Options for Evaluating Fire Damaged Components of Historic Covered Bridges

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INTRODUCTION

- Objectives of this presentation:
  - Review the potential of damage to wood in a fire
  - Review the available options for assessing the potential damage

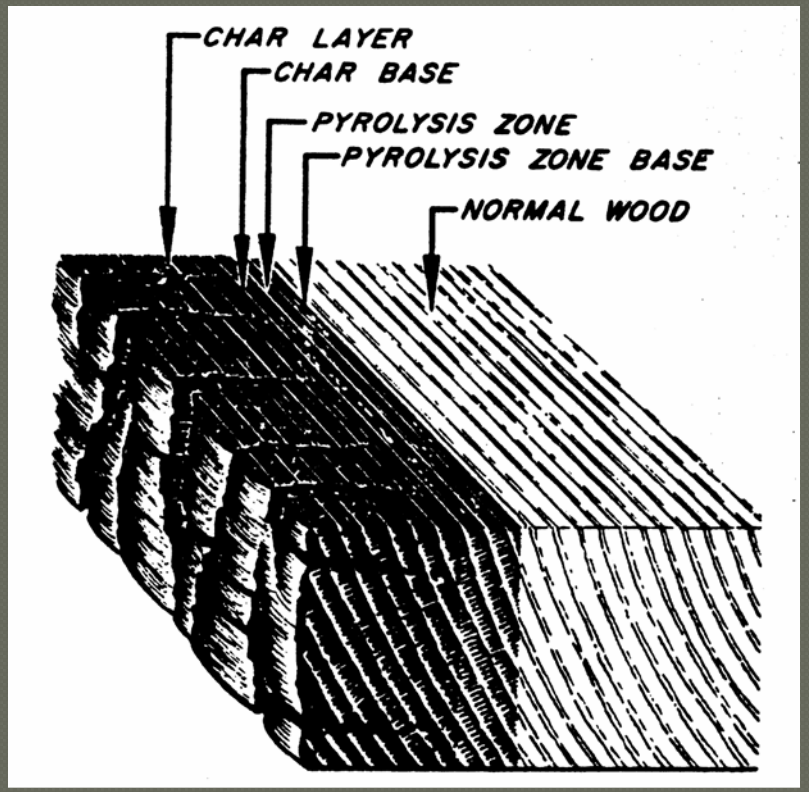
Creosote-treated wood bridge deck crib under fire test hood at FPL

Effect of Fire on Wood

- Thermal degradation causes a loss in density
- Visual damage
- Elevated temperature affects the mechanical properties

Effect of Fire on Wood

- Zones of degrees of the thermal degradation (pyrolysis)
- Combustible gases - flaming combustion
- Char layer –reduced interior temperatures
- Density of the char layer approximately 20% of wood

