THE SLAB DESIGNER.

www.theslabdesigner.com

The capacity of a slab is not defined by “thickness”

Slab Design Webinar

THE SLAB DESIGNER.

Noon – 12.10	Nigel Parkes | **The Need & Introductions**
12.10 –12.30	Juan Pablo Covarrubias | **The How & Proof of Concept**
12.30 – 12.55	Dr. Lev Khazanovich | **The Numerator**
12.55 – 1.20	Dr. Jeff Roesler | **The Denominator**
1.20 – 1.30	Nigel Parkes | **Curl Data Collection**
1.30 – 2.00	Robert Rodden | **The SLABS™ Software Demo & Work Queue**
2.00 – 2.20	All | **Questions & Answers**
2.20 – 2.30	Nigel Parkes | **Closing Remarks and Next Steps**

Sponsored by

The Denominator

Limitations of Beam Test and Advancements in Slab Capacity Estimation

Slab Design Workshop
International Webinar
August 19, 2026

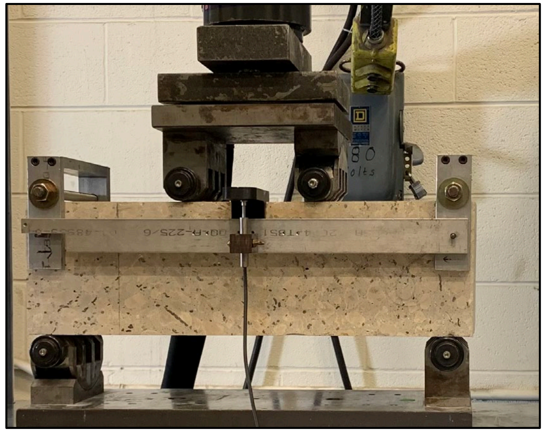
Jeffery Roesler, Ph.D., P.E.
Ernest J. Barenberg Endowed Professor
Department of Civil and Environmental Engineering

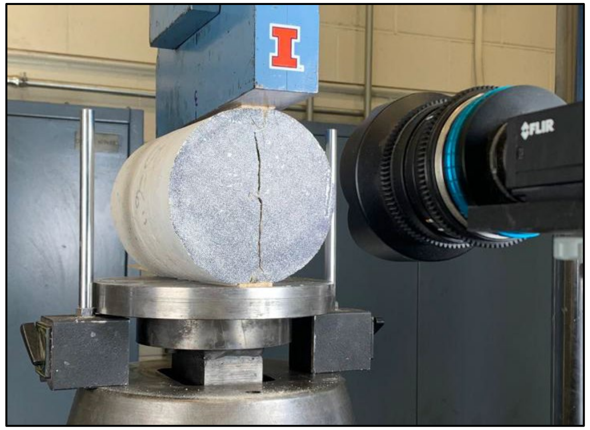
Question#1

- What concrete strength (R) measure should we use for concrete slab design?

Stress ratio = $\frac{\sigma}{R}$

- *σ = Slab Tensile Stress*
- R = Concrete Strength

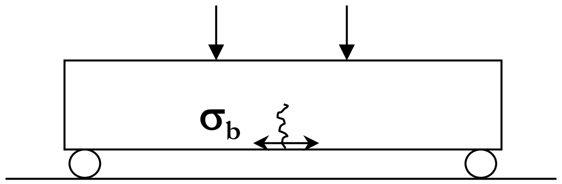




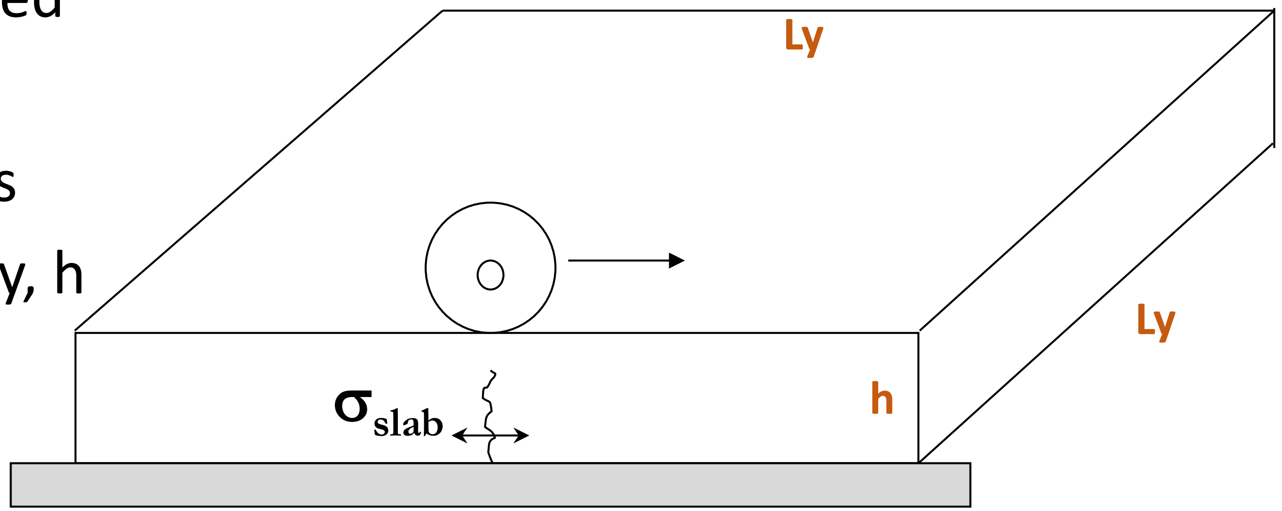
?

Concrete "Strength" Statement

- **Observations: Concrete Slab "strength" greater than beam strength**
  - Designs assume $\sigma_b = MOR = \sigma_{slab}$
- **Strength difference exists:**
  - Incorrect definition of strength
  - Other mat'l properties ignored
    - G_c- fracture toughness
  - Loading configuration effects
  - Slab geometry effects – Lx, Ly, h
  - Boundary condition effects



$$\sigma_b \neq \sigma_{slab}$$



$\sigma_b = MOR = flexural\ strength$

Presentation Objectives:
Defining Concrete Strength for Design

1. What do we currently use (σ_{max} /R) in the denominator for strength (R) and what does it actually measure?

2. What should we use in the denominator for strength (R), e.g., MOR, σ_{split}, σ_{cs}, σ_{ts}?

3. What are necessary concrete "strength" inputs for slab design?

4. *How do we determine slab capacity (slab strength)?*

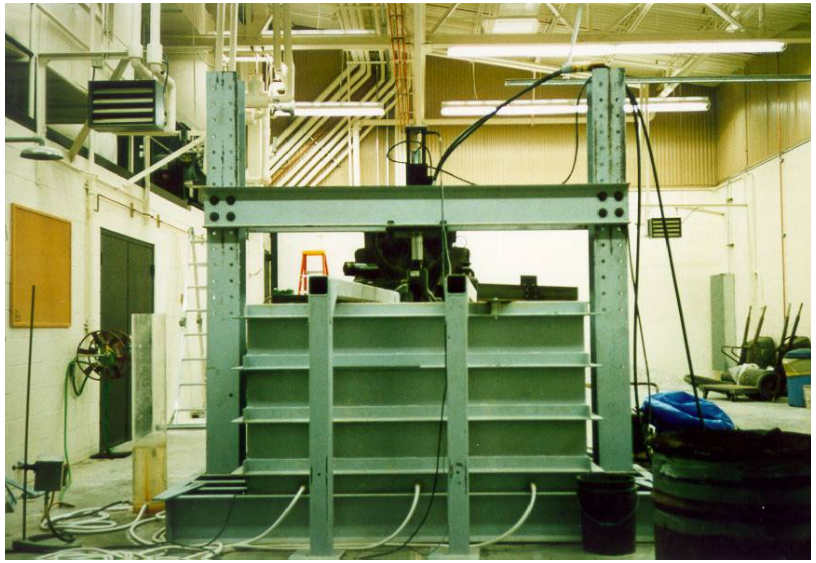
Outline for Presentation

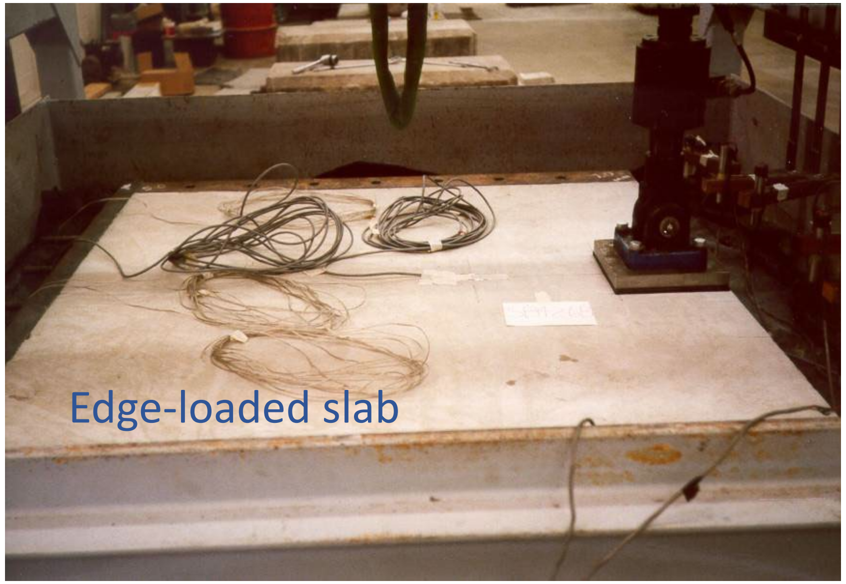
- Slab tests in laboratory
  - Plain and fiber reinforced concrete
- Full-scale slab tests - field
- Flexural beam test (MOR) re-interpretation
- Goal - Slab Capacity

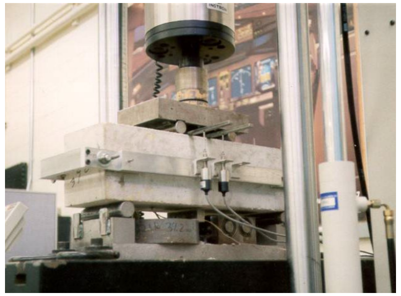
Monotonic and Fatigue of Concrete Slabs

<u>*Fully Supported Slabs*</u>

- 1.22m x 1.22m x 0.15m
- 10 slabs cyclically loaded
- 2 slabs statically tested
- 24 beams for flexural strength

