NON-DESTRUCTIVE EVALUATION METHODS FOR COMPOSITE PILES

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SUMMER INTERNSHIP
RESEARCH PROGRAM

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PRESENTATION OUTLINE

- Introduction
- The Pearson Composite Piling System
- Objectives
- Ultrasonic Testing
- UT NDT Methods for Composites piles
- Experimental program: Tension Tests
- Conclusions
- Acknowledgements

INTRODUCTION

- The use of piles is particularly important in the transportation infrastructure for coastal regions like Rhode Island.

- The state of the practice for the construction of pile foundations is to use traditional materials such as timber, steel, and concrete.

Deterioration of piles

Steel

Concrete

Wood

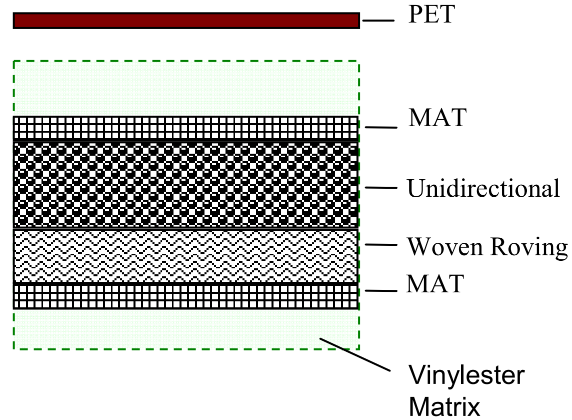
(Pando, 2003)

PEARSON COMPOSITE PILINGS

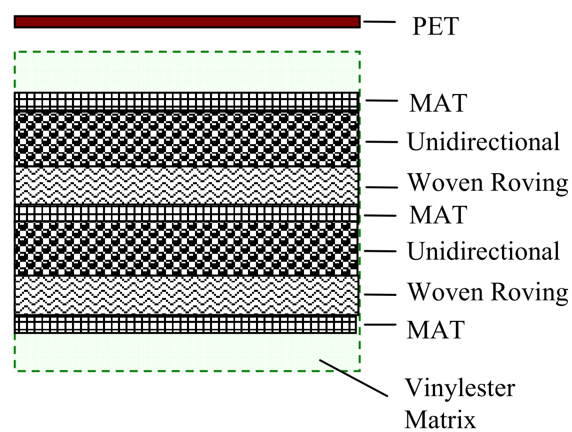
Material Characteristics:

- Glass Fibers reinforcing Vinylester Matrix.
- Modified vacuum assisted Resin Transfer Molding VARTM.
- Layers woven in the outplane direction.
- PET Thermoplastic for protection against UV radiation.

Ø 10 in piles Layout



Ø 12 in piles Layout

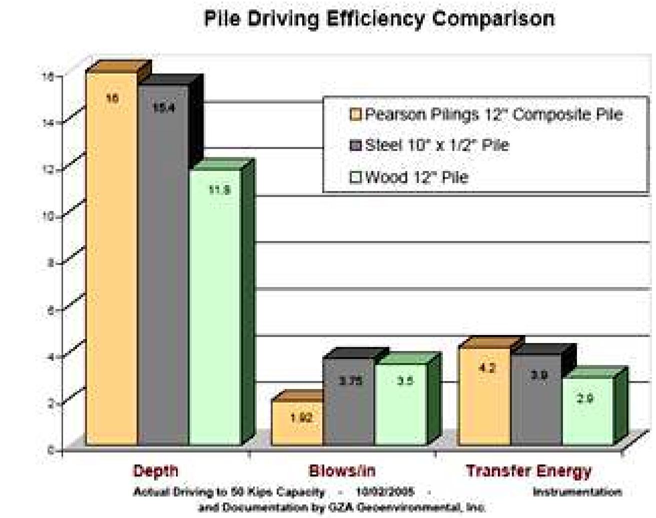


(Http://pearsonpilings.com)

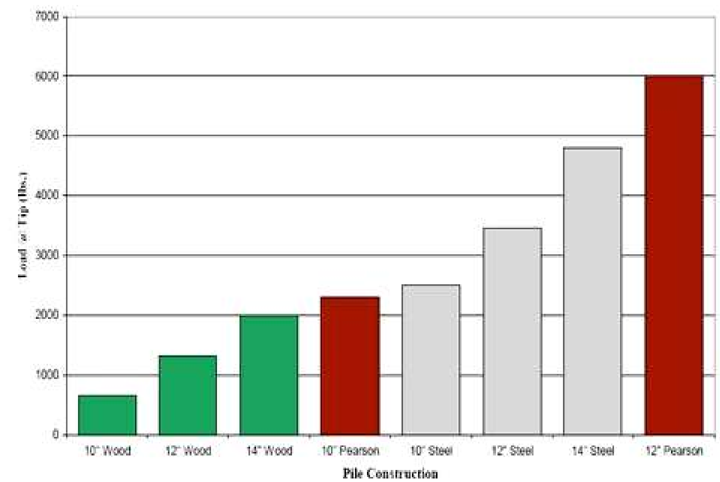
(Http://pearsonpilings.com)

PEARSON COMPOSITE PILINGS

- Pile Driving Efficiency study (2005):
  - The composite pile was driven to an similar ultimate capacity to comparable steel and timber piles without apparent damage.



