FRP-Reinforced Glulam Bridges: Development and Implementation

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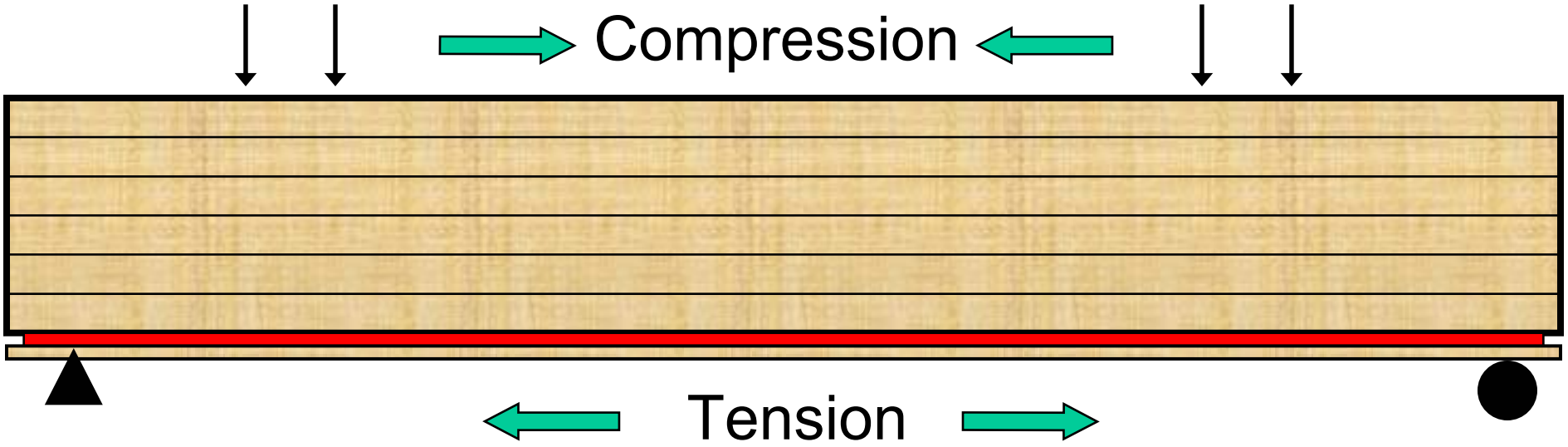
FRP-Reinforced Glulam



- Low grades stronger in compression
- Reinforced concrete analogy – by using FRP as tension reinforcement, we mitigate tension failure

Can we build beams with low-quality, cheap laminations and a small amount of FRP that are stronger than beams with high-grade tension laminations?

FRP-Reinforced Glulam Beams

Strength model and beam strength testing

(H. Dagher and R. Lindyberg)

Wood-FRP bond integrity

(H. Dagher, R. Lopez-Anido, B. Goodell, D. Gardner, Y. Hong, B. Herzog, L. Muszyński, C. Tascioglu)