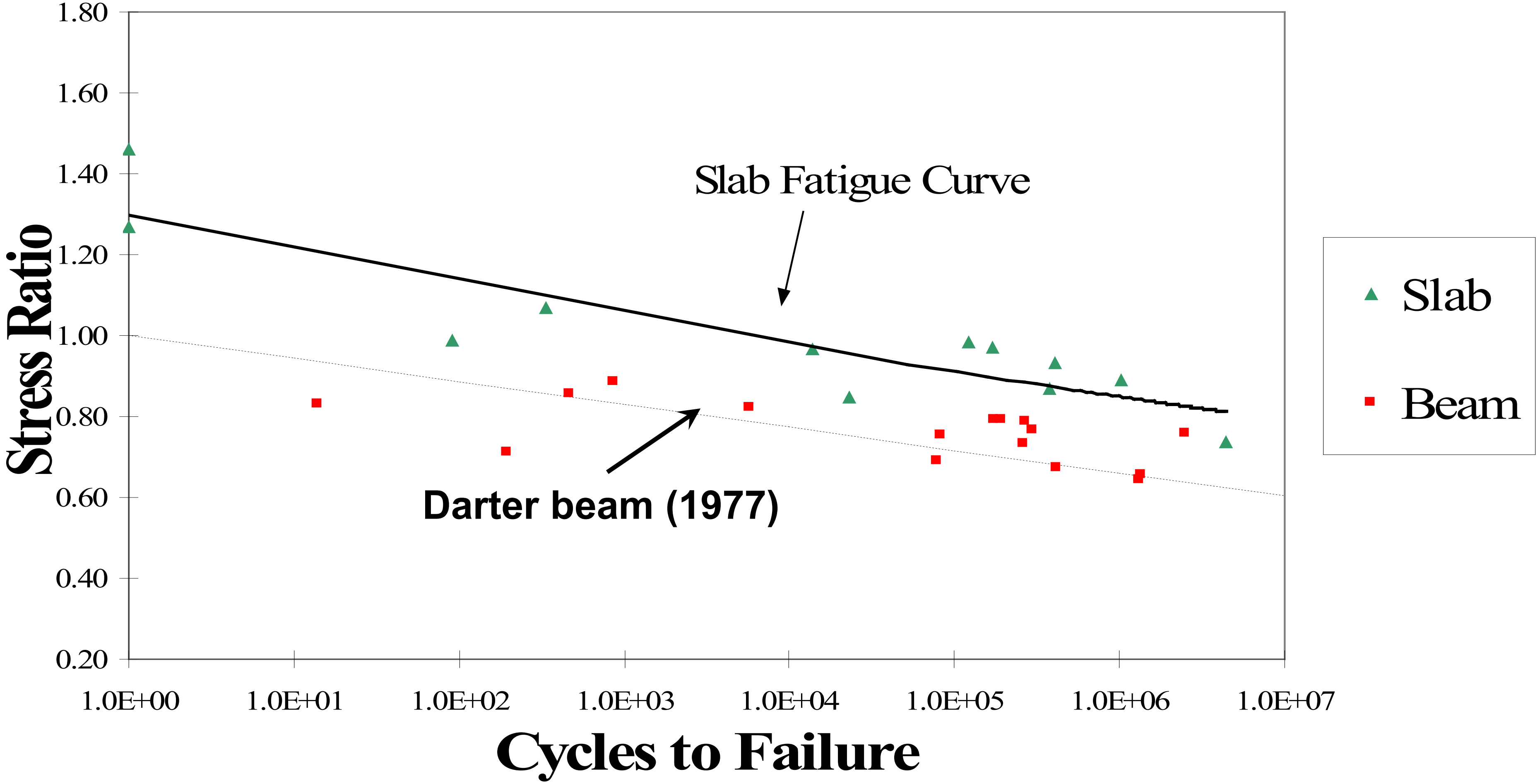






Roesler (1998)

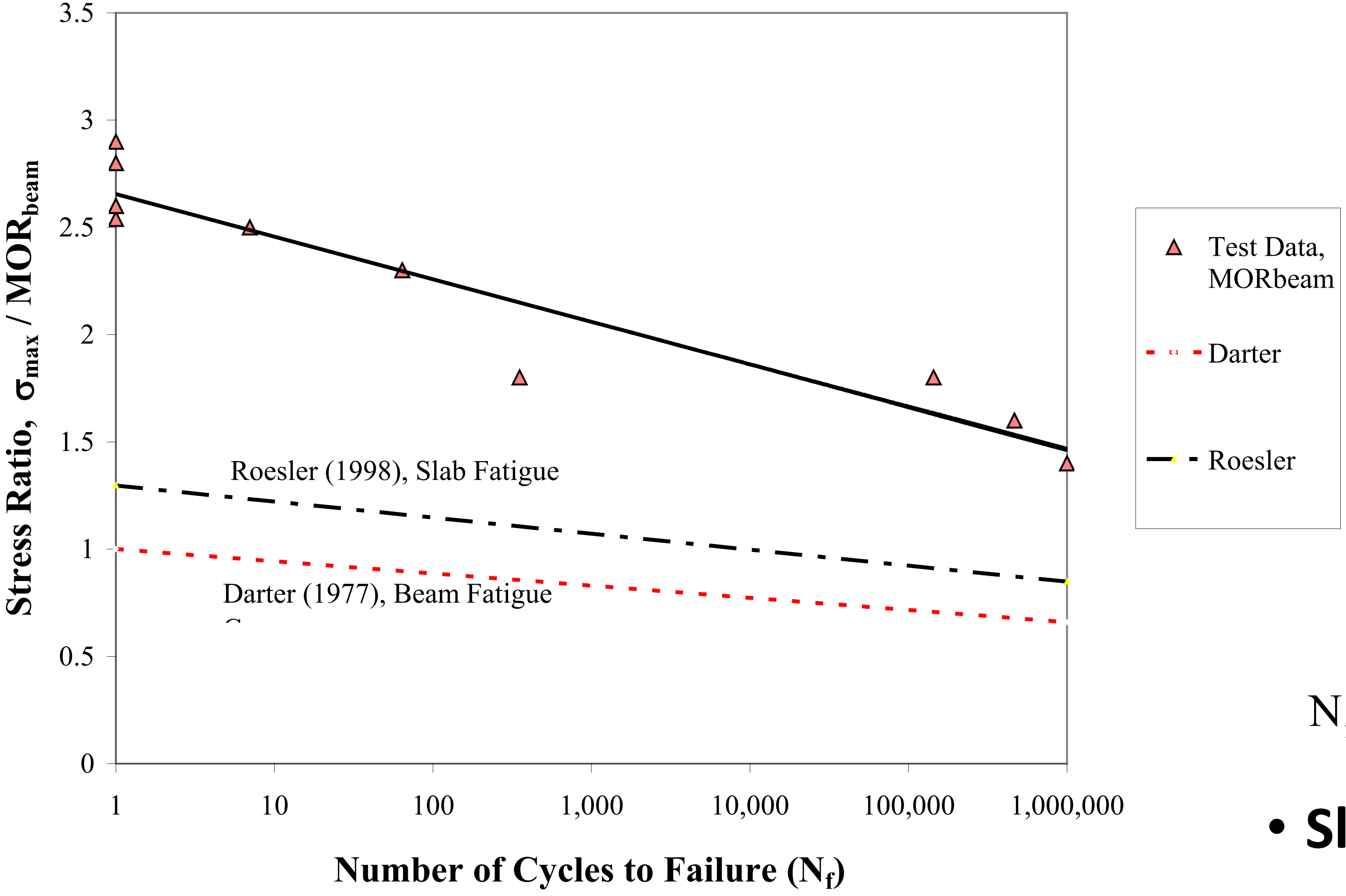
Beam and Slab Fatigue Curves



$$N_f = \left[\frac{1.2968}{(\sigma / MOR_{beam})} \right]^{32.57}$$

Q#2 - Is beam to slab strength fixed or variable?

Concrete Slab Test Results - Single Pulse



$$N_f = \left[\frac{2.689}{\left(\sigma / MOR_{beam}\right)} \right]^{21.79}$$

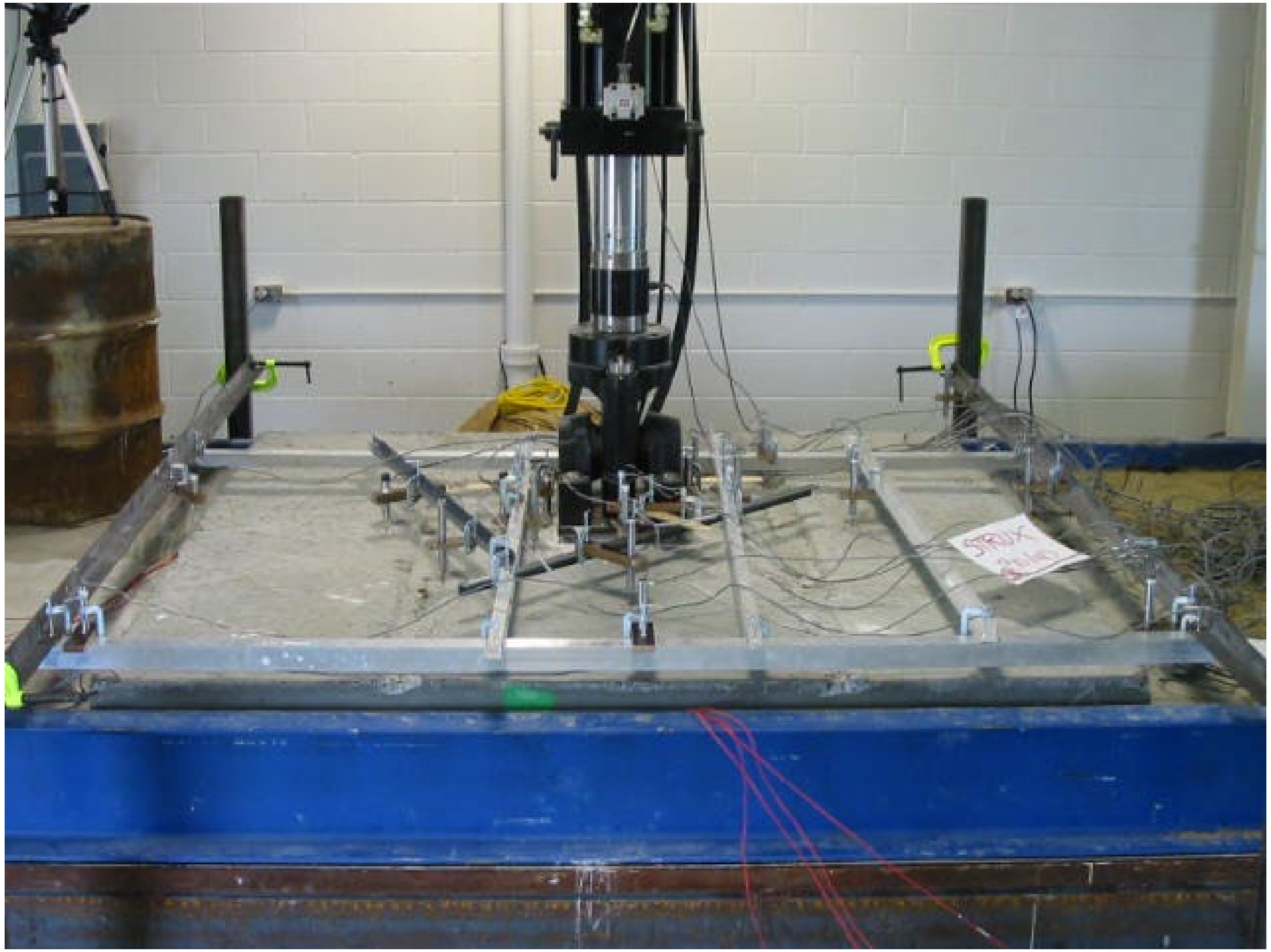
- **Slab strength = 2.7 *MOR**

Roesler et al. (2005)

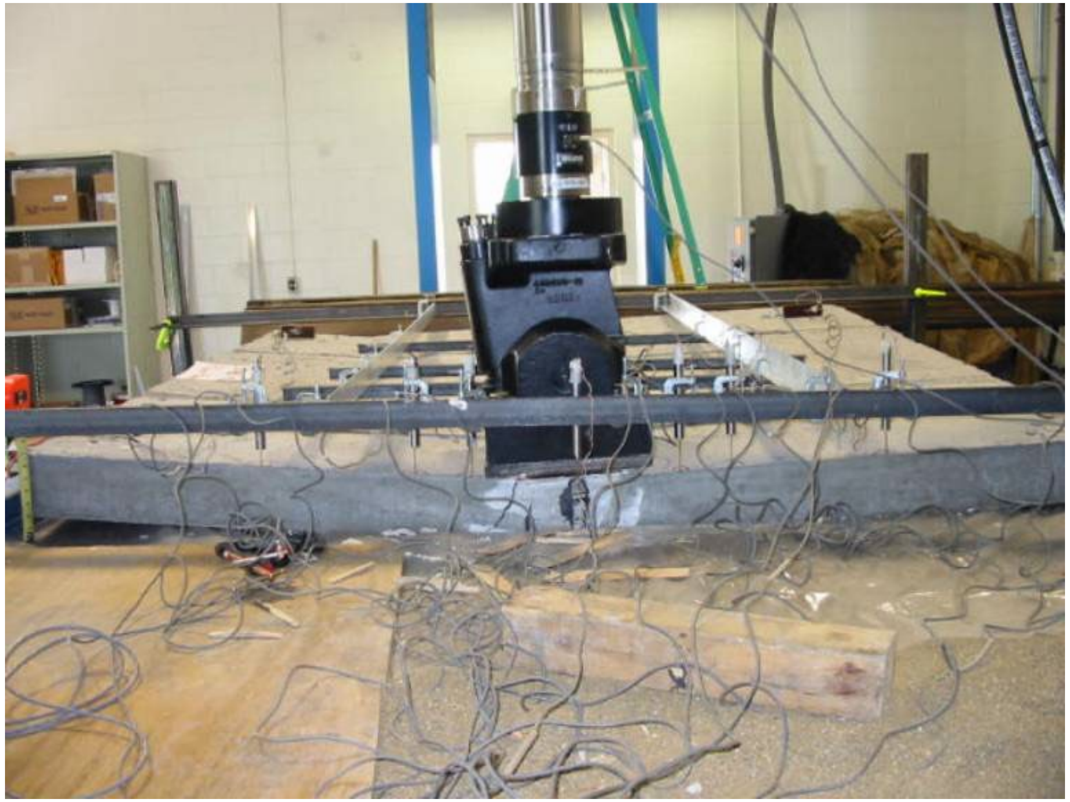
Q#3 - Does slab materials affect capacity?

