FRP Composite Piles – Applications & Durability Considerations

by

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Outline

- **Case Histories involving use of FRP piles:**
  - **Route 40 bridge**
  - **Route 351 bridge**
  - **Cost comparison**
- **Durability Studies**
  - **Work at Virginia Tech and with NCSU (w/ Amir Fam)**
  - **Joint work Virginia Tech and UPRM**
- **Recommendations for future work**
- **Acknowledgments**

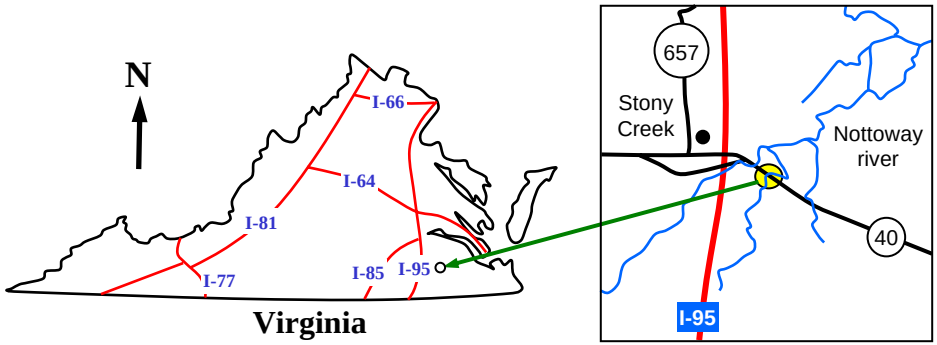
Background

- **Recent work at Virginia Tech (Pando, Lesko, Filz - FHWA project)**
  - **Investigate the feasibility of using composite piles for load bearing applications such as in bridge substructures.**
  - **Assessment of driveability, axial capacity, lateral capacity, and long-term durability of composite piles**
    - **Route 40 project ← This presentation**
    - **Route 351 project ← This presentation**
  - **Evaluate their long-term durability ← This presentation**

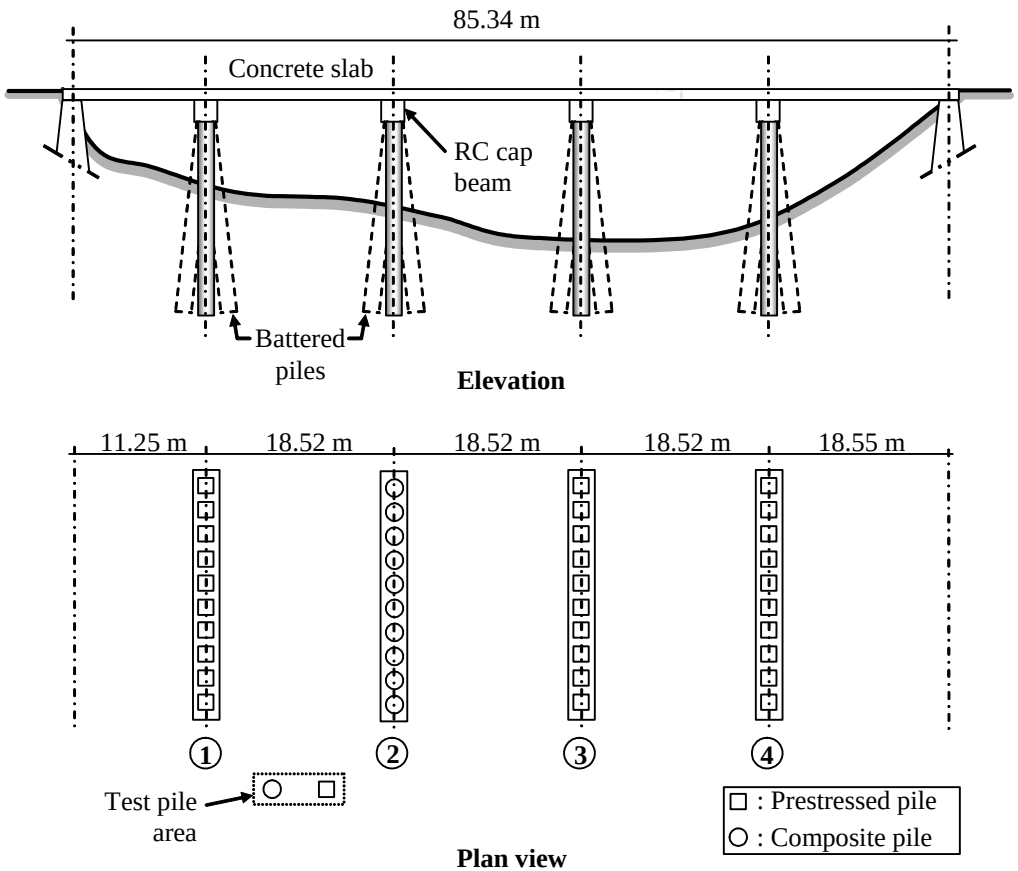
Case Histories:

- **Rte. 40 Bridge**
- Rte. 351 Bridge

Route 40 Bridge

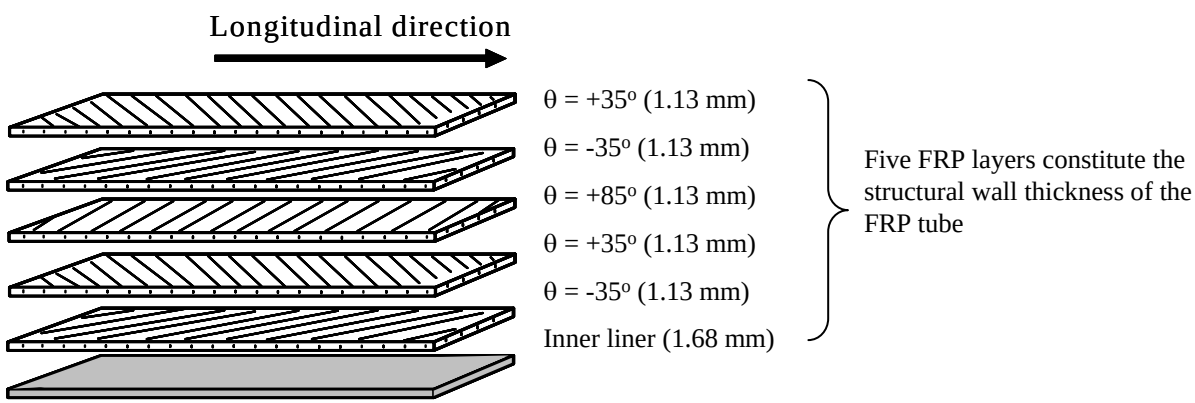


Location of FRP Piles

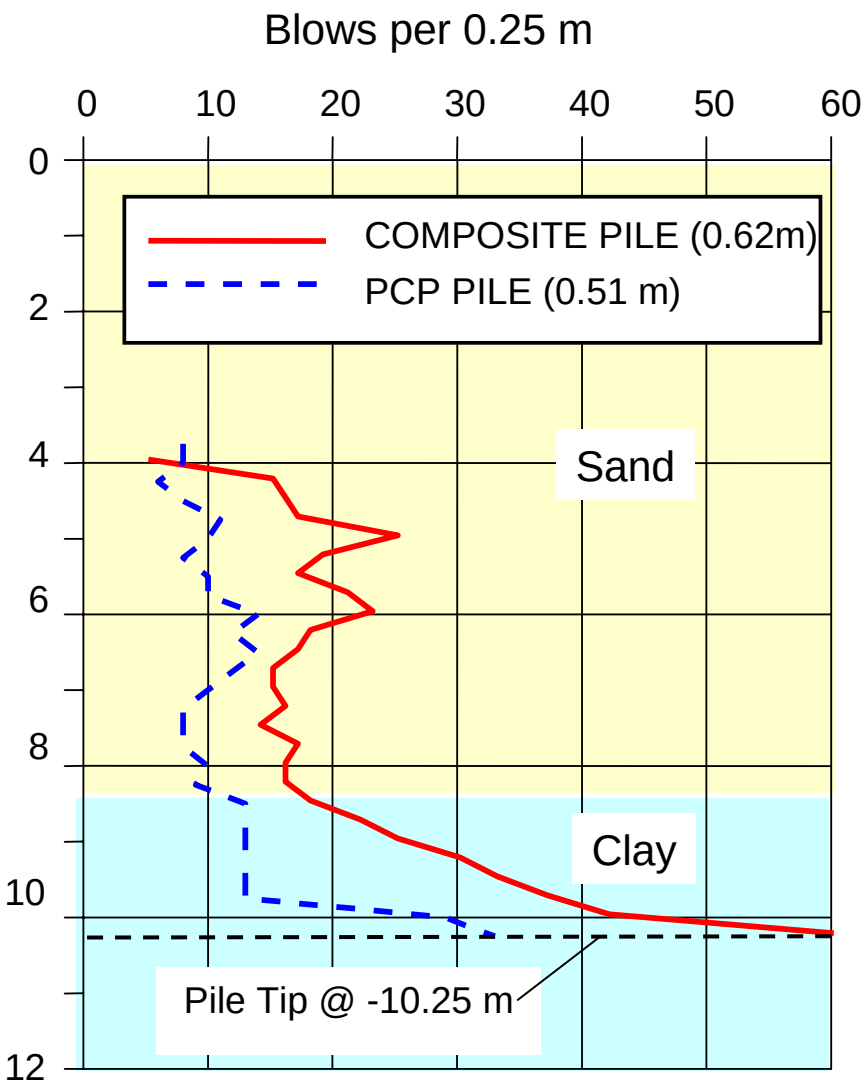


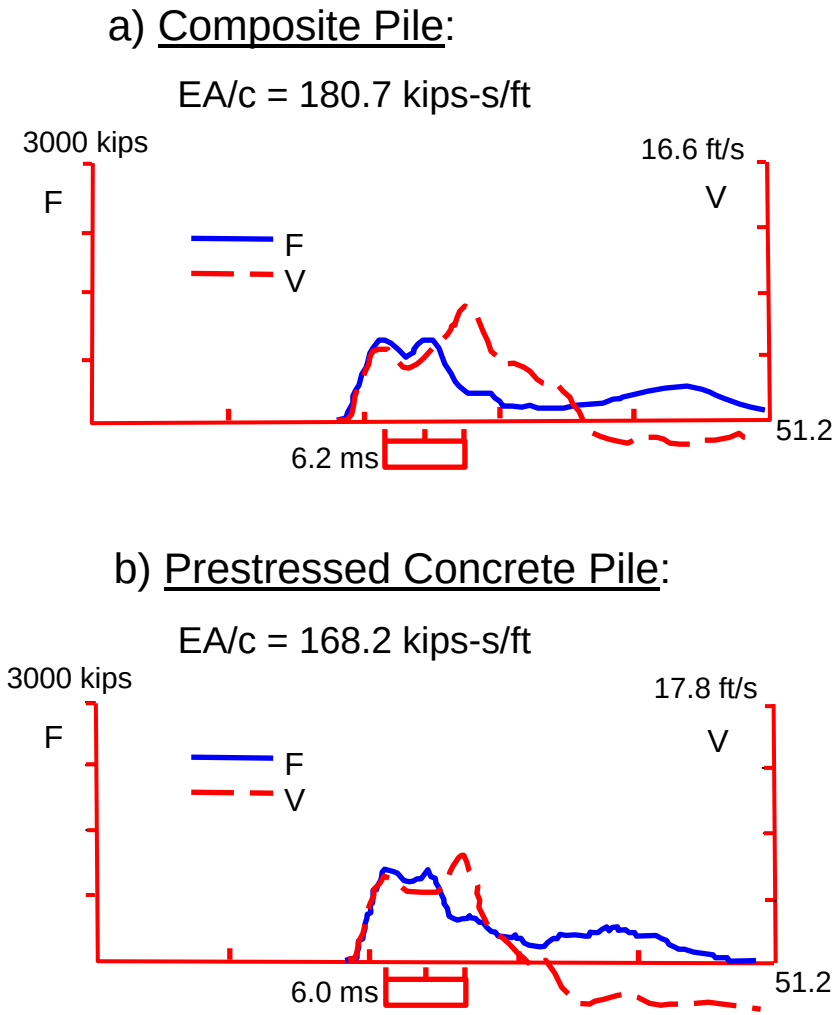
Route 40 Bridge

a) Photograph of composite piles installed at Pier No. 2 of the Route 40 Bridge



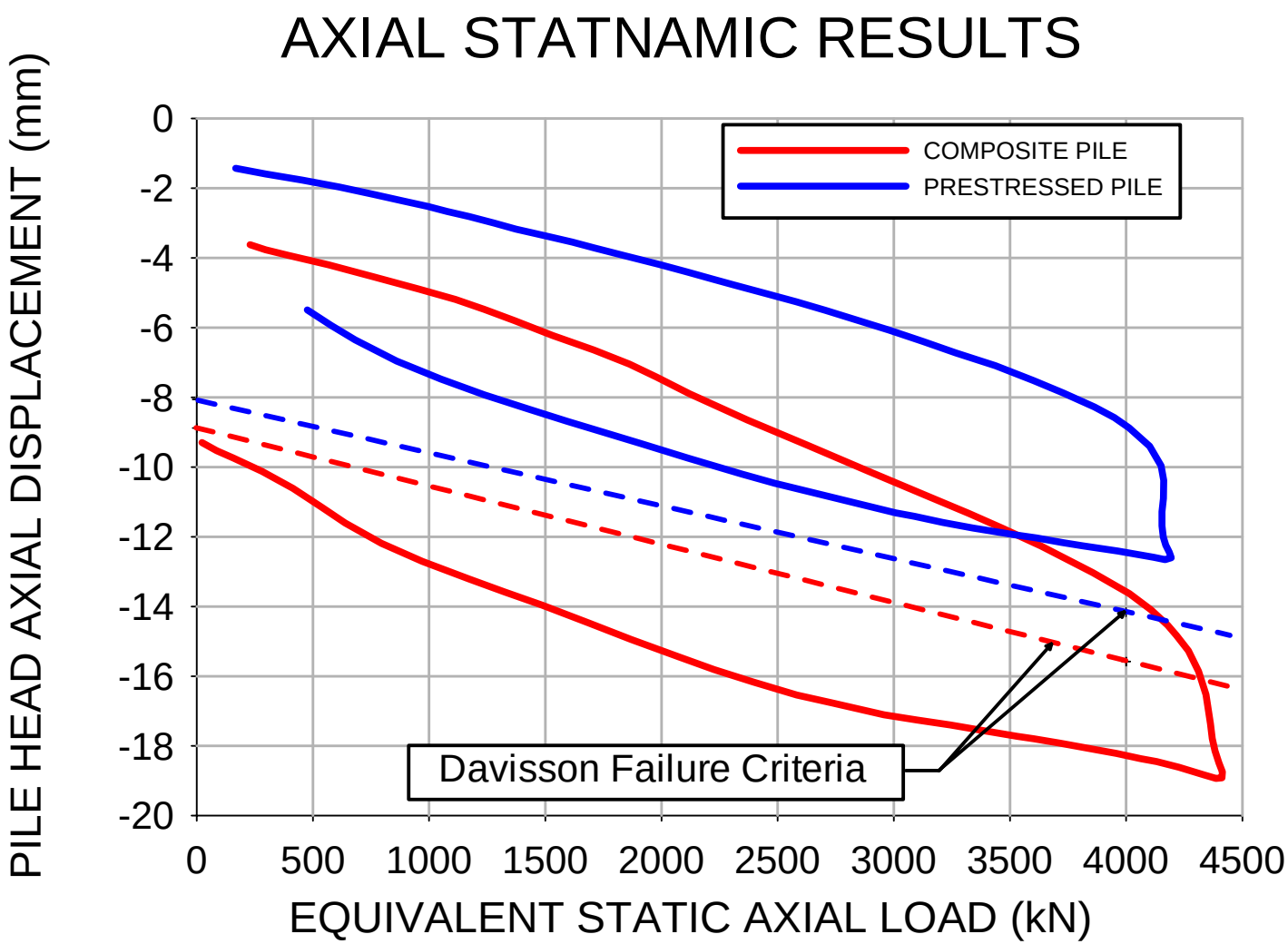
b) FRP tube laminate structure of composite pile

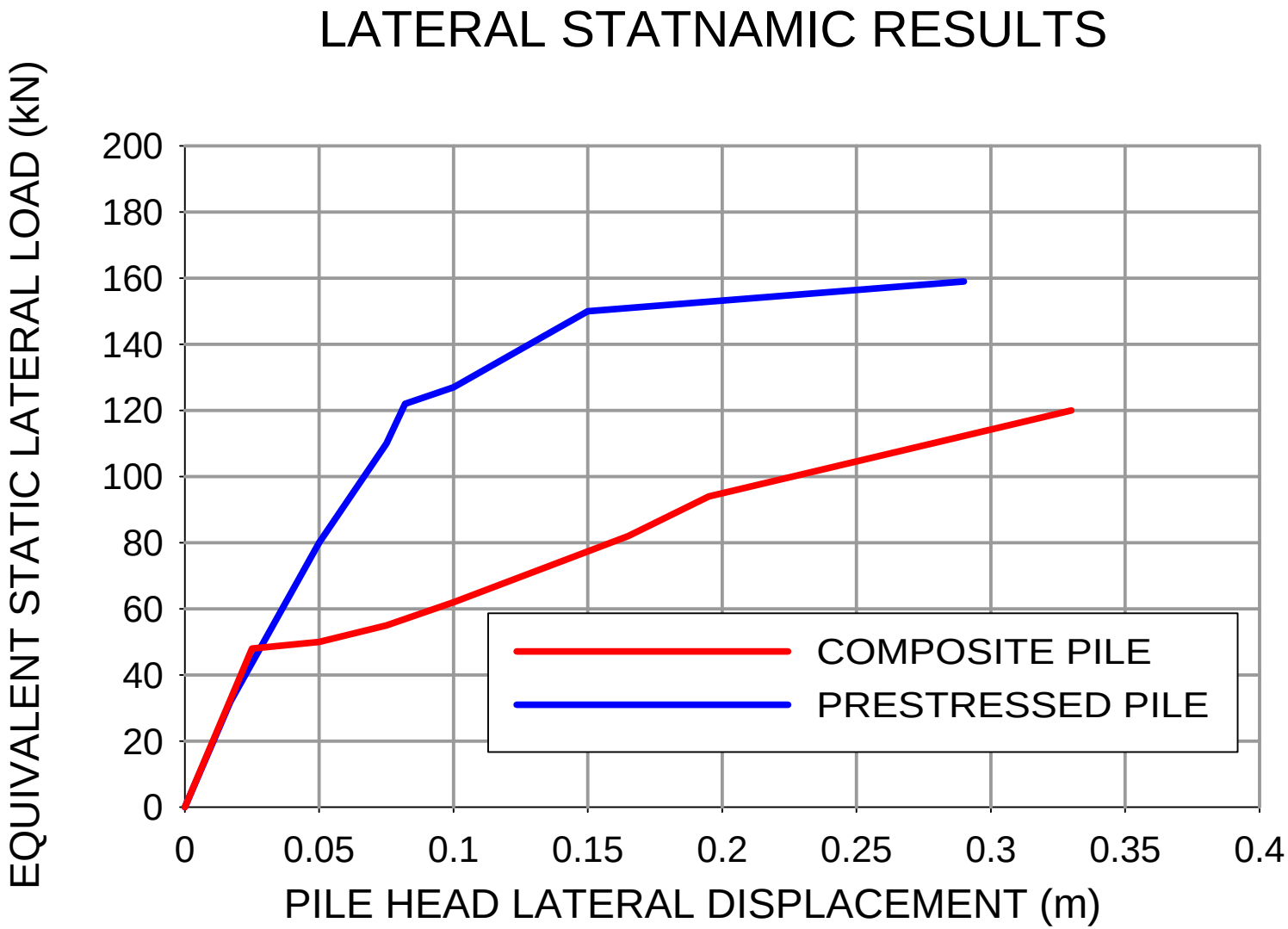




PILE DRIVING RECORDS

END-OF-DRIVING PDA


AXIAL STATNAMIC RESULTS
PILE HEAD AXIAL DISPLACEMENT (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
500
1000
1500
2000
2500
3000
3500
4000
4500
EQUIVALENT STATIC AXIAL LOAD (kN)
COMPOSITE PILE
PRESTRESSED PILE
Davisson Failure Criteria


LATERAL STATNAMIC RESULTS
EQUIVALENT STATIC LATERAL LOAD (kN)
200
180
160
140
120
100
80
60
40
20
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
PILE HEAD LATERAL DISPLACEMENT (m)
COMPOSITE PILE
PRESTRESSED PILE