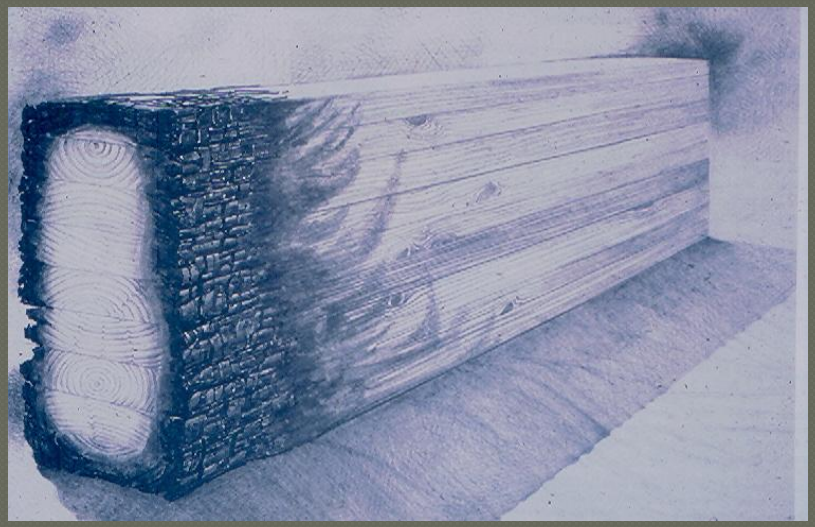


Post-fire Evaluation

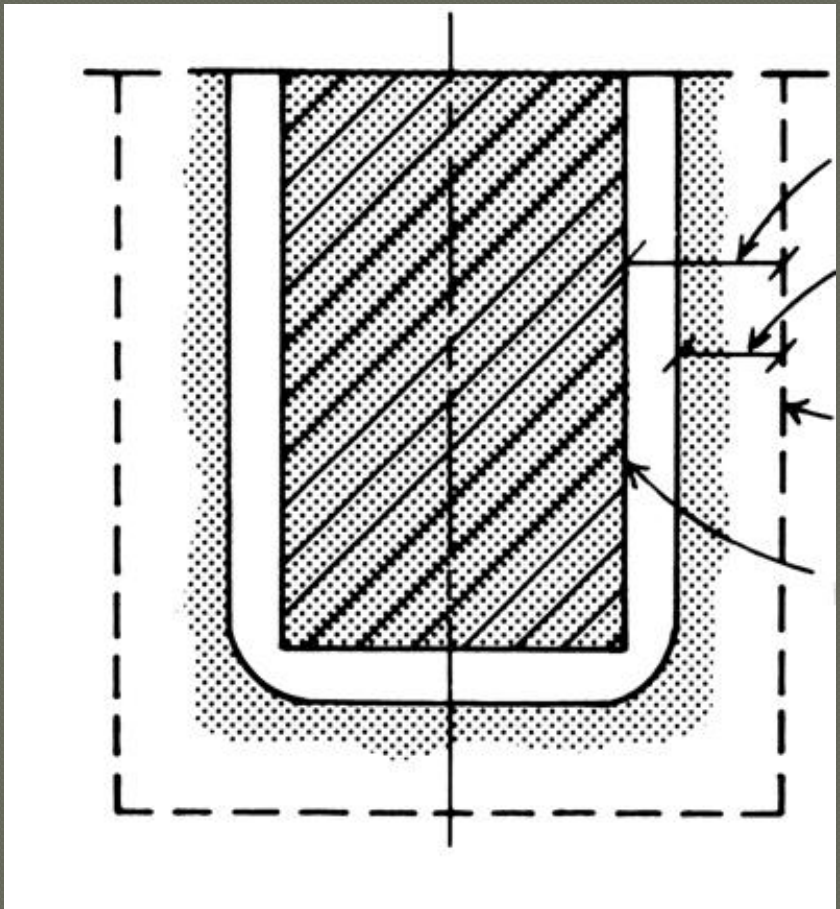
- For charred members, the first steps are:
  - Remove char and
  - Measure dimensions of residual cross sectional area
- Quick calculations to determine residual load capacity and need to replace members

Post-fire Evaluation

- If initial calculations indicate the residual cross-section has potential to be sufficient for continued use, we need to consider the potential loss in load capacity of the residual wood.

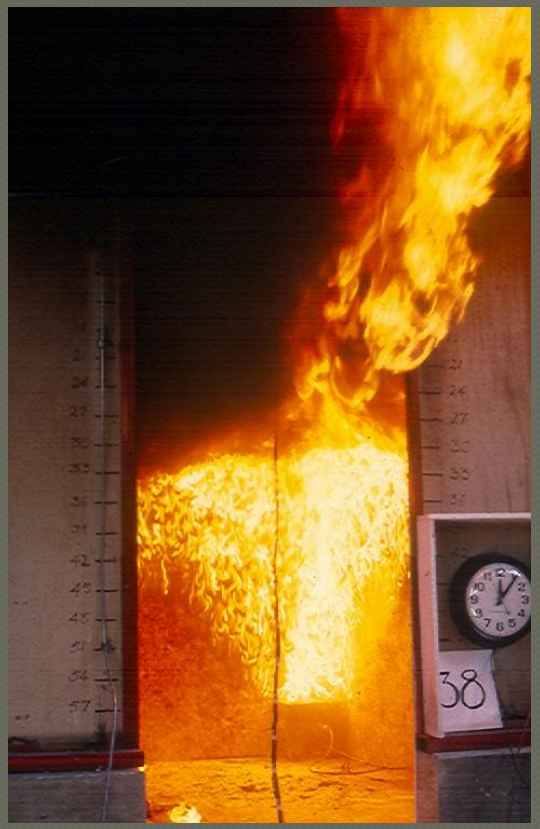


Calculation of Residual Load Capacity of Charred Wood Components



Effect of Fire on Wood

- Post-flashover fires generally have temperatures of 800 to 1100°C (1500 to 2000°F)
- Base of the char layer in such a fire is approximately 300°C (550°F)

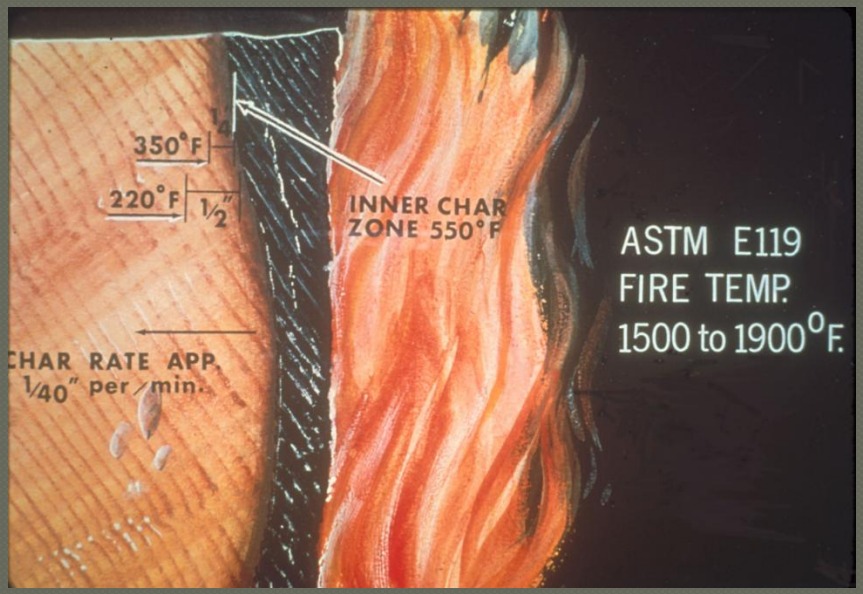


Room-corner test at FPL

Effect of Fire on Wood in Standard Fire Resistance Test

- Temperature gradient fairly steep beneath the char layer
- Temperature drops to
  - 180°C and 105°C at 3 and 6 mm
  - 350°F and 220°F at ¼ and ½ inch,

respectively, from base of char layer, in the standard fire test



Effect of Fire on Wood

- Knowledge in this area is from research on fire resistance of structural member in standard fire test (ASTM E119)
- The normal assumption of 38 mm (1.5 in.) char depth per hour in the standard test should not part of a post-fire evaluation