Monotonic FRC Slab Testing (macrofibers)

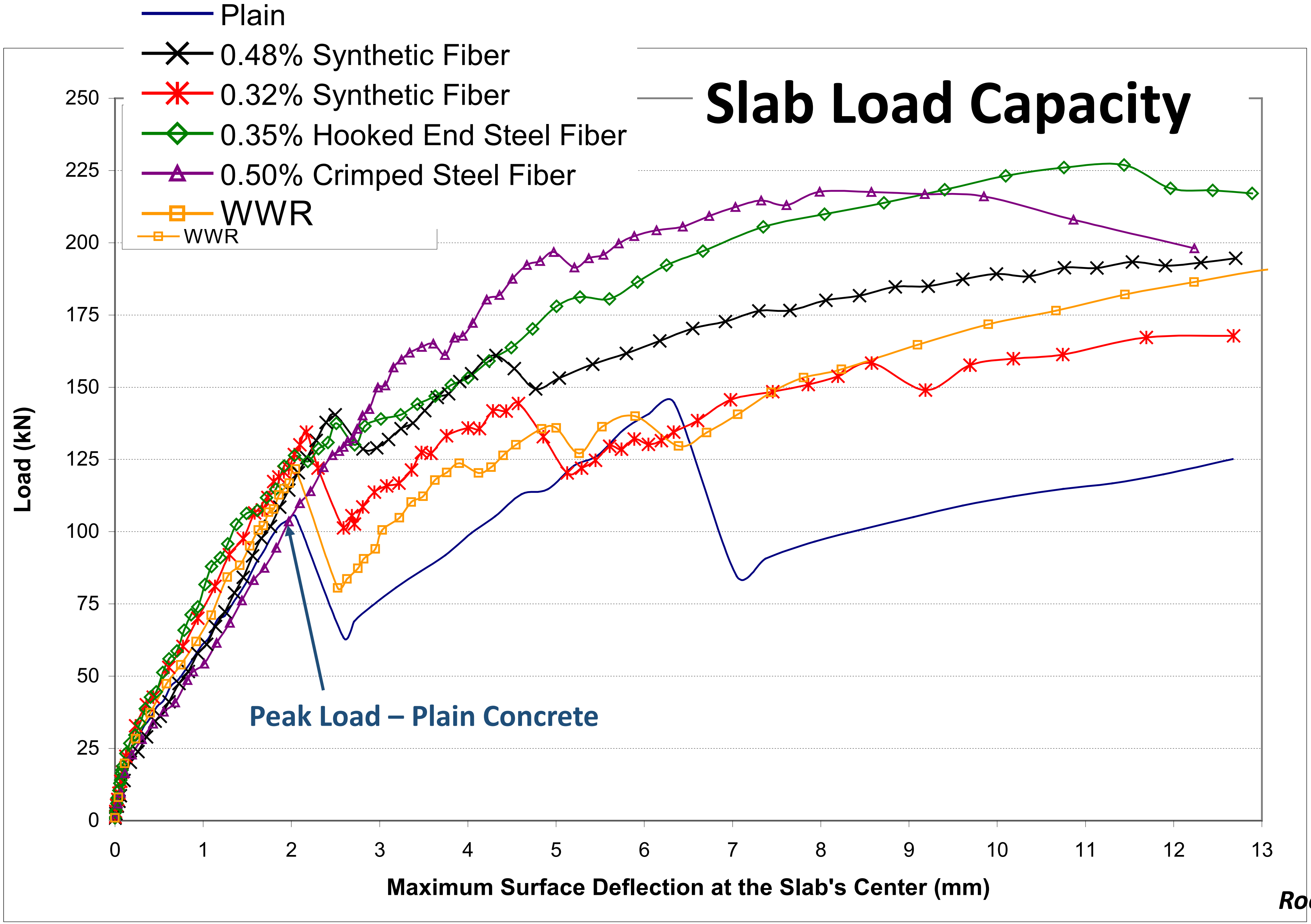
Interior Loading



Edge Loading



Slab Load Capacity



Roesler et al. (2004)

Slab Failure Load Summary (kN)

Roesler et al. (ASCE 2004)

Slab Type	Tensile	Flexural	Ultimate	Slab/Beam Flex. Strength
Plain	75	108	135	1.39
STRUX 90/40 (0.48%)	70	143	195	2.09
STRUX 90/40 (0.32%)	75	135	174	1.82
Dramix 65/60 (0.35%)	70	141	228	2.01
Tabix 1.3/50 (0.50%)	90	167	220	2.22
WWR	65	122	201	1.53

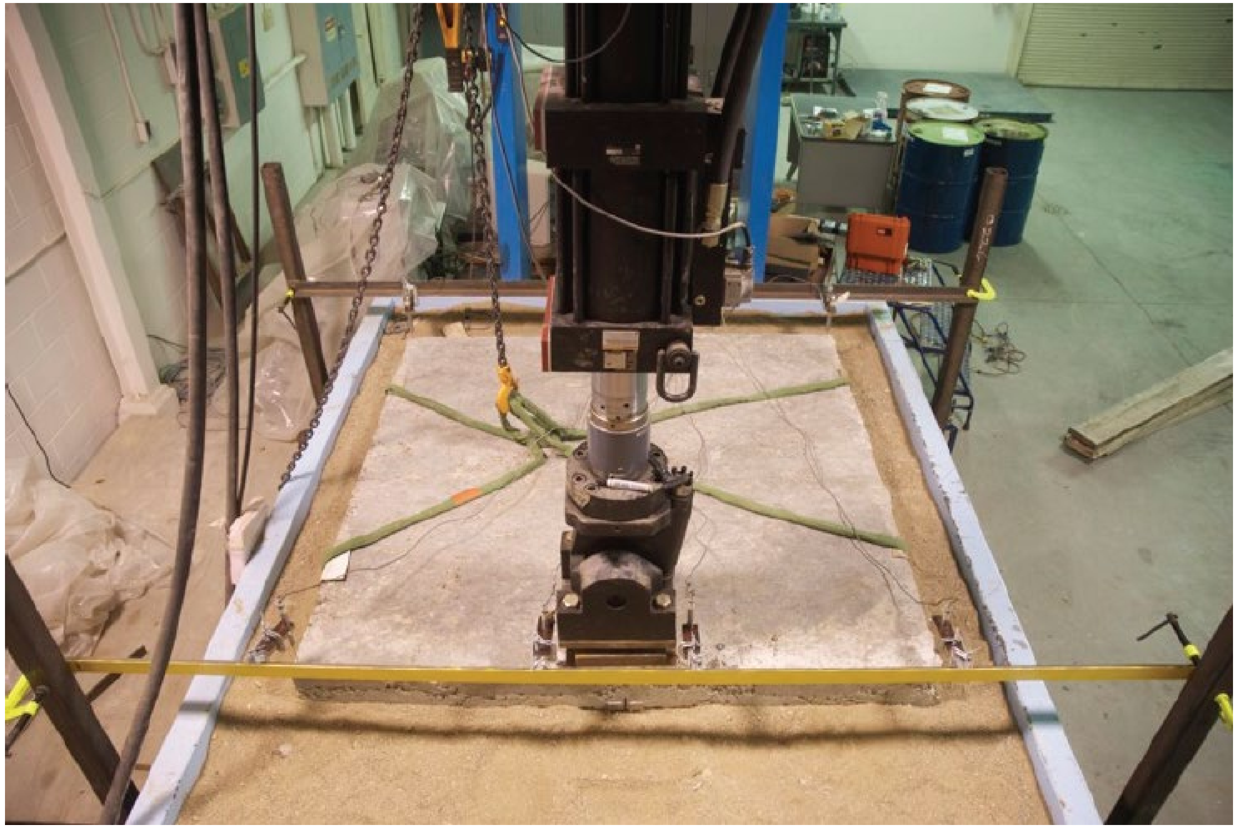
Summary of Concrete Slab Testing (Abridged)

Reference	Concrete Materials	Slab dimensions	Monotonic / Fatigue	Load Location	Slab to beam Strength
Roesler (1998)	Plain Concrete	1.22 x 1.22 x 0.152 m	Both	Edge	1.3
Roesler et al. (2004a)	Plain Concrete	2.0x2.0x 0.15m	Both	Edge	2.8
Kohler (2005)	CRCP[1]	Variable	Fatigue	Edge	>1.0
Rao (2005)	FSHCC[2]	Variable	Fatigue	Edge	2.3
Roesler et al. (2004b, 2006)	Plain and FRC[3]	2.2x2.2x 0.125m	Monotonic	Edge and interior	1.4 Plain; 1.8 to 2.2 (FRC)
Beckett and Humphreys (1989)	FRC and plain	3.0 x3.0 x 0.15m	Monotonic	Interior	2.0 Plain; 2.2 to 3.2 (FRC)
Falkner and Teutsch (1993)	FRC and plain	3.0 x3.0 x 0.15m	Monotonic	Interior	2.1
Jensen and Hansen (2001)	Plain Concrete	3.0 x 1.8 x 0.25m	Monotonic	Uniaxial tension	N/A

Roesler (2006)