- Ultimate Lateral Load study (2005):
  - The composite piles have a greater capacity for lateral loading at lower deflections in comparison with timber piles.



(Http://pearsonpilings.com)

OBJETIVES

GLOBAL RESEARCH PROJECT:

- To evaluate the feasibility and accuracy of Ultrasonic NDE/NDT for the integrity of timber and composite piles.
- To evaluate the integrity of composite piles through a combination of field and laboratory testing programs.

SUMMER INTERNSHIP:

- To review the literature about the NDT/NDE methods for composite materials.
- To perform mechanical tests for the determination of the tensile properties of the composite material that make up the Pearson Piling System.

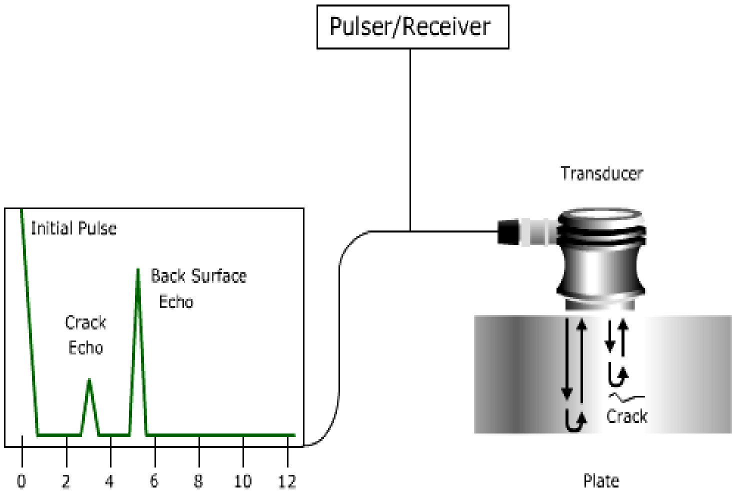
ULTRASONIC NDE/NDT TESTING

- Uses High Frequency Sound Energy to conduct examinations and make measurements in a material.

- Used for Flaw Detection, Dimensioning, Material Characterization.

- **Functional Units:**
  - Pulser/ Receiver: Generates high voltage pulses.
  - Transducer: Transform Voltage in high frequency sound energy, Sound Waves.

- **Sound Waves:**
  - Longitudinal, Transverse (Shear).
  - Surface, Plate, Leaky, Sezawa.



(Http://NDT-ed.org)

UT NDE METHODS FOR COMPOSITE PILES

Motivation for the use of UT-NDE in composites:

- The composites are susceptible to flaws during production.
- The inspection costs suggest the use NDE methods.

Inherent complex conditions in the piles:

- Presence of different mediums (soil, water, structural connections, etc.) surrounding the pile.
- Multi-layered non-homogeneous anisotropy of the material.

❑ Applications from Deep Foundation NDE Technology:

- Pulse Echo Method
- Bending Wave

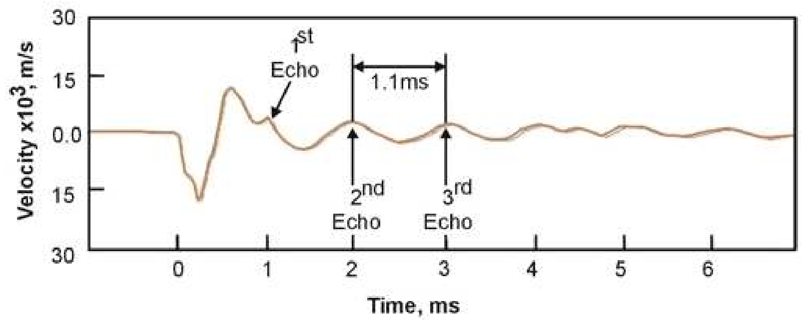
❑ Applications from Composite Alternative NDE Technology:

- Acousto-Ultrasonic

THE SE/IR PULSE ECHO METHOD

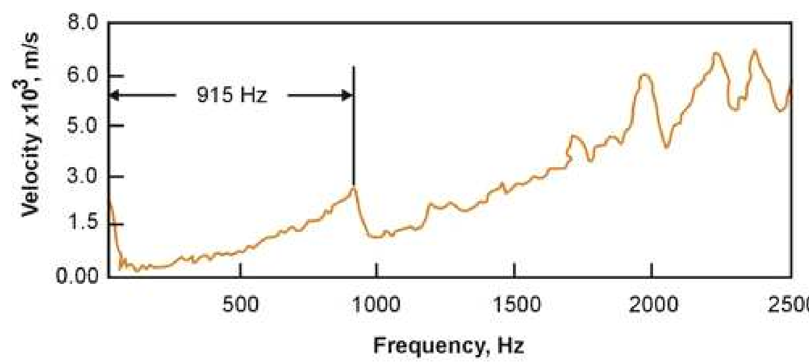
- A source placed at distance from a receiver can be used to get a first arrival signal to compute the P-wave velocity.
- Generation of a wave from an impulse hammer travels down a pile until a change in acoustic impedance is encountered where the wave reflects back and is recorded again.
- The Sonic Echo method requires a measurement of the travel time of seismic waves (time domain)
- The Impulse Response method uses spectral analysis (frequency domain)

Sonic Echo (Time Domain)



Depth = V xΔt/2 = 3,652 × 1.1 × 0.001/2 = 2.01 m

Impulse Response (Freq. Domain)



Depth = V/(2 xΔf) = 3,652/(2 x 915) = 1.98 m

(FHA – Geophysical Imaging Resource Site)

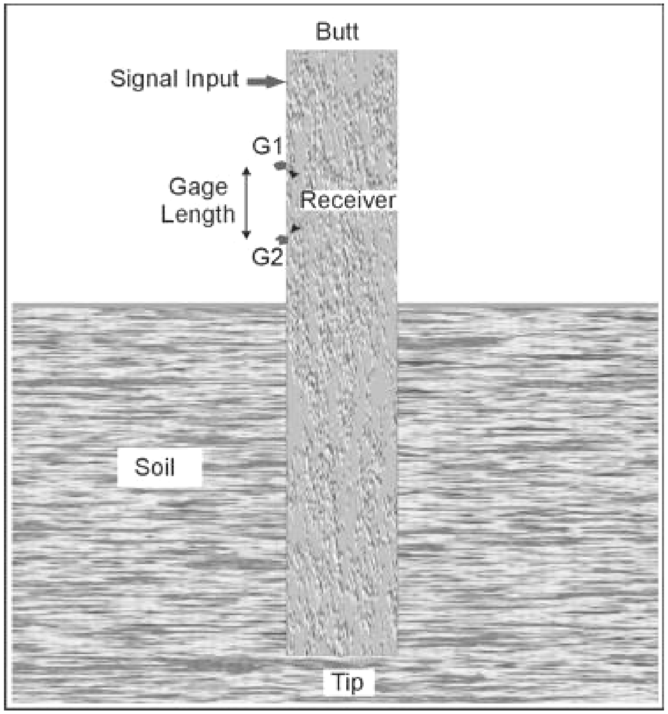
THE BENDING METHOD

- This method uses flexural (bending) waves, rather than the compressional waves to determine the integrity of deep foundations.

- Two accelerometers (G1 and G2) in the same plane of the hammer blow are used to measure the initial bending wave arrivals and subsequent reflections.

- Bending wave velocity is computed as the difference of two cross-correlated peak responses. (Freq domain).

- For both, the SE/IR and the bending Method an inverse problem solution technique can be used to find the elastic properties of the pile.



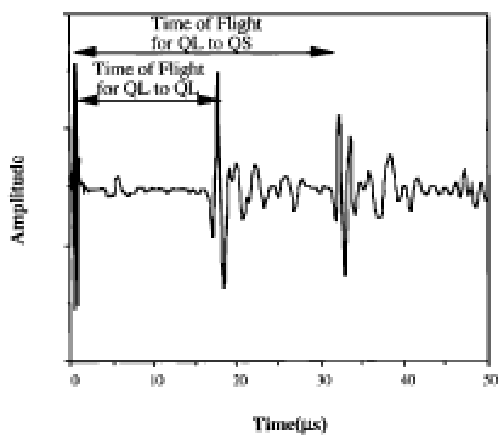
(FHA – Geophysical Imaging Resource Site)

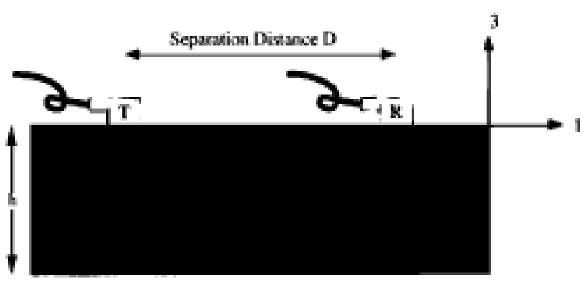
THE ACOUSTO-ULTRASONIC METHOD

- The Acousto-Ultrasonic method can be used for composite material flaw detection and material elastic characterization having access only to one side of the laminate.

