There's always a solution in steel.

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STEEL

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Course Description

Get Fired Up: What Structural Engineers Should Know About Fire Design

February 22, 2017

Typically, fire protection is the responsibility of the architect, but it is becoming more common today that the structural engineer is involved when the prescriptive approach is inadequate and fire engineering becomes desirable. The presentation begins with a background on the current state of fire design including governing standards and the impact of historical fires. Then, the behavior of steel structures in fire conditions is discussed including beams and columns, connections, tensile membrane action and web-buckling. This lecture will focus on what the structural engineer needs to know about fire protection and design and what benefits and advantages steel structures offer in fire resistance.

Learning Objectives

- Identify key differences between prescriptive fire protection and structural fire engineering.
- Identify codes and standards that address fire design
- Describe how historical fires have shaped current codes and practice
- Understand behavior of steel structures in fire conditions including beams and columns, connections, tensile membrane action and web-buckling

There's always a solution in steel.

Get Fired Up: What Structural Engineers Should Know About Fire Design

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Associate Professor
Dept. Civil & Environmental Engineering
Princeton University
Princeton, NJ

Creative Resilient Urban Engineering

PRINCETON UNIVERSITY

structural STEEL


"Big picture" message:
You do not need to forgo efficiency, economy, and elegance in steel structures for fire protection reasons…
SFE Project: BuroHappold
Image : Roger Strike Harbour
9


1 BACKGROUND
– Fires that transformed USA history
10

1 BACKGROUND / Fires That Transformed USA History /

Great Chicago Fire of 1871

11

1 BACKGROUND / Fires That Transformed USA History /

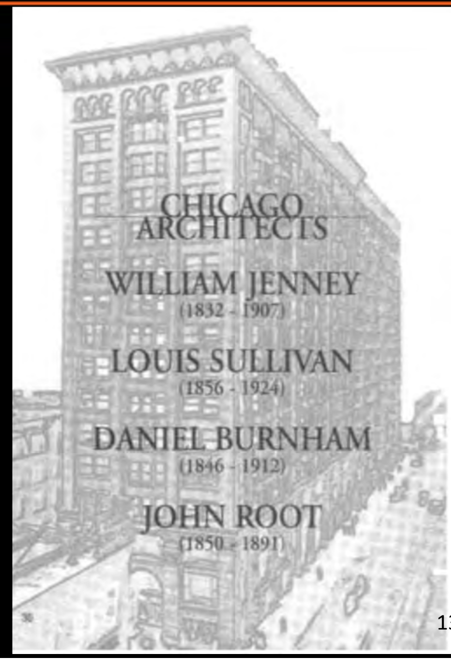
Great Chicago Fire of 1871

12

① BACKGROUND / Fires That Transformed USA History /

Great
Chicago Fire
of 1871

Transformation of:
- Building codes
- Architecture



13

① BACKGROUND / Fires That Transformed USA History /

NYC, 1911
Triangle
Shirtwaist Co.

Transformation of…
- politics & labor laws
- bldg. fire safety

14

① BACKGROUND / Fires That Transformed USA History /

NYC: Sept. 11, 2001
(WTC 1, 2, 5, 7)

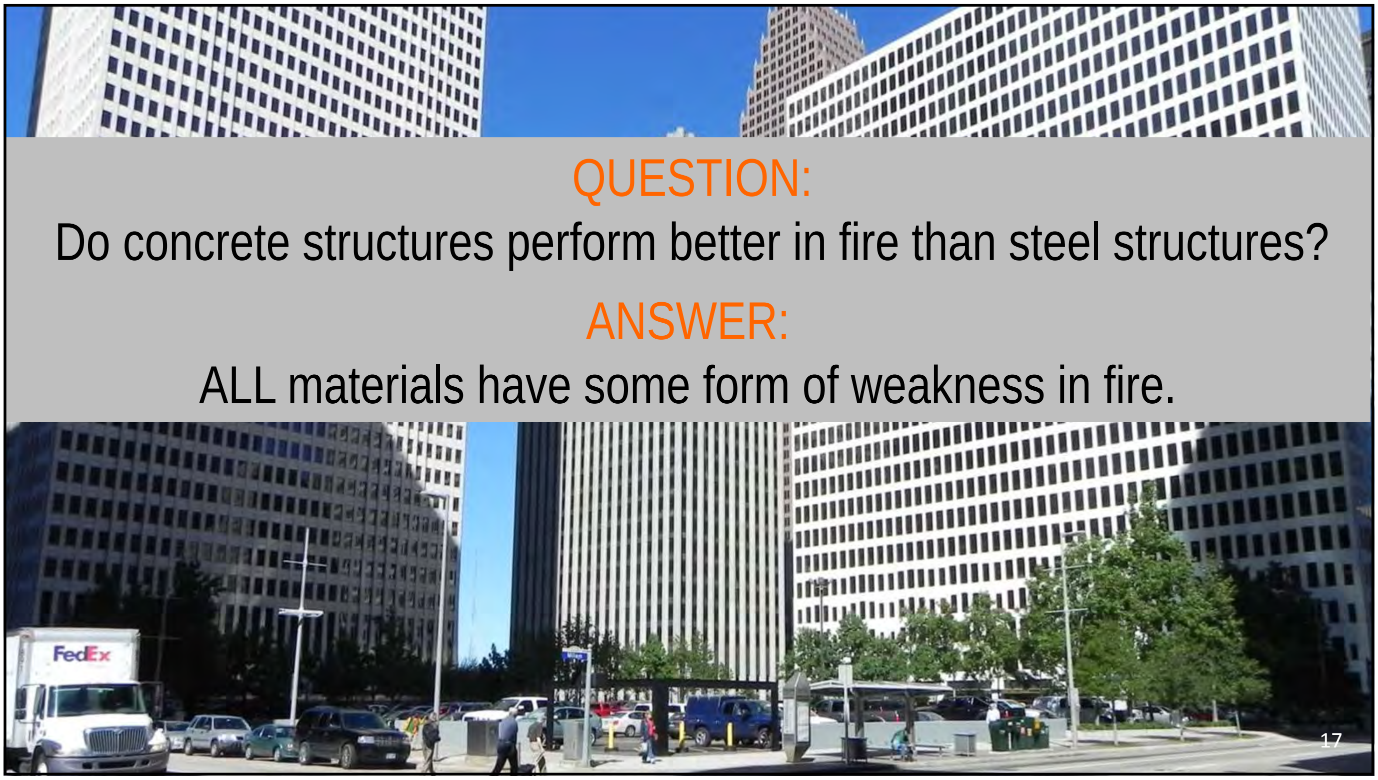
Transformation of…
the way we think
about fire design of
structures

Figure 2. Internal Collapse Area in WTC 5 (World Trade…, 2002).

15

QUESTION:
Do concrete structures perform better in fire than steel structures?

16



QUESTION:

Do concrete structures perform better in fire than steel structures?

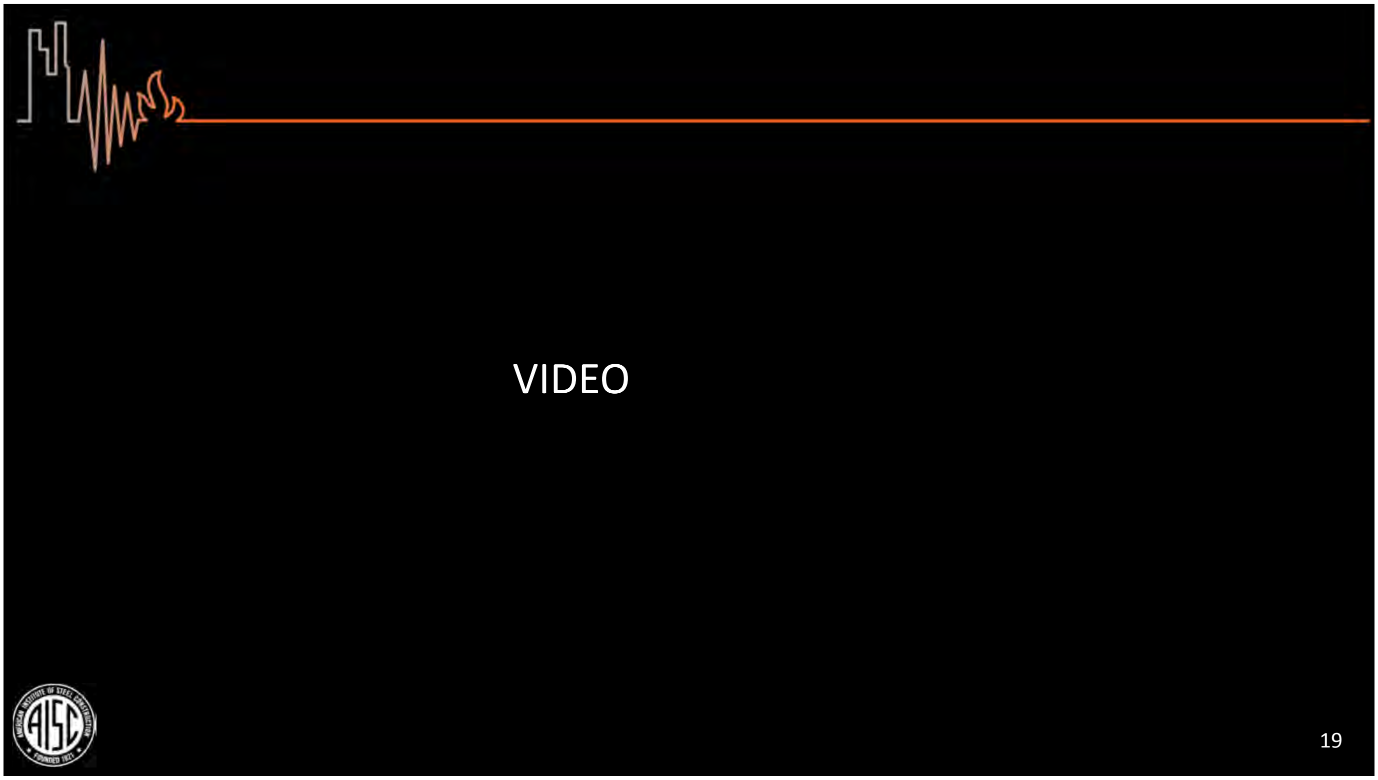
ANSWER:

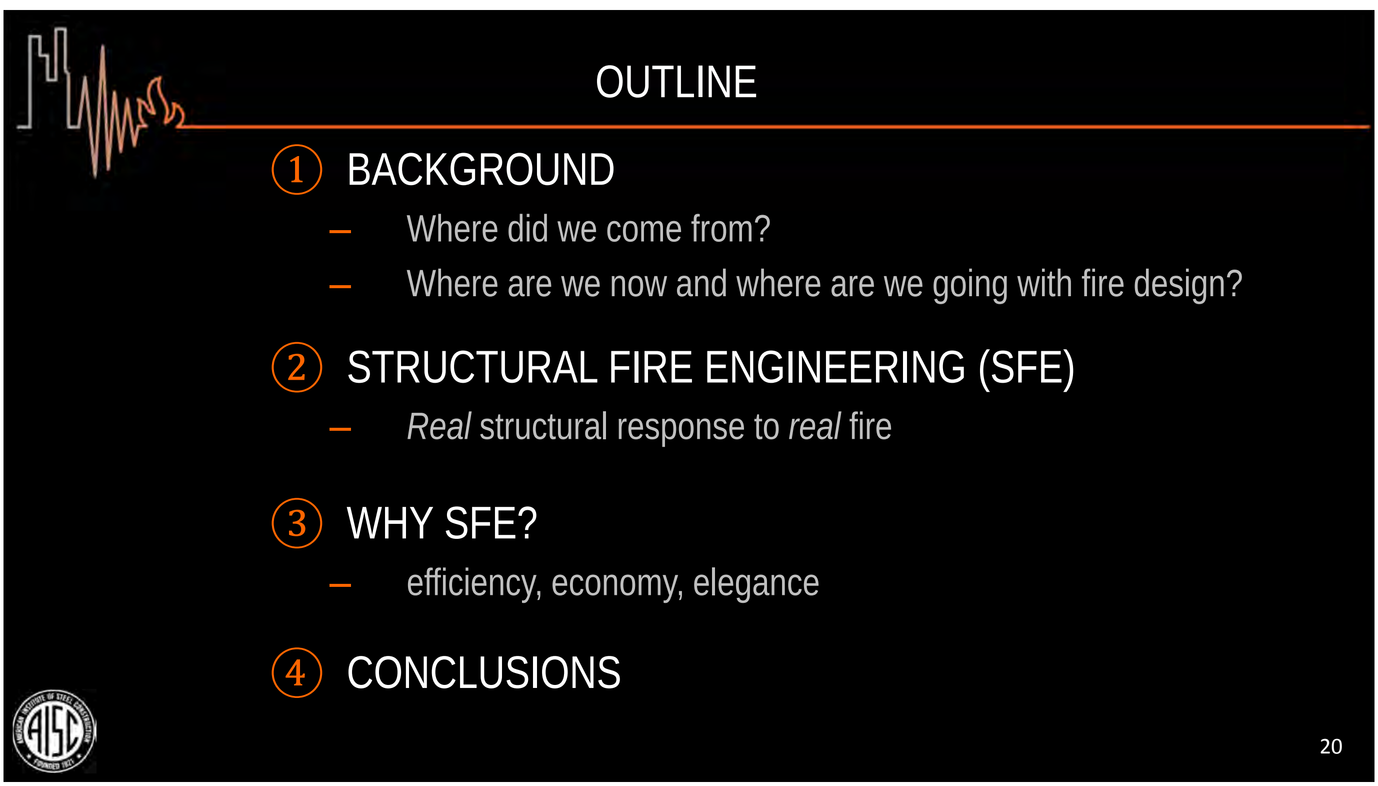
ALL materials have some form of weakness in fire.

17

https://www.youtube.com/watch?v=gwQfpMnSh90

18


VIDEO
19


OUTLINE
1 BACKGROUND
– Where did we come from?
– Where are we now and where are we going with fire design?
2 STRUCTURAL FIRE ENGINEERING (SFE)
– *Real* structural response to *real* fire
3 WHY SFE?
– efficiency, economy, elegance
4 CONCLUSIONS
20

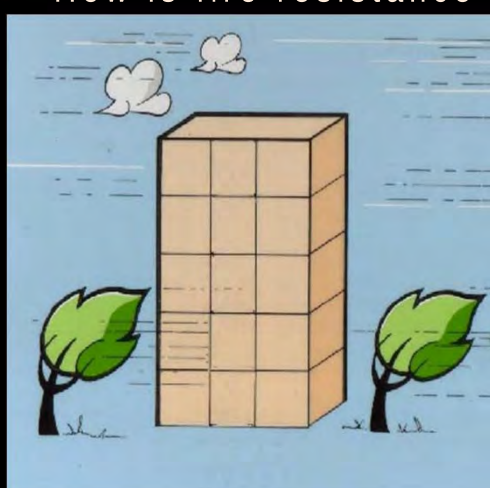
1 BACKGROUND / Current Practice in USA /

How is fire resistance traditionally determined?

21

1 BACKGROUND / Current Practice in USA /

How is fire resistance traditionally determined?



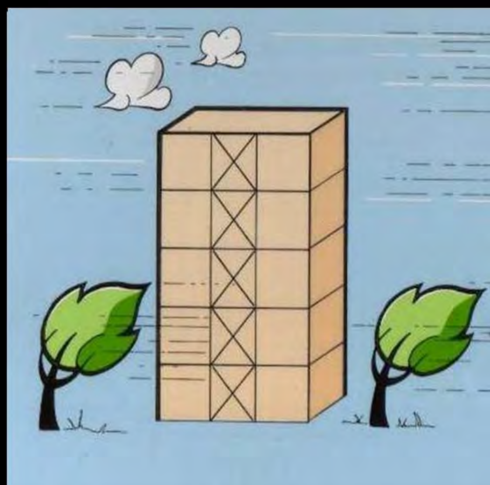
How does a building resist wind?

slide credit: Jeff Robison, British Steel

22

1 BACKGROUND / Current Practice in USA /

How is fire resistance traditionally determined?



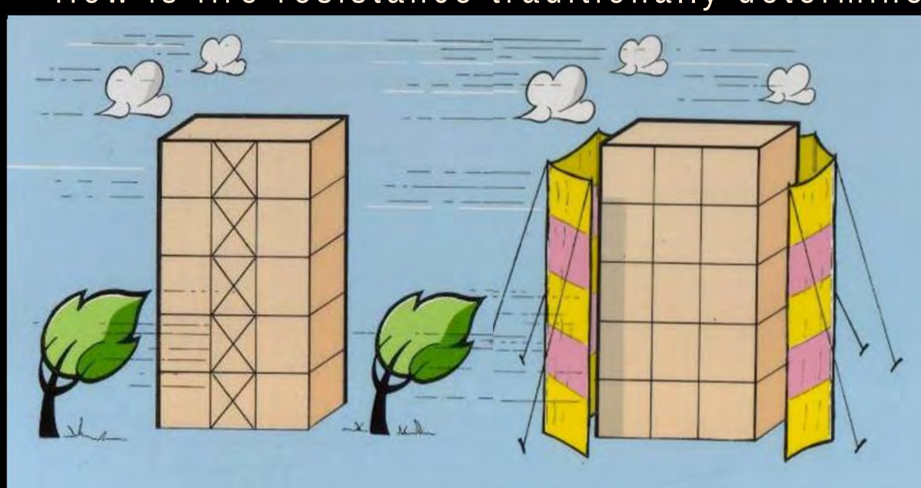
One solution is to design the building to resist wind using bracing.

slide credit: Jeff Robison, British Steel

23

1 BACKGROUND / Current Practice in USA /

How is fire resistance traditionally determined?



One solution is to design the building to resist wind using bracing.

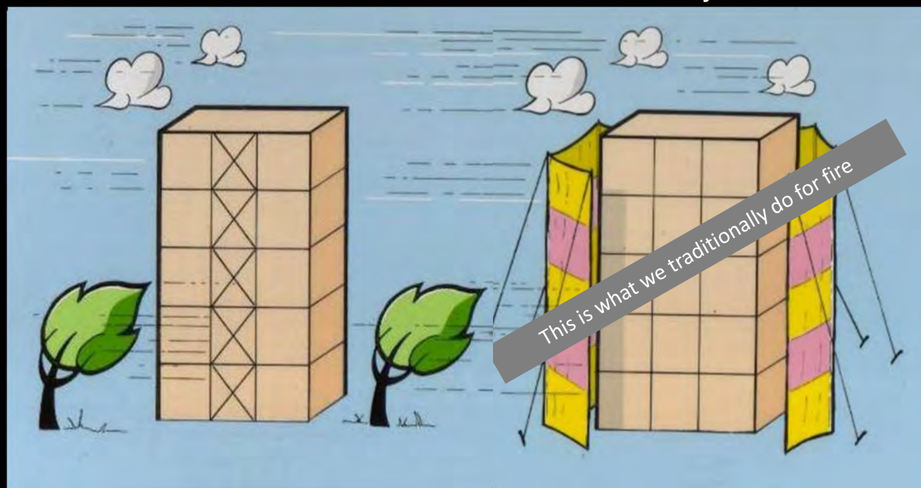
An alternative is to protect the building from wind.

slide credit: Jeff Robison, British Steel

24

1 BACKGROUND / Current Practice in USA /

How is fire resistance traditionally determined?



One solution is to design the building to resist wind using bracing.

An alternative is to protect the building from wind.

slide credit: Jeff Robison, British Steel

25

1 BACKGROUND / Current Practice in USA / *Prescriptive*

Designers select materials and assemblies to meet fire resistance using "approved methods":

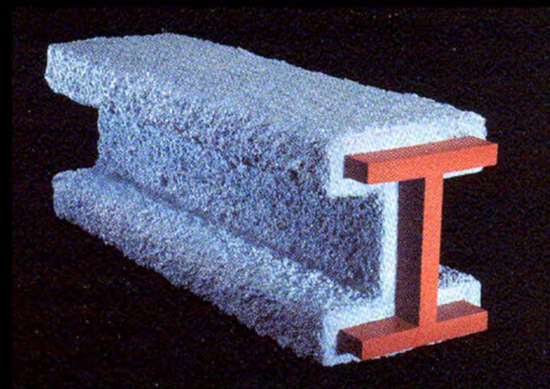
- qualification testing (ASTM E119)
- computational methods that show ASTM E119 equivalence

26

1 BACKGROUND / Current Practice in USA / *Prescriptive*

Protection Systems for Steel

- Board Systems
- Spray on Systems
- Intumescent Paint
- Concrete Encasement
- Concrete Filling
- … etc …

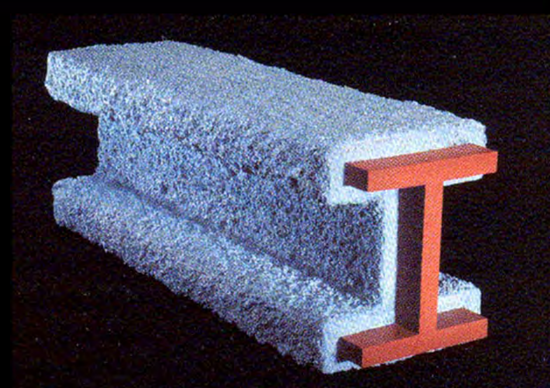


27

1 BACKGROUND / Current Practice in USA / *Prescriptive*

Protection Systems for Steel

- Board Systems
- Spray on Systems
- Intumescent Paint
- Concrete Encasement
- Concrete Filling
- … etc …



Regardless of the system used, an engineered approach to fire safety will lead to more efficient, economical, and elegant solutions

28

1 BACKGROUND / Current Practice in USA / *Prescriptive*

QUESTION:
Does the fire resistive rating imply the *time* that the structural integrity is maintained?

29

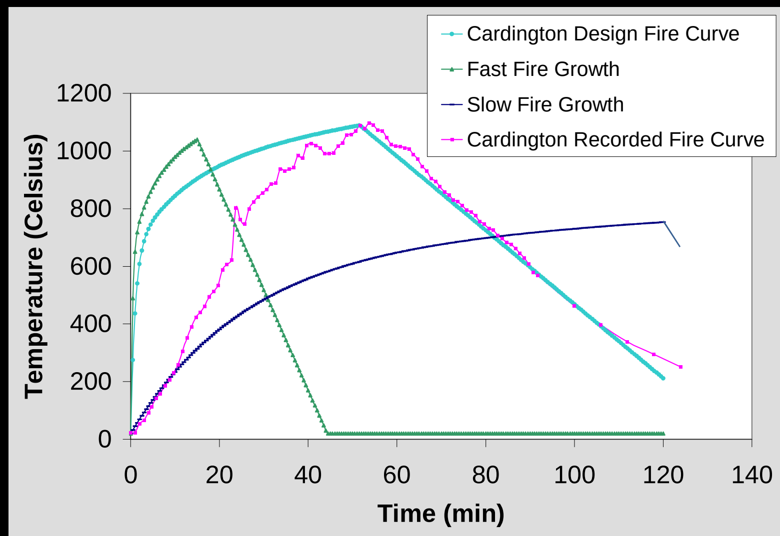
1 BACKGROUND / Current Practice in USA / *Prescriptive*

QUESTION:
Does the fire resistive rating imply the *time* that the structural integrity is maintained?

