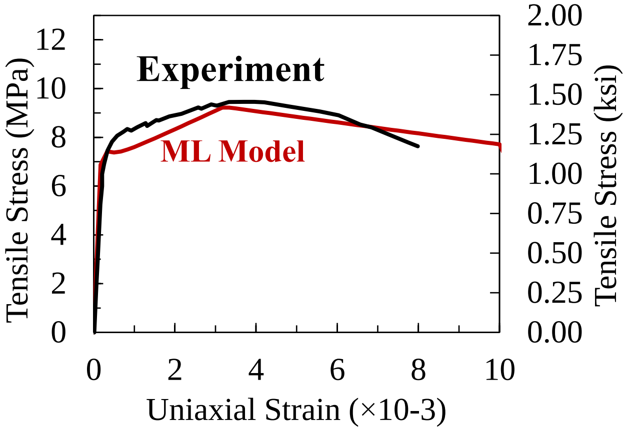
Modeling UHPC Beams Using ML and FEA

Increased our ability to model beams tested in the literature!

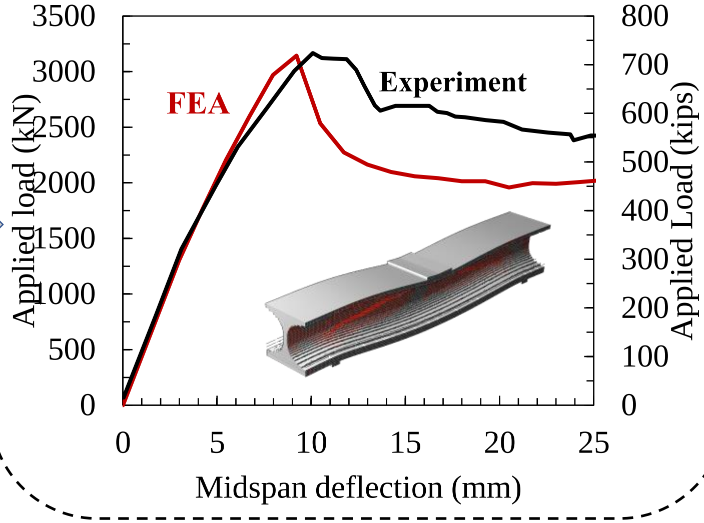
ML model used for the prediction of the UHPC tensile properties