Bridge girder fatigue behavior

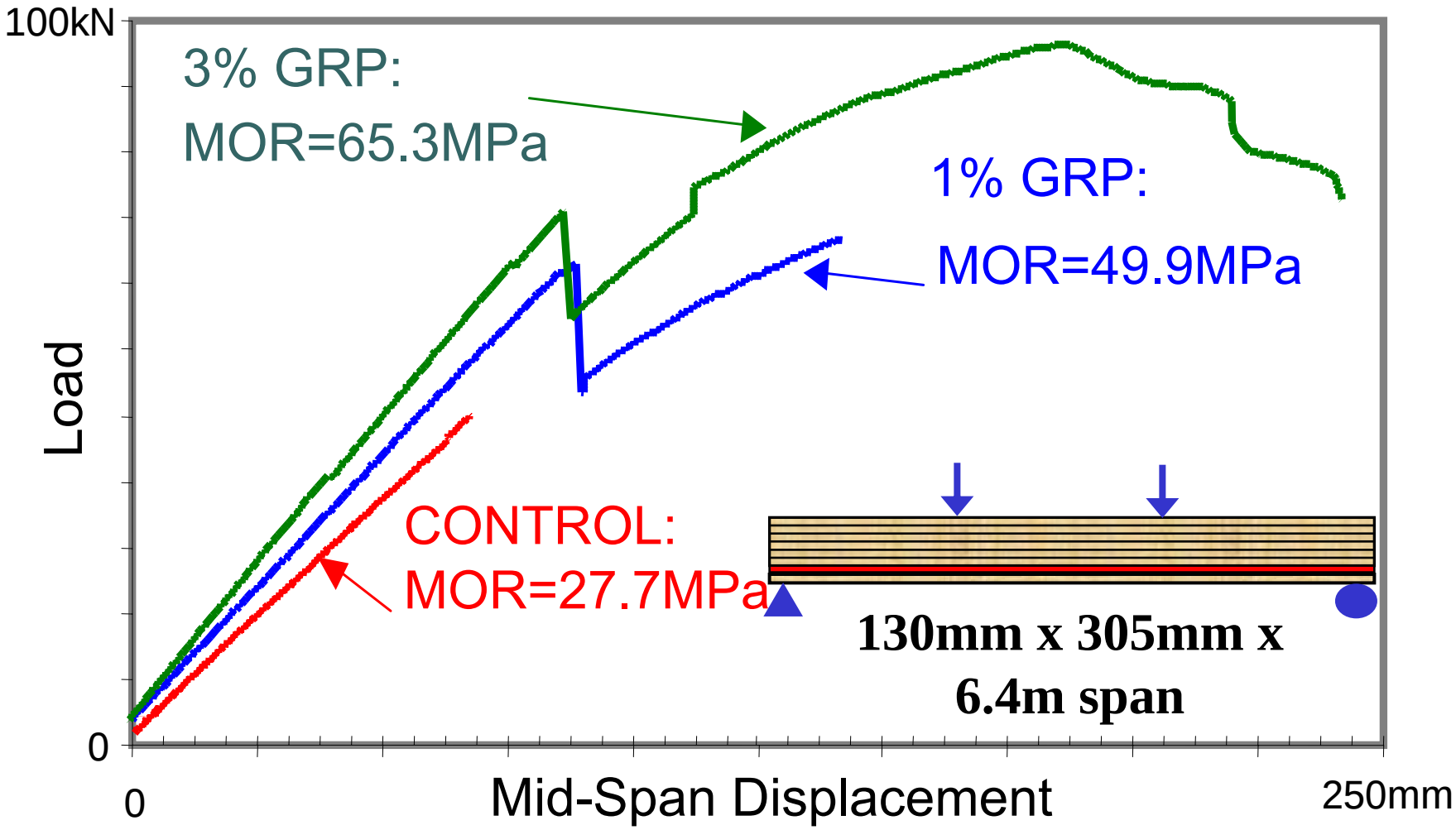
(W. Davids, M. Richie)

Demonstration structures

(H. Dagher, W. Davids, R. Lindyberg, R. Lopez-Anido)

