INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

Compression/Recovery of Goose Down
Part II - Neural Network Analysis

by

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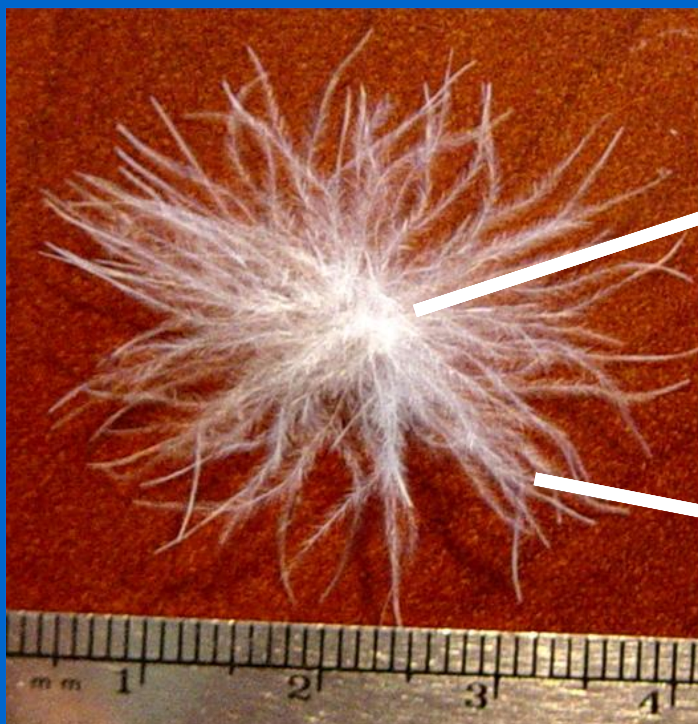
PROJEKT OPTIS PRO FT, reg. č.: CZ.1.07/2.2.00/28.0312 JE SPOLUFINANCOVÁN EVROPSKÝM SOCIÁLNÍM FONDEM A STÁTNÍM ROZPOČTEM ČESKÉ REPUBLIKY

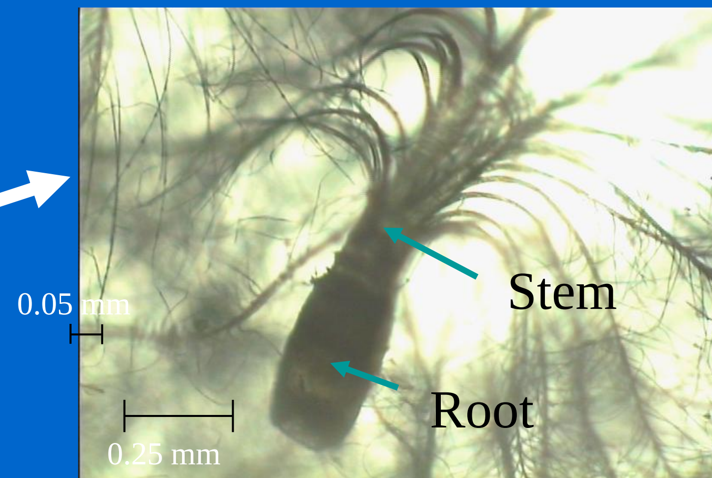
Objective

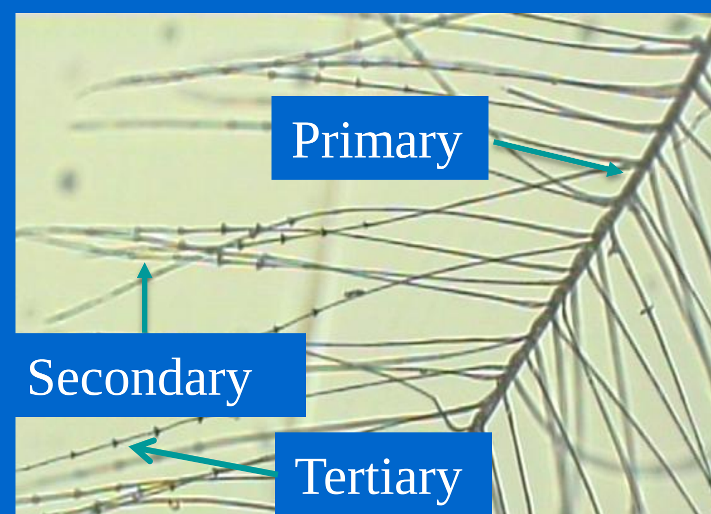
- To understand the compression/recovery behavior of goose down and synthetic fibers
- To provide design inputs for compression structures using synthetic fiber

Components of a Goose Down Cluster



Single Cluster



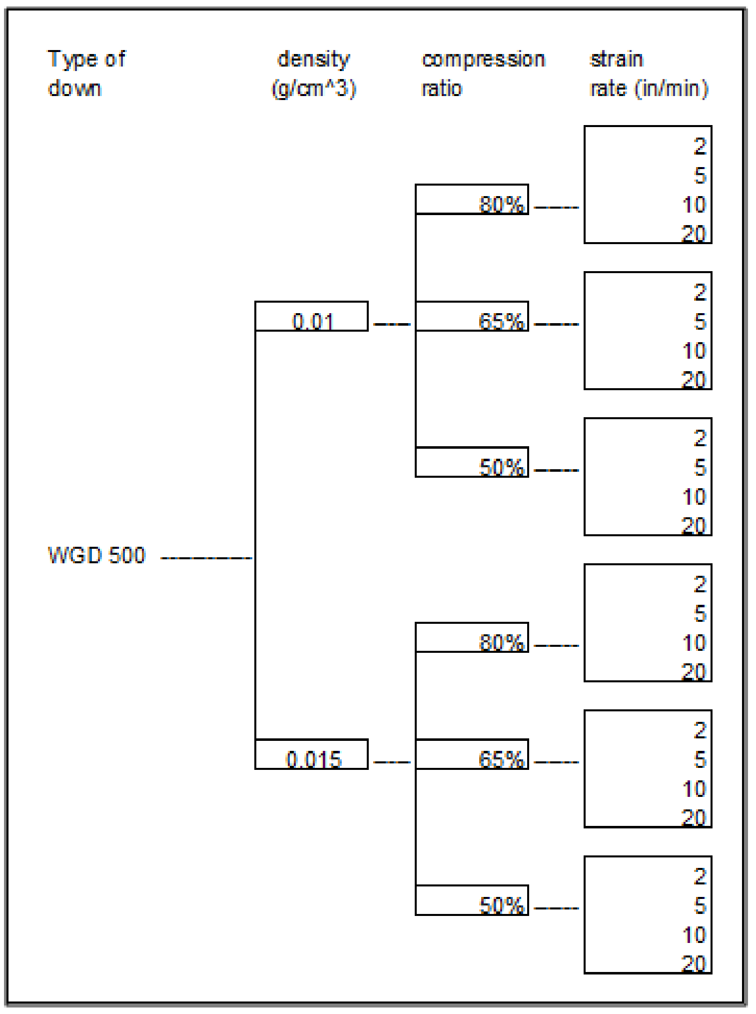


Experimental Set-up

- Down is loaded into a metallic container with small holes on it
- The piston compresses the feather and reverses at same strain rate
- There is a 5-minutes recovery period before it is compressed again
- Each sample will be compressed 5 times

Experimental Set-up

- Each sample is compressed 5 times with five minutes for recovery
- Four independent variables are studied:
  - Types of feathers (fill power 500, 600, 750 800 in^3/oz)
  - Bulk Density (0.01, 0.015 g/cc)
  - Percent compression (50, 65, 80%)
  - Strain rate (2, 5, 10, 20 in/min)

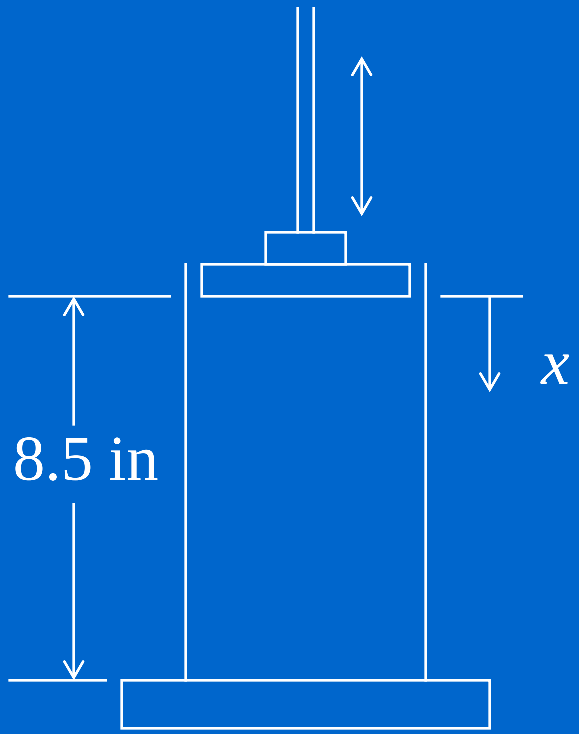


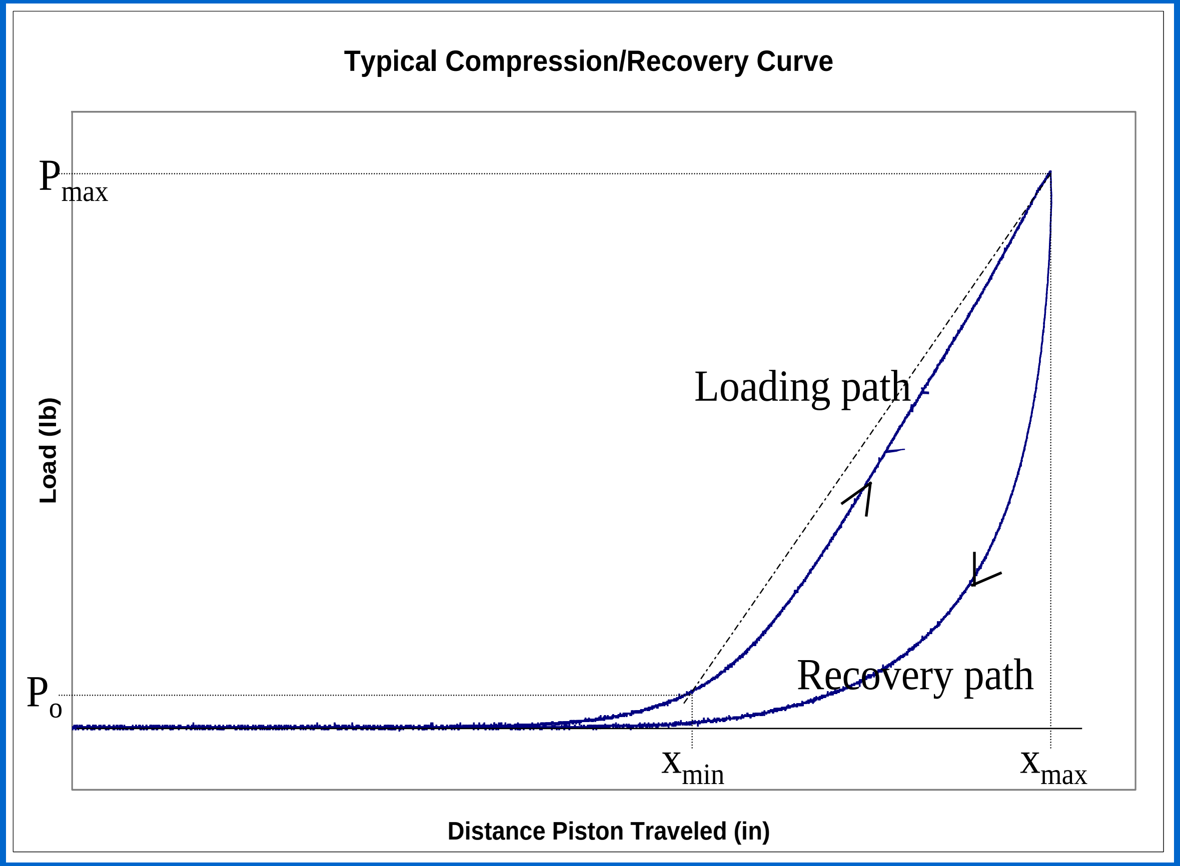
Synthetic Fibers for Comparison

- **Synthetic Fiber Preparation on Rando Blowing System Before Loading (Three Steps):**
  - **Pre-feeding clumped fibers**
  - **Opening of fibers via mechanical cylinder conveyors**
  - **Air transport of fibers (200 lbs/hr) into storage**
- **Three types of Synthetic Fibers Used:**