SHORT ANSWER:
no

30

① BACKGROUND / Current Practice in USA / *Prescriptive*

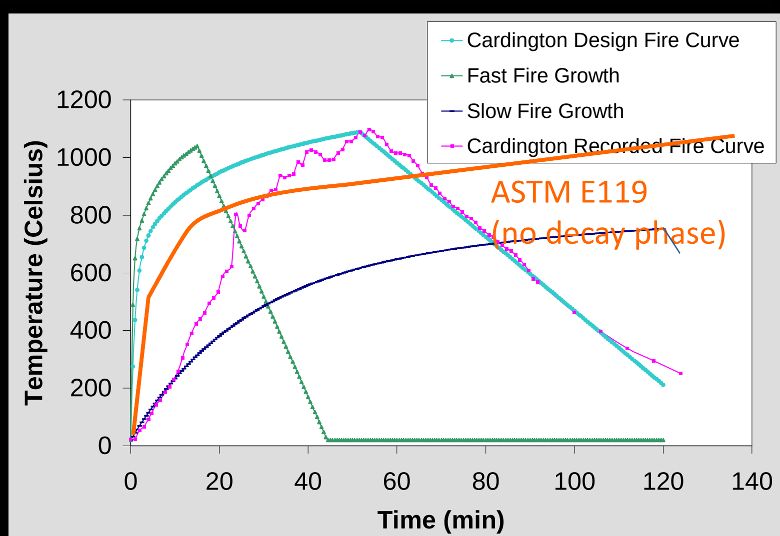


31

① BACKGROUND / Current Practice in USA / *Prescriptive*

ASTM E119 Fire Resistance

- Comparative test, not a predictive test
- Principally a thermal test, not a structural test



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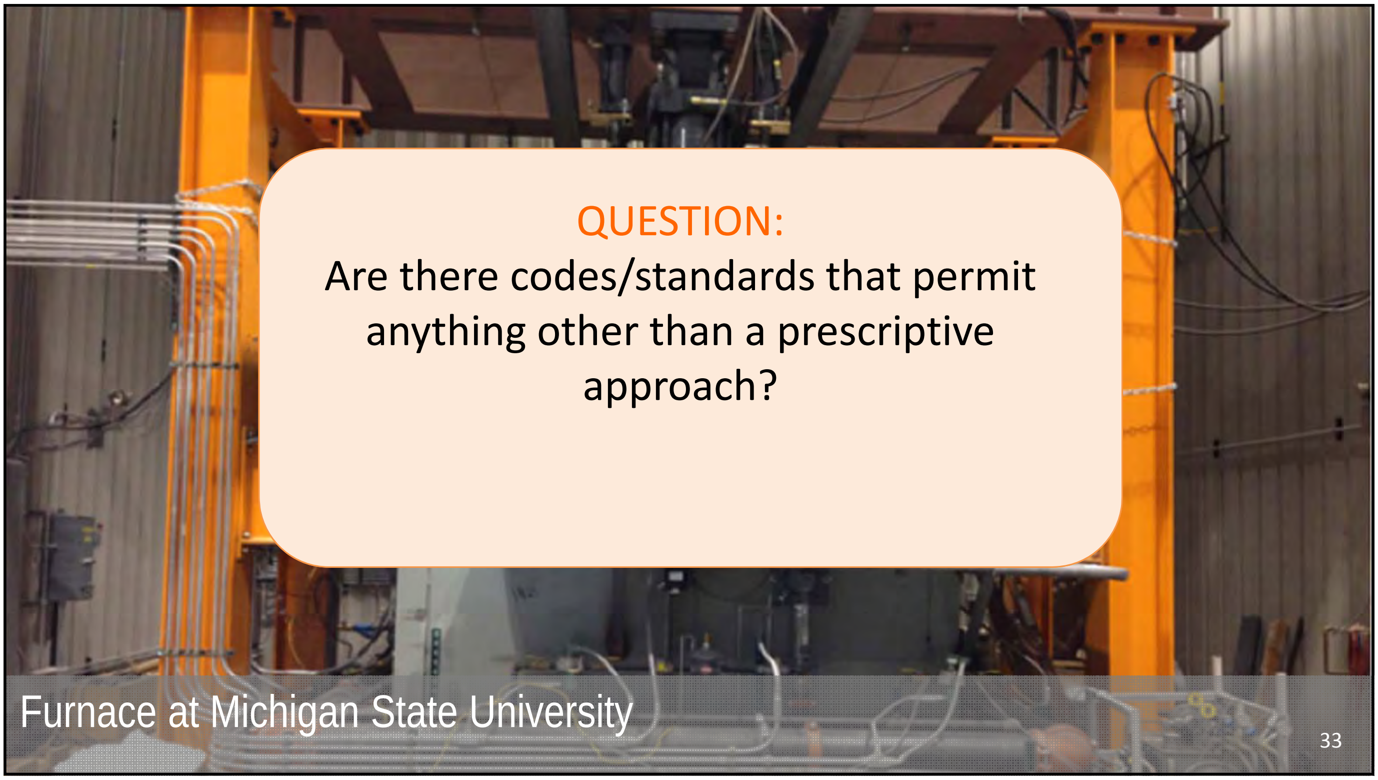
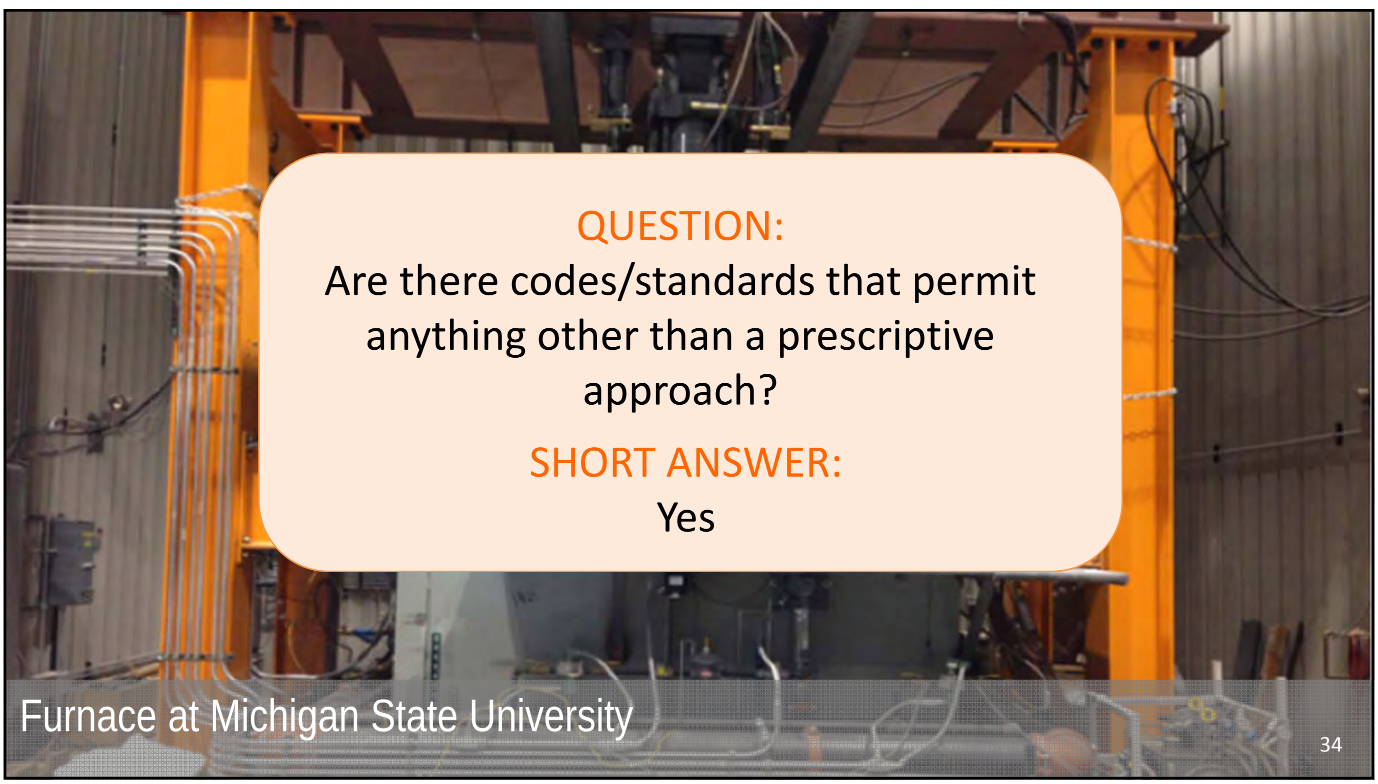
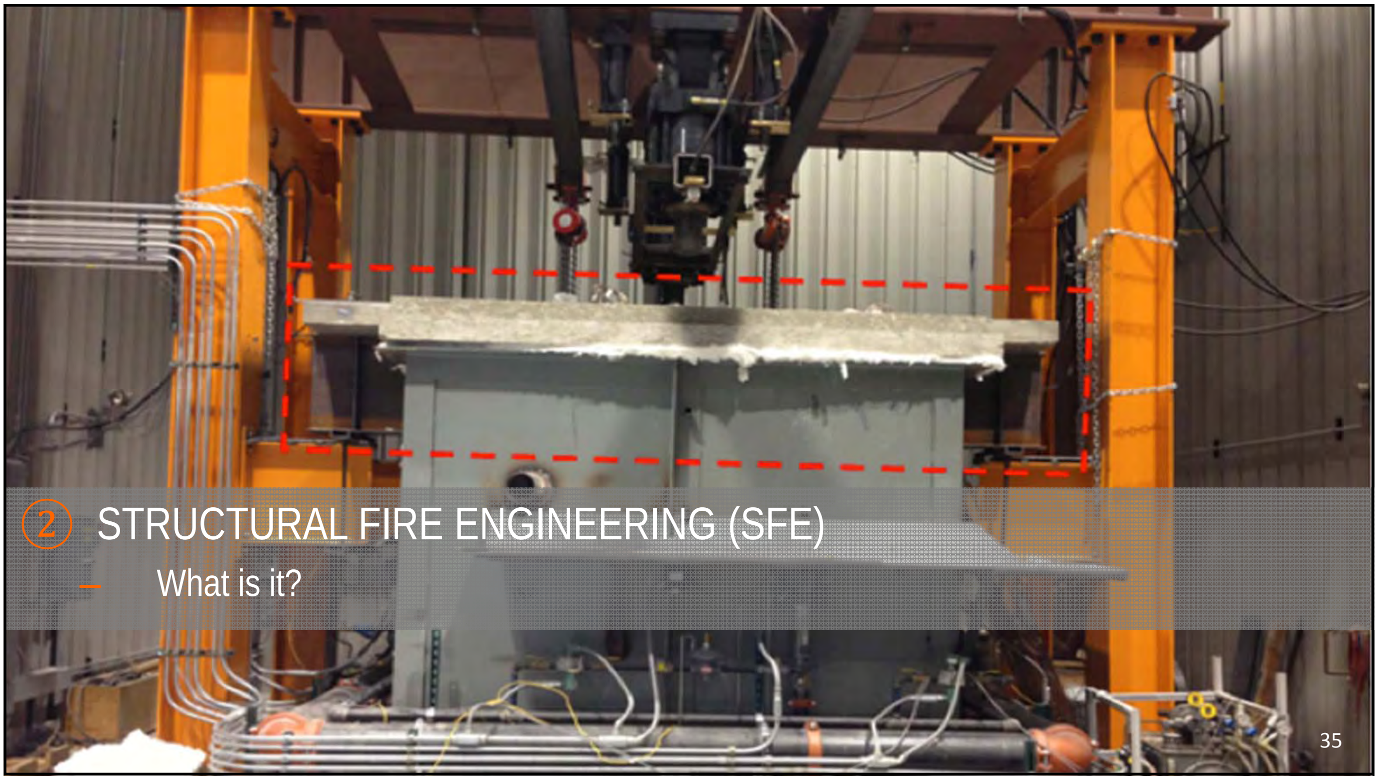
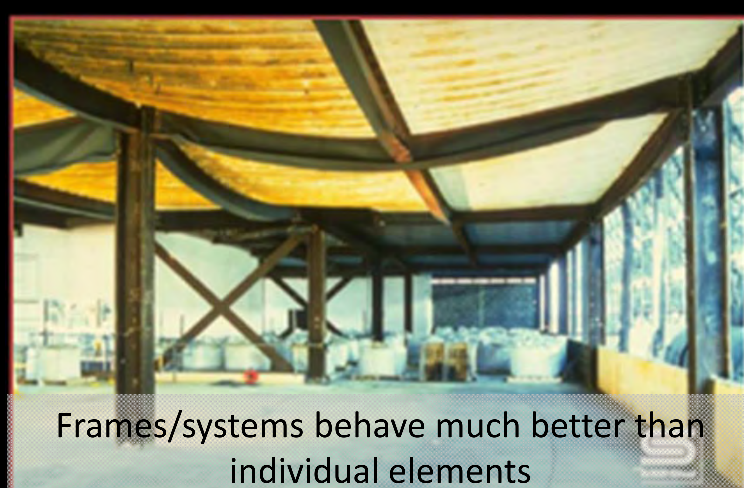

QUESTION:
Are there codes/standards that permit anything other than a prescriptive approach?
Furnace at Michigan State University
33


QUESTION:
Are there codes/standards that permit anything other than a prescriptive approach?
SHORT ANSWER:
Yes
Furnace at Michigan State University
34



2 SFE / What is it? /

Structural Fire Engineering (SFE) → Performance based design for fire



36

② SFE / What is it? /

Structural Fire Engineering (SFE) → Performance based design for fire

- Fire is treated as a "load" (like wind, earthquake, etc...)
- Can evaluate systems and components.
- *Where possible*, design the structure to withstand fire rather than protect against it.

Frames/systems behave much better than individual elements

37

② SFE / What is it? / *Difference with Prescriptive?*

	Prescriptive	SFE
States how a building is to....	... be constructed	... perform

38

2 SFE / What is it? / *Difference with Prescriptive?*

	Prescriptive	SFE
States how a building is to….	… be constructed	… perform
Knowledge of structural behavior needed?	NO	YES

39

2 SFE / What is it? / *Difference with Prescriptive?*

	Prescriptive	SFE
States how a building is to….	… be constructed	… perform
Knowledge of structural behavior needed?	NO	YES
Primary role in domain of…	architect (non-engineered)	engineer (engineered)

40

2 SFE / What is it? / *Analysis Steps*

- FIRST STEP: Define Performance Objectives

41

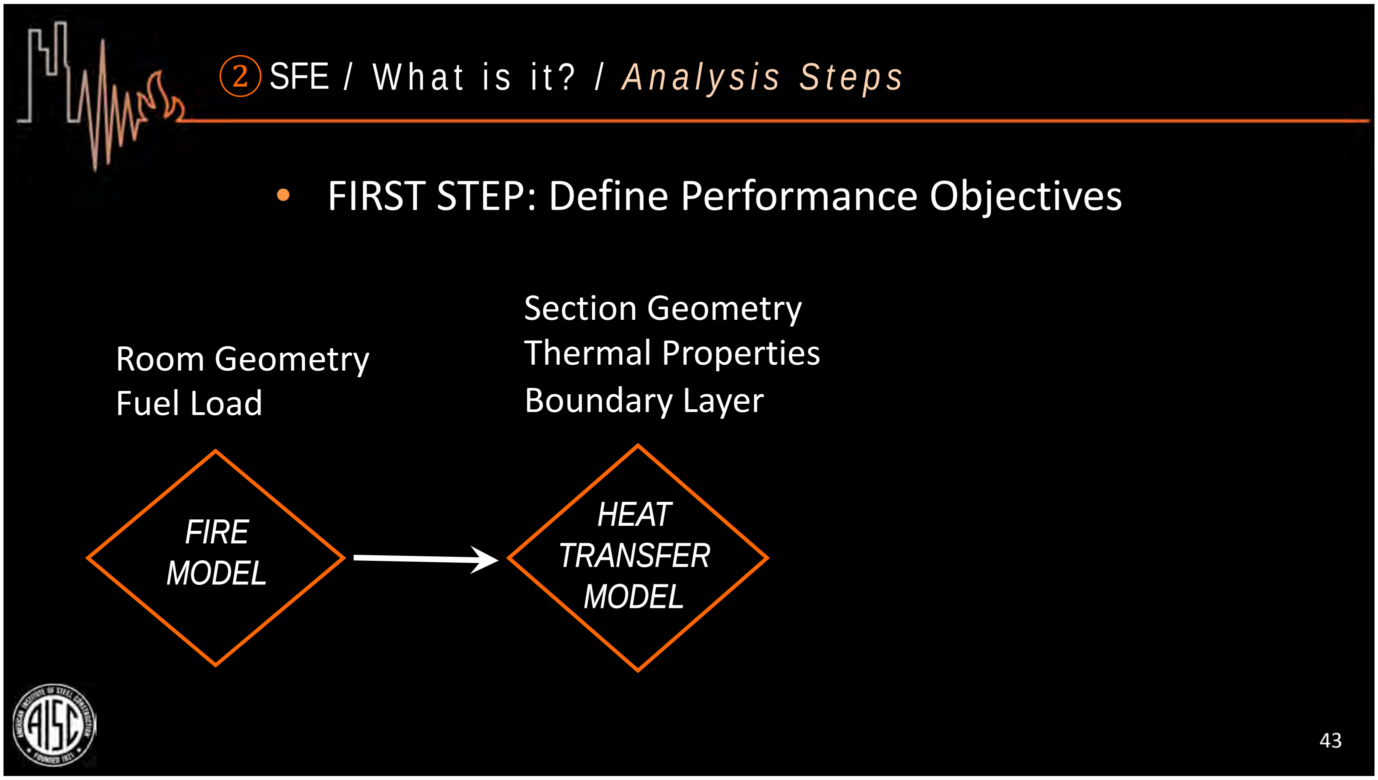
2 SFE / What is it? / *Analysis Steps*

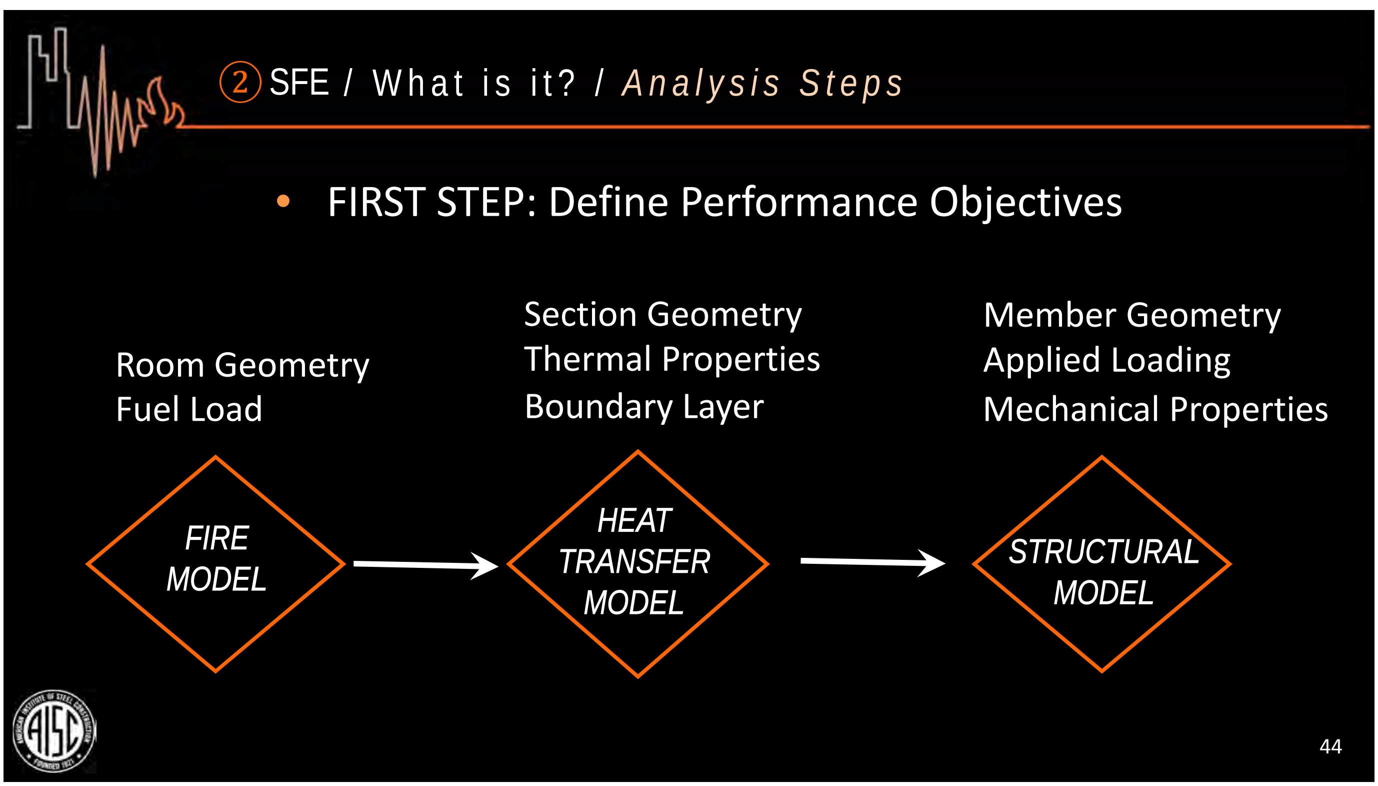
- FIRST STEP: Define Performance Objectives

Room Geometry
Fuel Load

FIRE MODEL

42


2 SFE / What is it? / Analysis Steps
• FIRST STEP: Define Performance Objectives
Room Geometry
Fuel Load
Section Geometry
Thermal Properties
Boundary Layer
FIRE MODEL
HEAT TRANSFER MODEL
43


2 SFE / What is it? / Analysis Steps
• FIRST STEP: Define Performance Objectives
Room Geometry
Fuel Load
Section Geometry
Thermal Properties
Boundary Layer
Member Geometry
Applied Loading
Mechanical Properties
FIRE MODEL
HEAT TRANSFER MODEL
STRUCTURAL MODEL
44

2 SFE / What is it? / *Codes and Standards*

Natl. bldg. codes include SFE:

- NFPA 5000 (2012)
- IBC (2012)

2012 IBC Section 101.3 **Intent:** "To establish minimum requirements to safeguard public health, safety, and general welfare through structural strength, means of egress facilities, stability, sanitation, adequate light and ventilation, energy conservation, and safety to life and property from fire and other hazards attributed to the built environment and to provide safety to fire fighters and emergency responders during emergency operations."

45

2 SFE / What is it? / *Codes and Standards*

Natl. bldg. codes include SFE:

- NFPA 5000 (2012)
- IBC (2012)

Advances in Building Standards in USA since 9/11

- AISC 360 (two types of analyses)

User Note: Design by qualification testing is the prescriptive method specified in most building codes. Traditionally, on most projects where the architect is the prime professional, the architect has been the responsible party to specify and coordinate fire protection requirements. Design by analysis is a new engineering approach to fire protection. Designation of the person(s) responsible for designing for fire conditions is a contractual matter to be addressed on each project.