ML-based UHPC tensile model versus experimental results comparison

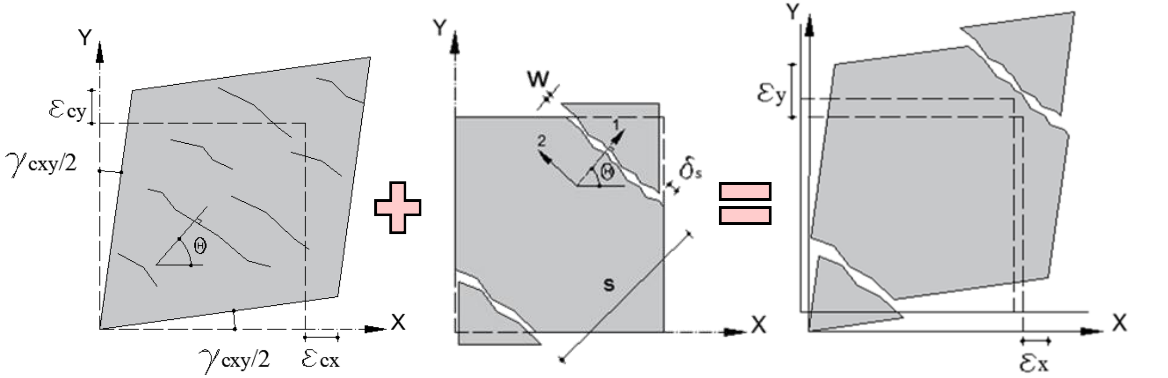


FEA versus experimental results



Finite Element Analysis: Methodology

Compatibility requirements



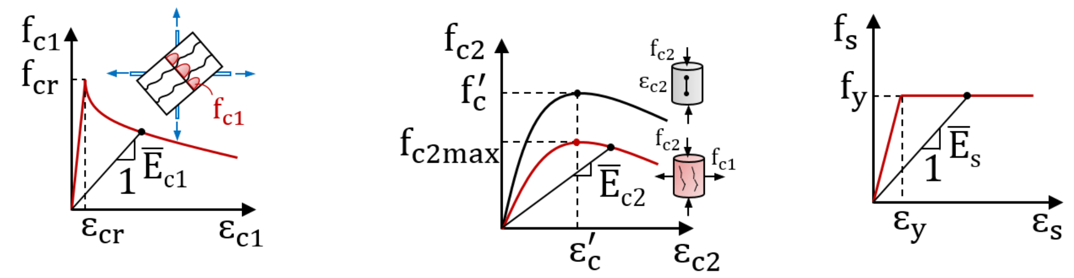
Deformation due to the average constitutive response

Crack shear slip deformation

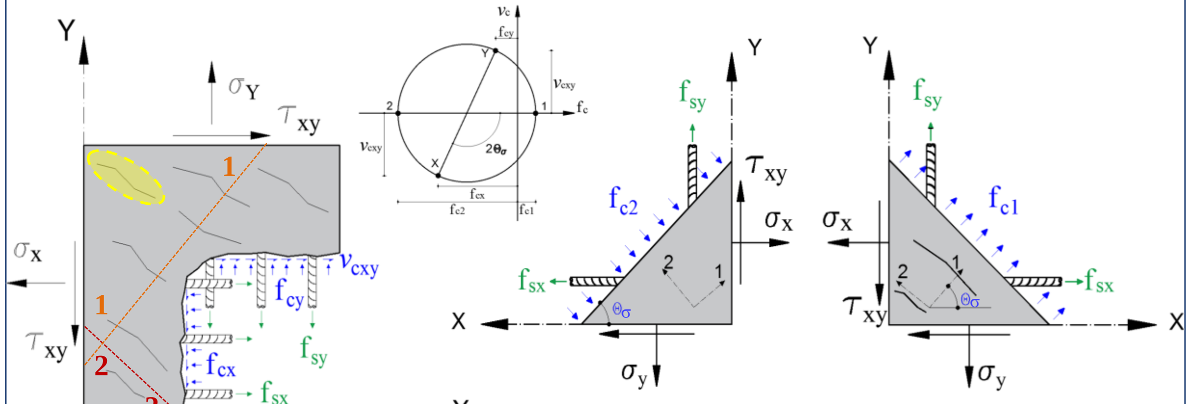
Total deformation

Constitutive relationships

UHPC in tension *UHPC in compression* *Reinforcement response*



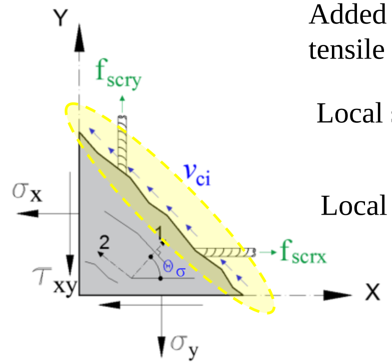
Equilibrium in terms of average stresses



Section 1-1

Section 2-2

Equilibrium in terms of local stresses at a crack



Added local strain in the principal tensile direction: $\varepsilon_{1cr} = \varepsilon_1 + \Delta\varepsilon_{1cr}$

Local strain in the reinforcement: $\varepsilon_{scr.i} = \varepsilon_{s.i} + \Delta\varepsilon_{1cr} \cdot \cos^2\theta_{n.i}$