AASHTO design specifications

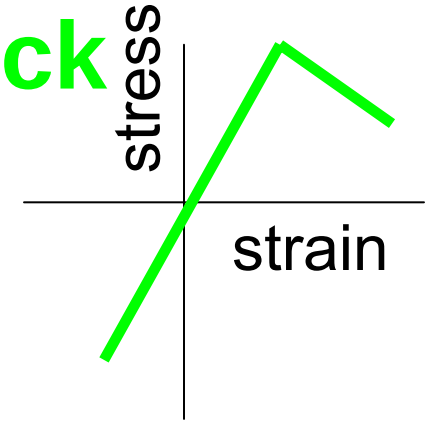
FRP-Glulam Strength and Ductility



Bending Strength Prediction

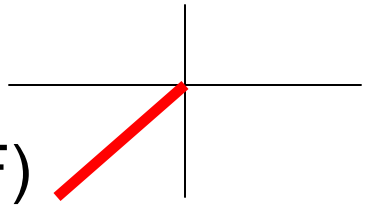
Lamstock

UTS, UCS, E
(mean, COV, PDF)
- 3x3 correlation matrix

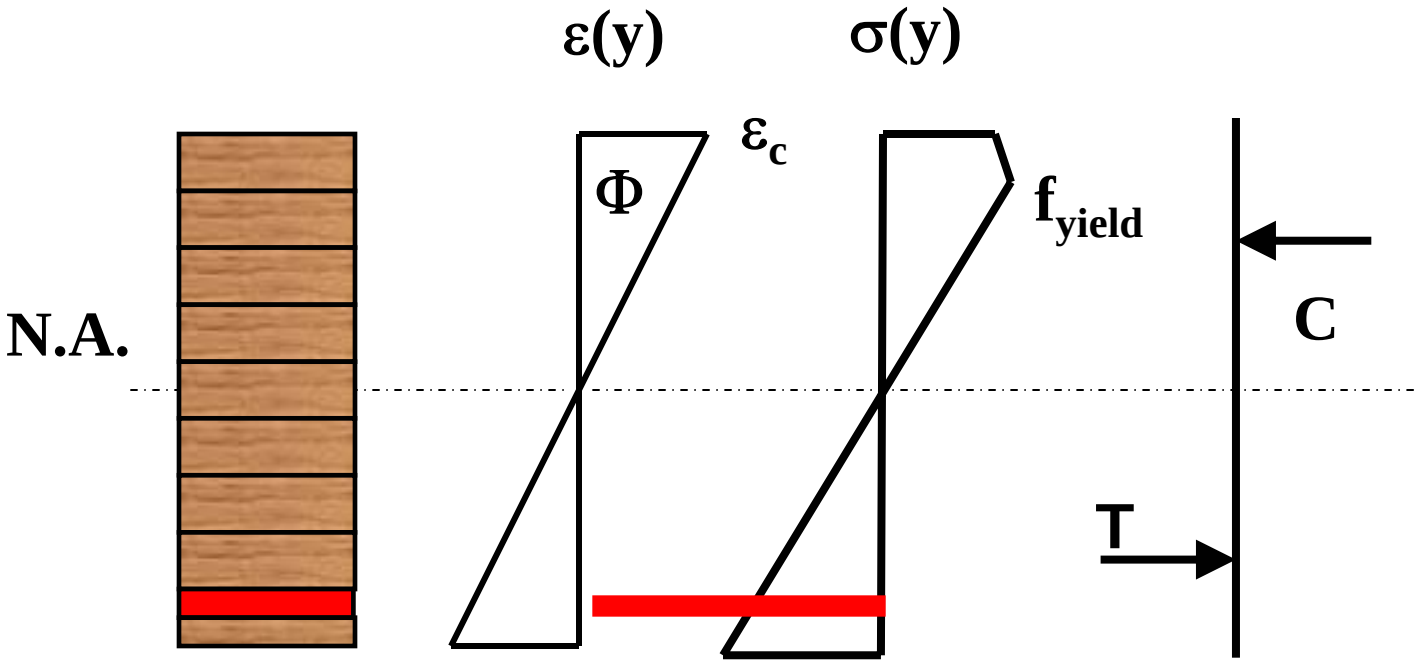


FRP

UTS, E (mean, COV, PDF)



