IMPORTANCE OF CROSS-SECTIONAL SHAPE FACTOR PARAMETER RESOLUTION IN ACCURATE ASSESSMENT OF TRANSFER LENGTH FOR NON-PRISMATIC RAILROAD CROSSTIES

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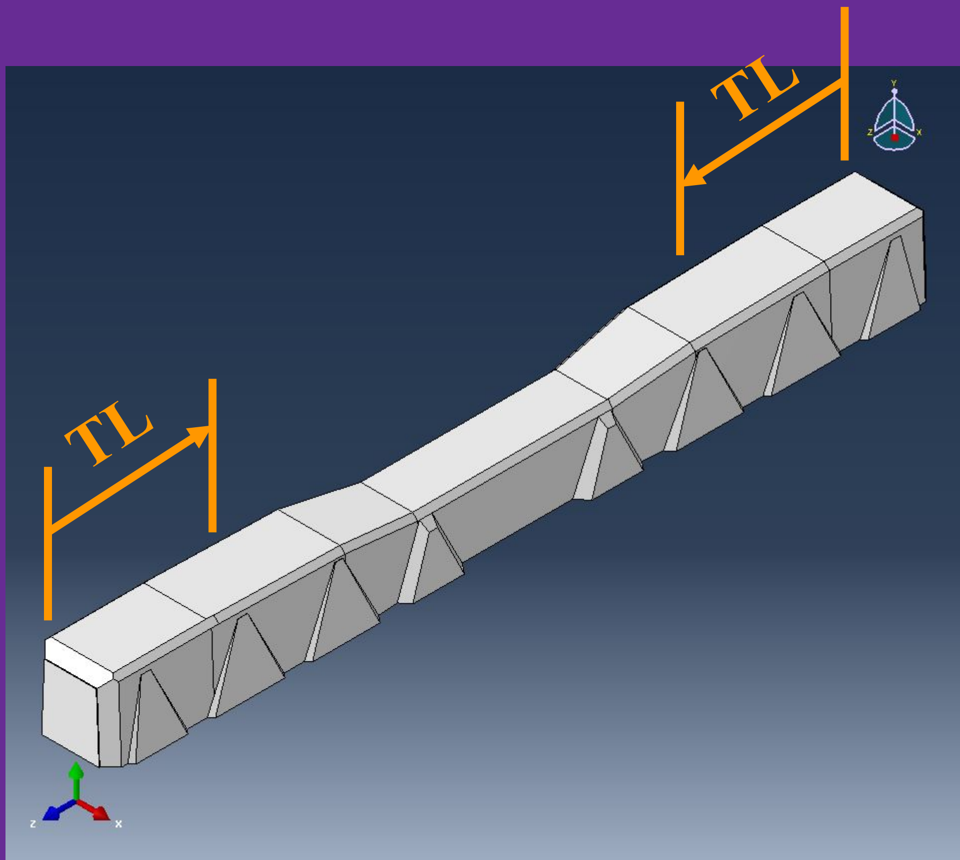
Presentation Outline:

- Introduction—Importance of Transfer Length
- Transfer Length Measurement from Strain
- Parameters Affecting Transfer Length Assessment
- Objectives—Importance of Shape Factor
- Role of 3D Scanning for Cross-Sectional Parameters
- Effect of Shape Factor Resolution
- Conclusions and Future Work

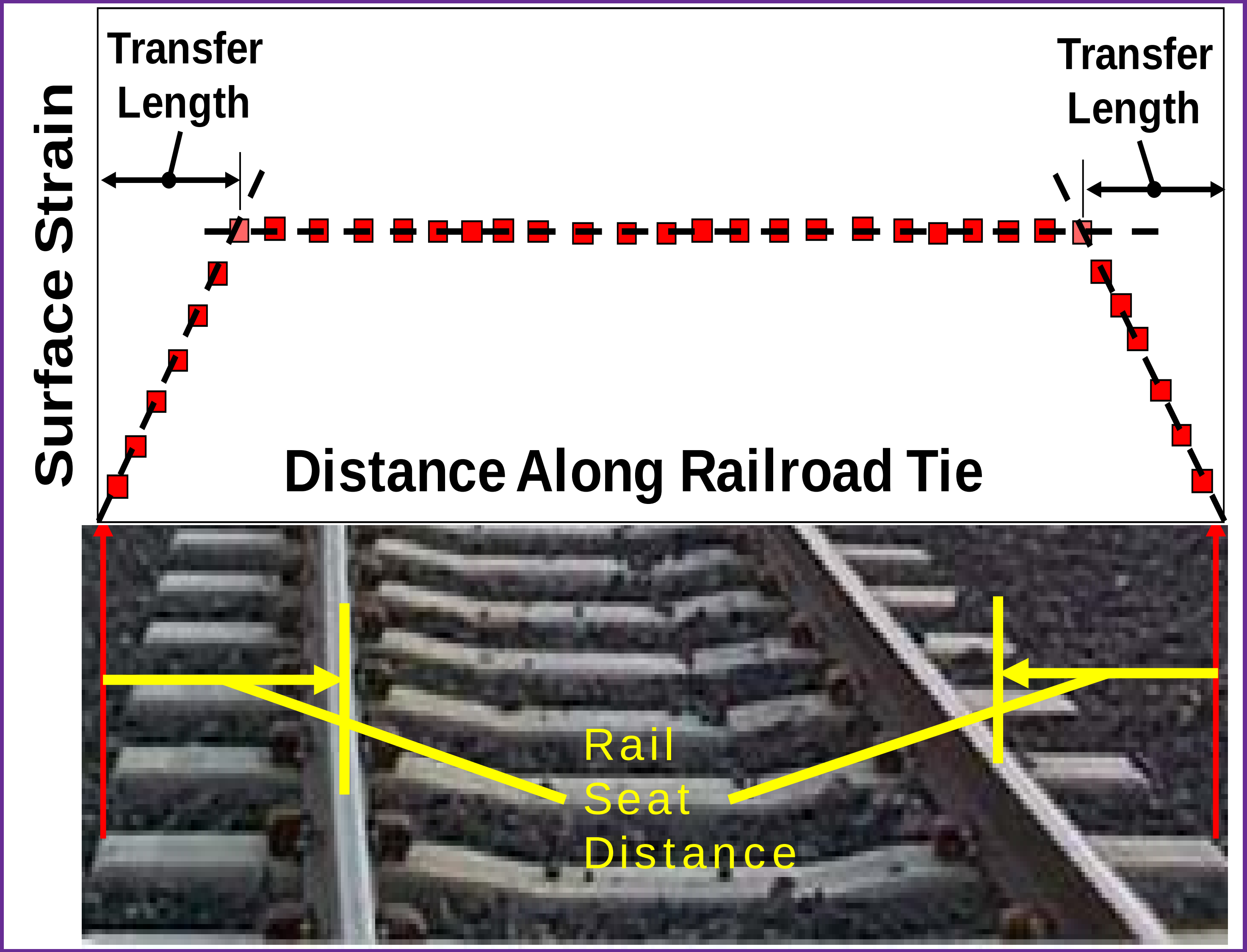
Importance of Transfer Length

The Transfer Length



The Transfer Length (TL) is the distance required to transfer the entire prestressing force into the concrete cross-tie member

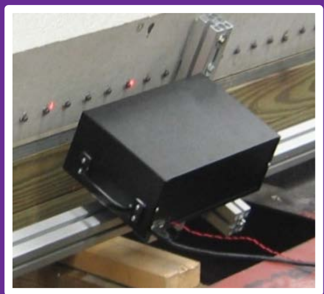
The Transfer Length

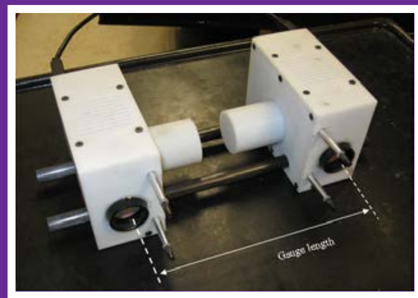


Goal: Avoid In-Track Cross-tie Failure

Transfer Length Measurement—Role of Automated Surface Strain Measurement

Historical Development of Non-Contact (Optical) Automated Transfer Length Measurement System



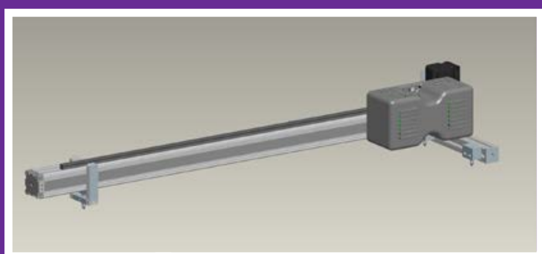


Early Rail-Mounted Manual Prototype

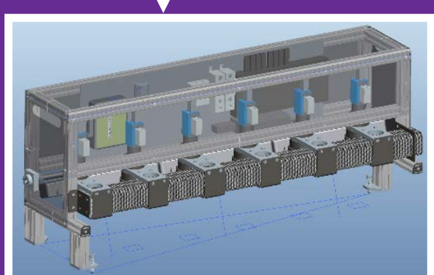
Modular System Design; Patented

Patent No.: US 8,917,384 B2

Date of Patent: Dec. 23, 2014

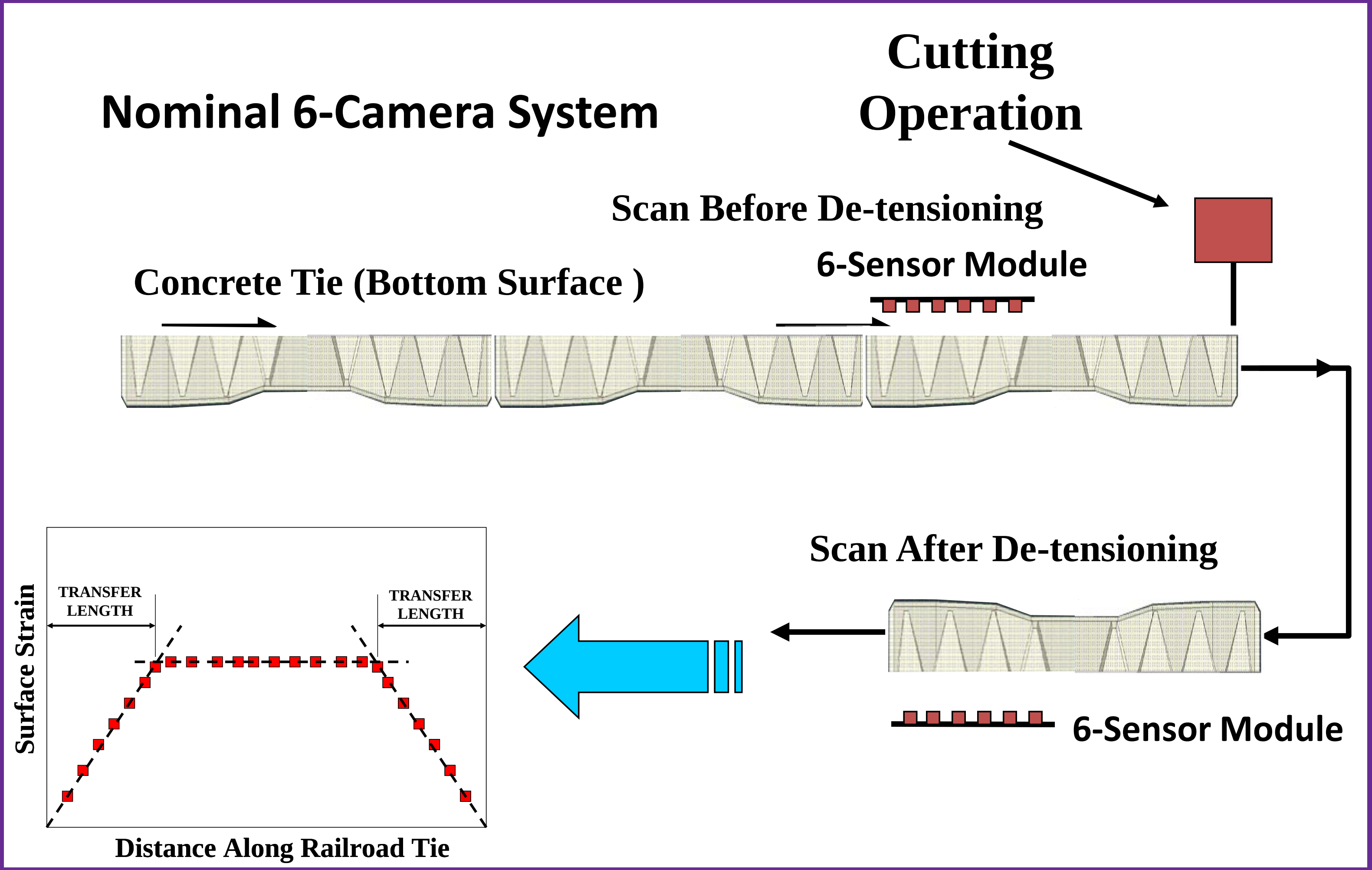


Automated Dual-Camera System
(Computer-Controlled Traversing)



Current Prototype 6-Camera System
(Full-Field Strain Capture)

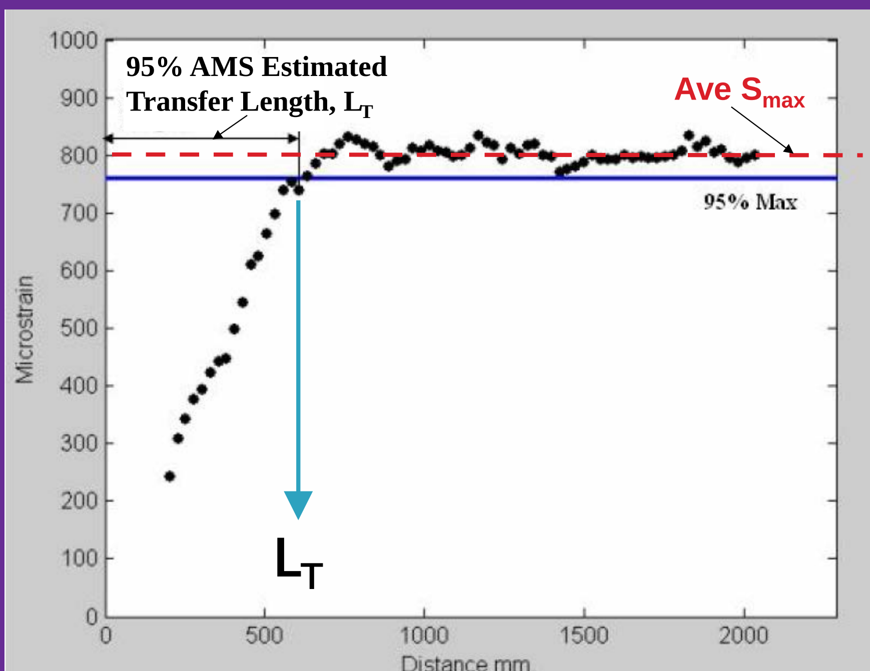
Automated Transfer Length Measurement for In-Plant Quality Control



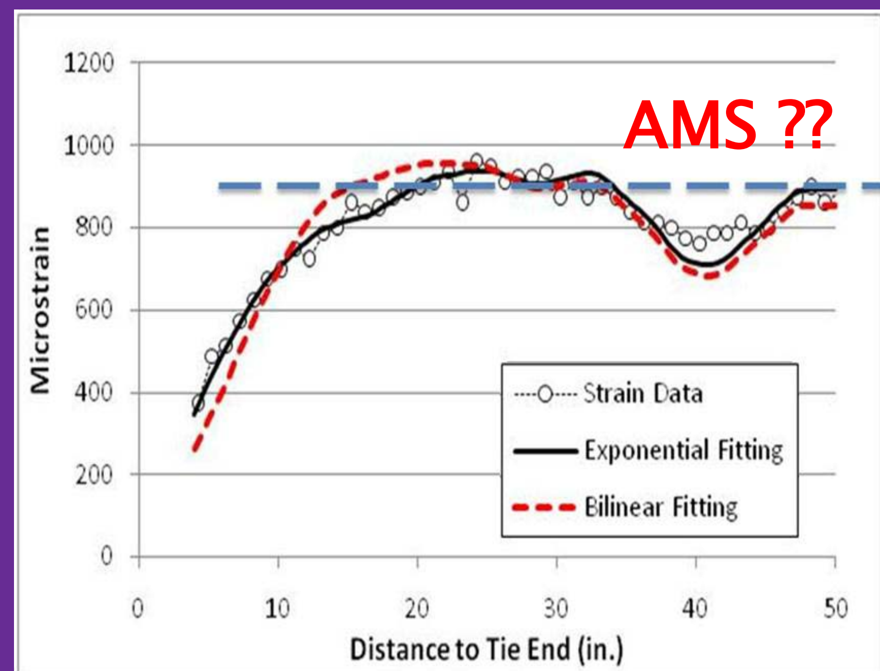
The Zhao–Lee (ZL) Method of Unbiased (Least Squares) Transfer Length Assessment

The Need for Unbiased Transfer Length Algorithm

Prismatic Members

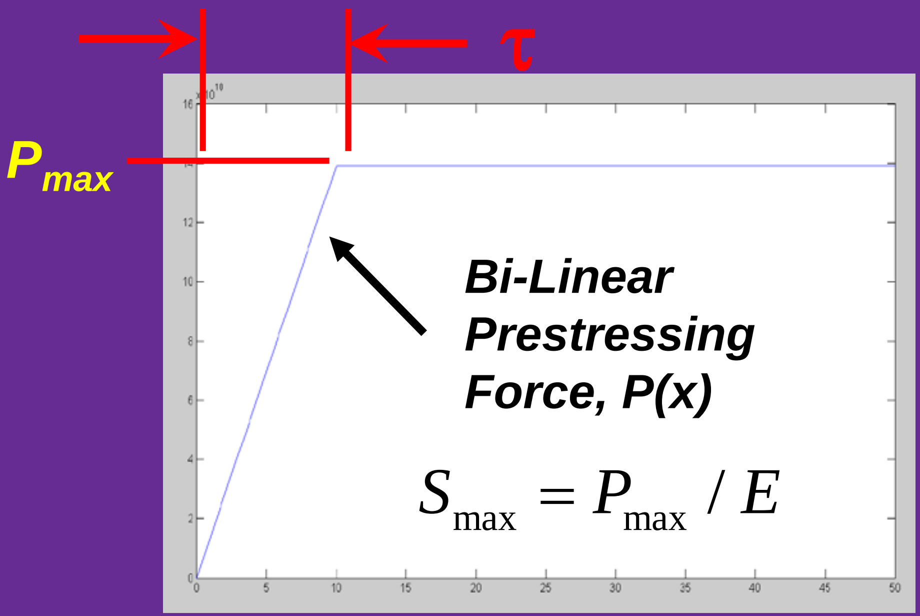


Non-Prismatic Members



Importance of Accounting for Tie Shape Variation

The Statistical ZL Strain Fitting Algorithm:



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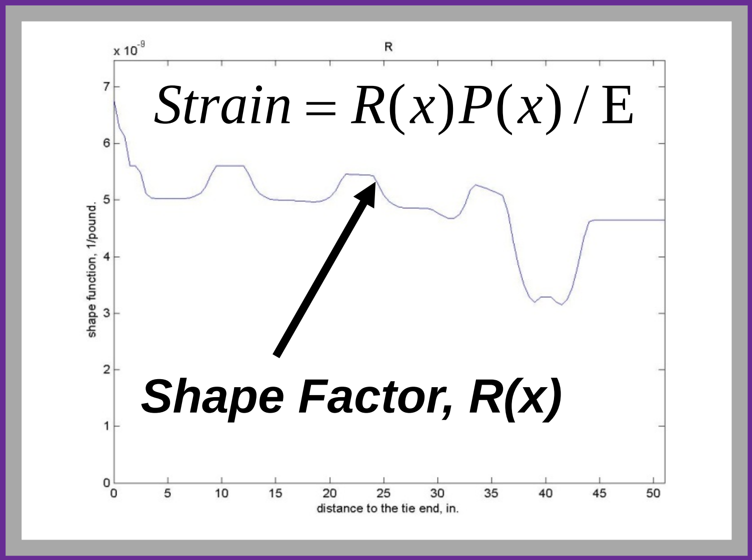
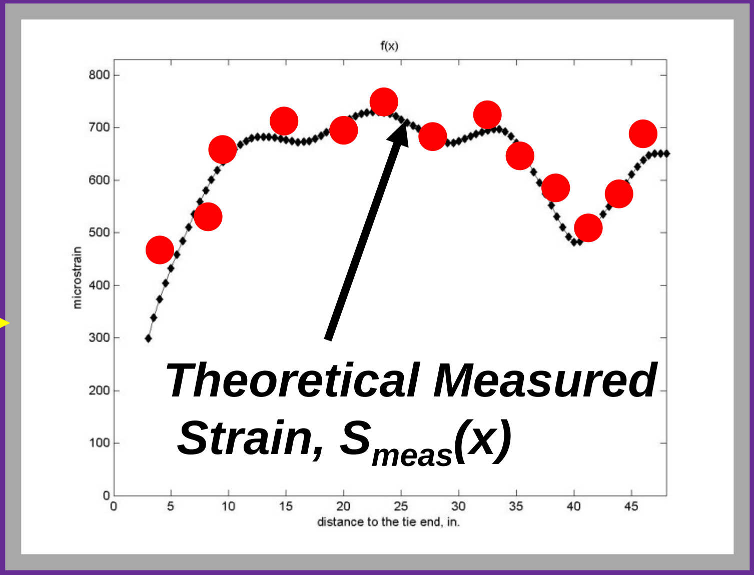


+

$$S_{meas}(x, P_{max}, T_L, TS) = \frac{1}{L}\int_{x-\frac{L}{2}}^{x+\frac{L}{2}} \left[Strain(x, P_{max}, T_L) + TS \right] dx$$

Averaging over Finite Gauge Length



Generalized "Zhao-Lee" (ZL) Transfer Length Algorithm:

Find T_L and TS to Minimize MSE:

$$MSE(P_{\max}, T_L, \mathrm{TS}) = \frac{\sum_i (S_{meas}(x_i, T_L, TS) - y_i)^2}{N}$$

Where

MSE = Mean Squared Error

y_i = Measured Strain Data

S_{meas} = Theoretical Measured Strain

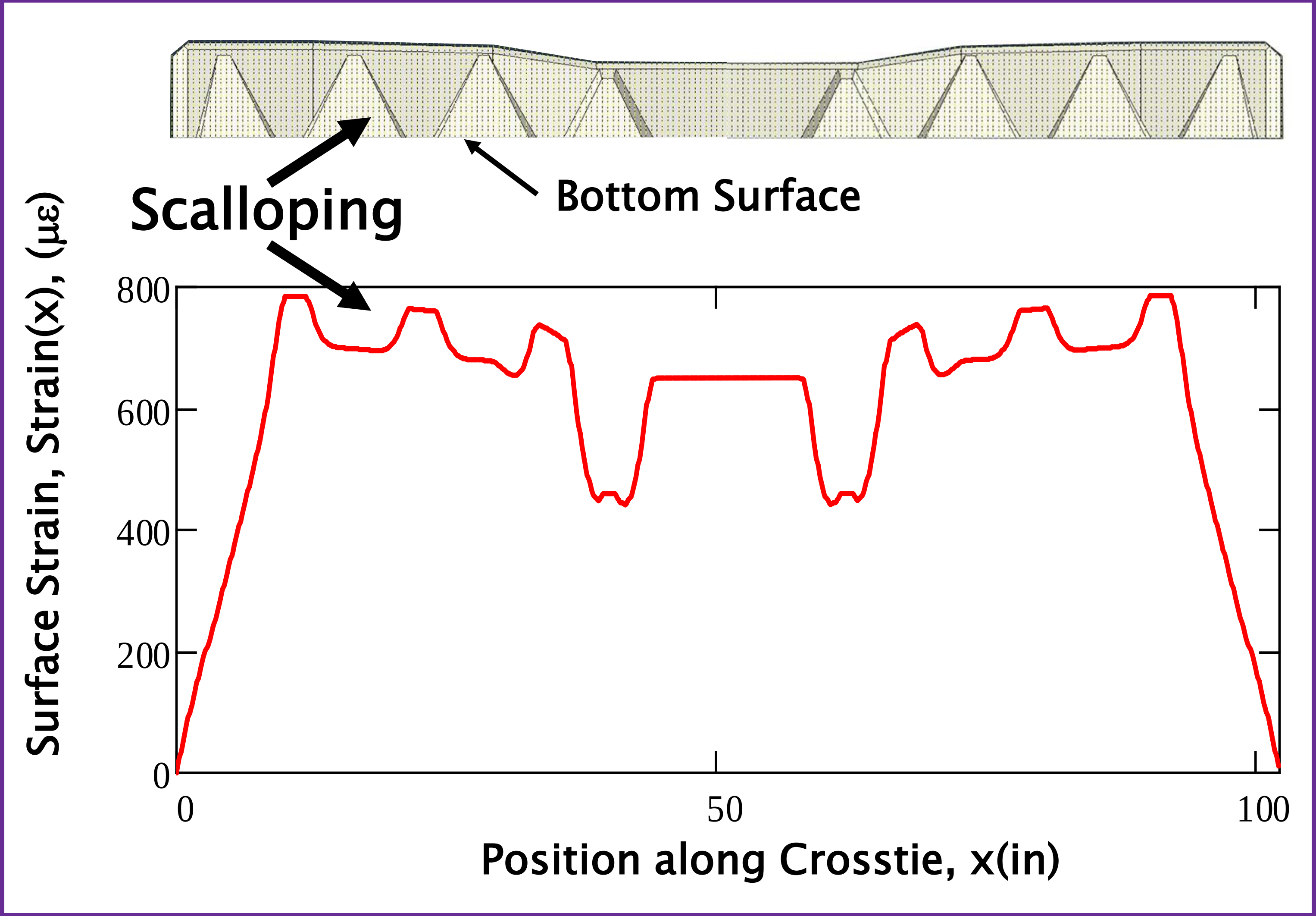
TS = Thermal Strain Offset

Parameters Affecting Transfer Length Measurement from Longitudinal Surface Strain

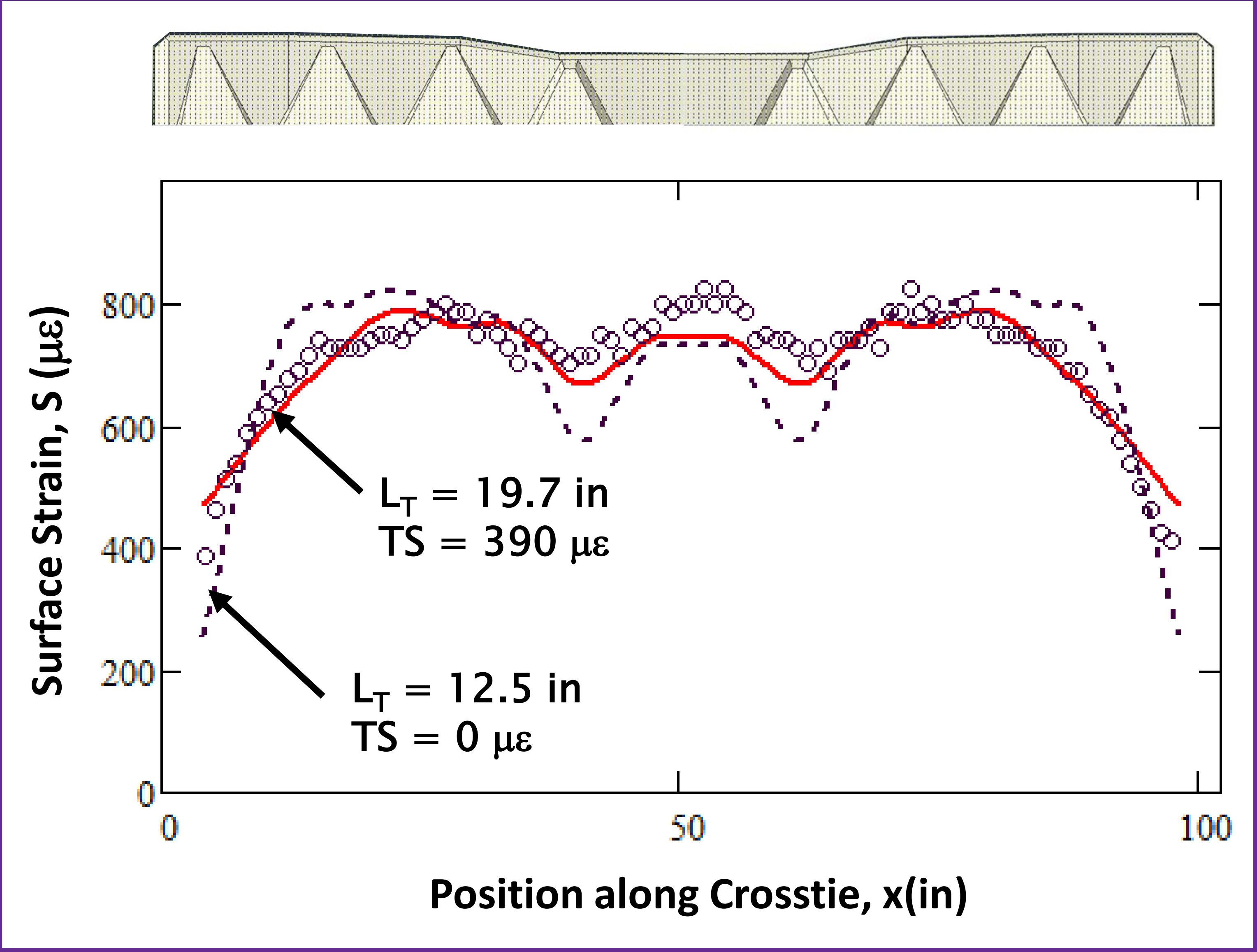
Parameters that Affect Transfer Length Measurement

- Surface Strain Measurement Accuracy
- Strain Measurement Span and Sampling Interval
- Strain Instrument Gauge Length
- Assumed Shape of Prestressing Force Distribution
- Effect of Thermal (Offset) Strain
- Extraction Algorithm (95% AMS or Zhao-Lee)
- Cross-Section Shape (Shape Factor Variation)

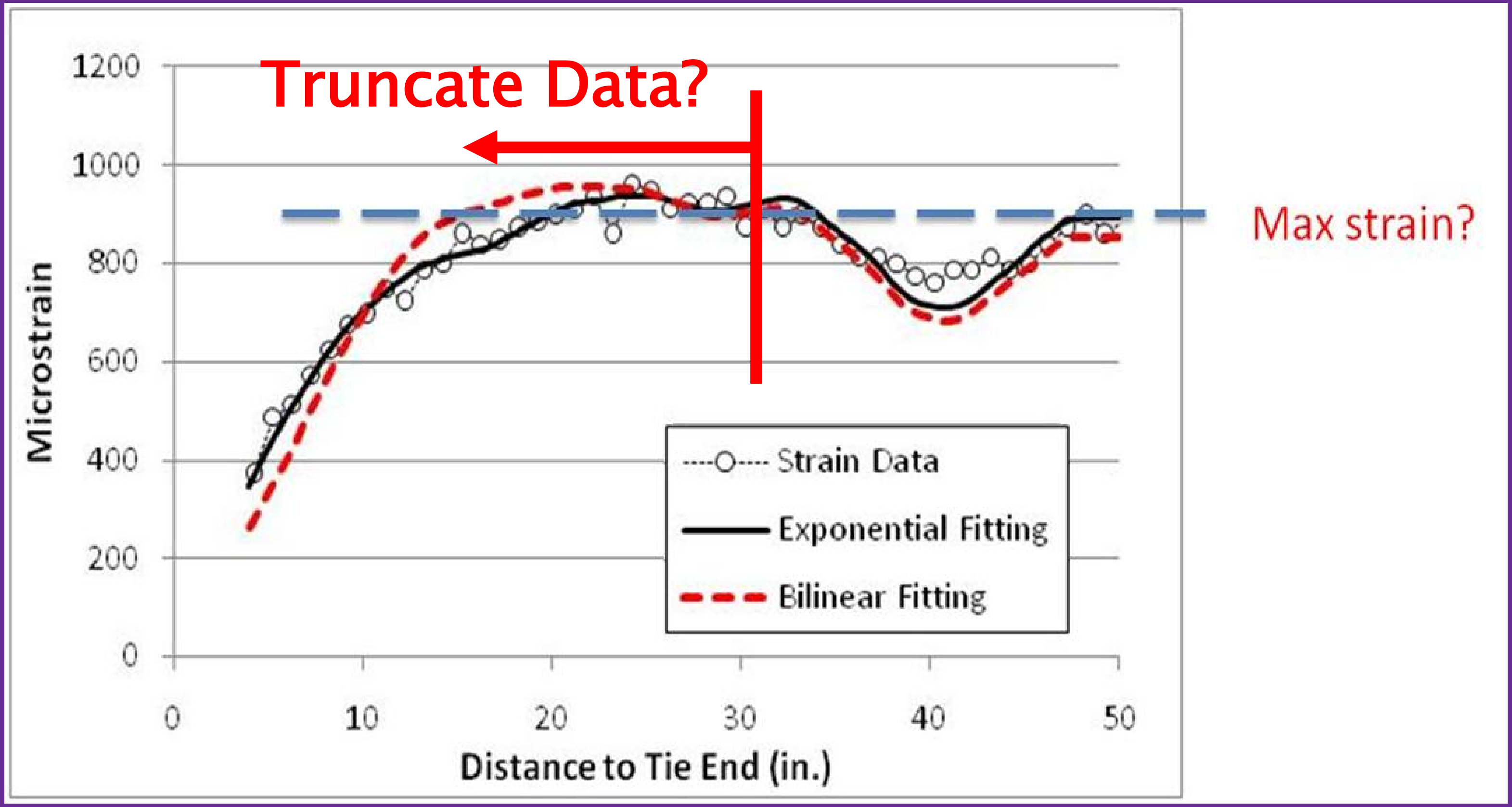
Complex Crosstie Strain Distribution



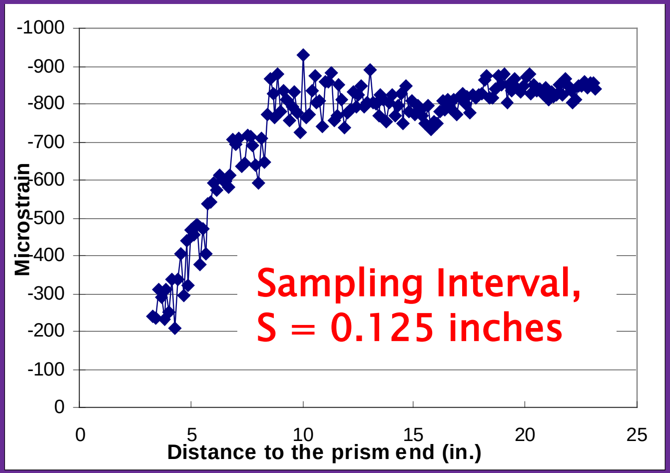
Effect of Thermal (Offset) Strain

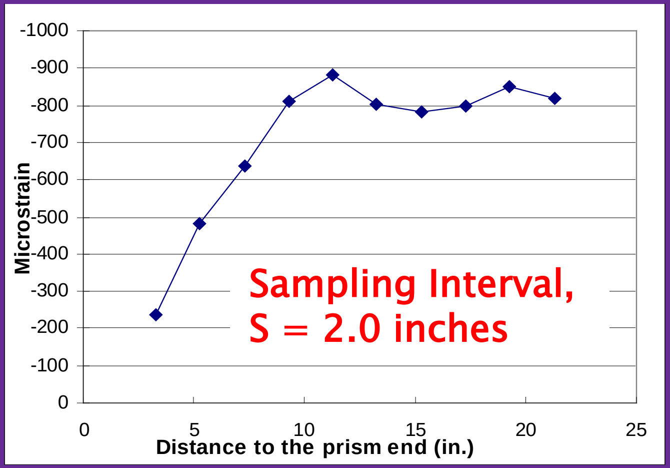


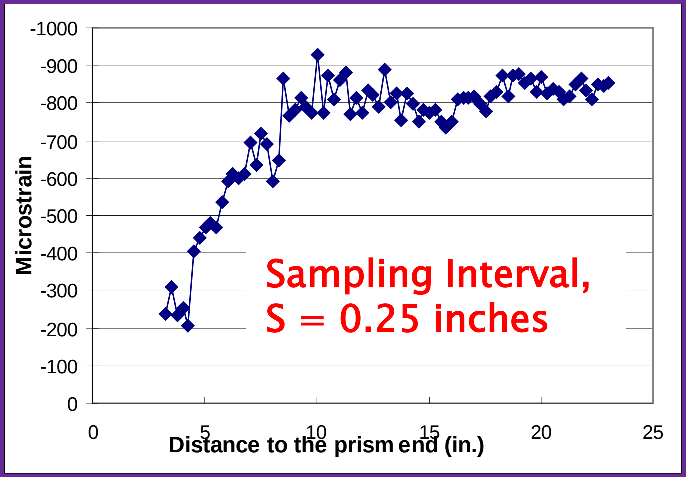
What is the Average Maximum Strain (AMS)?