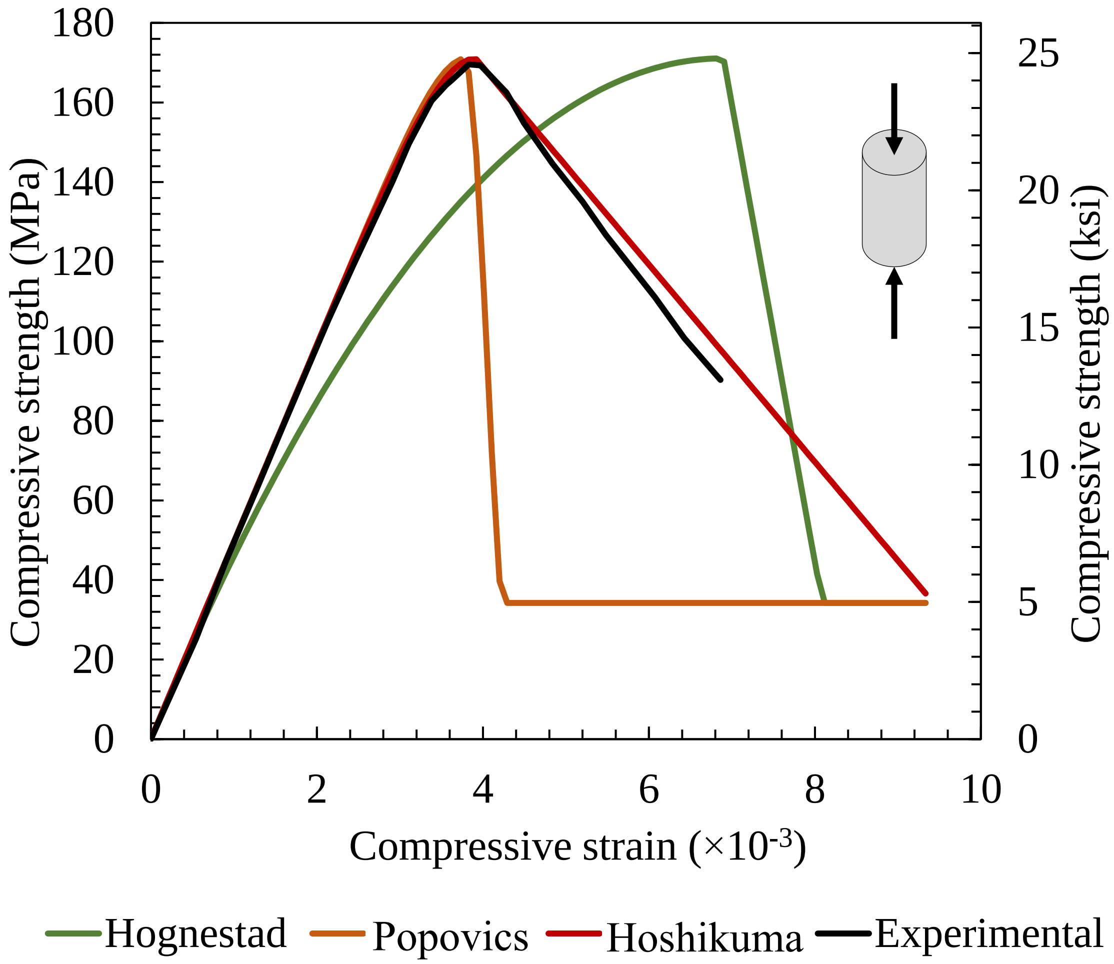
Local stress in the reinforcement: $f_{scr.i} = E_s \cdot \varepsilon_{scr.i} < f_{y.i}$