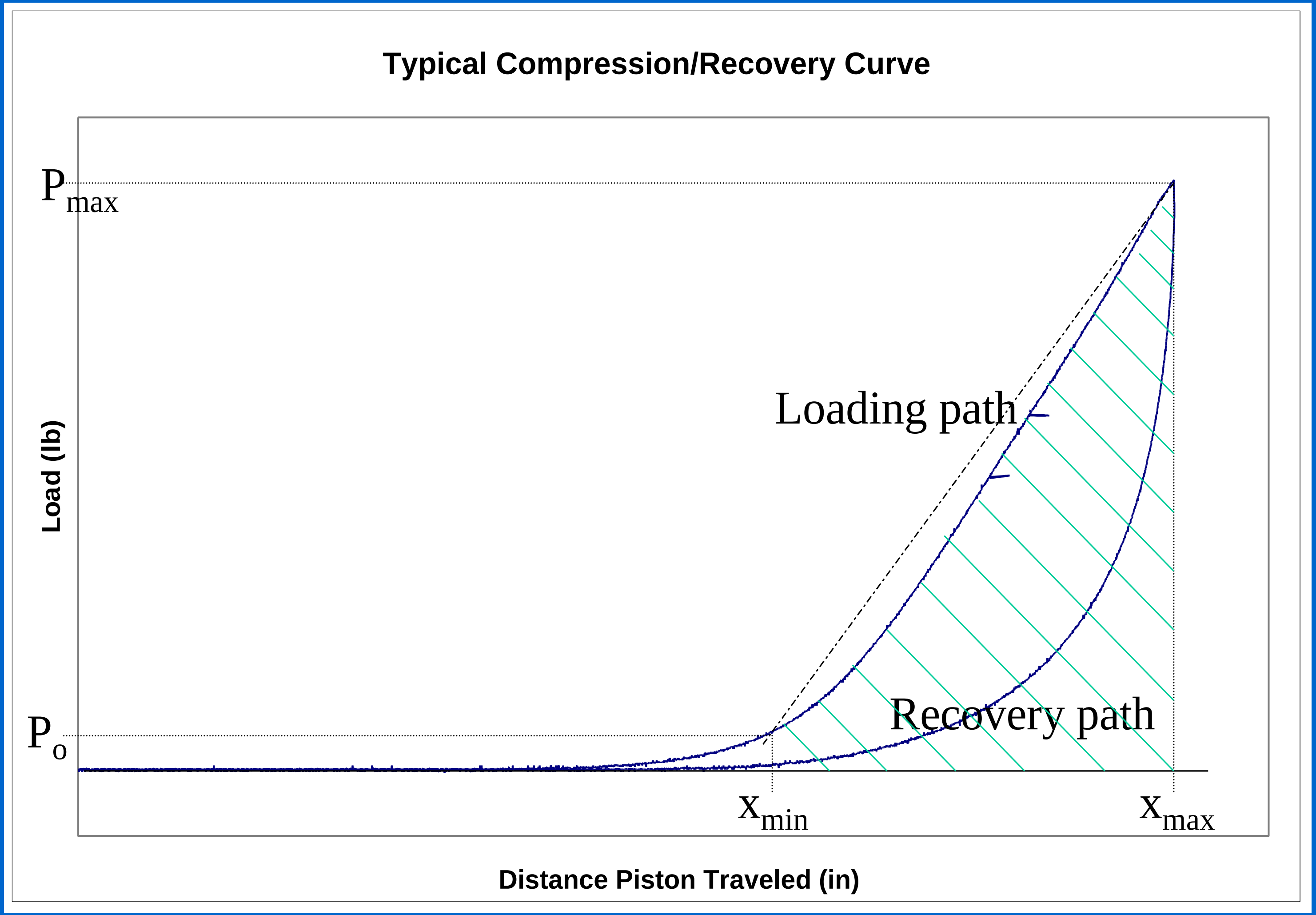
Type	DPF	CTU	CPI	shape	Polymer
233A	1.65	30	12.8	round	homopolymer
667	6.5	38	4	round	bi-component
118	6	28.5	8.5	round	homopolymer