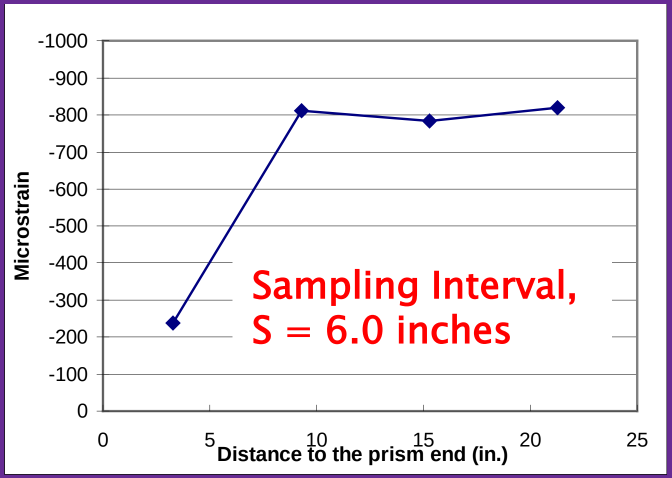


Automated Strain Measurements at Various Strain Sampling Intervals, S





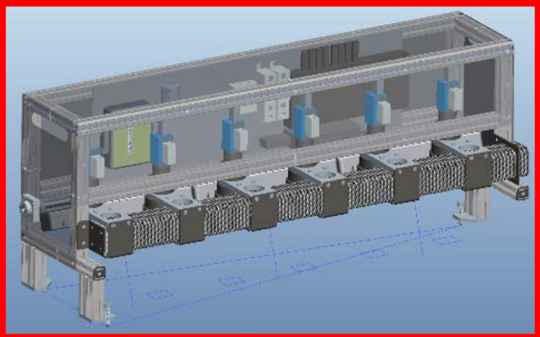




Independence of Transfer Length Assessment (ZL Method) at Various Sampling Intervals

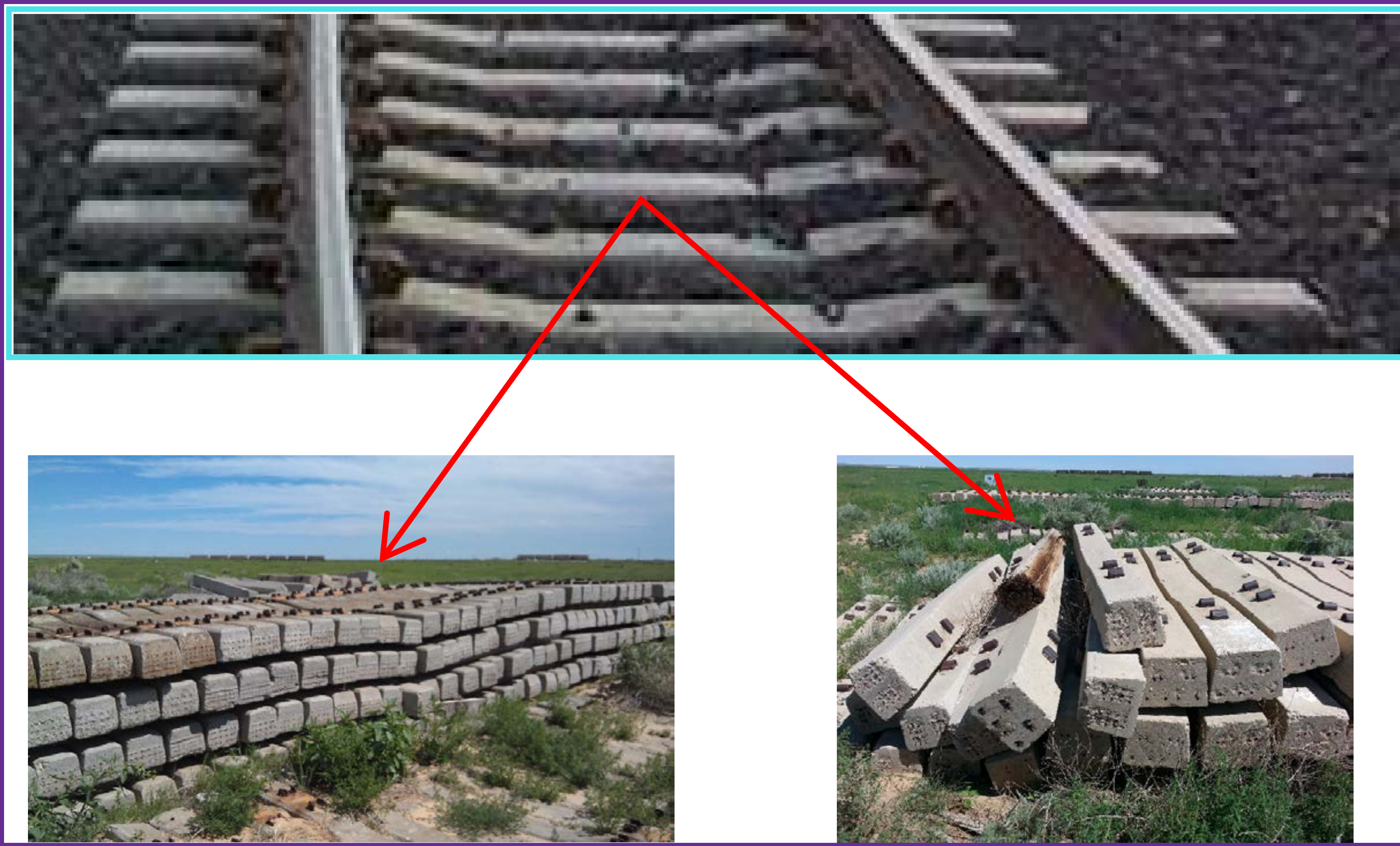
Sampling Interval (in.)	Estimated Transfer Length (in.)
0.125	9.1
0.25	9.0
0.5	9.2
1	9.5
2	9.0
4	9.6
6	9.0
8	10.3

6-Camera System



The Role of 3D Optical Scanning in Current Research Efforts

In-Service Crossties at Pueblo Colorado Facility (TTCI)—Major Source of Ties

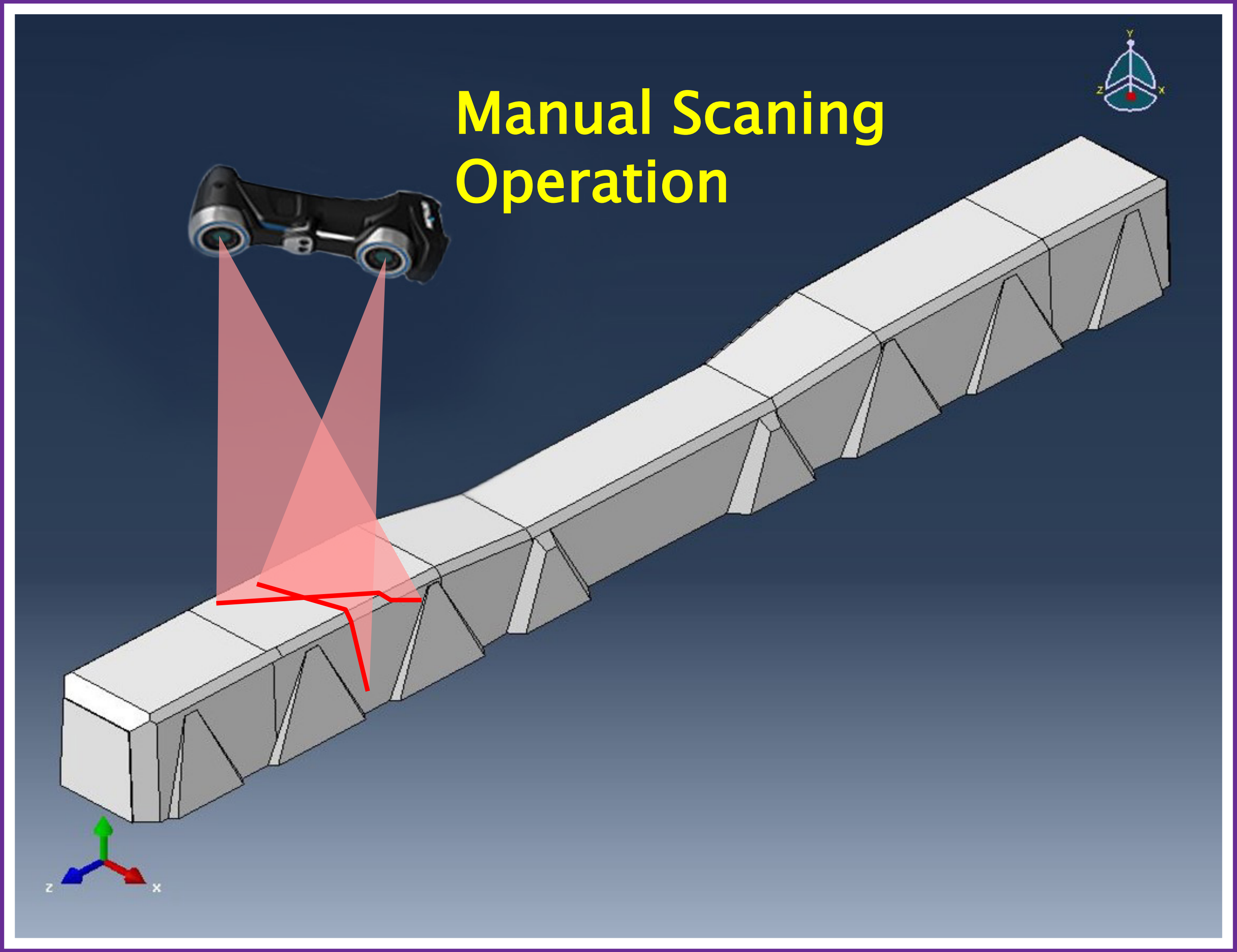


CXT Crossties from In-Track TTCI Facility

KEY Role of 3D Scanning:

- Quantify Surface Geometry of Previously Manufactured Ties that have been in Service
- Produce Accurate 3D Solid Body Models of In-Service Ties for Later Analysis
- Direct Comparison of Overlapping Images of 3D Scanned Ties
- Quantify the Amount of Abrasion Which Has Occurred During the Life of In-Service Ties

Schematic of 3D Optical Scanning of Railroad Crosstie Using Commercial Device

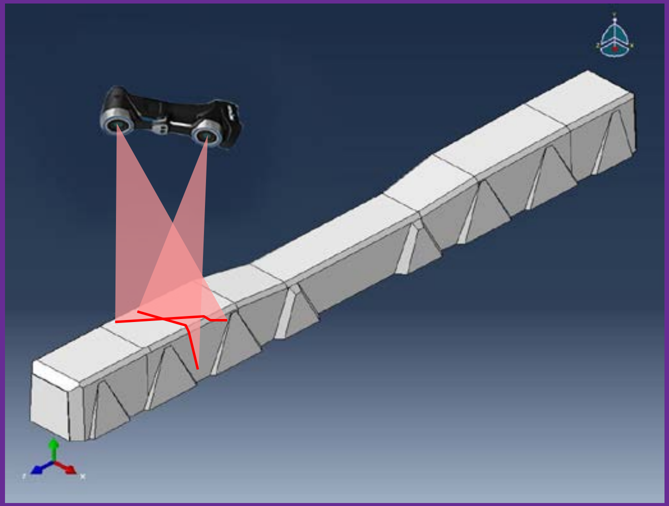


Commercial 3D Scanner Specifications:

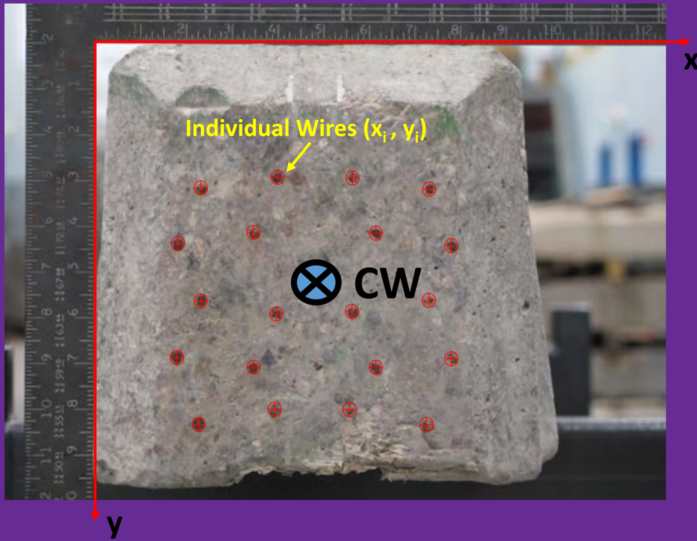
- <u>7 Pair Intersecting Laser Light Sheets</u>
- Local Scanning Area: 275 x 250 mm (10.8 x 10 in.)
- <u>Resolution: 0.050 mm (0.002 in.)</u>
- Accuracy: 0.030 mm (0.0012 in.)
- Volumetric Accuracy: 0.020 mm + 0.060 mm/m (0.0008 in. + 0.0007 in./ft)
- <u>Depth of Field: 250 mm (10 in.)</u>

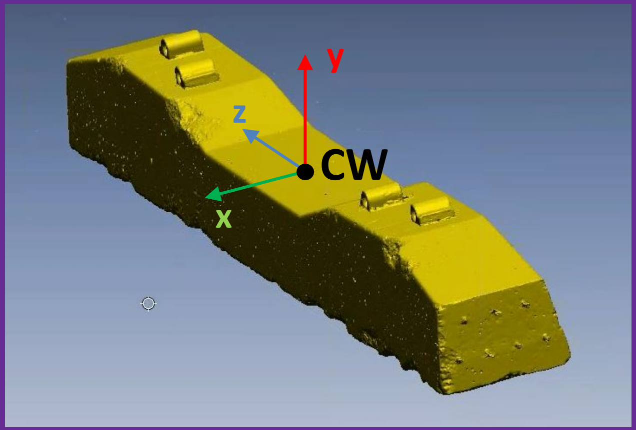
Slicing of Solid Model & Parameter Analysis

3D to Point Cloud Model of Tie

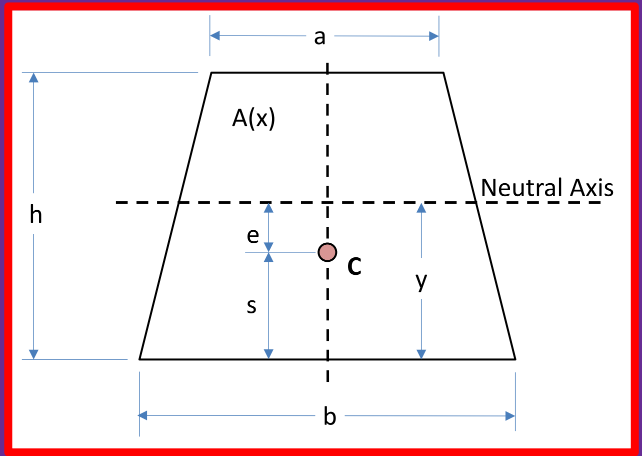


Photograph Crosstie End Wire Configuration (Establish Wire centroid Position, CW)