Moment-Curvature Analysis

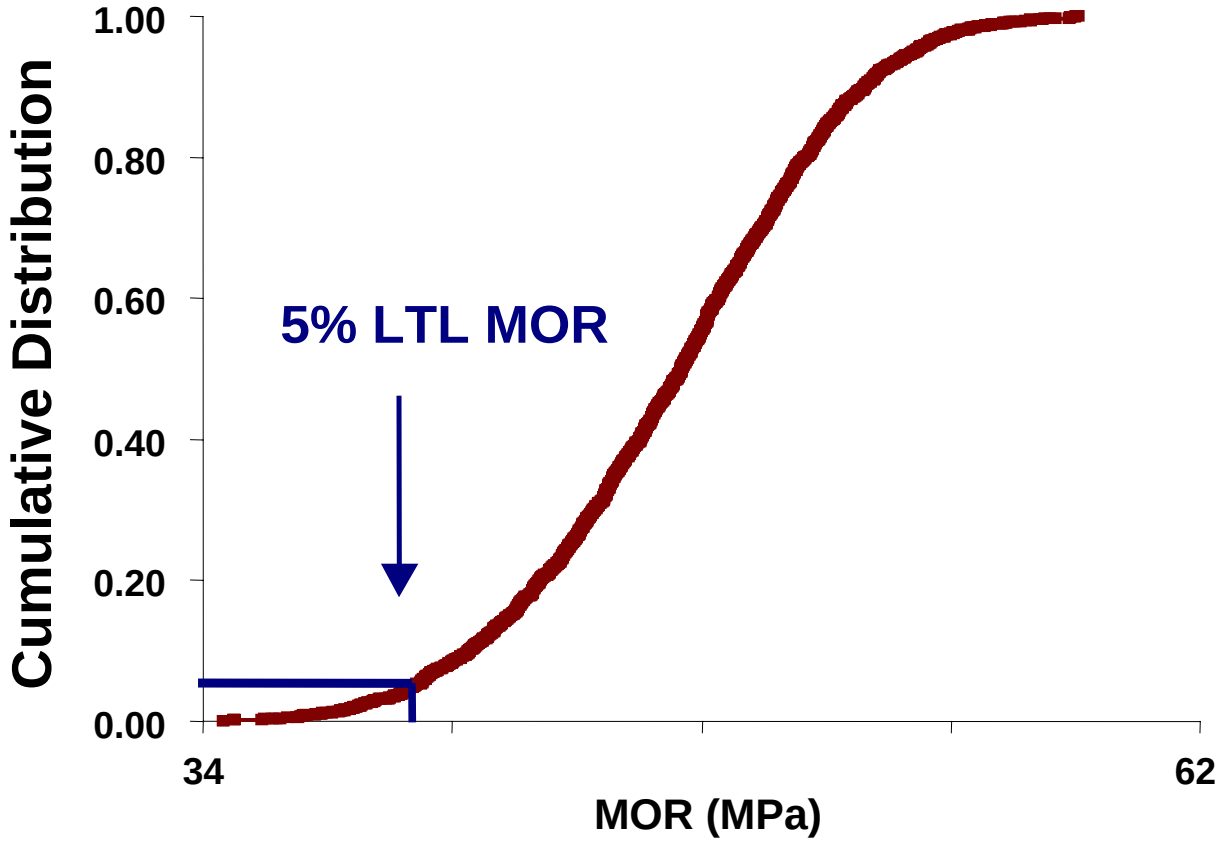


$$\sum F = 0 \Rightarrow \int \sigma dA = 0 \longrightarrow \text{Gives NA location}$$

$$\sum M = \int \sigma y dA \longrightarrow \text{Gives M corresponding to } \Phi$$

Monte Carlo Simulation

- M-Φ simulations repeated many times for different randomly generated cross-sections
- Result is the CDF of beam MOR and MOE
- Allowable Bending Stress F_b= 5%LTL MOR/2.1



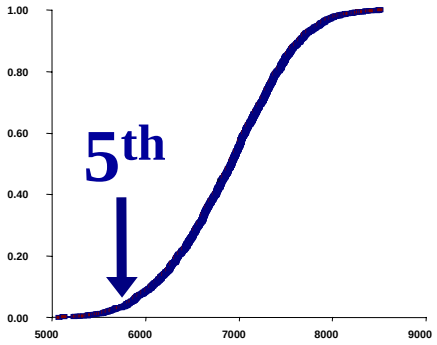
FRP-Glulam Testing

(11m span – 1.2% GFRP)