Charred wood slab in FPL wall furnace

Effect of Fire on Wood

- More gradual temperature profile if:
  - Prolonged low level heating during the fire exposure at or away from "fire"
  - Post-extinguishment heat redistribution
  - Smaller dimension members with elevated center temperatures (i.e. not semi-infinite slab)

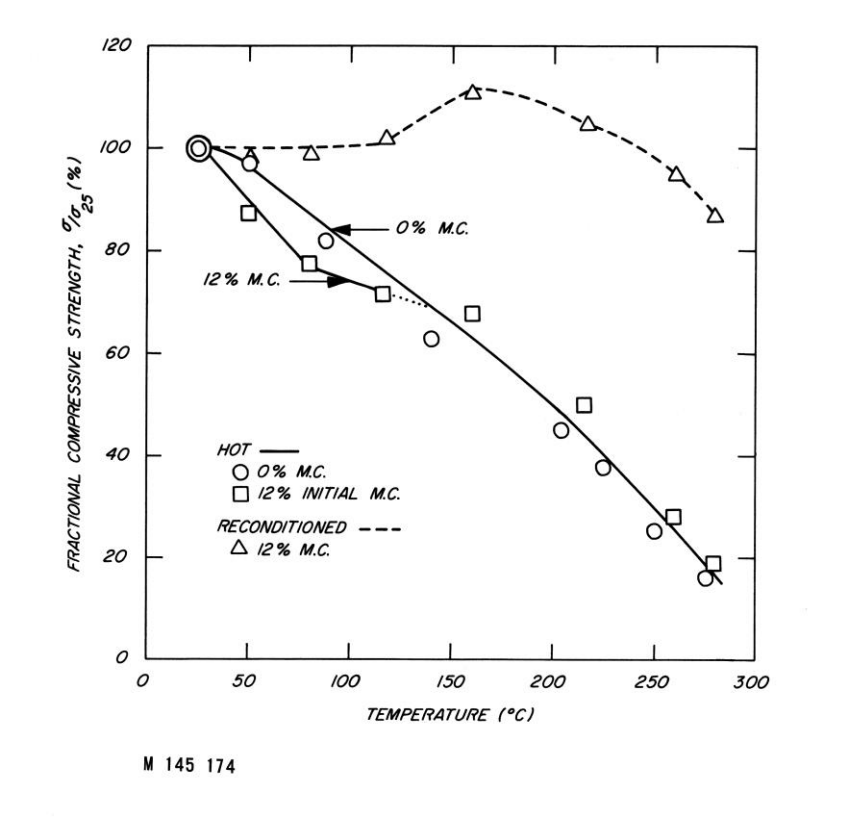
Effect of Fire on Wood

- Reversible and irreversible effects on the strength and stiffness of wood
- Due to:
  - Changes in chemical composition
  - Changes in density
- Depends on both the temperature and the duration
- Except for prolonged exposures, 212°F (100°C) is considered lower limit

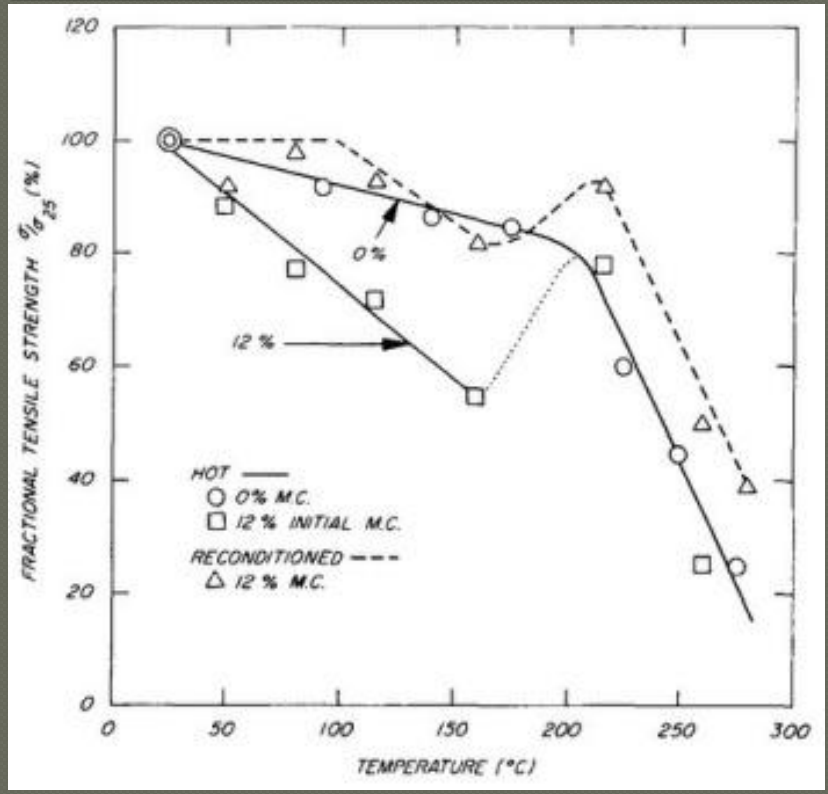
Bending test of slightly charred I-joist.