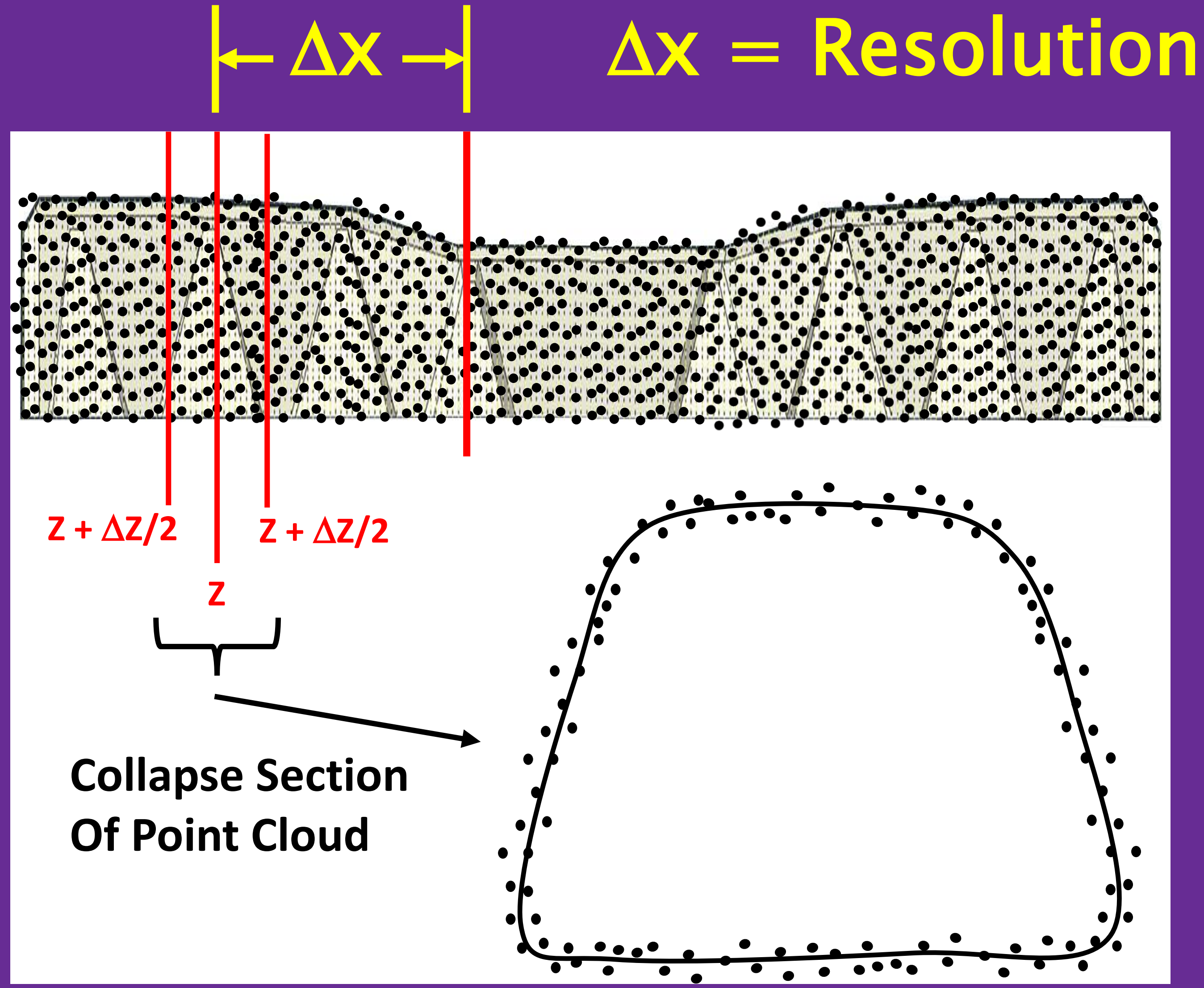


Establish x,y,z Coordinate System

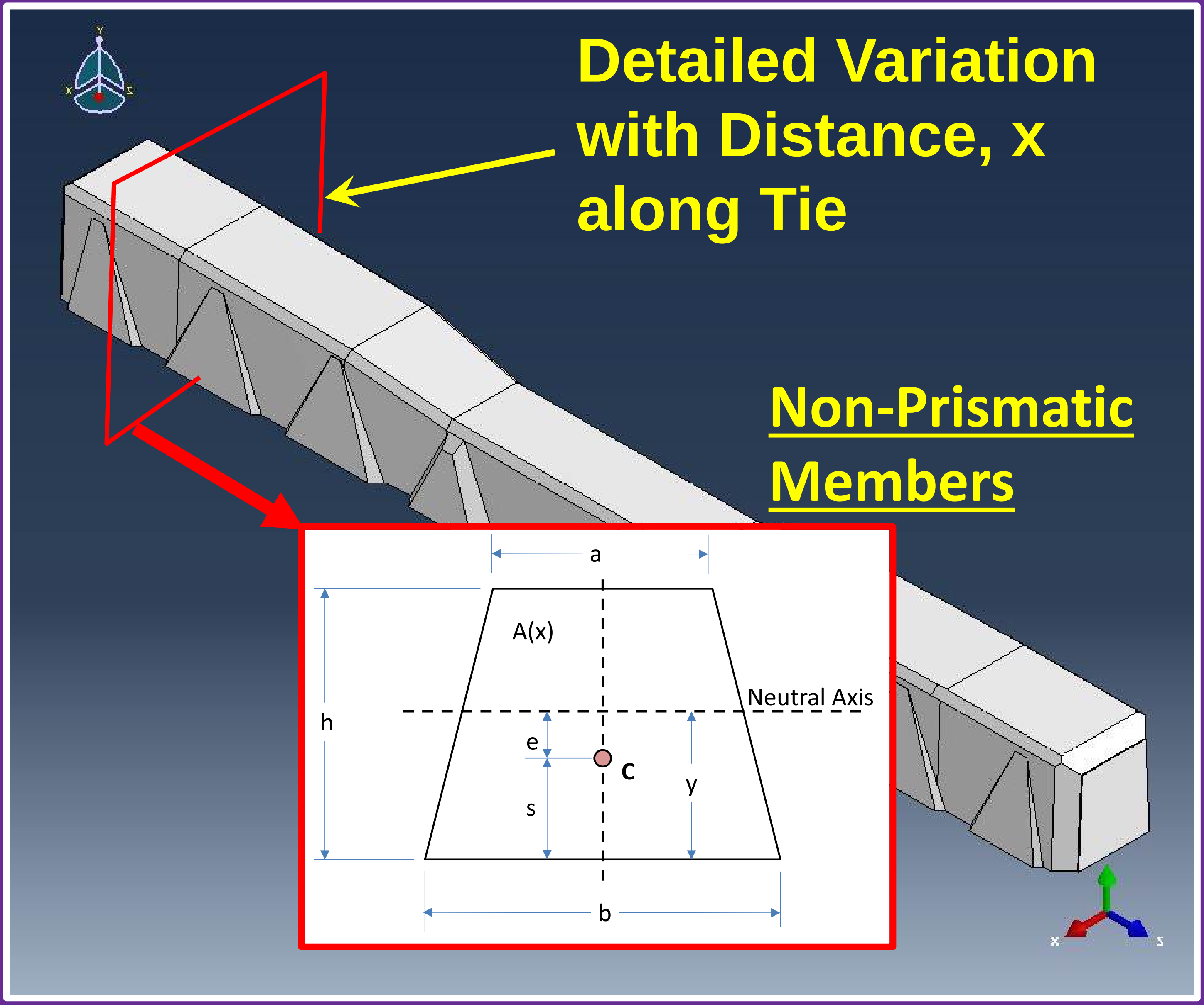


Extract Cross-section Parameters

Extracting Slices from Crosstie Point Cloud



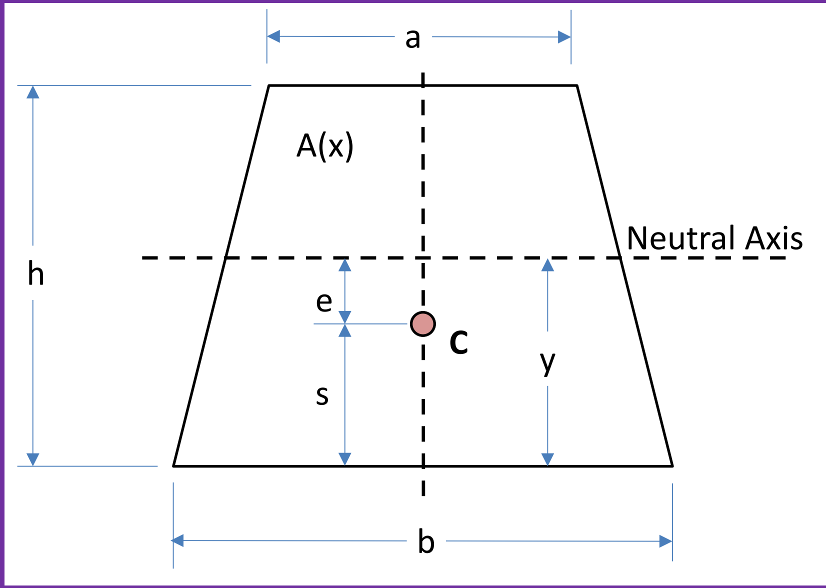
Extraction of Tie Parameters From CAD or Scan



Shape Factor, R(x), for Crosstie

$$Strain(x) = \frac{P(x)R(x)}{E}$$

$$R(x) = \frac{1}{A(x)} + \frac{e(x)y(x)}{I(x)}$$

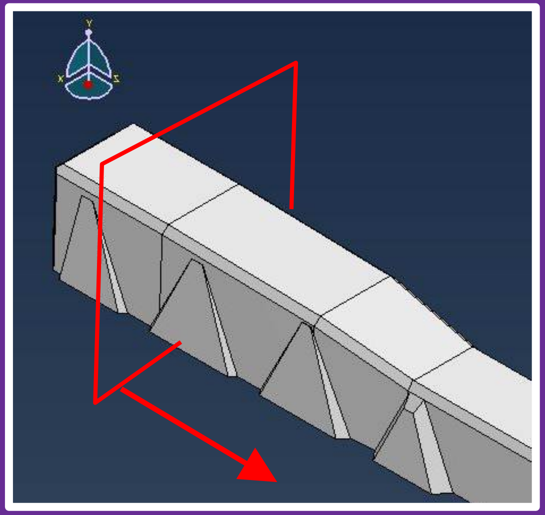


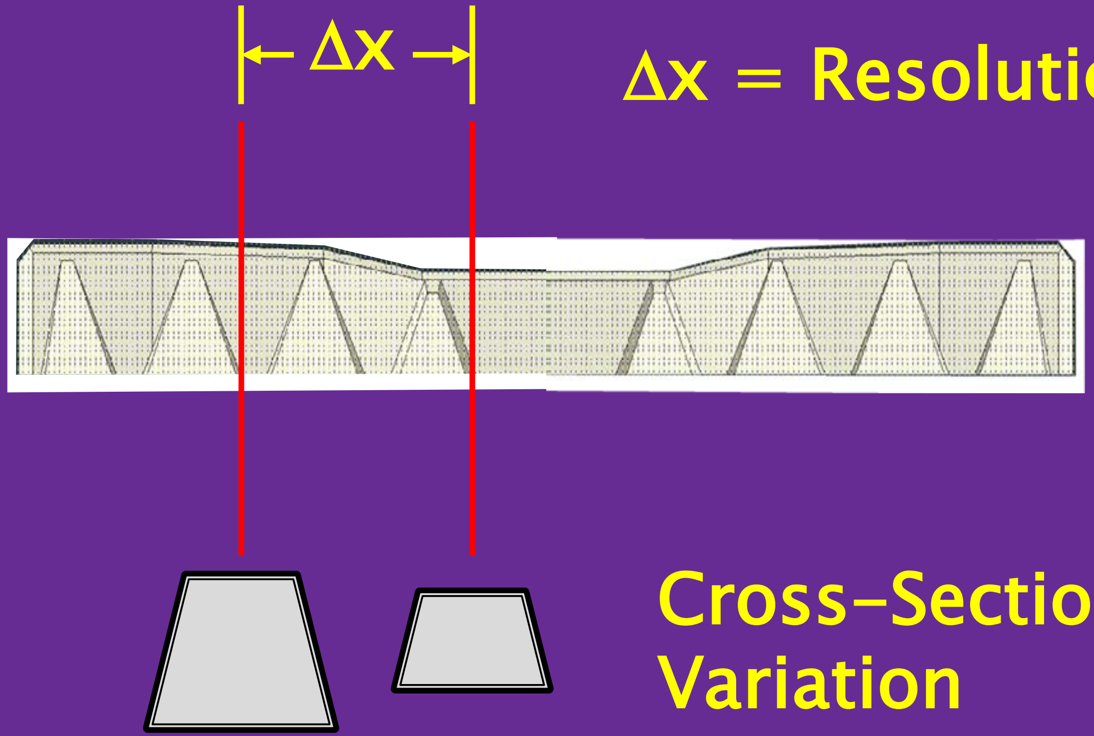
where

P(x) = Prestressing force
A(x) = Cross-sectional area
e(x) = Eccentricity
y(x) = Distance to neutral axis
I(x) = Area Moment of Inertia
E = Young's Modulus

Effect of Shape Factor Resolution on Crosstie Shape Parameters And Transfer Length

<u>Question</u>: How Does Shape Factor Resolution Affect Transfer Length Assessment?





