Evaluation of Fire-Exposed Structural Members

All Structures
Safety and Information Gathering

- Verify structure is safe to enter
  - Excessive deflections?
  - Indications of excessive heat exposure?
- Construction drawings available?
- Shoring necessary?
- Have authorities released site?
- Ask questions about fire:
  - Reported location of origin?
  - Time and duration of fire?
  - Fuel sources?
- Hazardous materials present?

Evaluation of Fire-Exposed Structural Members

All Structures
Condition of Nearby Components

Fire Investigations (Non-Structural)
References

What Happens to Concrete During a Fire?

- 2250 °F: Concrete melts
- 1850 °F: Cement paste decomposes to powder
- 1000 °F: Dehydration complete
- 212 °F: Concrete loses free water, cement paste dehydrates (and shrinks), aggregate undergoes volumetric expansion
- > ambient temperature, all materials begin to expand

THERMAL EXPANSION
UNCHANGED TEMP. AND VOLUME
**Reinforced Concrete Structures**

**Distress Mechanisms**

Internal Pressure Due to Steam

- STEAM BUILDUP

**Reinforced Concrete Structures**

**Distress Mechanisms**

Rapid Heating and Cooling – Thermal Shock

**Reinforced Concrete Structures**

**Distress Mechanisms**

Varying Thermal Properties

- AGGREGATE EXPANDS - CEMENT PASTE SHRINKS

**Reinforced Concrete Structures**

**Petrographic Examination**

- ASTM C856 Standard Practice for Petrographic Examination of Hardened Concrete
  - Petrology: The science that deals with the mode of occurrence, composition, classification and origin of rocks
  - Petrography: An adjunct to Petrology and Field Geology. Petrography uses laboratory methods to characterize the texture and composition of rock bodies and interpret their history.
  - Concrete Petrography: Used similar methods to characterize the composition and condition of concrete in a structure.
Reinforced Concrete Structures

Petrographic Examination

- 1100 °F - 1740 °F
- 550 °F - 1100 °F
- < 550 °F

Evaluation of Fire-Exposed Structural Members

Reinforced Concrete Structures

Strength Loss

Factors Affecting Strength:
- Type of aggregate
- Ratio of cement/aggregate
- Air content
- Duration of exposure
- Rate of cooling
- State of stress

Evaluation of Fire-Exposed Structural Members

Reinforced Concrete Structures

Investigation

- Field Investigation Tools
  - PPE (hard hat, goggles, respirator, gloves, etc...)
  - Tape measure, flashlight, notepad, camera, level
  - Field Microscope
  - Hammer/Chain
  - Rebound Hammer
    - Qualitative only

Evaluation of Fire-Exposed Structural Members

Reinforced Concrete Structures

Strength Loss

Residual strength unaffected until about 1300 degrees Fahrenheit

Evaluation of Fire-Exposed Structural Members

Reinforced Concrete Structures

Investigation

- Cores for petrographic assessment
  - Metal detector to locate reinforcement
  - Mark location and orientation (up/down or inside/outside of cores)
  - Reasonable size (at least 3-4 inch diameter)
  - Takes cores in “control” area, not exposed to significantly elevated temperature
  - Compression tests typically not useful

Evaluation of Fire-Exposed Structural Members
Reinforced Concrete Structures

Plot of Petrographic Results

Reinforced Concrete Structures

Structural Damage?

- Has the residual strength of the concrete been affected?
- Is compression strength important?
  - Does concrete have higher strength than required by design?
- Is the damage at a critical section?
- How close is reinforcing to the surface?
- Has the concrete to reinforcing bond been disrupted?

Reinforced Concrete Structures

References

- ACI 216.3R-06: Code Requirements for Determining Fire Resistance of Concrete and Masonry Assemblies*, American Concrete Institute, 2006
- ASTM B66 Standard Practice for Petrographic Examination of Hardened Concrete, ASTM International
- Erlin, Bernard, and Hime, William, Kuenning, William, Evaluating Fire Damage to Concrete Structures, Concrete Construction, Dec. 1972

Concrete Masonry Unit (CMU) Structures

CMU versus Concrete

What Happens to CMU During a Fire?

- Similar behavior to concrete (both cementitious materials); however, common differences:
  - CMU typically has more void space
    - Allowance for expansion without disruption of matrix
  - Reinforcement if present often near center of CMU
    - Loss of strength on tension face may have no effect on ultimate capacity, no disruption of bond due to bar being in center of wall
  - Completed masonry wall not homogeneous
    - Masonry units experience different behavior than mortar joints (mortar joints more susceptible to damage)

CMU Structures

Visual Distress
CMU Structures

**Visual Distress**

- Soft or friable mortar
- Bond line separations

**Investigation**

- Field Investigation Tools
  - PPE (hard hat, goggles, respirator, gloves, etc...?)
  - Tape measure, flashlight, notepad, camera, level
  - Field Microscope
  - Hammer/Chain
  - Awl/probe – mortar joints
  - Rebound Hammer
  - Qualitative only
- Cores for petrographic examination

**References**

- Many references listed for concrete structures applicable
- TEK 7-9A, Evaluating Fire Exposed Concrete Masonry Walls, National Concrete Masonry Association, 2006
- Assessing the Condition and Repair Alternatives of Fire-Exposed Concrete and Masonry Members, National Codes and Standards Council, 1994

Steel Structures

**Behavior**

**What Happens to Steel During a Fire?**

- Strength and modulus of elasticity decrease with increasing heat.

