Implementation of a multi-axial loading path material characterization system

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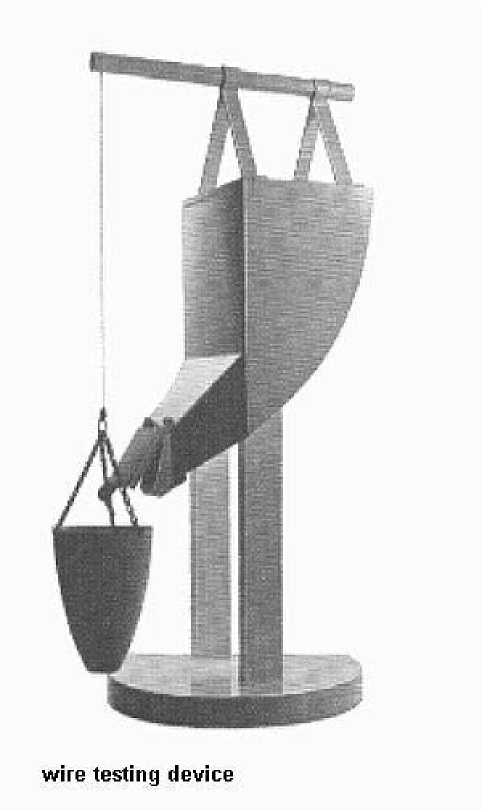
Objectives

- Point out that structural material characterization has not changed in principle in 500 years
- Demonstrate that a need exists for alternative methods for material characterization
- Provide overview of the methodology
- Show results through examples

The Beginnings of Mechanics

- Leonardo da Vinci (1452-1519)

  “Testing the Strength of Iron Wire of Various Lengths"



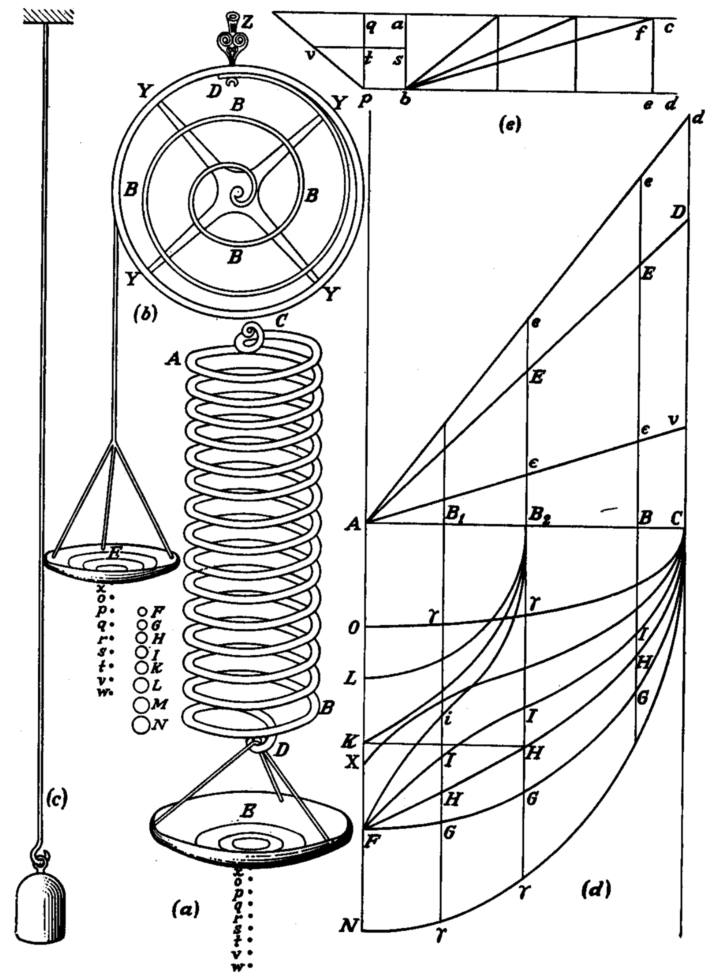
Timoshenko, “History of Strength of Materials”

The Beginnings of Mechanics

Robert Hooke (1635-1703)

Hooke's Law

[redacted]



William Oughtred (1632)
Invented the logarithmic slide rule

Timoshenko, "History of Strength of Materials"

The Beginnings of Mechanics

Cauchy (1789-1857)

Generalized Hooke’s Law

Timoshenko, “History of Strength of Materials”

Operational Philosophy

- Why change?
- Science “Push” vs Industry “Pull”
- Computational power of the computer
- Resistance to change
- Standards Organizations (ASTM etc)
- Building Codes
- End users
- Academic Scientific Method

Operational Philosophy

- Industry Pull
- Realistic Systemic Simulation/ Prediction
- Inexpensive Material Qualification/Certification
- Quick Material Insertion
- Rapid Prototyping and Production

Operational Philosophy

- Technology Pull
- Computational Technology
- Automation
- Computational Symbolic Math
- Automated Software Synthesis

Operational Philosophy

- Producers view:
- Rapid and inexpensive characterization of new materials
- Utilization of existing material behavior databases constructed from massive automated testing
- Automated synthesis of material behavior theories and finite element models for structures of interest
- Studies of material/structural behavior as a function of operational system requirements

Operational Philosophy

- Measure first, then Model (Data driven Modeling)
- Interpolate, NOT Extrapolate
- Locally flat Parameter Spaces (Continuity of parameters)
- Work only with commonly accepted composition rules
- Automate, then Apply