Δx = Resolution

Cross-Section Variation

Photographs of Typical CXT Ties

(a) Left tie end

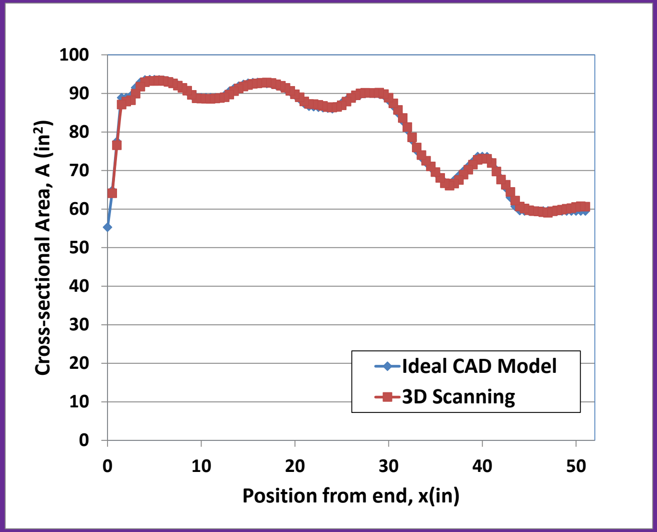
(b) Right tie end

(c) Enlarged left end

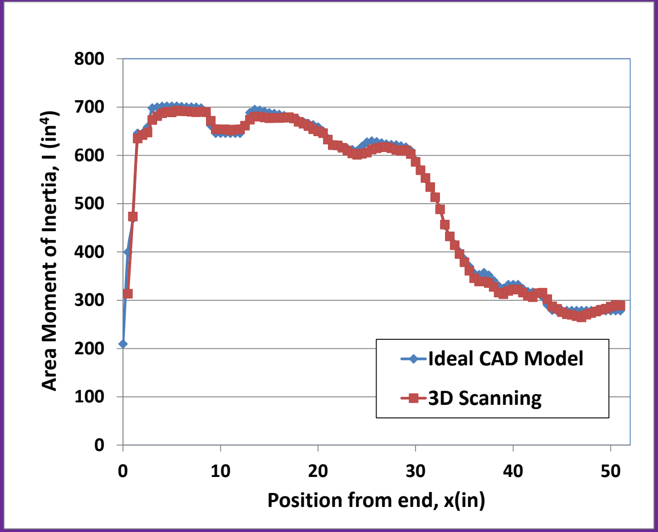
(d) Enlarged right end

Extracted CXT Crosstie Cross-Section Parameters

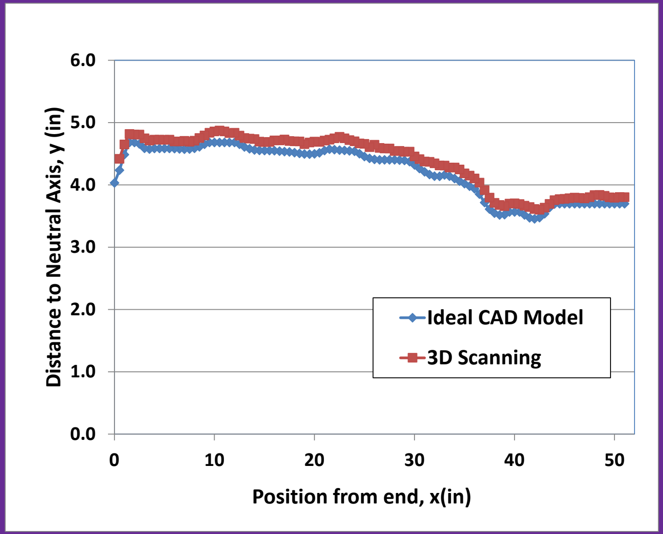
Cross Sectional Area, A



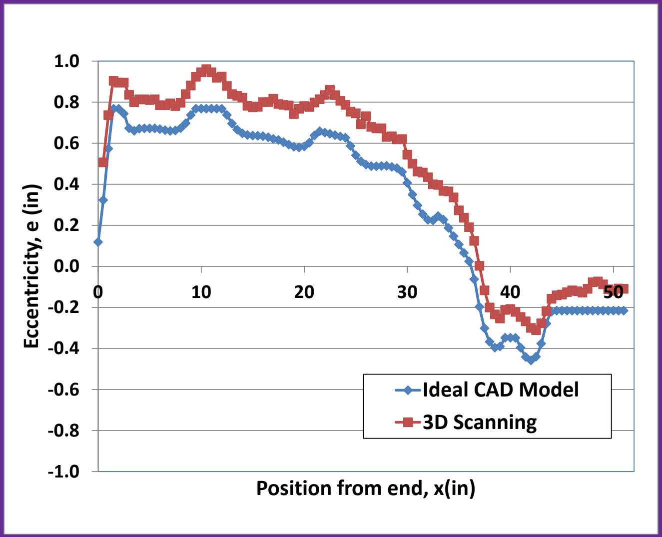
Area Moment of Inertia, I



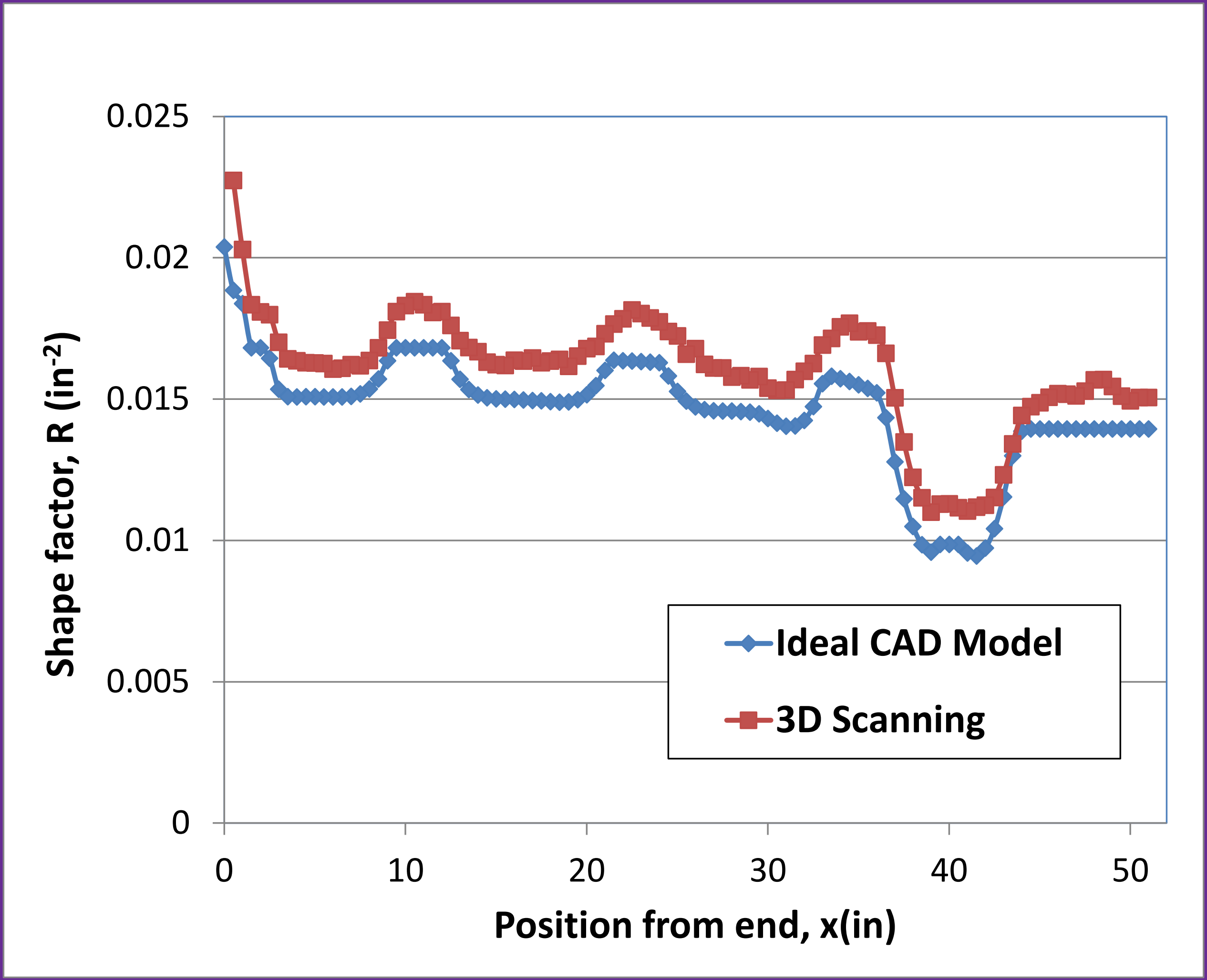
Neutral Axis Position, y



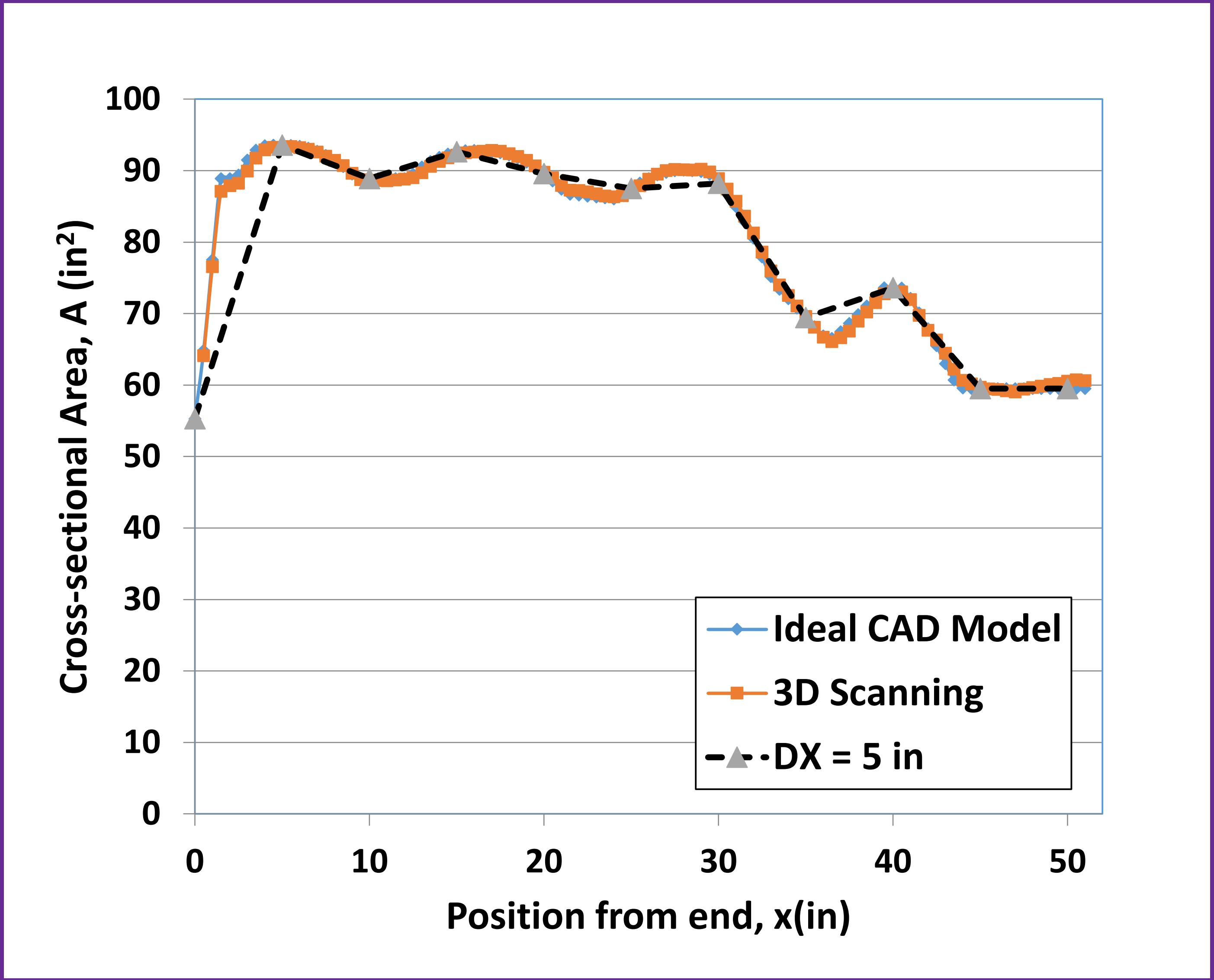
Eccentricity, e



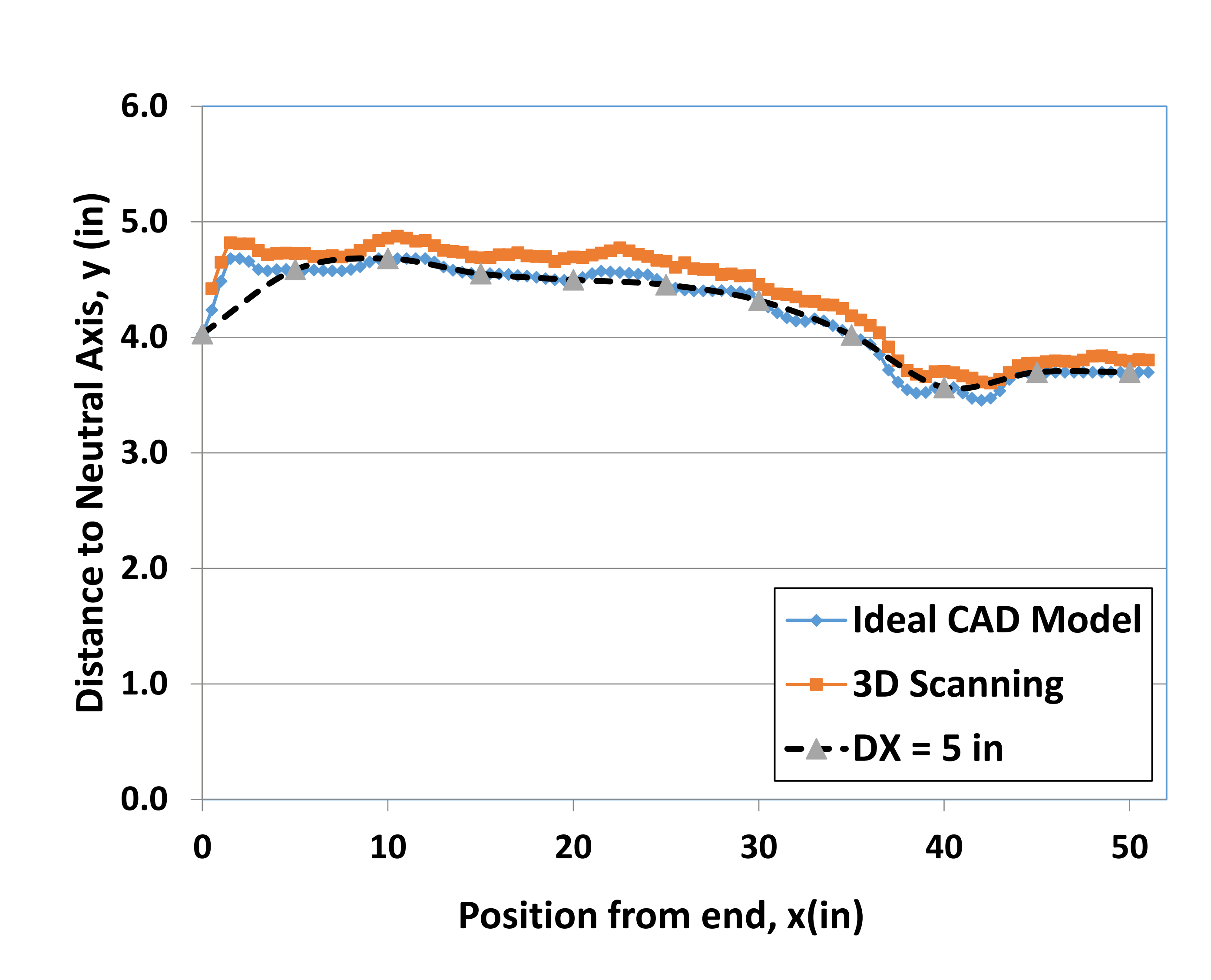
CXT Crosstie Shape Factor



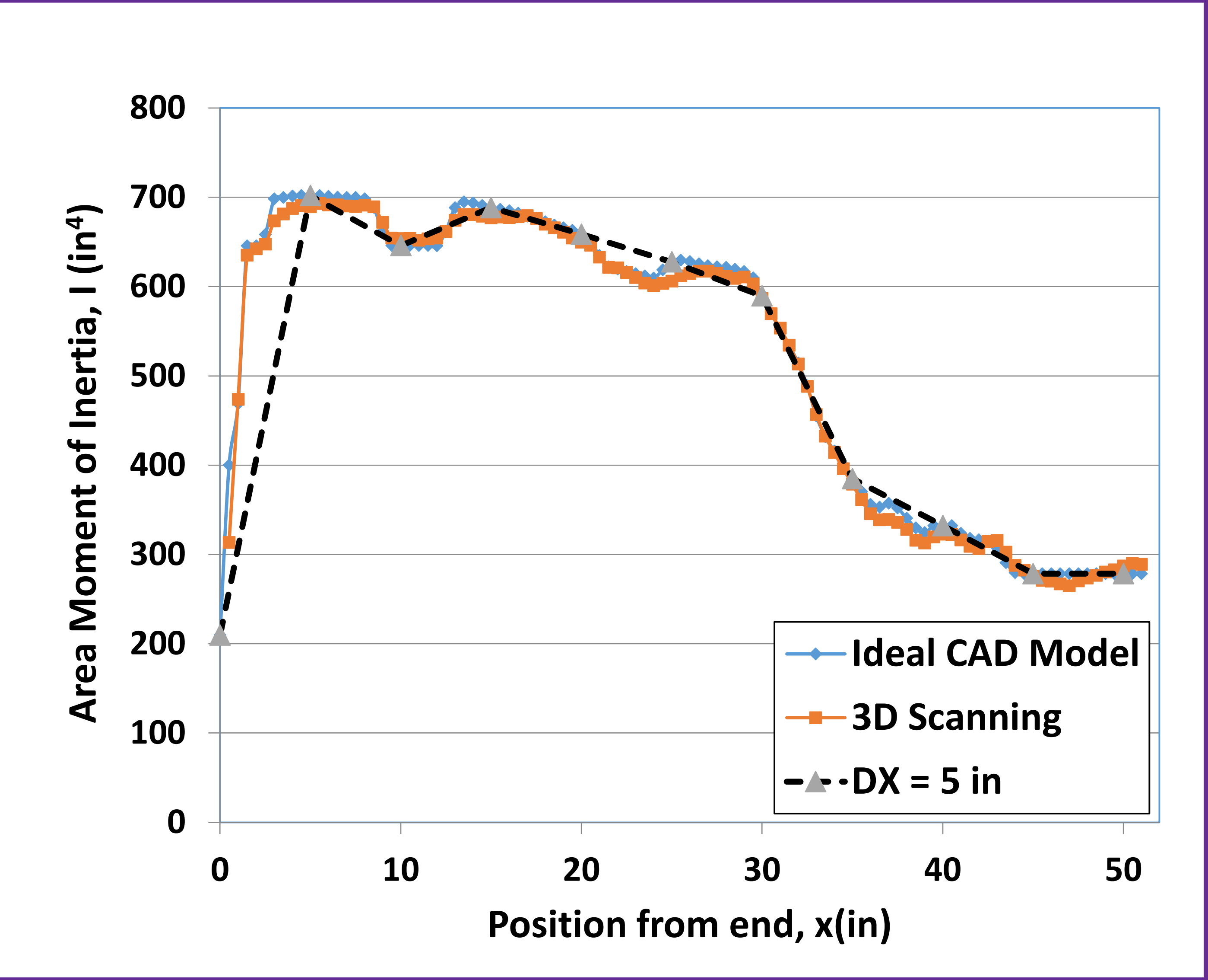
Reduced Resolution Crosstie Area, A