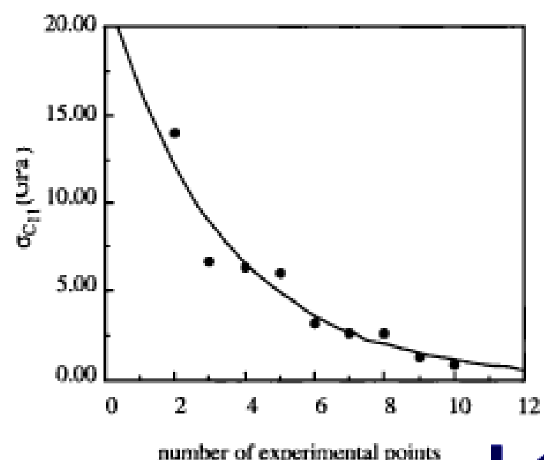
- For a transversally isotropic composite material, as in the case of the present study, the 5 independent elastic constants (C_{33},C_{44},C_{55},C_{11},C_{13}) can be determined.

- The accuracy of the results obtained would be inadequate if an insufficient number of experimental data points are used.





(Minachi, 1994)



ACOUSTO-ULTRASONIC APPLICATIONS

- Digital Ultrasonic Panametrics -NDT™ EPOCH 4 uses a Square Wave Pulser with a narrow band filtering process to optimize penetration on thick or attenuating materials as Composites.

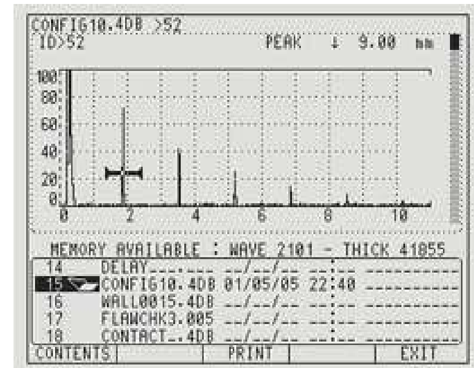
- TSCOUT - This device uses an oblique incidence angle wave to penetrate through different layers of composites.

  – It has been used to detect the presence of primary defects as delaminations and to obtain the elastic properties.

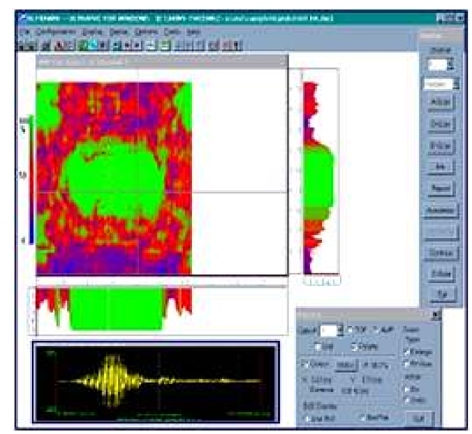
  – TSCOUT technology is most usable where other inspection technologies cannot effectively be employed from a single side of a structure.

EPOCH 4

(www.olympusndt.com)



TSCOUT



(www.ndtautomation.com)

EXPERIMENTAL PROGRAM

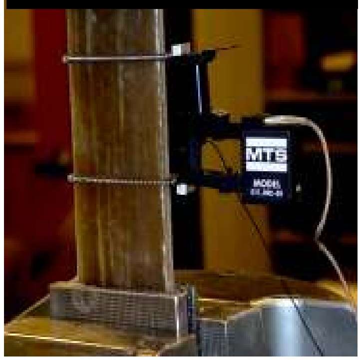
- TENSION TESTS (ASTM D 3039)

TESTING MATRIX FOR TENSILE CHARACTERIZATION

TEST SET	SAMPLE SIZE	SPECIMEN DIMENSIONS	
		Length (in)	Wide (in)
Short Specimens			
Preliminary	15	12	2
Long Specimens			
Resin Region	8	18	2
Middle Region	8	18	2
Vacuum Region	12	18	2