Result and Discuss

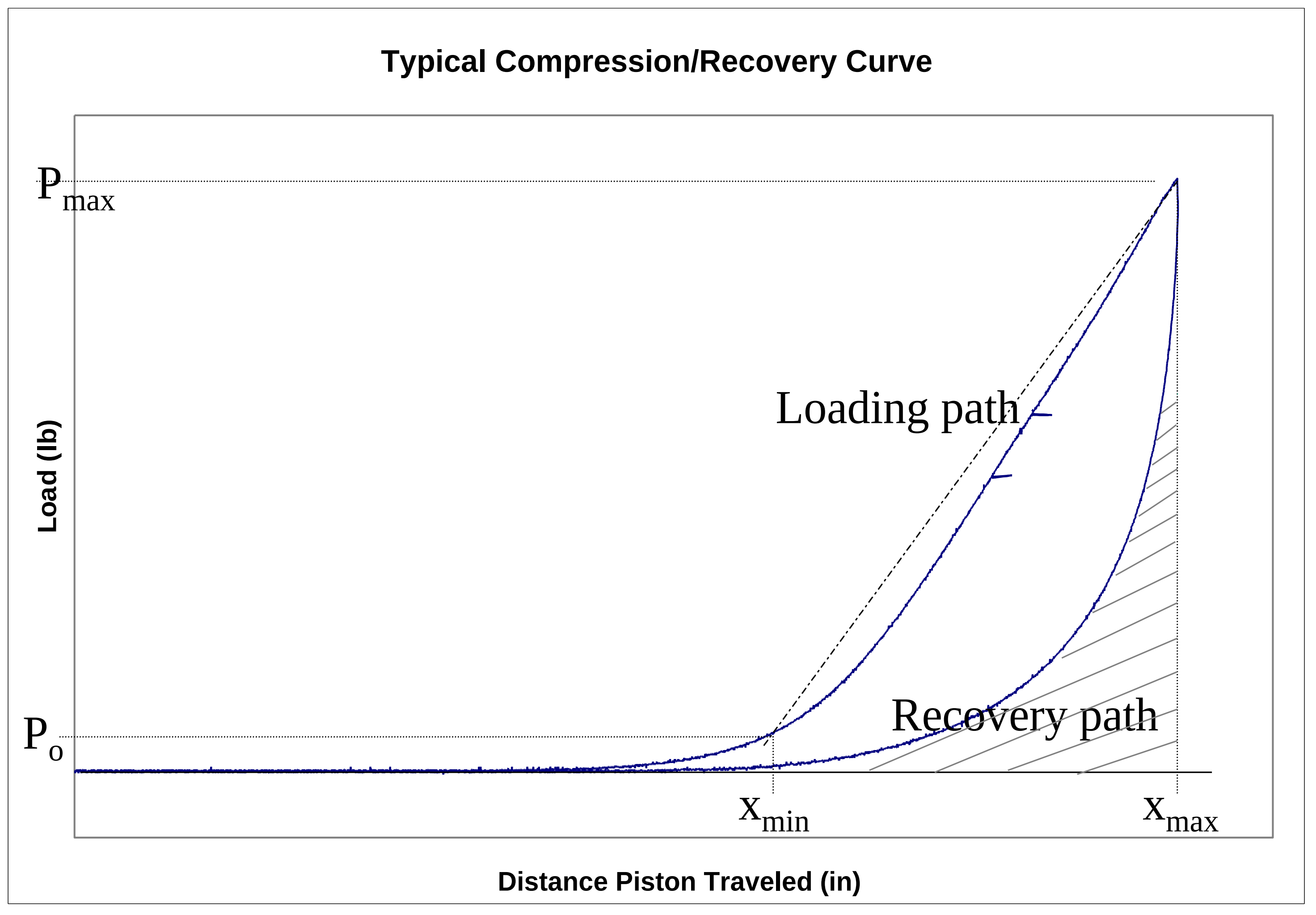




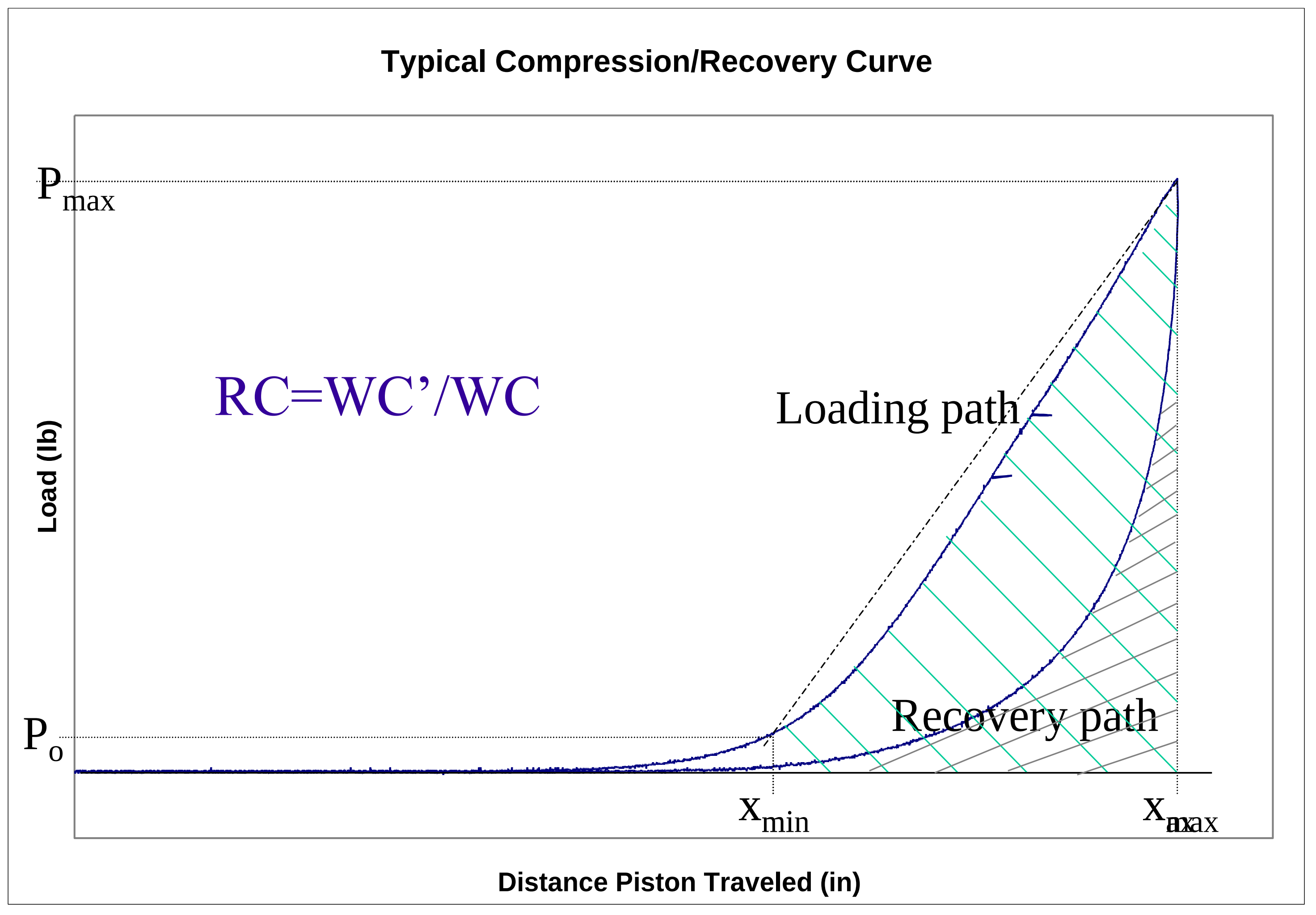
Energy Compression - WC



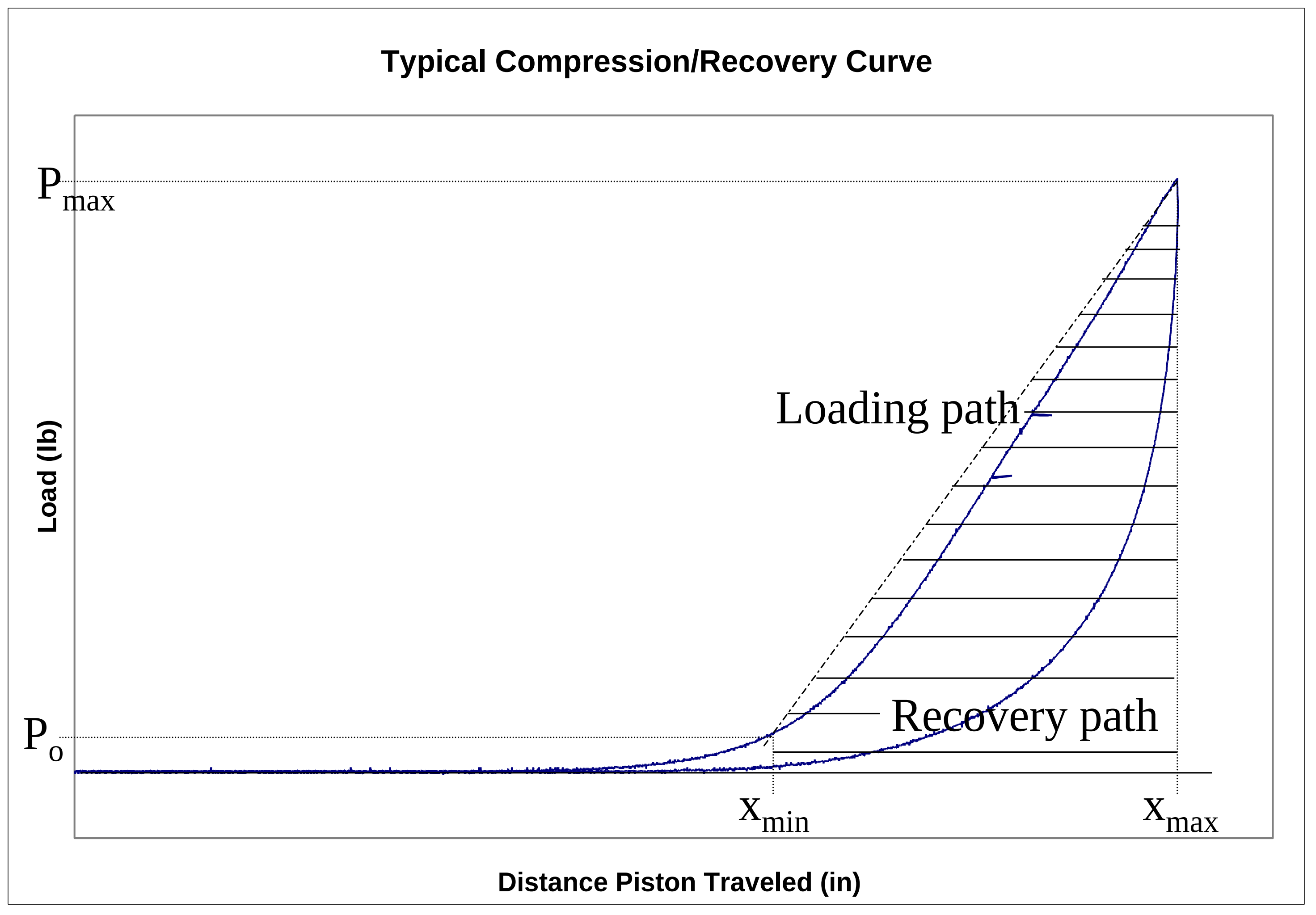
Energy Recovered - WC'



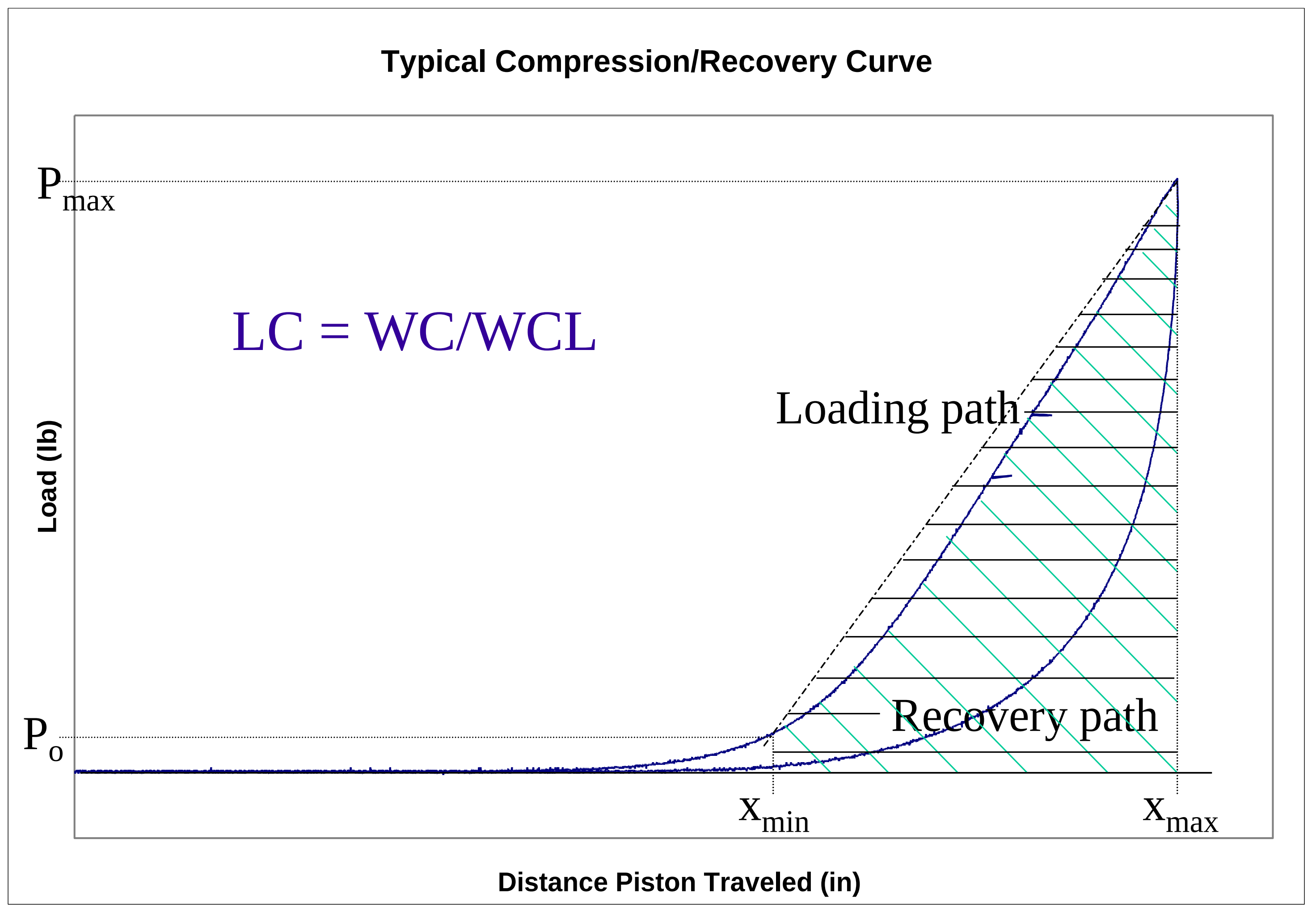
Resilience - RC



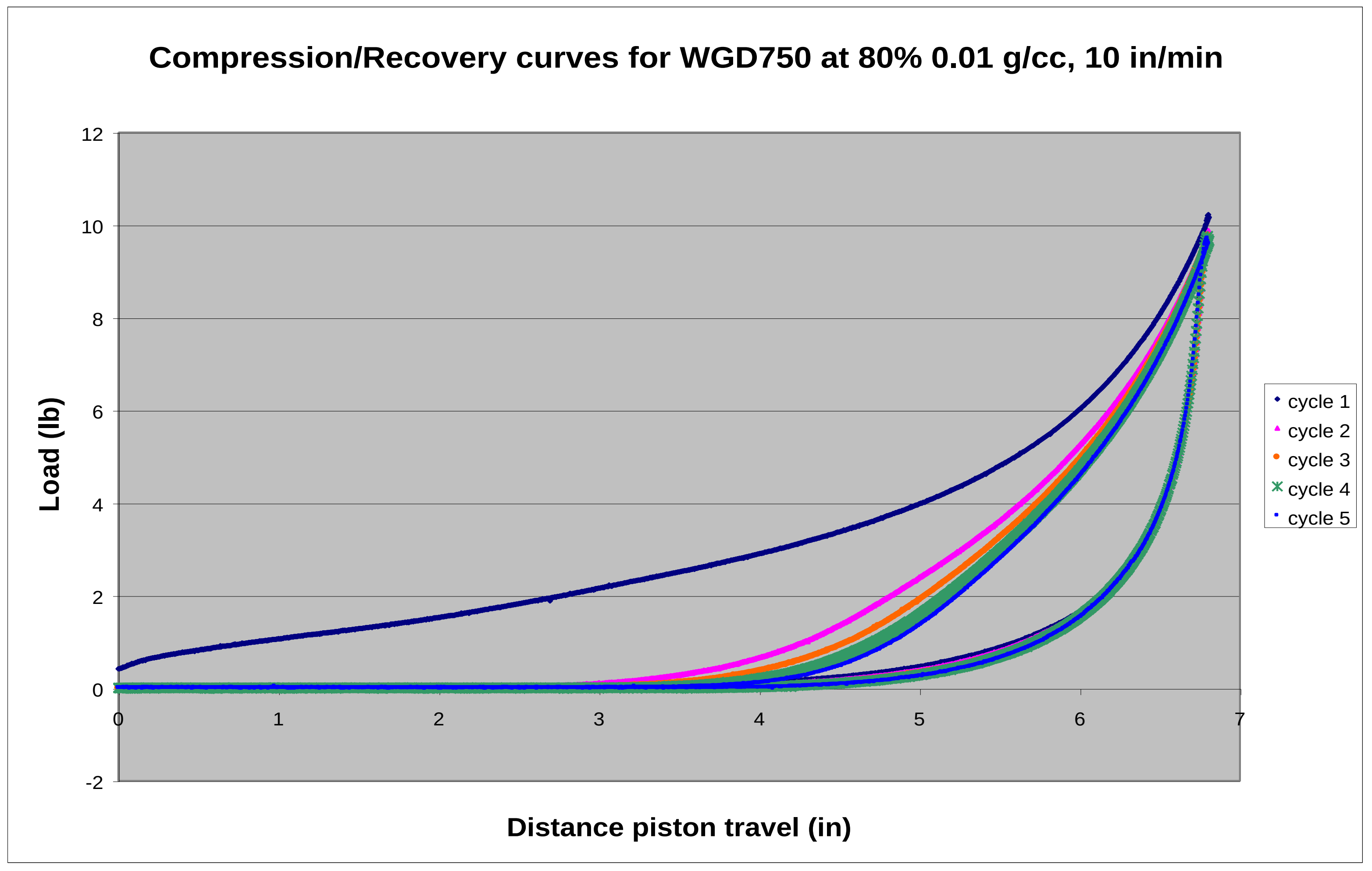
Linear Energy - WCL



Linearity - LC



Typical Compression/recovery Curves



Conclusion - Physics of Down Deformation

- **Reasons for difference between first and subsequent compression cycles**
  - **Initially, the primary structures undergo irreversible re-orientation and translational change**
  - **The degree of change is a function of the initial density**
    - **Less dense samples have fewer interactions to drive re-orientation**