The new Route 40 Bridge over the Nottoway river in Virginia

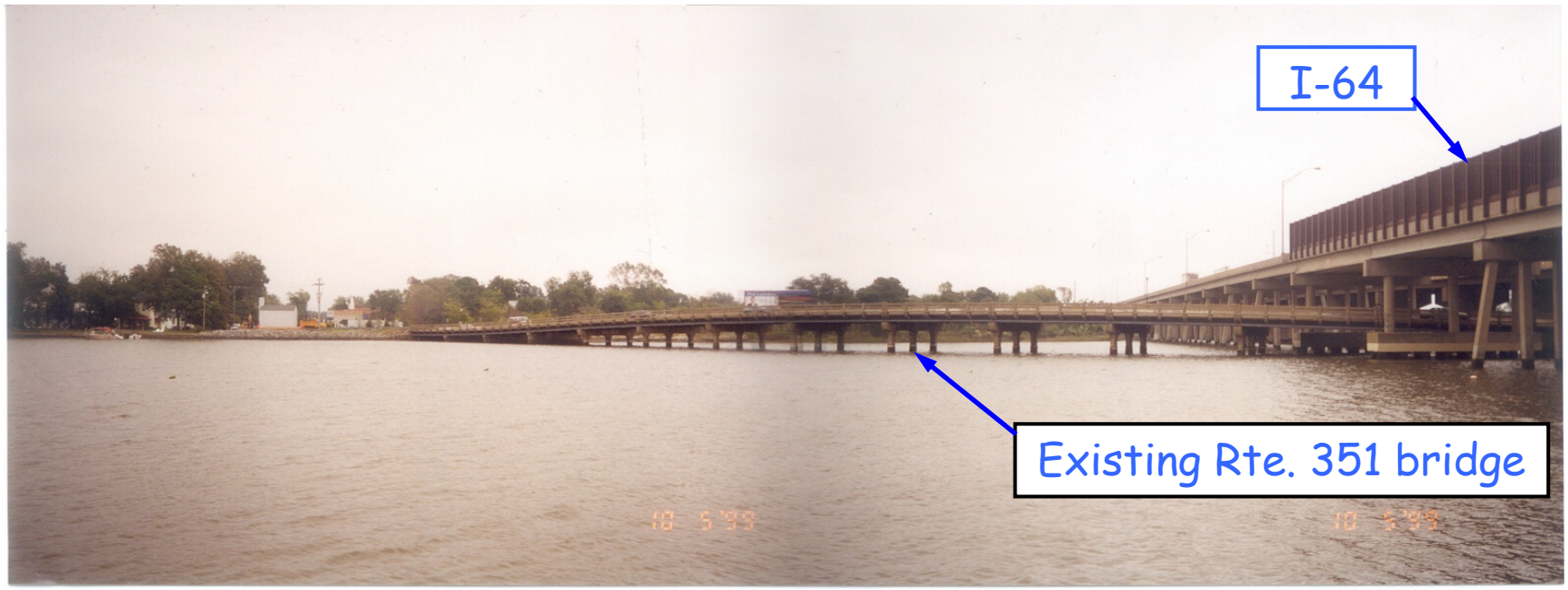
Lessons from Route 40

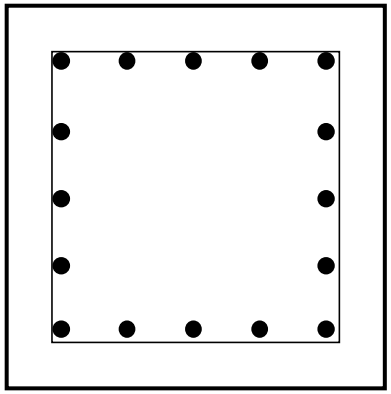
- Driveability:
  - No major differences in driving behavior (FRP piles can be installed)
- Axial Capacity:
  - Both piles performed similarly
  - Composite pile: P_{ult} = 4360 kN (Δy =18 mm)
  - PCP pile: P_{ult} = 4190 kN (Δy = 13 mm)
- Lateral Capacity:
  - Both piles appeared to have similar ultimate lateral load capacity
  - Composite pile had lower flexural stiffness after initial concrete cracking which appeared to occur at 50 kN
  - Composite piles were designed as specified for axial load only
- Use of concrete-filled FRP composite piles for bridge foundations feasible & practical based on this project.

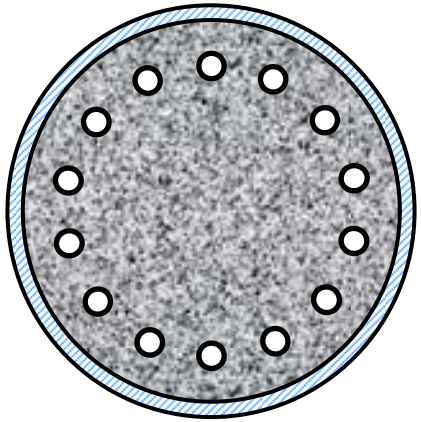
Case Histories (continued):