- Many common steel coatings that are not intended for high-temperature applications will blister, burn, or melt between 250 °F and 600 °F
Steel Structures
Behavior

Consider the following regarding steel fabrication:

- Steel ingots prior to rolling: 1900 to 2300 °F
- Final rolling for hot-rolled shapes: >1600 °F
- Stress relieving: 1100 to 1200 °F
- Annealing and normalizing: 1500 to 1600 °F

Steel Structures
Behavior

What Happens to Steel During a Fire?

- Strength and modulus of elasticity decrease with increasing heat.

Steel Structures
Distress Mechanisms

Failure due to reduction in material properties – deflection

Steel Structures
Distress Mechanisms

Restrained Expansion - Buckling

Steel Structures
Visual Distress

What Happens to Steel During a Fire?

- Significant stress development due to restraint

\[ \sigma = \frac{P}{A} = \frac{\Delta \epsilon E}{L} \]

Steel Structures
Behavior

Visual Distress
Steel Structures

Visual Distress

Field Investigation Tools
- PPE (hard hat, goggles, respirator, gloves, etc...)?
- Tape measure, flashlight, notepad, camera,
- Level, plumb bob, string line, laser level
- Extraction of coupons typically unnecessary

Suggested Categorization
- Category I: “Straight” members that appear unaffected.
  - Confirm slight dimensional changes are within fabrication/erection tolerances or if not, if dimensional variations are OK
- Category II: Member noticeably deformed but could be heat straightened if deemed economical
  - Clearly beyond typical fabrication tolerance, but may be salvaged with straightening or reinforcing
- Category III: Severely deformed members
  - May have exceeded temperature that alters material properties; however generally a mute point since typically well beyond repair

References
- Tide, R.H.R, Integrity of Structural Steel After Exposure to Fire, American Institute of Steel Construction, Engineering Journal, First Quarter, 1998
What Happens to Wood During a Fire?

- **Pyrolysis:** decomposition of a material into simpler compounds brought about by heat
- **Up to 212 °F:** Residual material properties generally unaffected after reconditioning
  - As low as 250 °F: Could result in permanent alteration during prolonged exposure — not typical in common structure fire
- **550 °F:** Base layer of char
  - Can occur as low as 400 °F during prolonged exposure
  - Most structure fires — high heat, relatively short duration
  - Basis for information presented

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![Graph](image1.png)

**Figure 4.1.**—Predicted tensile strength as a function of temperature (Schulter 1977, 1986).

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![Graph](image2.png)

**Figure 4.2.**—Illustration of a charring wood member exposed to the standard fire exposure of 815° to 1,038°C.
Wood Structures
Visual Distress

Wood Structures
Visual Distress

Wood Structures
Visual Distress

Wood Structures
Determination of damage

- Thin members: plywood, OSB, 1x boards
  - If any char, heat affected zone renders significantly damaged
- Most light-framed construction: 2x members
  - If charred, detailed evaluation likely necessary to determine structural significance – however, typically not cost effective
- Heavy timber members: 4x and greater
  - Determine depth of char and heat affected zone
  - Estimate remaining cross-section and strength
  - Consider re-grading

Field Investigation Tools
- PPE (hard hat, goggles, respirator, gloves, etc...)?
- Tape measure, flashlight, notepad, camera,
- Level, plumb bob, string line, laser level
- Chisel, calipers
- Extraction samples to identify species if no stamps visible
**Evaluation of Fire-Exposed Structural Members**

### Wood Structures

**Re-grading**

- Wood Handbook: Wood as an Engineering Material, United State Department of Agriculture, Forest Products Laboratory, 2010
- Evaluation, Maintenance and Upgrading of Wood Structures, American Society of Civil Engineers, 1982
- Western Lumber Grading Rules, Western Wood Products Associates, 2004

### Wood Structures

**Post-fire damage due to moisture/exposure**

### All Structures

**Demolish, Repair, Re-use?**

- Questions to answer prior to re-use or repair:
  - May depend on client type (owner vs. insurance company)
  - Pre-existing damage?
  - What temperature did the structural element reach?
  - Which face (tension/compression)?
  - What temperature did the surrounding finishes reach?
  - Is loss of strength likely?
  - Is it significant? Code required demands vs. capacity in current condition?
  - “Significant structural damage” to building per IBC?

### All Structures

**Summary**

- Verify structure is safe to enter; use proper PPE
- Identify needs of client.
  - Extent of damage? Pre-existing?
- Determine type of structure. How is it intended to behave?
- How hot and how long was fire?
- What temperature did structural elements likely reach?
  - What temperature did non-structural elements likely reach?
  - Is this significant? What temperature truly affects the pertinent material properties.
- Determine if structural element is able to be re-used
  - Develop repairs; existing structure code considerations

### Questions?

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