46

② SFE / What is it? / *Codes and Standards*

Natl. bldg. codes with SFE:

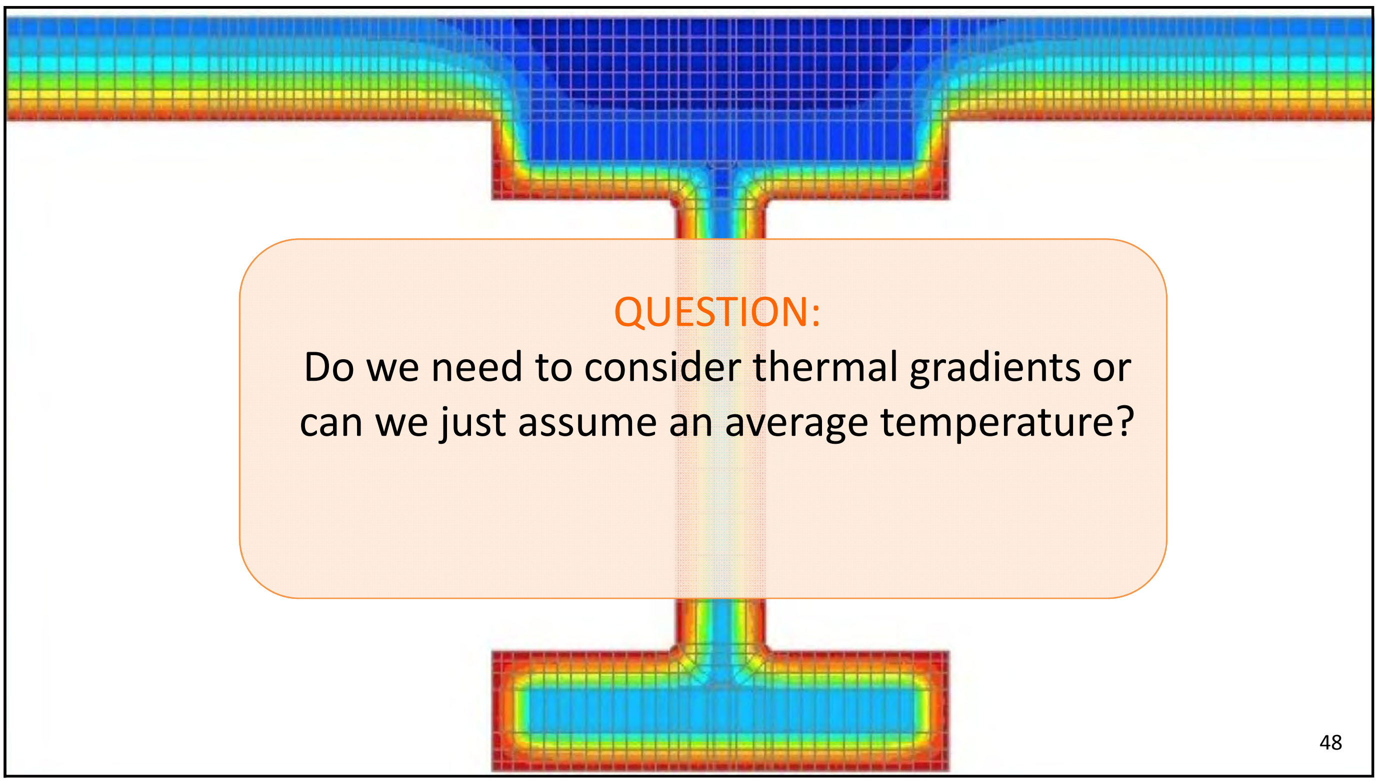
- NFPA 5000 (2012)
- IBC (2012)

Advances in Building Standards in USA since 9/11

- AISC 360
- ASCE DOCUMENTS

WHAT	*ASCE 7-16: Performance-based Design Procedures for Fire Effects on Structures*
HOW	*ASCE/SEI Guideline: Structural Fire Engineering (in progress)*

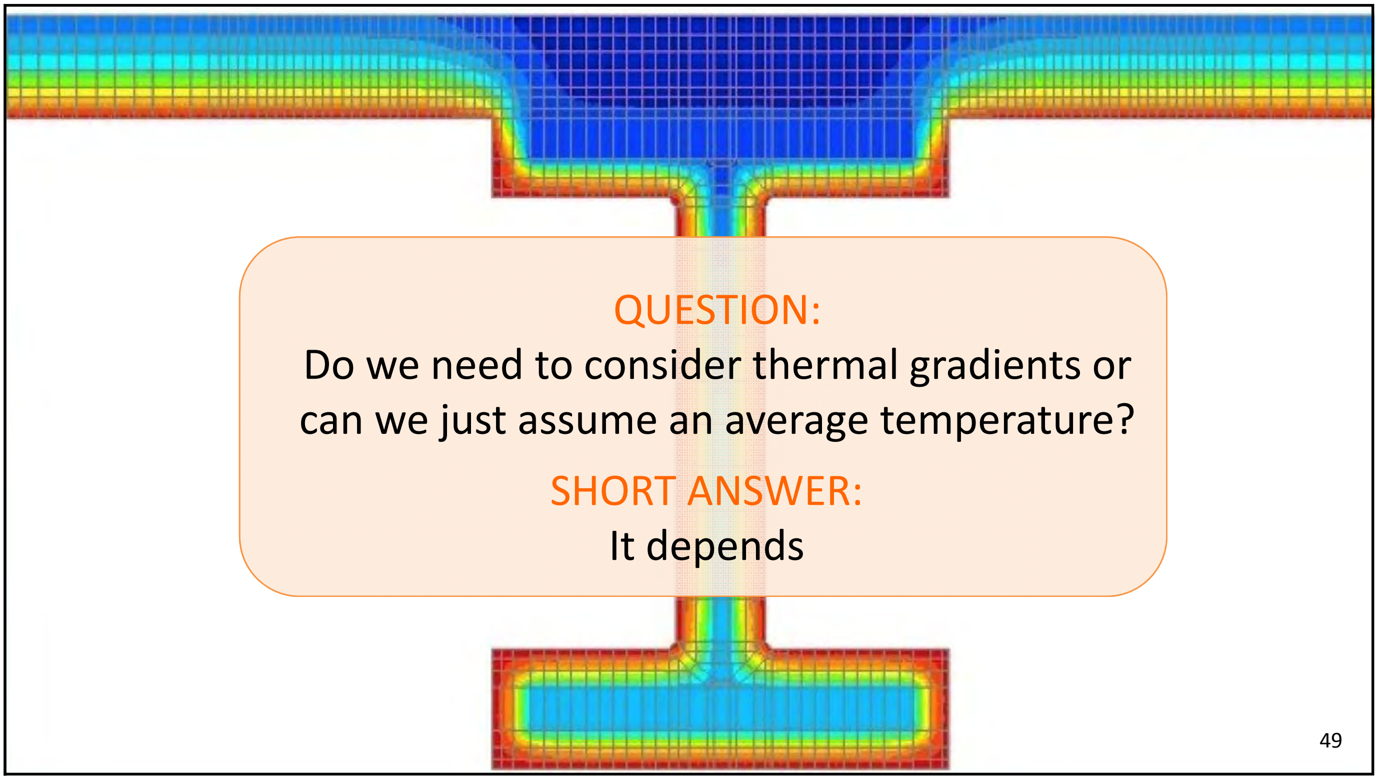
47



QUESTION:

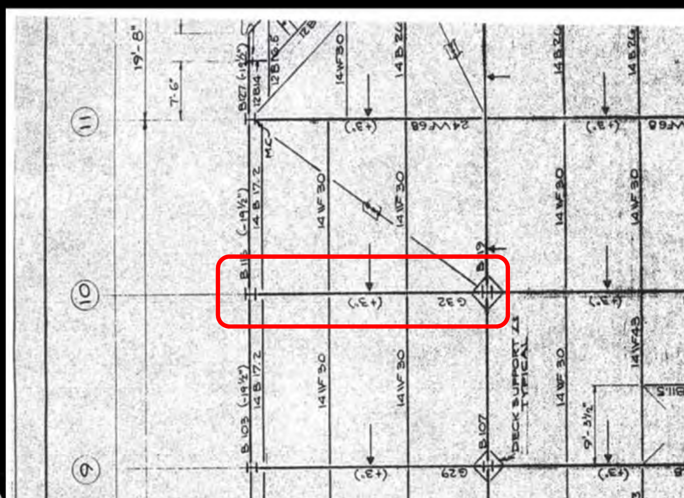
Do we need to consider thermal gradients or can we just assume an average temperature?

48


QUESTION:
Do we need to consider thermal gradients or can we just assume an average temperature?
SHORT ANSWER:
It depends
49

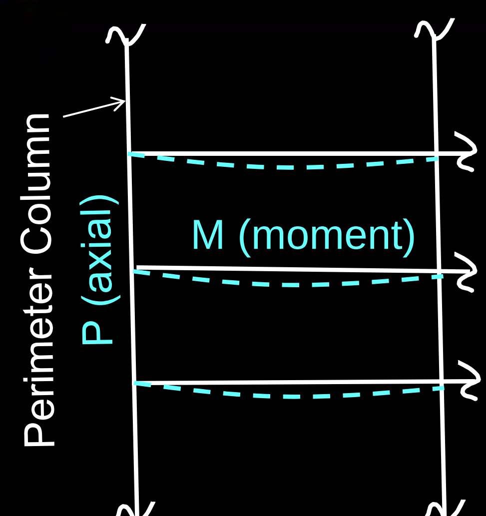

2 STRUCTURAL FIRE ENGINEERING (SFE)
– Beam-Columns
50

2 SFE / Beam-Columns/



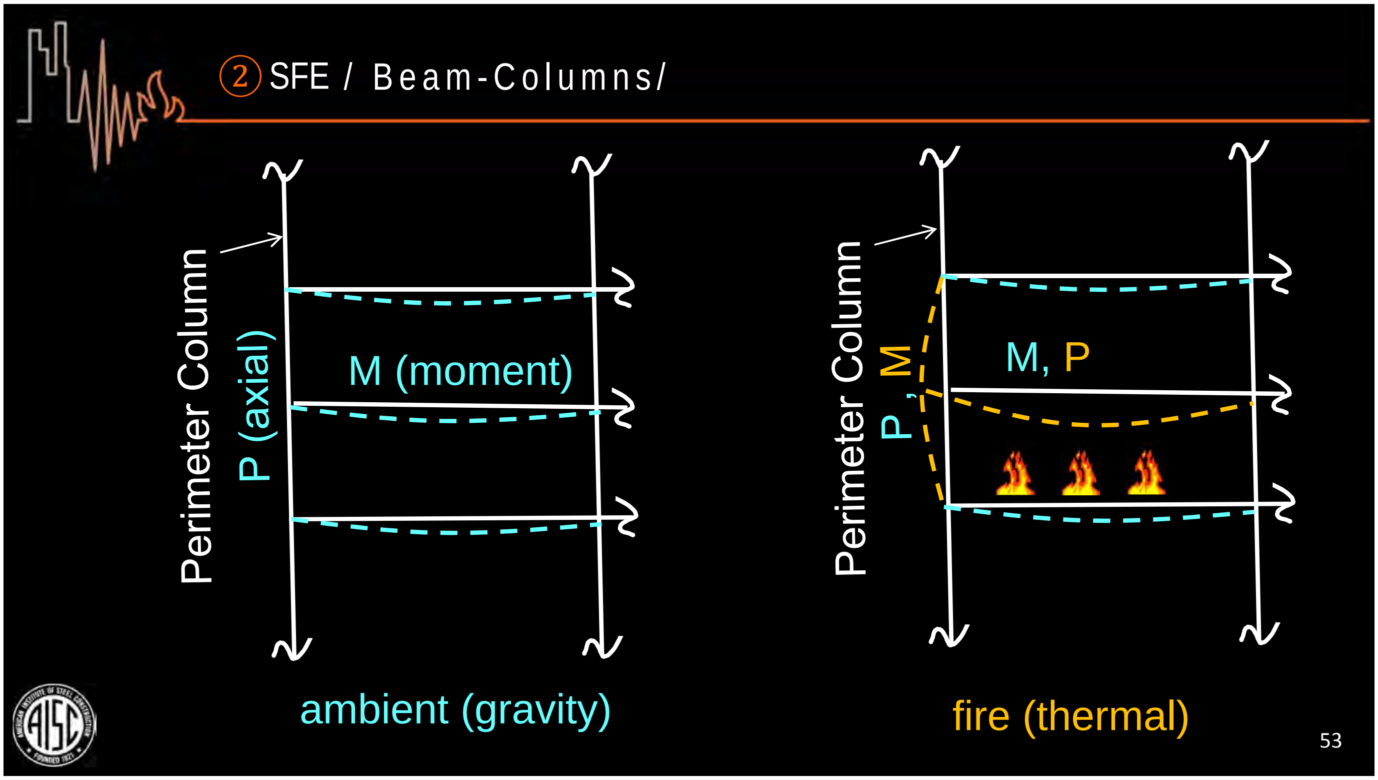
51

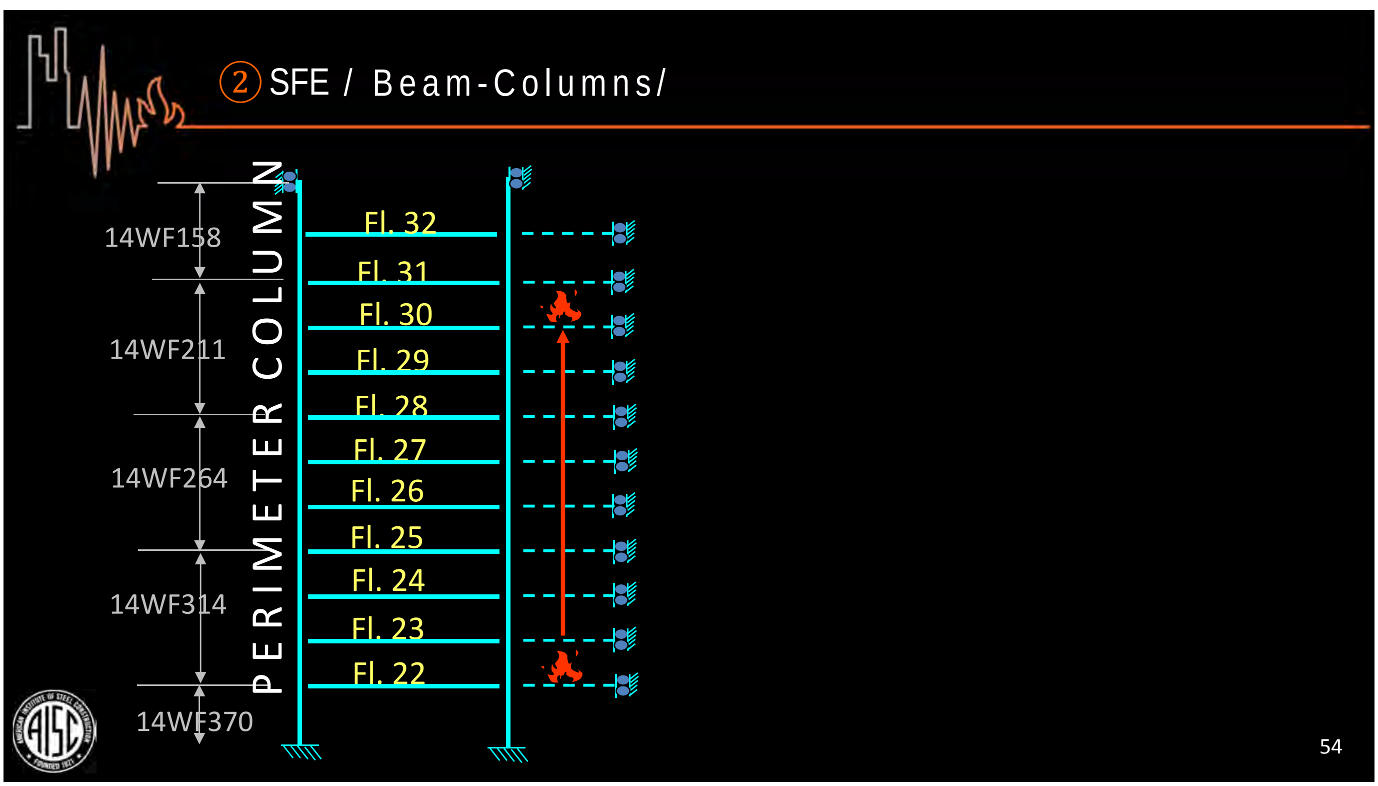
2 SFE / Beam-Columns/

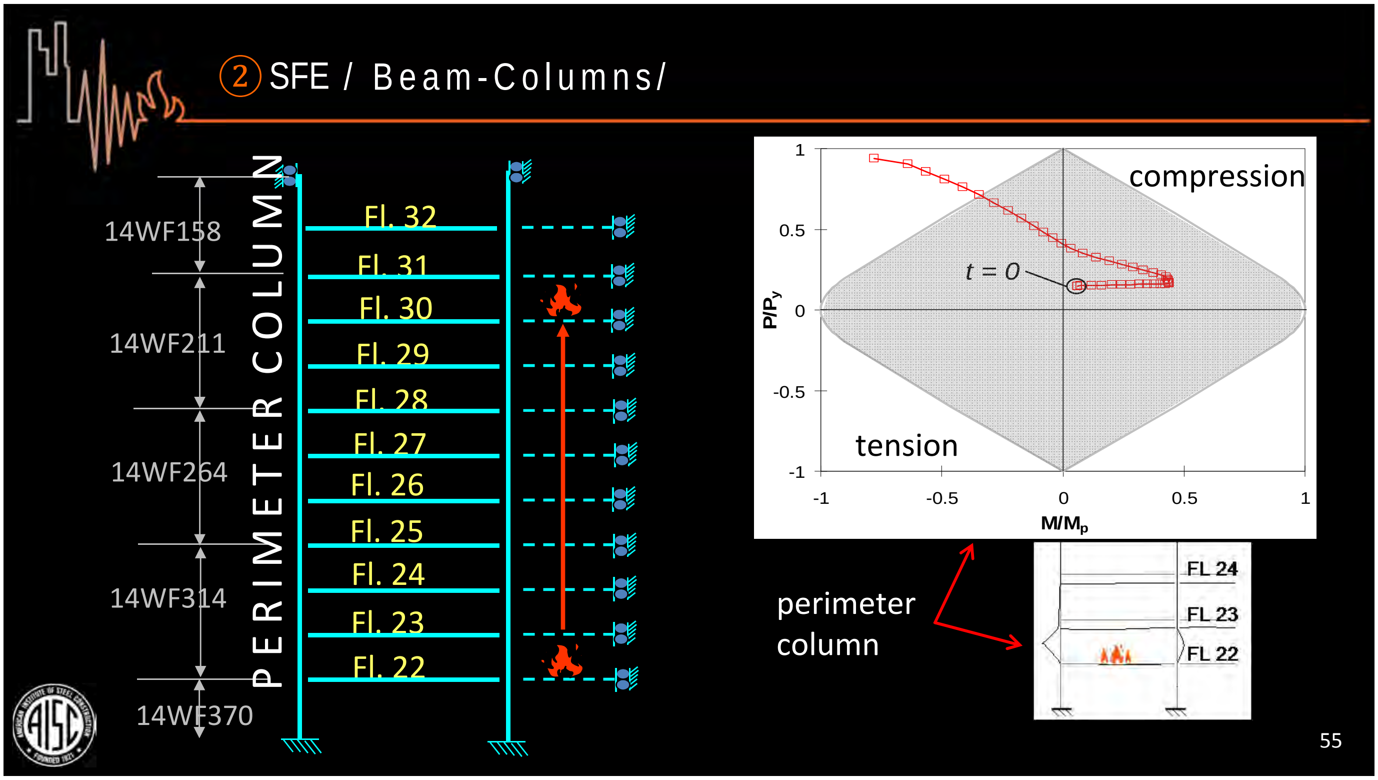


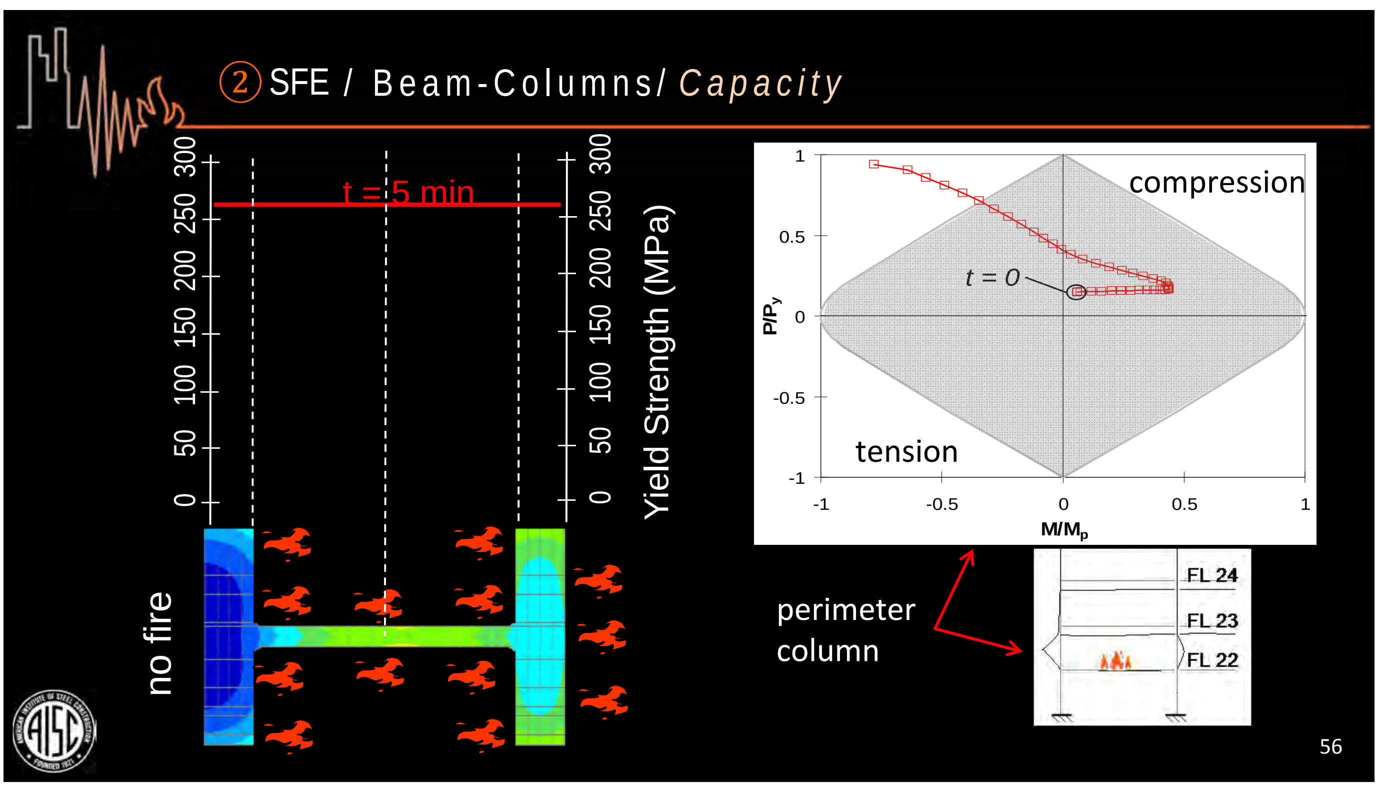
ambient (gravity)