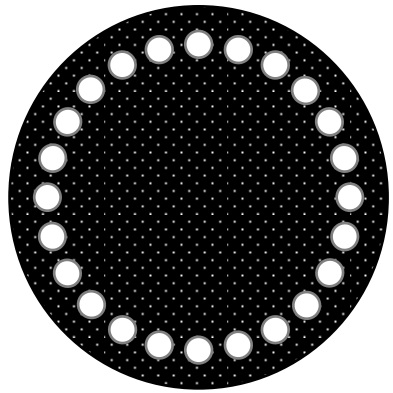
- Rte. 40 Bridge
- **Rte. 351 Bridge**

Rte. 351 Bridge in Hampton, VA

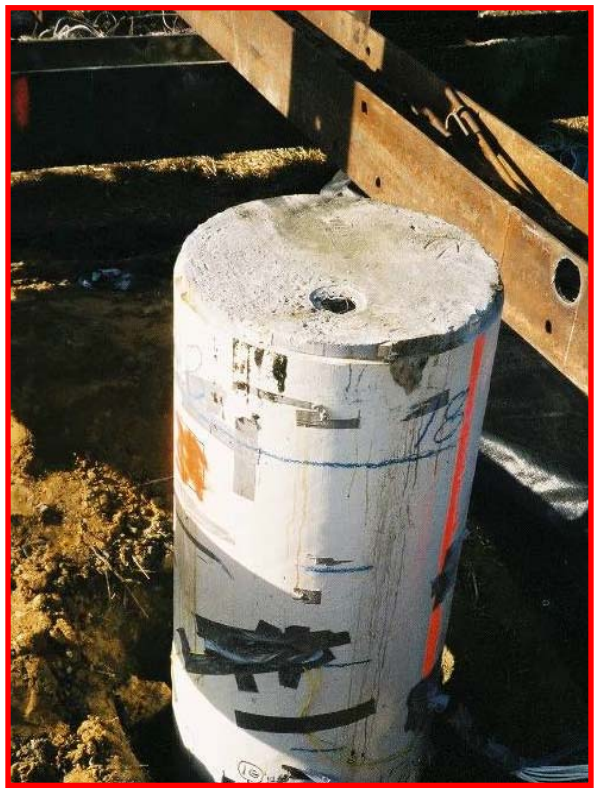




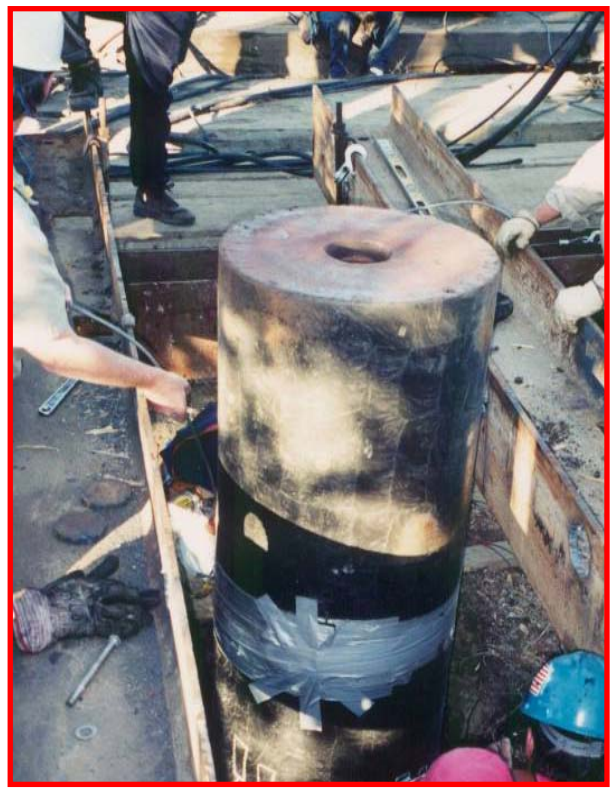




Prestressed Pile

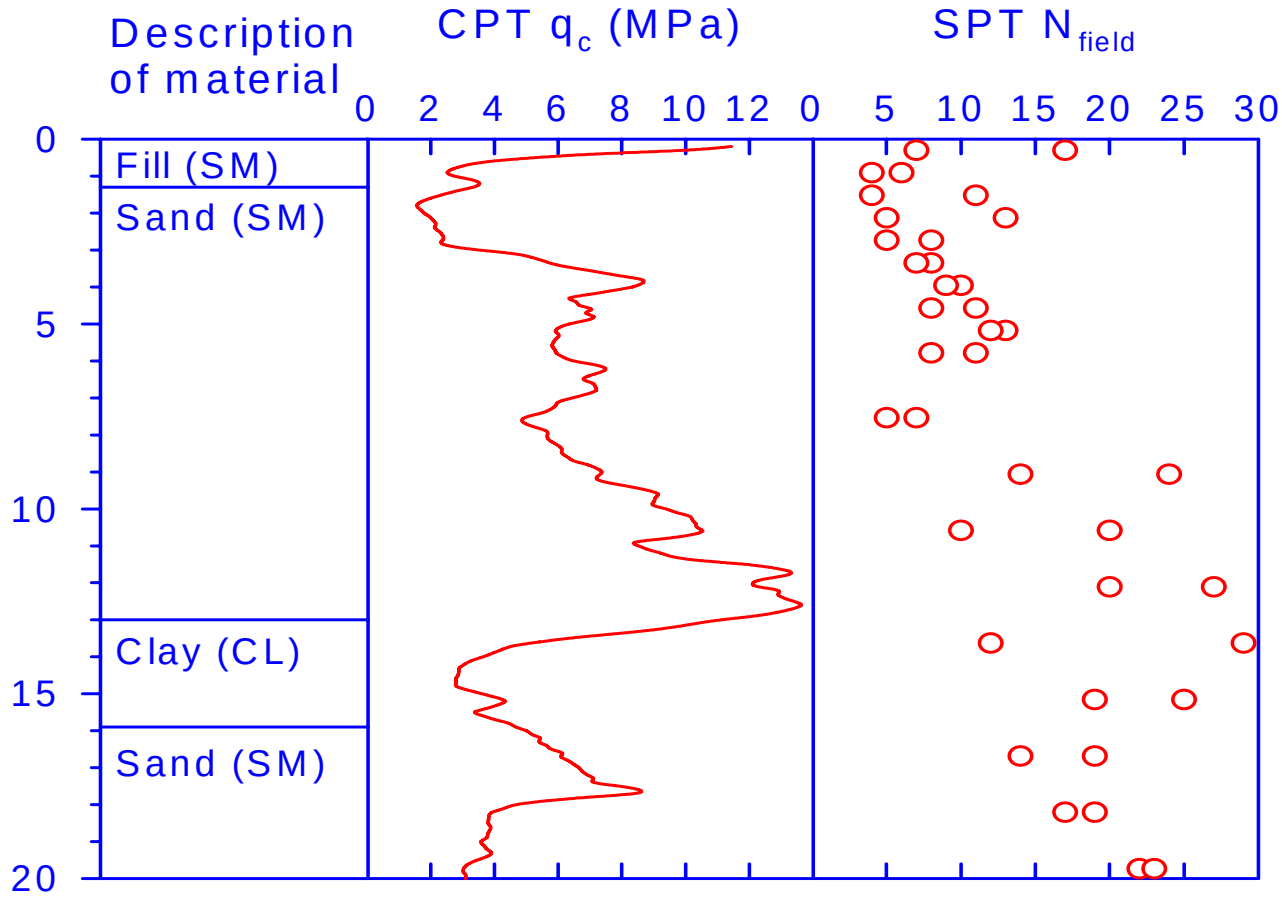


Composite Pile

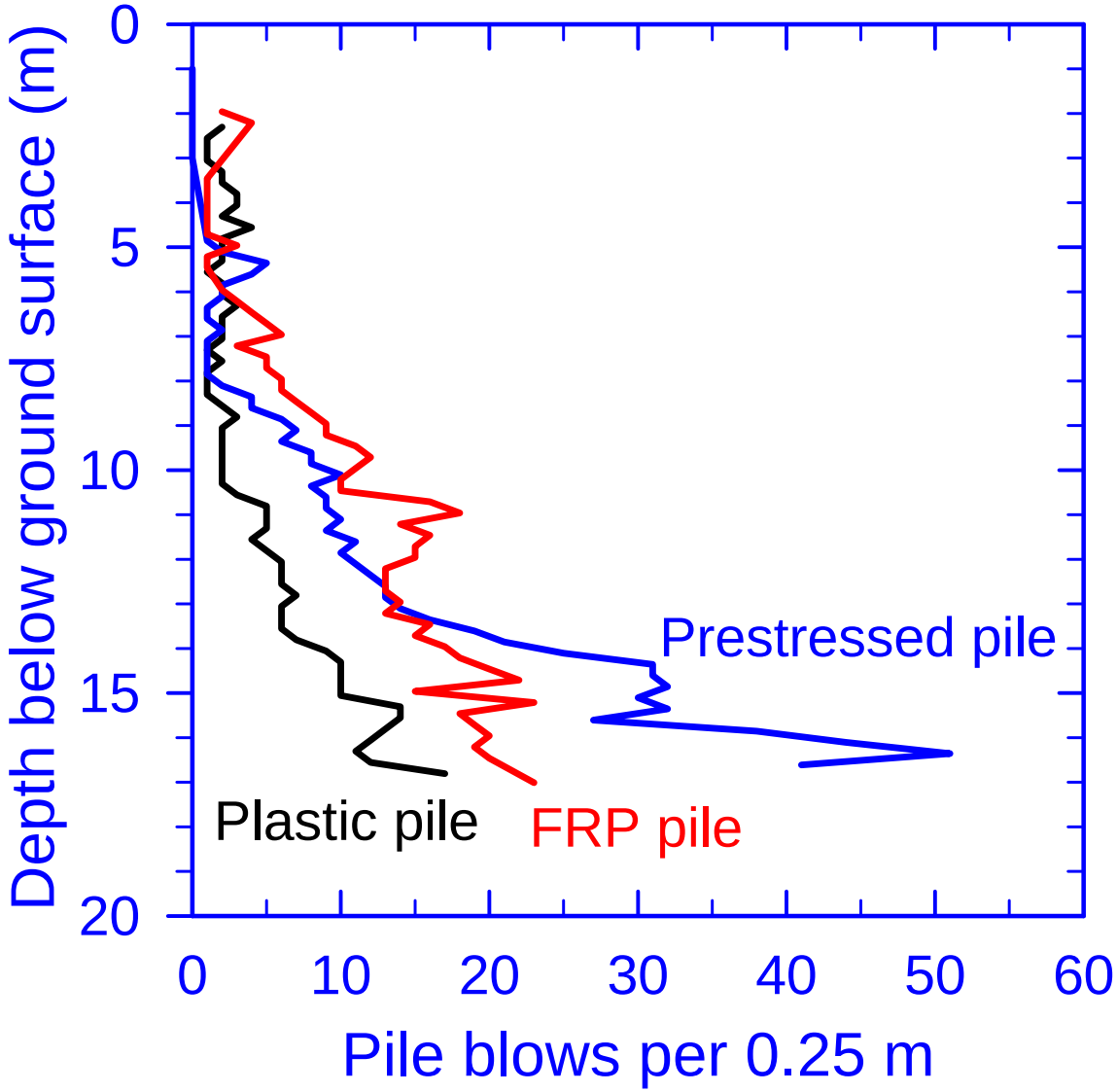


Recycled Plastic Pile

Subsurface conditions

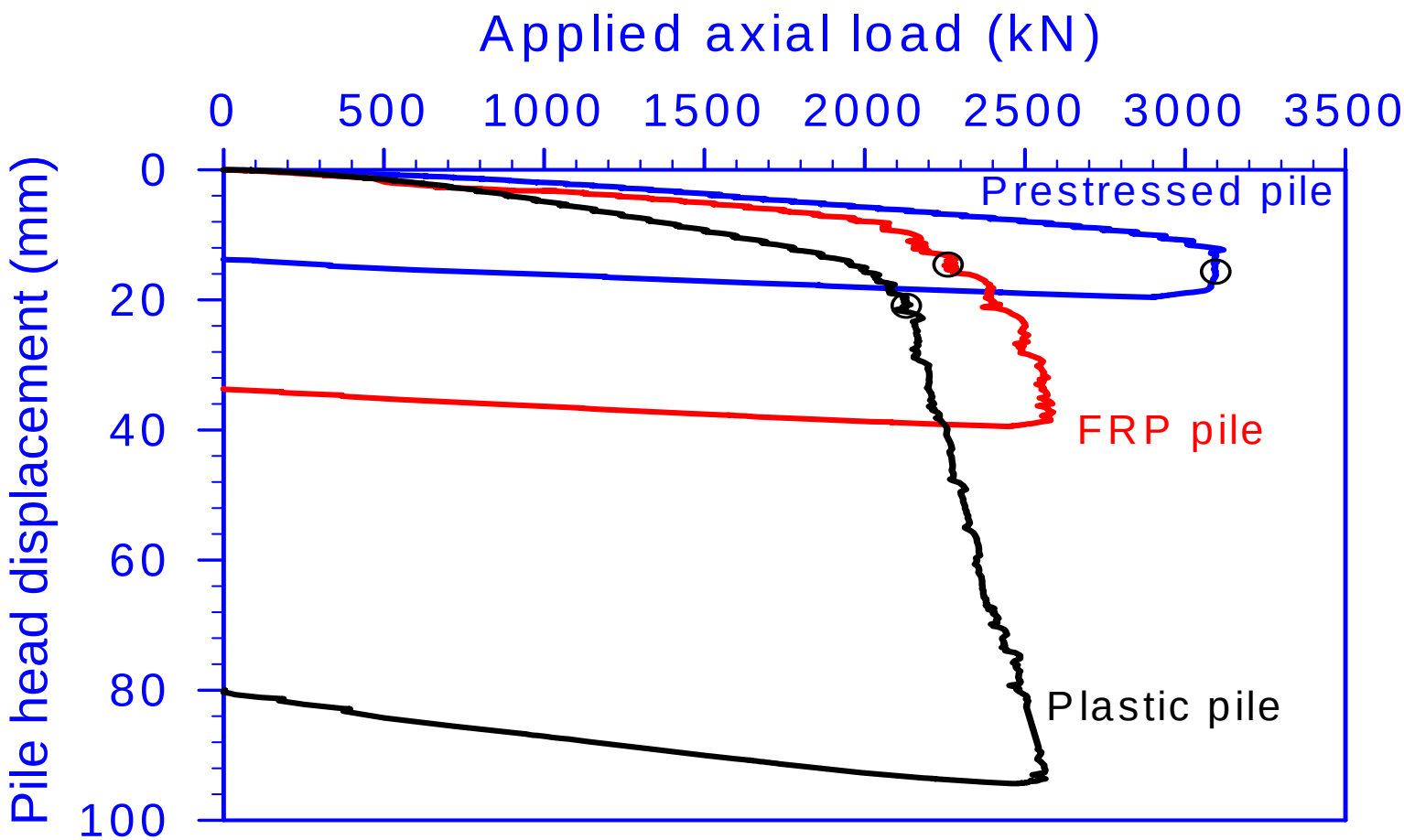


Pile driving records

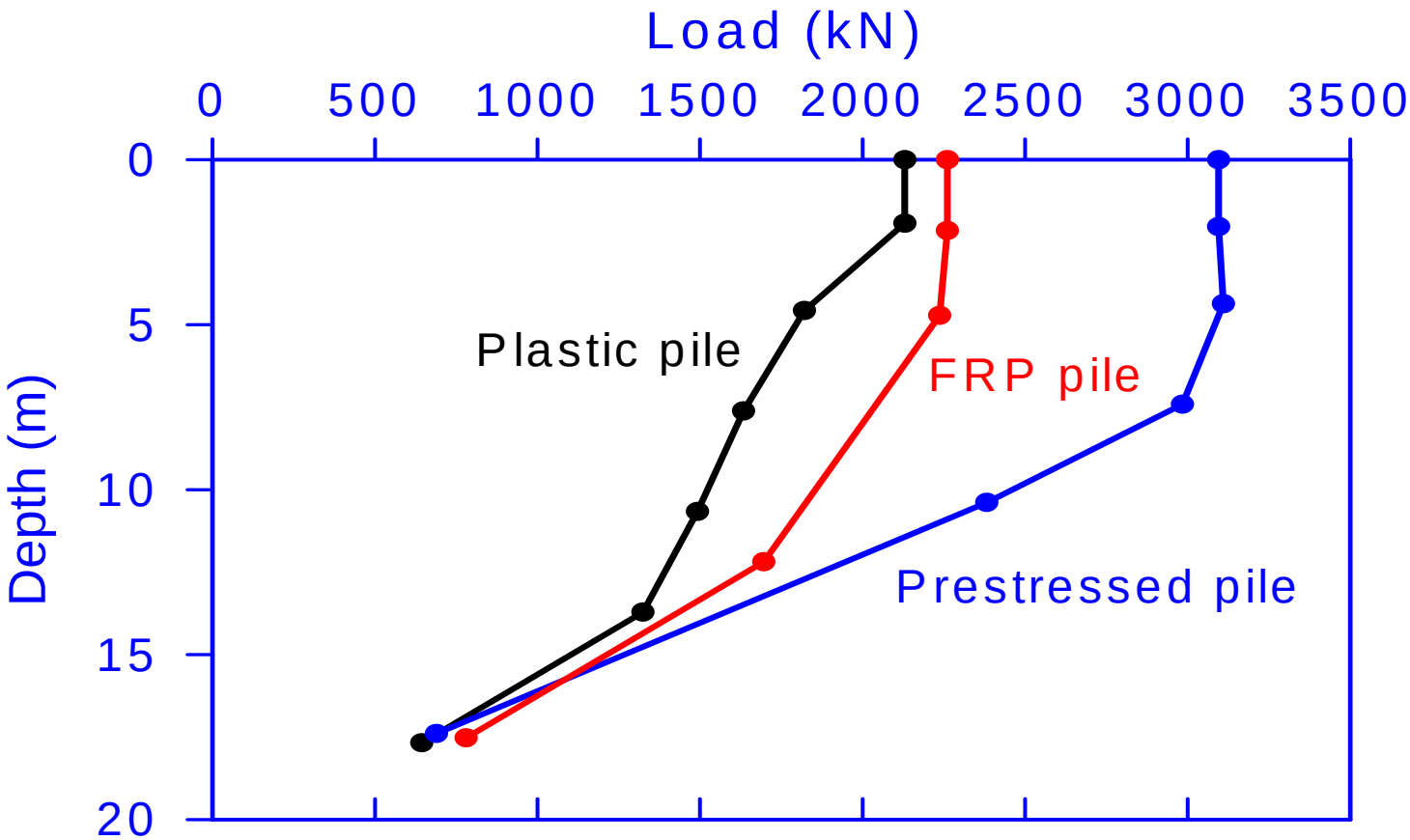


Static Axial Load Tests

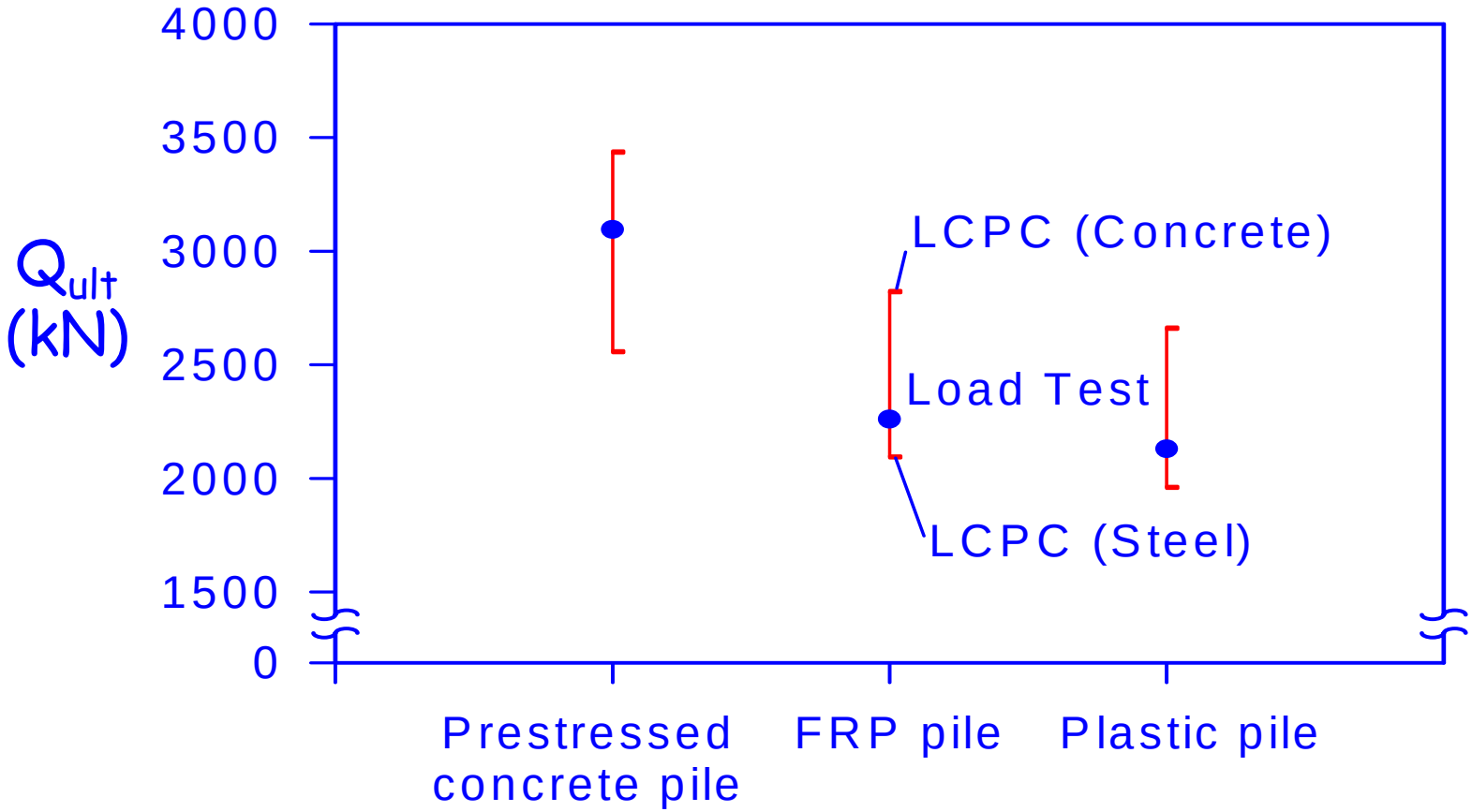
Static Axial Load Test Results



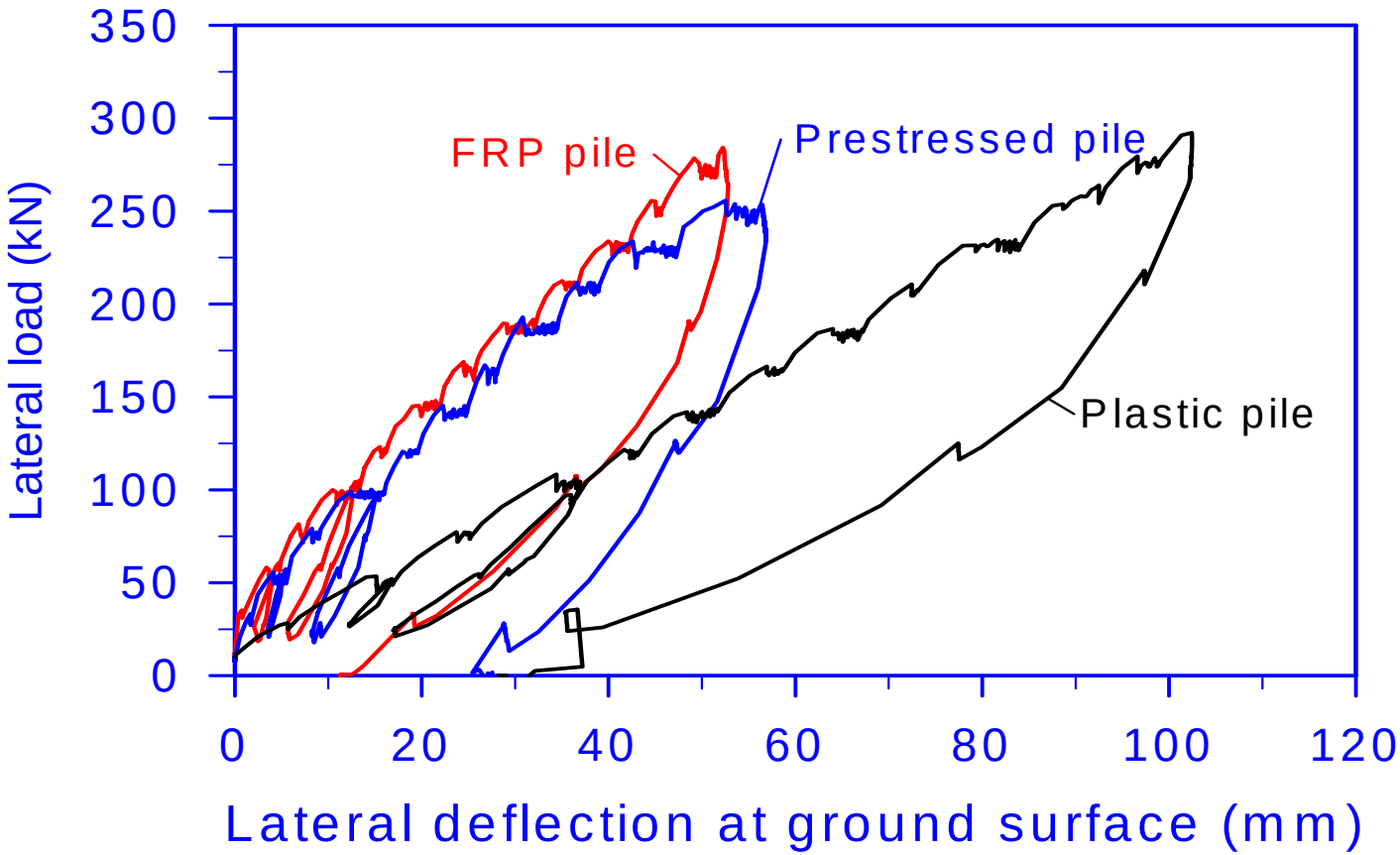
Load Transfer during Static Load Tests



Comparison of Axial Load Test Results with LCPC Method



Static Lateral Load Test Results



Lessons Route 351

- Penetration resistance during driving increases in order: plastic pile, FRP pile, prestressed concrete pile
- Pile capacities (Davisson) increase in the same order:
  - Plastic pile, Q_{ult} = 2130 kN (239 tons)
  - FRP pile , Q_{ult} = 2260 kN (254 tons)
  - Prestressed concrete pile, Q_{ult} = 3095 kN (348 tons)
- Traditional methods
- FRP pile and prestressed concrete pile exhibit similar stiffnesses in axial loading, plastic pile is not as stiff