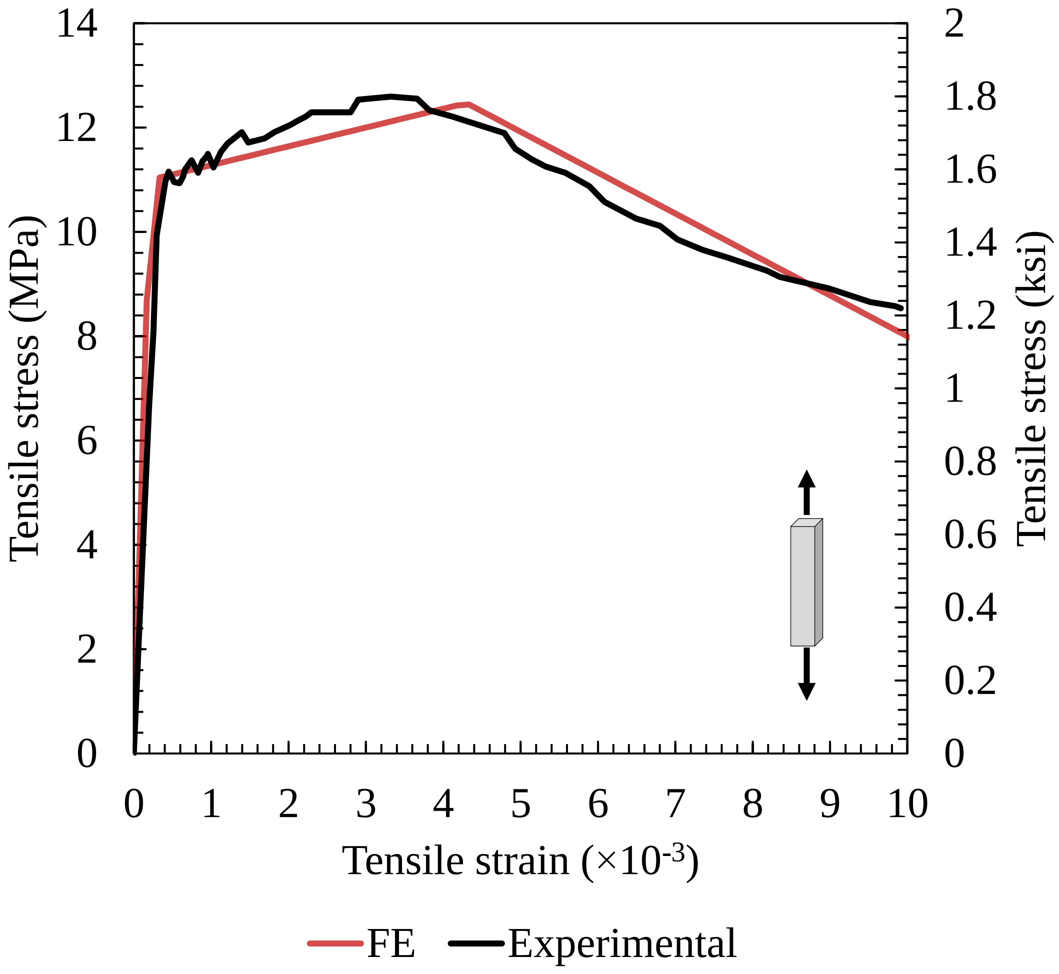
FINITE ELEMENT ANALYSIS

BEHAVIORAL MODELS EMPLOYED

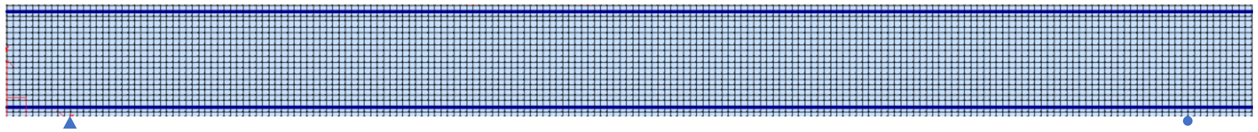
Concrete Models			
Compression Pre-Peak	Hoshikuma	**Dilation**	Variable-Kupfer
Compression Post-Peak	Hoshikuma	**Cracking Criterion**	Mohr-Coulomb (Stress)
Compression Softening	Vecchio 1992-A	**Crack Stress Calculation**	Basic (DSFM/MCFT)
Tension Stiffening	Lee 2010	**Crack Width Check**	10 mm max crack width
Tension Softening	Custom input (ML)	**Crack-Slip Calculation**	Walraven
FRC Tension	-	**Creep and Relaxation**	Not Considered
Confined Strength	Kupfer / Richart	**Hysteretic Response**	Nonlinear w/ Plastic offsets
Reinforcement Models			
Hysteretic Response	Bauschinger Effect (Seckin)	**Buckling**	Akkaya 2012
Dowel Effect	Tassios (Crack Slip)	**Concrete Bond**	Eligehausen