Effect of Fire on Wood

COMPRESSIVE STRENGTH



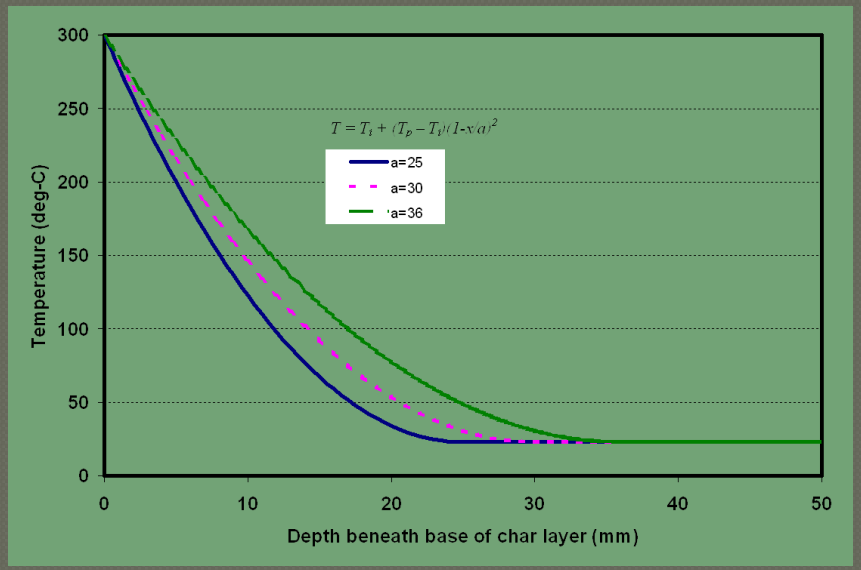
TENSILE STRENGTH



Ref: Schaffer, E.L. State of structural timber fire endurance. Wood and Fiber 9(2):145; 1977.

Effects of Fire on Wood

- Concerned about wood exposed to temperatures between
  - 100 and 300°C
  - (212 and 550°F)
- We want to know the equivalent depth for the damage
- To help determine additional adjustment to the dimensions for the structural calculations

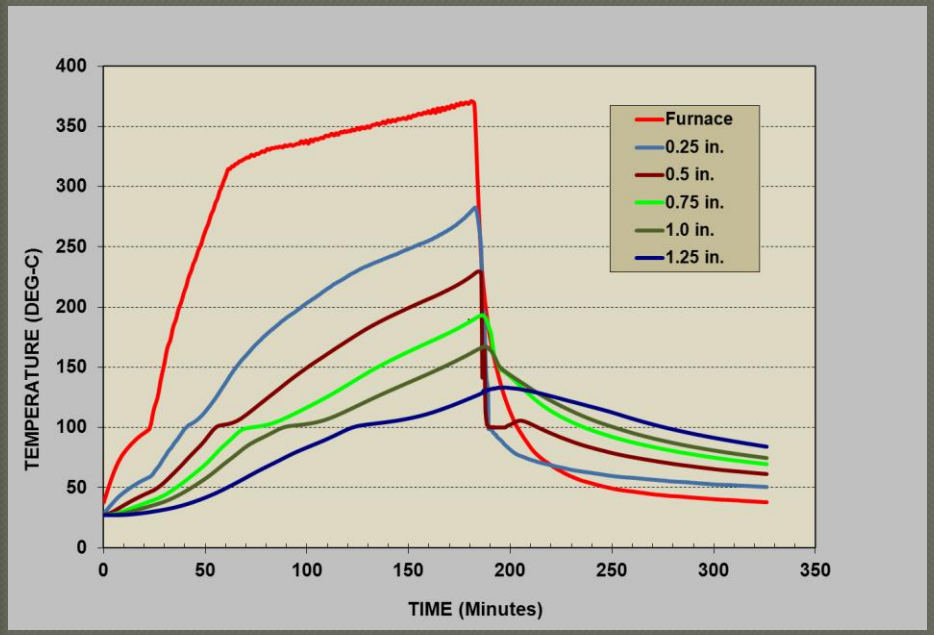


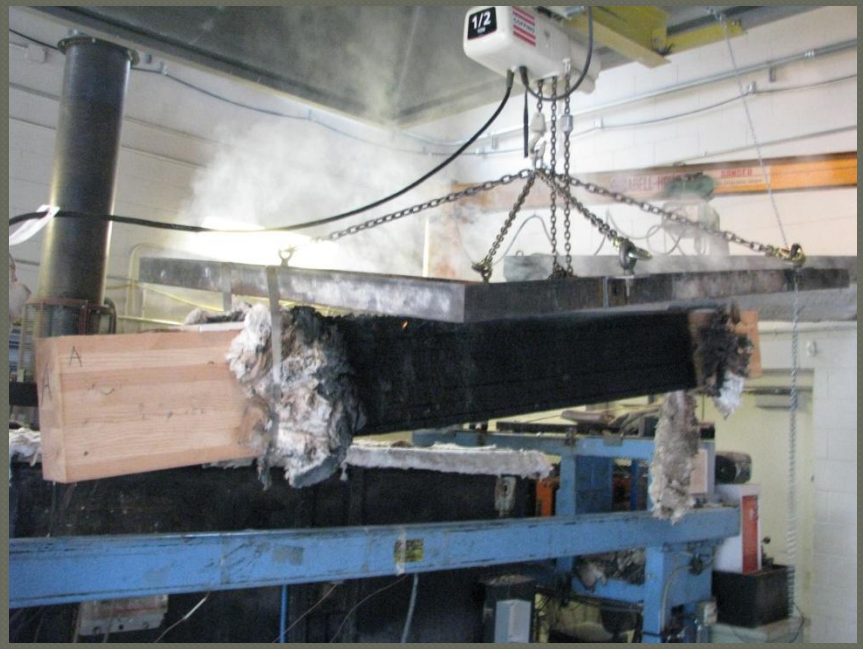
Ref: Janssens, Marc L.; White, Robert H. Short communication: Temperature profiles in wood members exposed to fire. Fire & Materials, 18, 263-265 (1994)