- FRP pile and prestressed concrete pile exhibit similar stiffnesses in lateral loading, plastic pile is not as stiff

Cost information at two case studies

- Initial costs of composite piles were higher than those for prestressed concrete piles
  - 77 % higher at Route 40 bridge project
  - 289% and 337% higher for plastic and FRP piles, respectively, at Route 351 bridge

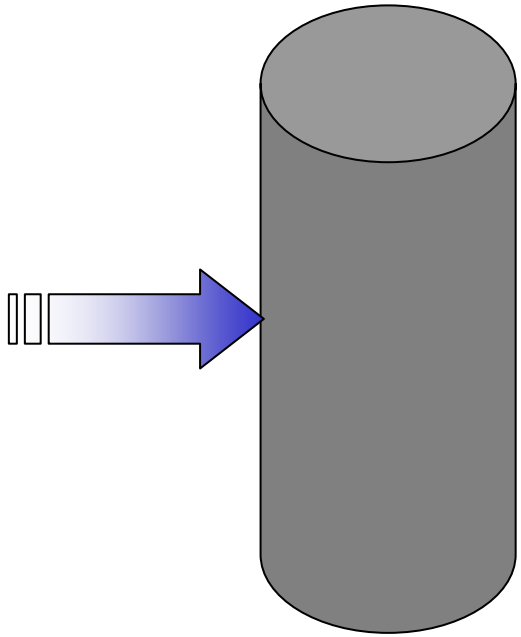
- Cost effectiveness of composite piles is expected to improve as production volume increases, and by considering life-cycle costs of low-maintenance composite piles

Durability Studies

Experimental durability study

Assumptions:

- Moisture is the dominant damage mechanism
- Homogenized FRP
- Residual strength is only moisture dependent
- Moisture diffusion is not stress dependent
- No chemical processes
- Creep rupture behavior is not considered
- FRP-concrete friction is not affected



- ✓ Track FRP moisture content
- ✓ Track FRP residual stiffness/strength
- ✓ FRP Pile strength (Fam & Rizkalla, 2001)
- ✓ Prediction of Residual Pile Life

Material characterization

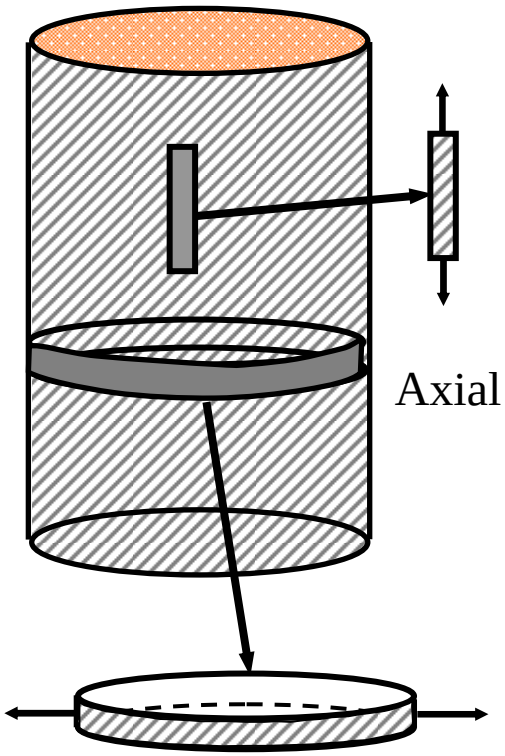
Lancaster 12- and 24-inch:

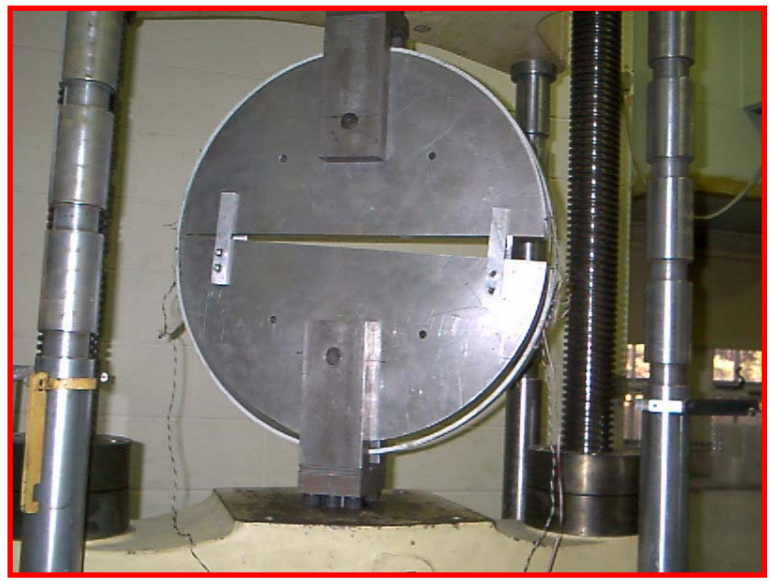
- Filament wound
- E-glass fiber
- 12-inch = epoxy, [-88/+8/-88/+8/-88/+8/-88/+8/-88], t = 6 mm
- 24-inch = polyester, [+35/-35/+85/+35/-35], t = 7.3 mm

Hardcore 12- and 24-inch:

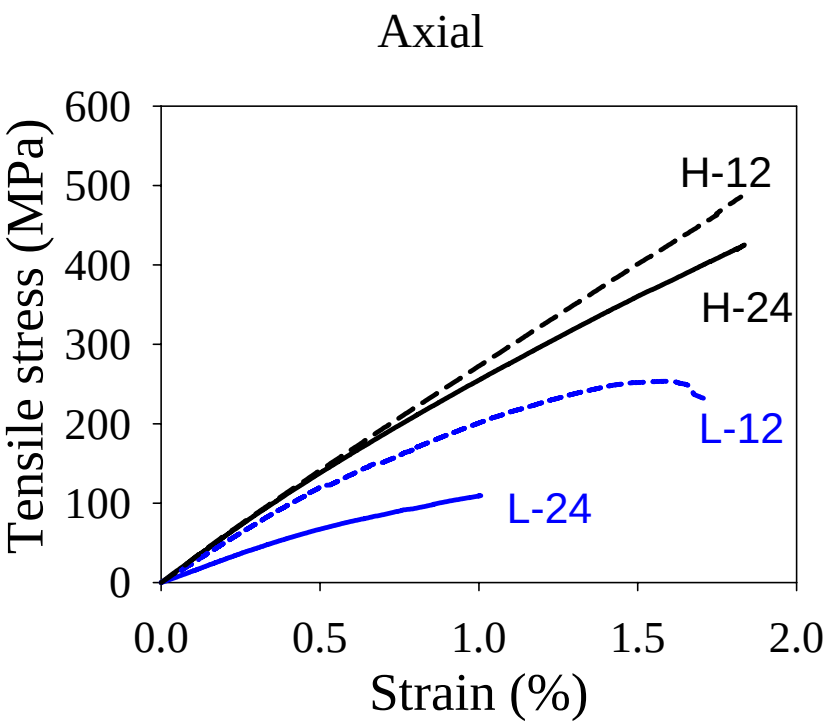
- VARTM
- E-glass fiber (multi-axis fabric Quad Q-9100)
- Vinyl ester
- 12-inch = 3 plies [0/+45/-45/90], t = 5.7 mm
- 24-inch = 4 plies [0/+45/-45/90], t = 8.9 mm

