

# Design Strength Requirements for Externally Applied Reinforcing Systems

Tarek Alkhrdaji  
Structural Technologies

# Strengthening of Concrete Structures



# External Reinforcing Systems

- Steel Plates



# External Reinforcing Systems

- External Post-tensioning



# External Reinforcing Systems

- Fiber Reinforced Polymer (FRP) Systems



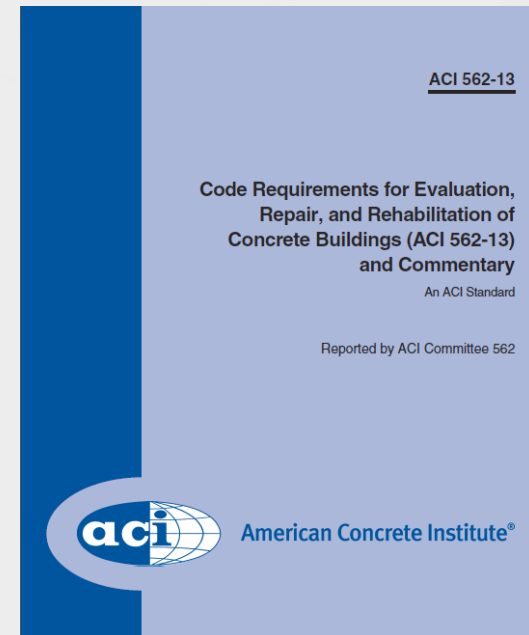
# ACI 562-13

- CHAPTER 5—LOADS, LOAD COMBINATIONS, AND STRENGTH REDUCTION FACTORS

## 5.5—Load combinations for structures repaired with *external reinforcing systems*

5.5.1 For repairs achieved with unprotected *external reinforcing systems*, the required strength  $U$  of a structure without repair shall be at least equal to the effects of factored loads in Eq. (5.5.1).

$$U_{ex} \geq 1.2D + 0.5L + A_k + 0.2S \quad (5.5.1)$$



# ACI 562-13

$$U_{ex} \geq 1.2D + 0.5L + A_k + 0.2S \quad (5.5.1)$$

- For External reinforcing systems:
  - Fiber Reinforced Systems (FRP)
  - Steel Plates
  - External Post-tensioning
- To Ensure that the unrepaired structure maintains a minimum strength should failure of the repair system occur due to:
  - Fire, impact, or blast
  - Wind and earthquake forces are not included
- To maintain sufficient strength until the damaged repair system is repaired

## ACI 562-16 (revision)

- To distinguish between adhesively bonded and mechanically bonded systems
- To provide separate design strength limits for damage during normal operations versus for a fire event
- To provide guidance for fire rating evaluation
- Other extreme events such as blast and removed



# ACI 562-16 (revision)

## 5.5—Load combinations for structures repaired with *external reinforcing systems*

**5.5.1** For rehabilitation achieved with external reinforcing systems that are susceptible to damage by fire, vandalism or collision, the required strength of the structure without rehabilitation shall equal or exceed the effects of the load combinations specified in **5.5.2**, and **5.5.3**.

## ACI 562-16 (revision)

**5.5.2** For non-mechanically bonded external reinforcement and all FRP systems, the required strength of the structure *without* external reinforcement shall satisfy Equations 5.5.2a and 5.5.2b

$$\phi R_n \geq 1.1D + 0.5L + 0.2S \quad (5.5.2a)$$

$$\phi R_n \geq 1.1D + 0.75L \quad (5.5.2b)$$

- $\phi$  is the strength-reduction factor is 5.3 or 5.4, as applicable
- $R_n$  is the nominal strength of the structure *without* the external reinforcement
- Equation (5.5.2b) is similar to limit in ACI 440.2R-08 (FRP)

# ACI 562-16 (revision)

- For FRP and Non-Mechanically Bonded Systems



## ACI 562-16 (revision)

**5.5.3** To account for potential performance issues during a fire event, the required strength of the structure without external reinforcement shall satisfy Eq. (5.5.3)

$$\phi_{ex} R \geq (0.9 \text{ or } 1.2)D + 0.5L + 0.2S \quad (5.5.3)$$

- $\phi_{ex}$  is equal to 1.0 (no strength reduction)
- R is the nominal strength of the structural element  
*considering reduced material strength*
- ACI 216 provides guidance on determining material strength during a fire event