BEHAVIORAL MODELS

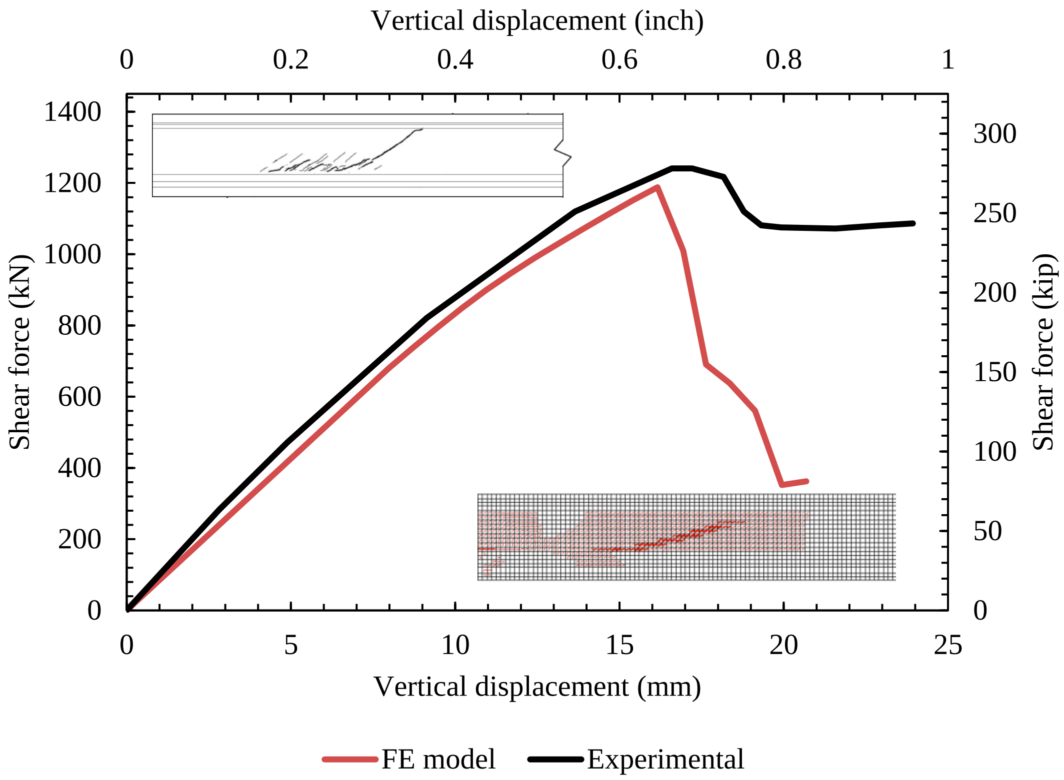




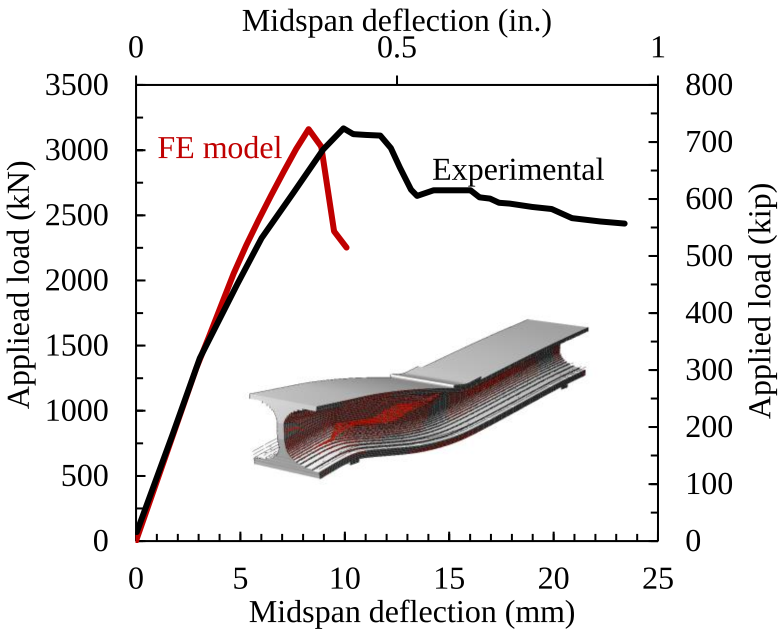
FINITE ELEMENT RESULTS