EXPERIMENTAL SETUP

EXTENSOMETER
MTS - S632



MTS LOAD UNIT S622
Max. Cap: 110 kips

HYDRAULIC GRIP SUPPLY

LOAD CELL
MTS - S661

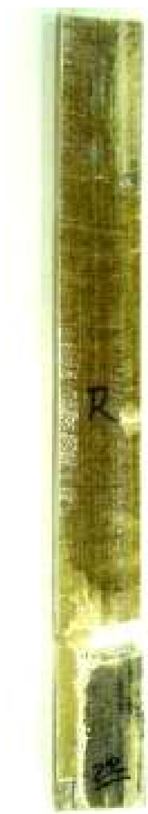
MTS TESTAR II – TESTWARE SX

HYDRAULIC POWER UNIT
S510

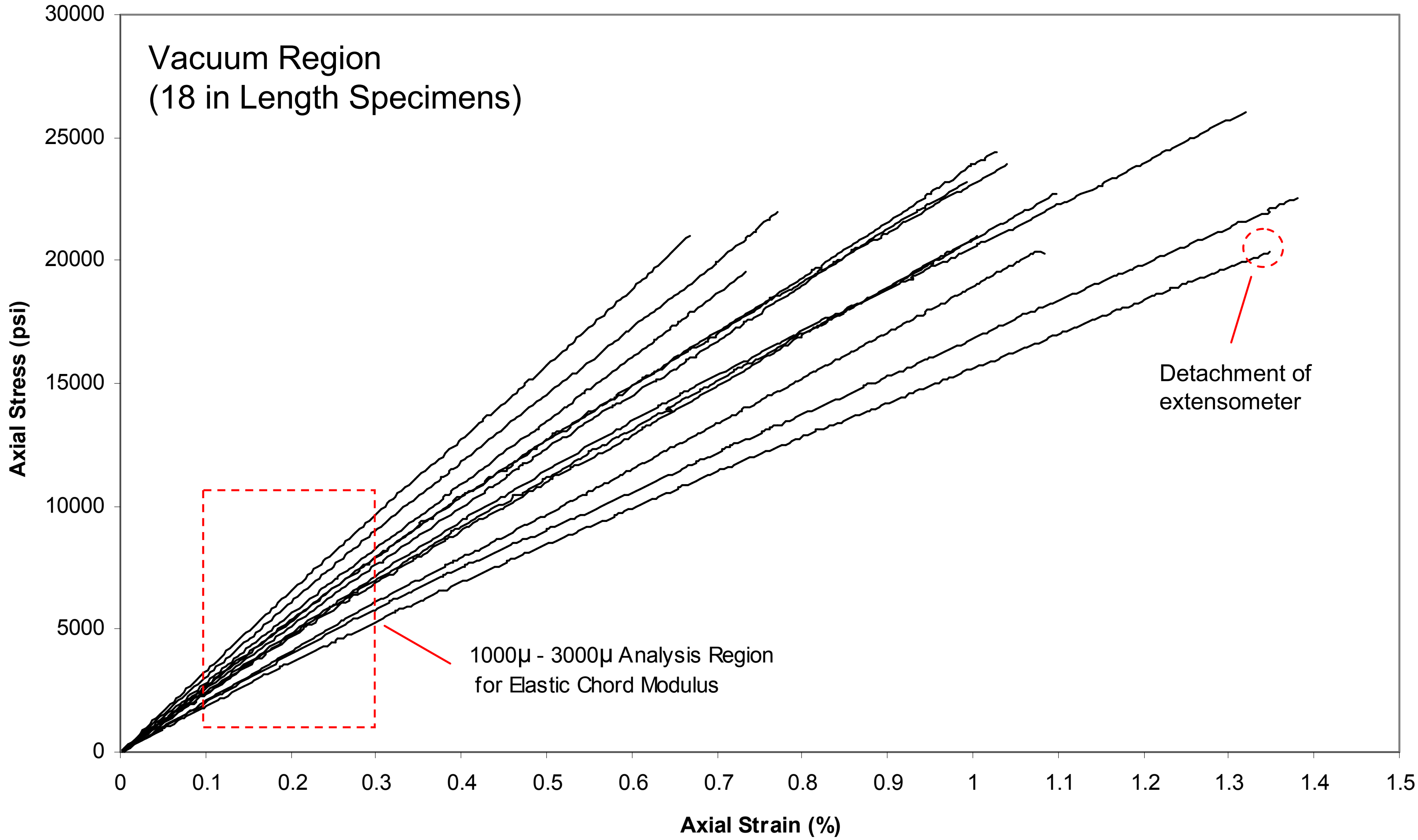
SPECIMEN PREPARATION

- Sizing
  - Cutting:
    - Titanium Indentation Saw
  - Vacuum Assisted Sanding
    - Roto-Vibrational Sander
- Metallic Tab Set
  - Curve surface contact
  - Alignment with specimen
- Specimen Installation
  - Alignment with grips
  - Increased pressure at grips
- Extensometer Attachment
- Safety Accessories