Exposure of 5 x 11 beams to a low temperature fire exposure

Horizontal/Tension Furnace at FPL

Exposure of 5 x 11 beams to a low temperature fire exposure



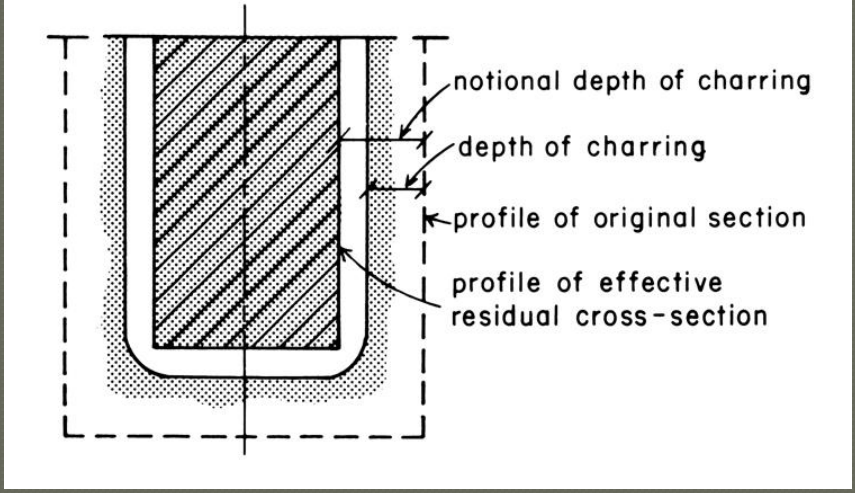


Temperature from exposed wood surface

Effect of Fire on Wood

- 54% reduction in failure load (lbs.)
- 46% reduction in MOR (lbs/in^2) based on the residual cross-sectional areas
- 20% reduction in MOE

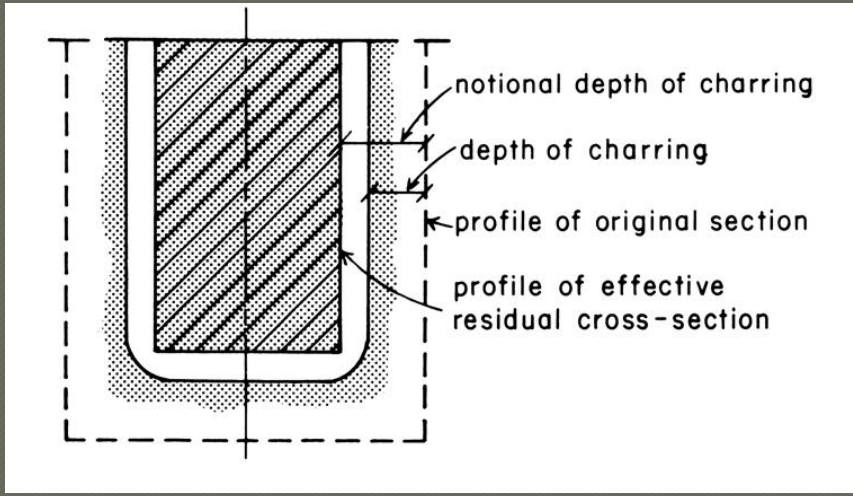
Calculation of Residual Load Capacity of Charred Wood Components



- Equivalent to adding 0.8 inch to the 0.3 inch char depth

Calculation of Residual Load Capacity of Charred Wood Components

- For calculation of load capacity, we assume an equivalent zero-strength layer:
  - Reduce the cross section by 0.1 to 0.3 inch beyond the base of the char layer for members loaded in compression
  - Reduce the cross section by 0.3 to 0.5 inch beyond the base of the char layer for members loaded in tension or bending



These recommended values for the zero-strength layer in post-fire analysis assume the wood is not removed

More research is needed to validate these recommendations

Calculation of Residual Load Capacity of Charred Wood Components

- Adjust if removing layer of wood beneath char base for appearance, etc.
- Changes in dimensions of an structural wood components necessitates the re-grading of the wood members
- For duration of fire exposure as reflected in char depth and location of member relative to the fire

Post-Fire Investigation

- Understanding fire itself provides insights
- Consider
  - Likely temperatures
  - Likely duration
  - Degree of external heat to wood member
- Correlate that with amount of visible char damage
- NFPA 921 Fire..Investigations Standard