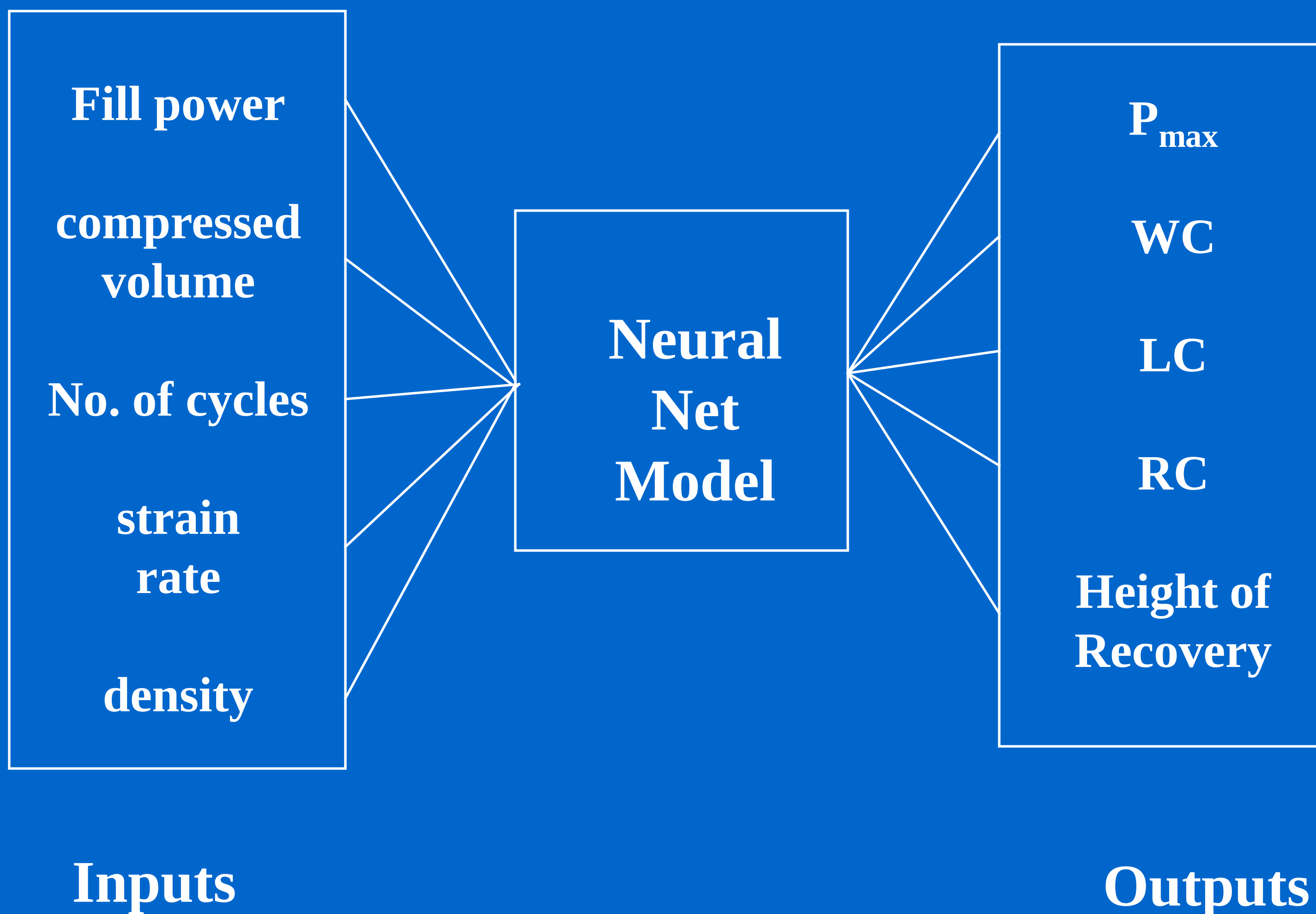
Conclusion - Physics of Down Deformation - Cont

- The hysteresis in loading and unloading paths is due to energy expended in re-orienting & translating the primary structures
- The sharp drop in recovery curve is due to combination of orientation and density effects:
  - The density of tertiary contacts has increased
  - Orientation distribution of primary structures has evolved with resultant stable contacts
  - These phenomena leads to stiffer response

Empirical Model - Neural Network

- Neural Network analysis is a method to develop a mathematical model using statistical data.
- The data set is divided into two sets: train data set and test data set.
- The train data set is used to compute the model and the accuracy of the model is verified by the test data set.
- The network is "Trained" to find the Weights and hidden units (determines complexity) which give the appropriate Input-Output Map .

Neural Network (con't)



Strategy for Model Development

- Three hidden units gave best results
- The 3x5 matrix projects 5 inputs into 3 hidden units
- The 3x1 vector is the bias of inputs into hidden layers
- $\overline{h}$ stores hidden units obtained by substituting $\overline{a}$ into nonlinear function *f*
- The 5x3 matrix projects 3 hidden units into 5 outputs
- The 5x1 vector is the bias of hidden units in output layer
- The final output obtained by substituting each term in $\overline{b}$ into function *f*

Neural Network Model – Matrix Form

$$\begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix} = \begin{bmatrix} 0.499 & -0.076 & 8.794 & 0.035 & 0.275 \\ -0.181 & -2.447 & 0.247 & -0.063 & -0.508 \\ 1.793 & -1.319 & -0.263 & -0.11 & 1.419 \end{bmatrix} \cdot \begin{bmatrix} fill\_power \\ comp.\_volume \\ \#cycle \\ strain\_rate \\ density \end{bmatrix} + \begin{bmatrix} 2.636 \\ 6.419 \\ -0.4 \end{bmatrix}$$

$$\vec{h} = f(\vec{a}) \qquad \text{where} \qquad f(x) = \frac{1}{1+e^{-x}}$$

$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \end{bmatrix} = \begin{bmatrix} 7.994 & -118.331 & 1.408 \\ -31.688 & -82.149 & 1.668 \\ -7.592 & 105.239 & 0.412 \\ 69.309 & 6.6 & -1.151 \\ -28.197 & 14.194 & 2.719 \end{bmatrix} \cdot \left[\vec{h}\right] + \begin{bmatrix} 107.412 \\ 110.703 \\ -96.907 \\ -75.171 \\ 112.127 \end{bmatrix}$$

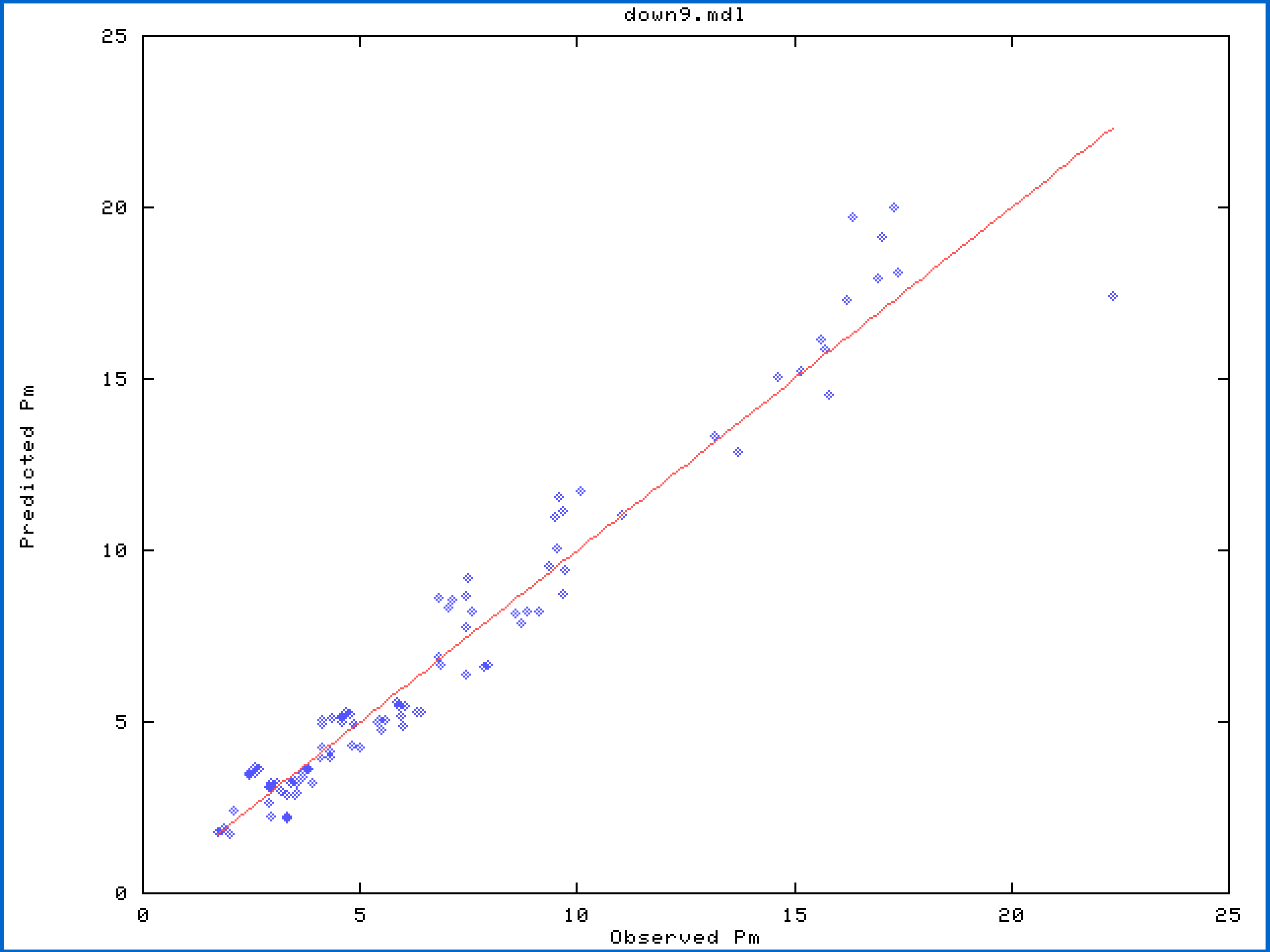
$$\begin{bmatrix} P_m \\ WC \\ LC \\ RC \\ \mathrm{Recovery}\_Height \end{bmatrix} = f(\vec{b})$$

Neural Network (con't)

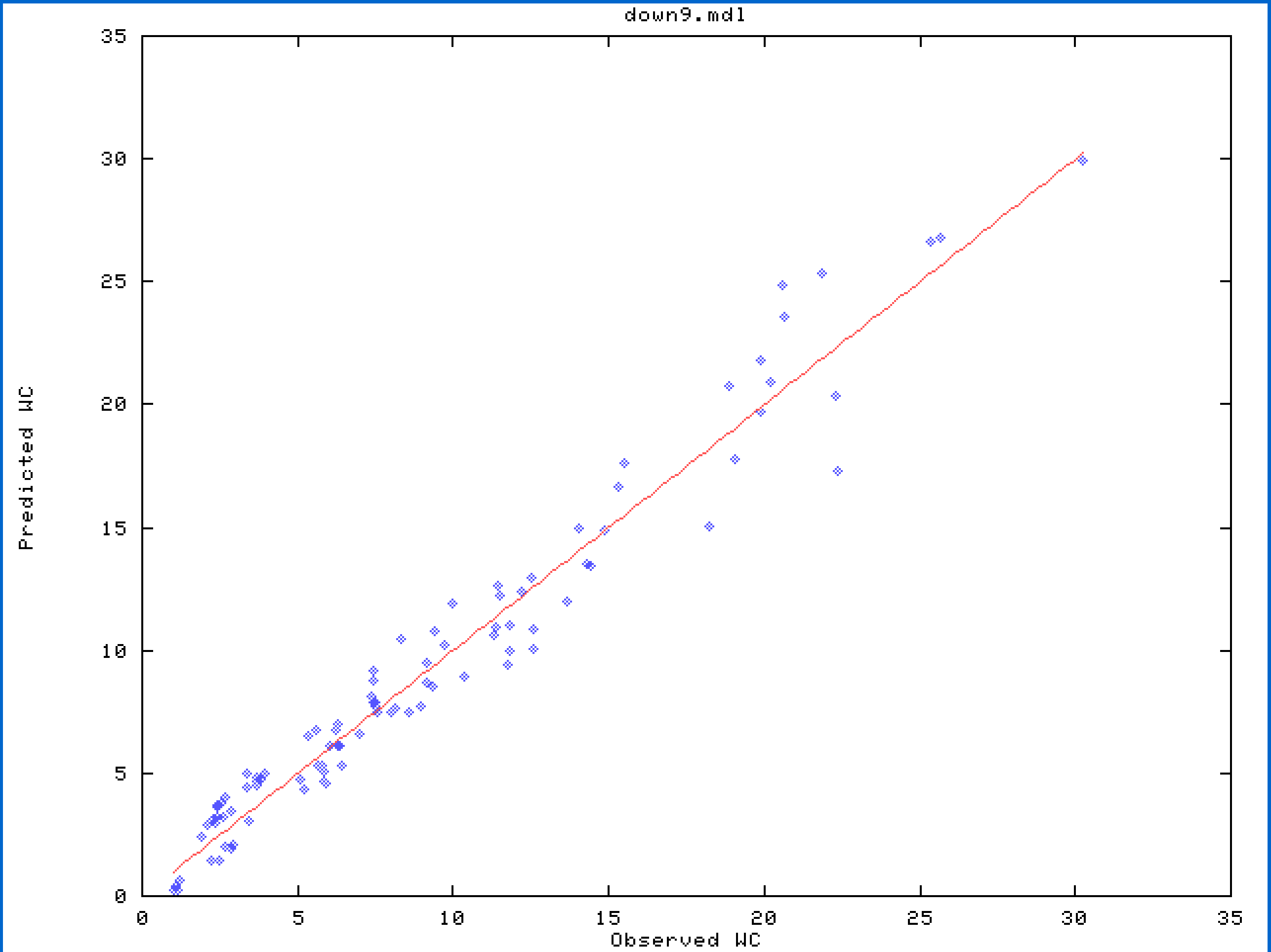
	P_m	WC	LC	RC	Height of recovery
Train data set	0.9539	0.9471	0.8699	0.7997	0.9624
Test data set	0.9470	0.9561	0.9021	0.8582	0.9615