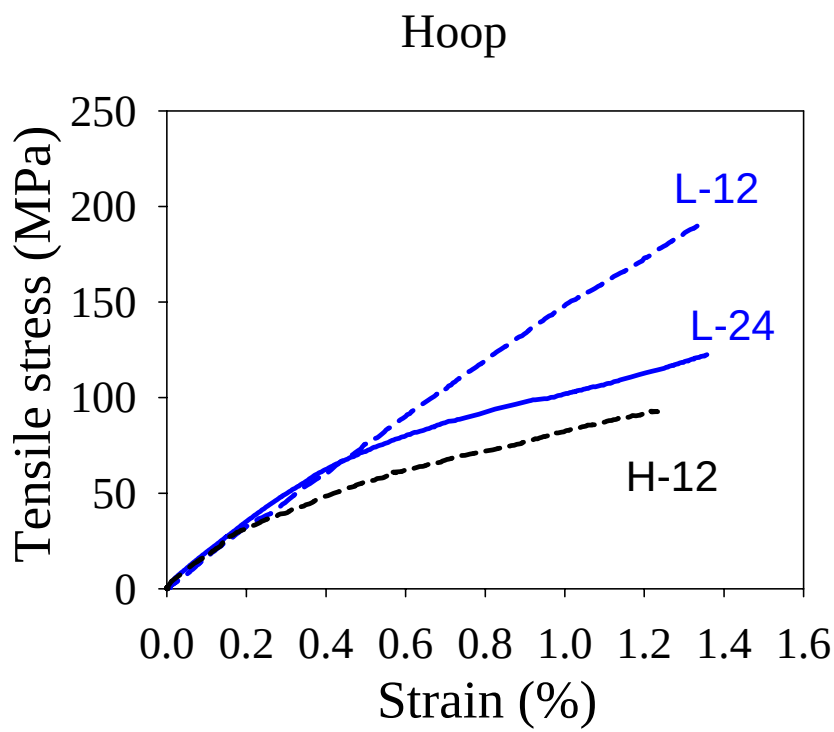
Evaluation of FRP Shell Properties



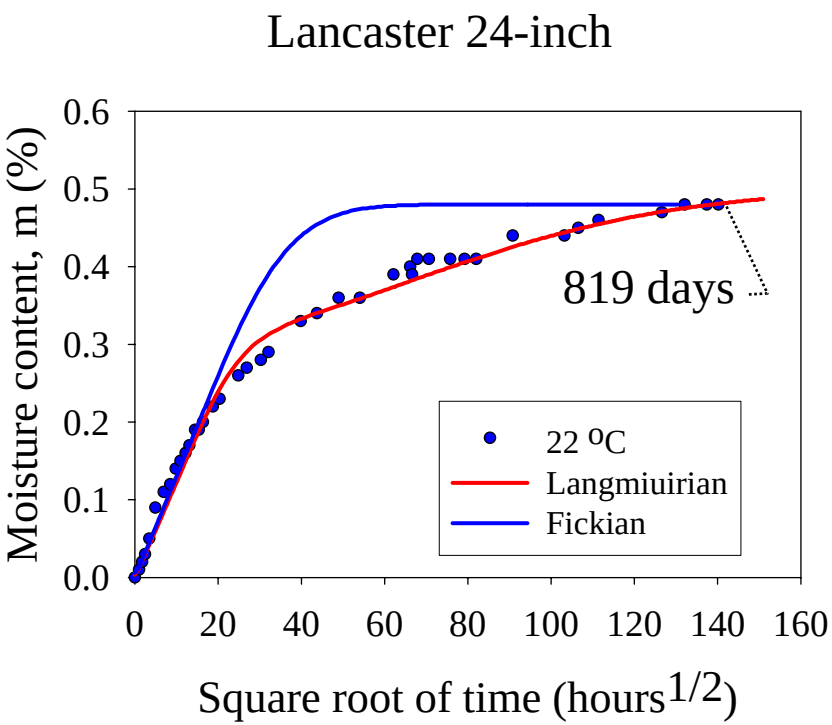


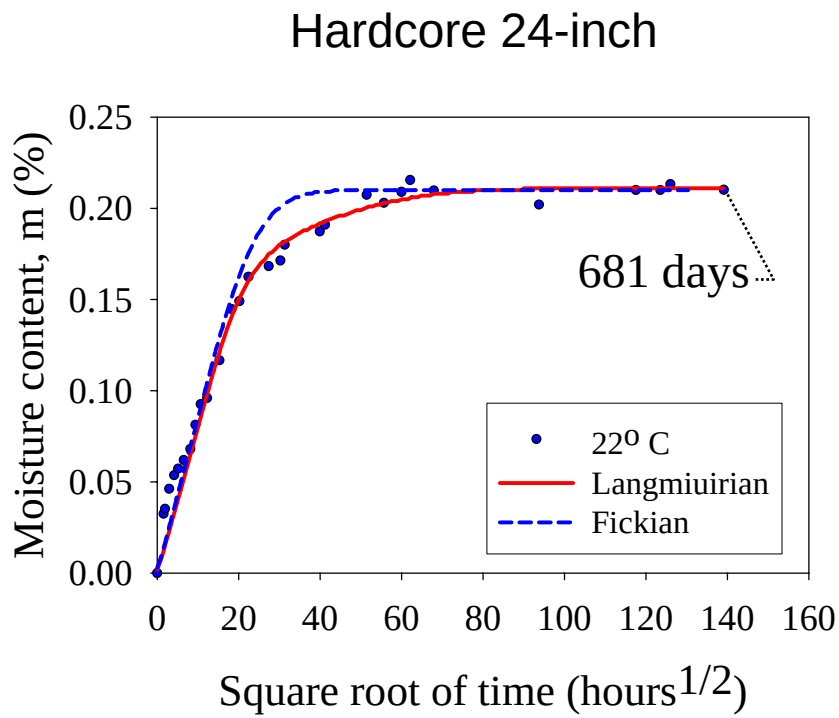
Testing – As received properties



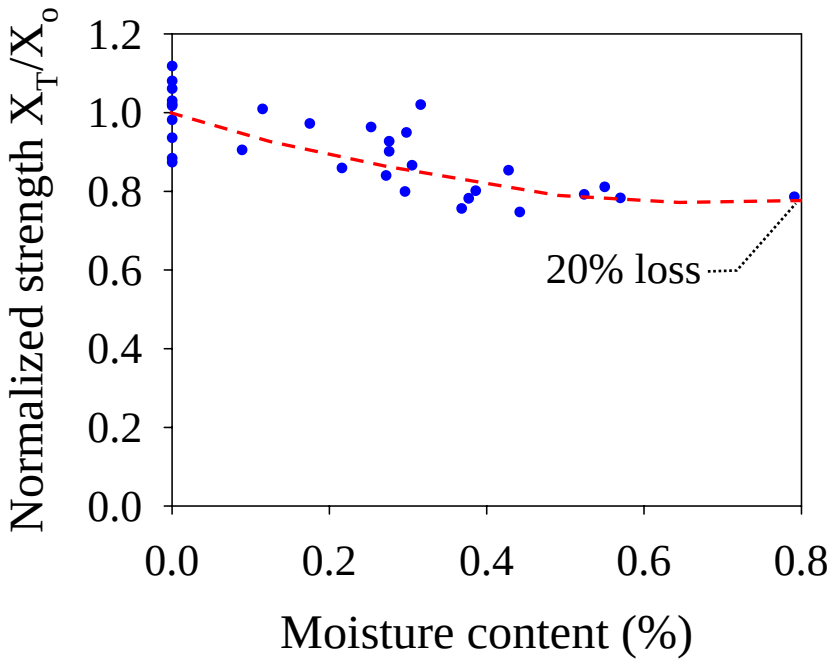


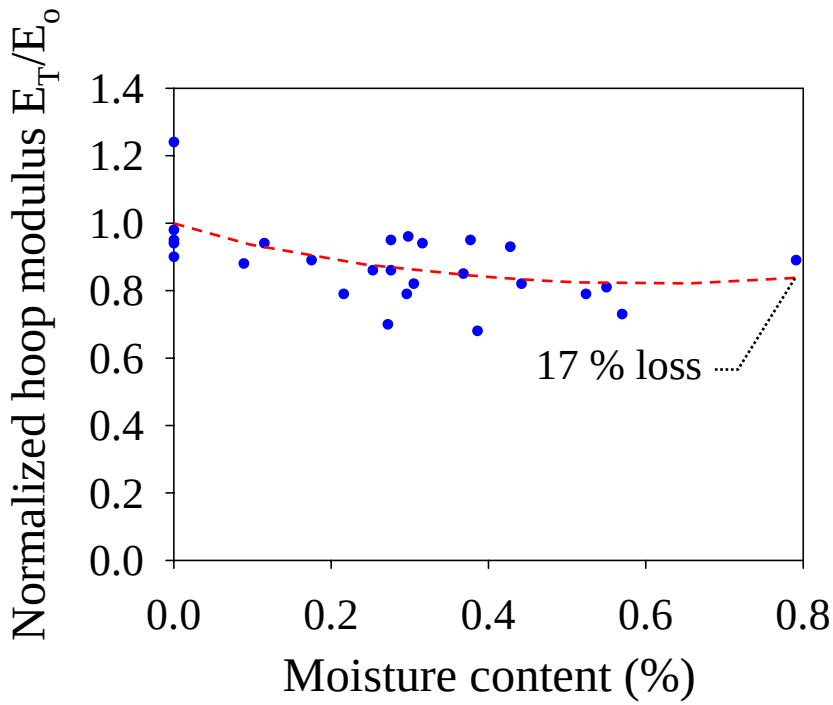
Moisture absorption





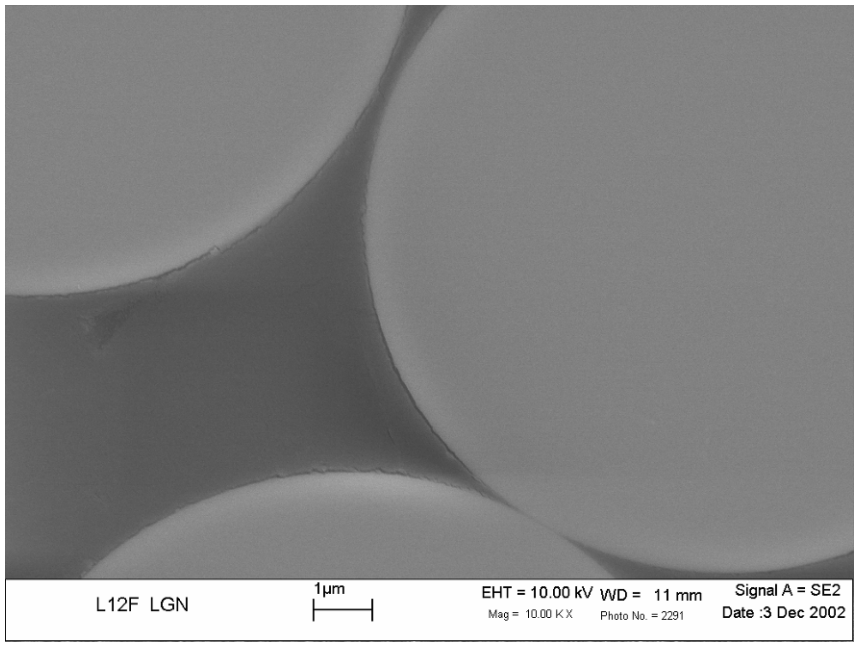
Property degradation



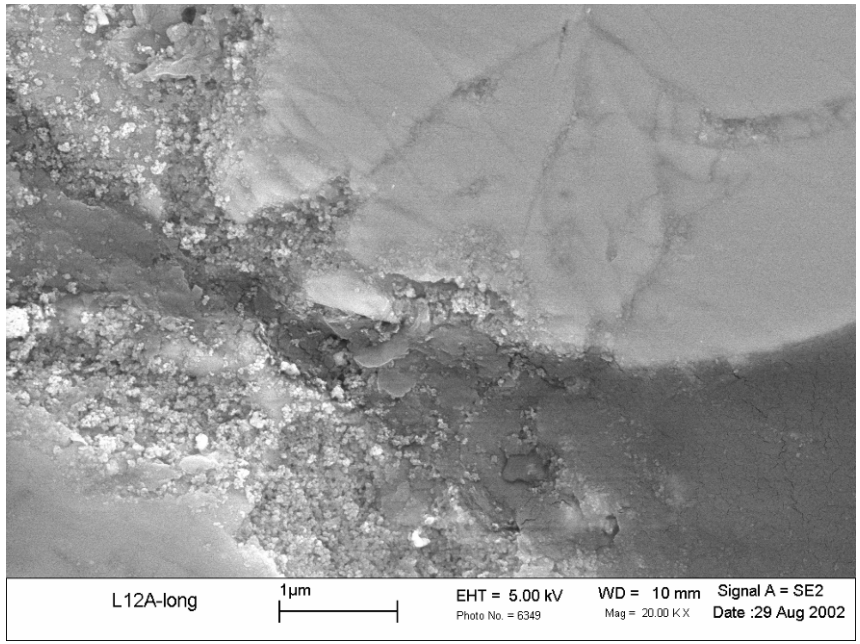


(Data for Hoop tests on Lancaster 12-inch)