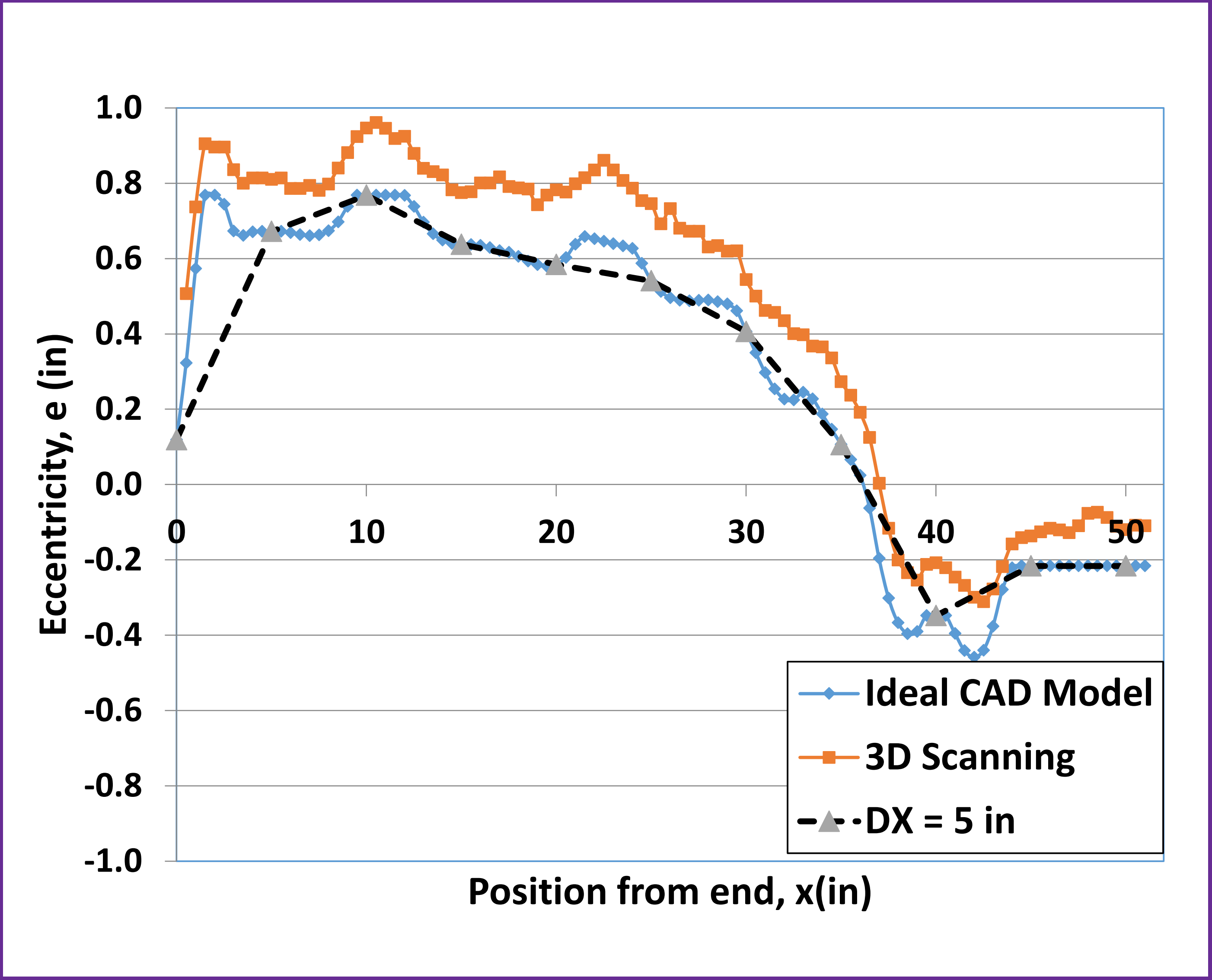
Reduced Resolution Area Centroid, y



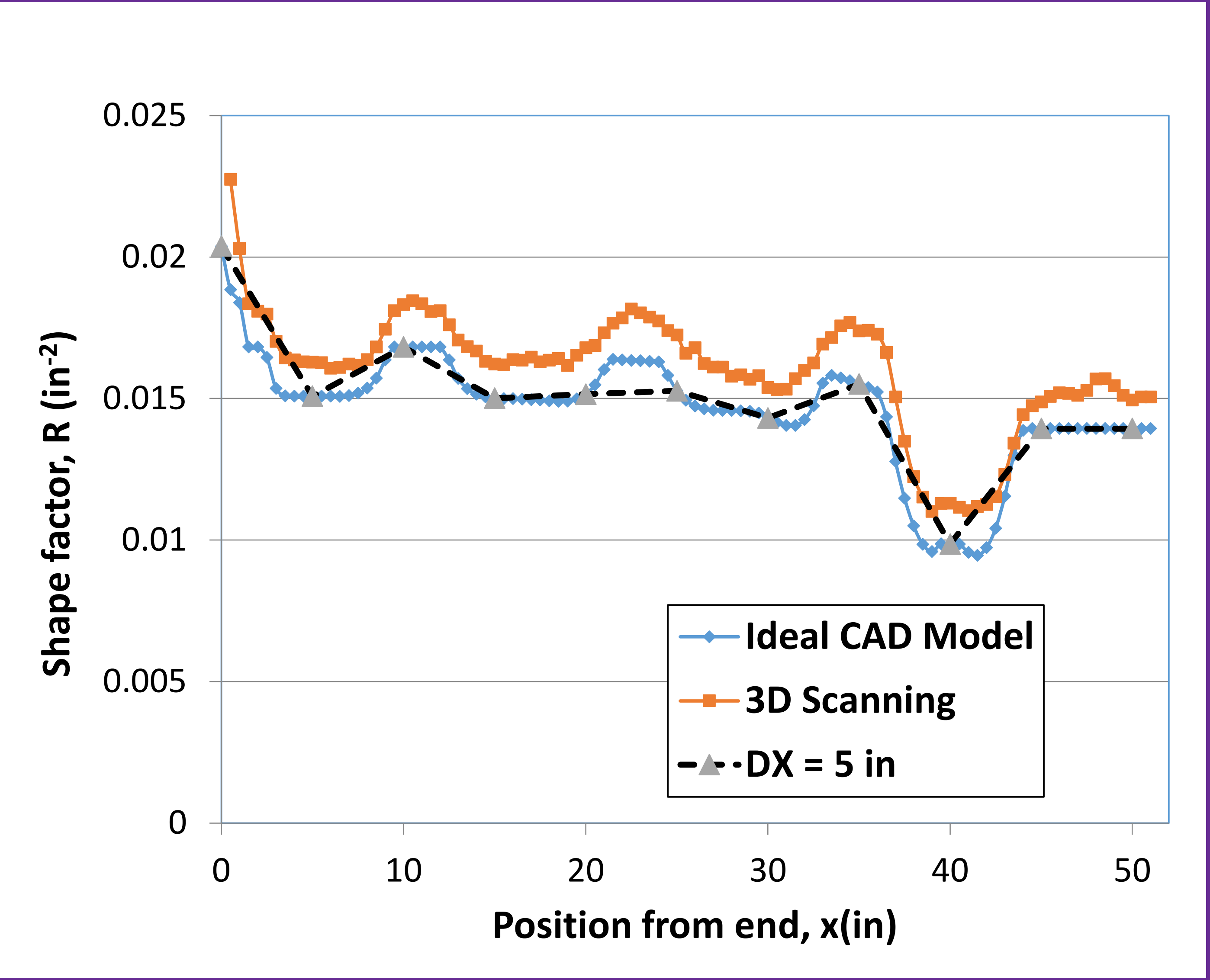
Reduced Resolution Crosstie Area Moment, I



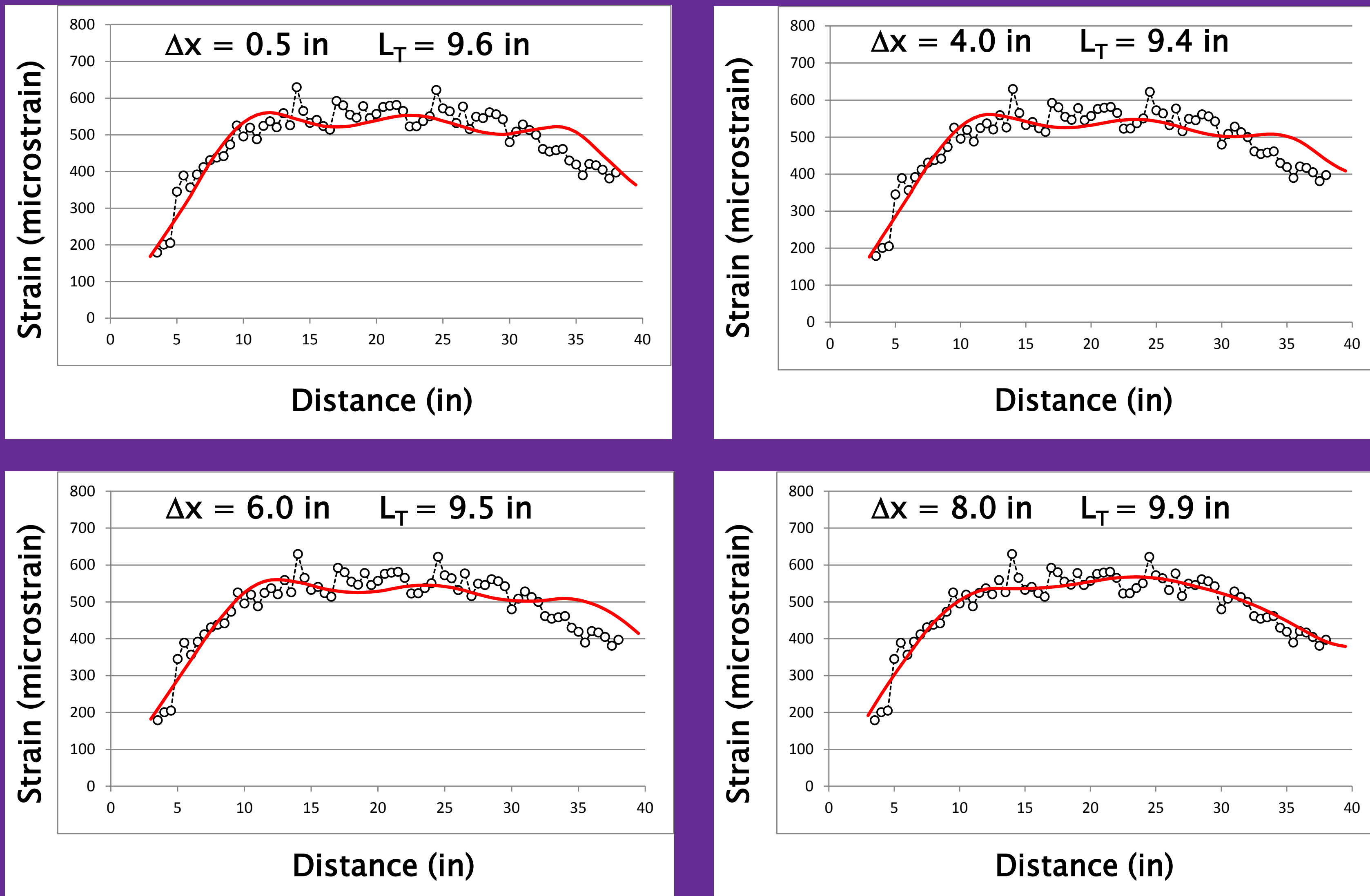
Reduced Resolution Crosstie Eccentricity, e



Reduced Resolution Crosstie Shape Factor, R



Effect of Resolution on Strain Profile



Transfer Length Assessment—Effect of Reduced Slicing Resolution (CXT Tie Results)

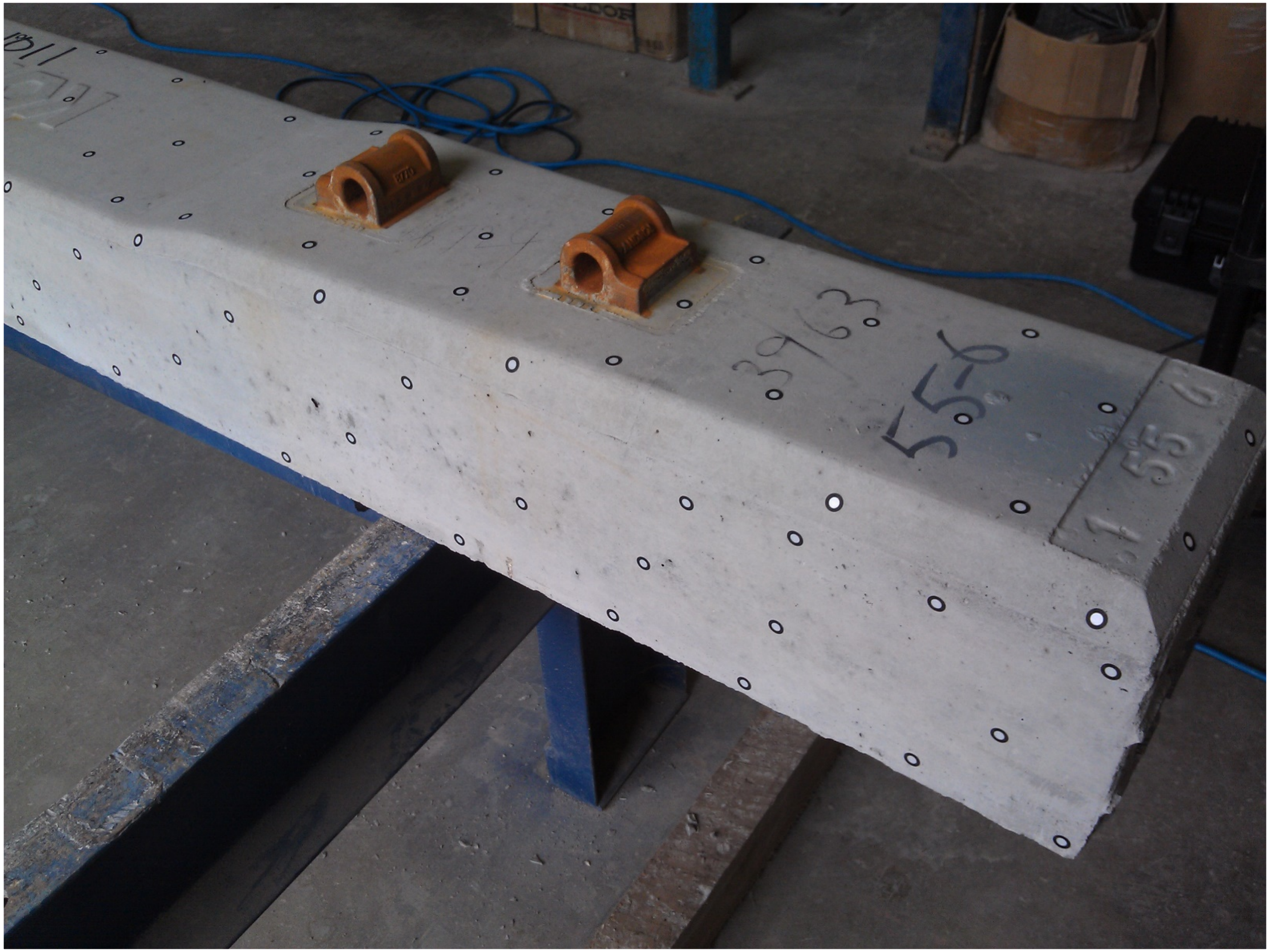
CAD (Simulated)

Δx (in)	L_T (in)
0.5	10.0
1.0	10.0
2.0	10.0
4.0	9.9
5.0	10.4
6.0	10.0
7.0	9.8
8.0	10.2

CAD (Real Data)

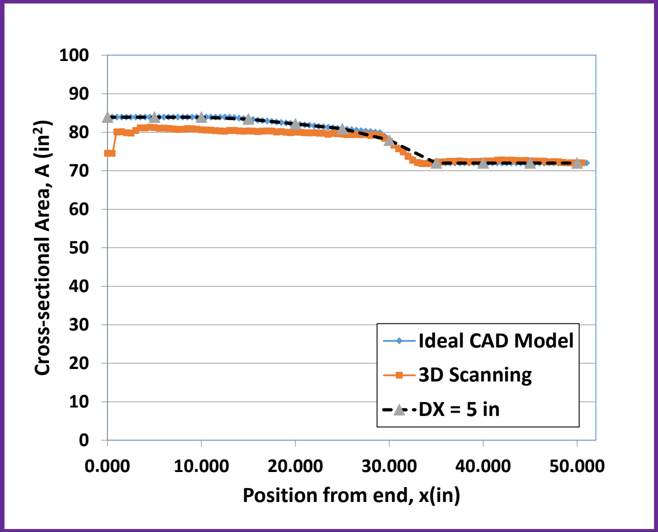
Δx (in)	L_T (in)
0.5	9.6
1.0	9.6
2.0	9.6
4.0	9.4
5.0	10.0
6.0	9.5
7.0	9.3
8.0	9.9