TENSION TEST RESULTS

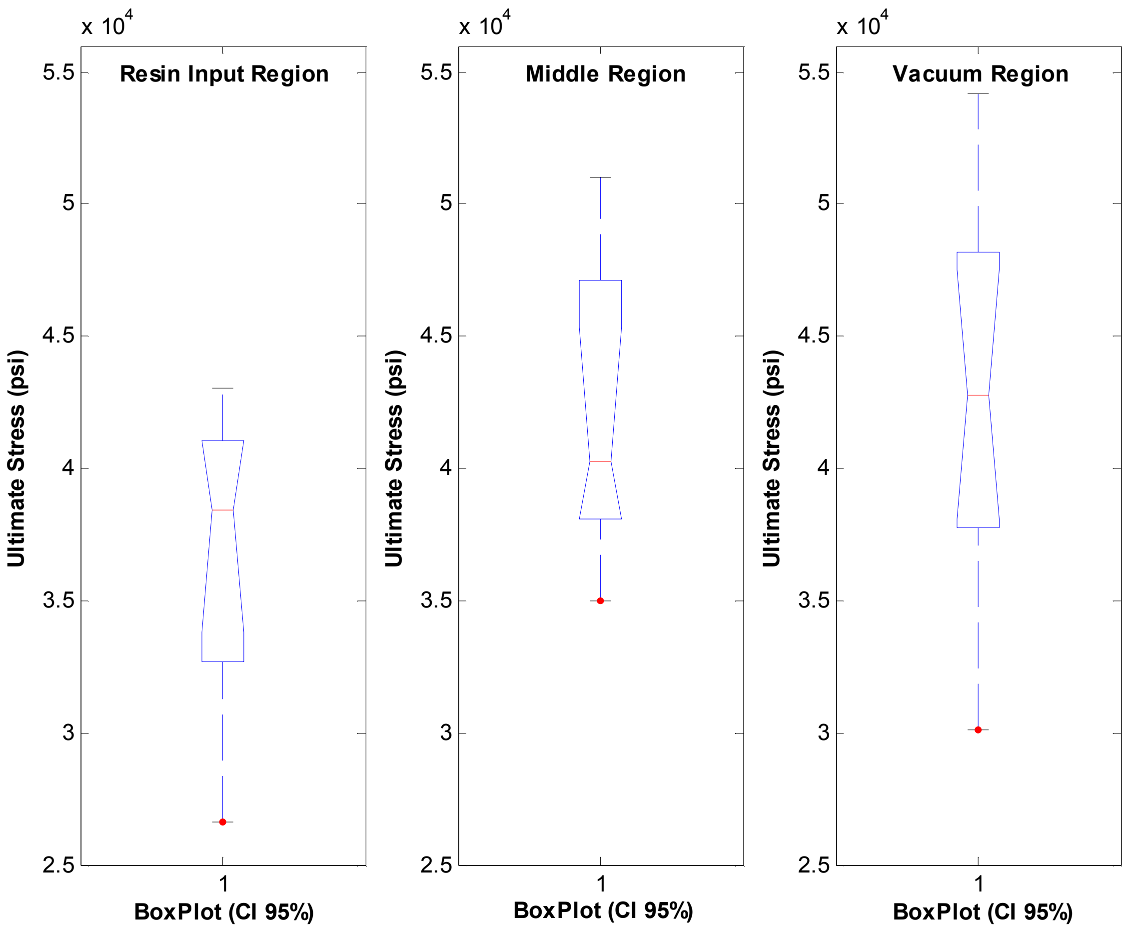
TYPICAL FAILURE MODES			
At Center	Inside the Grip	Near The Grip	Combined
			