# ACI 562-16 (revision)

- 5.5.3 applies to all mechanically and adhesively bonded reinforcing systems



Steel Plates



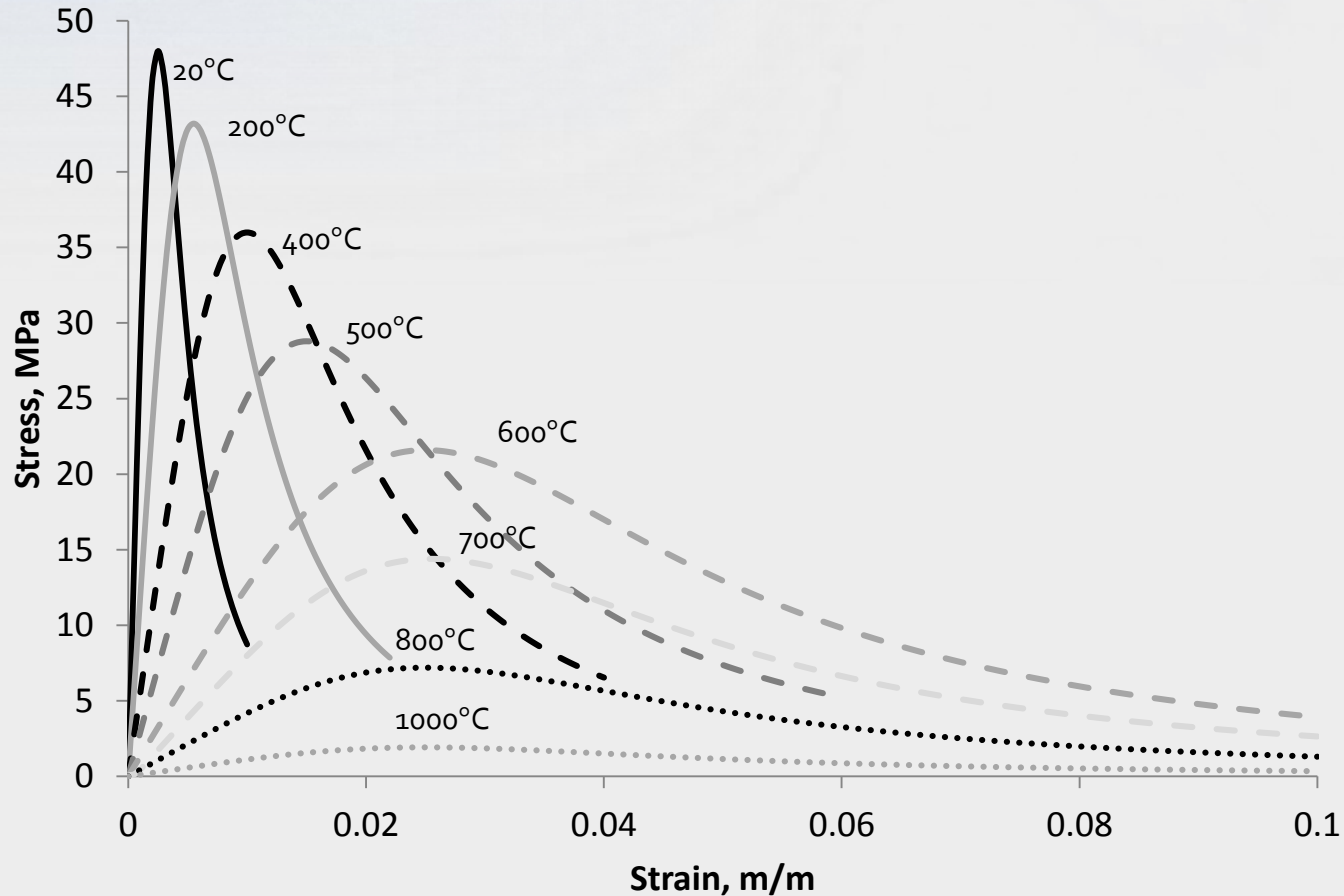