Post-Fire Assessment of Individual Wood Components

- Removal of representative samples for static bending test

- Various proof loading techniques

Post-Fire Assessment of Individual Wood Components

- Technique developed at Montana Tech as part of Covered Bridge Project

- Subject of 2013 ASCE Structures Congress presentation and paper and future FPL publication

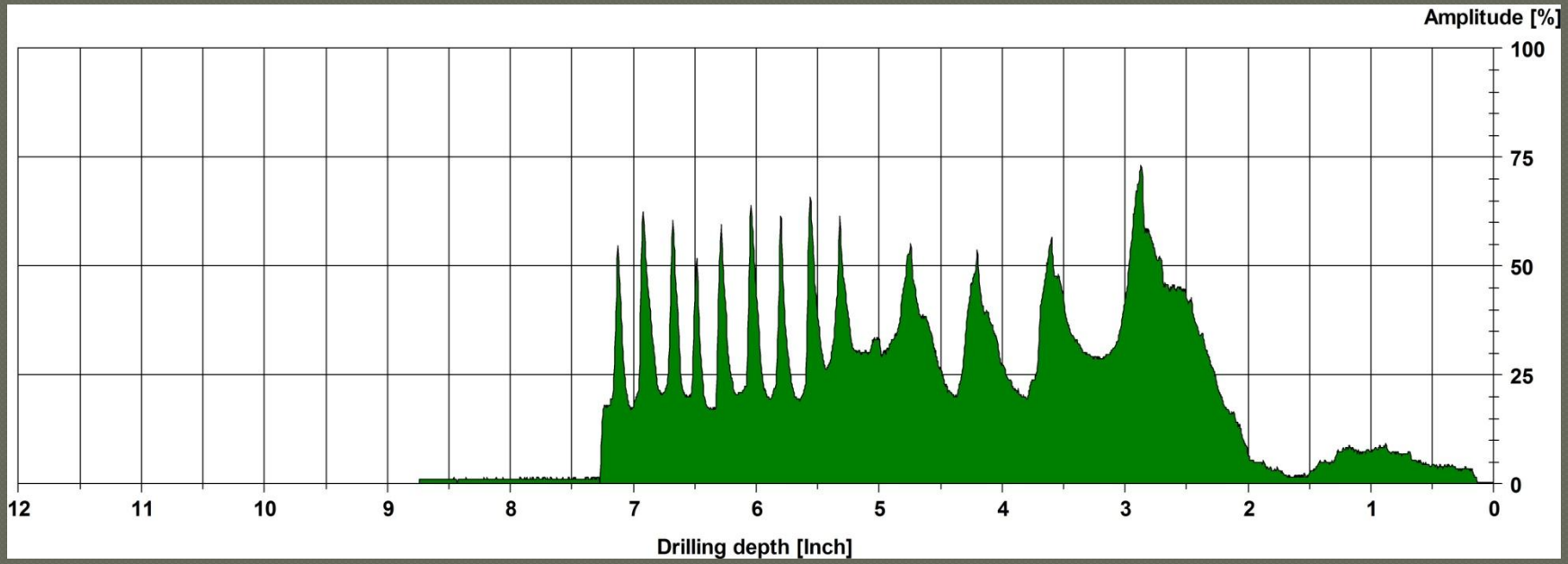
Post-Fire Assessment of Individual Wood Components

- Screw withdrawal:
  - Investigated as method for FRT damaged plywood
  - Evaluation concentrated in outer portion of member
  - Screw withdrawal load correlated with density

Post-Fire Assessment of Individual Wood Components

- Resistance micro-drilling technology
- Being used to evaluate decayed damaged wood

Post-Fire Assessment of Individual Wood Components



Graph from Resistance Micro-Drilling of charred beam

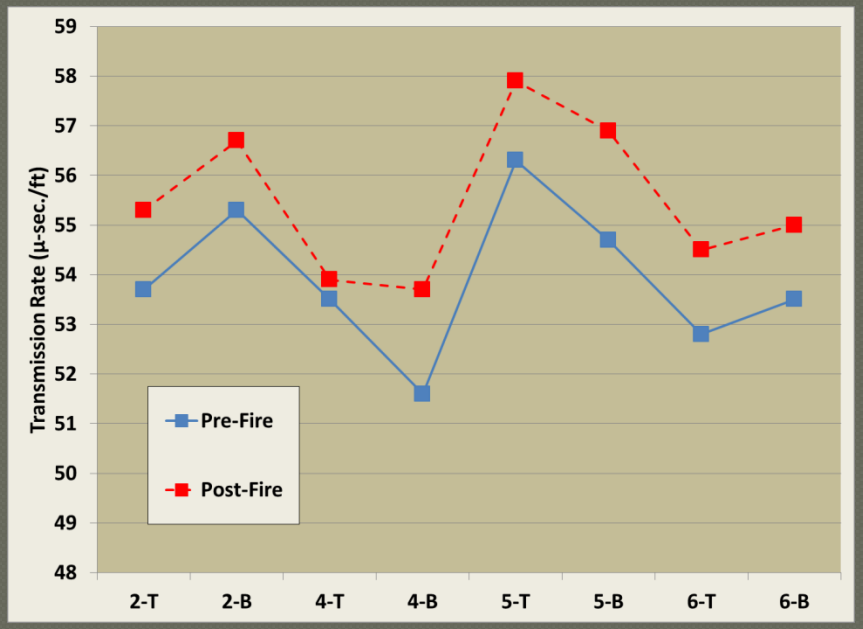
Post-Fire Assessment of Individual Wood Components