TENSION TEST RESULTS



TENSION TEST RESULTS

BOX PLOTS FOR ULTIMATE STRESS



TENSION TEST RESULTS

Analysis of Variance for Chord Modulus

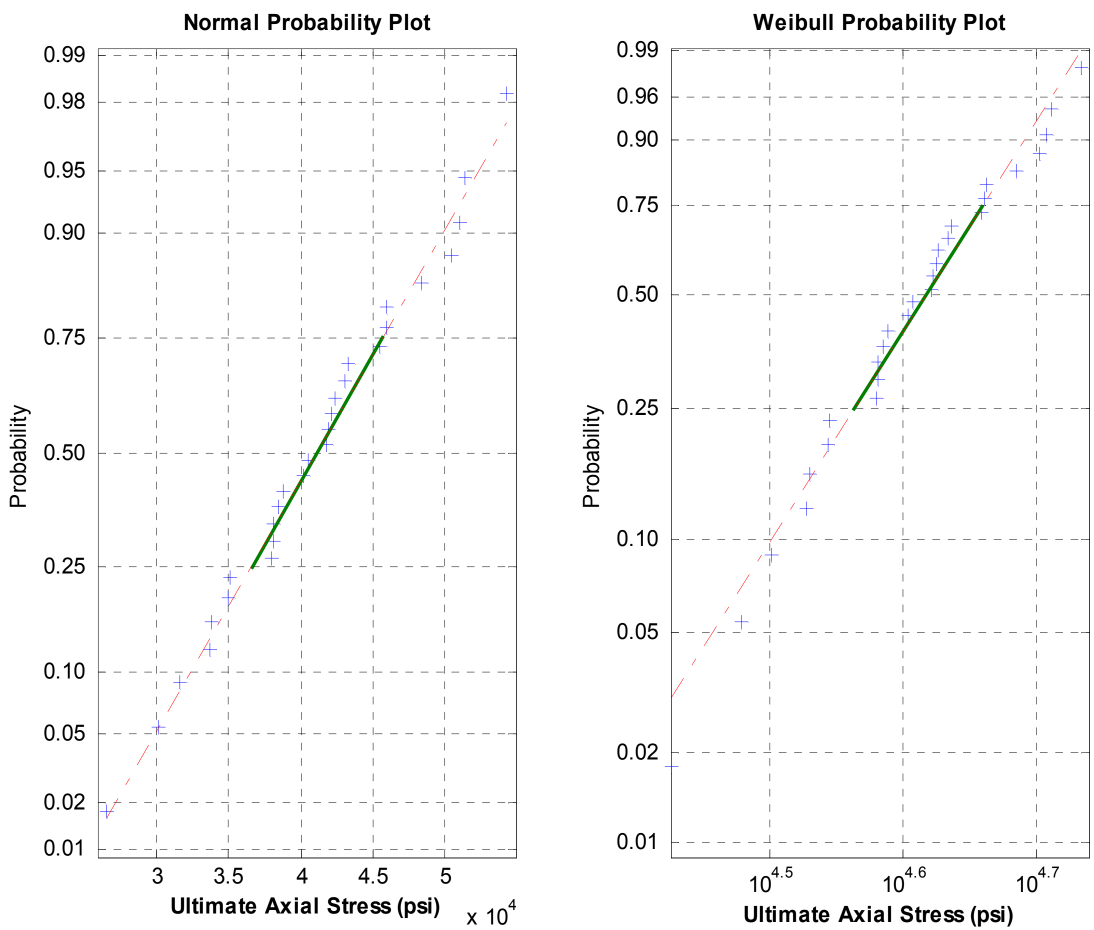
```
Source  DF           SS           MS     F       P
Factor   2  1.06186E+11  53093220254  0.30   0.744
Error   25  4.44042E+12  1.77617E+11
Total   27  4.54661E+12
S = 421446   R-Sq = 2.34%   R-Sq(adj) = 0.00%
                             Individual 95% CIs For Mean Based on Pooled StDev
Level    N     Mean   StDev      --+---------+---------+---------+-------
Resin    8  2264826  323648      (--------------*---------------)
Middle   8  2415188  486750             (---------------*---------------)
Vacuum  12  2387934  431562               (-----------*------------)
                                 --+---------+---------+---------+-------
                             2000000   2200000   2400000   2600000
```

Analysis of Variance for Ultimate Axial Stress

```
Source  DF          SS          MS     F       P
Factor   2   195827211    97913605  2.36   0.116
Error   25  1039102608    41564104
Total   27  1234929819
S = 6447   R-Sq = 15.86%   R-Sq(adj) = 9.13%
                          Individual 95% CIs For Mean Based on Pooled StDev
Level    N   Mean  StDev      +---------+---------+---------+---------
Resin    8  36747   5634      (-----------*-----------)
Middle   8  42115   5735                    (-----------*-----------)
Vacuum  12  42859   7303                        (---------*---------)
                              +---------+---------+---------+---------
                          32000     36000     40000     44000
```

TENSION TEST RESULTS

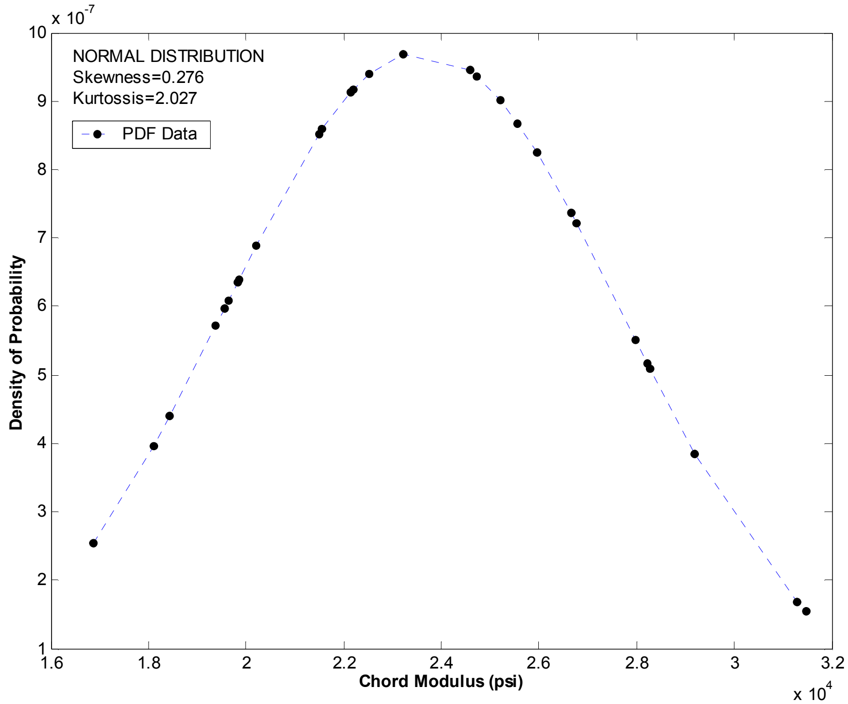
Goodness of Fit Probability Model Test for Ultimate Stress