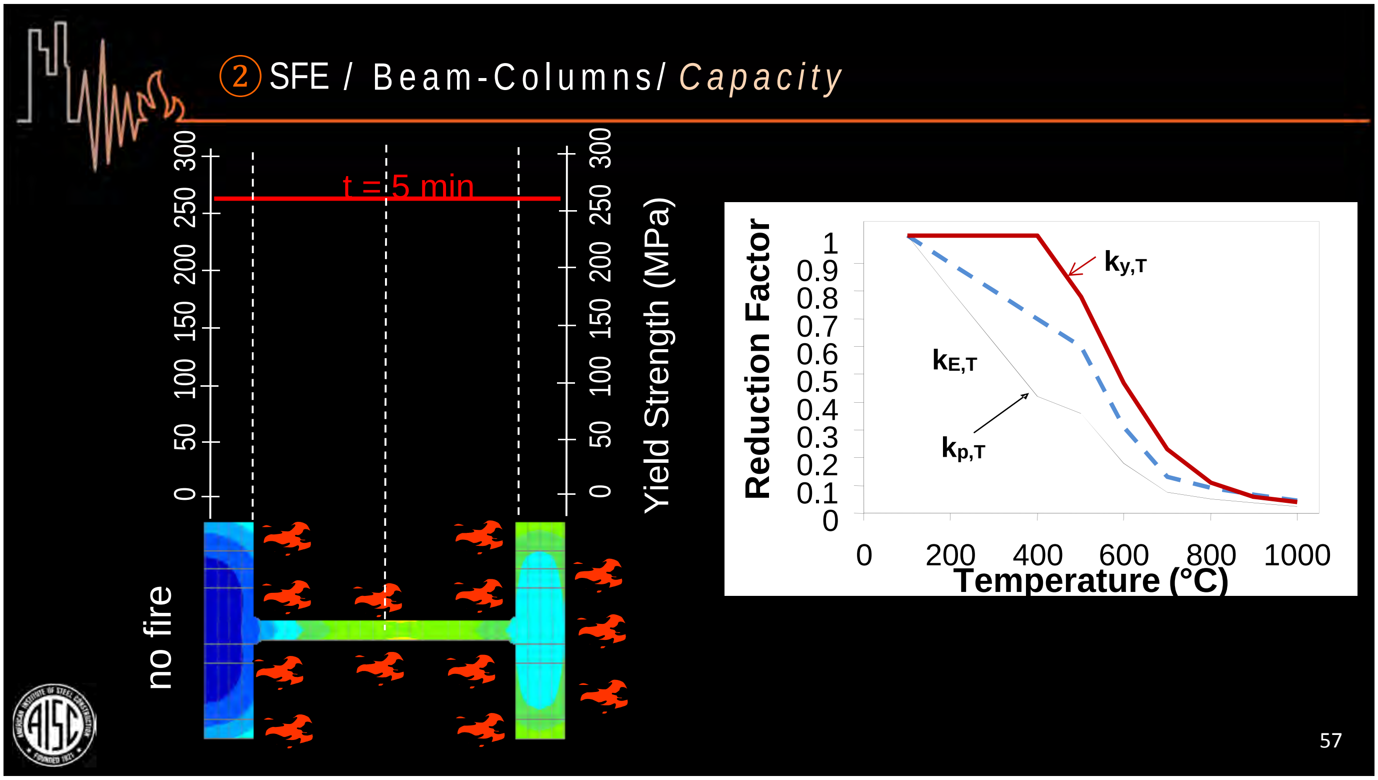
52

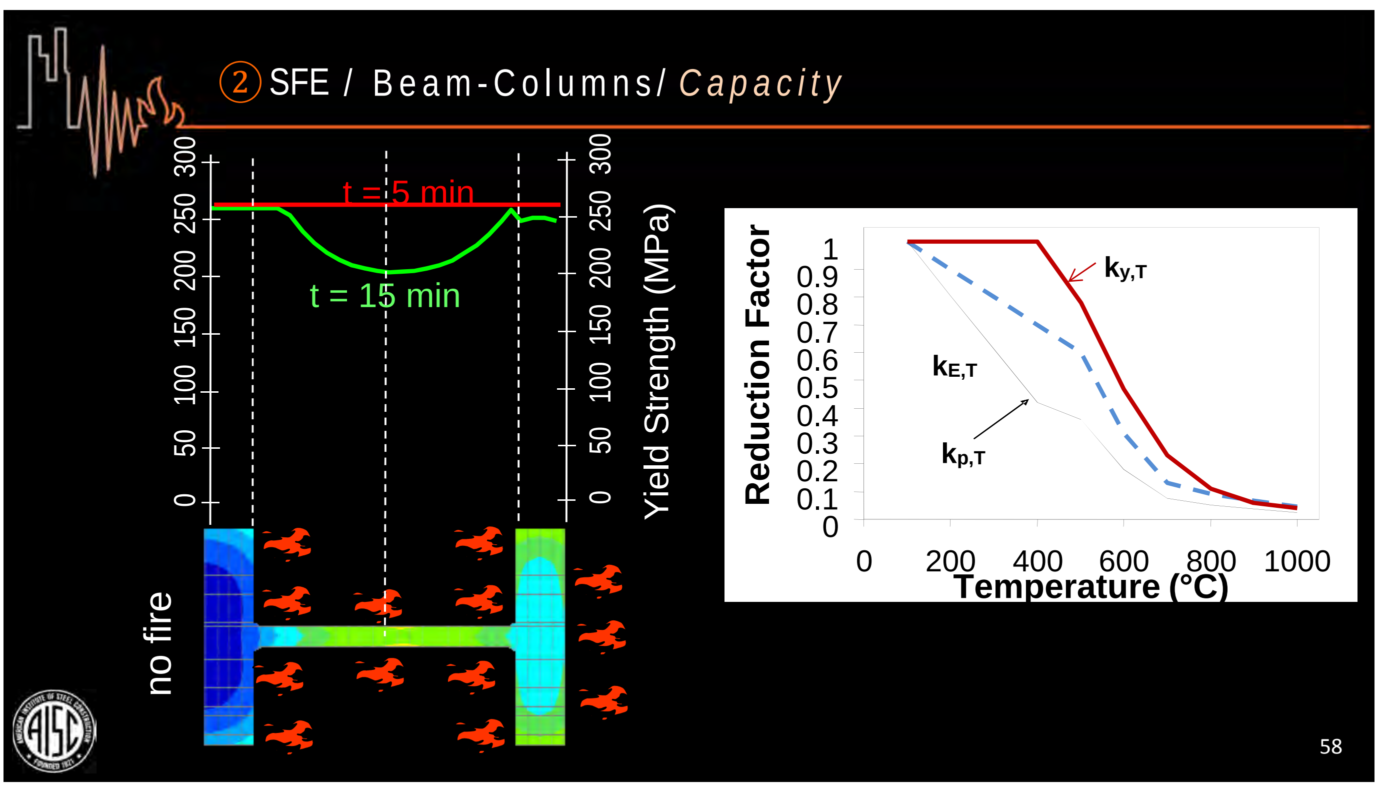

2 SFE / Beam-Columns/
Perimeter Column
P (axial)
M (moment)
ambient (gravity)
Perimeter Column
P, M
M, P
fire (thermal)
53

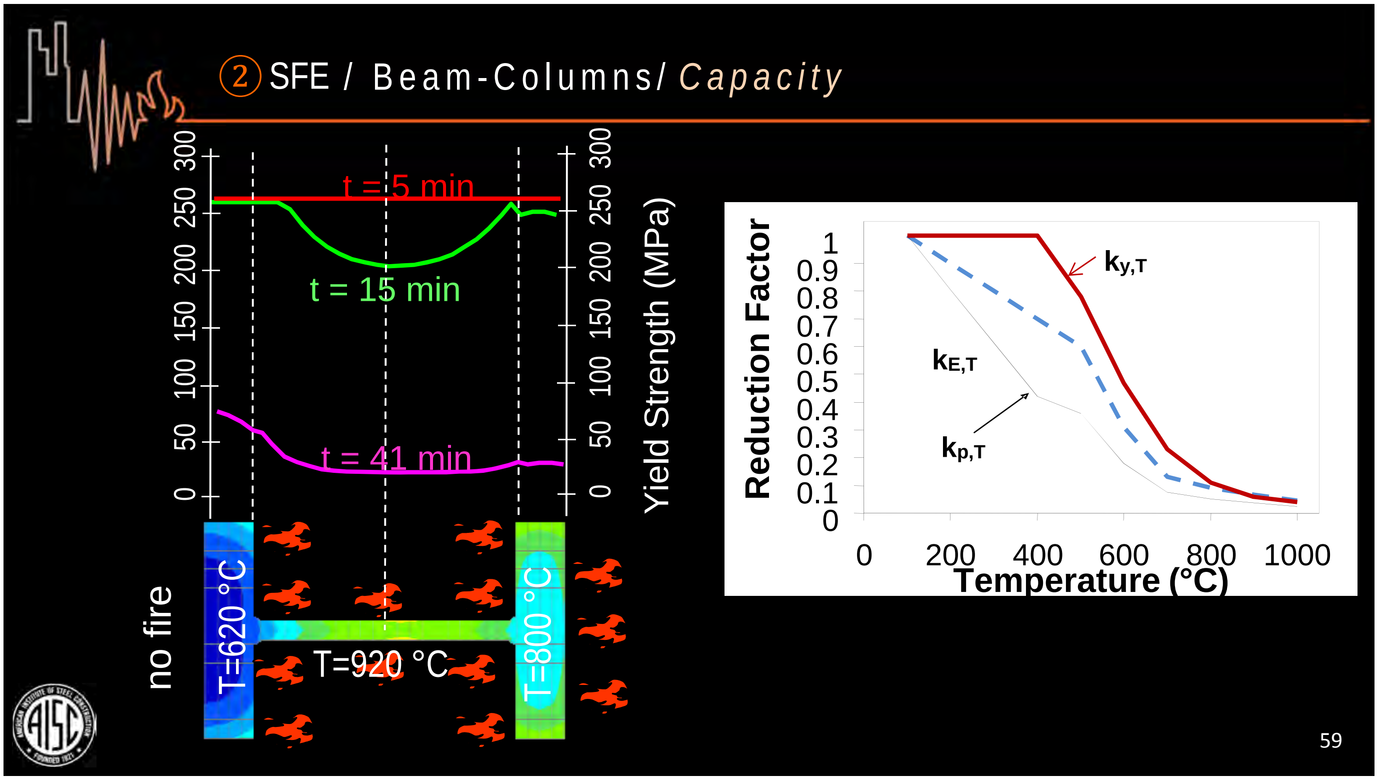

2 SFE / Beam-Columns/
PERIMETER COLUMN
14WF158
14WF211
14WF264
14WF314
14WF370
Fl. 32
Fl. 31
Fl. 30
Fl. 29
Fl. 28
Fl. 27
Fl. 26
Fl. 25
Fl. 24
Fl. 23
Fl. 22
54

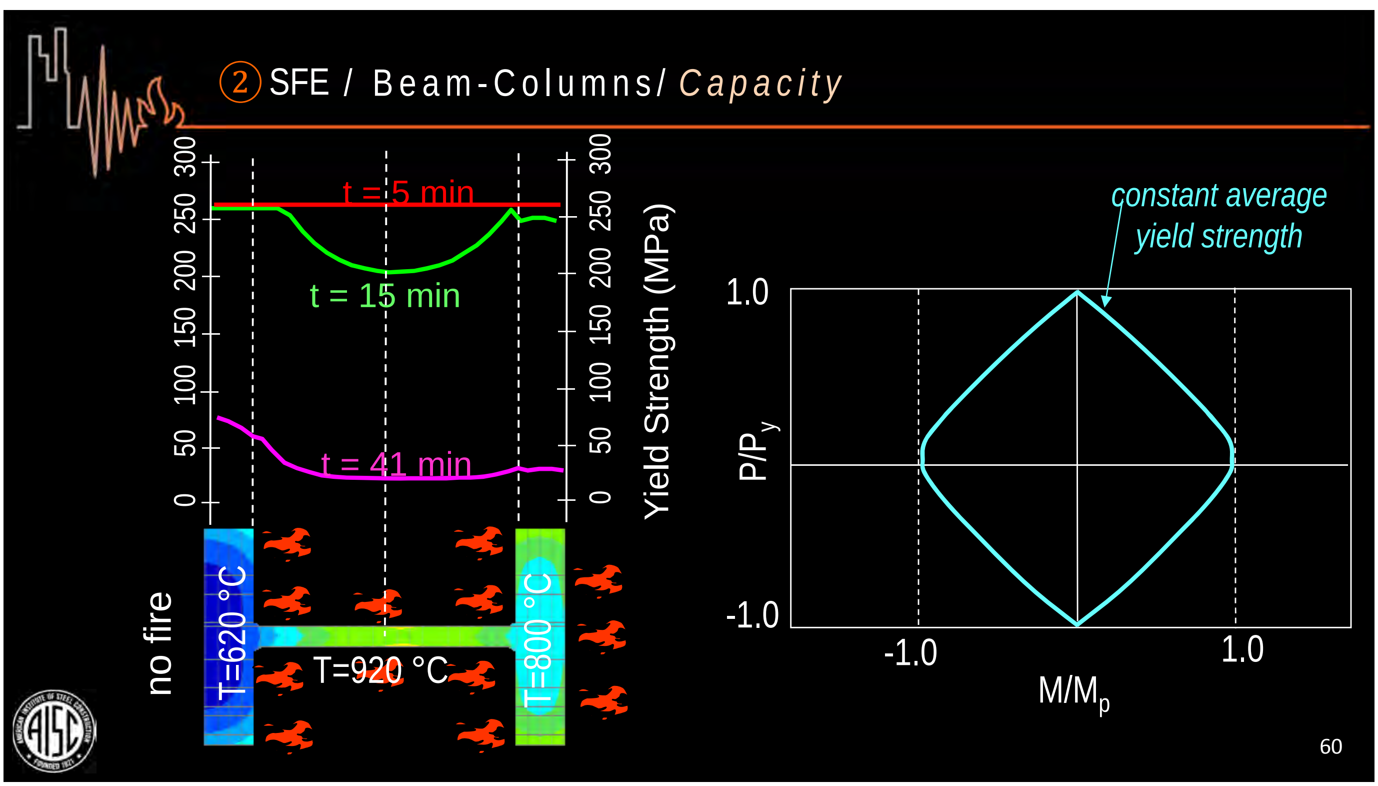

2 SFE / Beam-Columns/
PERIMETER COLUMN
14WF158
14WF211
14WF264
14WF314
14WF370
Fl. 32
Fl. 31
Fl. 30
Fl. 29
Fl. 28
Fl. 27
Fl. 26
Fl. 25
Fl. 24
Fl. 23
Fl. 22
compression
tension
t = 0
P/Py
M/Mp
perimeter column
FL 24
FL 23
FL 22
55

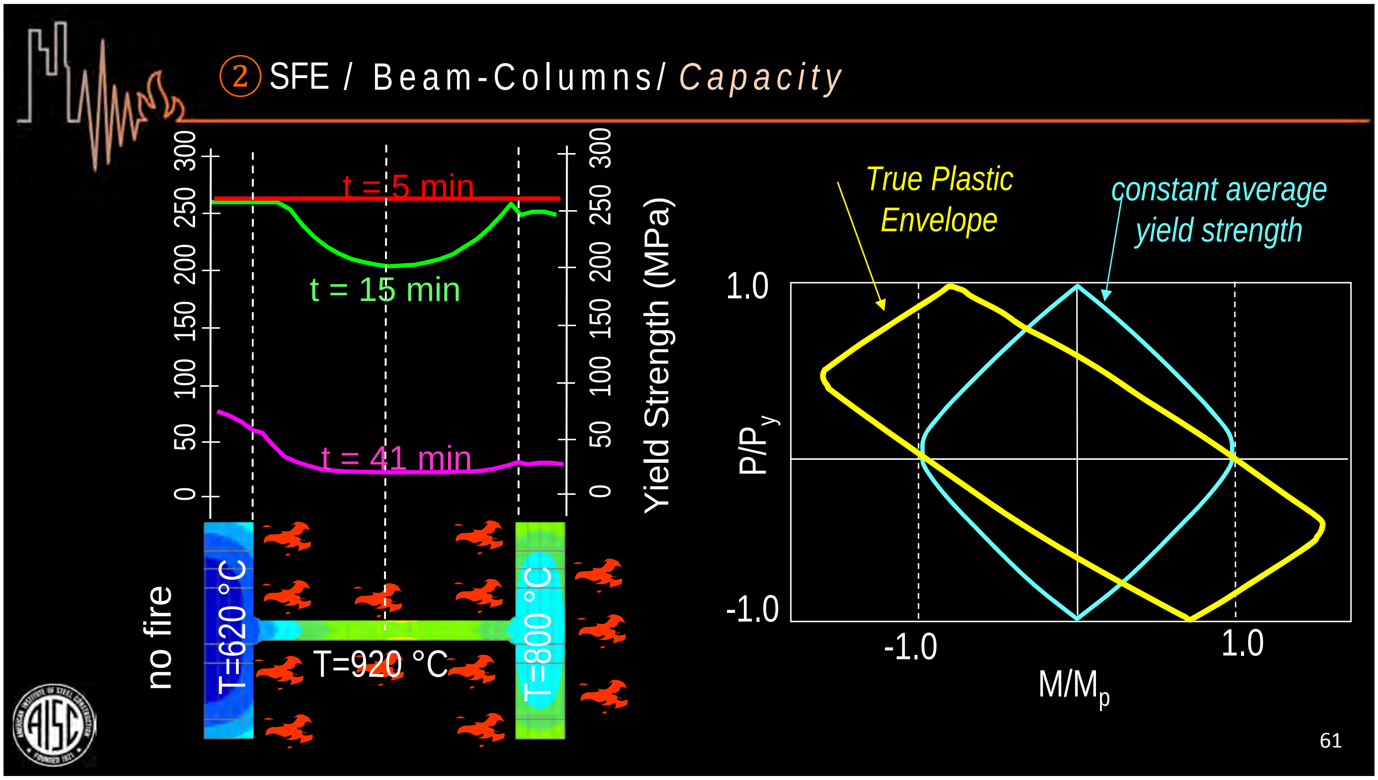

2 SFE / Beam-Columns/ Capacity
t = 5 min
Yield Strength (MPa)
0 50 100 150 200 250 300
no fire
compression
tension
t = 0
P/Py
M/Mp
perimeter column
FL 24
FL 23
FL 22
56

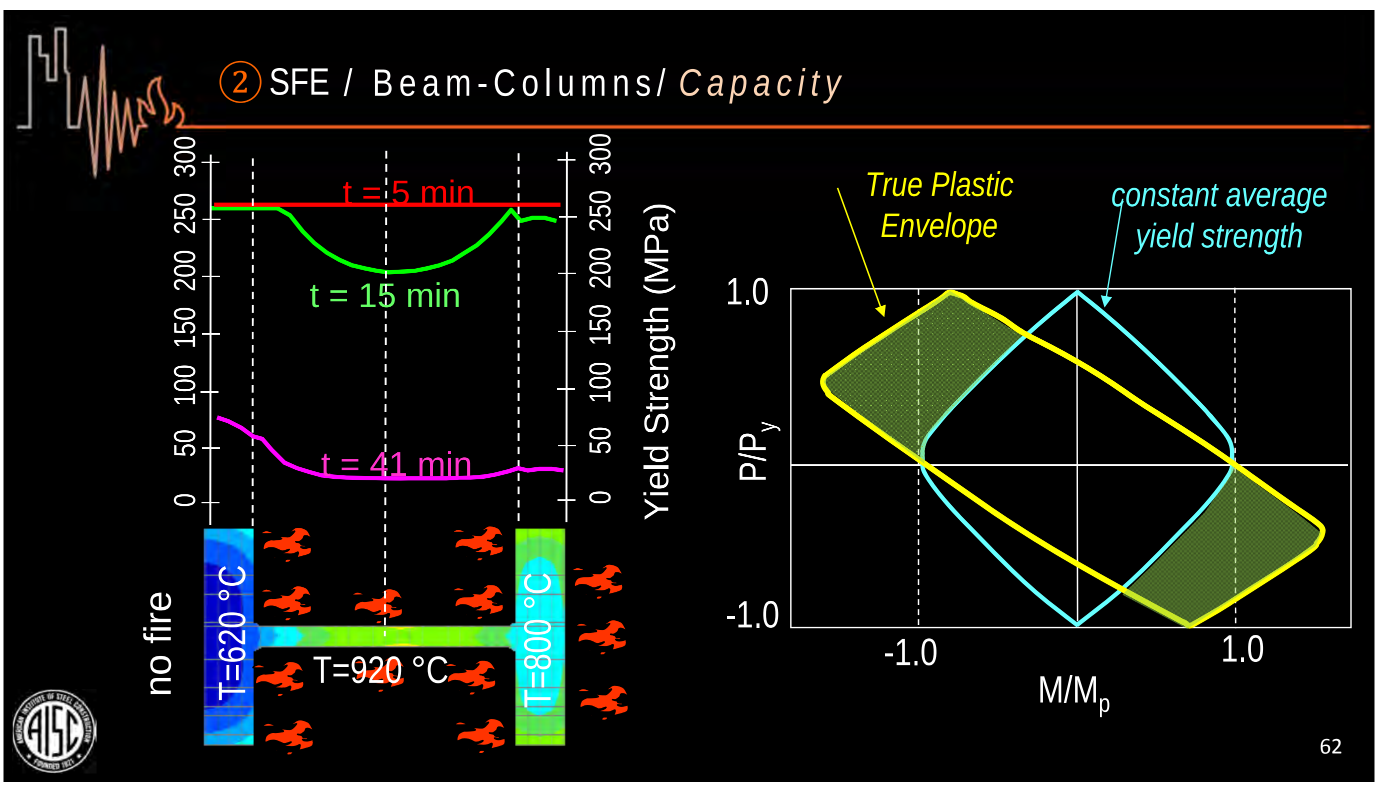

2 SFE / Beam-Columns/ Capacity
t = 5 min
Yield Strength (MPa)
no fire
Reduction Factor
Temperature (°C)
ky,T
kE,T
kp,T
57

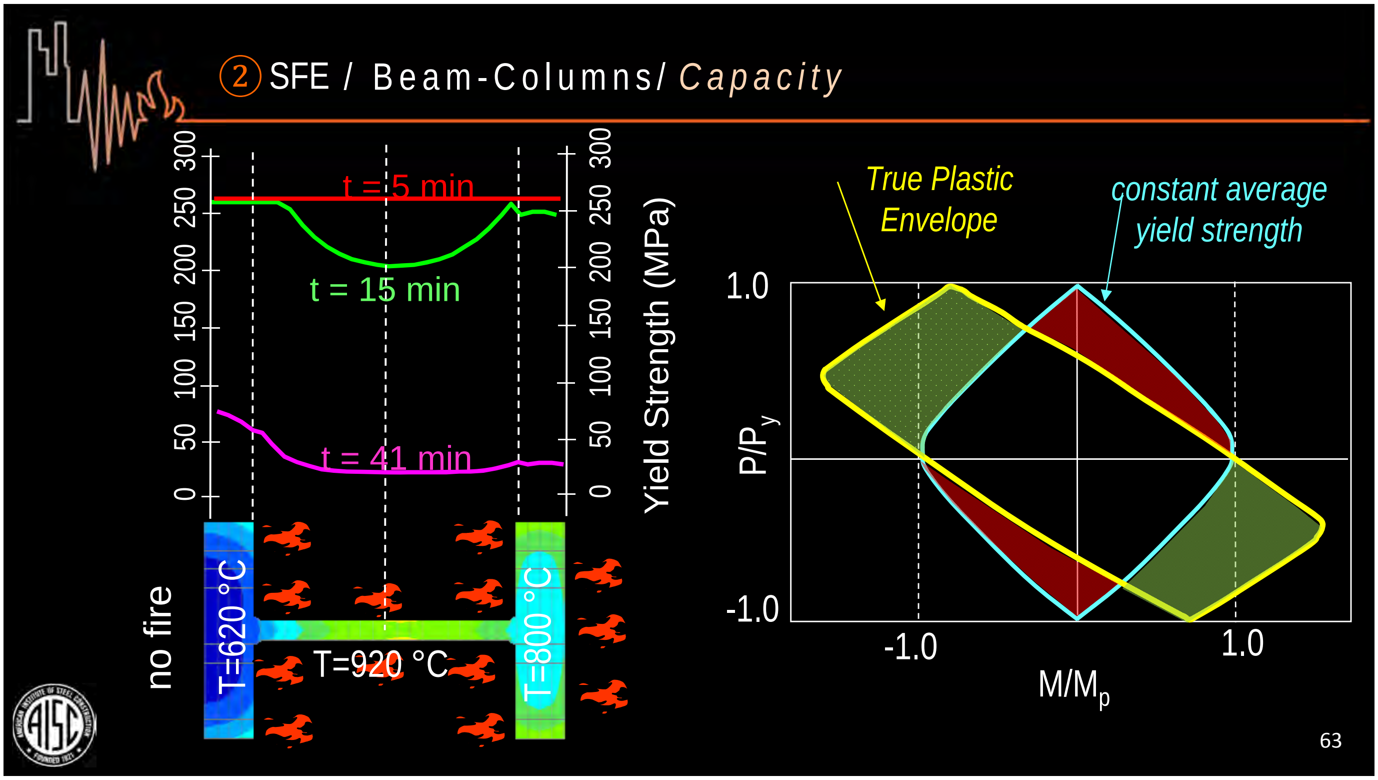

2 SFE / Beam-Columns/ Capacity
t = 5 min
t = 15 min
Yield Strength (MPa)
no fire
Reduction Factor
Temperature (°C)
ky,T
kE,T
kp,T
58