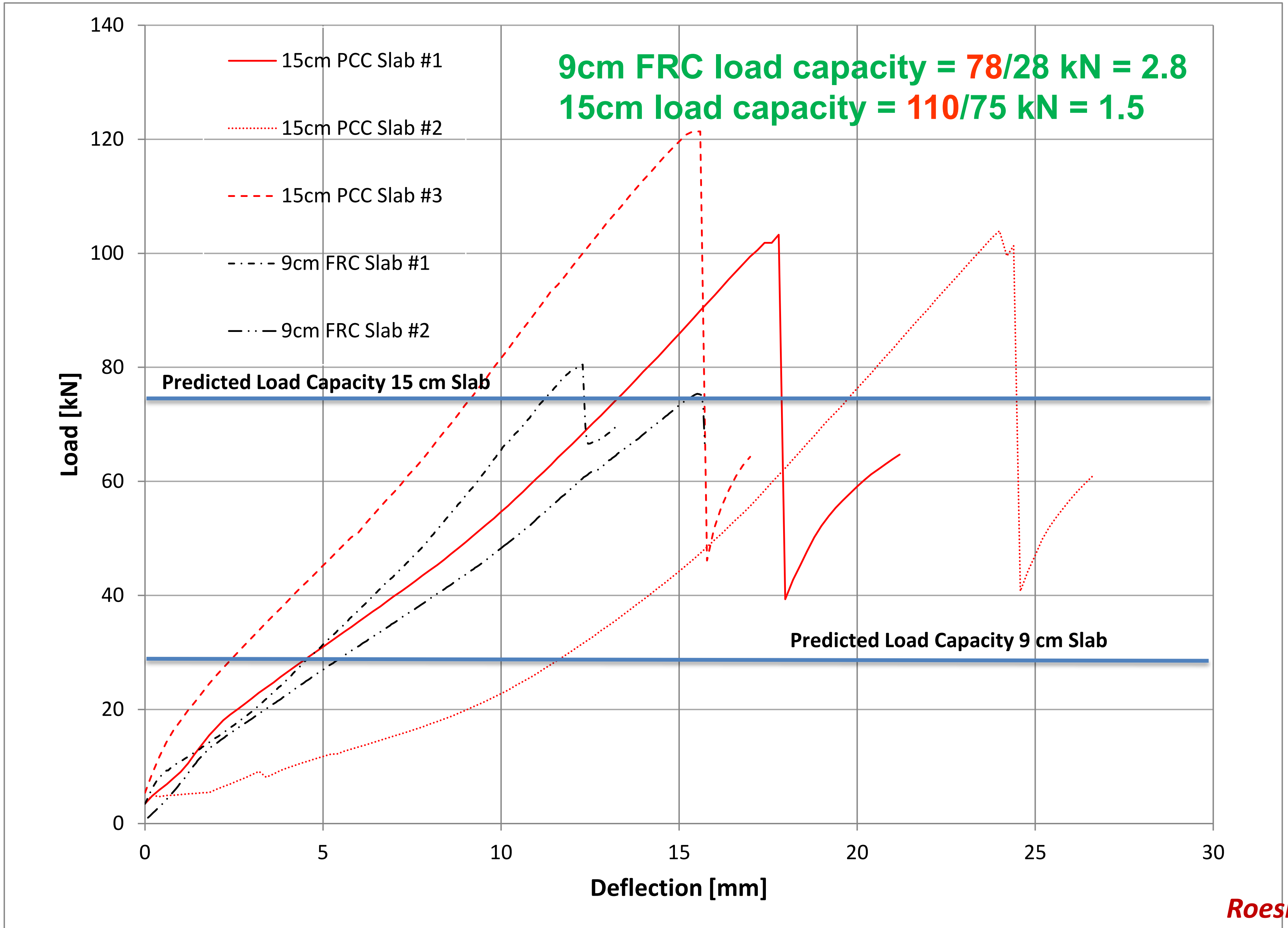
9cm and 15cm Concrete Slab Tests (2010)

1.8m x1.8m slab size by 9cm thick



Edge loading: 9cm (FRC) or 15 cm (plain) thickness

Actual vs. Predicted Slab Capacity



Roesler et al. 2013, IJPE

Short Jointed Slab Fatigue Design

$$\log\left(N_{ijkl}\right) = 2 \times \left(\frac{C_3 \times \sigma_{ijkl}}{MOR \times C_1 \times C_2} \right)^{-1,22}$$

C_1= Slab Geometry & Thickness factor
C_2= macro-fiber correction factor
C_3= Edge loading correction factor

N_{ijkl}= allowable passes for axle position k, curling i (temperature), load level j, and critical top or bottom stress location *l*
σ_{ijkl} = principal stresses calculated with ISLAB2000 for axle position k, curling i and load j, and critical top or bottom stress location *l*
MOR= Flexural strength of concrete at 90 days

Covarrubias, Roesler, Covarrubias (2010)

What does the concrete beam test measure?

- Third-point loading:

$$S_{max} = \frac{P_{max}L}{DH^2}$$

- S_{max} (MOR) = ?
- P_{max} = peak load
- L = span
- H = beam height or depth
- D = beam width

Q#4 - Is it a fundamental material property?

How long have we been studying flexural strength (MOR) for concrete?

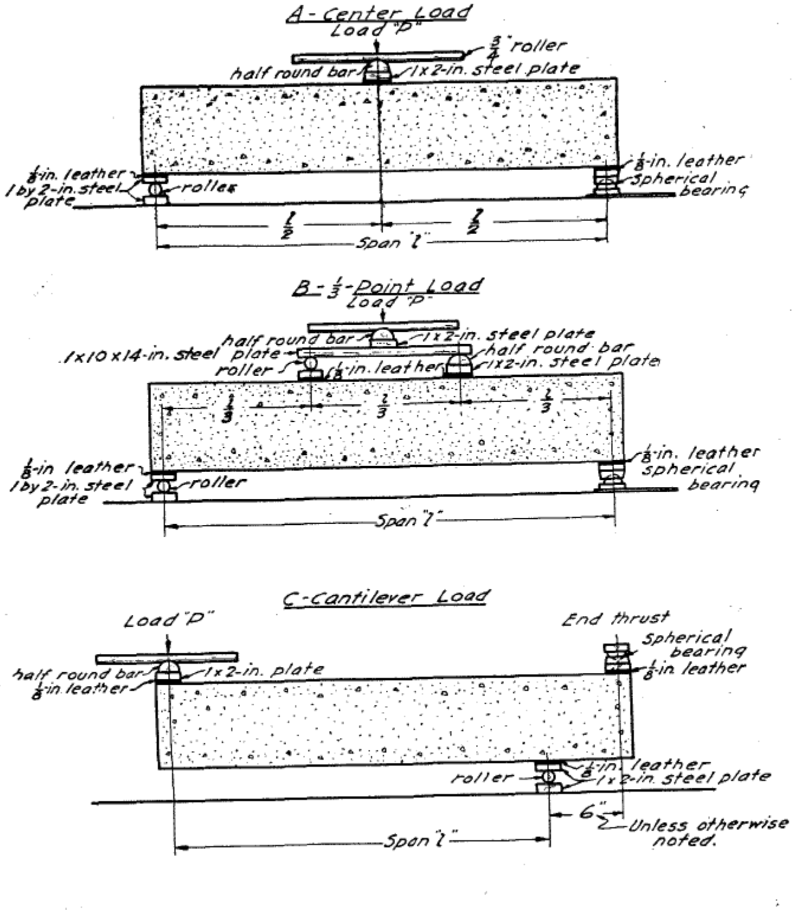


Fig. 16—Methods of Loading Concrete Beams.

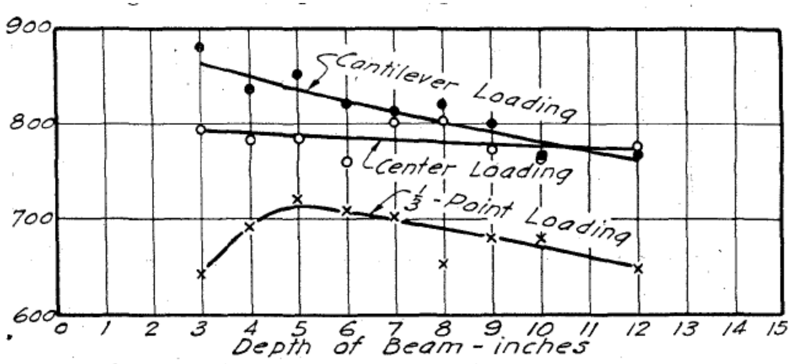


Fig. 17—Relation between Modulus of Rupture and Depth for Constant Width of Beam.

Mix 1-4 by volume. Age at Test, 28 days. Data from Table 1.

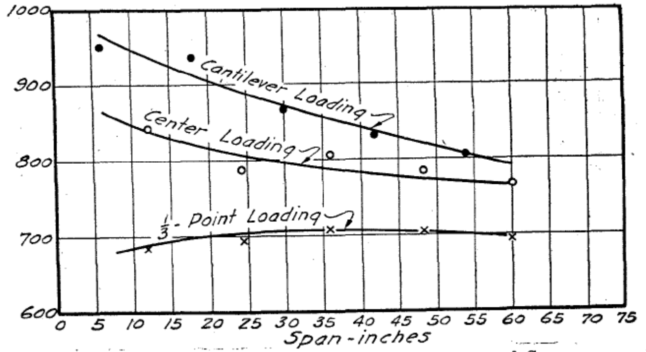


Fig. 20—Relation between Modulus of Rupture and Span.

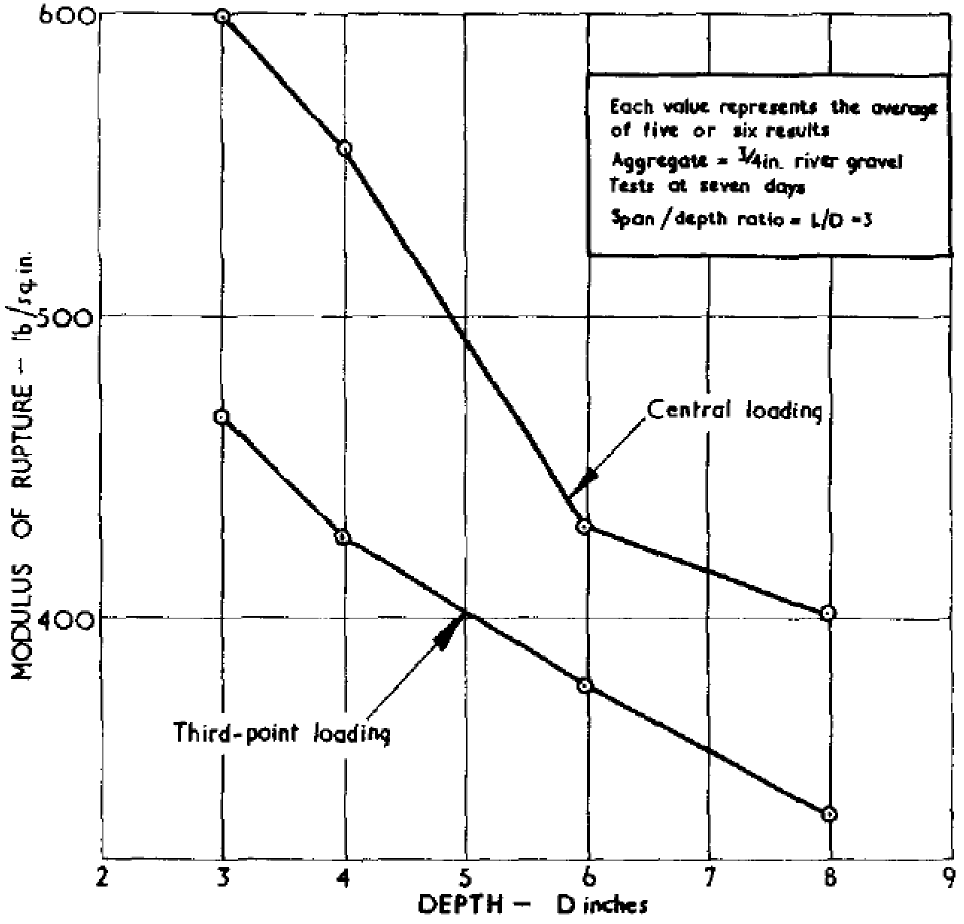
Mix 1-4 by volume. Age at Test, 28 days. Data from Table 1.