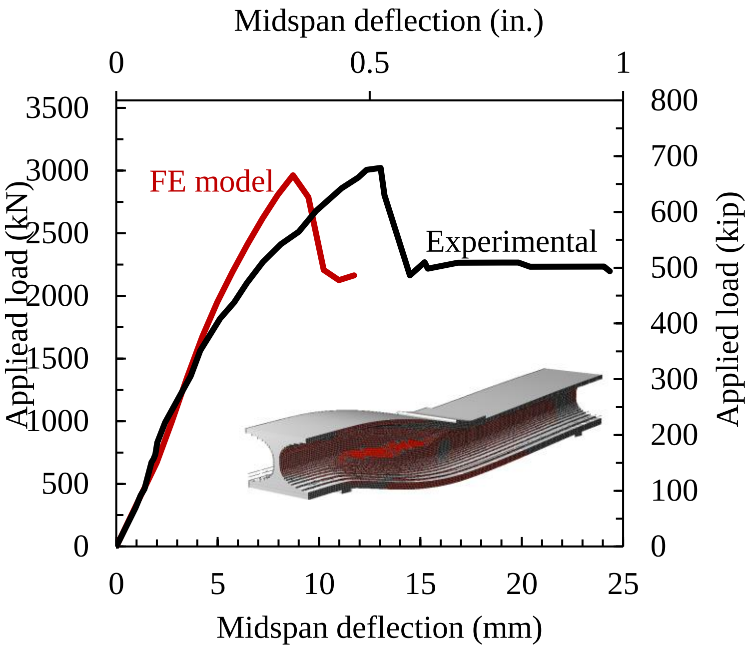


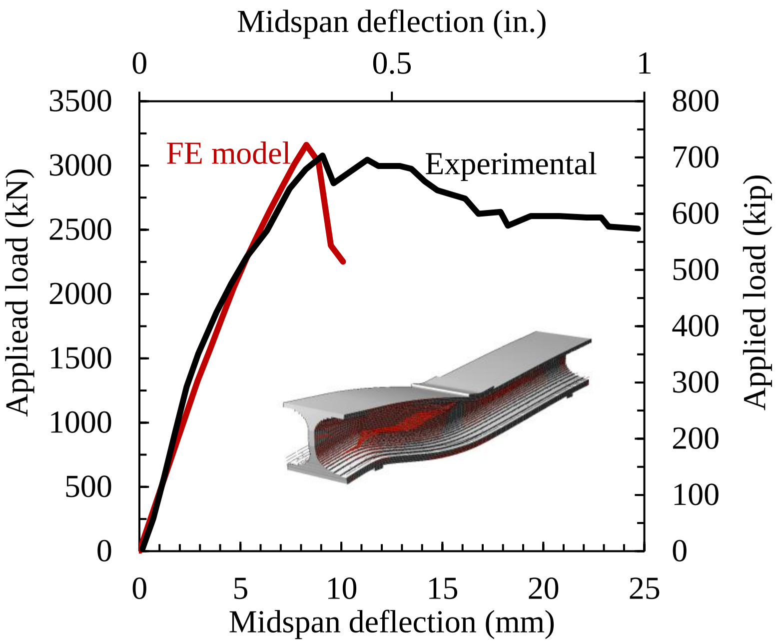
H-P1 FE model (El-Helou 2022)