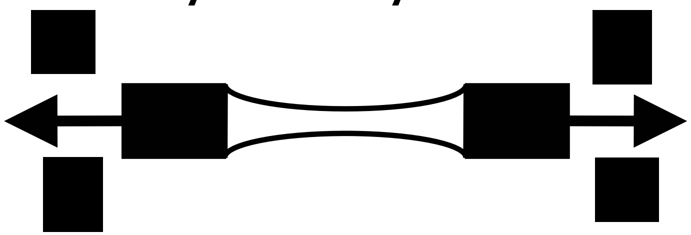
Physical System Identification

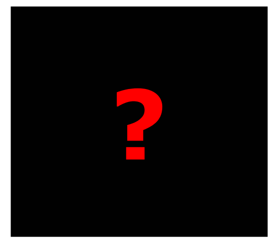
Physical World

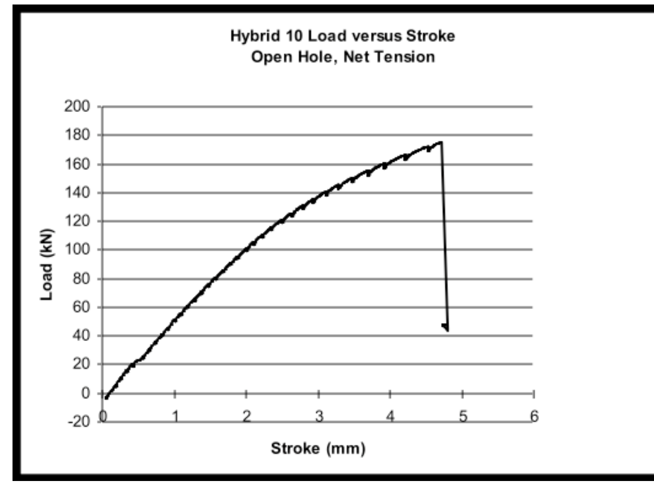
Conceptual World

External Appearance	Internal Appearance	Behavior Appearance

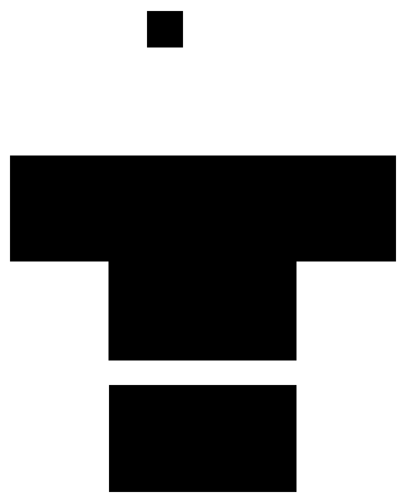
Physical System

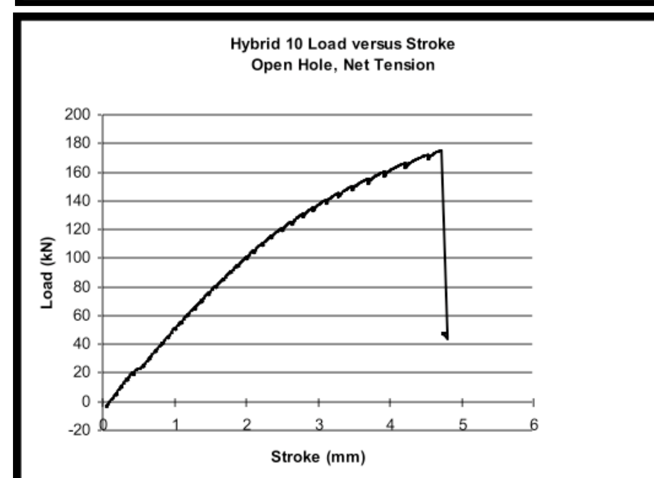






Modeled System





Physical System Identification

- Axioms of Enrichment:
- The Axiom of Continuous Behavior
- The Axiom of Composition Behavior
- The Axiom of Zero Order of Reality

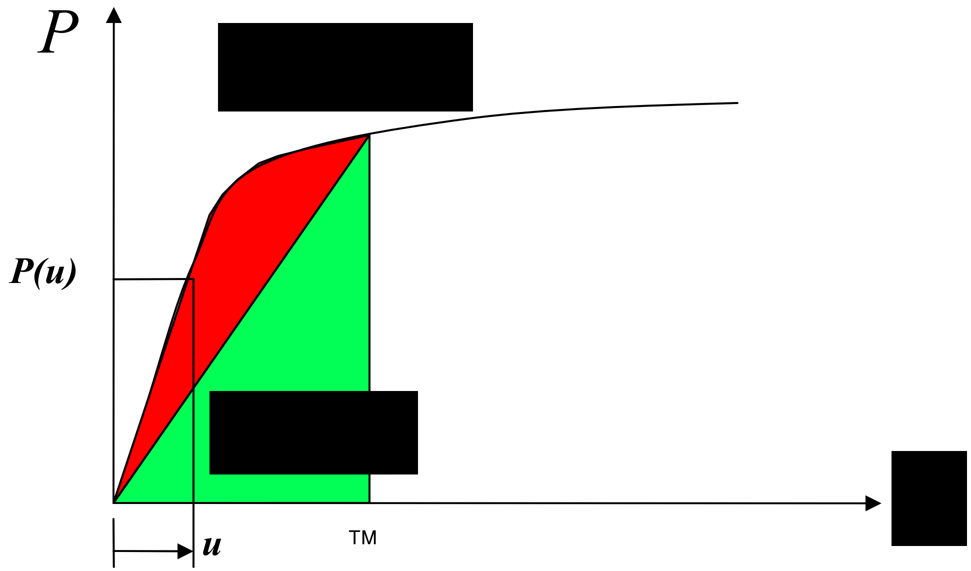
Physical System Identification

Physical System Identification

- “Mechanics is the paradise of mathematical science because here we come to the fruits of mathematics.”

- Leonardo da Vinci

Physical System Identification



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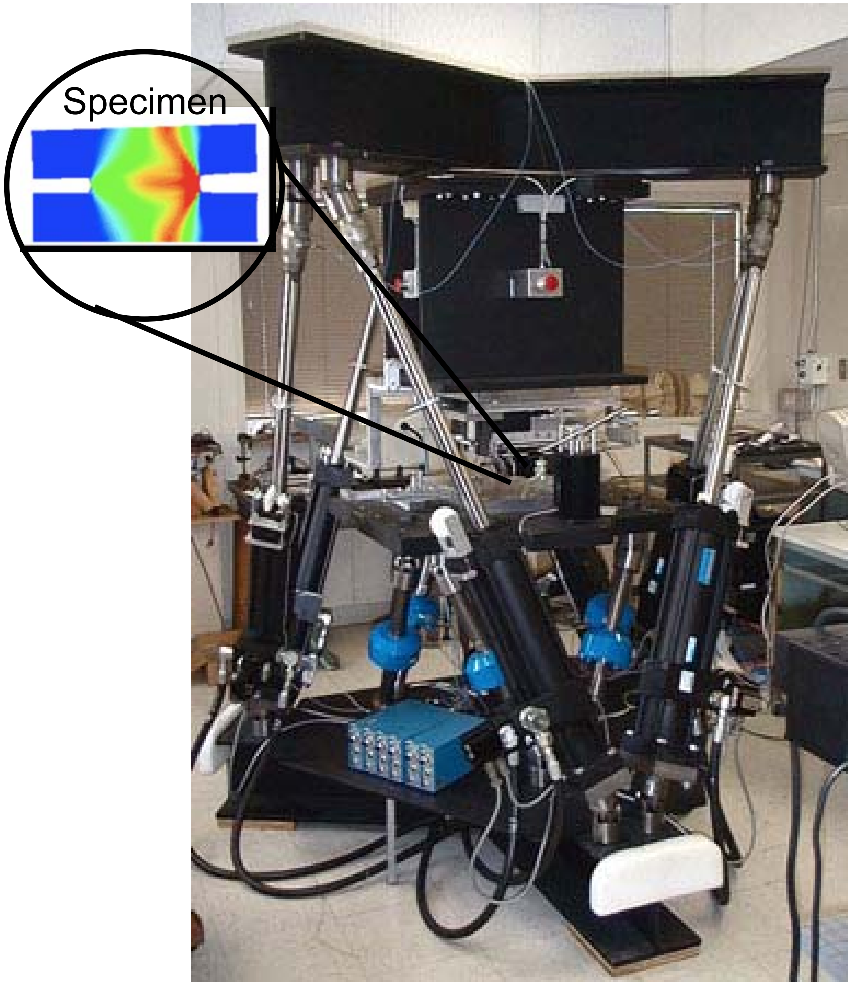
Physical System Identification

General Case and Planar Mode:

3 displacements + 3 rotations + 3 forces + 3 moments + Np x 6 strains + Np x Nf = 12+ (6+Nf)xNp Datastreams



FPL & NRL's Automated 6-D Loader

Special Case: In-Plane Mode

2 displacements + 1 rotation=3 DOFs=6 Datastreams

DATA ACQUISITION & CONTROL

COMPUTE COEFFICIENTS OF [redacted] THAT MINIMIZE THE SYSTEM OF EQUATIONS DERIVED FROM THE ENERGY BALANCE:

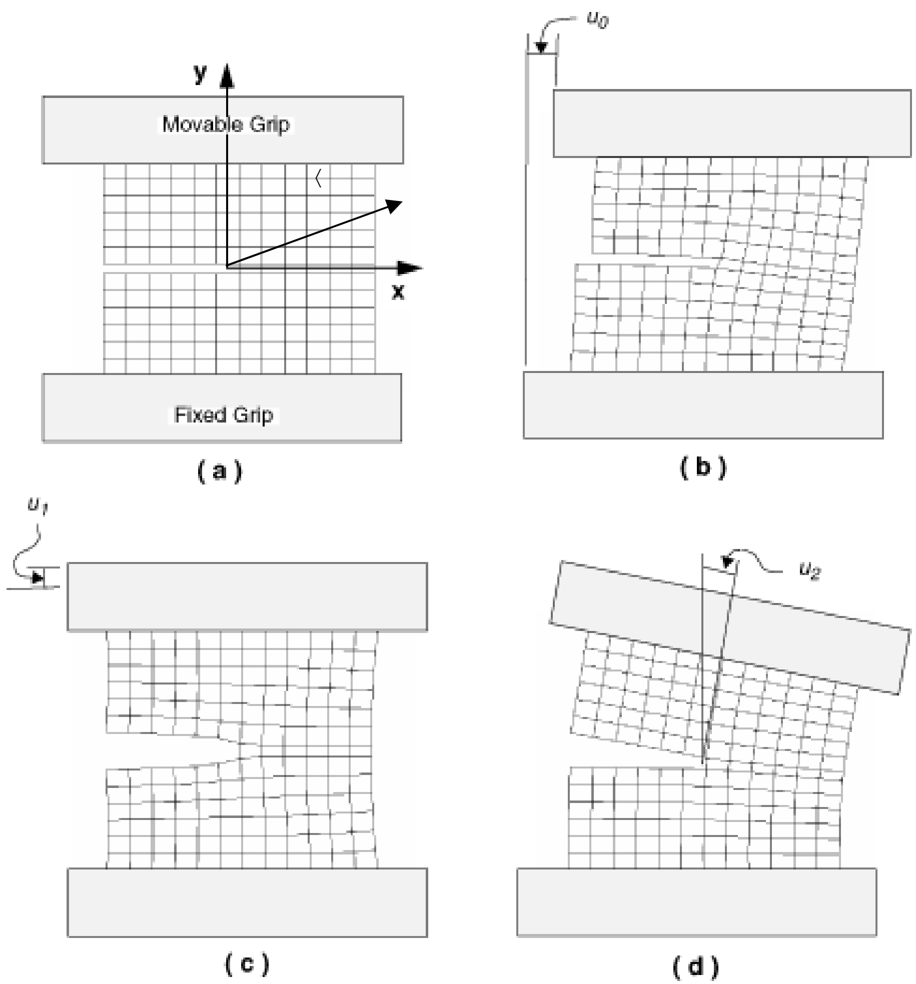
$$\int_0^{u} t_u q_v dq^v - \frac{1}{2} t_s u_t u^v + Q = \int_{\partial V} \phi\left(\varepsilon_i(x_j), f_k(x_j)\right) dx_j$$

STORE MEASURED COEFFICIENTS OF (DISSIPATED ENERGY DENSITY) IN DATA BASE

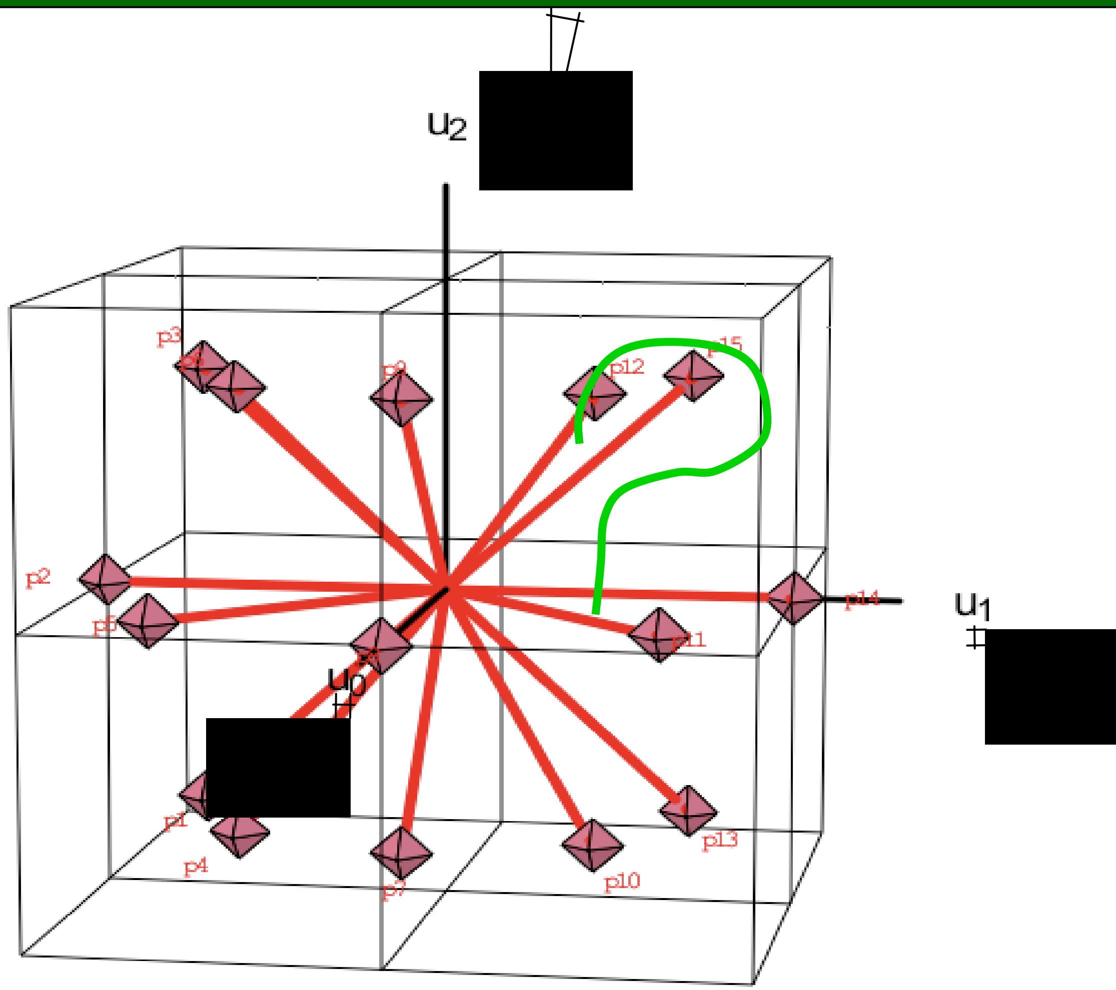
[redacted]

Physical System Identification

Systematic Material Identification, 3 DOF Motions:

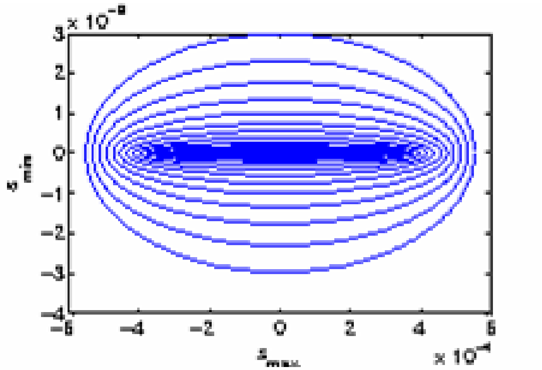


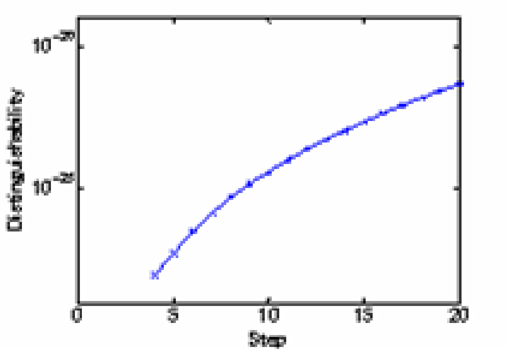
Physical System Identification

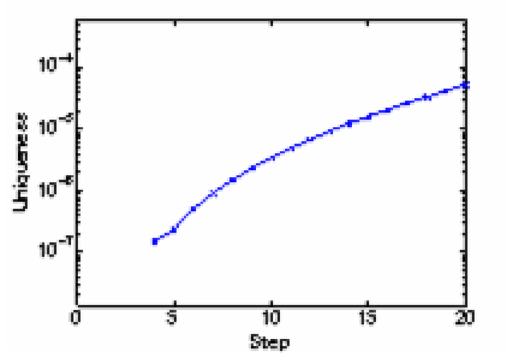


Physical System Identification

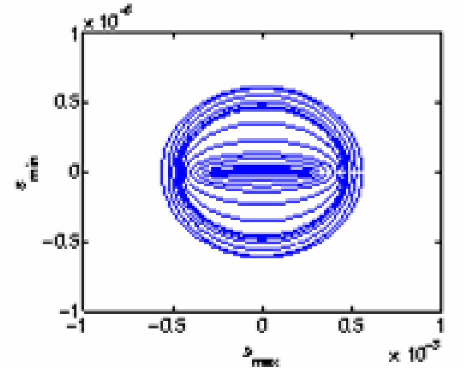
Proportional Path

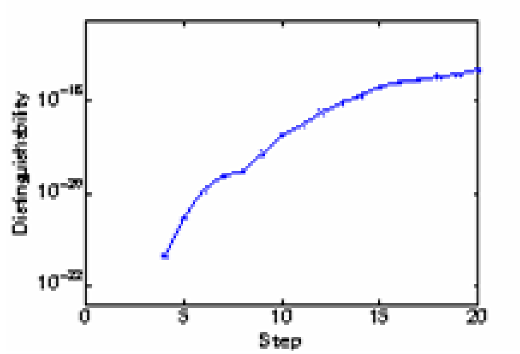


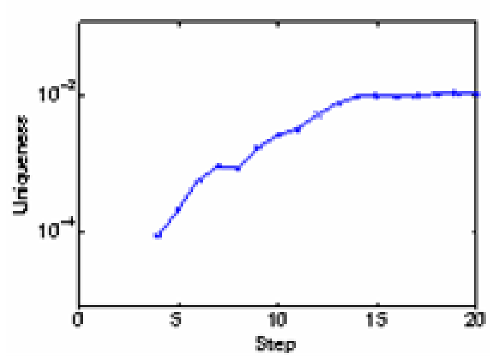




Winding Path

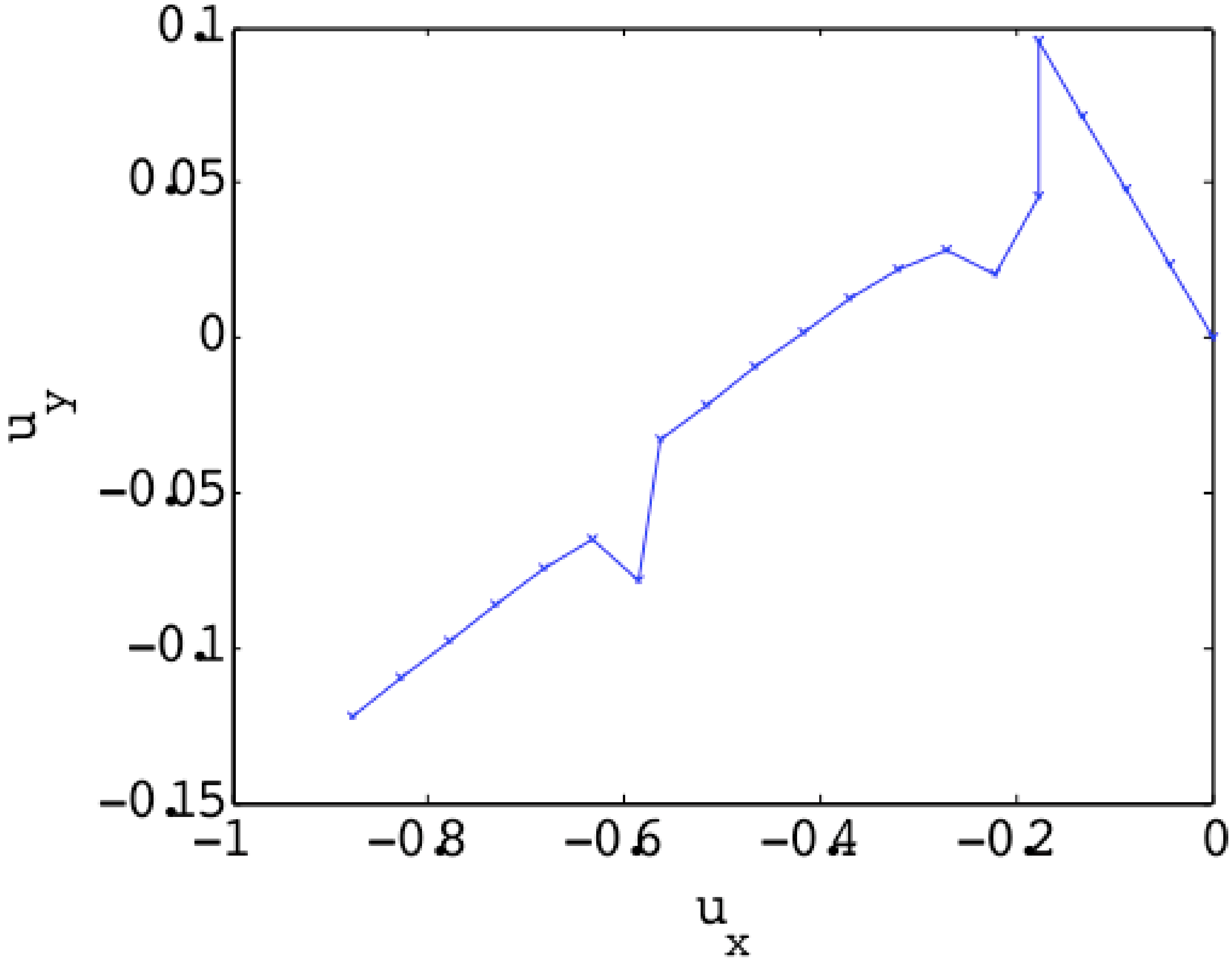






Physical System Identification

Optimal Solution:



Wood-Plastic Composites

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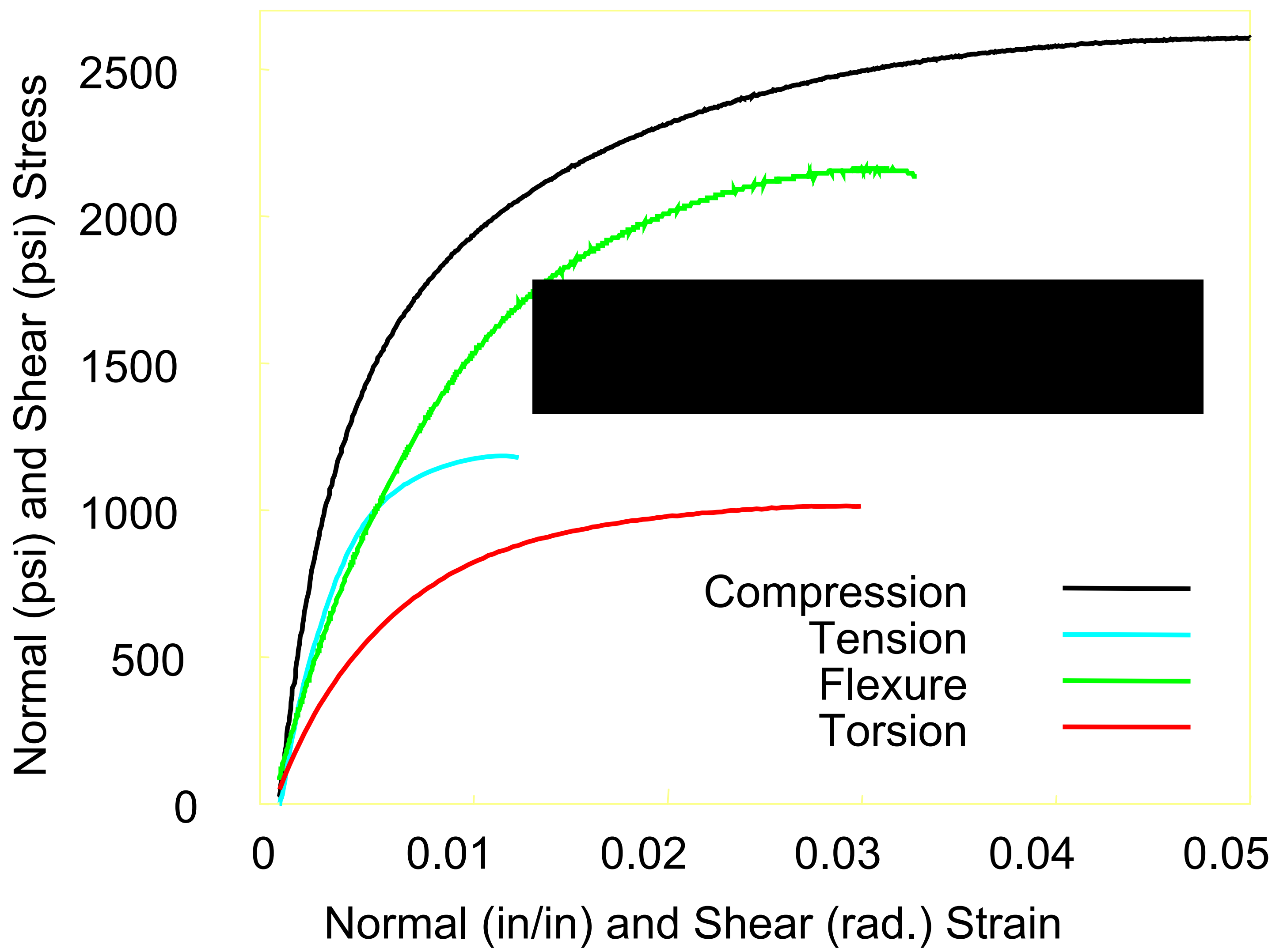
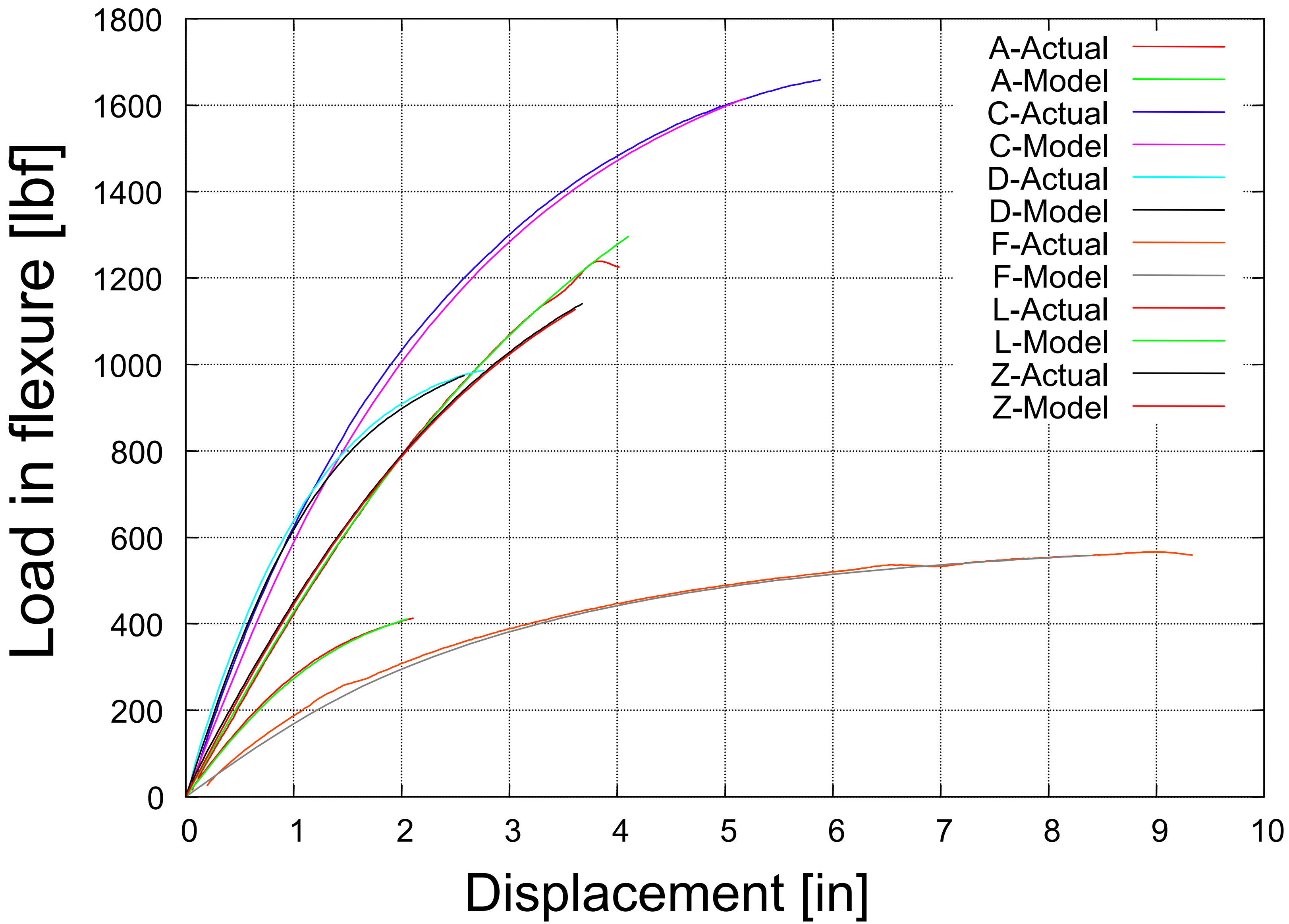


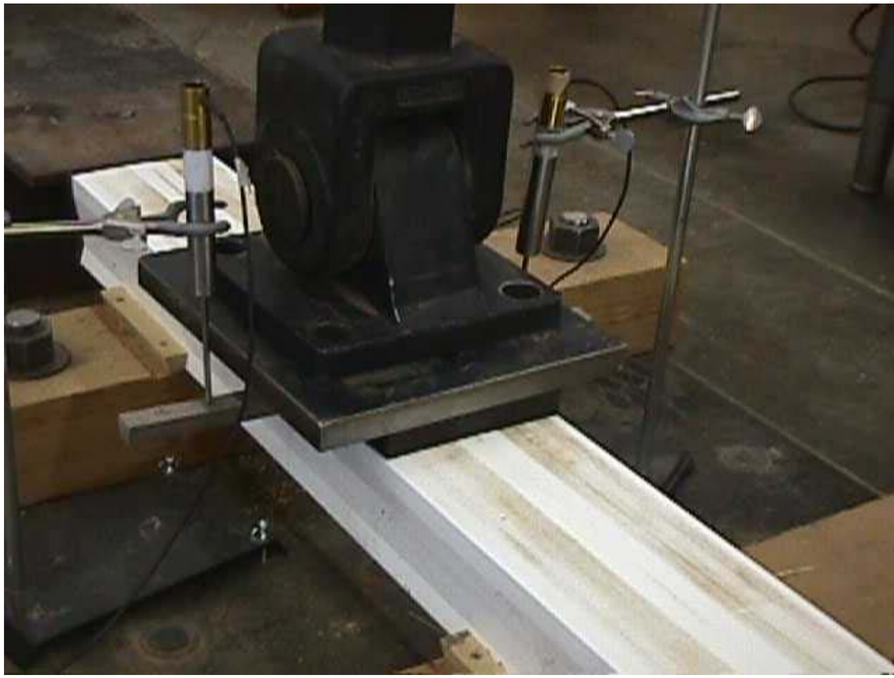
Wood-Plastic Composites

Profile	*Ef* Actual (psi)	*Ef* Predicted (psi)	⊗%
ASTM	311000	319000	2.6
Box	182000	179000	-1.6