Photographs of Scanned Rocla Tie

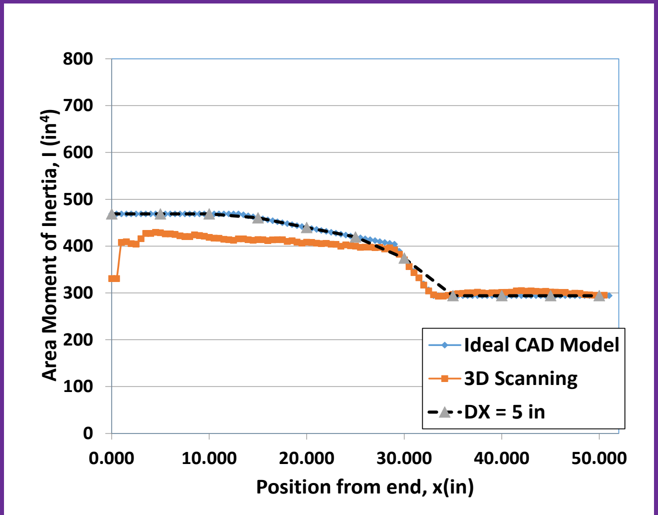


Extracted Rocla Crosstie Cross-Section Parameters

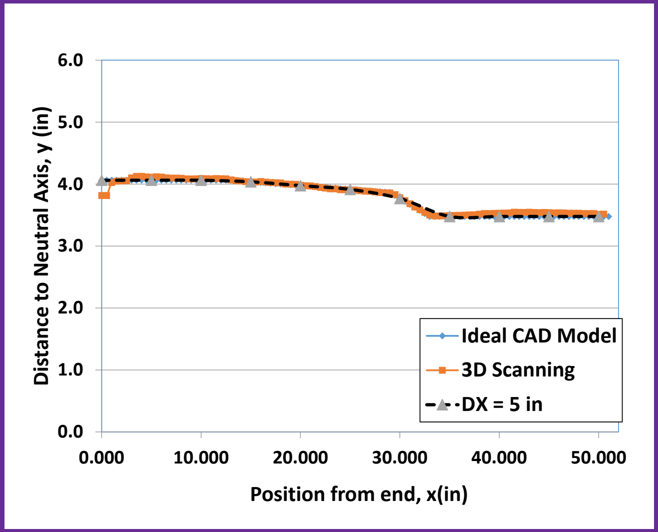
Cross Sectional Area, A



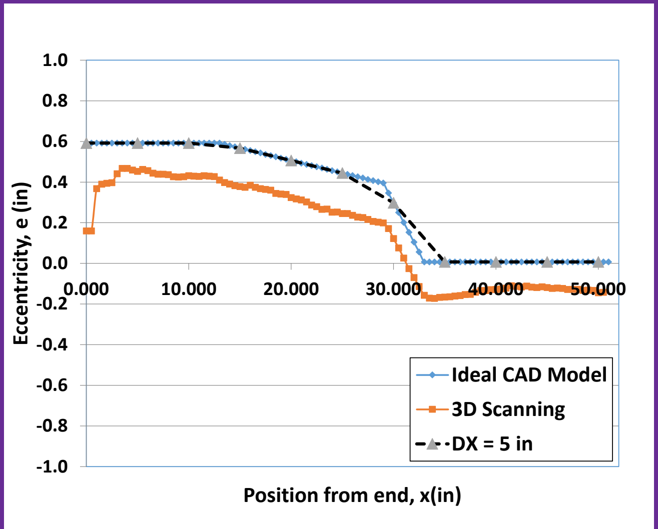
Area Moment of Inertia, I



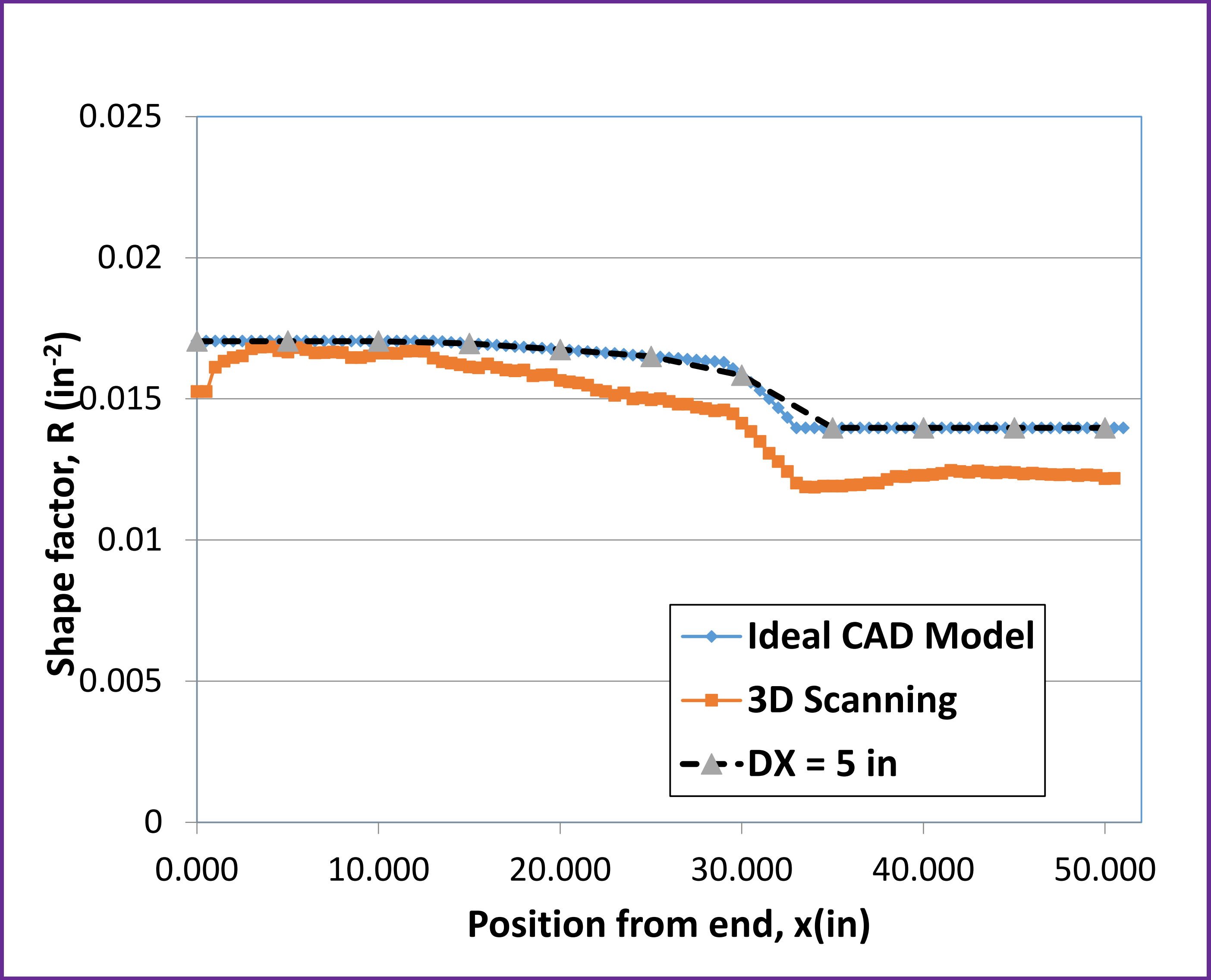
Neutral Axis Position, y



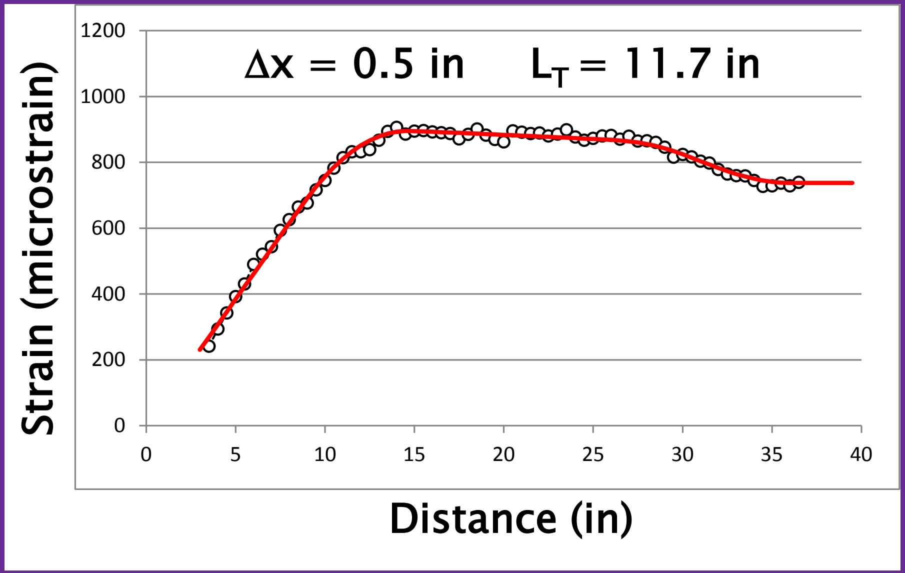
Eccentricity, e

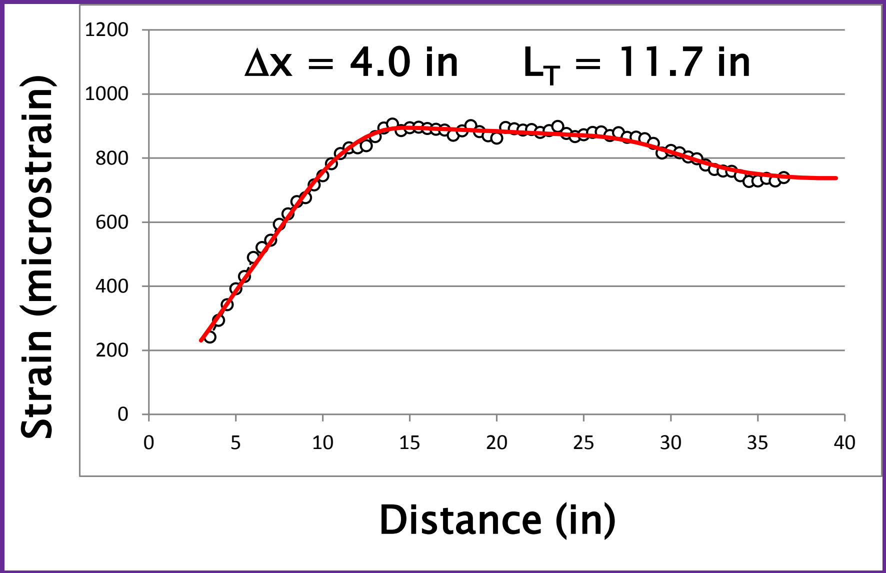


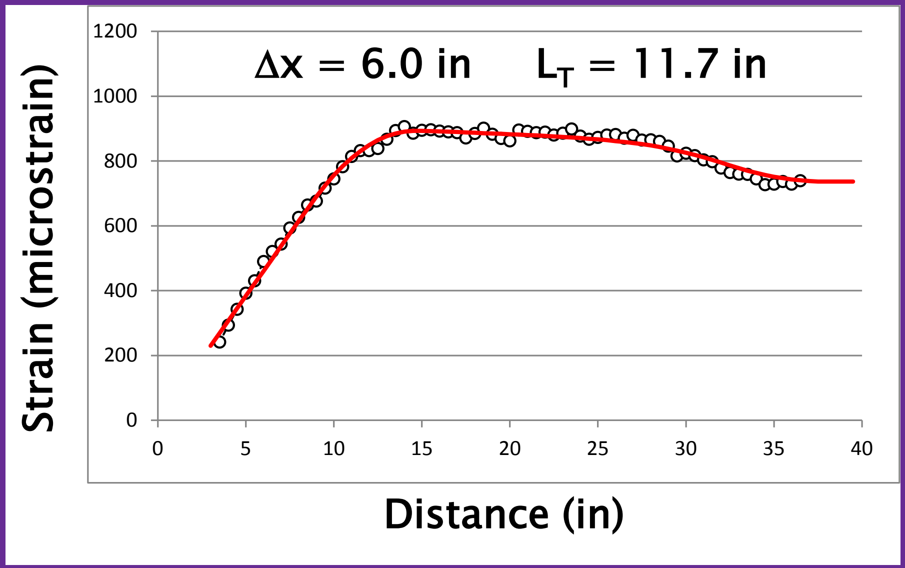
Reduced Resolution Crosstie Shape Factor, R

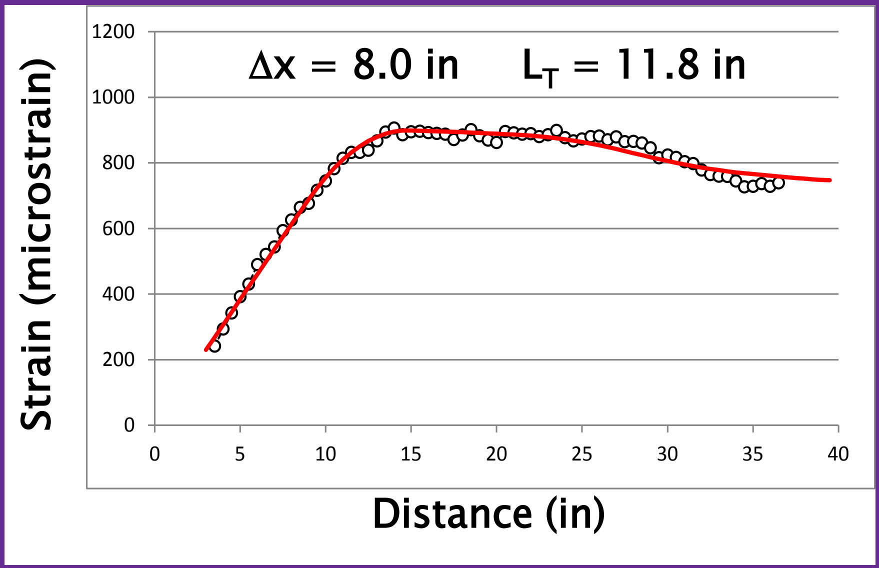


Effect of Resolution on Strain Profile

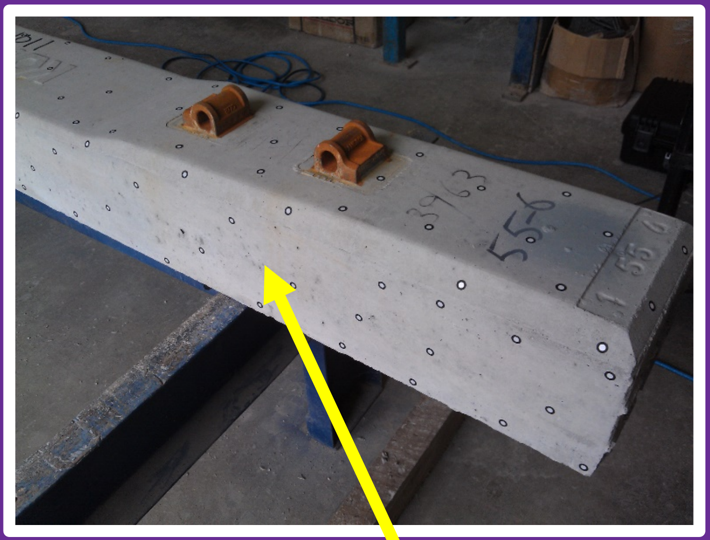








Transfer Length Assessment—Effect of Reduced Slicing Resolution (Rocla Tie Results)



Semi-Prismatic Features

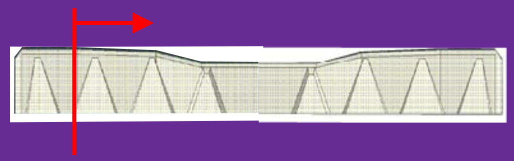
Rocla CAD Tie

Δx (in)	L_T (in)
0.5	11.7
1.0	11.7
2.0	11.7
4.0	11.7
5.0	11.7
6.0	11.7
7.0	11.7
8.0	11.8

Conclusions

- Detailed 3D Geometrical Cross-Section Parameters Were Extracted (I, y, A, ε) from Crossties.
- Excellent Agreement with Existing 3D CAD Models
- Preliminary Results Indicate that Shape Factor Resolution Effect on Transfer Length is Small
- Gauge Length Smooths Influence of Complex Shape Factor (Scalloping)
- Coarse Shape Factor Resolution Even Less Sensitive when Complex Scalloping is Absent.

3D Scanning Work in Progress:



- **Systematically Scan** Large Sampling of In-Service Ties
- Extract **3D Geometrical Cross-Section Parameters** (I, y, A, e).
- **High-Speed Algorithm** for Cross-Section Parameter Assessment is **Nearly Complete**.
- Assessment of **Parameter Measurement Uncertainty** is in Progress.
- **Support Ongoing Testing** of In-Service Crossties

Project Sponsors:

Federal Railroad Administration

Department of Transportation, United States of America

LBFoster

CXT® Concrete Ties

KSU Participants:

Kansas State University Transportation Center

K-State UTC

Sustainability and safety of rural transportation systems and infrastructure

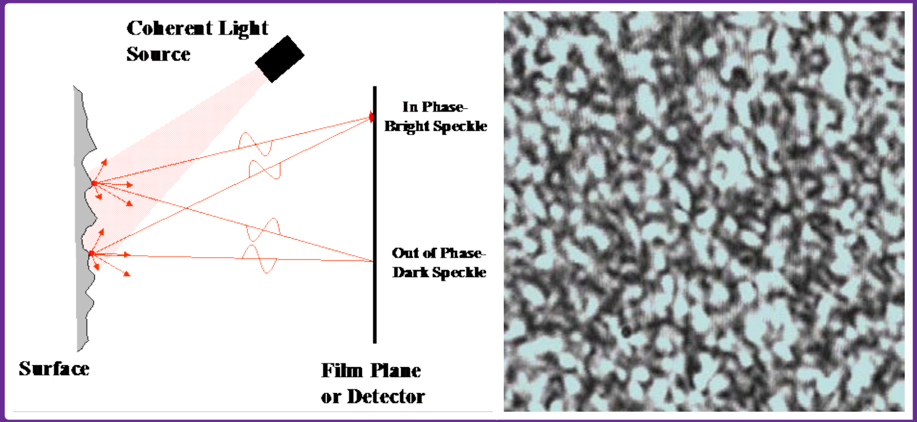
AMI

ADVANCED MANUFACTURING INSTITUTE

Engineering Success

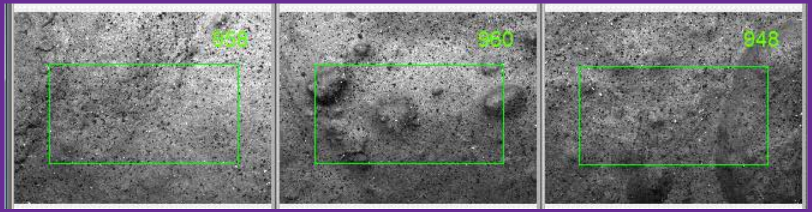
Questions?

Non-Contact Strain Measurement —Speckle (Feature) Tracking Principle



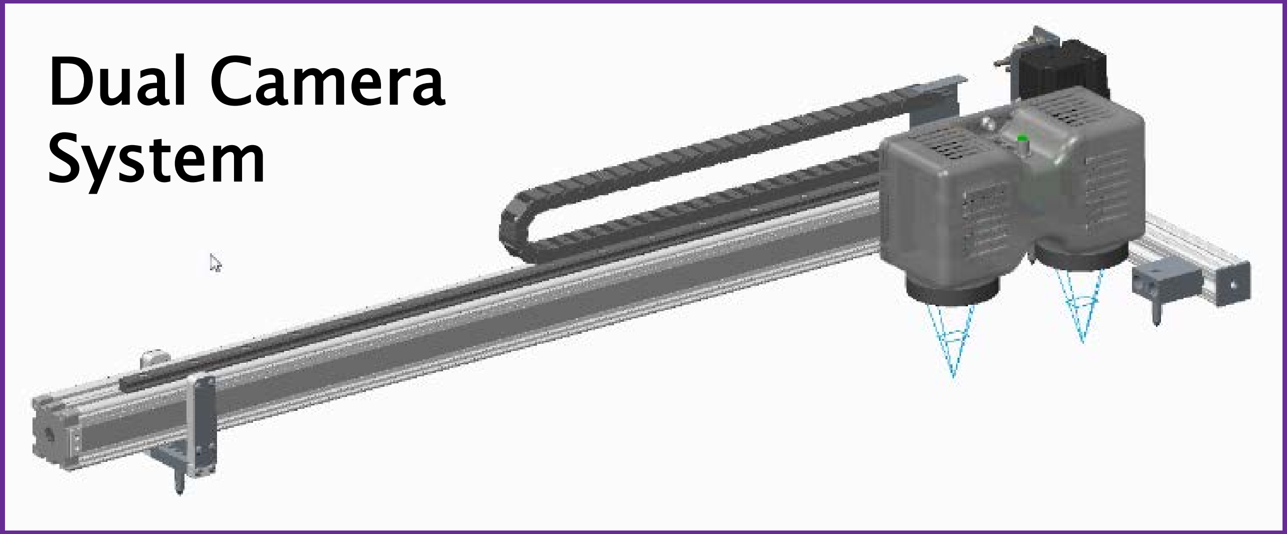
Laser Speckle Imaging (LSI)