(7) The tests show that 1/3-point loading has some important advantages over center and cantilever loading for determining the modulus of rupture of concrete. If, on account of ease of making tests, the cantilever method is preferred, it should be more thoroughly standardized than at present so that tests will be carried out under uniform conditions as to a rate and method of loading,

Curing	Coarse Aggregate	Relative Strengths of Concrete (From curves Fig. 7)—%							
		Compressive Strength				Modulus of Rupture			
		7d.	28d.	3m.	1y.	7d.	28d.	3m.	1y.
Under wet burlap; tested damp		100	100	100	100	100	100	100	100
Air of Laboratory; tested dry	Gravel	90	84	75	65	84	77	78	75
	Limestone	101	85	80	62	95	86	90	87
Air of Laboratory; tested wet	Gravel	91	65	54	49	101	110	96	81
	Limestone	102	62	61	53	110	110	107	98
Air of Laboratory; lower half wet	Gravel	86	64	53	51	104	100	82	70
	Limestone	101	68	62	53	97	83	86	76
Air of Laboratory; paraffin coated; tested as cured	Gravel	88	97	87	81	108	102	93	91
	Limestone	101	93	97	80	119	124	120	103
Air of Laboratory; sodium silicate coated, tested as cured	Gravel	98	89	76	65	101	90	87	76
	Limestone	104	75	72	61	91	85	84	87

Gonnerman and Shuman (1928) – Flexural and Tension Tests of Plain Concrete, *PCA Report*

Other Historical Beam Studies



Wright (1952)

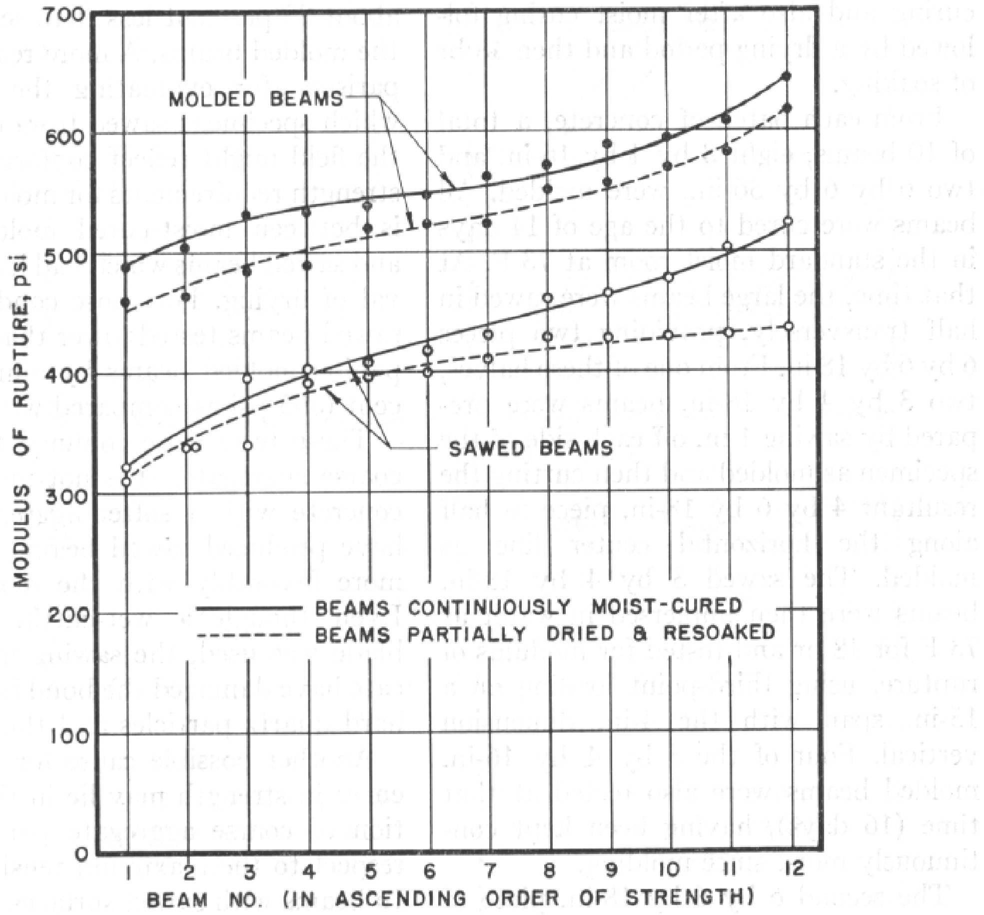


FIG. 4.—Relationship Between Flexural Strengths of Sawed and Molded Beams of Same Concrete (Series 155 E).

Walker and Bloem (1957)

What assumptions have been made incorrectly about beam flexural strength test?

1. *Concrete beam fails when the tensile stress in beam is reached at a critical point/location, e.g., bottom of the beam in the middle third.*
   - No, beams fail when a certain region of the beam exceeds the strength surface [*F(σ)*]; and then nucleates & propagates a crack.

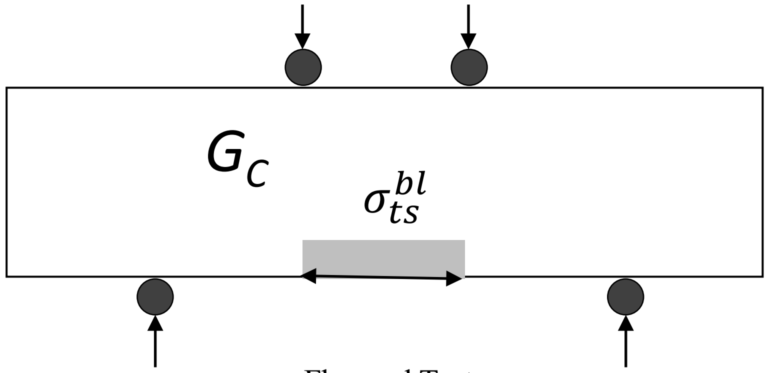
$$\mathcal{F}(\sigma) = \sqrt{J_2} + \frac{\sigma_{cs} - \sigma_{ts}}{\sqrt{3}\,(\sigma_{cs} + \sigma_{ts})} I_1 - \frac{2\sigma_{cs}\sigma_{ts}}{\sqrt{3}\,(\sigma_{cs} + \sigma_{ts})} = 0,$$

2. *Tensile strength of concrete changes with height of the specimen*
   - No, "flexural strength" reduces with ↓ beam height, but the ***tensile strength*** is the same for any specimen height.

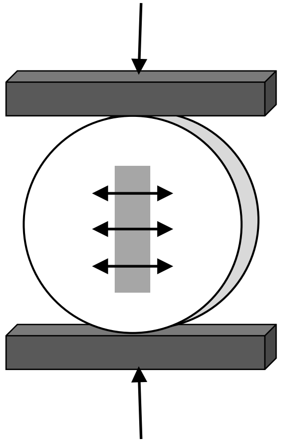
3. *Concrete slabs fail when the applied tensile stress reaches the beam "flexural strength"*
   - No, same as (1) above

What does beam test measure?

- Flexural strength (MOR) combines ***concrete tensile strength, G_C, loading configuration, and specimen geometry*** (*structural strength*)
- Tensile strength near the (bottom) boundary layer of the specimen affects the flexural strength.
- Not true for Brazilian split tensile test – interior of the specimen



Flexural Test



Split Tensile Test

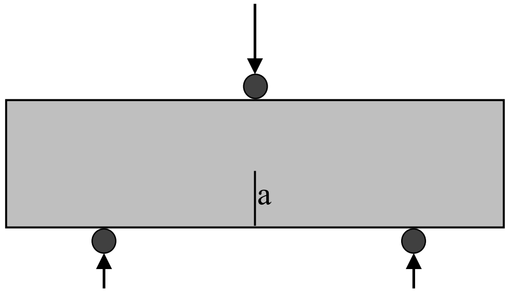
$\sigma_{ts}^{bl} = tensile\ strength\ of\ boundary\ layer$

σ_{ts}^{Int} = tensile strength of interior

$\sigma_{ts}^{bl} = or\ \neq \sigma_{ts}^{Int}$

What is G_C for concrete materials?

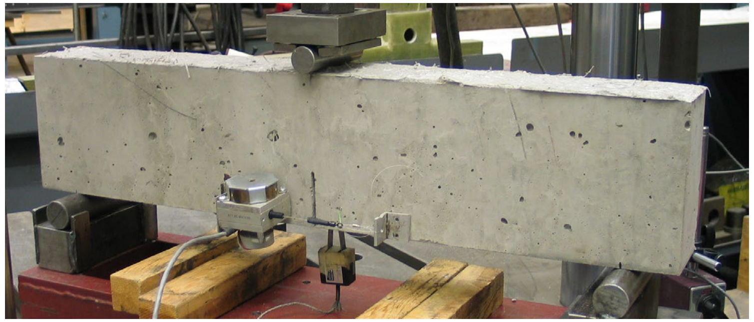
- Critical strain energy release rate or *fracture toughness* (Griffith) - $\mathbf{G_C}$
- Material fracture property
  - minimum energy required to create new material surface
- How do we measure it $\longrightarrow$ Notched specimen tests
- G_C value – 10 to 50 N/m
  - Depends on w/c, aggregates, ITZ, air voids, etc.
  - Toughening mechanisms – fibers



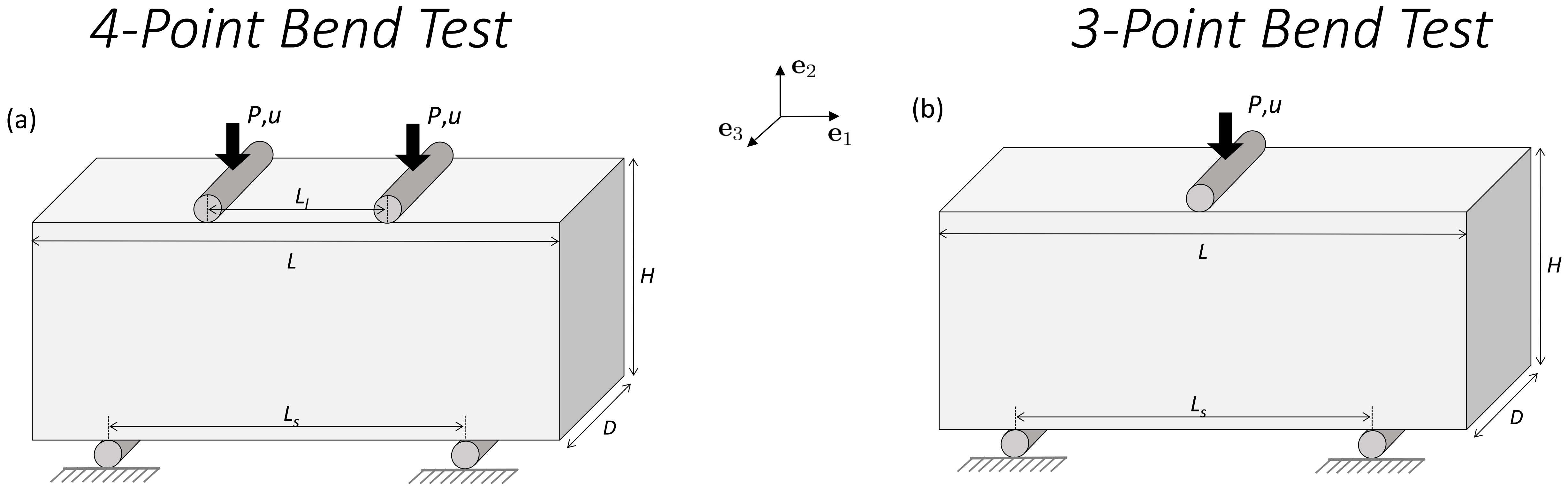
Single Edge Notched Beam

$$
\begin{cases}
\mathrm{Div}\left[v_k^2 \boldsymbol{\sigma}(\mathbf{X}, t_k)\right] = \mathbf{0}, & \mathbf{X} \in \Omega \\
\mathrm{Div}\left[\varepsilon\, \delta^{\varepsilon} G_c \nabla v_k\right] = \dfrac{8}{3} v_k W(\mathbf{E}(\mathbf{u}_k)) + & \\
\dfrac{4}{3} c_{\mathrm{e}}(\mathbf{X}, t_k) - \dfrac{\delta^{\varepsilon} G_c}{2\varepsilon} + \dfrac{8}{3\,\zeta} p(v_{k-1}, v_k), & \mathbf{X} \in \Omega
\end{cases}
$$

Fig. 2. WST specimen setup



Is there a theoretical difference in flexural strength?