FRP



Post-Tensioning

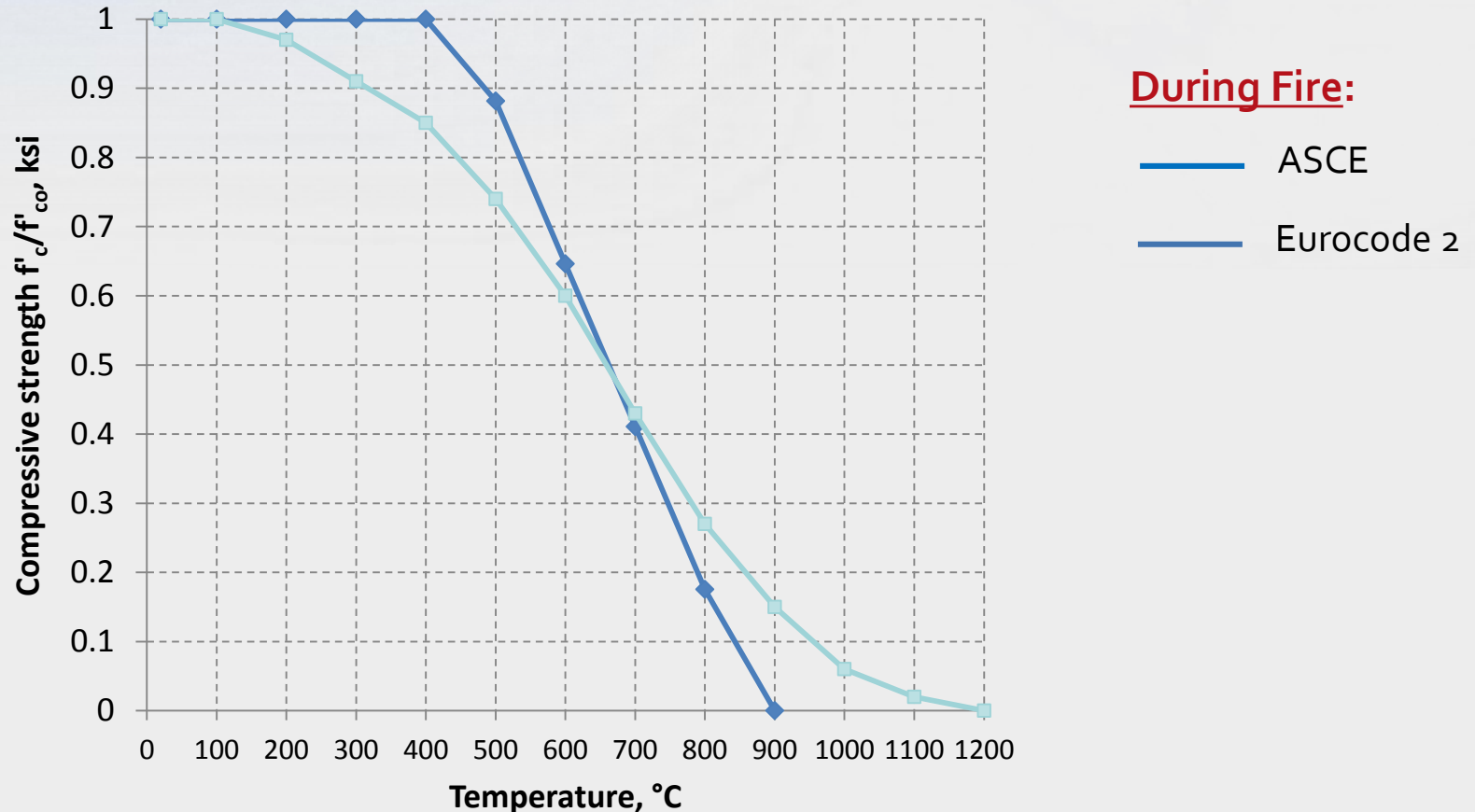
# Effects of Fire on Concrete

Stress-strain relationship for concrete