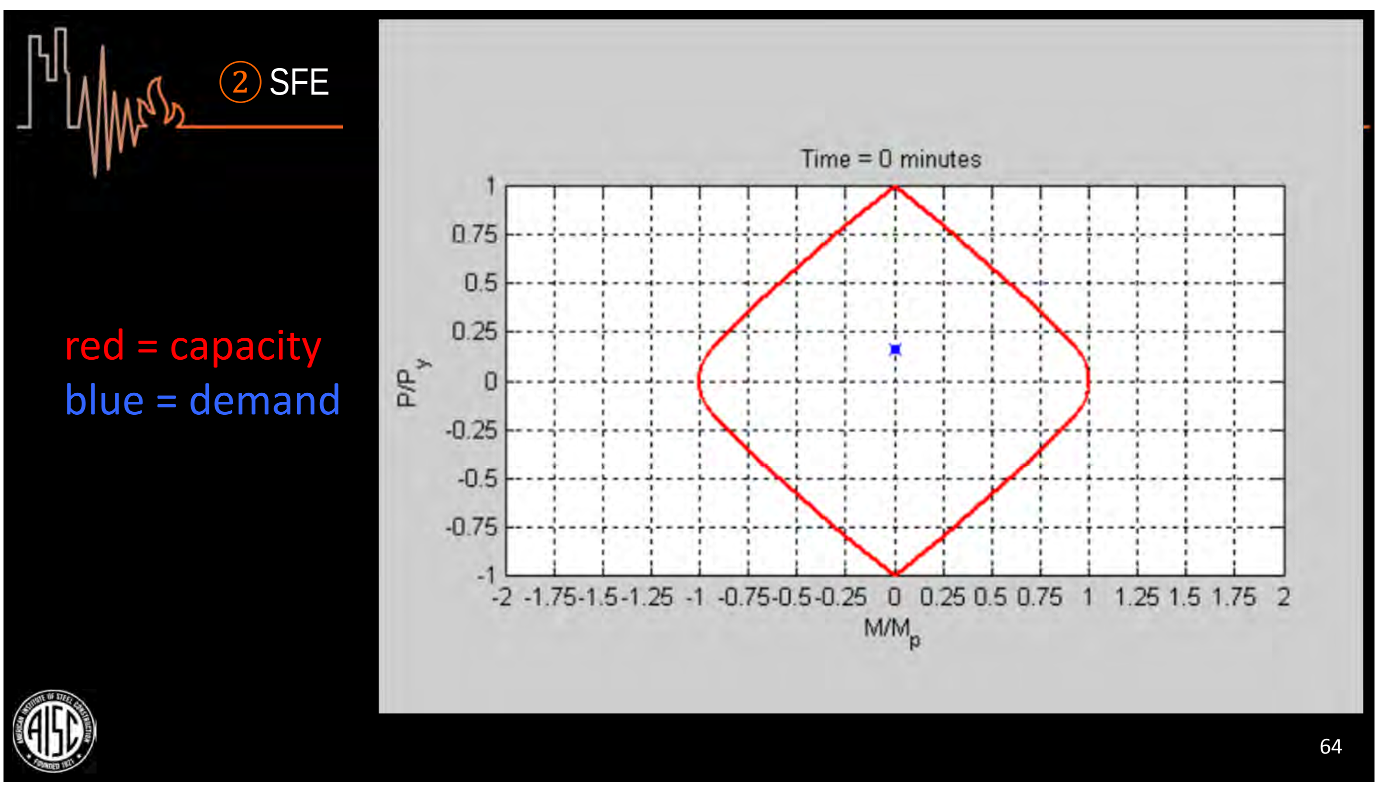

② SFE / Beam-Columns/ Capacity
t = 5 min
t = 15 min
t = 41 min
Yield Strength (MPa)
no fire
T=620 °C
T=920 °C
T=800 °C
Reduction Factor
Temperature (°C)
$k_{y,T}$
$k_{E,T}$
$k_{p,T}$
59


② SFE / Beam-Columns/ Capacity
t = 5 min
t = 15 min
t = 41 min
Yield Strength (MPa)
no fire
T=620 °C
T=920 °C
T=800 °C
constant average yield strength
P/P_y
M/M_p
60


2 SFE / Beam-Columns/ Capacity
t = 5 min
t = 15 min
t = 41 min
Yield Strength (MPa)
no fire
T=620 °C
T=920 °C
T=800 °C
True Plastic Envelope
constant average yield strength
1.0
-1.0
P/P$_y$
M/M$_p$
61


2 SFE / Beam-Columns/ Capacity
t = 5 min
t = 15 min
t = 41 min
Yield Strength (MPa)
no fire
T=620 °C
T=920 °C
T=800 °C
True Plastic Envelope
constant average yield strength
1.0
-1.0
P/P$_y$
M/M$_p$
62

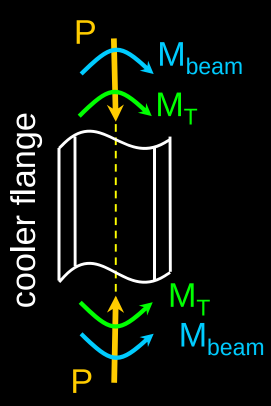

2 SFE / Beam-Columns/ Capacity
t = 5 min
t = 15 min
t = 41 min
0 50 100 150 200 250 300
Yield Strength (MPa)
no fire
T=620 °C
T=920 °C
T=800 °C
True Plastic Envelope
constant average yield strength
1.0
-1.0
P/P$_y$
M/M$_p$
63

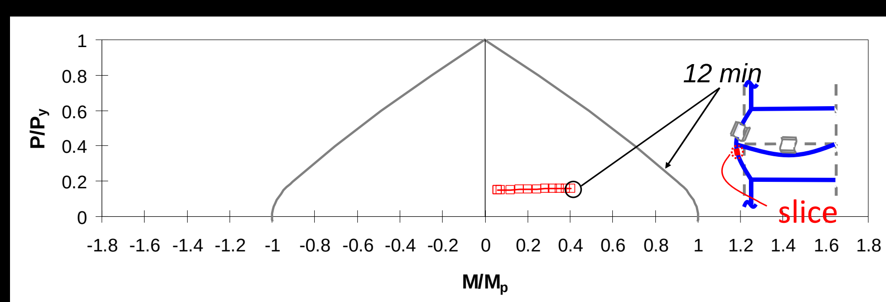

2 SFE
red = capacity
blue = demand
Time = 0 minutes
P/P$_y$
M/M$_p$
1 0.75 0.5 0.25 0 -0.25 -0.5 -0.75 -1
-2 -1.75 -1.5 -1.25 -1 -0.75 -0.5 -0.25 0 0.25 0.5 0.75 1 1.25 1.5 1.75 2
64

VIDEO

65

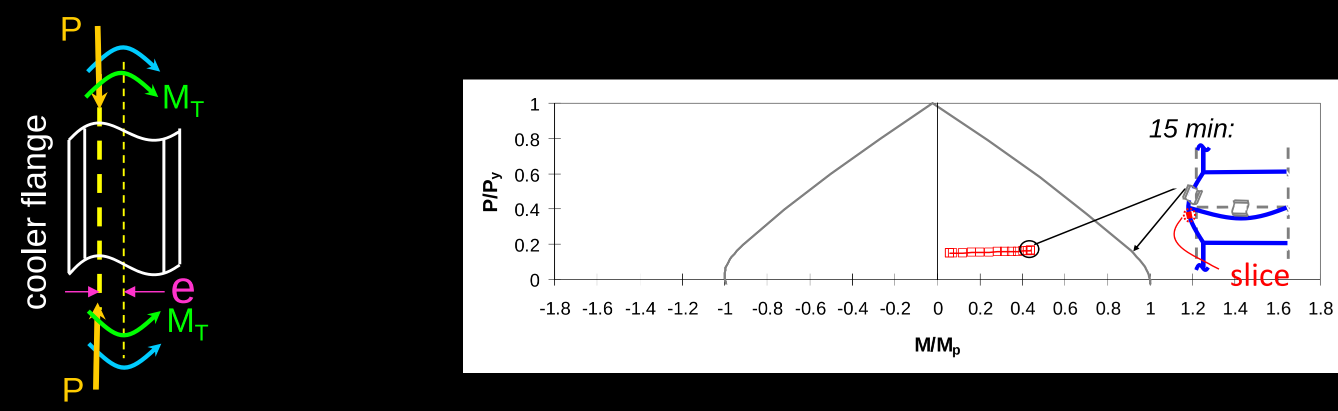
2 SFE / Beam-Columns/ *Demand*





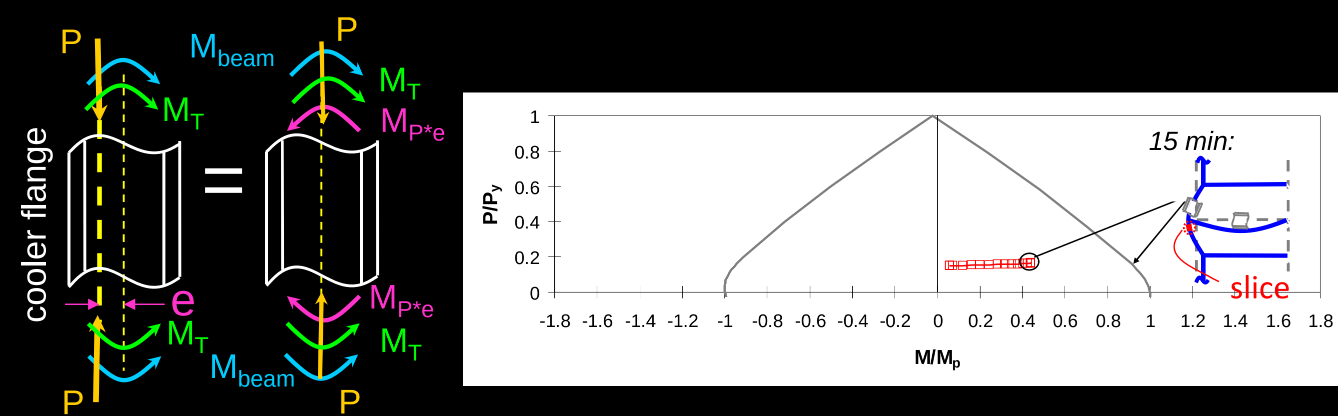
66

② SFE / Beam-Columns/ *Demand*

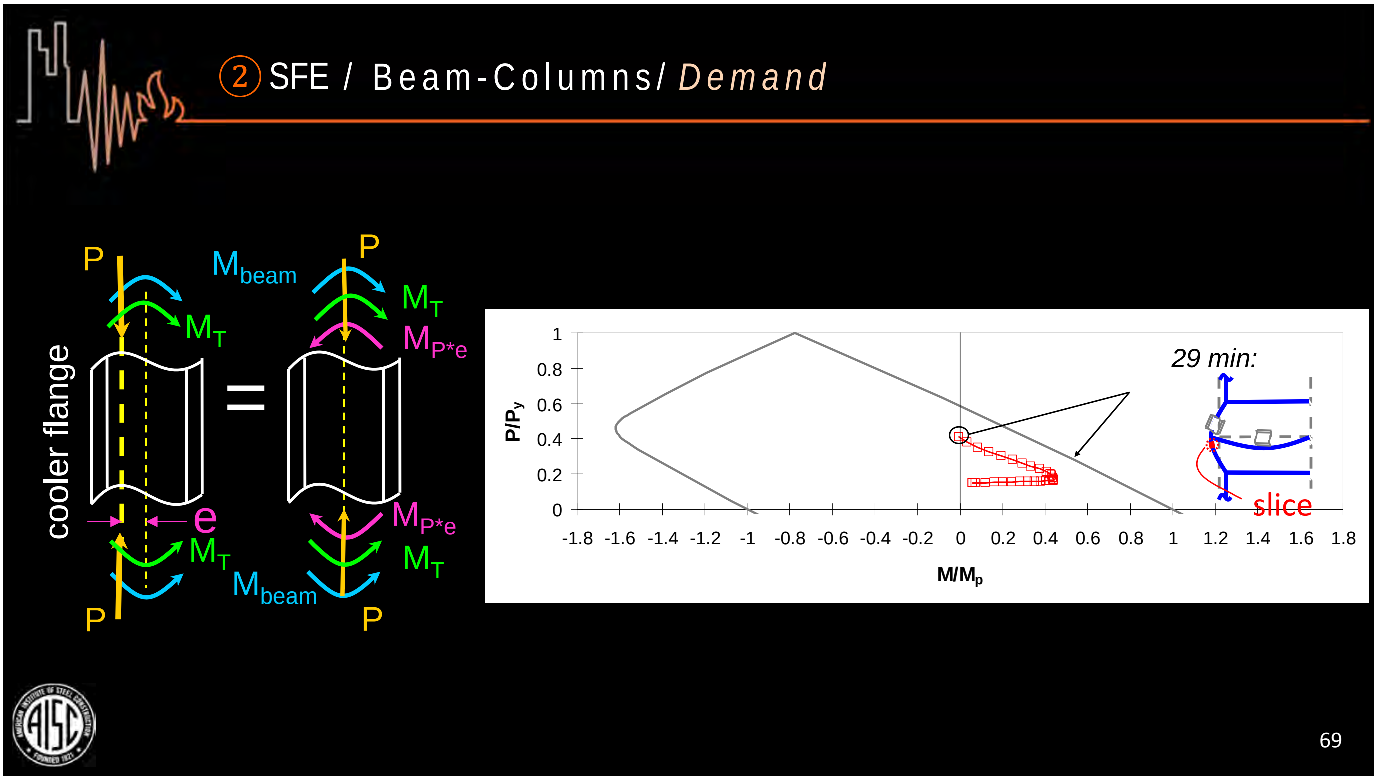


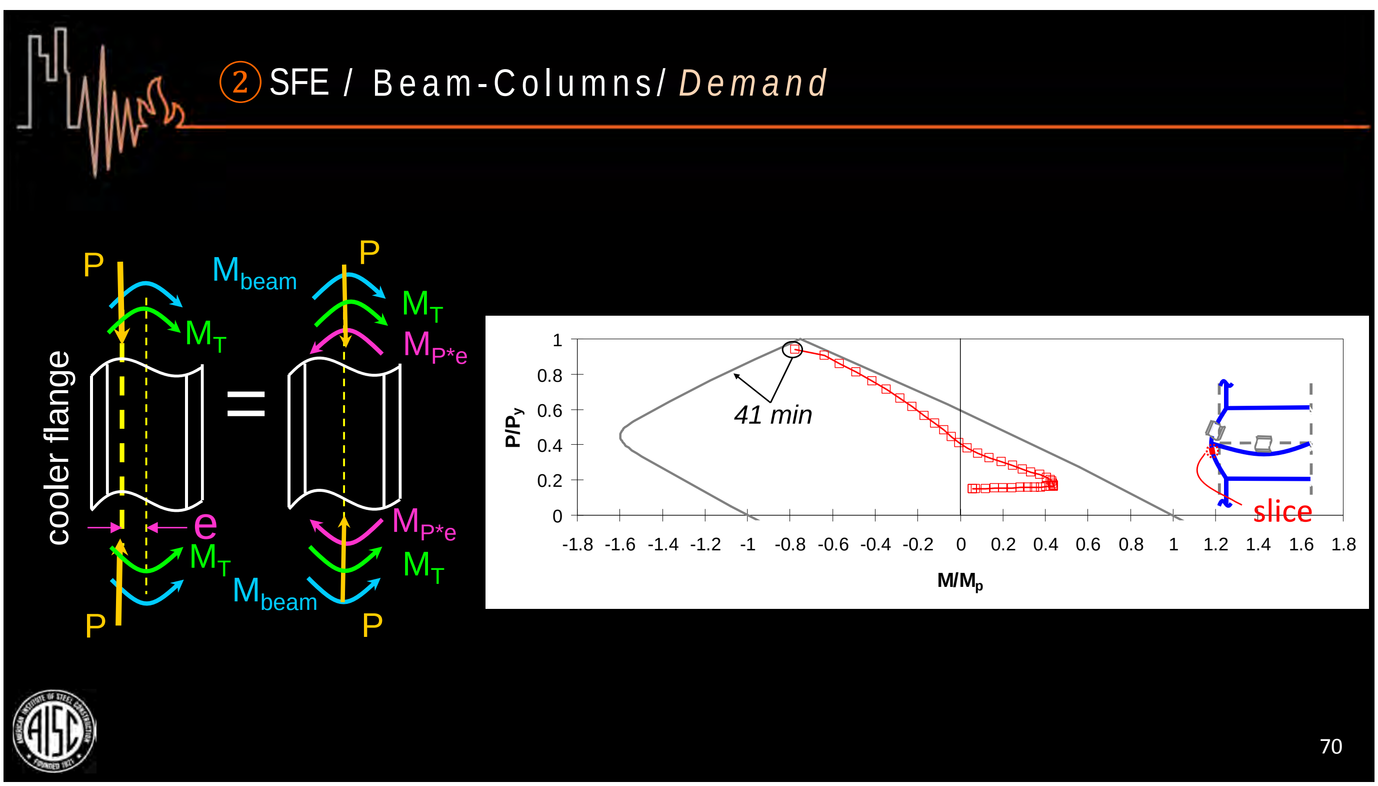
67

② SFE / Beam-Columns/ *Demand*



68

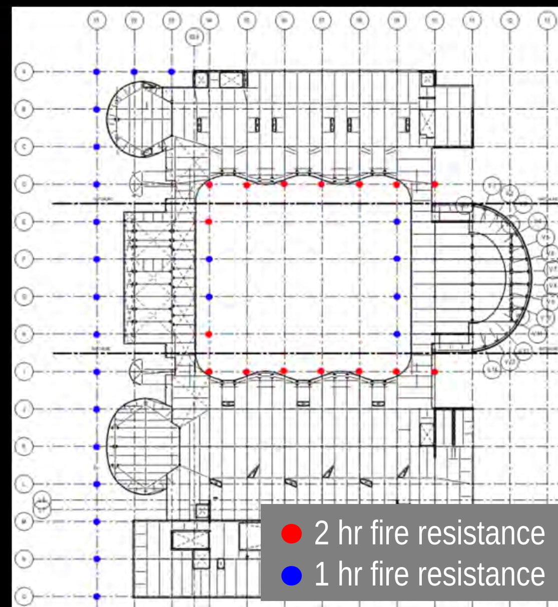

2 SFE / Beam-Columns/ Demand
cooler flange
P
Mbeam
MT
MP*e
e
=
1
0.8
0.6
0.4
0.2
0
P/Py
-1.8 -1.6 -1.4 -1.2 -1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8
M/Mp
29 min:
slice
69


2 SFE / Beam-Columns/ Demand
cooler flange
P
Mbeam
MT
MP*e
e
=
1
0.8
0.6
0.4
0.2
0
P/Py
41 min
-1.8 -1.6 -1.4 -1.2 -1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8
M/Mp
slice
70

② SFE / Beam-Columns/ *case study*

University Building (SFE: BuroHappold)

- Estimated cost of fire protection per column: $20,000 (2 hours)
- SFE: assuming average temperature was NOT conservative
- Did not need to fire protect columns

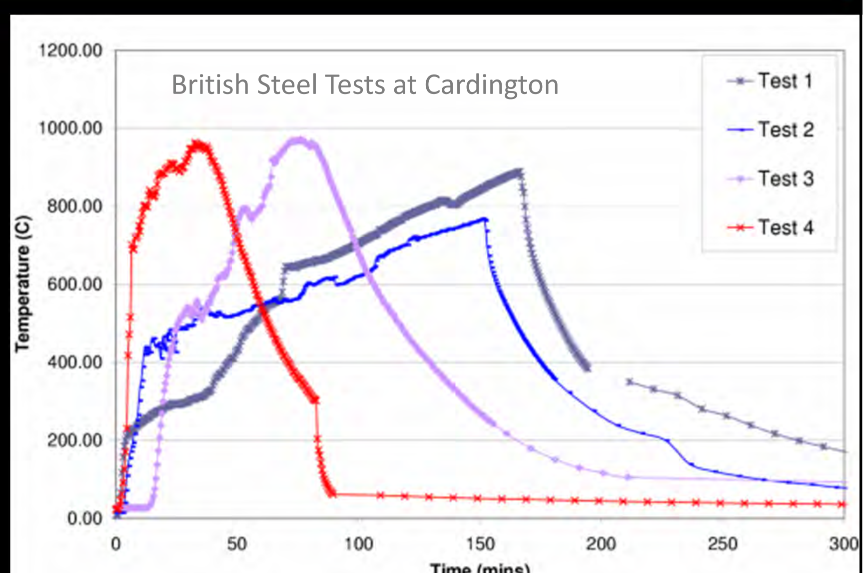


slide credit: F. Block, BuroHappold

71

② SFE

QUESTION:
Do structural failures *always* happen during the heating phase?

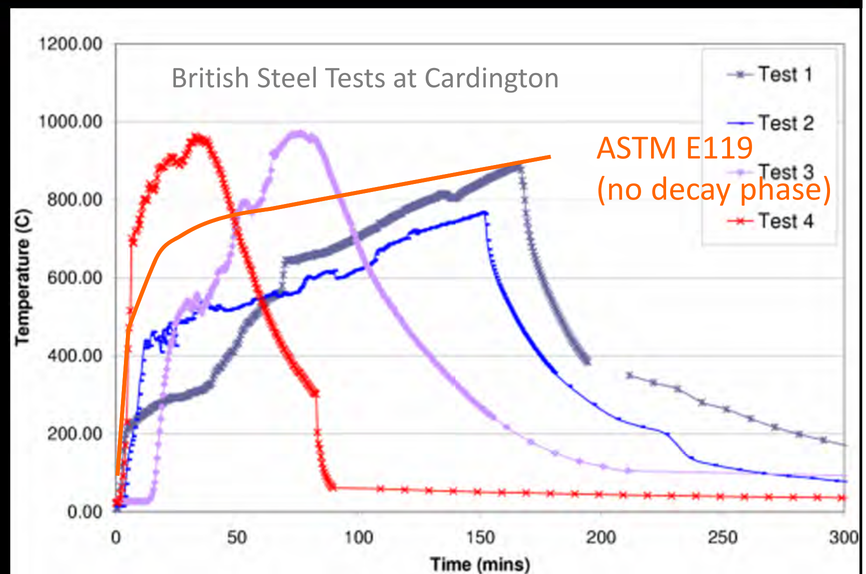


72

2 SFE

QUESTION:
Do structural failures *always* happen during the heating phase?