$L_s/H = 4$
$L_l/H = 2$
D = H = 1
L= 1.0 m
H = 0.2 m

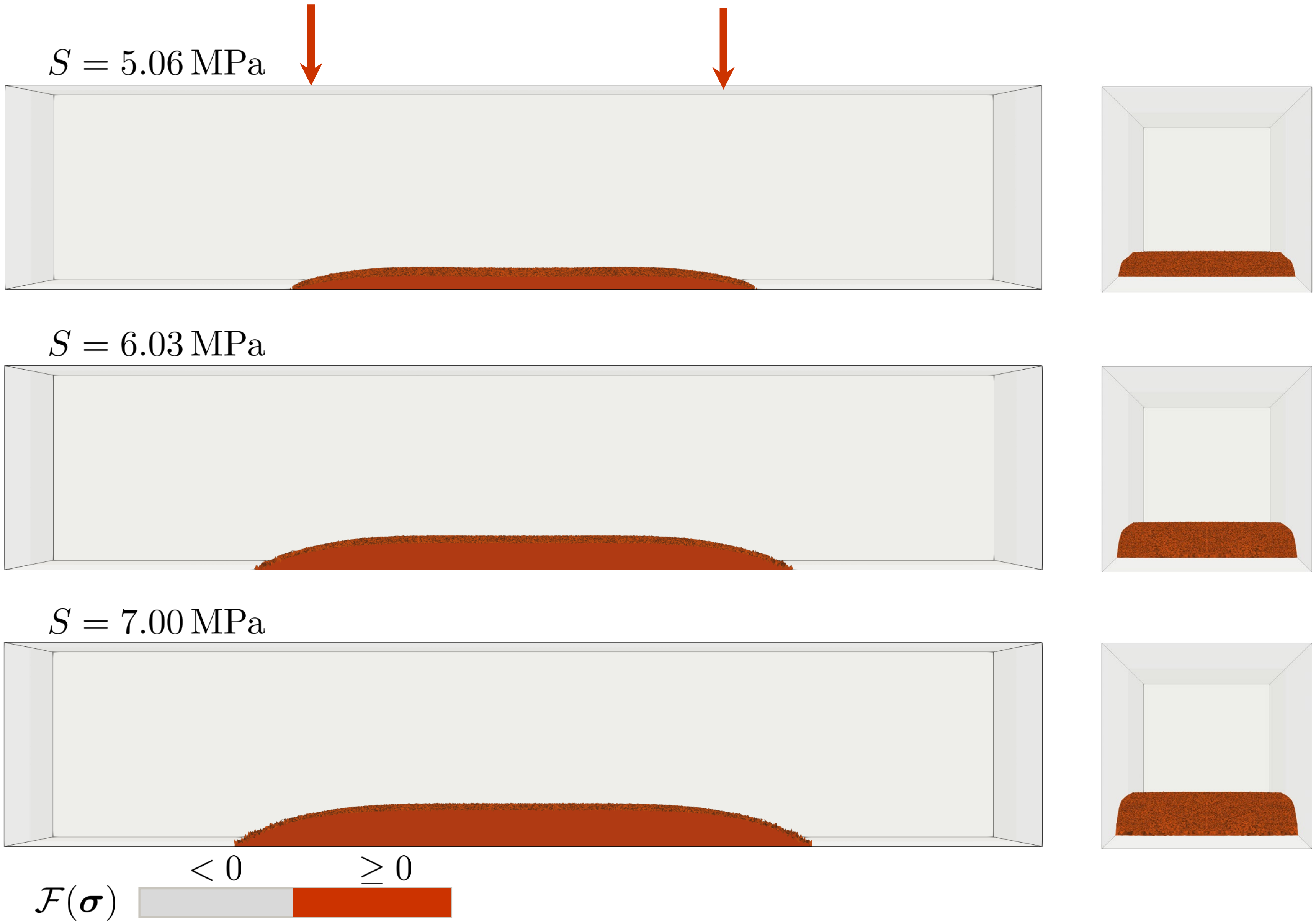
$L_s/H = 4$
$L_l/H = 0$
D = H = 1
L= 1.0 m
H = 0.2 m

Complete Theory of Fracture for Elastic Brittle materials, e.g., concrete, glass, cermaics, elastomers, etc.

1. Must respect material separation of length scales
   - min. H,W=10*D_{max}
2. Must violate strength surface [$F(\sigma)$] in a region for cracks to nucleate
   1. Necessary but not sufficient condition
   2. Cracks can only nucleate in violation set
3. Energetic competition in the set of strength surface violation between elastic energy + G_C*A_c or more elastic energy and no crack extension.
4. ***Min. material properties: σ_{ts}, f'_c, G_C, E_c, v***

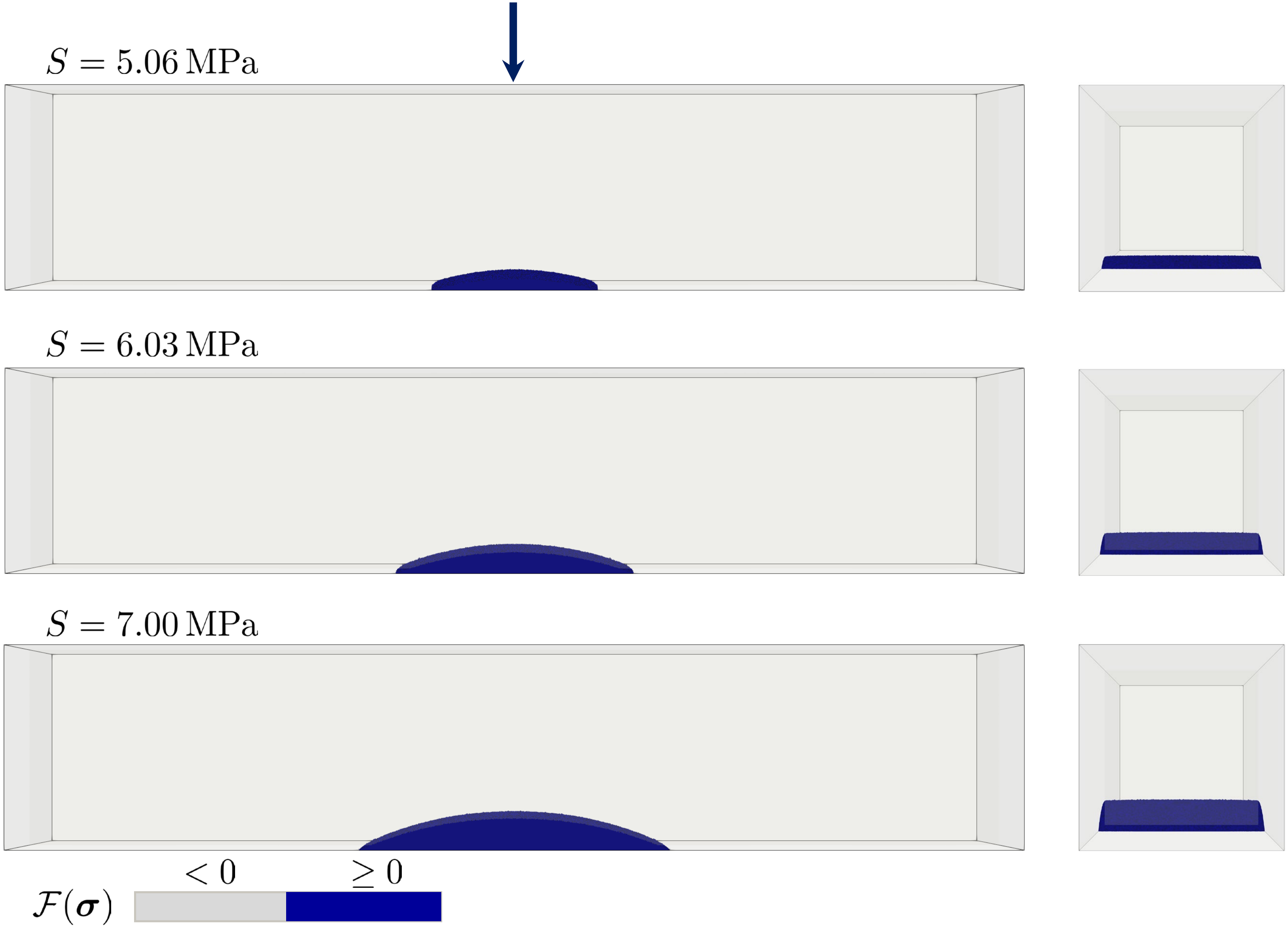
S. Saha, J.R. Roesler, and O. Lopez-Pamies (2026), "Breaking Four-Point and Three-Point Bending Tests," *International Journal of Solid and Structures*, V.339, https://doi.org/10.1016/j.ijsolstr.2026.114169.