Beam 37-B-3

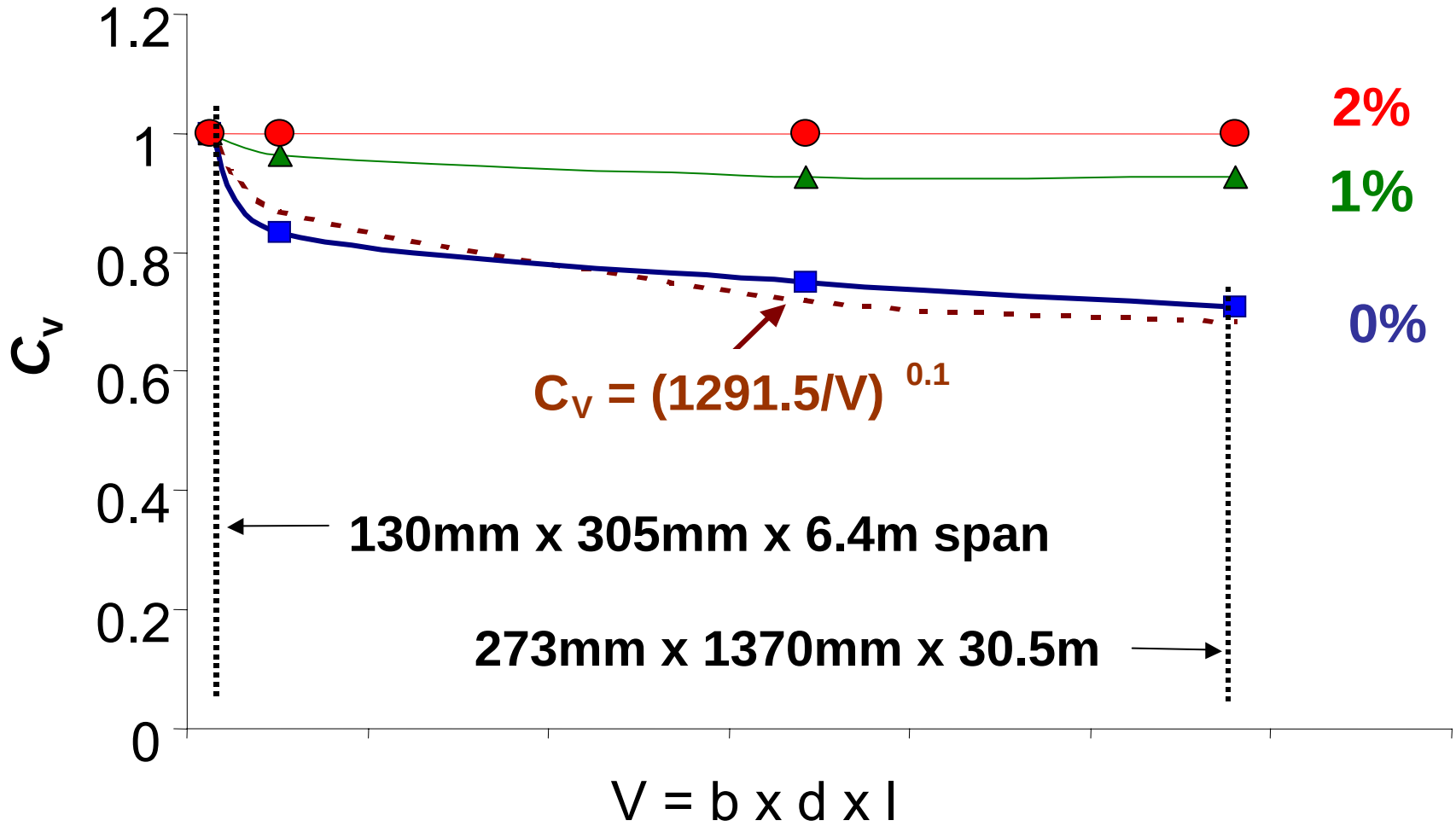
MOR = 46.9 MPa

Validation of Analyses 279 Beam Tests