SHORT ANSWER:
no



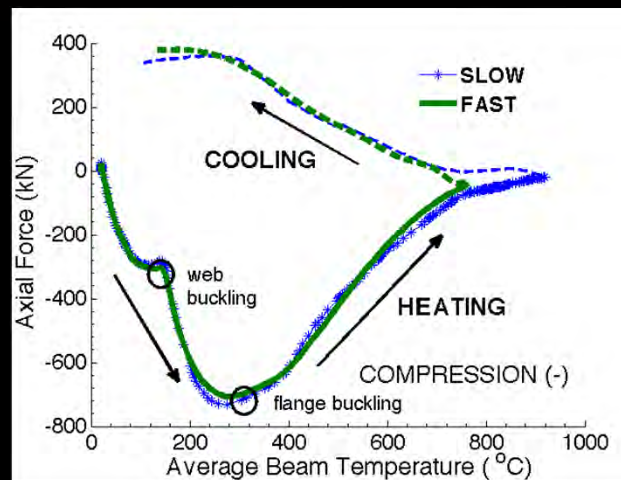
73

2 STRUCTURAL FIRE ENGINEERING (SFE)

– Connections

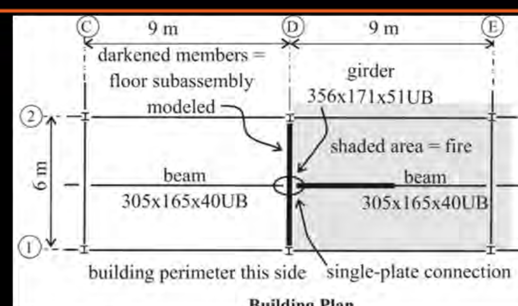
74

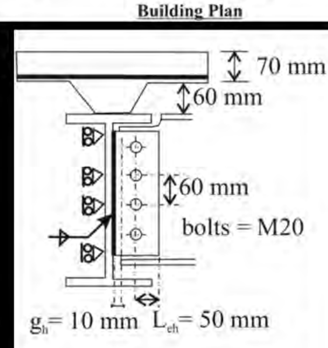
2 SFE / connections /



75

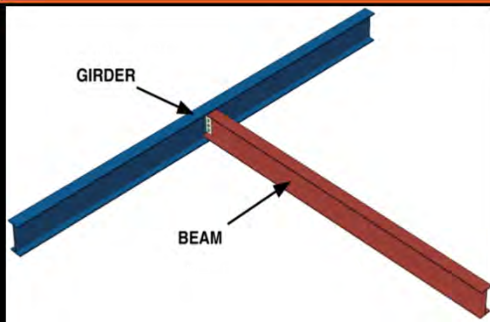
2 SFE / connections /

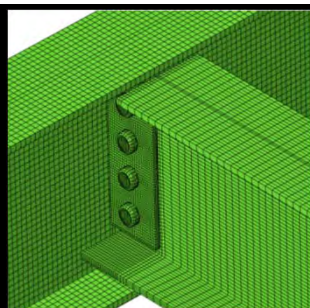


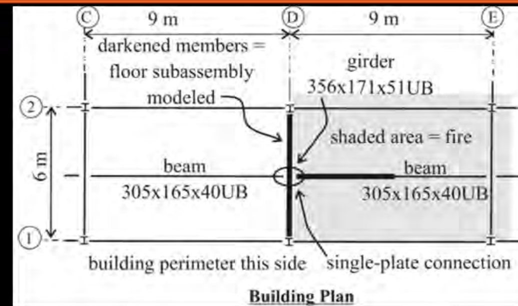


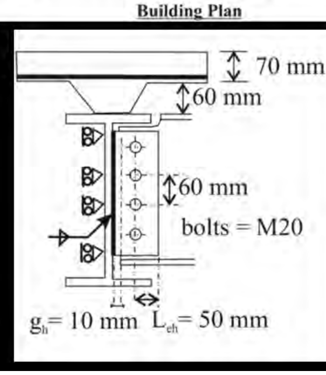
76

② SFE / connections /





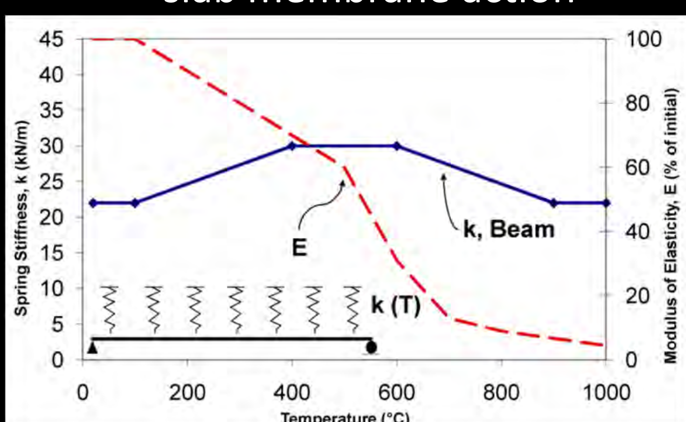


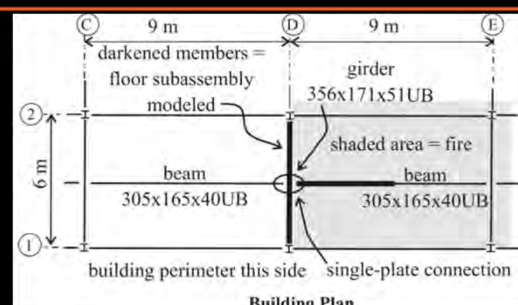


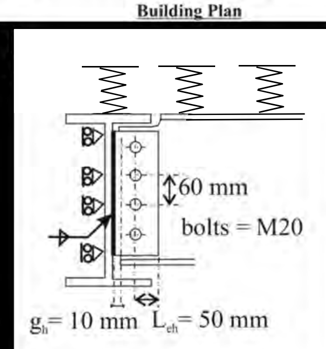
77

② SFE / connections /

- heat sink effects
- slab membrane action



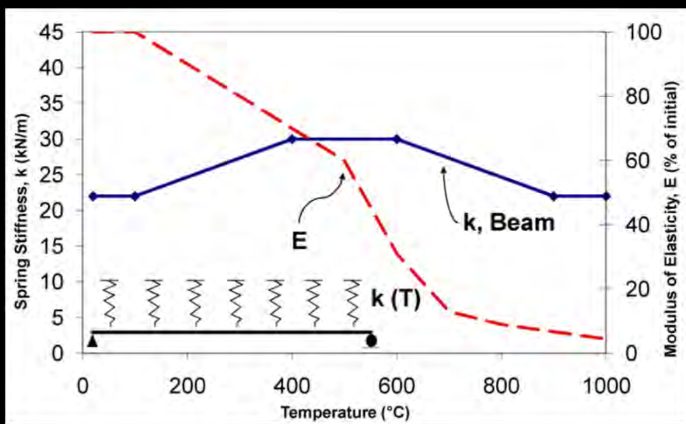


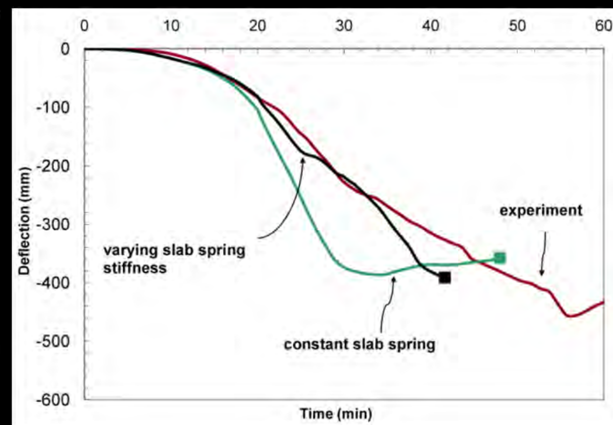


78

② SFE / connections /

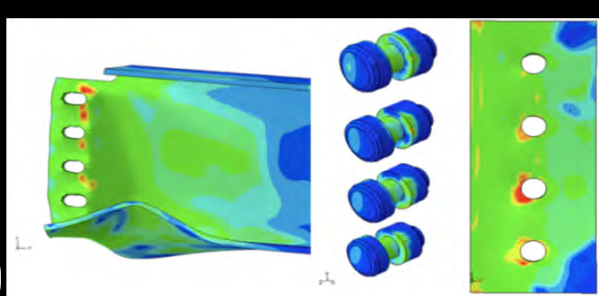
- heat sink effects
- slab membrane action

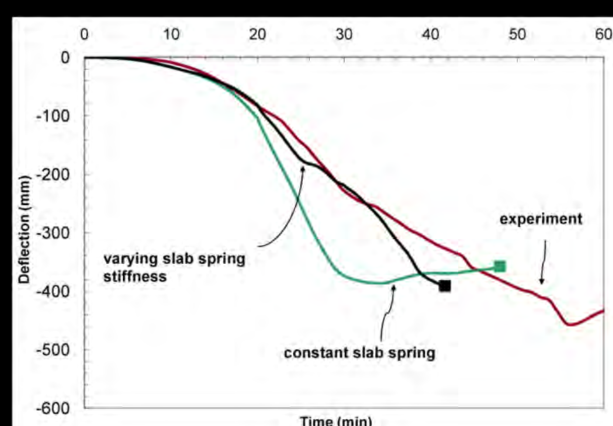




79

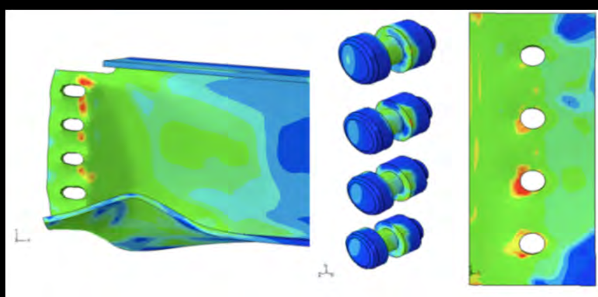
② SFE / connections /





80

② SFE / connections /



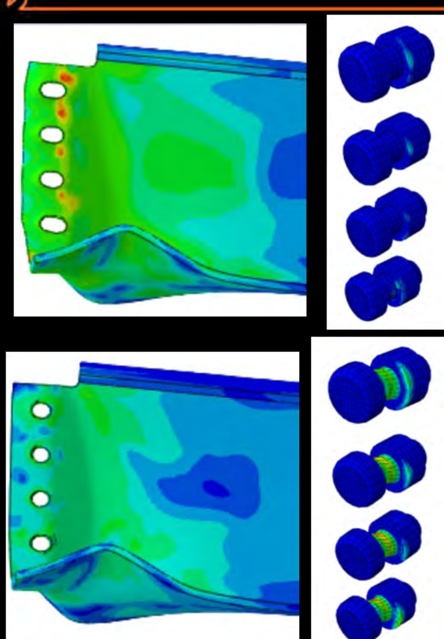
- Bolt grade
- Web reinforcing plate
- Shear tab thickness
- g_h

81

② SFE / connections /

Grade 8.8 (Cardington)

Grade 5.6



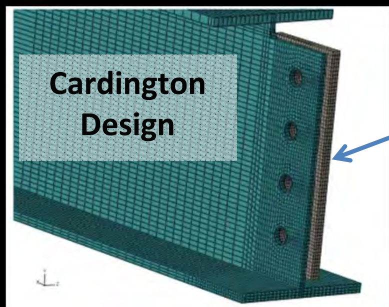
- Bolt grade
- Web reinforcing plate
- Shear tab thickness
- g_h

Cardington:
- End time: 123 min
- Max Tension: 359 KN

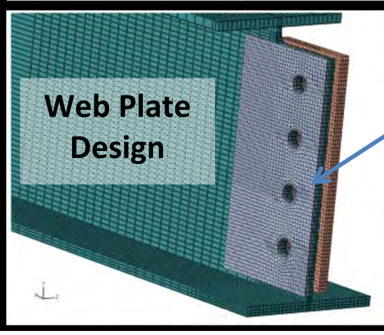
Modification:
- End time: 101 min
- Max Tension: 192 KN

82

② SFE / connections /



10 mm
Shear tab



4 mm
Web reinf.
plate

- Bolt grade
- Web reinforcing plate
- Shear tab thickness
- g_h

Cardington:
- End time: 123 min
- Max Tension: 359 KN

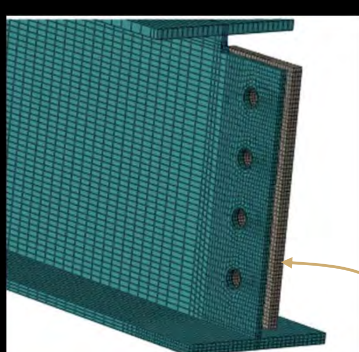
Modification:
- End time: 202 min **
- Max Tension: 622 KN

** = no failure

83

② SFE / connections /

Web thickness = 6 mm



Shear tab
original: 10 mm
modified: 6 mm

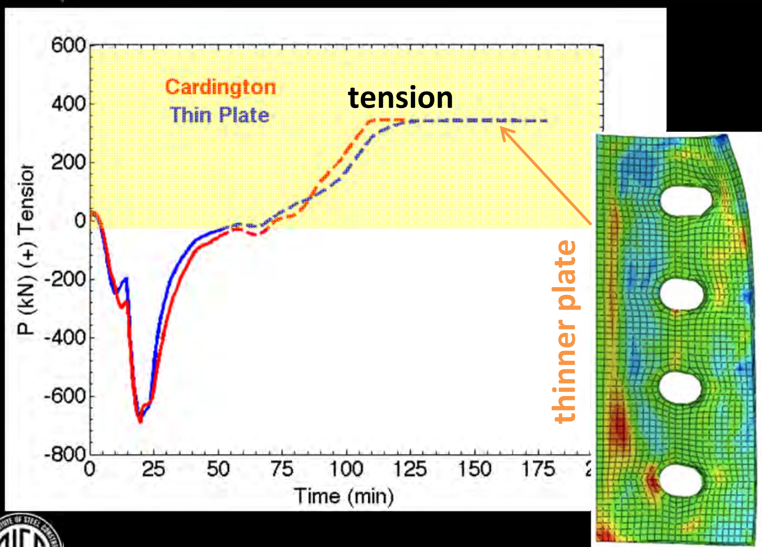
- Bolt grade
- Web reinforcing plate
- Shear tab thickness
- g_h

Cardington:
- End time: 123 min
- Max Tension: 359 KN

Modification:
- End time: 178 min
- Max Tension: 348 KN

84

2 SFE / connections /



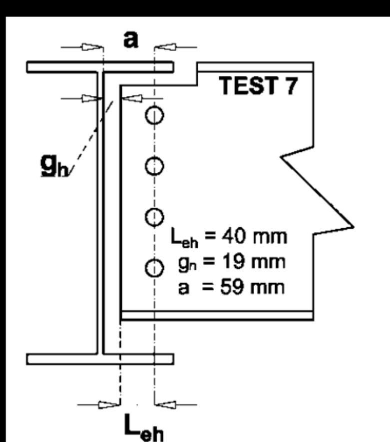
- Bolt grade
- Web reinforcing plate
- Shear tab thickness
- g_h

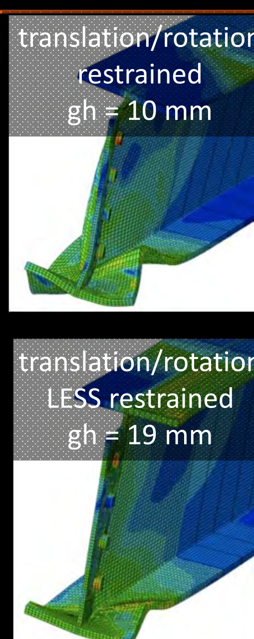
Cardington:
- End time: 123 min
- Max Tension: 359 KN

Modification:
- End time: 178 min
- Max Tension: 348 KN

85

2 SFE / connections /



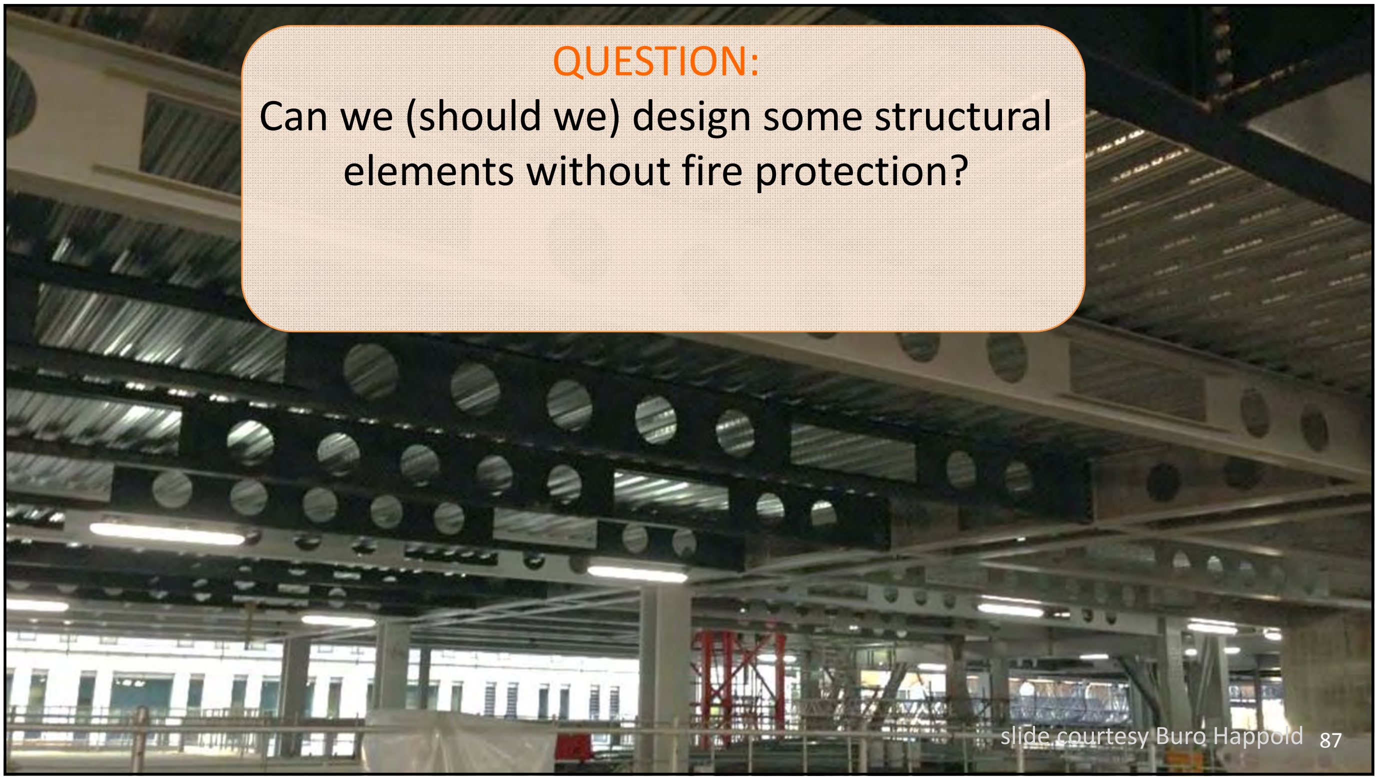


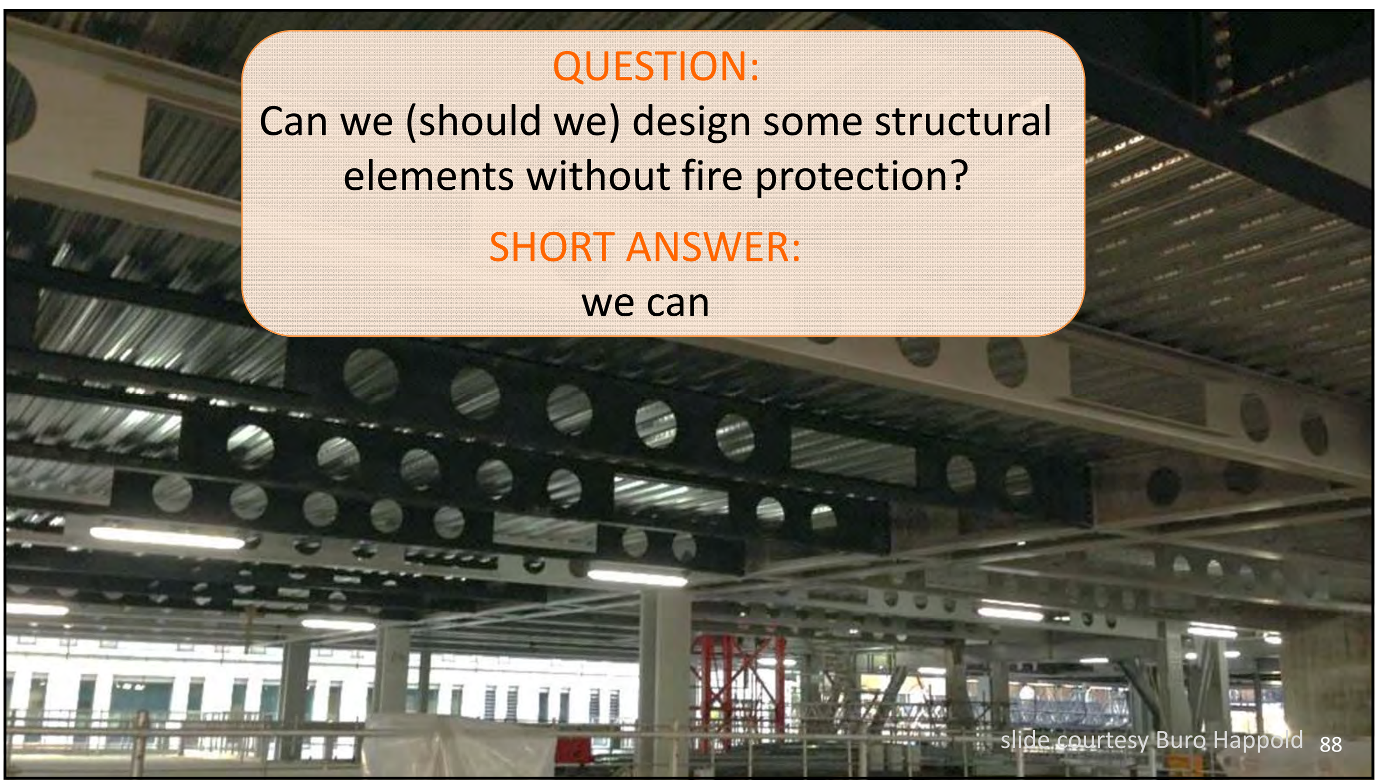
- Bolt grade
- Web reinforcing plate
- Shear tab thickness
- g_h

Cardington:
- End time: 123 min
- Max Tension: 359 KN

Modification:
- End time: 165 min
- Max Tension: 407 KN

86


QUESTION:
Can we (should we) design some structural elements without fire protection?
slide courtesy Buro Happold
87


QUESTION:
Can we (should we) design some structural elements without fire protection?
SHORT ANSWER:
we can
slide courtesy Buro Happold
88

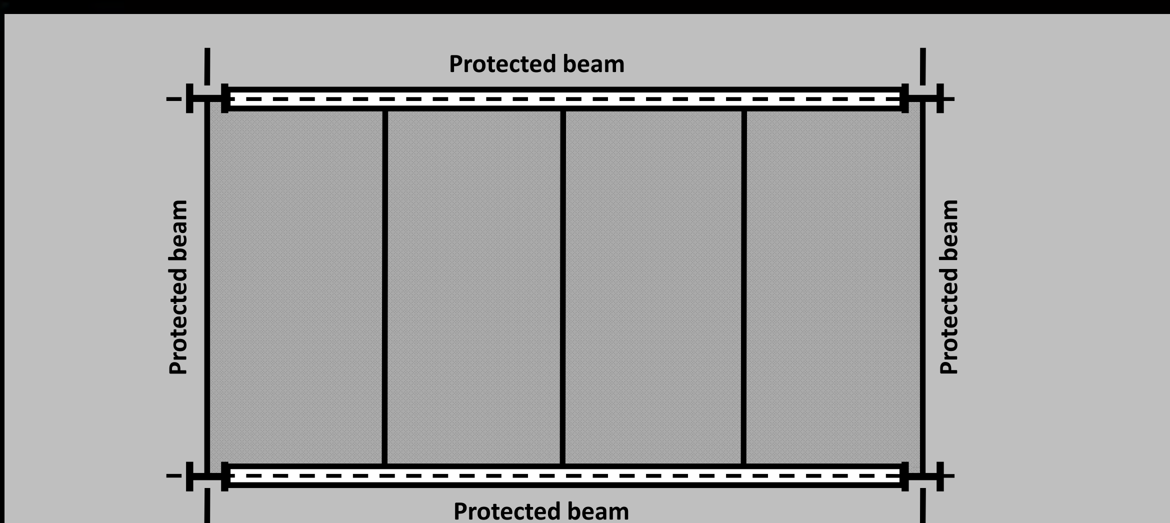
2 STRUCTURAL FIRE ENGINEERING (SFE)