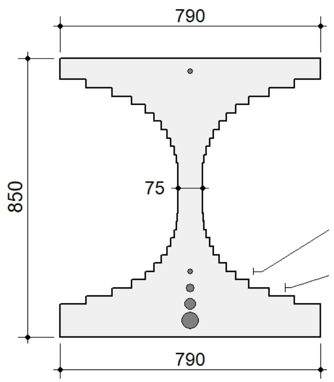


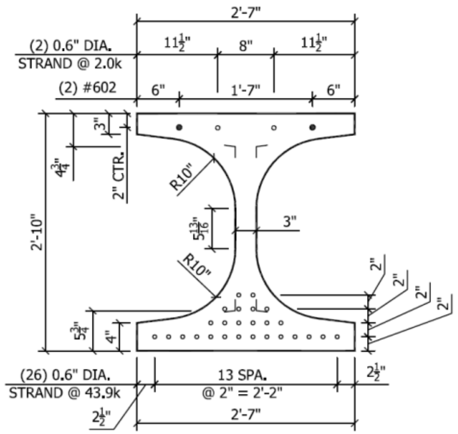
Finite element results











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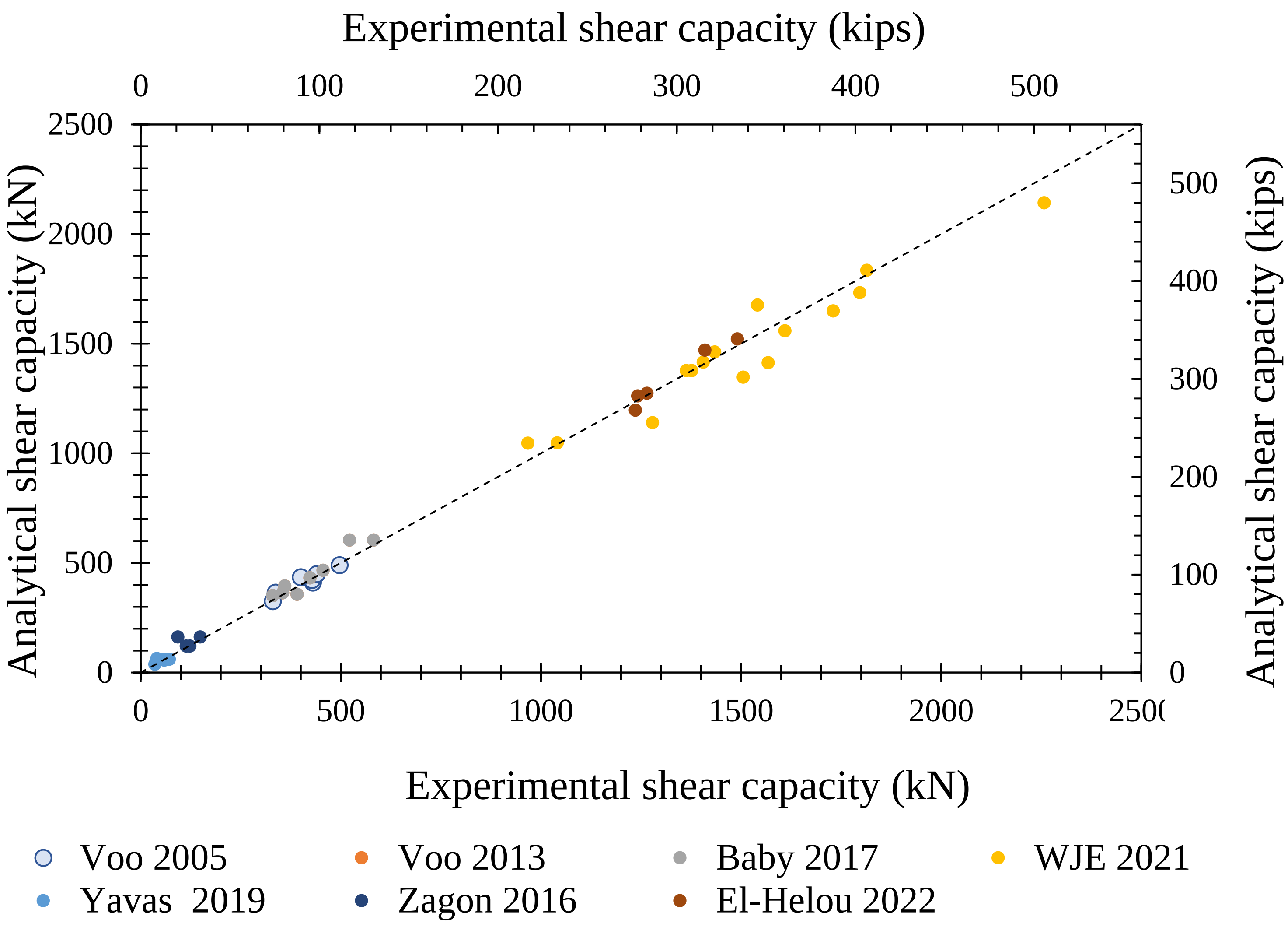

Conclusions & Future Work

Conclusions

- The ML-based model developed for predicting the tensile response of UHPC proved to be reasonably accurate.
- It is feasible to employ an ML-based tension response model of UHPC within a NLFEA framework.

Future Work

- Analyze a compression softening model and tension stiffening model for UHPC elements.
- Improve the current shear design models based on the ML tensile strength response algorithms and the finite element models.


THANK YOU!