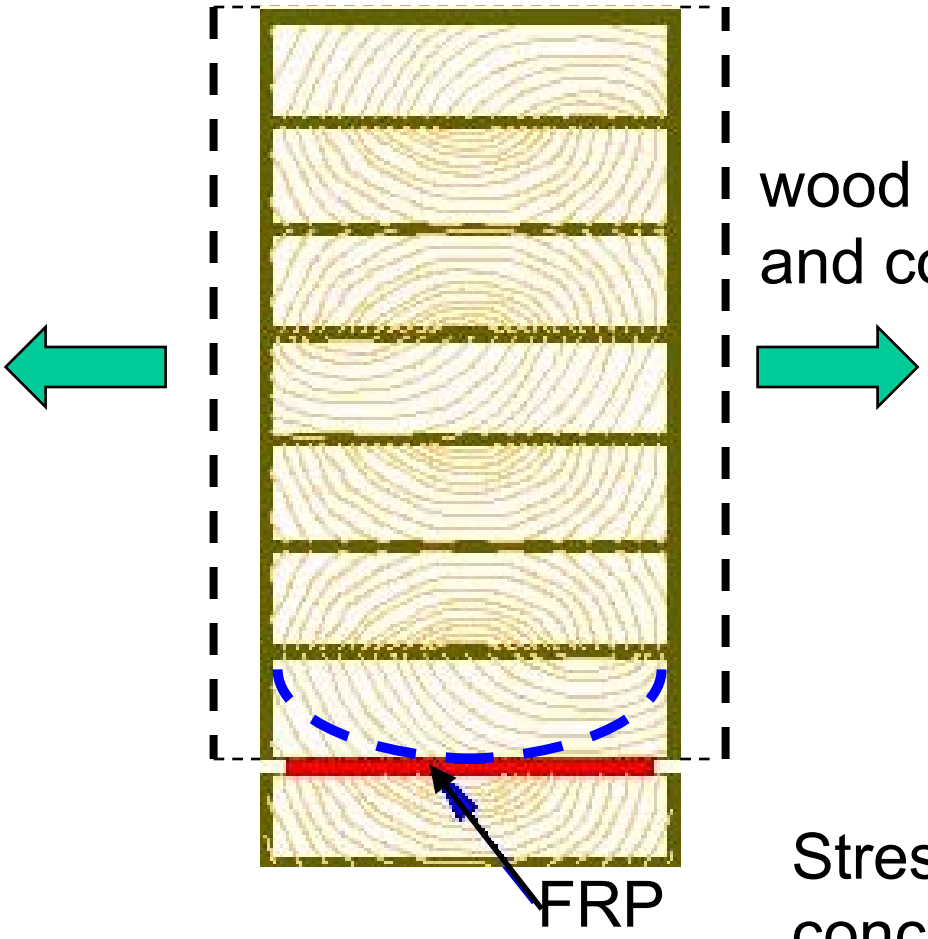
Test Series	Sample size	Difference 5^{th} F_b
6.4m	90	1 %
11.0m	66	4 %
15.2m	48	7 %
2.9m- 19.5m	75	5 %