– Tensile Membrane Action

Research by British Steel, BRE, and Colin Bailey, UK

89

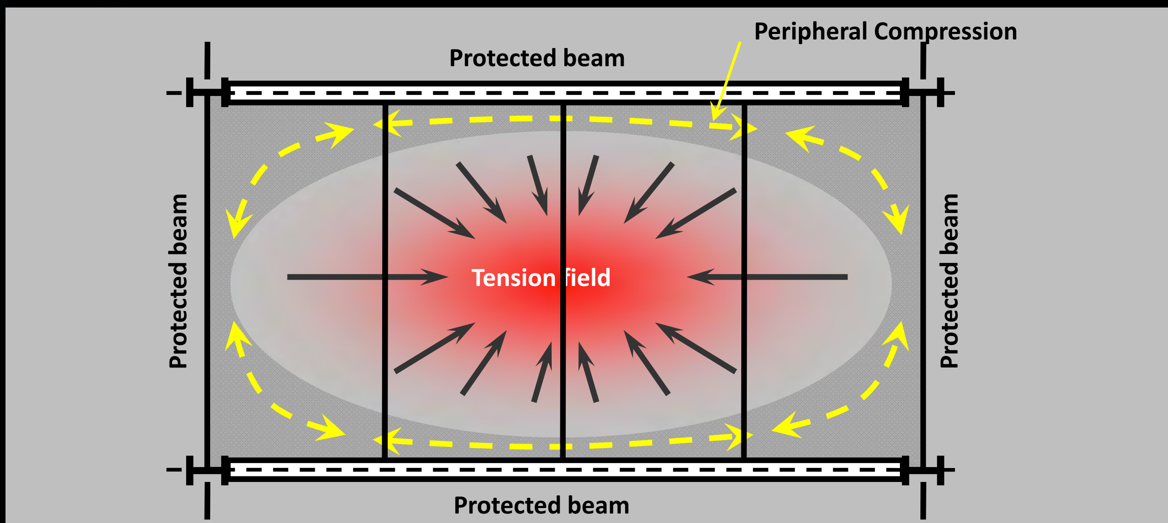
2 SFE / tensile membrane action/



slide credit: F. Block, BuroHappold

90

2 SFE / tensile membrane action/



slide credit: F. Block, BuroHappold

91

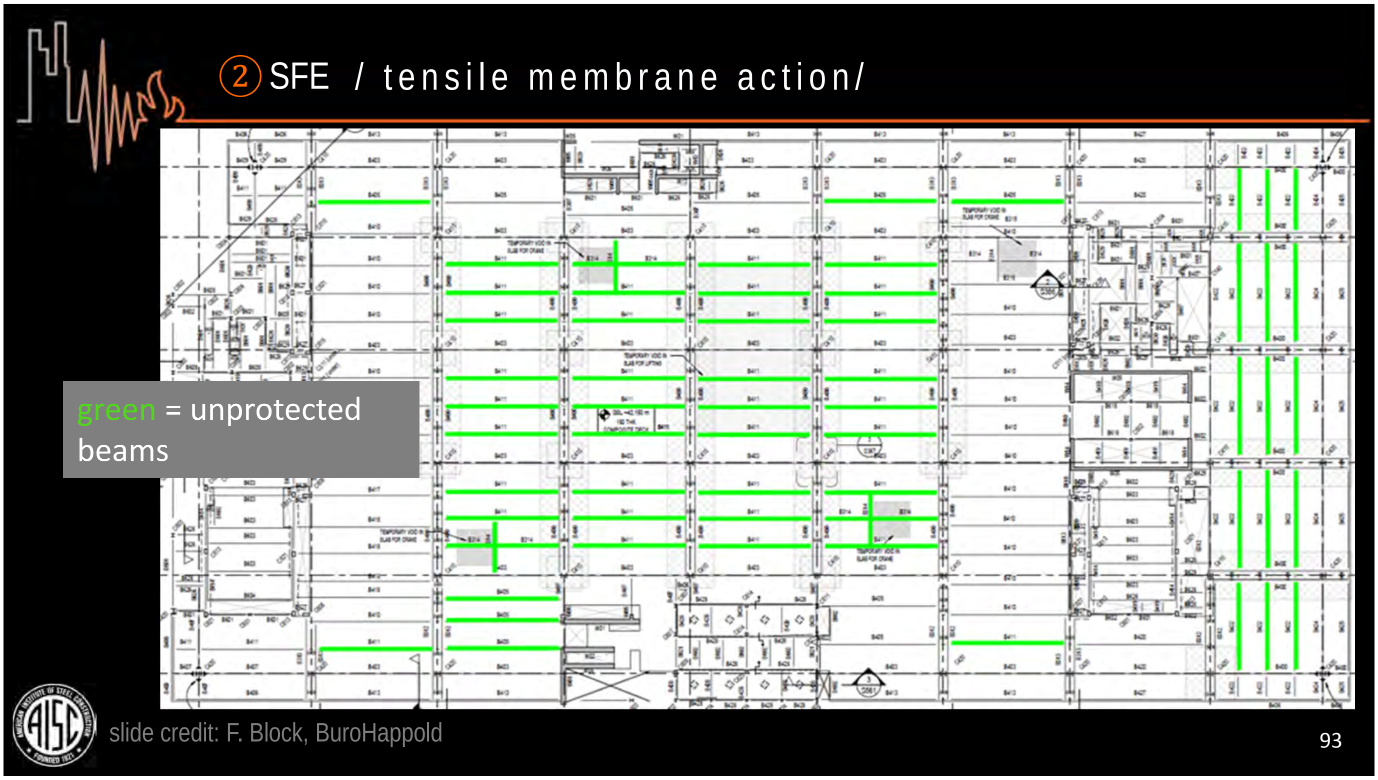
2 SFE / tensile membrane action/

5 Broadgate, UK
(SFE: BuroHappold)

- Accept local damage as long as stability of the overall building is maintained
- Utilize tensile membrane action (TMA)

image credit: Make Architects

92


2 SFE / tensile membrane action/
green = unprotected
beams
slide credit: F. Block, BuroHappold
93


2 SFE / tensile membrane action/
green = unprotected
beams
TMA allows to save ~40% of the fire protection cost
slide credit: F. Block, BuroHappold
94

2 SFE

/ unprotected steel /

Hotel Arts, Barcelona
(SFE: SOM)

- unfireprotected exoskeleton steel-braced megaframe

95

2 SFE

QUESTION:
Can we (should we) design some structural elements without fire protection?

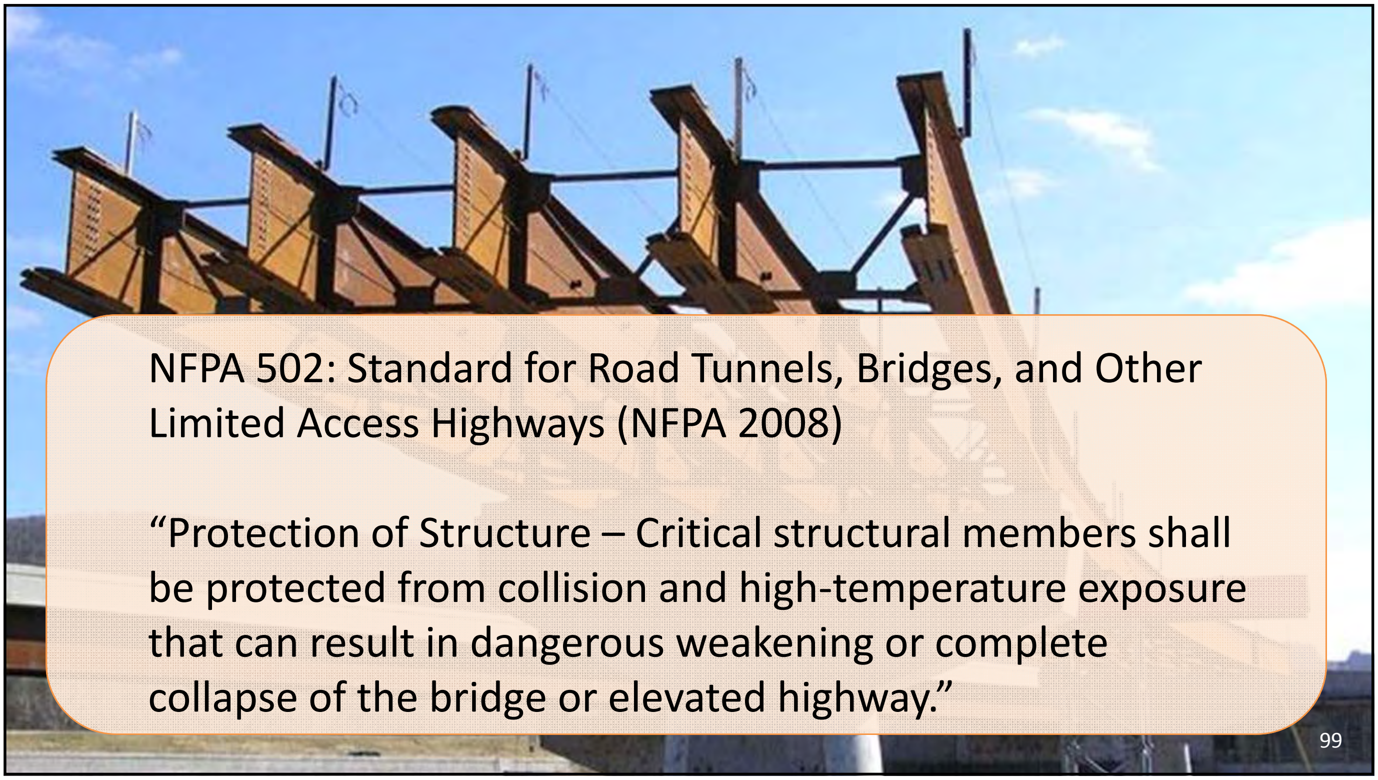
96

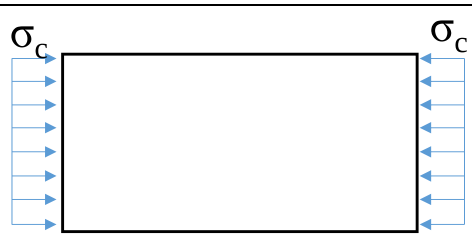
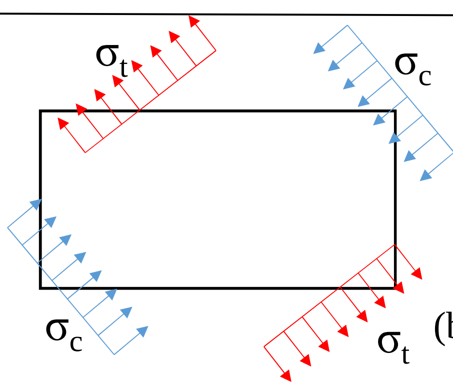
② SFE

QUESTION:
Can we (should we) design some structural elements without fire protection?

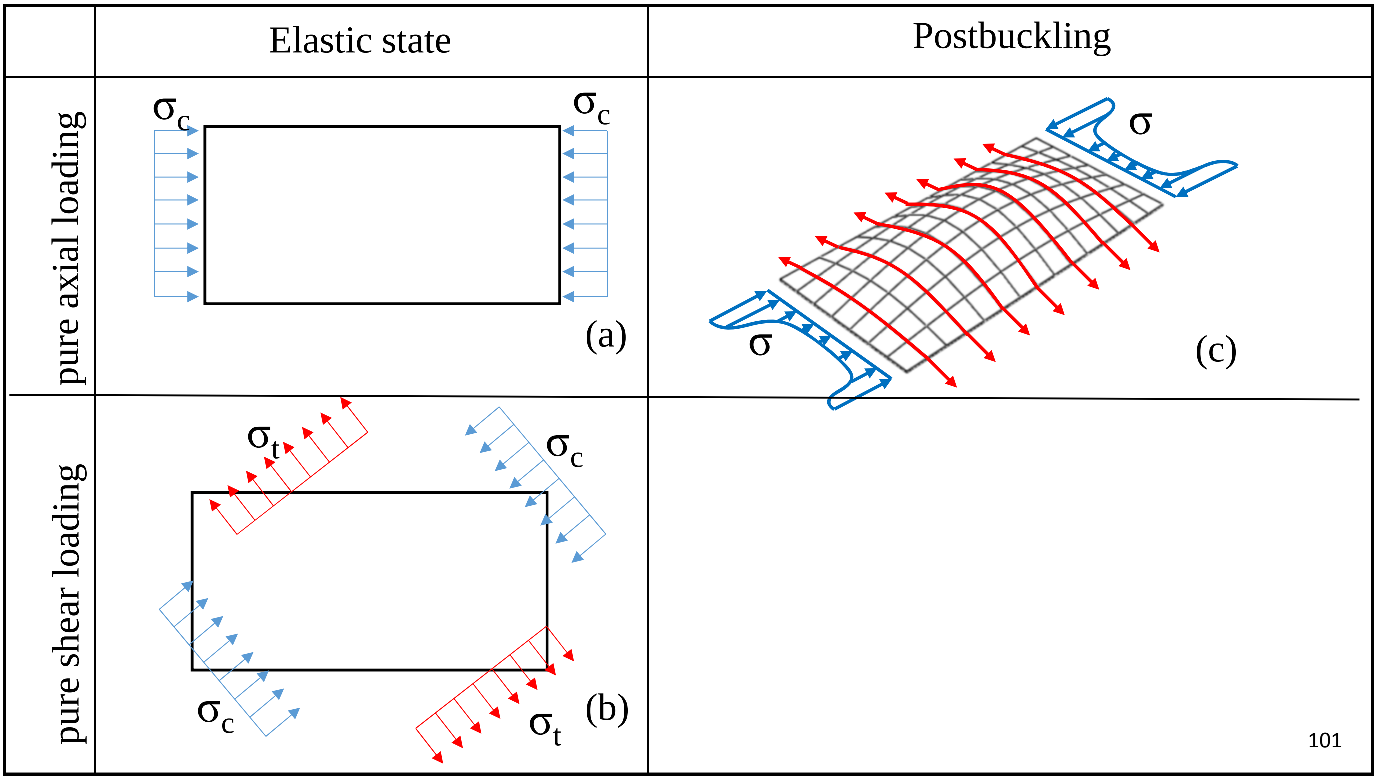
SHORT ANSWER:
sometimes, no choice

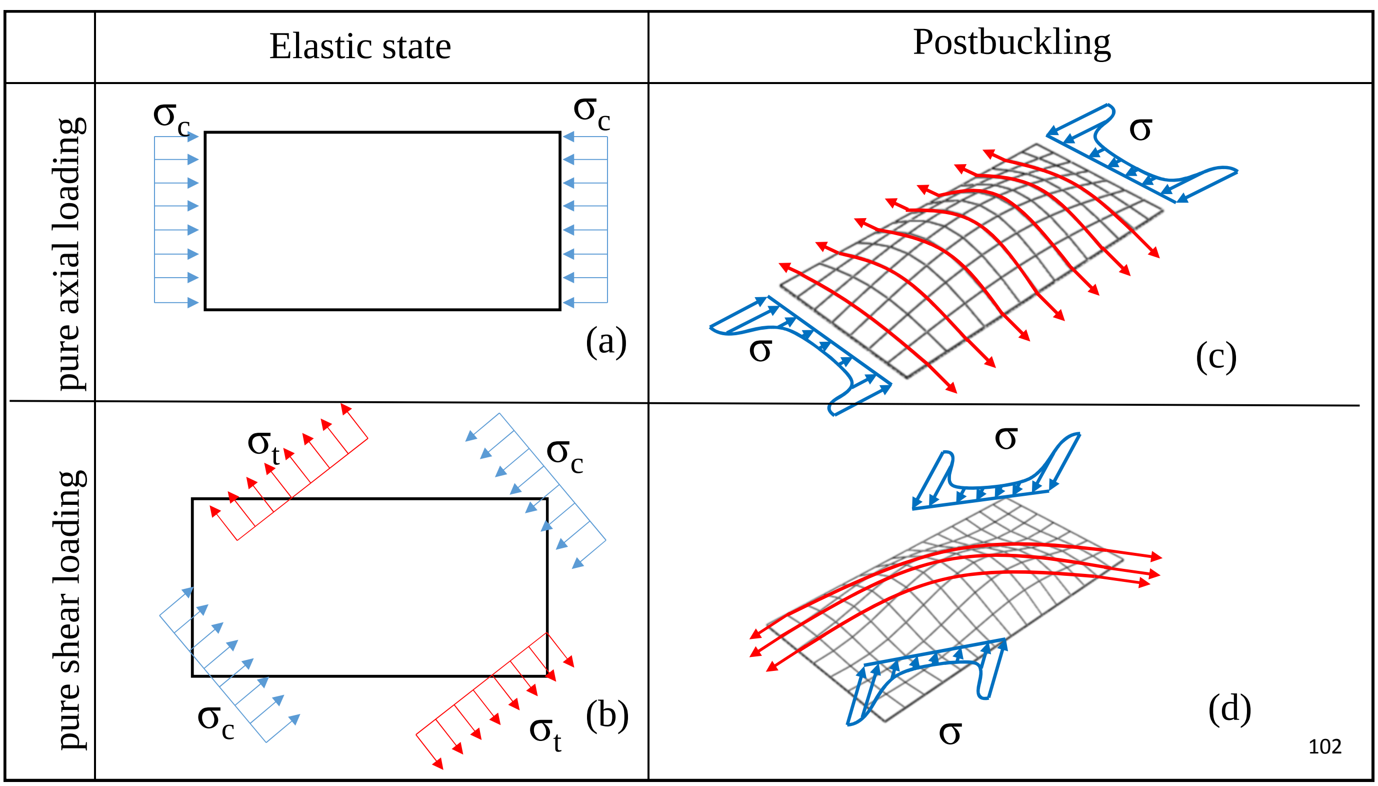
97

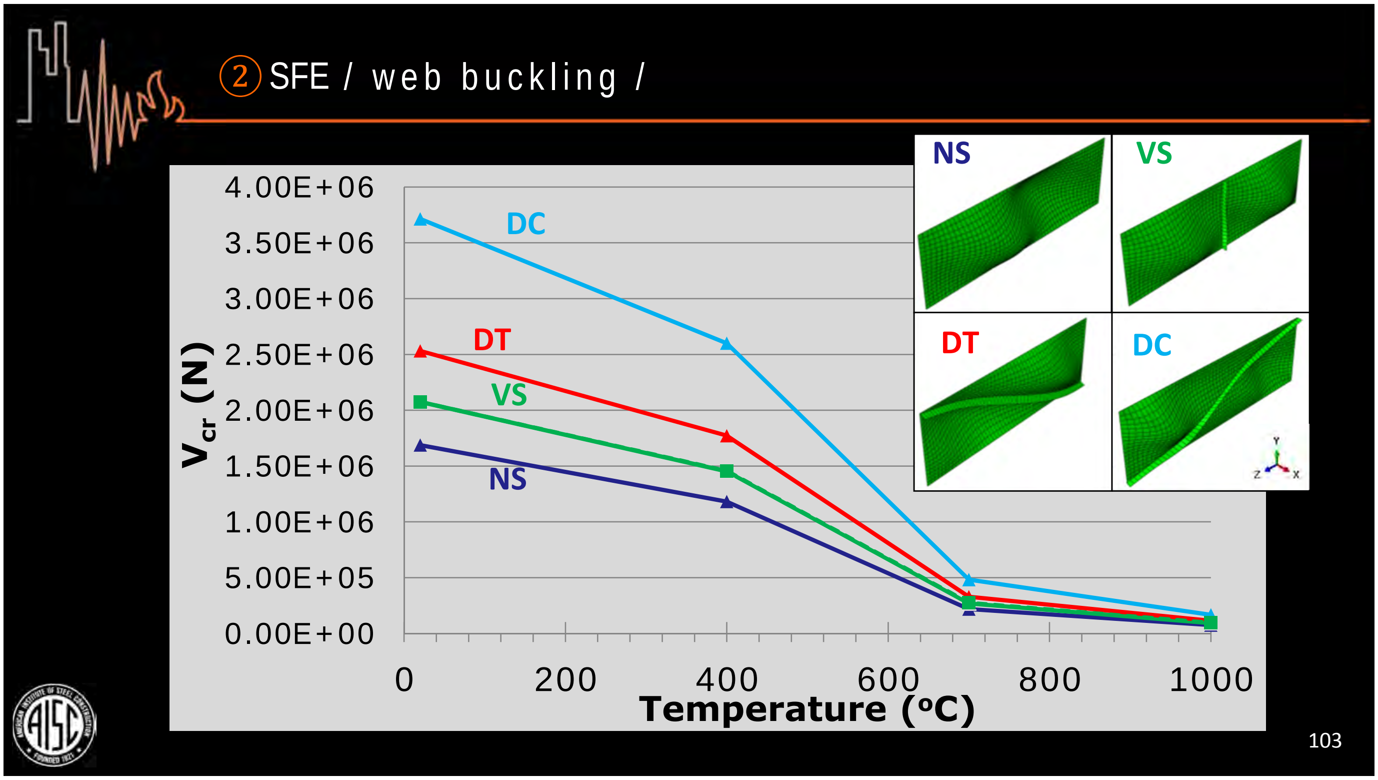


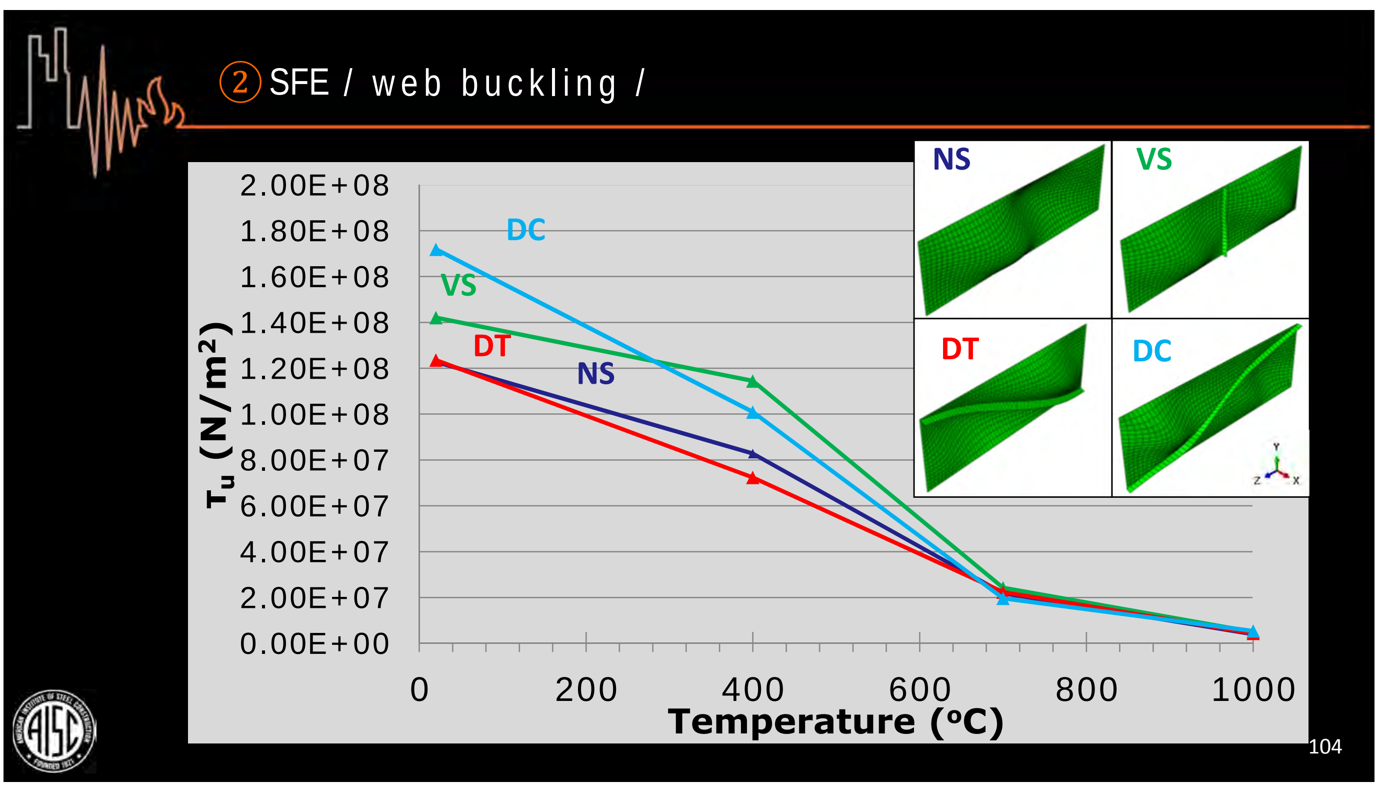
	Elastic state	
pure axial loading	 σ_c σ_c (a)	
pure shear loading	 σ_t σ_c σ_c σ_t (b)	