# Effects of Fire on Concrete

## Compressive Strength at Elevated Temperature



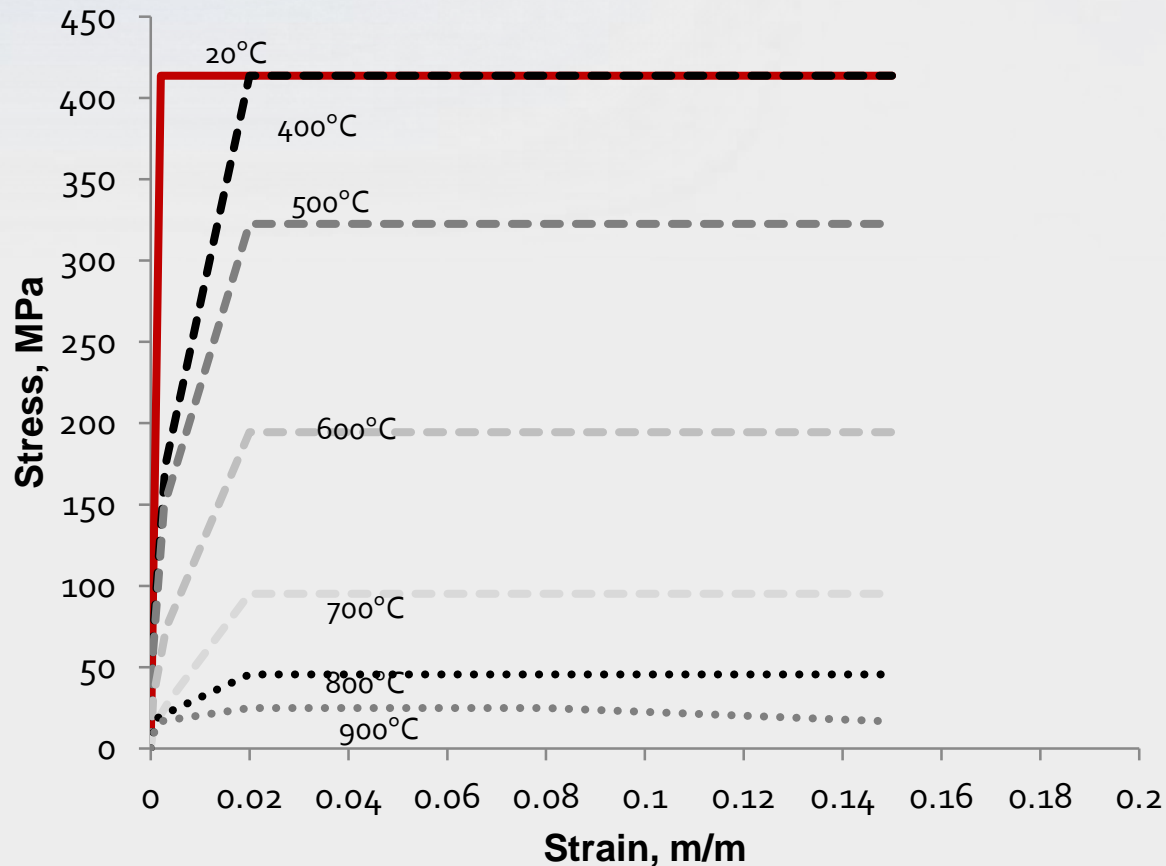
During Fire:

ASCE

Eurocode 2

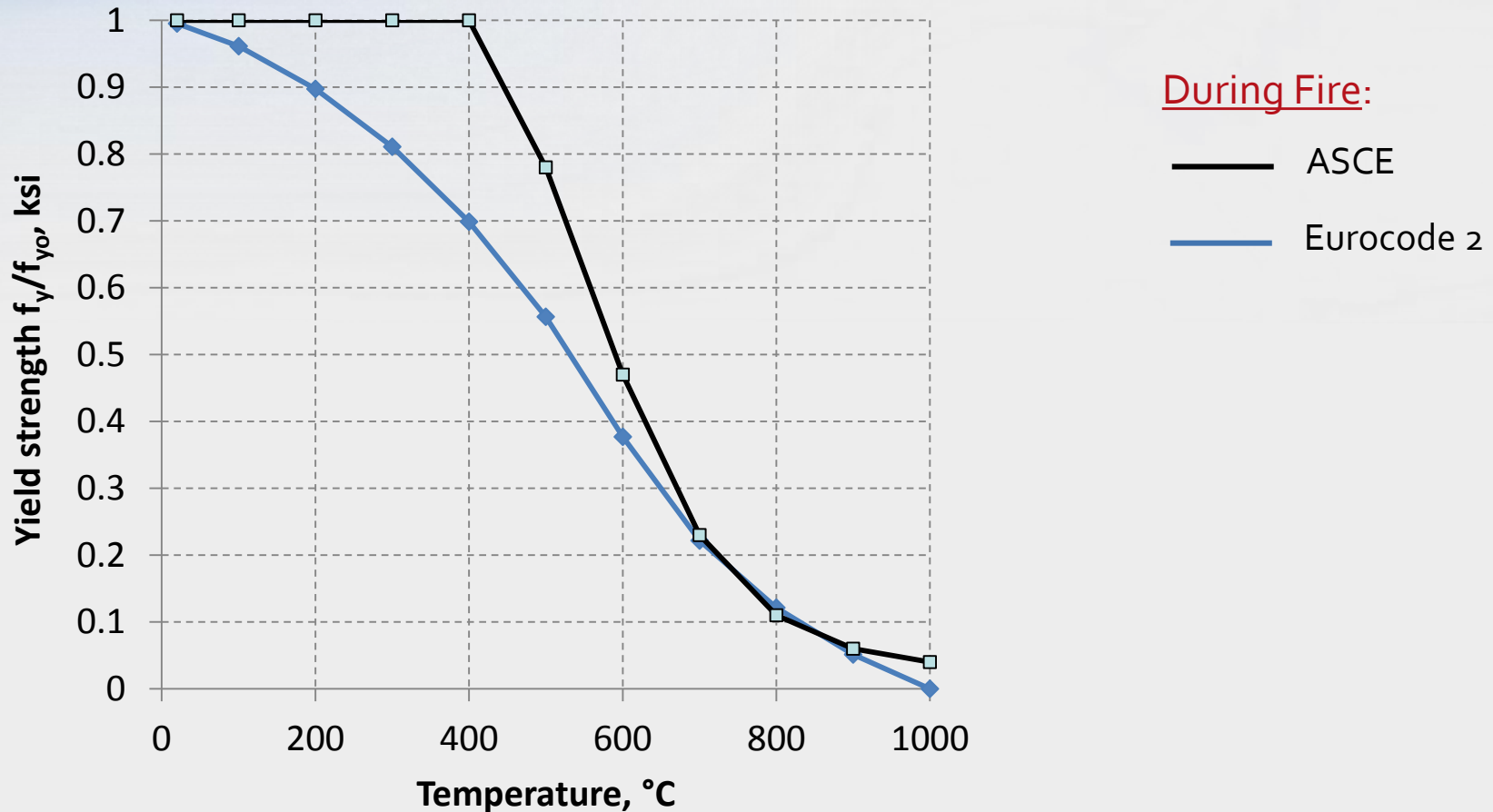
# Effects of Fire on Steel Bars

## Stress-strain relationship for reinforcing steel





# Effects of Fire on Steel Bars

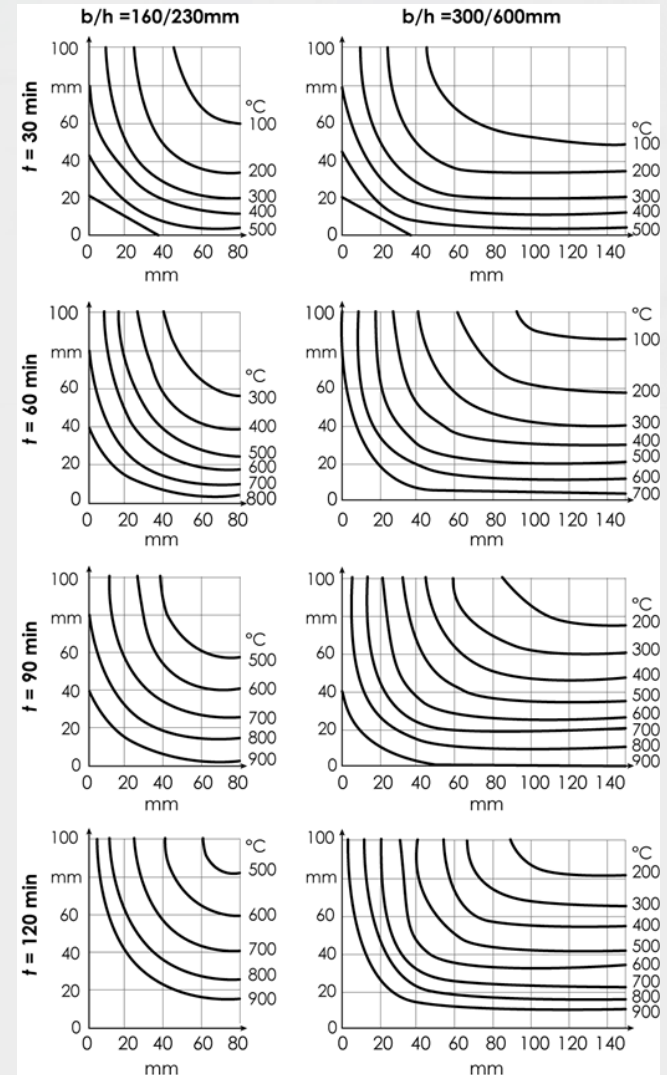
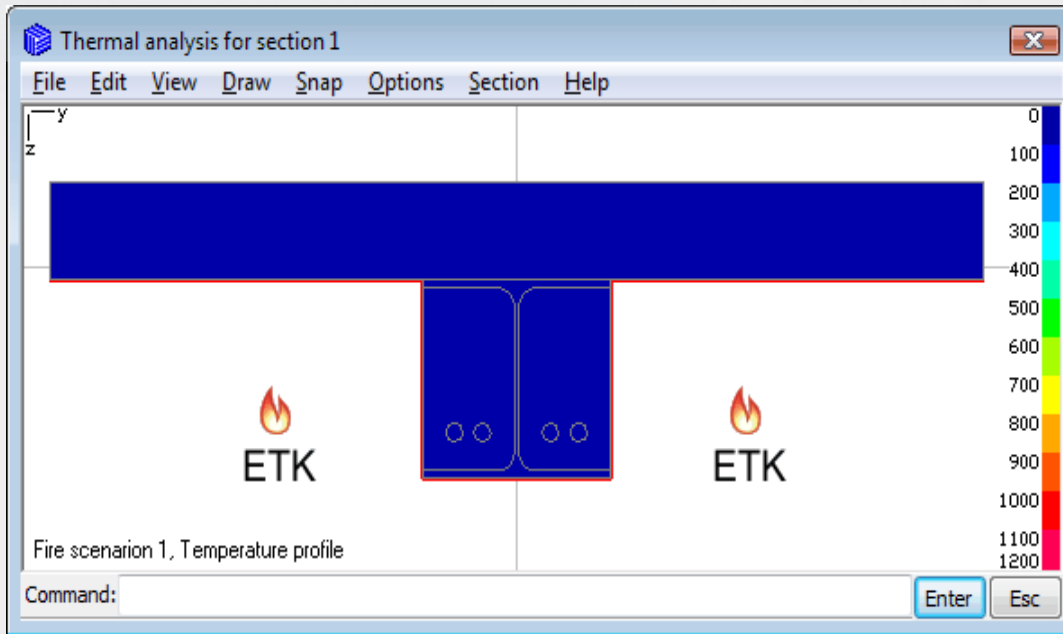


Ref. ASCE, "Structural Fire Protection," American Society of Civil Engineers, New York, Practice No. 78, 1992

Ref. Eurocode 2, "Design of concrete structures, Part 1-2: General rules-structural fire design. ENV 1992-1-2," CEN: European Committee for Standardization, UK, 2004.