Volume Effect

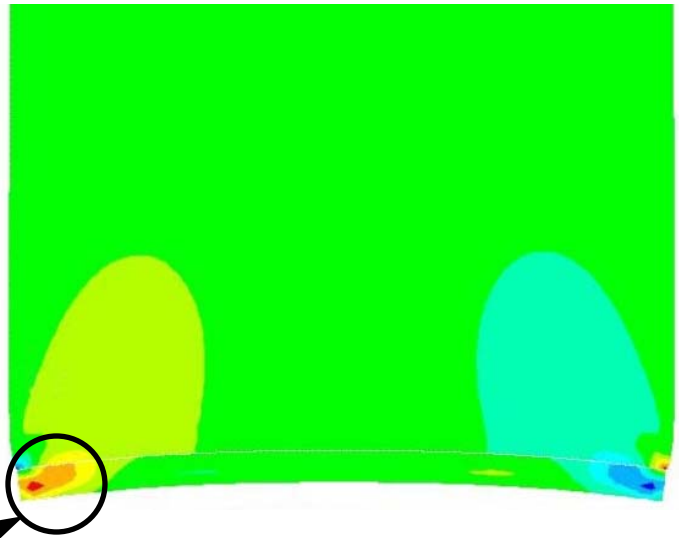


Wood-FRP Bond Integrity

Hygrothermal Effects are #1 Durability Issue



wood expands
and contracts



Stress
concentration

Wood-FRP Interface
Stresses

Screening Study: Nine FRP/Adhesive Systems ASTM D2559: 4 of 9 Passed

Material	Fiber type	Polymer matrix	FRP fabrication	Bonding process
A	E-glass	vinyl ester	Resin infusion	Fabric reinforcement bound and bonded by SCRIMP
B	E-glass	urethane	pultrusion	Pre-consolidated sheet bonded w/ urethane
C	E-glass	epoxy	continuous lamination	Pre-consolidated sheet bonded w/ epoxy
D	Carbon	vinyl ester	Resin infusion	Fabric reinforcement bound and bonded by SCRIMP

Fatigue Testing

- Eighteen 6.1m-span specimens loaded in 4-point bending
- Fatigued for 2 million cycles at 2Hz
- Loading to 81% of F_v concurrently with $1.5F_b$
- Stress ratio fixed at 0.33
- Daily static load tests
- Loaded to failure post-fatigue to quantify residual strength

Fatigue Testing Results

- 14 of 18 specimens failed in tension
- Two shear failures, two compression failures

Shear failure
(post-fatigue)

Compression failure
(post-fatigue)

Fatigue Testing Results

- Glulams with full-length reinforcing are not prone to fatigue failures
  - Potential for compression and shear failures at higher reinforcement ratios
  - Significant delaminations between wood and FRP can be tolerated in high shear regions

Fairfield Bridge

70’ span FRP-glulam with composite concrete deck

Milbridge Pier

Multiple-span FRP-reinforced glulam deck panels

Specification Development

ASTM D7199-07: *Standard Practice for Establishing Characteristic Values for Reinforced Glued Laminated Timber (Glulam) Beams Using Mechanics-Based Models*

- Passed in 2007
- Contains provisions for establishing FRP-glulam strength
- Methods based on moment-curvature analysis and Monte-Carlo simulation described earlier in presentation
- References ASTM D2559 for assessment of wood-FRP bond durability

Specification Development

AASHTO LRFD Bridge Design Specifications

- Section 8, various articles
- 8.4.1.3 Tension-Reinforced Glulams defined
  - Type and amount of reinforcement
  - Design values determined via ASTM D7199
- Modification to adjustment factors
  - 8.4.4.5 Volume factor – no reduction in F_b
  - 8.4.4.3 Wet service factor
  - 8.4.4.2 Format conversion factor (ASD – LRFD)

Specification Development

AASHTO LRFD Bridge Design Specifications

Philosophy:

- Design engineer specs a value for F_b and beam dimensions
- Laminator designs layup using ASTM D7199 provisions
- Lamstock species, grade, and layup may be varied
- FRP reinforcement type and percentage refined

Sample AASHTO Design Calcs

- Douglas fir L1-L2 layup (low grade laminations)
- Size beam for 56’ span bridge girders spaced at 4’-6”
- Reinforcing scenarios: 0%, 1%, 2% and 3% FRP

FRP Percentage	F_b (psi)	E (msi)	Beam depth (in)	Beam Width (in)
0%	1500	1.44	66	6.75
1%	2600	1.57	53	6.75
2%	3400	1.68	46	6.75
3%	3800	1.78	45	6.75

Conclusions

- Over a decade of research is bearing fruit
- Specifications capture results of research findings
- Ongoing collaboration between industry, the APA and UMaine to deliver FRP-glulam to market
- Economics of FRP-glulam are being studied

Acknowledgments

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