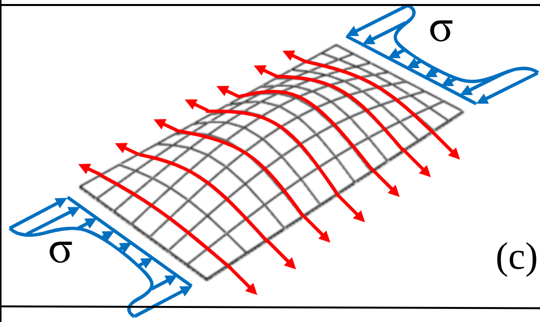
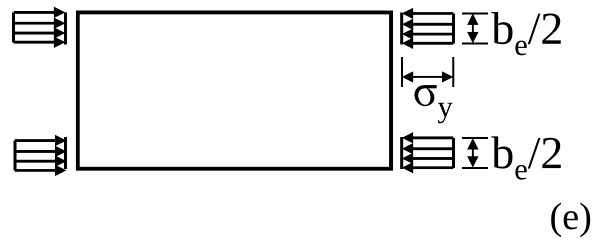
100


Elastic state
Postbuckling
pure axial loading
pure shear loading
σc
σc
(a)
σ
σ
(c)
σt
σc
σc
σt
(b)
101

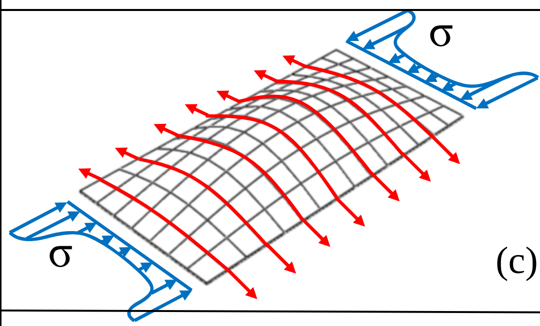
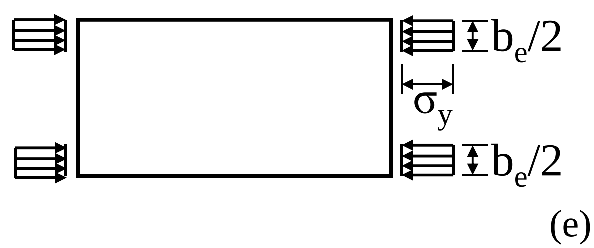
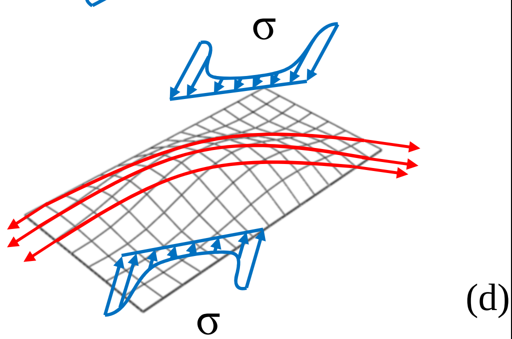

Elastic state
Postbuckling
pure axial loading
pure shear loading
σc
σc
(a)
σ
σ
(c)
σt
σc
σc
σt
(b)
σ
σ
(d)
102


2 SFE / web buckling /
NS
VS
DT
DC
4.00E+06
3.50E+06
3.00E+06
2.50E+06
2.00E+06
1.50E+06
1.00E+06
5.00E+05
0.00E+00
V_cr (N)
0
200
400
600
800
1000
Temperature (°C)
103

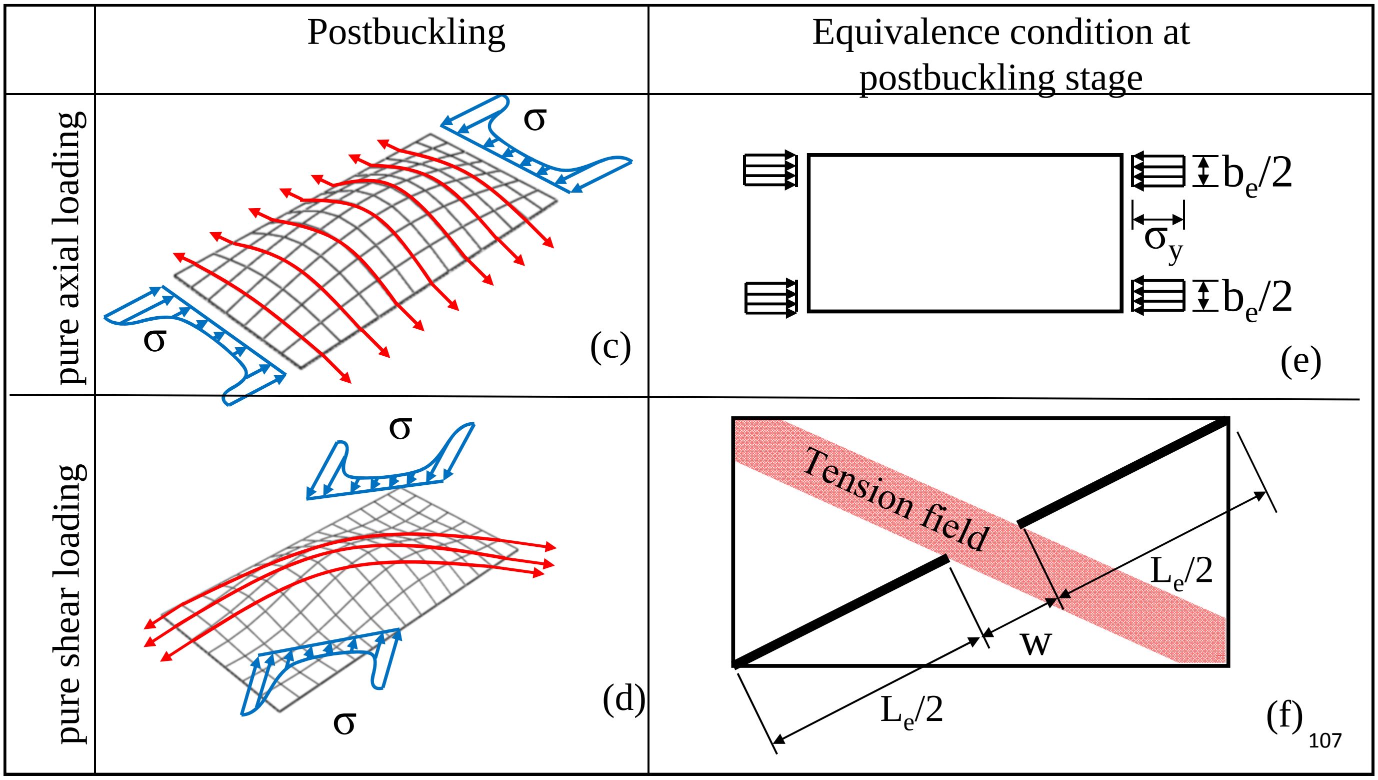

2 SFE / web buckling /
NS
VS
DT
DC
2.00E+08
1.80E+08
1.60E+08
1.40E+08
1.20E+08
1.00E+08
8.00E+07
6.00E+07
4.00E+07
2.00E+07
0.00E+00
τ_u (N/m²)
0
200
400
600
800
1000
Temperature (°C)
104

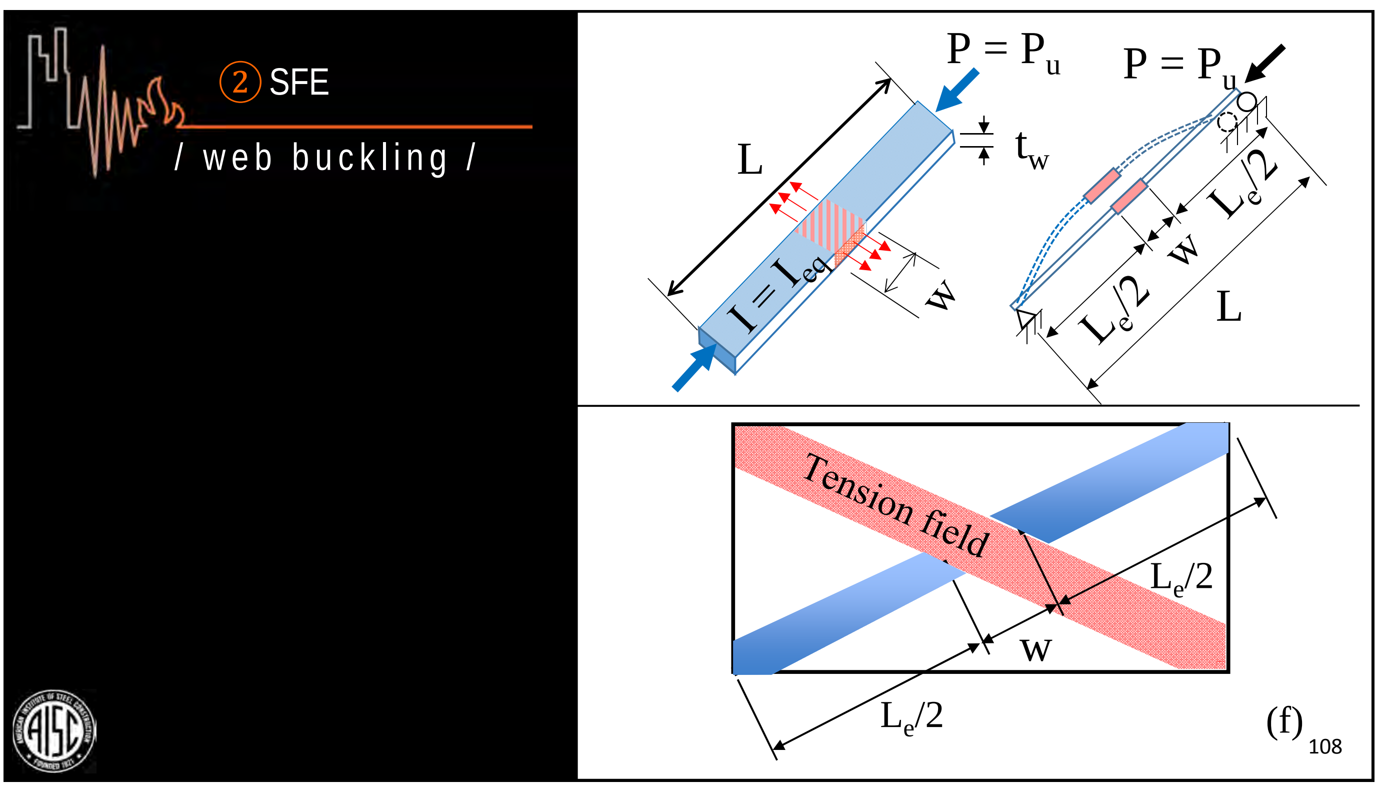
	Postbuckling	Equivalence condition at postbuckling stage
pure axial loading		
pure shear loading		

105

	Postbuckling	Equivalence condition at postbuckling stage
pure axial loading		
pure shear loading		

106


Postbuckling
Equivalence condition at postbuckling stage
pure axial loading
pure shear loading
σ
σ
(c)
$b_e/2$
σ_y
$b_e/2$
(e)
σ
σ
(d)
Tension field
$L_e/2$
w
$L_e/2$
(f)
107

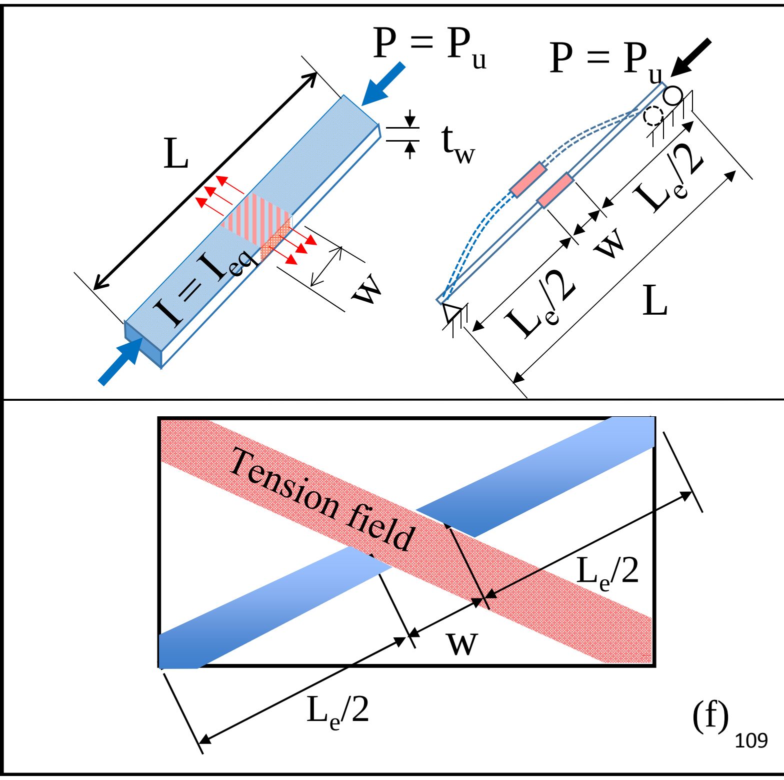

2 SFE
/ web buckling /
$P = P_u$
$P = P_u$
L
t_w
$I = I_{eq}$
w
$L_e/2$
w
$L_e/2$
L
Tension field
$L_e/2$
w
$L_e/2$
(f)
108

② SFE

/ web buckling /

The challenge is then to predict:

1) the width of the tension field, *w*
2) the axial load on this equivalent column, and
3) convert that axial load to a shear load.



109

② SFE

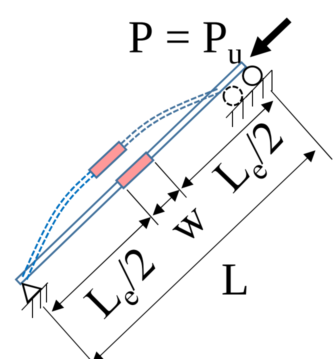
/ web buckling /

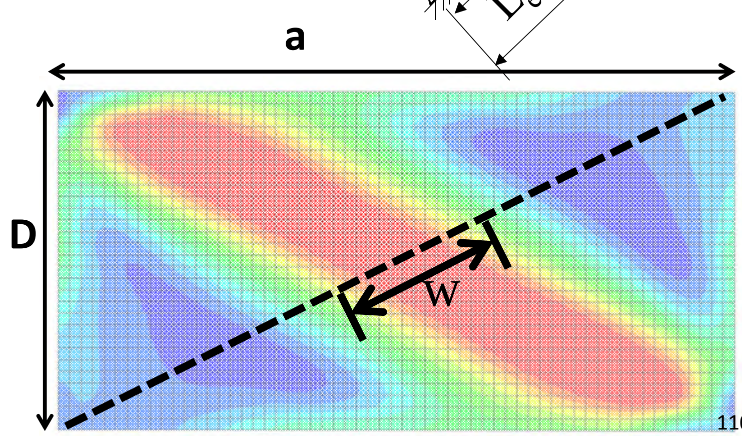
Finding *w*:

- calibrated with 60 FE models
- considers slenderness (D/t_w), aspect ratio (a/D) and scale (D)

ambient:

$$V_u = V_{cr}\left(\frac{L}{L_e}\right)^2 \cdot Q_v$$





110

② SFE

/ web buckling /

Finding *w*:

- calibrated with 60 FE models
- considers slenderness (D/t_w), aspect ratio (a/D) and scale (D)
- validated with 84 test specimens at ambient temperature

ambient:

$$V_u = V_{cr}\left(\frac{L}{L_e}\right)^2 \cdot Q_v$$

	V_u/V_u^{Exp}	
Set	Mean	Std. Dev.
A (n=27)	1.04	0.08
B (n =57)	1.20	0.41
A+B (n=84)	1.15	0.35

Set A:

- 26 ksi ≤ σ_y ≤ 61 ksi
- 100 ≤ D/t_w ≤ 300; 1.0 ≤ a/D ≤ 3.0
- t_f/t_w ≤ 5

111

② SFE

/ web buckling /

- same *w* as ambient
- β considers material effects:
  - ✓ 1.2 for σ_y = 250 MPa
  - ✓ 1.15 for σ_y = 345 MPa
- $\sqrt{K_{E,T} / k_{y,T}}$ considers temperature effects

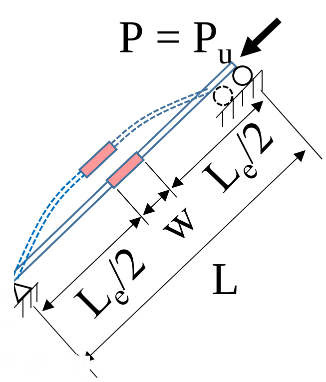
ambient:

$$V_u = V_{cr}\left(\frac{L}{L_e}\right)^2 \cdot Q_v$$

elev. temp:

$$V_u^T = V_{cr}^T\left(\frac{L}{L_e^T}\right)^2 \cdot Q_v^T$$

$$L_e^T = (L - w)\cdot \beta \cdot \sqrt{\frac{k_{E,T}}{k_{y,T}}}$$



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② SFE / web buckling /

Specimen	a/D	D/t_w	D (m)	T (^oC)	σ_y (MPa)	V_u^T (kN)	V_u^{Exp} (kN)	V_u^T/V_u^{Exp}
TG3	1.0	153	0.305	20	288	82.4	79.85	1.03
				400	288	59.2	67.63	0.87
				565	166	34.2	34.34	0.99
				700	66	13.6	17.15	0.79
TG4	1.0	113	0.305	20	233	109.4	111.8	0.98
				400	233	74.8	77.1	0.97
				700	54	17.2	15.94	1.08

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WHY SFE?
SAFETY (efficiency)
COST (economy)
ENCOURAGE INNOVATION (elegance)
Lewis Library, Princeton University
Architect: Frank Ghery
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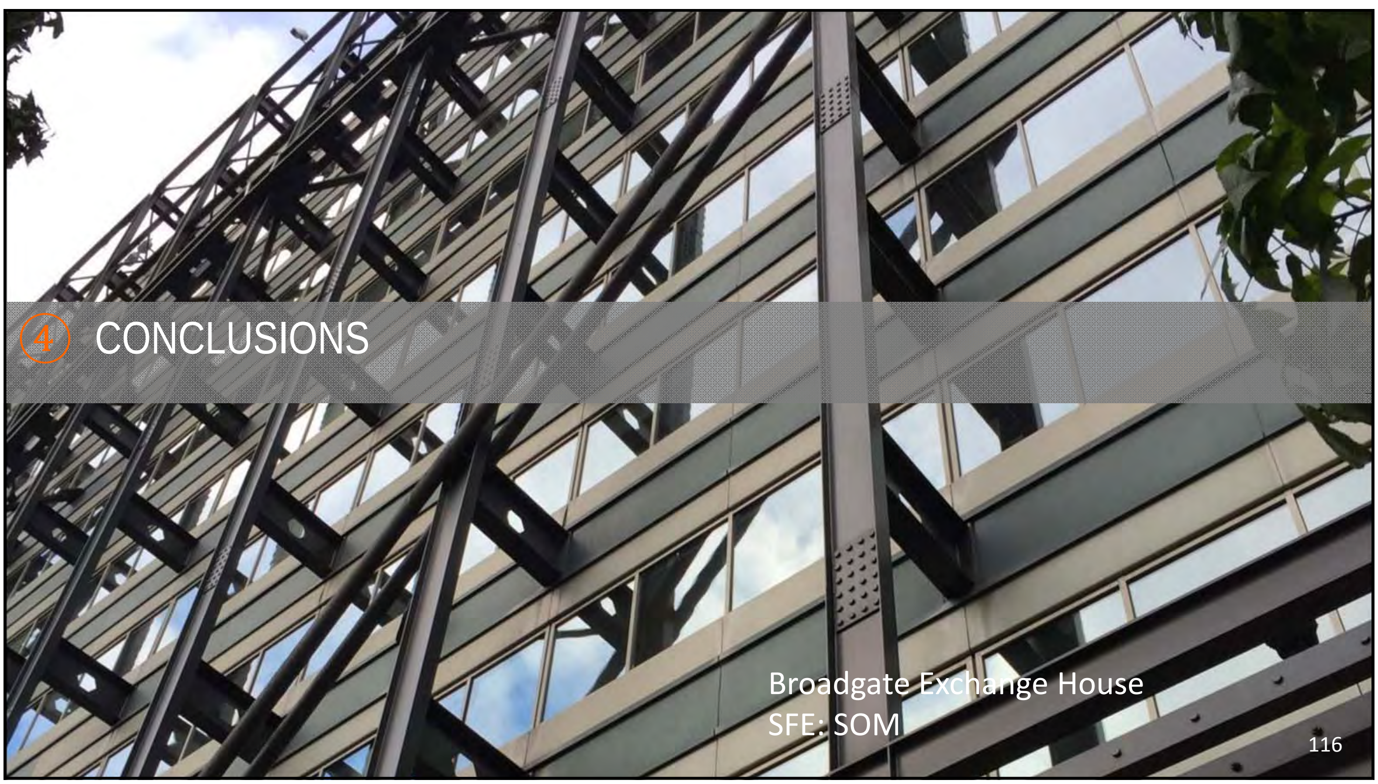
4 CONCLUSIONS
Broadgate Exchange House
SFE: SOM
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4 CONCLUSIONS

QUESTION	ANSWER
Do concrete structures perform better in fire than steel structures?	ALL materials have some form of weakness in fire.

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4 CONCLUSIONS

QUESTION	ANSWER
Do concrete structures perform better in fire than steel structures?	ALL materials have some form of weakness in fire.
Does the fire resistive rating imply the *time* that the structural integrity is maintained?	no

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4 CONCLUSIONS

QUESTION	ANSWER
Do concrete structures perform better in fire than steel structures?	ALL materials have some form of weakness in fire.
Does the fire resistive rating imply the *time* that the structural integrity is maintained?	no
Are there codes/standards that permit anything other than a prescriptive approach?	yes: NFPA 5000 (2012) IBC (2012)

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4 CONCLUSIONS

QUESTION	ANSWER
Do we need to consider thermal gradients or can we just assume an average temperature?	It depends (beam-columns)

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4 CONCLUSIONS

QUESTION	ANSWER
Do we need to consider thermal gradients or can we just assume an average temperature?	It depends (beam-columns)
Do structural failures *always* happen during the heating phase?	no (connections)

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4 CONCLUSIONS

QUESTION	ANSWER
Do we need to consider thermal gradients or can we just assume an average temperature?	It depends (beam-columns)
Do structural failures *always* happen during the heating phase?	no (connections)
Can we (should we) design some structural elements without fire protection?	• we can (TMA) • sometimes no choice (bridges)

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④ CONCLUSIONS

- Typical design for fire (prescriptive) does not consider the structural response
- Performance based design for fire, aka structural fire engineering (SFE), considers the *real* fire and the *real* response of the structure to that fire
- SFE offers opportunities to design steel structures that are efficient, economical, and elegant

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ACKNOWLEDGEMENTS

Creative
Resilient
Urban
Engineering

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- NIST
- AISC

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THANK YOU

Questions?

https://garlock.princeton.edu

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Polling Question

Which of the following is false regarding Structural Fire Engineering (SFE)?

A. In SFE, fire is treated as a “load“
B. SFE is based on standard fire tests such as ASTM E119
C. In SFE one sets 'performance objectives' regarding how the structure should perform.
D. SFE depends on structural behavior and thus it is an engineered approach to fire design

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Within 2 business days…

- You will receive an email on how to report attendance from: registration@aisc.org.
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!

PDH Certificates

Within 2 business days…

- Reporting site (URL will be provided in the forthcoming email).
- Username: Same as AISC website username.
- Password: Same as AISC website password.

There's always a solution in steel.

Thank You

Please give us your feedback!
Survey at conclusion of webinar.

structural
STEEL