Painted Reflective Particle Imaging



Concrete Surface Roughness Imaging

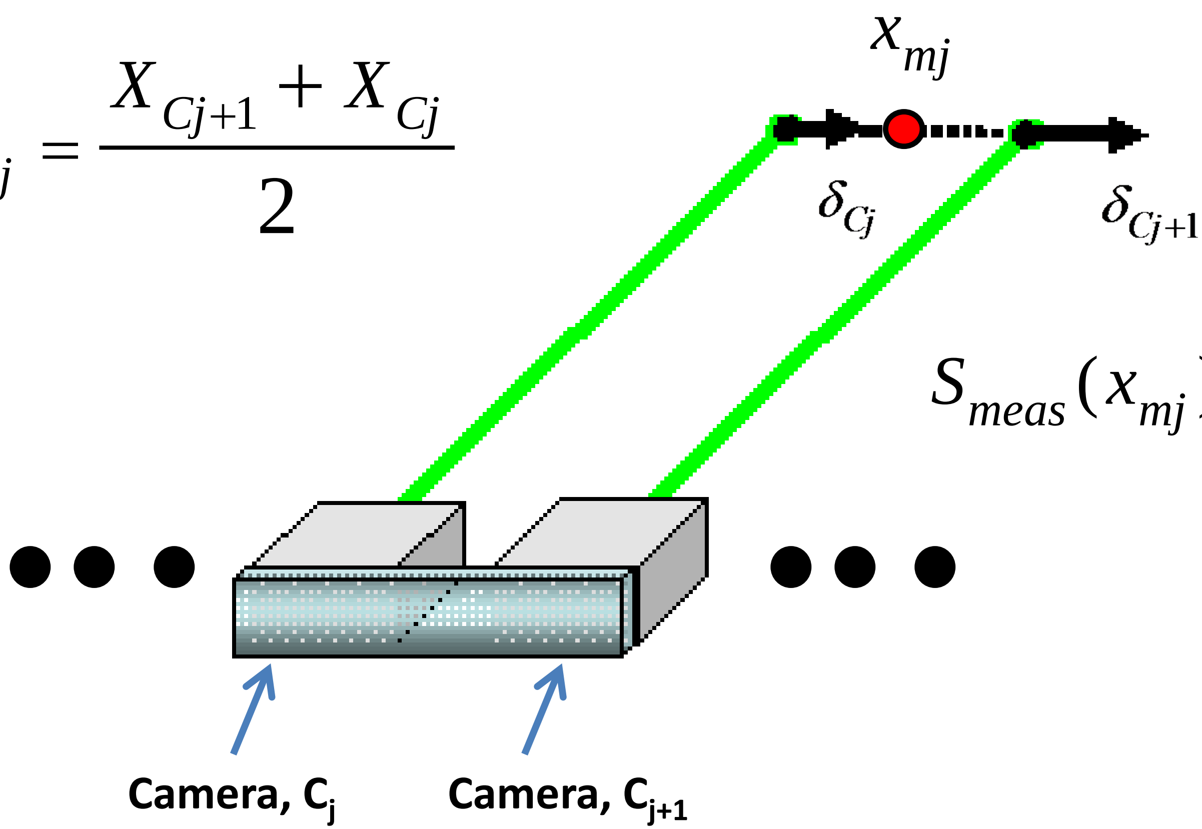
New Continuous Scanning/Traversing (CST) Strain Measurement System



- Features Improved Depth of Focus
- "Ring Light" (Strobed) Illumination
- Jog and Continuous Motion Option (inches/sec)
- Measurement Resolution (10-20 microstrain)
- LabVIEW Interface with "Stitching Capability"

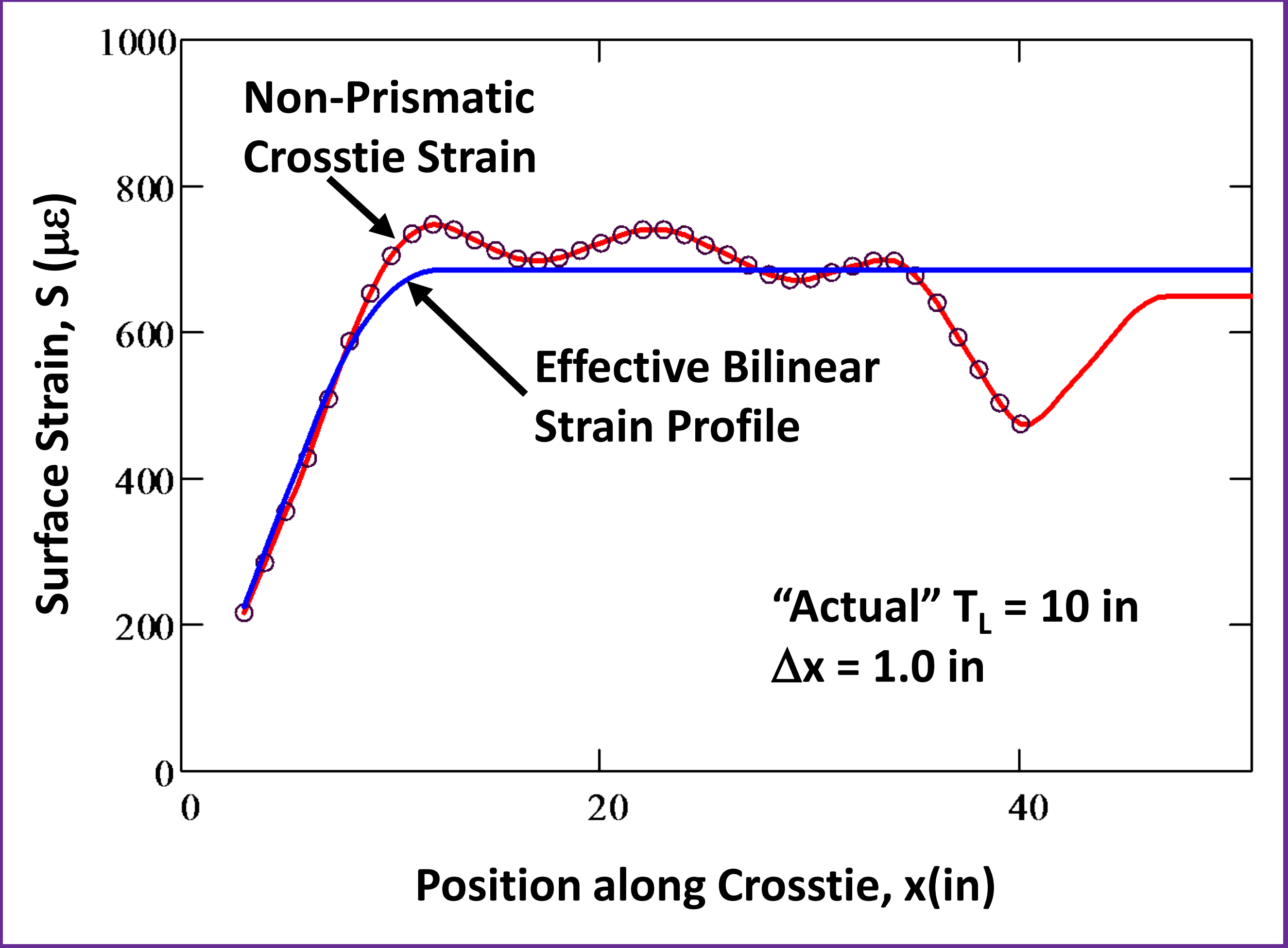
Local Strain from Adjacent Image Displacement Pairs:

$$x_{mj} = \frac{X_{Cj+1} + X_{Cj}}{2}$$

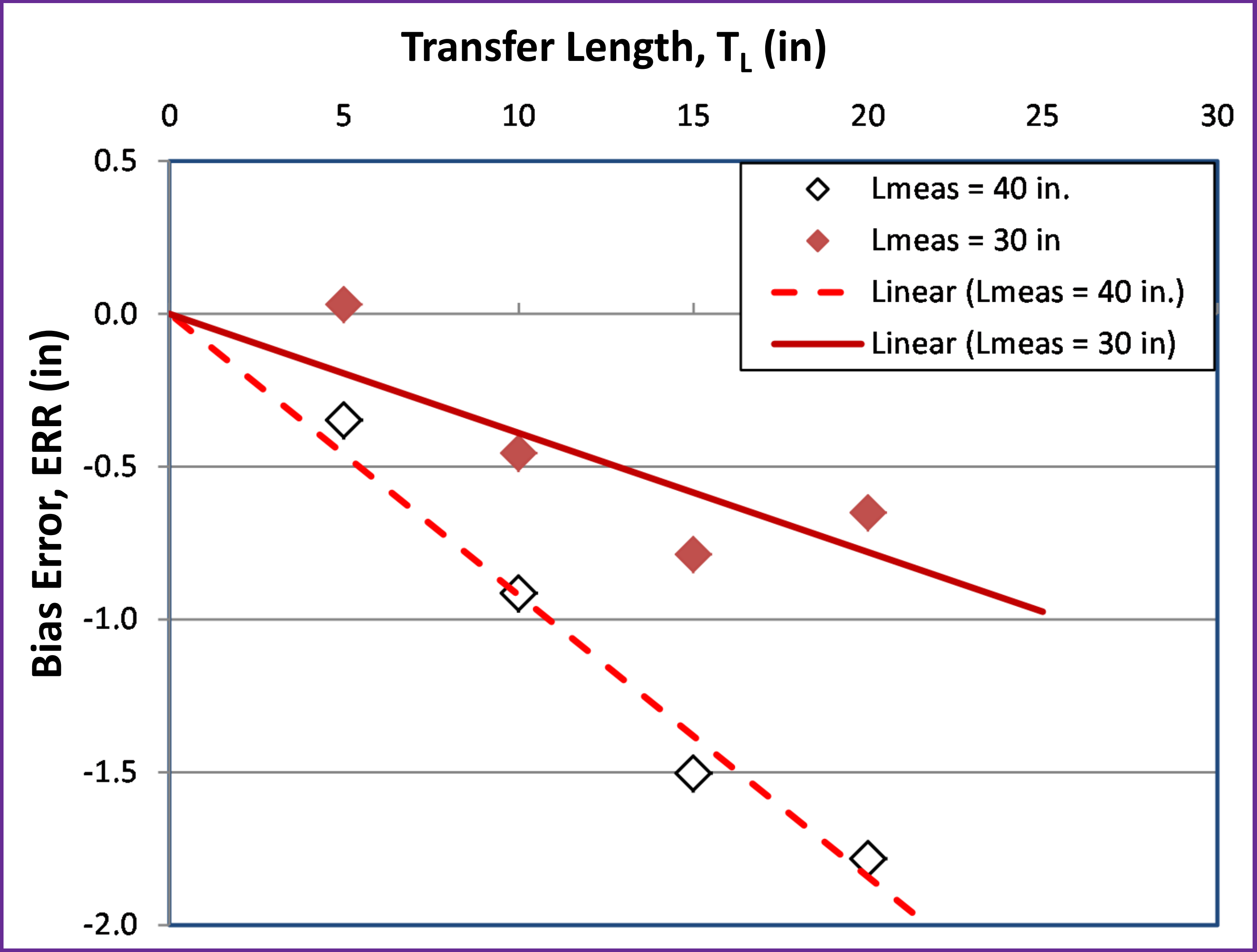


$$S_{meas}(x_{mj}) = \frac{\delta_{Cj+1} - \delta_{Cj}}{L_G}$$

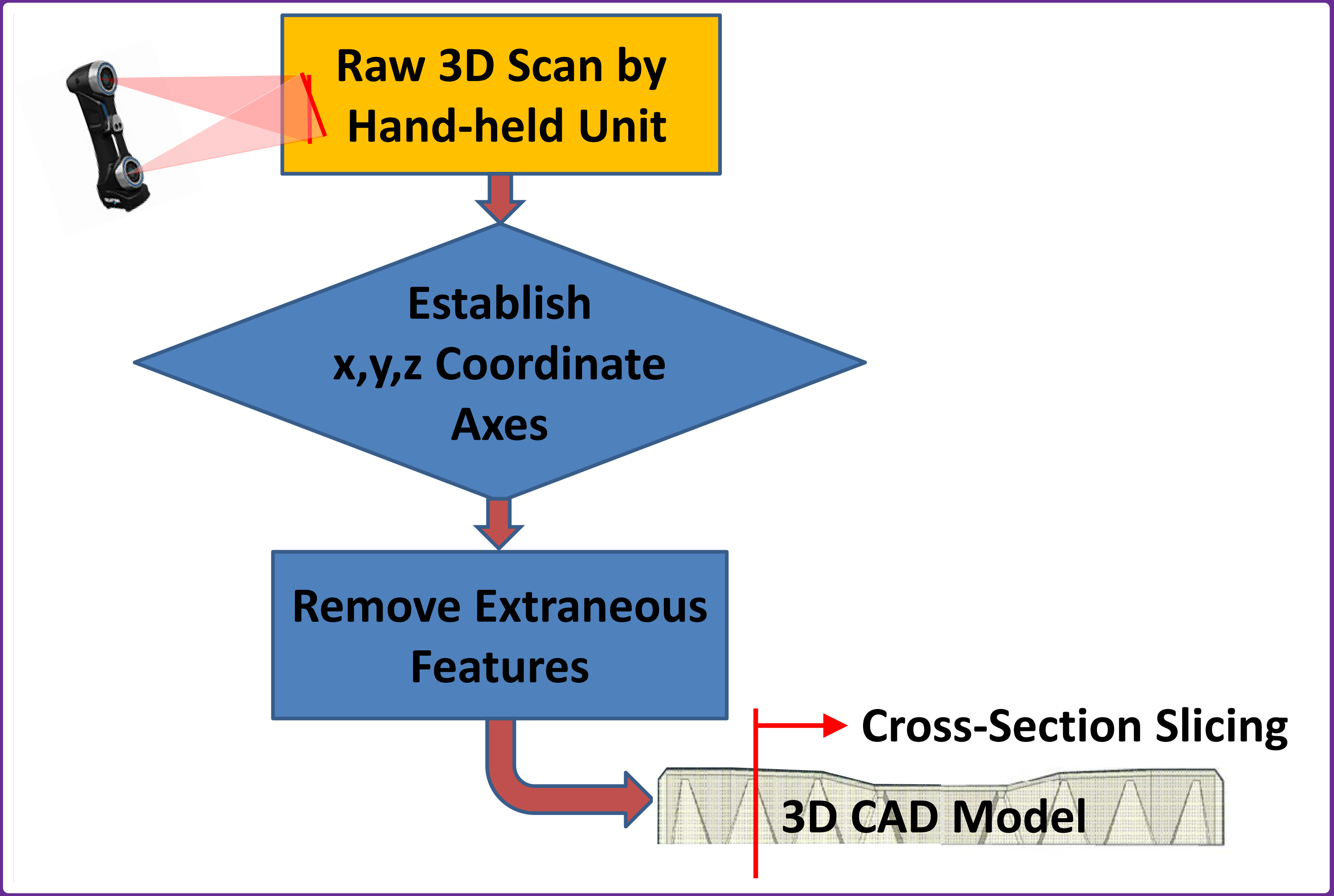
Comparison of Simulated Crosstie strain and effective bilinear strain profiles (L_{meas} = 40 in)



Bias in traditional assessment of transfer length based on bilinear surface strain



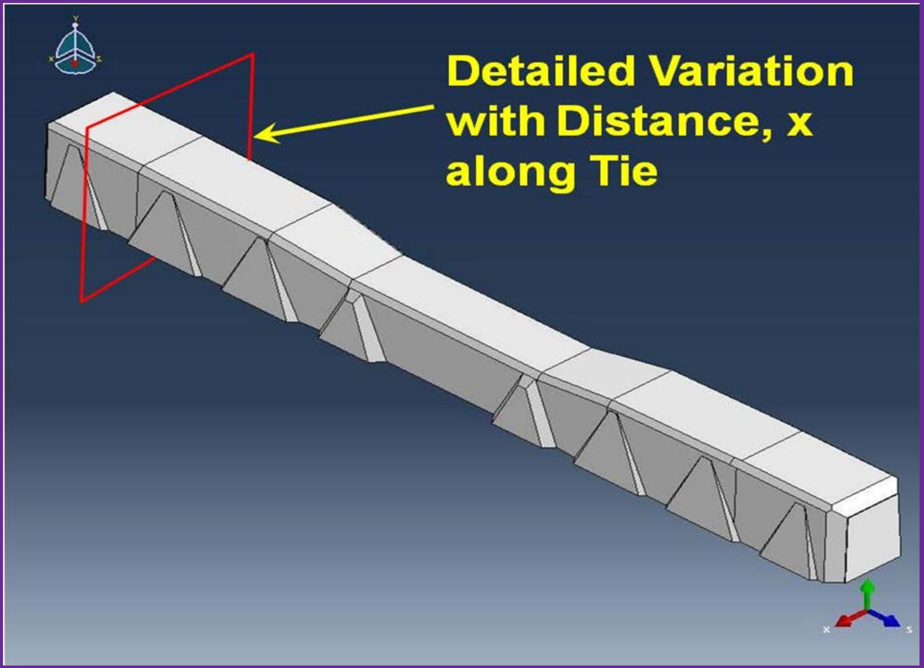
Flow Chart of Crosstie 3D Scan Processing

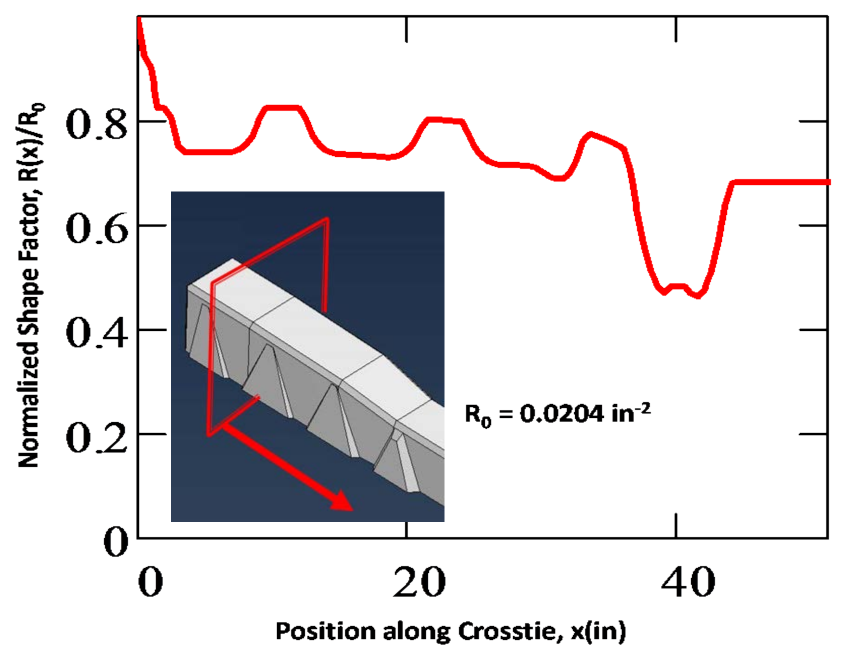


Current Work is being Conducted Under FRA Research Project Titled:

"Developing Qualification Tests to Ensure Proper Selection and Interaction of Pretensioned Concrete Railroad Tie Materials"

Geometry of Concrete Railroad Crosstie Yields Complex Shape Factor Variation





3D Shape of Crosstie
(CAD Model or 3D Scan)

Normalized Shape Factor

Traditional 95% AMS Transfer Length