- Chemical analysis
  - The mixture of sugars is separated by chromatography and each sugar is measured quantitatively
- Hemicellulose changes affects strength
- Chemical component initially affected by elevated temperatures

Post-Fire Assessment of Individual Wood Components

- Sound wave methodologies:
  - Used in evaluating decayed damaged wood
  - Evaluation based on entire cross-section
  - Assumes correlation between strength and stiffness

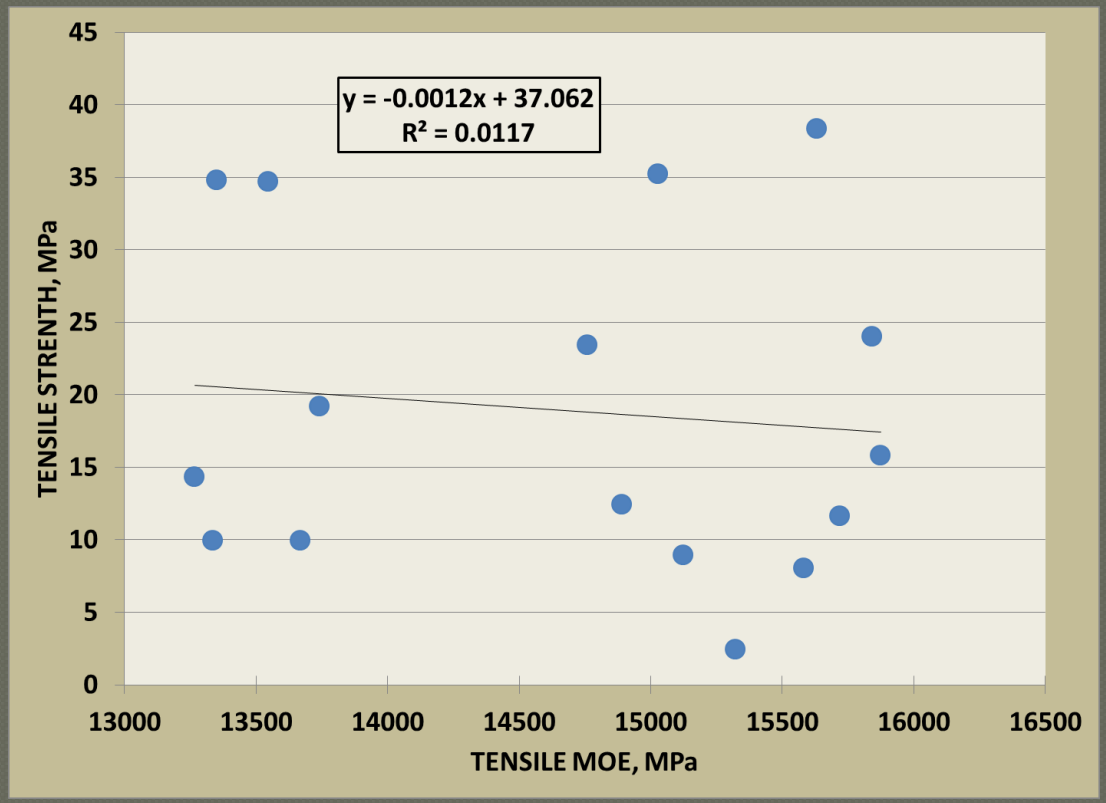
Post-Fire Assessment of Individual Wood Components



Pre-fire and post-fire results for four beams exposed in FPL furnace, two readings (T/B) per beam.

MOE vs. MOR Correlation

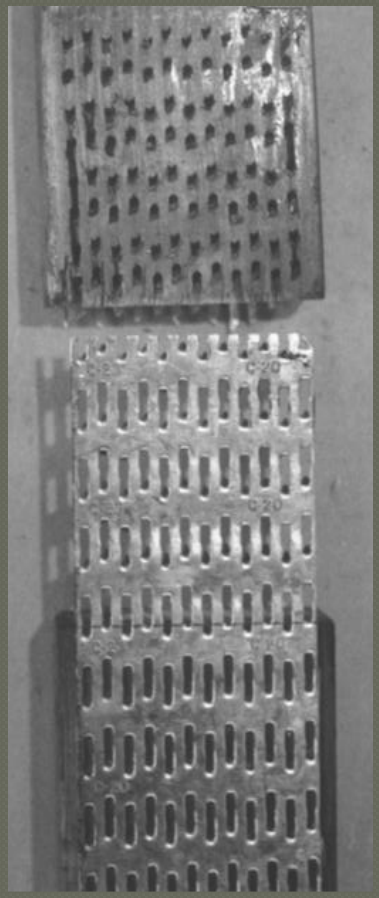
- Some methodologies depend on MOE to MOR correlations
- Relationship between MOE and MOR changes due to thermal exposure



Average values for "hot" samples subjected to different thermal exposures

Fire Damaged Connections

- Need to examine connections for evidence of fire damage
- Damage around metal penetrations due to heat conduction into wood



PREVENTION of FIRE AND FIRE DAMAGE

- Fire-Retardant-Treated Wood and Coatings
- Protective membranes
- Security and Fire Alarm Options
- Fire Extinguishment Options
- Design Considerations

Intumescent coated plywood before and after fire exposure.