- **Value of 1 means the model can explain 100% of the variations. Value of 0 means none of the variance is explained.**
- **The model can predict P_m, WC, LC RC and Height of recovery well.**
- **The model can explain between 80% to 95% of the variation in data.**

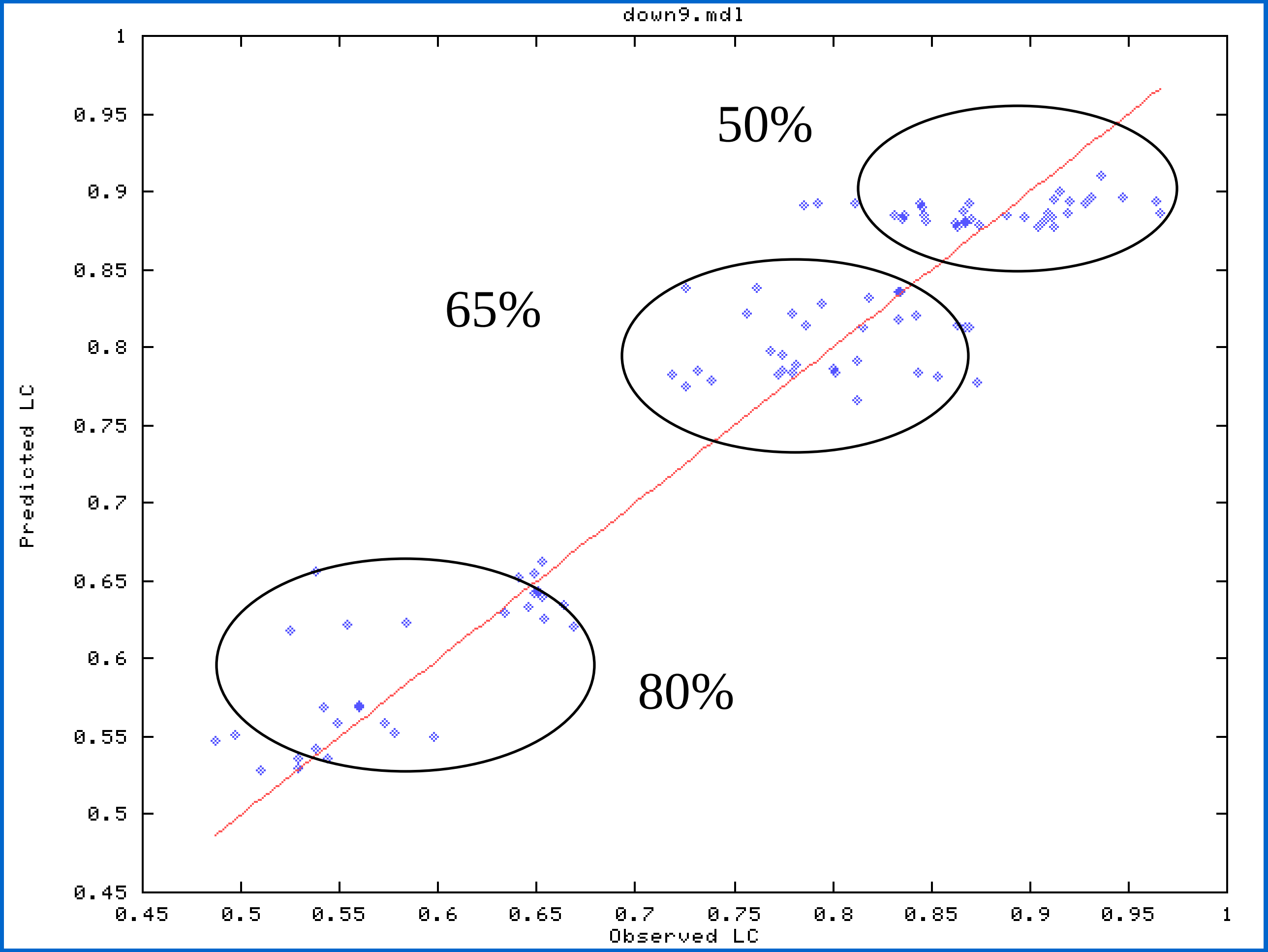
Goodness of Fit Plots-P_m



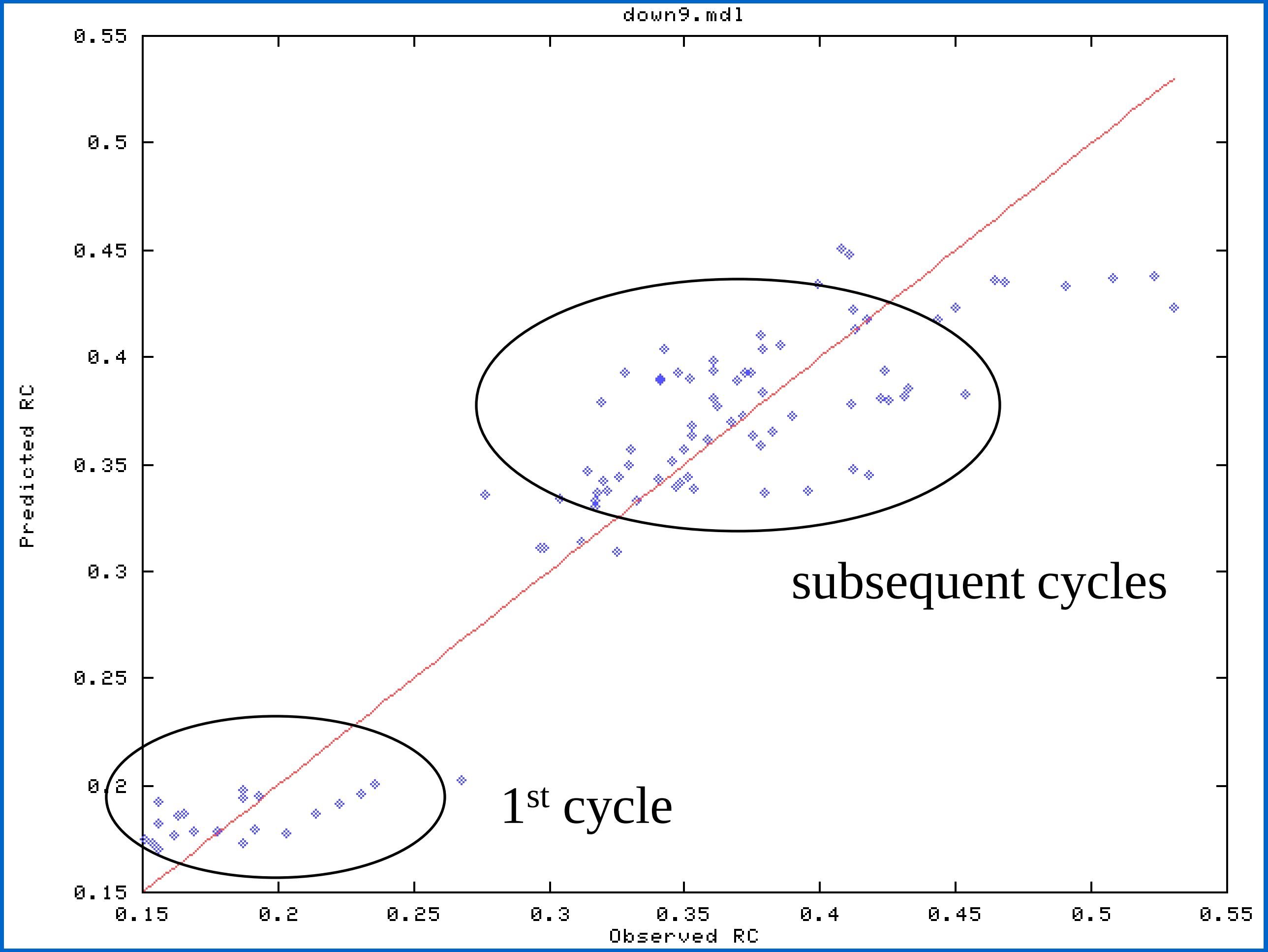
Goodness of Fit Plot-WC



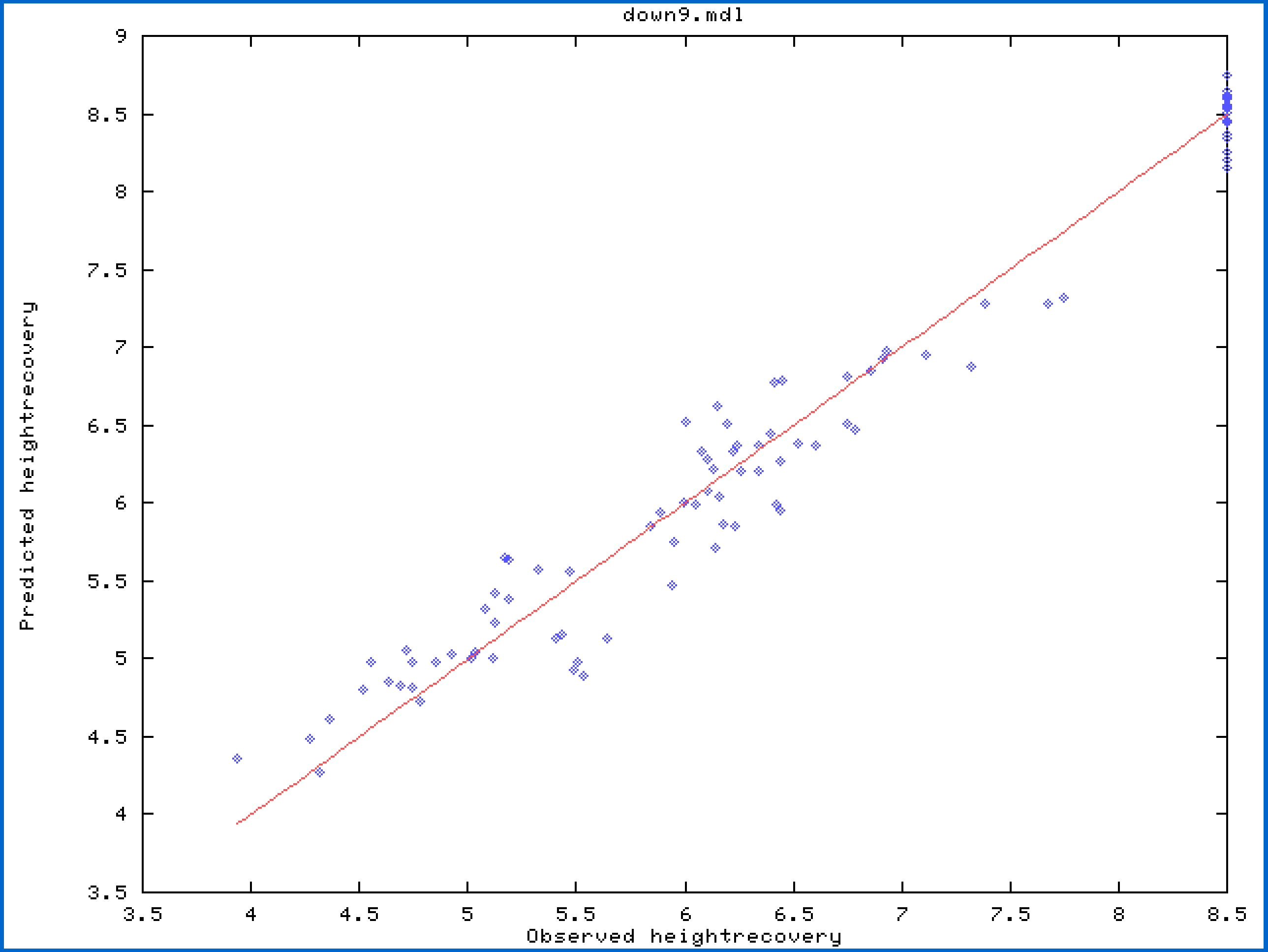
Goodness of Fit Plots-LC



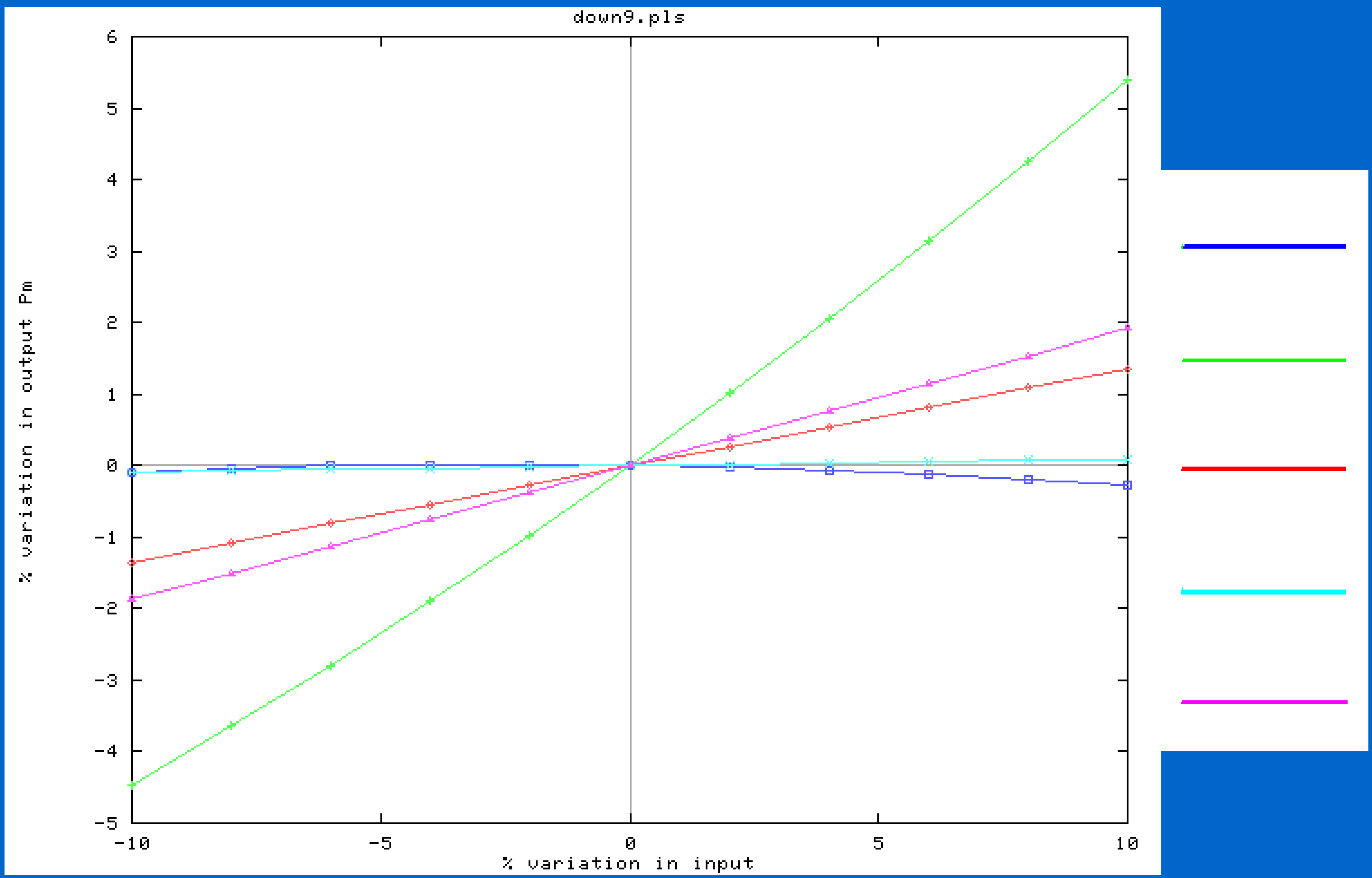
Goodness of Fit Plot-RC



Goodness of Fit Plot-Recovery