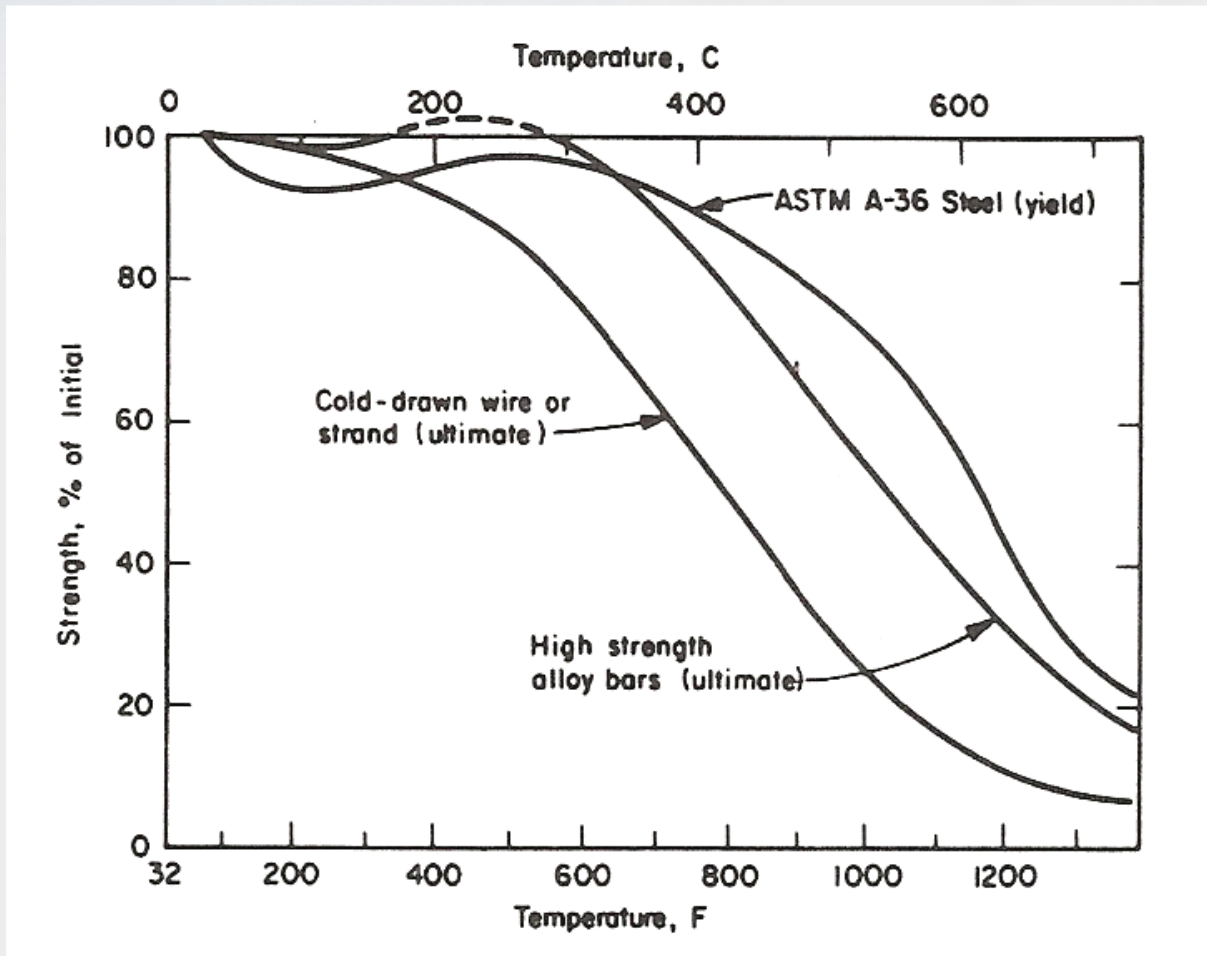
# Temperature Profile

## Thermal Modeling

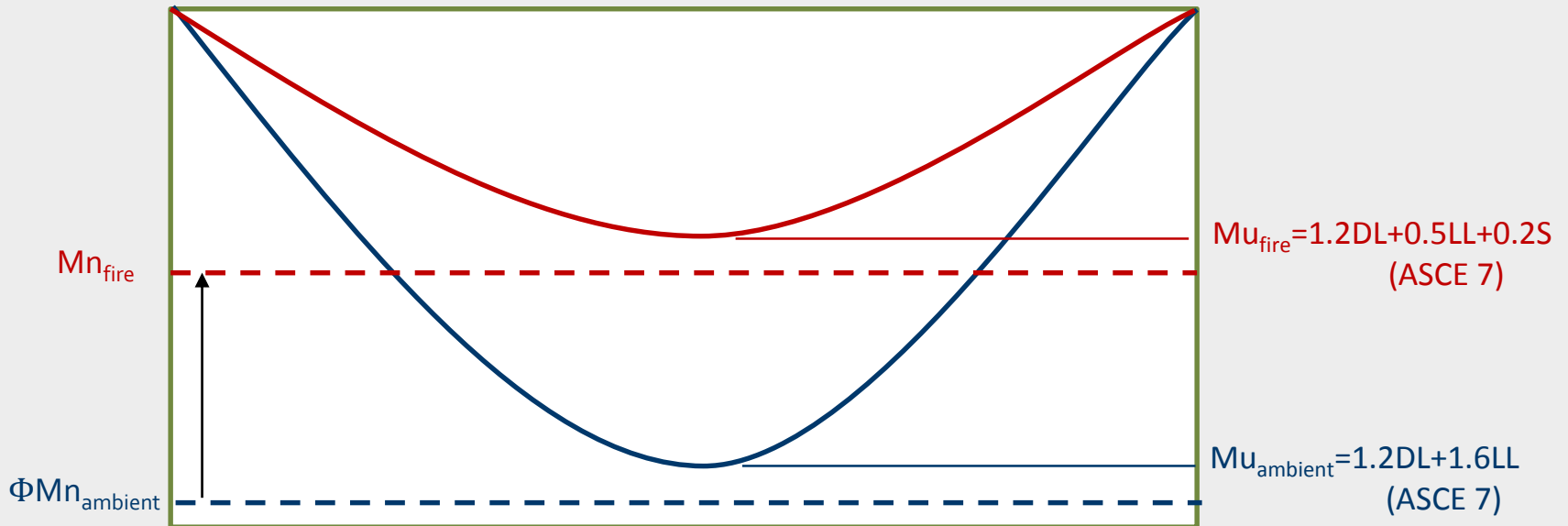
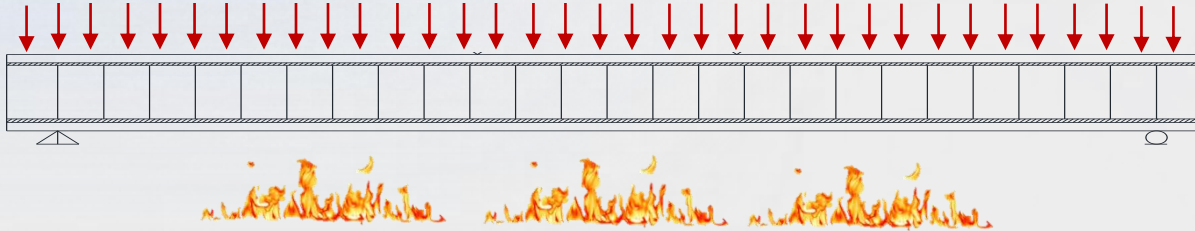


# Determining Yield Strength

## Yield Strength of Steel at Elevated Temp. (ACI 216)



# Demand vs. Capacity during Fire



## ACI 562-16 (revision)

- If strength (fire rating) is not adequate without the external reinforcing material then additional fire proofing is required
  - To protect the ext. reinforcing system
  - And/or to protect the existing member
- To increase the fire rating of the element
- In this case, the effect of the fire protection system on the external reinforcement and existing elements is considered

# Fire Protection

- Protecting FRP and Steel Plates with Fireproofing



## Other Strengthening Methods

- RC Concrete Enlargement



- Concrete cover provides required fire rating

## Other Strengthening Methods

- Ext PT Encased in Concrete Enlargement



- Concrete cover provides required fire rating



# ACI 562-16, Section 5.5 – Design Limits

## SUMMARY

- Two strength limits have been introduced to ACI 562-16 for external reinforcing systems:
  - Strength limit for normal operations
  - Strength limit for fire events
- All Non-mechanically bonded systems and FRP systems must meet the normal operations limit in 5.5.2
  - Based on design (or tested) material properties and typical  $\phi$  factors
  - Mechanically attached systems not included
  - Allows for approx. 40% strength increase
- All external system must be checked for adequate fire resistance per 5.5.3
  - Based on lower material strength and  $\phi = 1.0$
  - Ignoring the external system if not fire protected
  - Additional fire resistance can be provided using fireproofing materials
- Effectiveness of fire proofing materials must be established through material testing and full scale structural testing

# Thank You

# Questions

Design Strength Requirements for Externally Applied Reinforcing Systems

Tarek Alkhrdaji  
Structural Technologies