Acknowledgements

This study is part of the Research, Technology and Education portion of the **National Historic Covered Bridge Preservation** (NHCBP) Program administered by the Federal Highway Administration. The NHCBP program includes preservation, rehabilitation and restoration of covered bridges that are listed or are eligible for listing on the National Register of Historic Places; research for better means of restoring, and protecting these bridges; development of educational aids; and technology transfer to disseminate information on covered bridges in order to preserve the Nation's cultural heritage.

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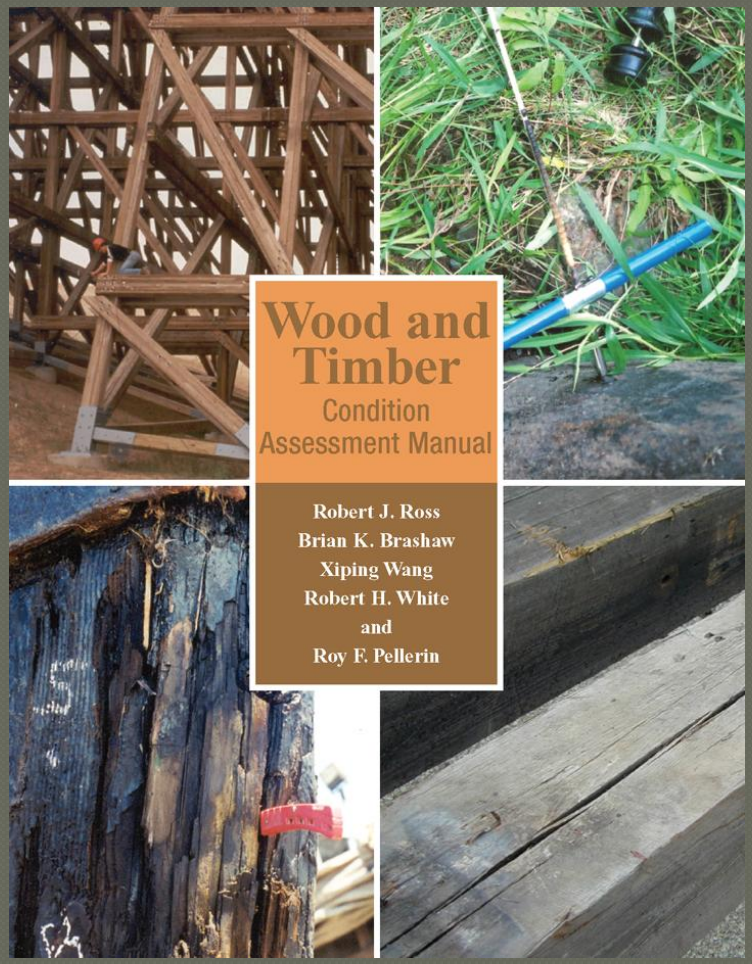
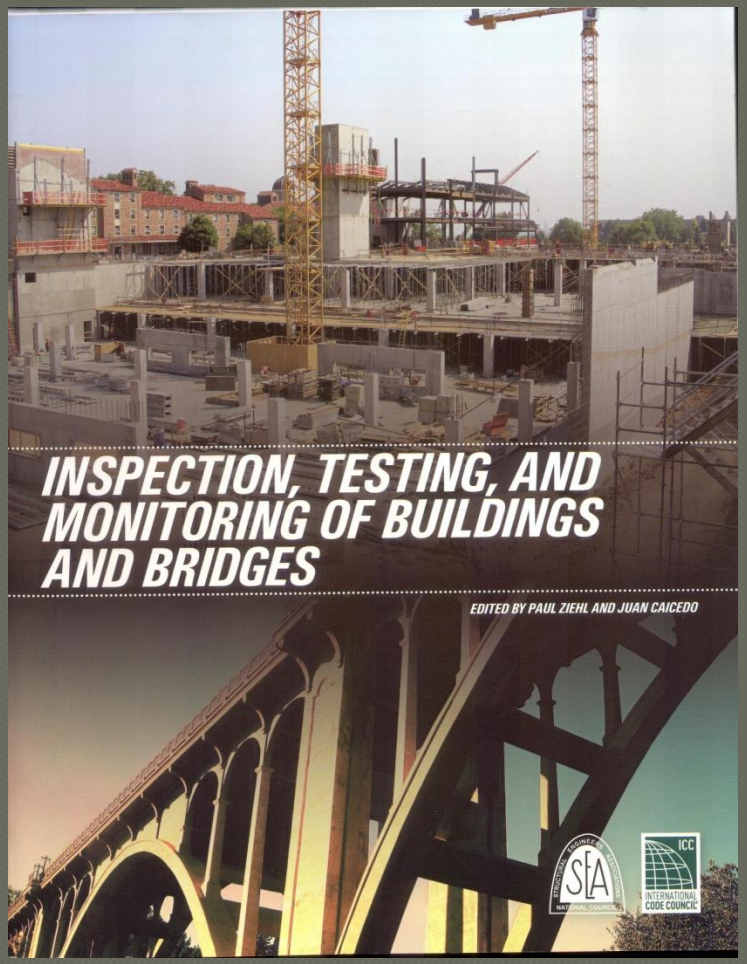
Sources for Additional Information





Q & A

- Questions?