Global Sensitivity Plots - P_m



no. of cycle

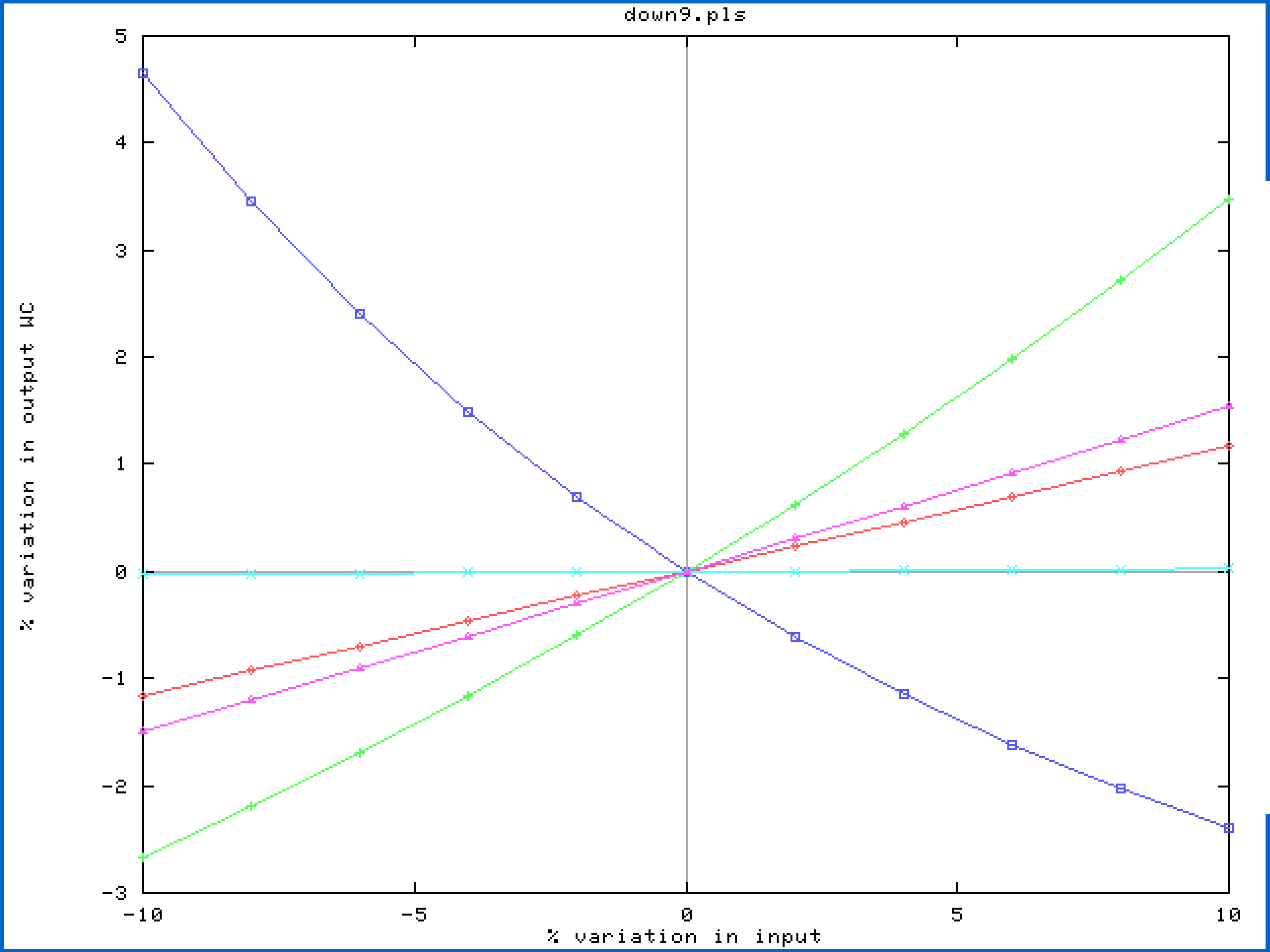
volume compressed

fill power

strain rate

density

Global Sensitivity Plots - WC



no. of cycle

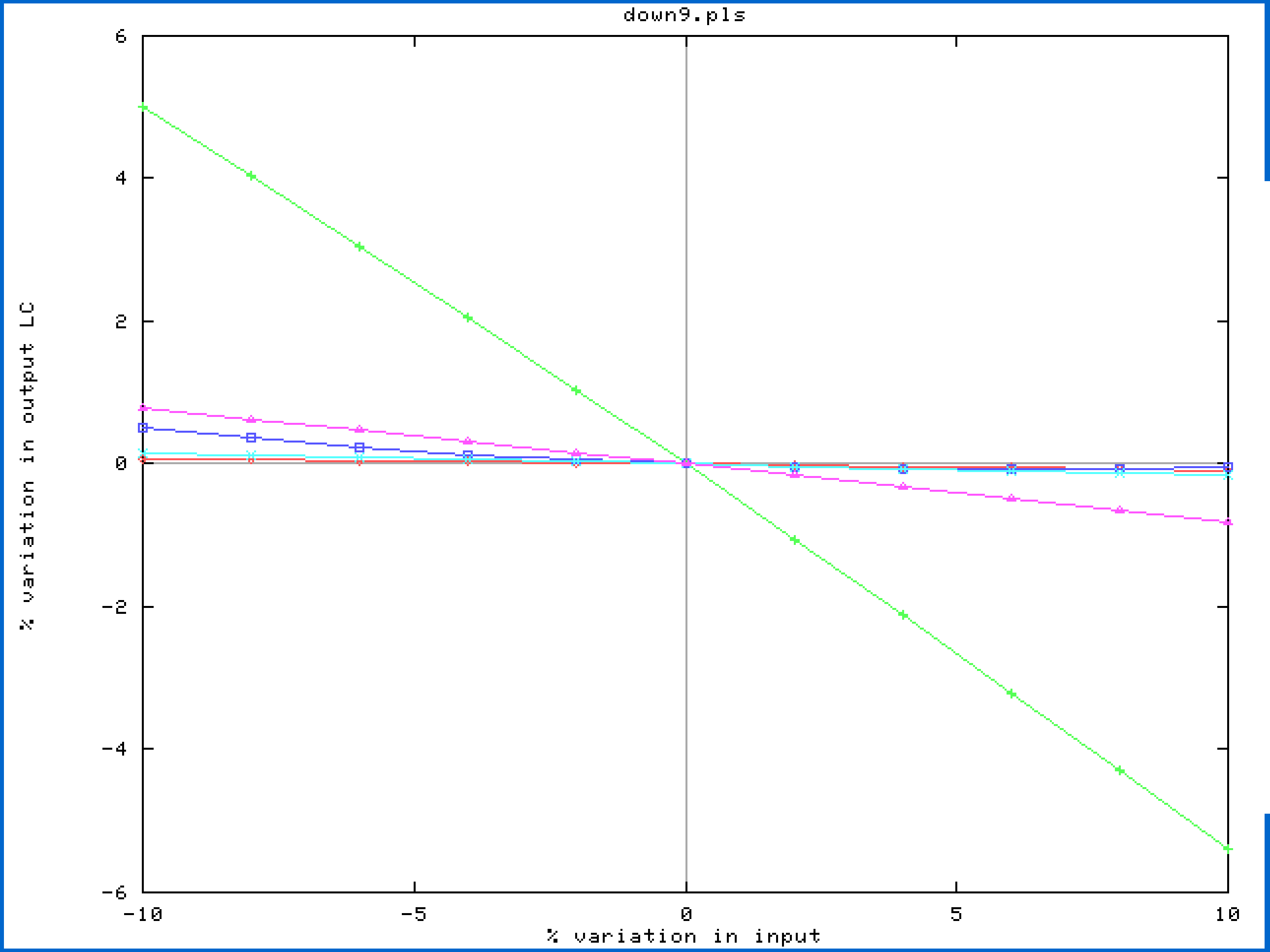
volume compressed

fill power

strain rate

density

Global Sensitivity - LC



no. of cycle

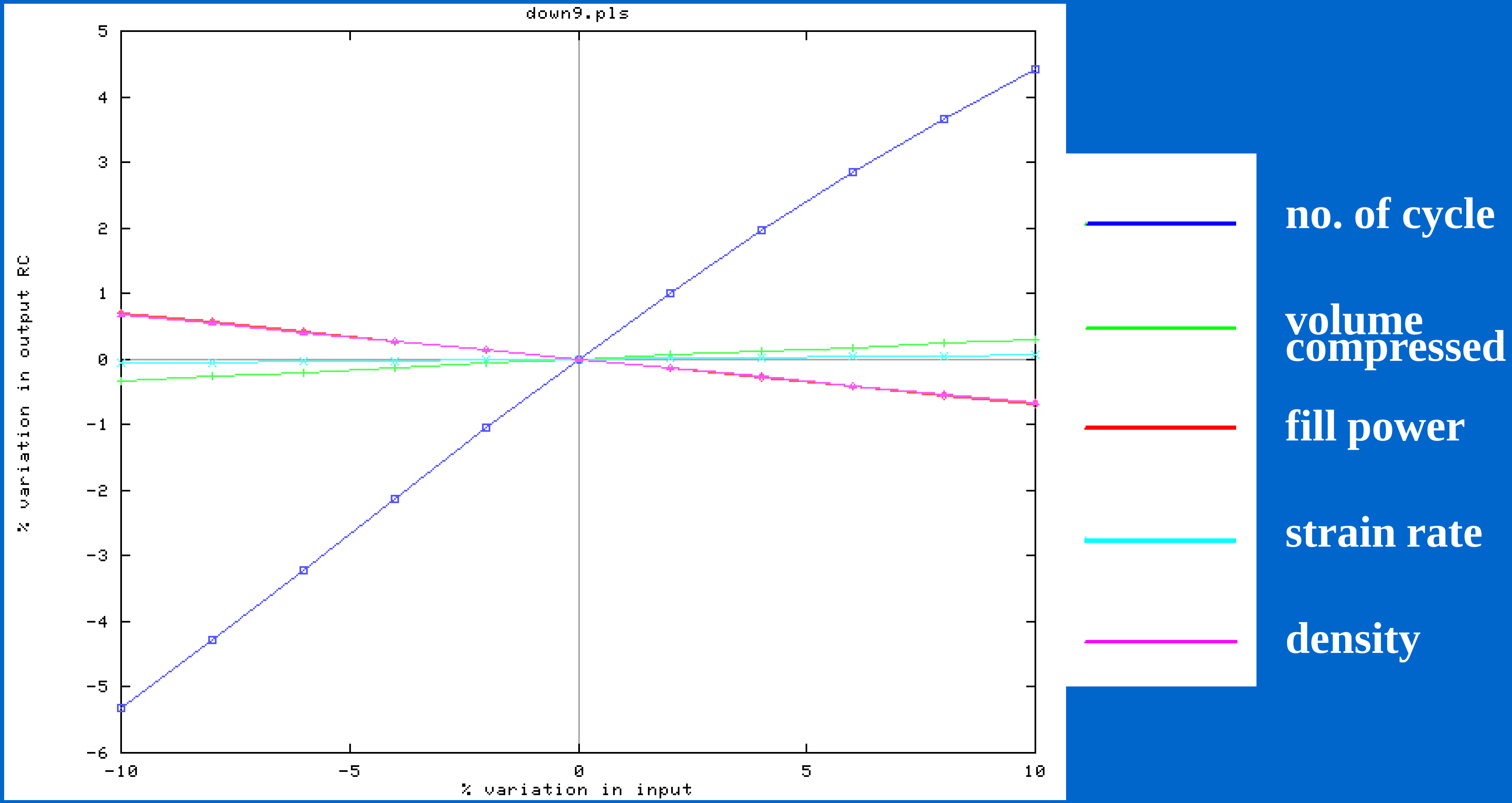
volume compressed

fill power

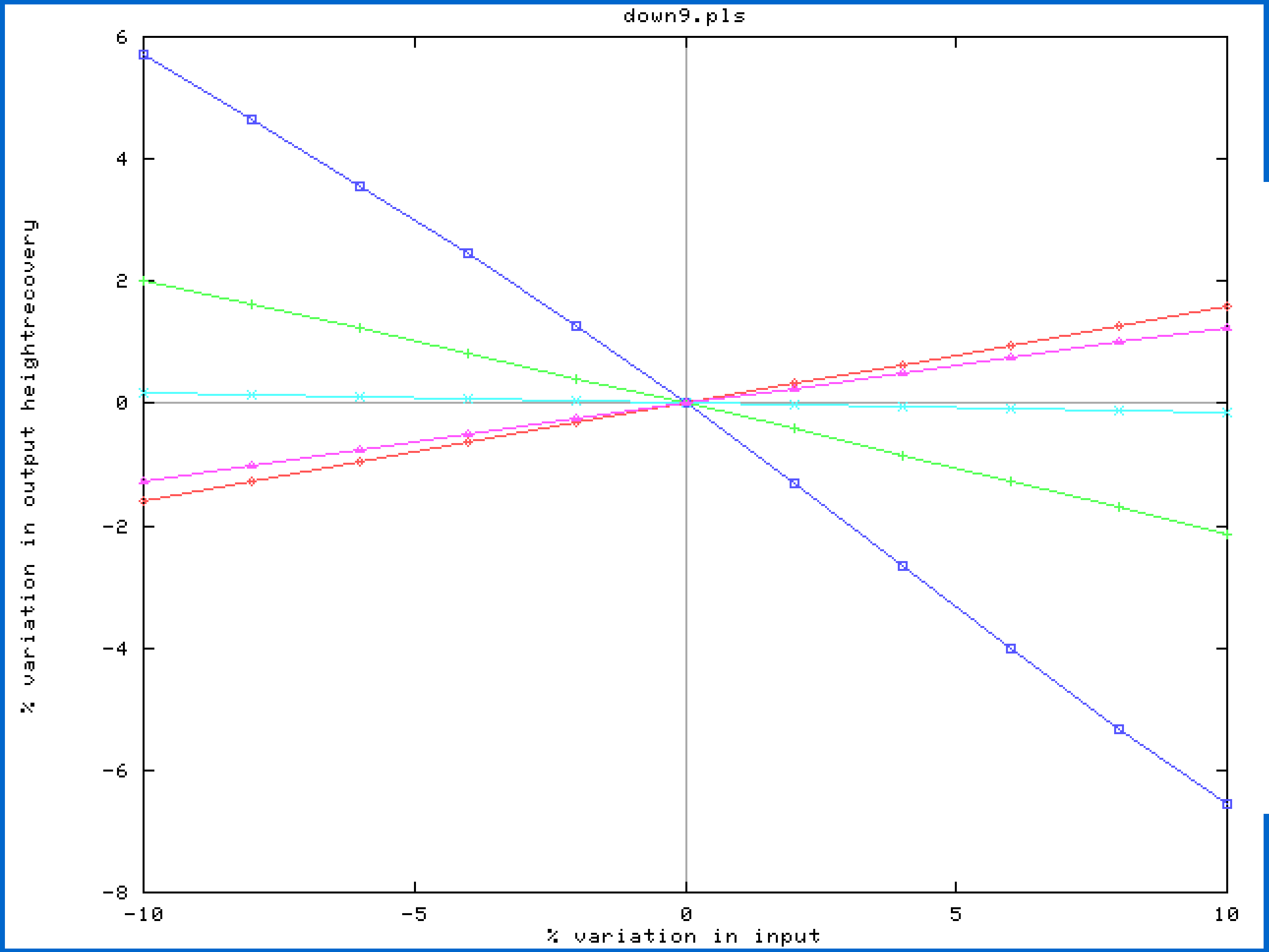
strain rate

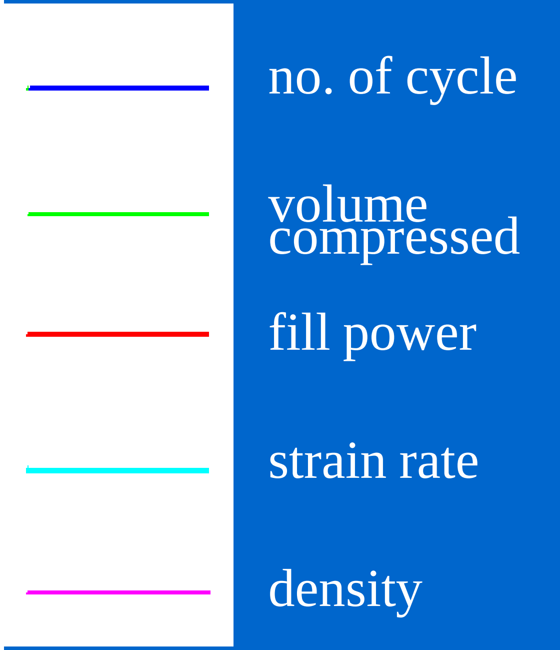
density

Global Sensitivity - RC

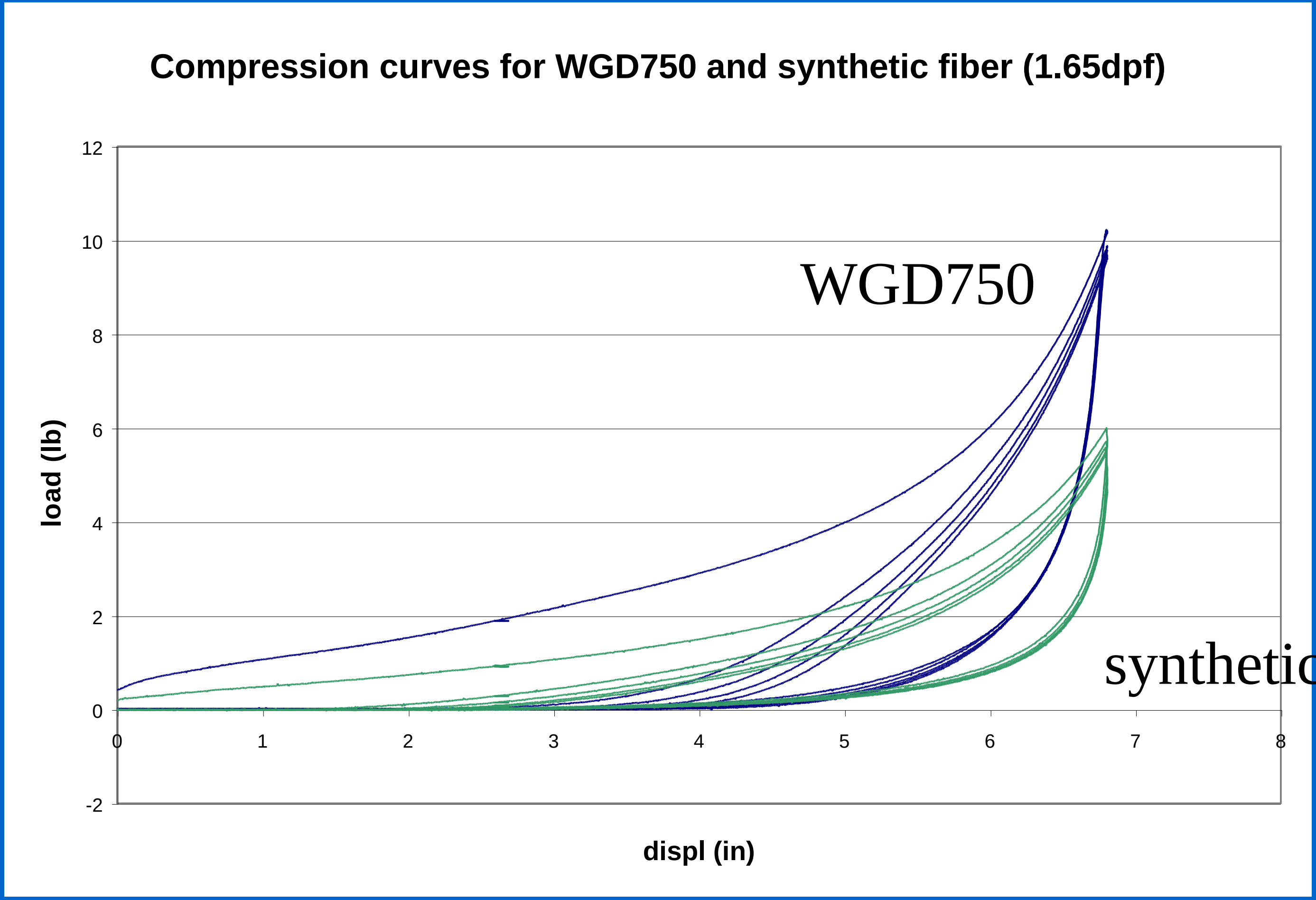


Global Sensitivity-Recovery Height