Violation of Strength Surface – 4-pt. loading



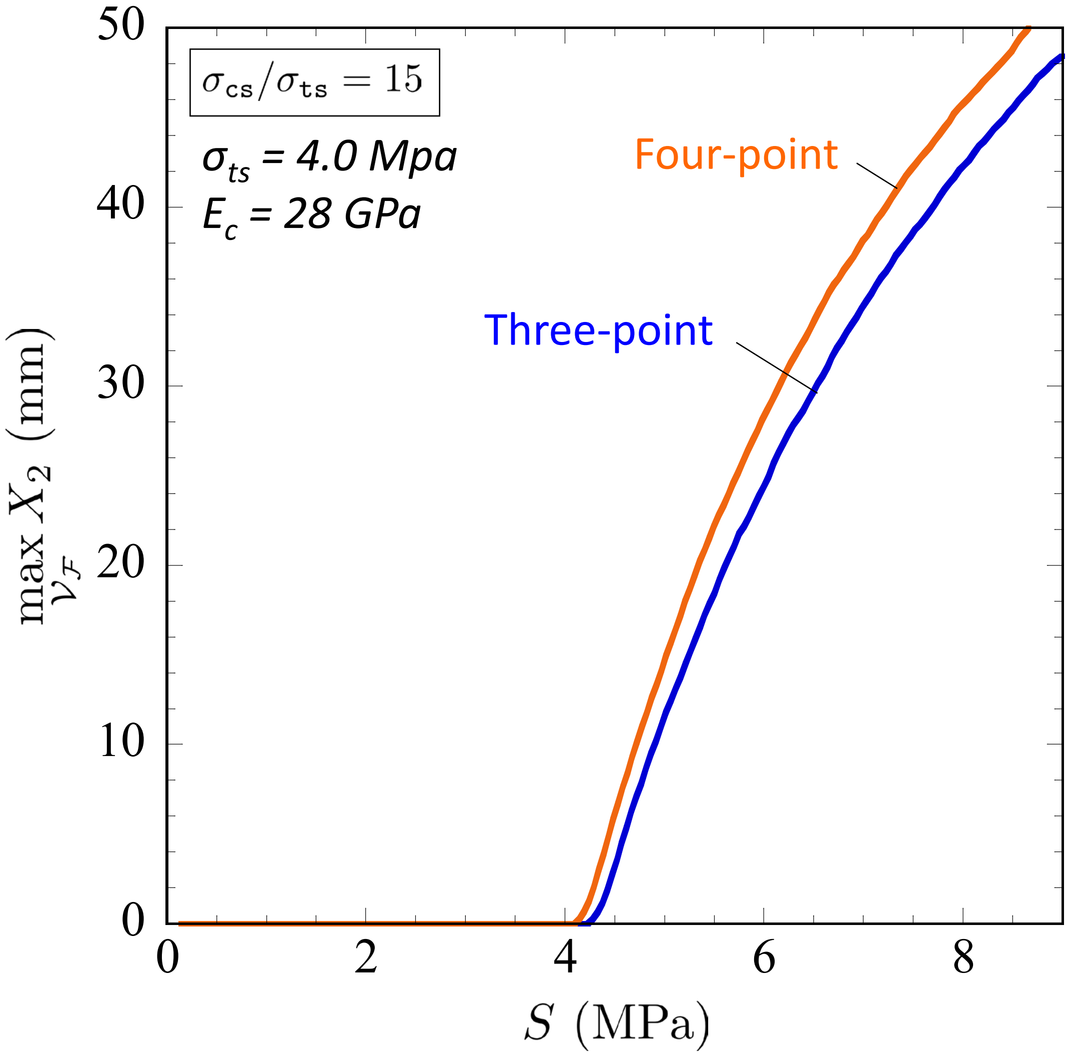
7 MPa ~ 1 ksi

Violation of Strength Surface – 3-pt. loading



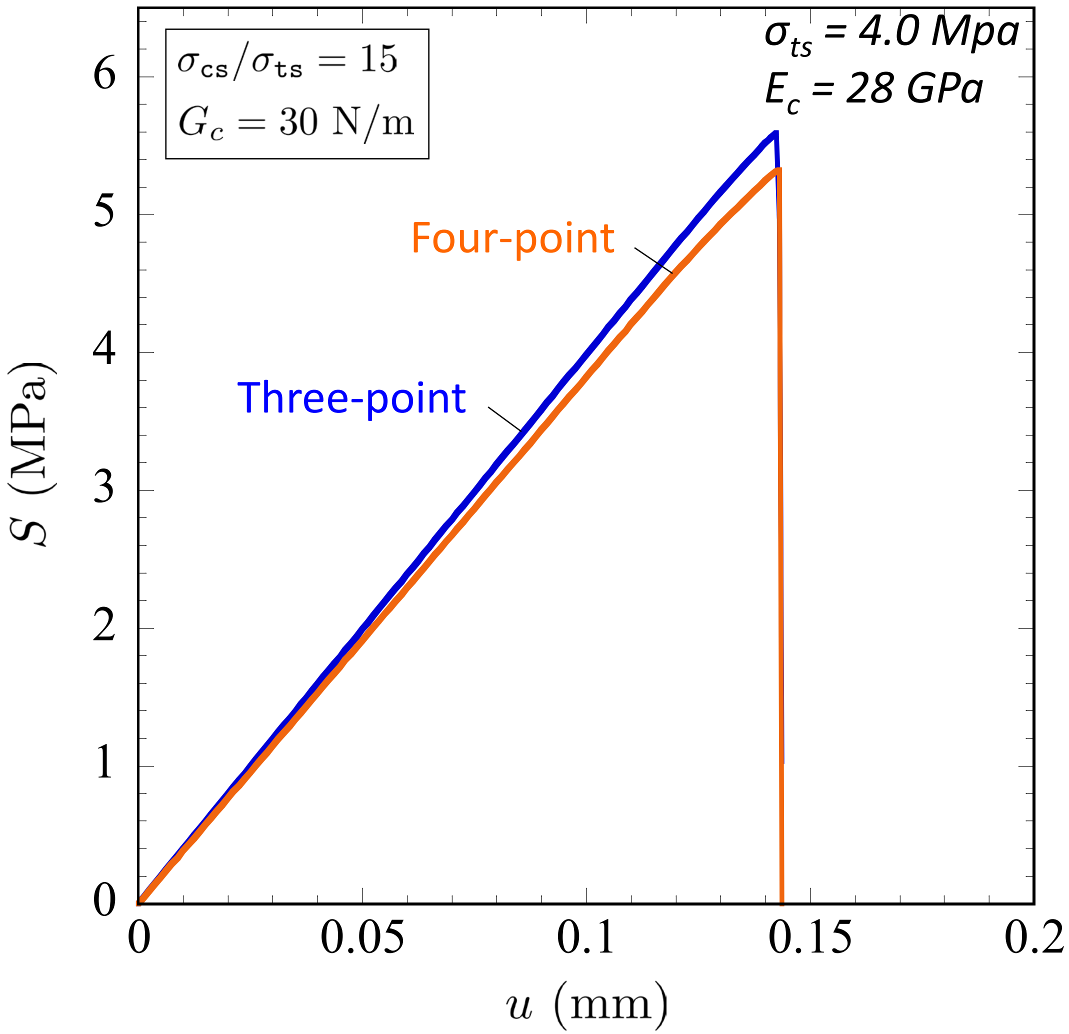
7 MPa ~ 1 ksi

Strength Surface Violation
Beam Height Comparison



7 MPa ~ 1 ksi

Difference in 3-pt & 4-pt flexural strength (S_{max})

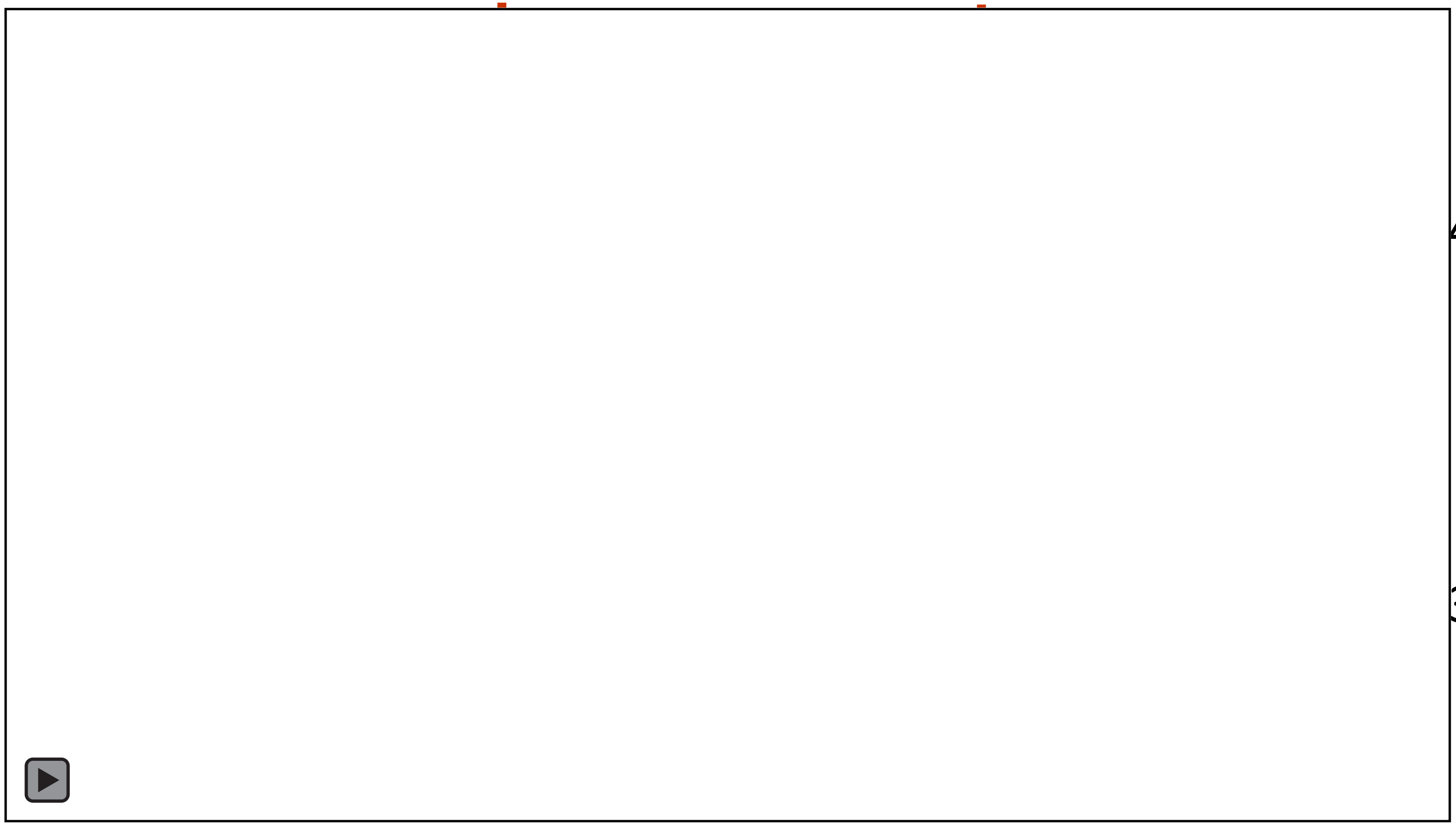


σ_{ts} = tensile strength
σ_{cs} = tensile strength
E_c = elastic modulus
G_C = fracture toughness