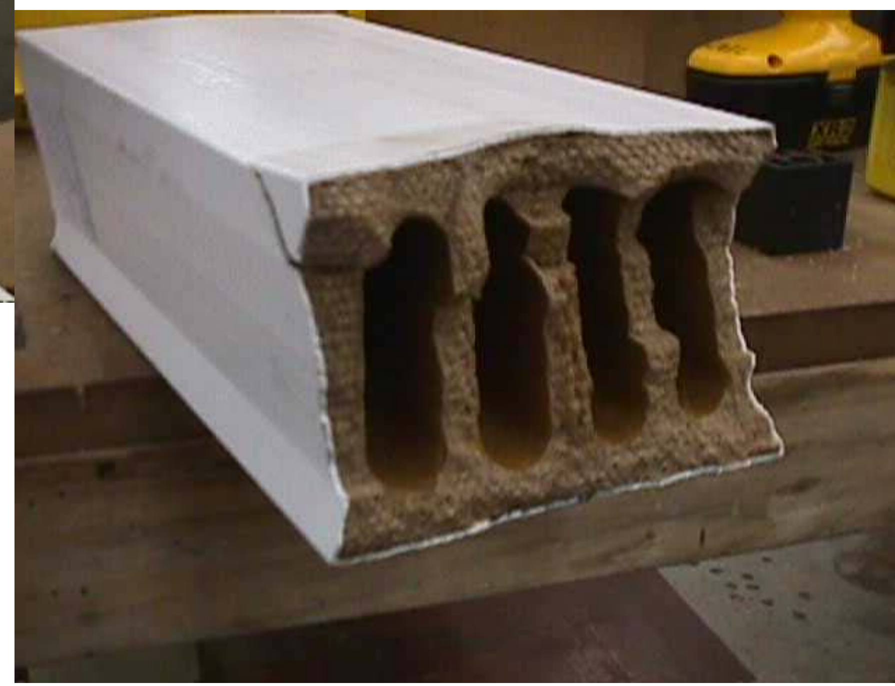
Wood Plastic Composites



Wood-Plastic Composites

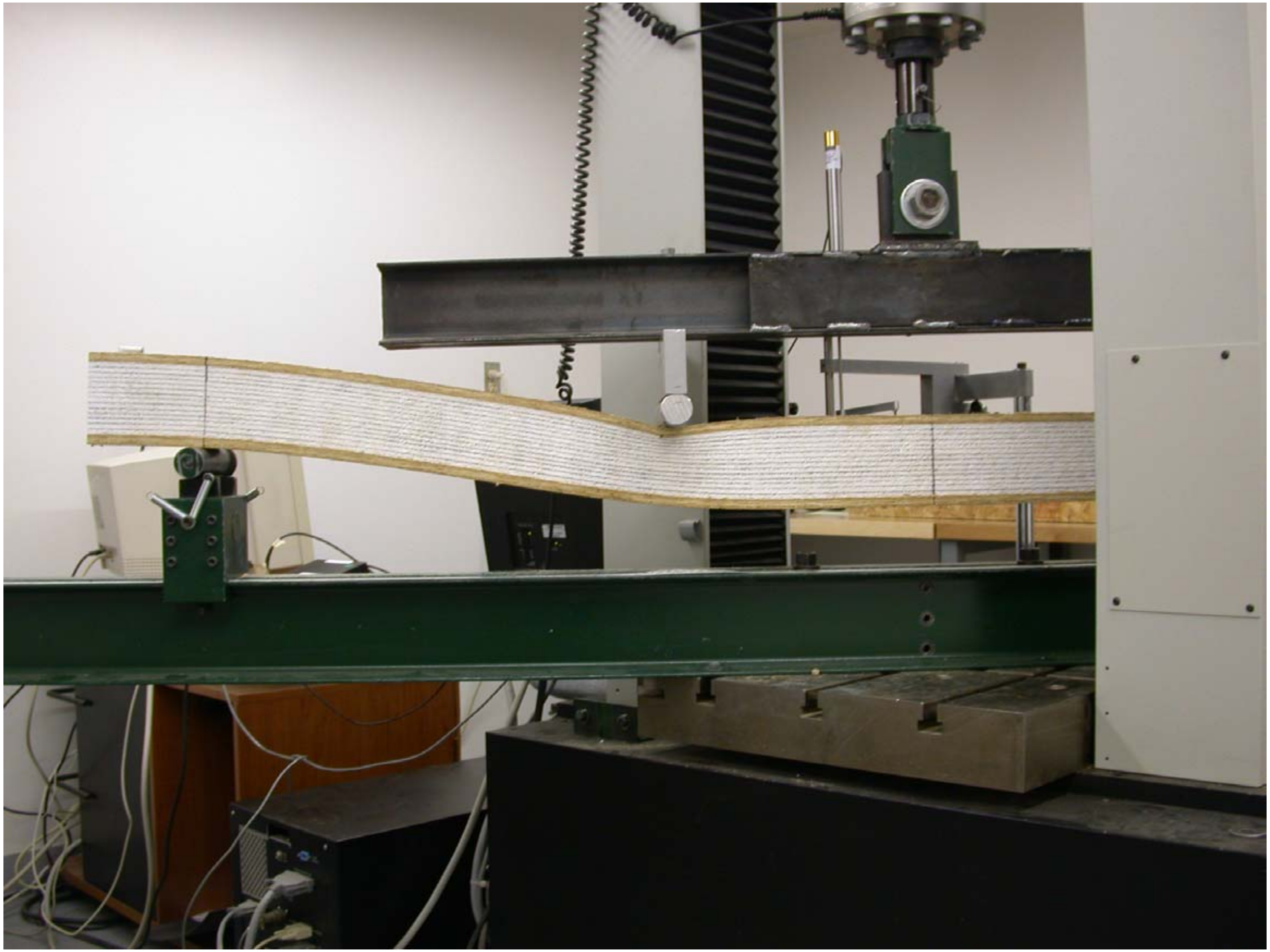


Design Load =
20000 lbss

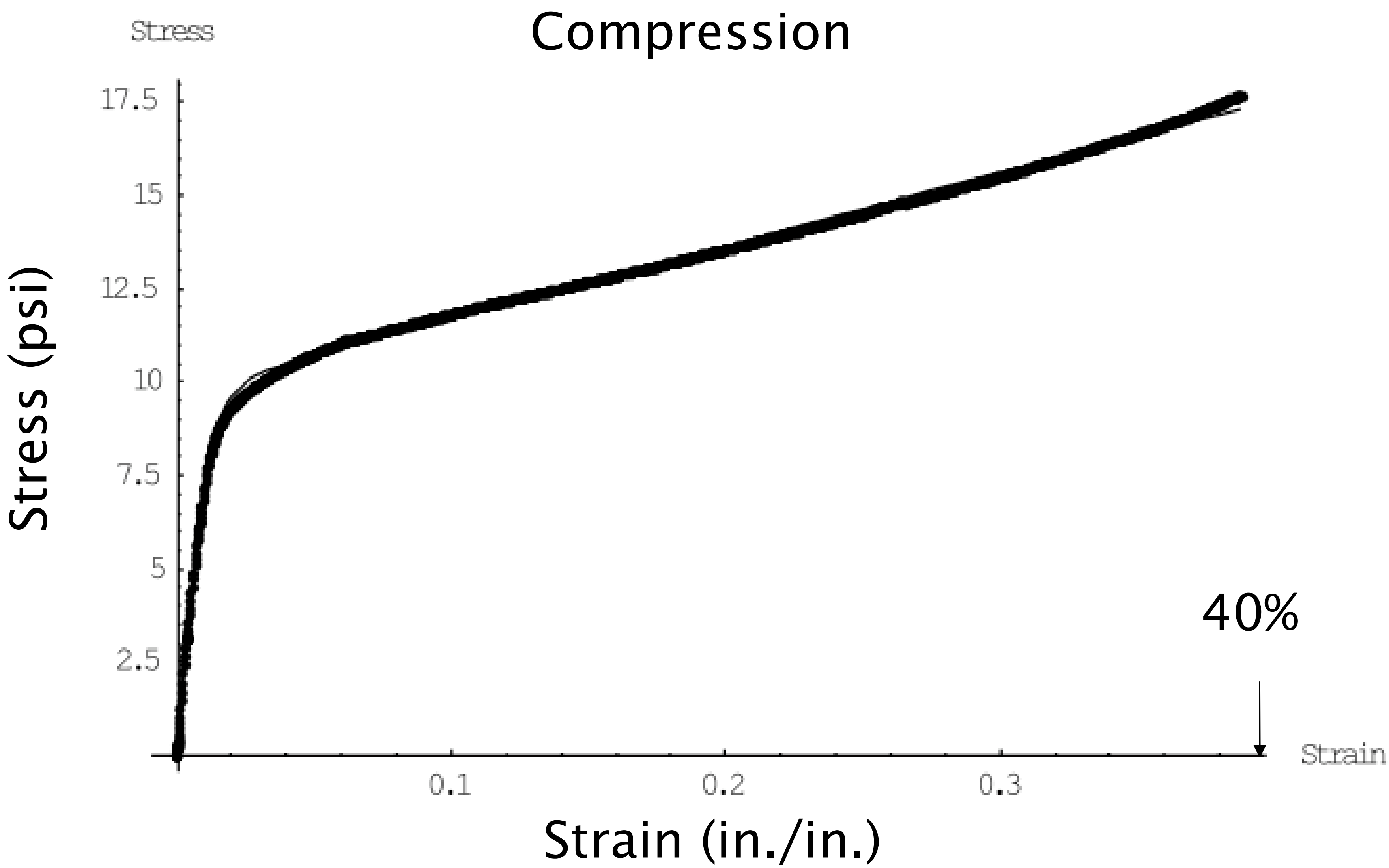


Actual Load =
20007 lbs
COV = 3.6%

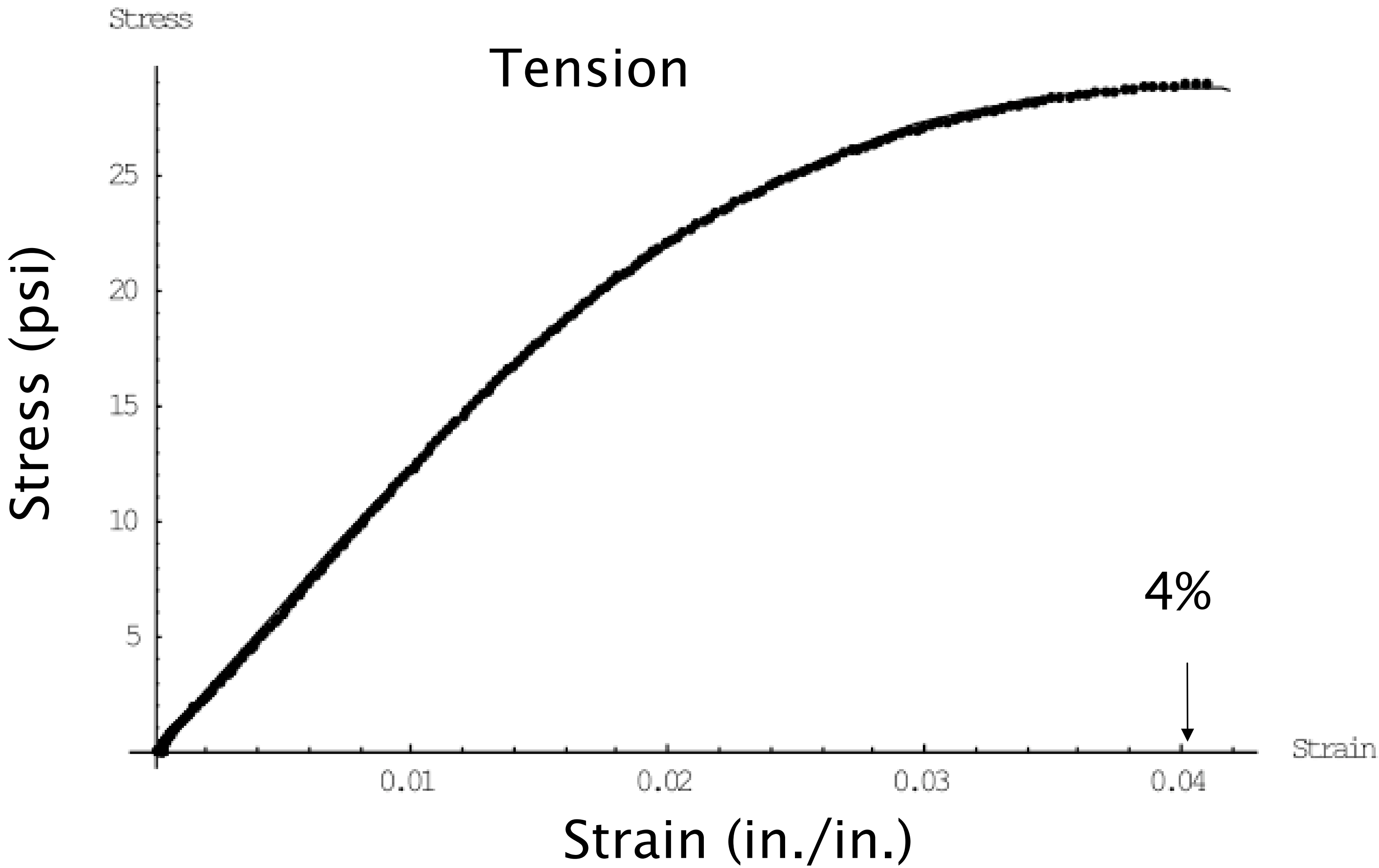
Modeling SIPs



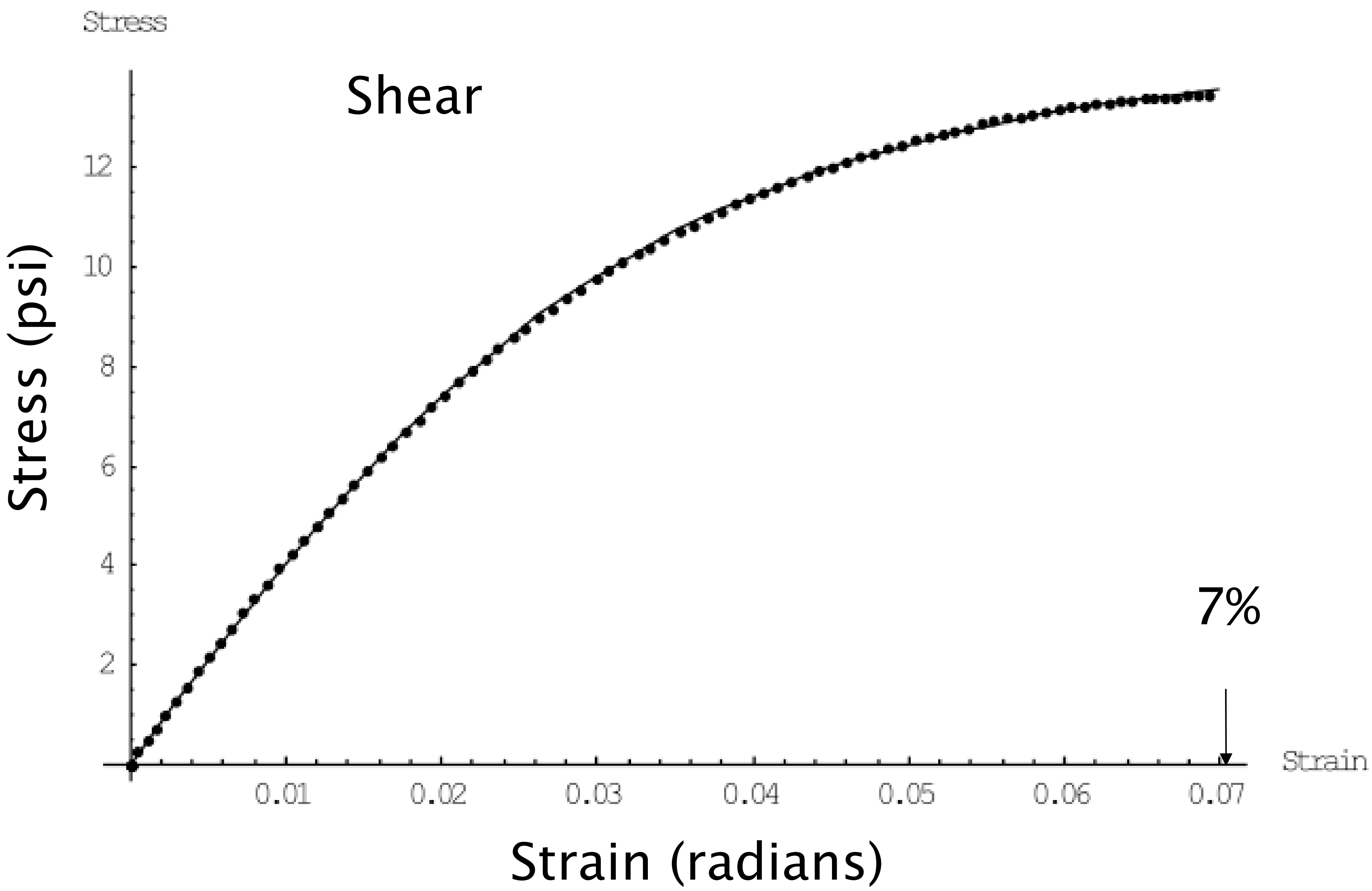
Modeling SIPs