SEM Images – As received & Aged



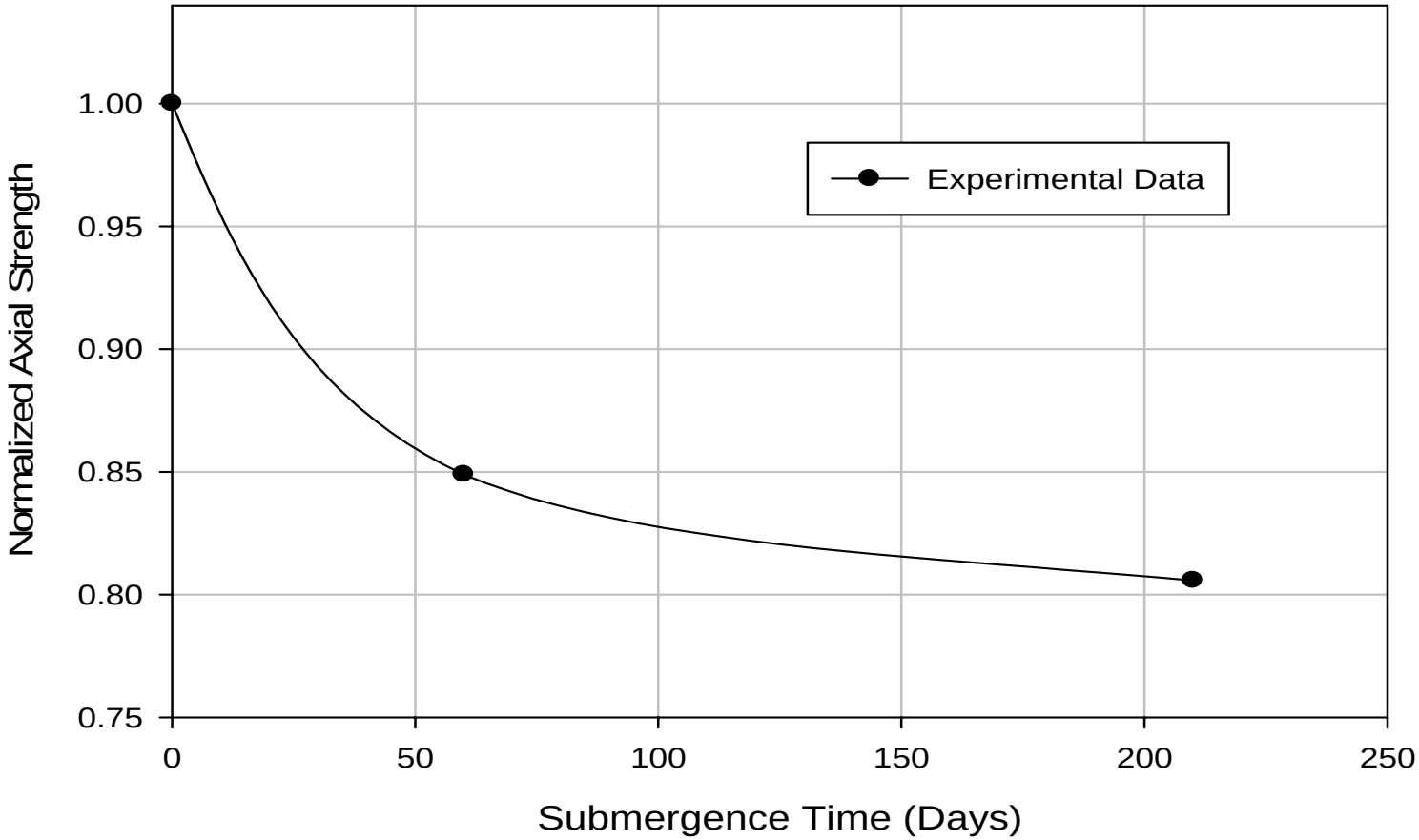
As-received



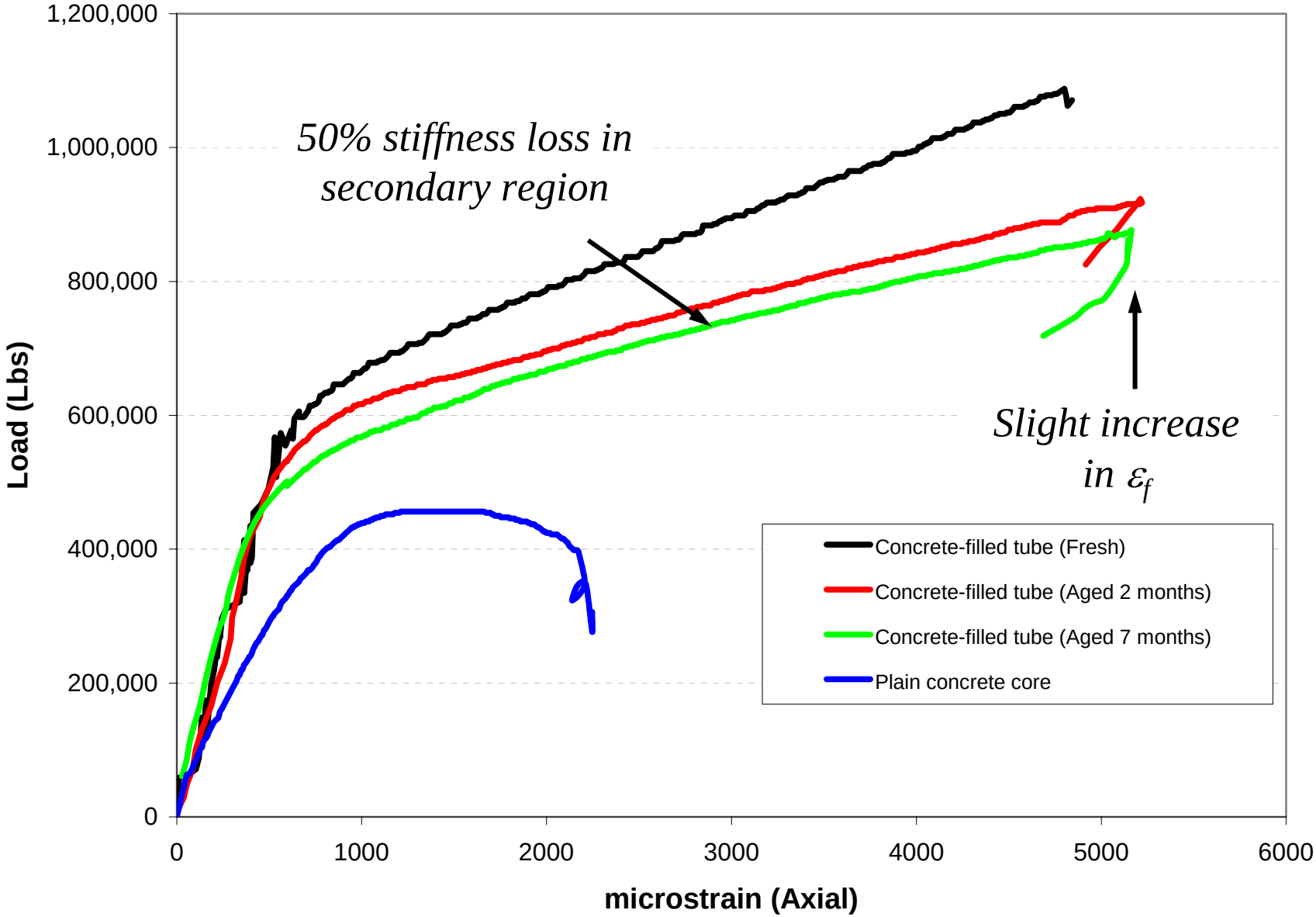
Aged

Hardcore
Lancaster

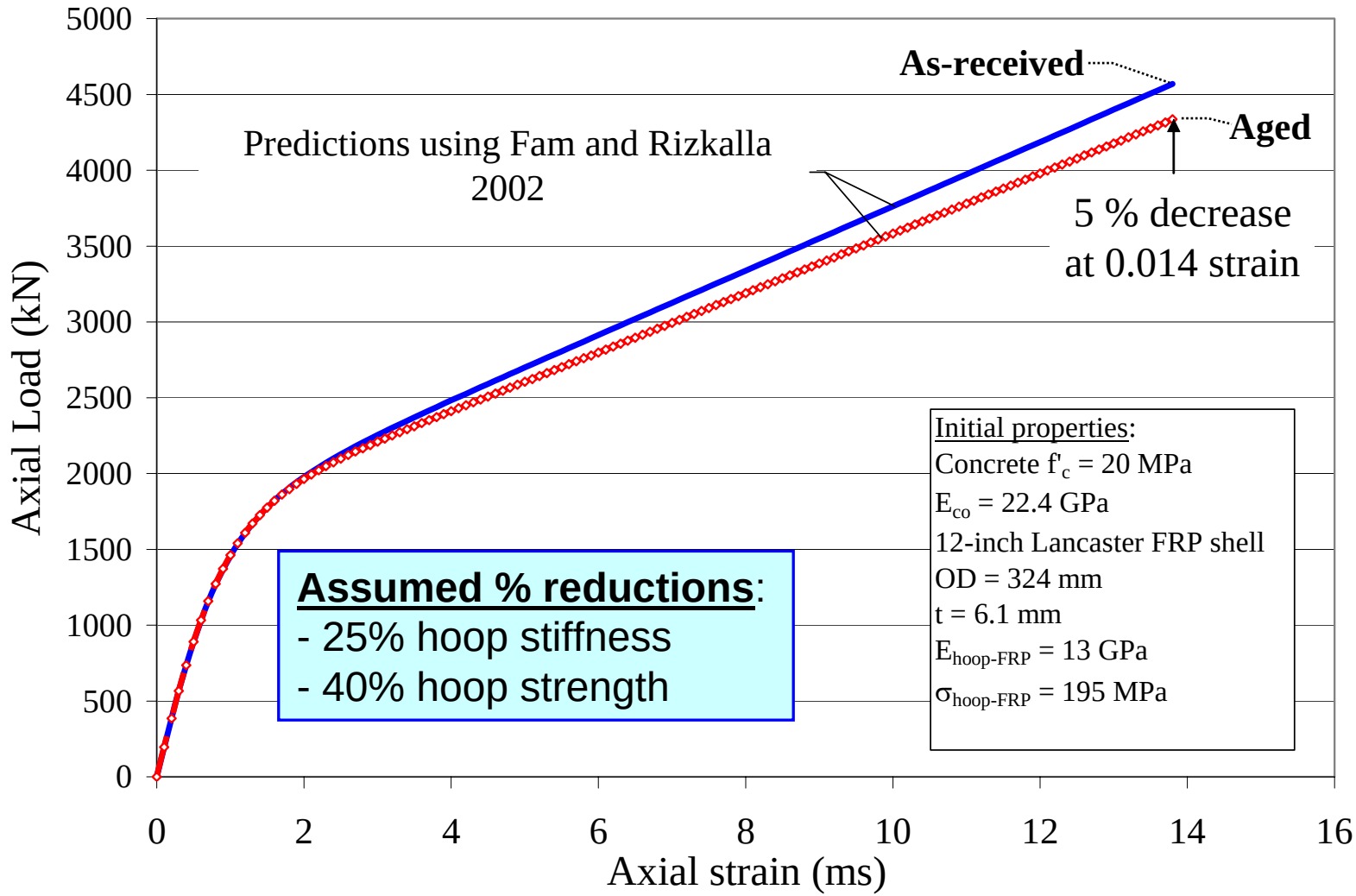
Normalized Axial Strength vs. Time



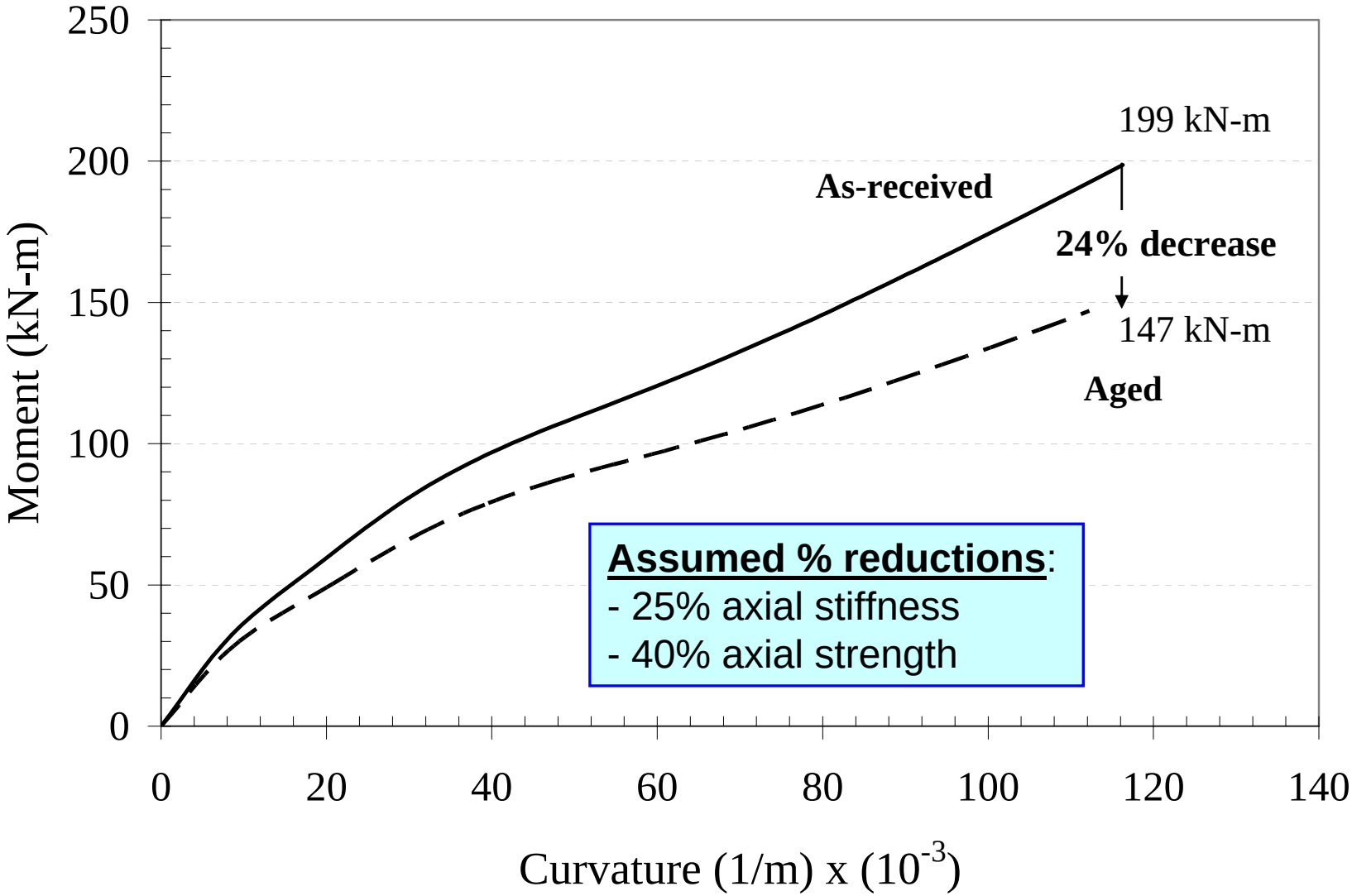
Axial testing of concrete-filled FRP stubs



Estimated long-term axial capacity



Estimated long-term flexural capacity



Joint Work VT and UPRM

- Objectives
  - To evaluate the material hygrothermal degradation of CFFRP tubes
  - Constituents level (FRP and concrete)
  - Structural level (CFFRP)
  - Include larger number of replicas using smaller size specimens

Experimental Program

- Aged FRP at three different water temperatures (30°C, 40°C, and 50°C)
  - Axial and hoop direction (Special fixture was designed for hoop tests)
- Aged CFFRP at 30°C
- Periodical tests over the course of 2,000 day long study (Near 300 days completion)
- Work distribution
  - CFFRP tubes and concrete (UPRM)
  - FRP tubes (VT)
  - Concrete subjected to triaxial loads (UPRM)

Conclusions – Durability study

- Significant strength and stiffness degradation due to moisture absorption
- Little degradation effect of exposure to freeze-thaw cycles on longitudinal tensile properties of saturated FRP tubes
- Small impact of FRP degradation on long term axial capacity
- Significant impact of FRP degradation on flexural capacity

Future work – Durability studies

- Durability studies involving small diameter concrete-filled FRP piles to study the durability of axial and flexural structural capacity
- A durability study that includes exposure to salt water and other aqueous solutions representing other groundwater conditions
- Other recommended studies
  - degradation due to UV and exposure to high temperatures
  - resistance to fire
  - corrosion of steel cage in PPI piles

Future work – Structural tests

- Determine the influence of temperature on structural behavior, and effects of differences in coefficients of thermal expansion of the different pile constituents on pile performance
- Expand testing under combined axial load and bending to establish the full interaction diagrams of composite piles
- Behavior under cyclic loading
- Creep under axial compression
- Establish design guidelines for design of composite piles (FAM's work is helping with this)

Acknowledgments

- Carl Ealy (FHWA)
- Mike Hall (VDOT)
- Dr. Ed Hoppe (VTRC)
- Drs. George Filz and Jack Lesko (VT)
- Dr. Amir Fam (Queen’s University)