UNIVERSITY OF Rhode Island

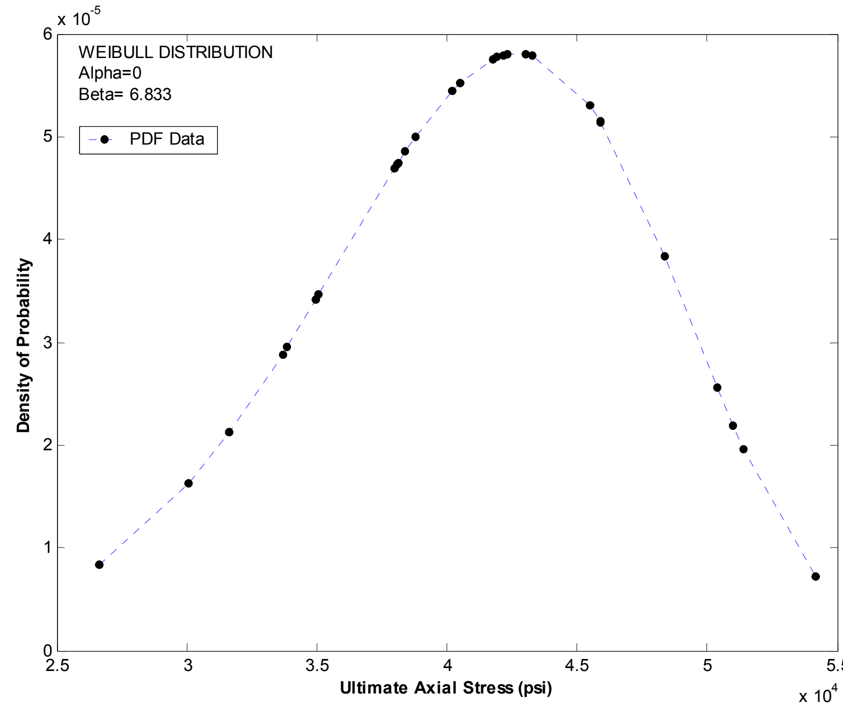
TENSION TEST RESULTS

Probability Density Function for Chord Modulus



Mean = 2360.54 ksi
COV = 17.4%

Probability Density Function for Ultimate Stress



Mean = 40.85 ksi
COV = 17.2%

CONCLUSIONS

- Due to the special characteristics of the composite piles, the application of a NDE/NDT method must consider the anisotropy of the composite material and the presence of different materials or mediums surrounding the installed pile.

- Ultrasonic wave speed measurements is one of the most commonly used methods for the determination of elastic constants of anisotropic laminates.

- Using the so called "effective modulus" theories the SE/IR and Bending Wave NDE methods can be used in composites for:
  - Flaw detection
  - Unknown depth exploration
  - Mechanical characterization

CONCLUSIONS

- The Acousto-Ultrasonics method can be used for composite material flaw detection and material elastic characterization having access only to one side of the laminate.

  Commercial Devices using this technique:
  - Panametrics - NDT™ EPOCH 4
  - TSCOUT Scanning system.

- The analysis of variance applied to the experimental results allows one to conclude that there does not exist a significant difference for the tensile properties in the pile regions (95 % confidence level).

CONCLUSIONS

- Tensile properties for Pearson Composite Piling System :
  - Chord Elastic Module: (Normal Distribution) — Mean Value = 2360.50 ksi; COV = 17.4%
  - Ultimate Axial Strength: (Weibull Distribution) — Mean Value = 40.85 ksi; COV_{eqv} = 17.2%
- The value of the elastic module in tension obtained could be used as a reference to that obtained using NDE/NDT methods.

ACKNOWLEDGEMENTS

- Eisenhower Fellowship Program
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THANK YOU