Comparison with Synthetic Fiber



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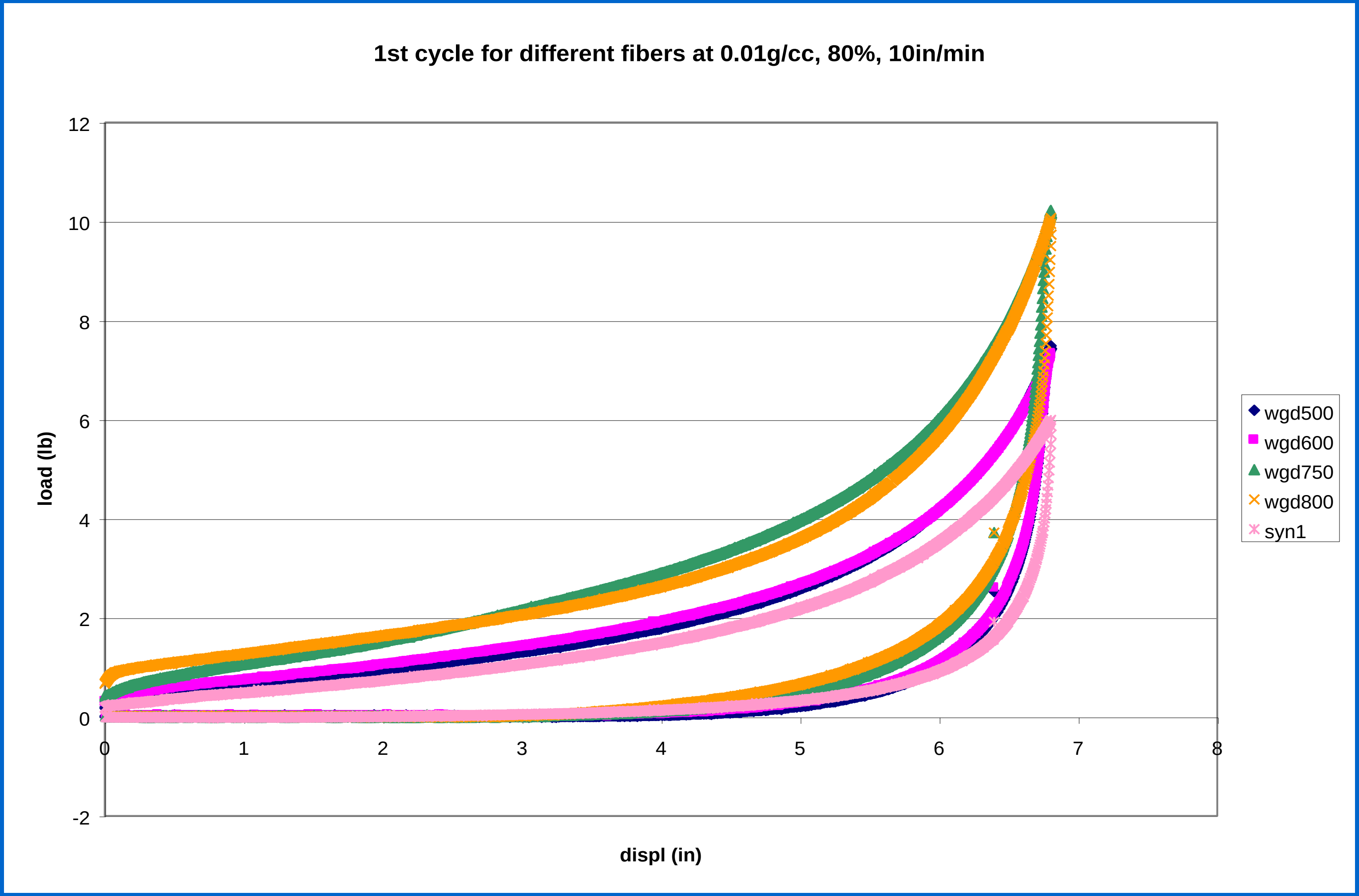
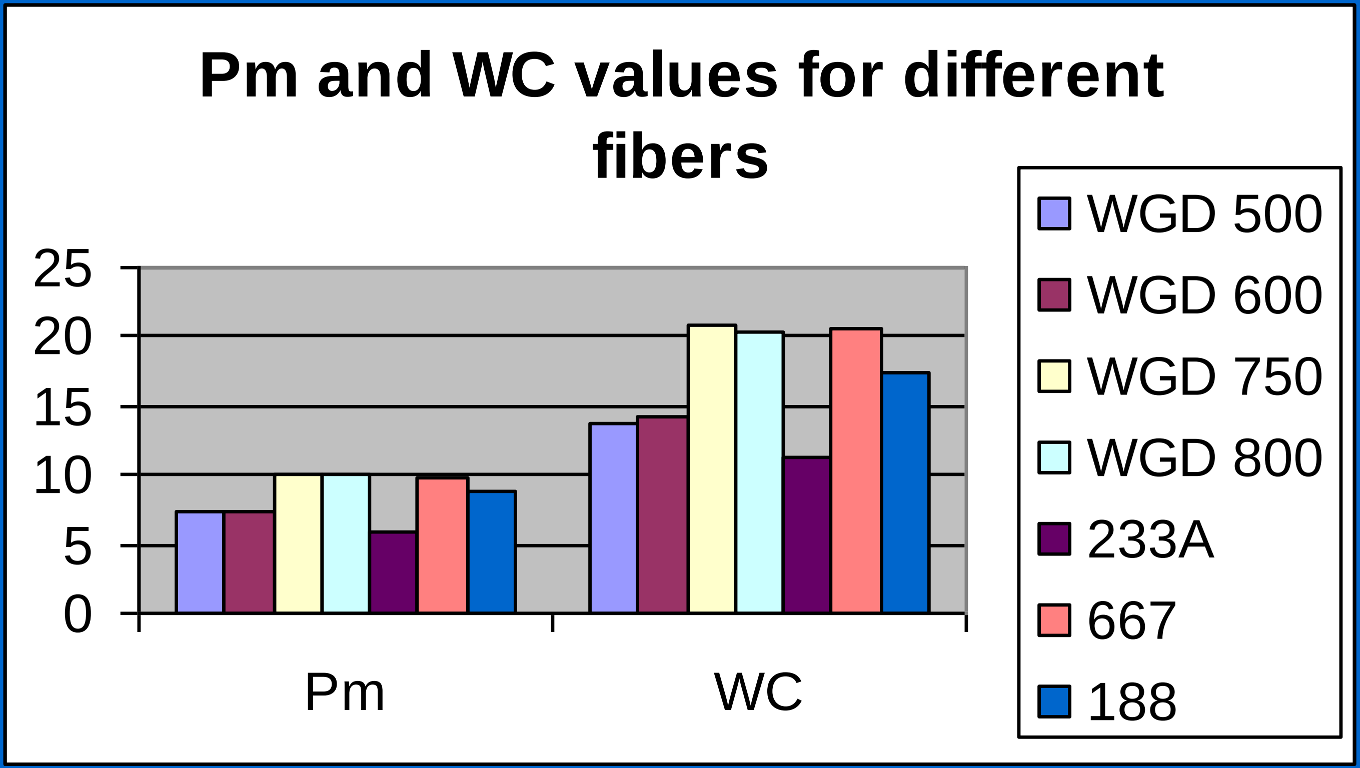
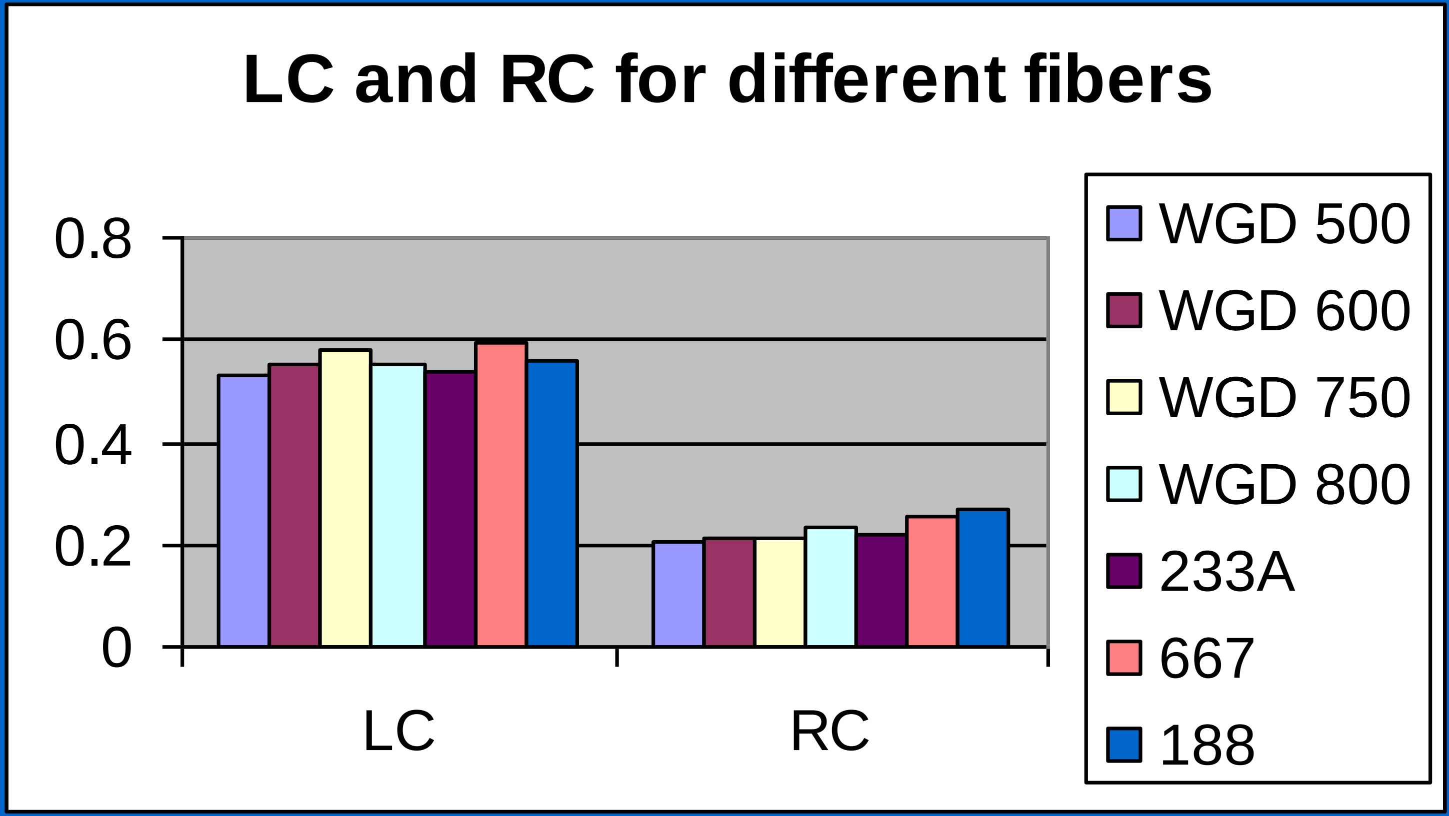


Bar Chart of P_m and *WC* for Different Fibers



Bar Chart of *LC* and *RC* for Different Fibers



Comparison with Synthetic Fiber

	WC		LC		RC	
	down	synthetic	down	synthetic	down	synthetic
50%	5.1-7.2	3.23	0.94-1.0	0.84	0.12-0.16	0.2
65%	8.1-10.8	6.4	0.80-0.89	0.76	0.15-0.20	0.2
80%	13.7-20.2	11.3	0.55-0.58	0.54	0.20-0.23	0.22

Target Outputs at 50% compression, 0.0036 lb/in^3

	WGD 500-600	WGD 700-800
Pm	2.2	2.8
WC	5.5	6.5
LC	0.95	0.9
RC	0.13	0.17

Conclusion

- An empirical model has been developed using Neural Network
- The model can predict P_m, WC, LC and Recovery height very well, but not as well for RC
- Strain rate has no impact on all the outputs
- For the first cycle Down has higher WC, higher LC and lower RC than the synthetic fiber tested with same amount of compression

Thank you

Next ...

- Run test with synthetic fiber
- Compute the WC, LC and RC, and compare them with those of down
- Provide input to develop new product