7 MPa ~ 1 ksi

Crack Nucleation / Propagation

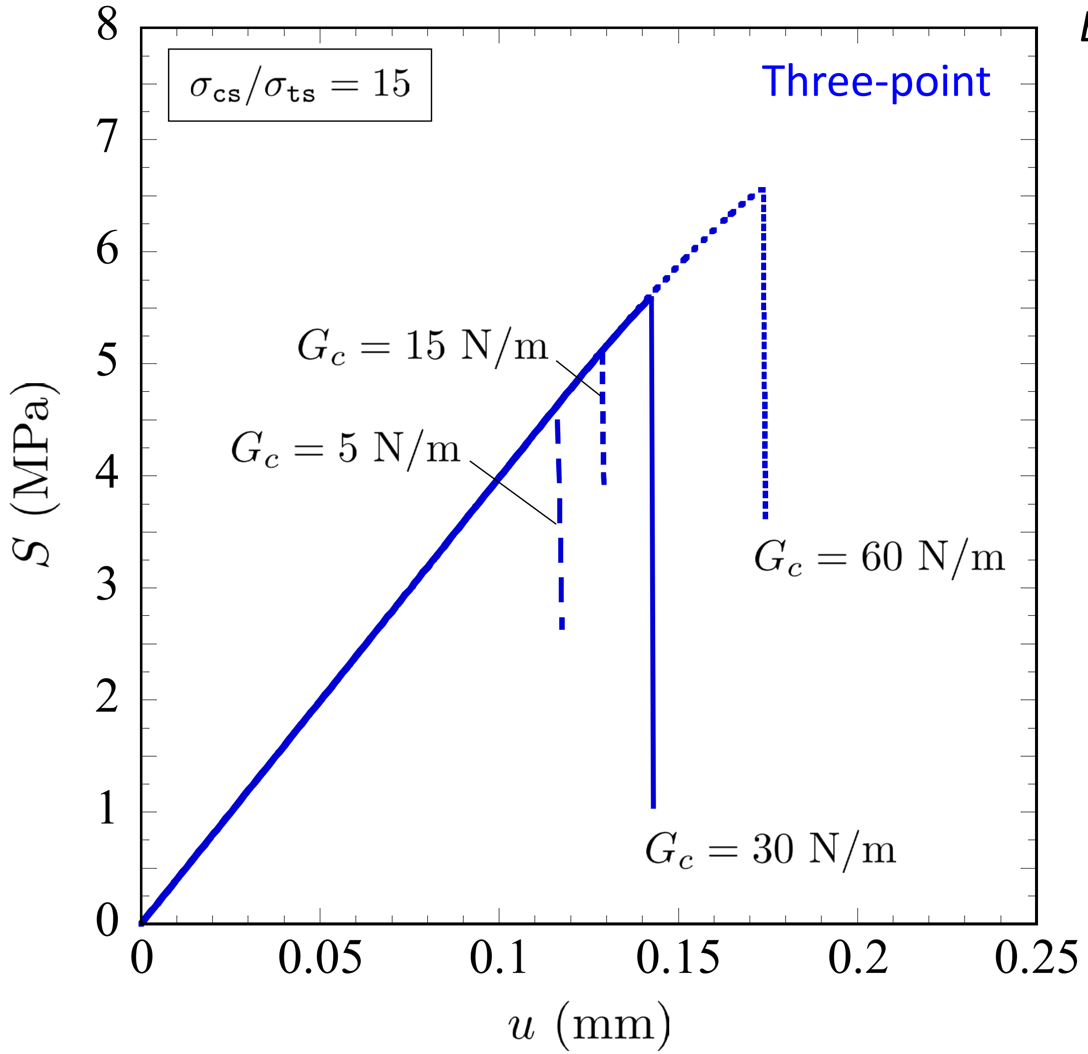
3-pt & 4-pt beams



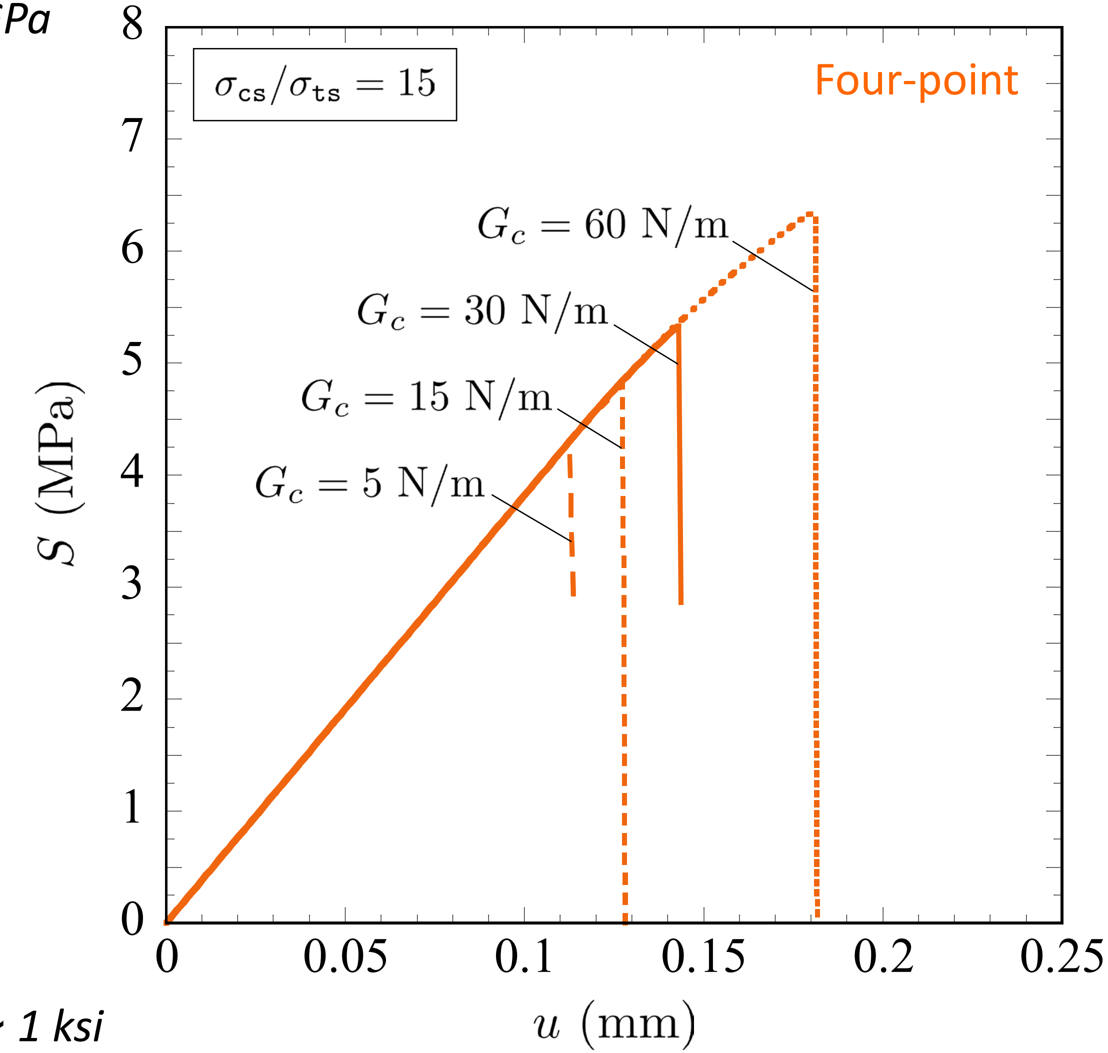
4-pt

3-pt

Comparing S_{max} for 3-pt vs 4 pt and varying G_C



σ_{ts} = 4.0 MPa
E_c = 28 GPa

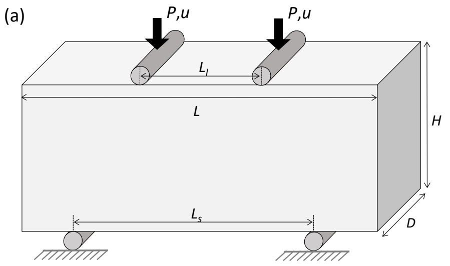


7 MPa ~ 1 ksi

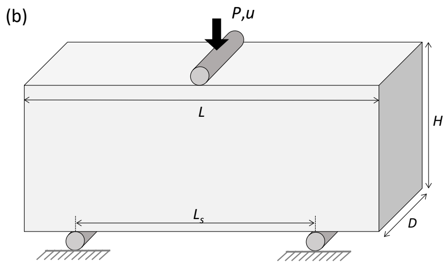
Predicting Beam "Flexural" Strength

$$S_{max} = S_{max}\left(\frac{L_s}{H}, \frac{D}{H}, H, \frac{L_l}{H}, \sigma_{\mathtt{ts}}, \frac{EG_c}{\sigma_{\mathtt{ts}}^2}\right). \quad \textbf{(1)}$$

$$S_{max} = g\left(\frac{L_s}{H}, \frac{D}{H}, \frac{L_l}{H}, \frac{EG_c}{H\sigma_{\mathtt{ts}}^2}\right)\sigma_{\mathtt{ts}}, \quad \textbf{(2)}$$



$$\ell_{\mathtt{ts}} = \frac{EG_c}{\sigma_{\mathtt{ts}}^2}. \quad \textbf{(3)}$$



$$S_{max}^{4p} = \left(1 + \alpha\left(\frac{EG_c}{H\sigma_{\mathtt{ts}}^2}\right)^{\beta}\right)^{\gamma}\sigma_{\mathtt{ts}} \quad \text{with} \quad \begin{cases} \alpha = 1.567 \\ \beta = 0.775 \\ \gamma = 0.678 \end{cases}. \quad \textbf{(4)}$$

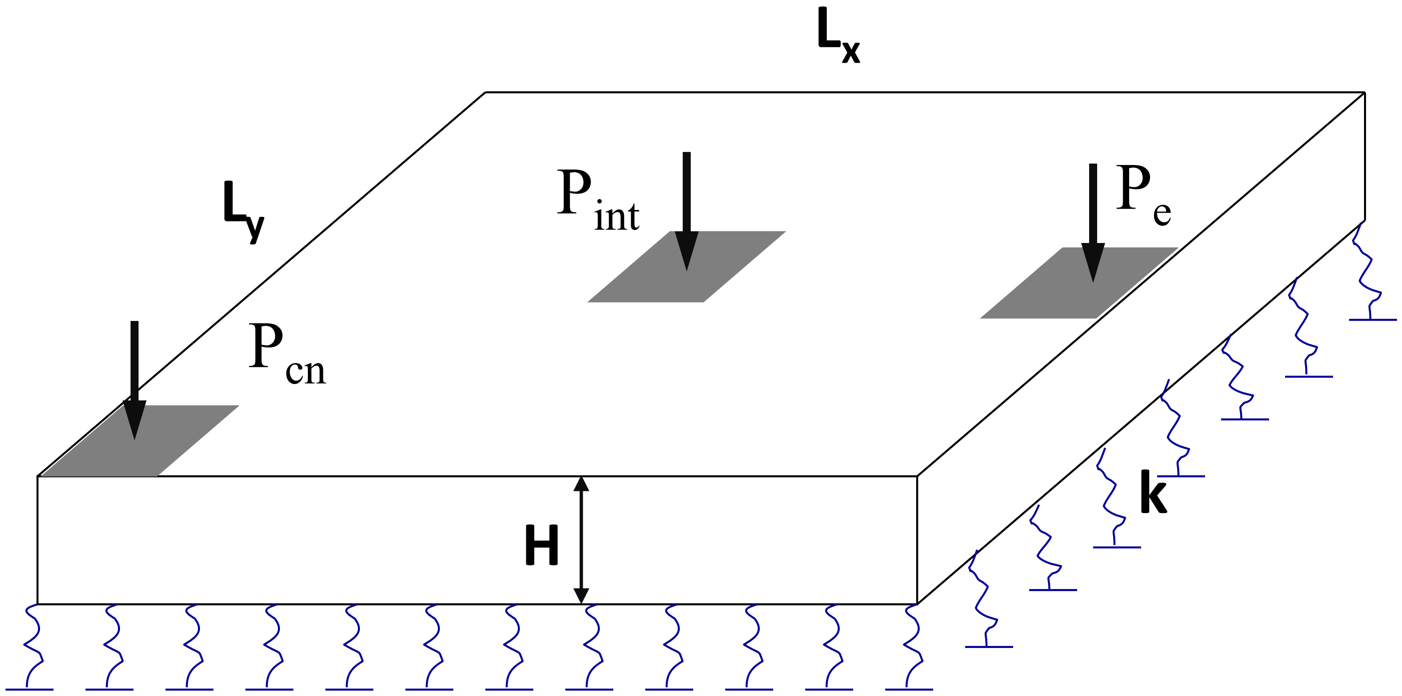
$$S_{max}^{3p} = \left(1 + \alpha\left(\frac{EG_c}{H\sigma_{\mathtt{ts}}^2}\right)^{\beta}\right)^{\gamma}\sigma_{\mathtt{ts}} \quad \text{with} \quad \begin{cases} \alpha = 1 \\ \beta = 0.621 \\ \gamma = 1 \end{cases} \quad \textbf{(5)}$$

Summary of 3-pt vs. 4-pt bending test

- For same concrete (w/o voids/defects), 3-pt and 4-pt beam test will give at least 6-9% difference (depends on H, L/H)
  - Higher diff. with lower L/H and material heterogeneity (20%-25%)
- Beam's boundary layer tensile strength and stochasticity greatly affects flexural strength values!!
  - 4-pt reflects minimum σ_{ts}^{bl} while 3-pt reflects the mean σ_{ts}^{bl}
- Need to measure σ_{ts} , G_C, and E_c to predict <u>slab capacity</u>

Slab Capacity – The Goal

$$F^{j}_{max} = f(L/RRS,\ a/RRS,\ L_x/L_y, \frac{\sigma_1}{\sigma_2},\ l_{ch}/H) * \sigma_{ts}$$



Summary of Concrete Strength (Denominator)

- MOR or Flexural Strength is "strength" standard for slabs but has *many limitations*
- Slab "strength" or capacity is much larger than beam strength
  - FRC slab strength > Plain concrete slab strength
- Slab design → Use slab flexural capacity
  - Depends slab geometry, loading, concrete materials, fibers, etc.
- Beam flex. strength (MOR)
  - Depends on σ_{ts}, G_C, E, and υ
- Slab capacity calculation is the goal for denominator!

Acknowledgements

- Slab Tests – many UIUC graduate students (2001-2015)

- Professor Oscar Lopez-Pamies
  - Professor, Civil & Environmental Engineering, University of Illinois
- Subhrangsu Saha
  - Graduate research student, CEE, University of Illinois

Slab Design Webinar

Noon – 12.10	Nigel Parkes | **The Need & Introductions**
12.10 –12.30	Juan Pablo Covarrubias | **The How & Proof of Concept**
12.30 – 12.55	Dr. Lev Khazanovich | **The Numerator**
12.55 – 1.20	Dr. Jeff Roesler | **The Denominator**
1.20 – 1.30	Nigel Parkes | **Curl Data Collection**
1.30 – 2.00	Robert Rodden | **The SLABS™ Software Demo & Work Queue**
2.00 – 2.20	All | **Questions & Answers**
2.20 – 2.30	Nigel Parkes | **Closing Remarks and Next Steps**

Sponsored by

THE SLAB DESIGNER.

Slab Design Workshop

Sponsored by