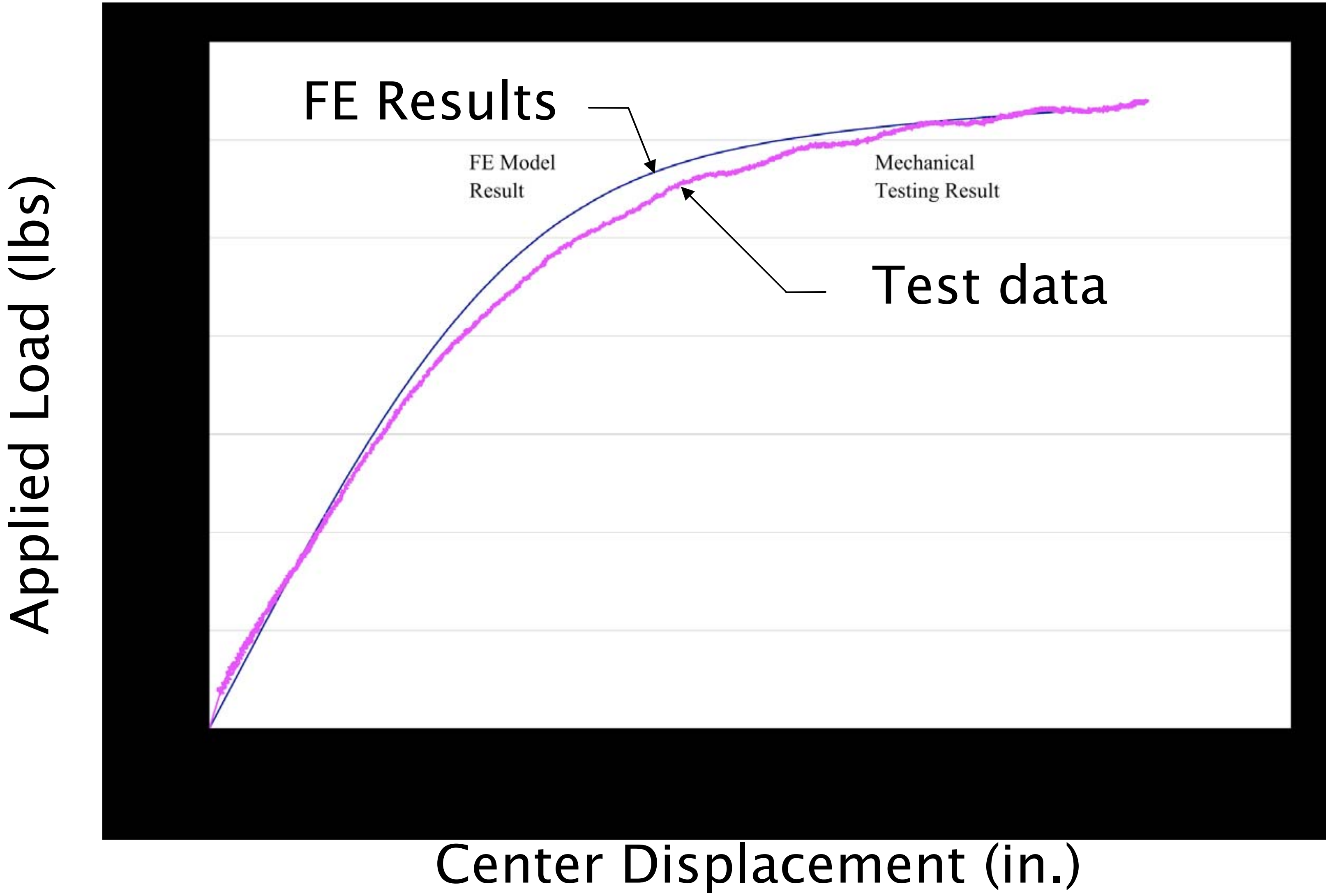
Modeling SIPs



Modeling SIPs



Modeling SIPs



Conclusions

- Hardware exists to evaluate materials in multi-physics environment.
- First generation software is available to analyze data.
- Second generation data is being developed.
  - Utilize objective functions to optimize loading path.
  - Non-proportional loading paths perform better.
- Data-Driven approach is appropriate to meets the demands of “Industry Pull.”
- Need to overcome resistance to implement changes.

Acknowledgements

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Questions?

- Nothing in Nature is random. ... A thing appears random only through the incompleteness of our knowledge.

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  Spinoza