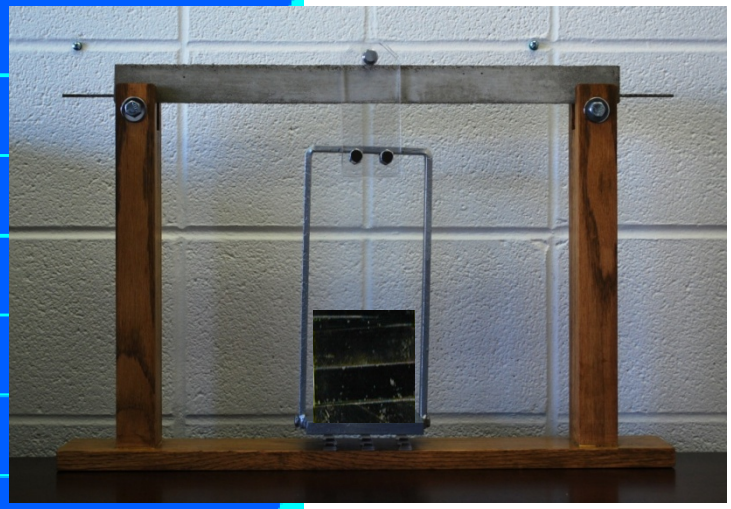
PCA

Concrete Technology and Codes

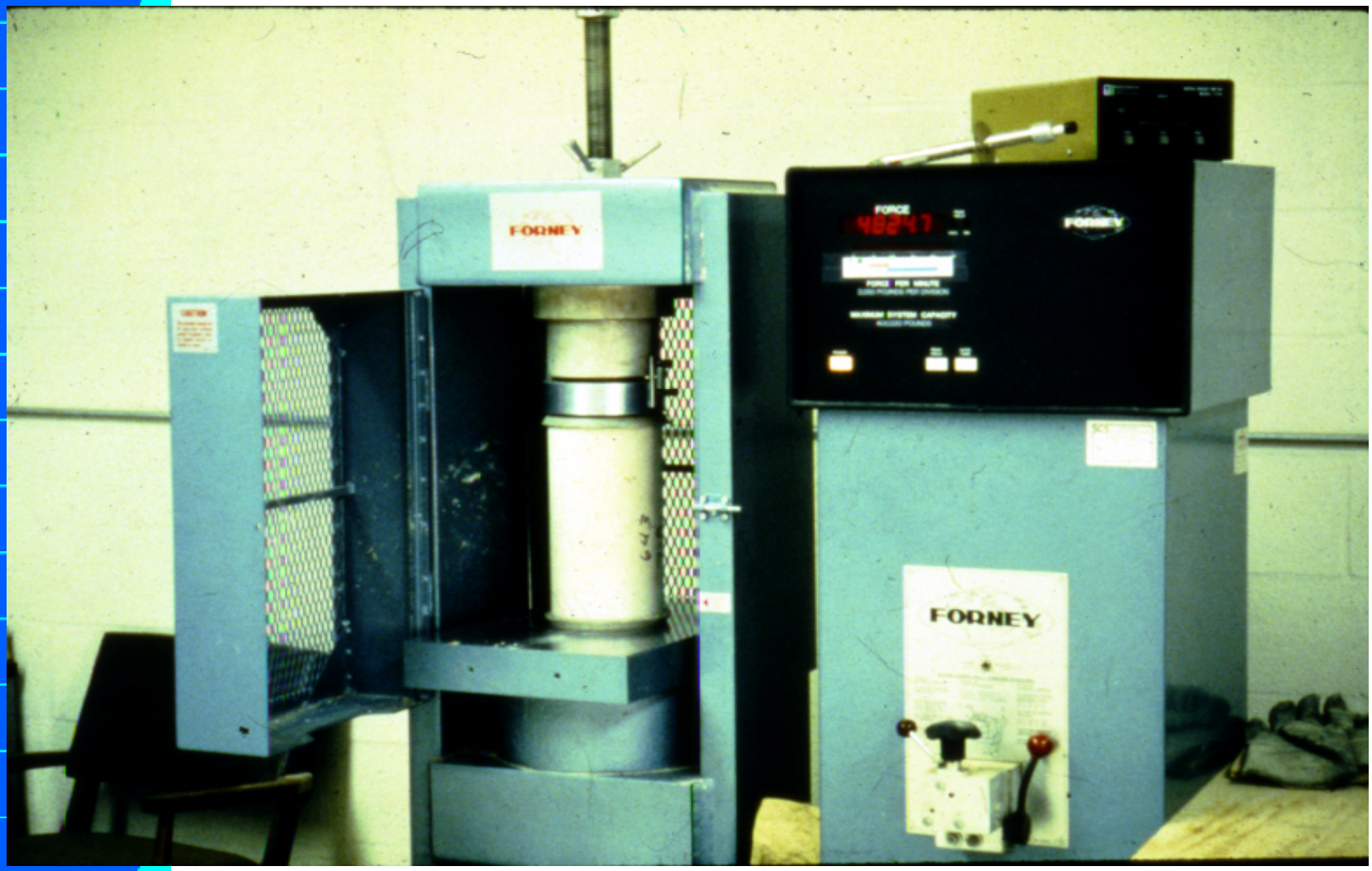
Reinforced Concrete

Outline



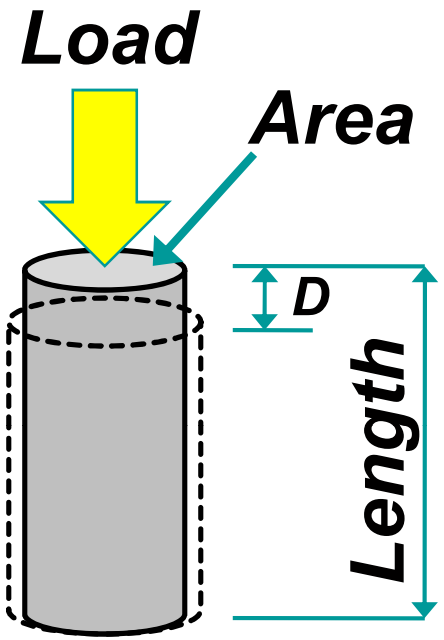
- Basic Material Properties
  - Concrete
  - Reinforcement
- Reinforced Concrete
  - Flexure
  - Bond
  - Shear
  - Creep and Shrinkage
- Prestressed & Post-tensioned Concrete

Compression Machine



Compression Testing to Failure

Definitions



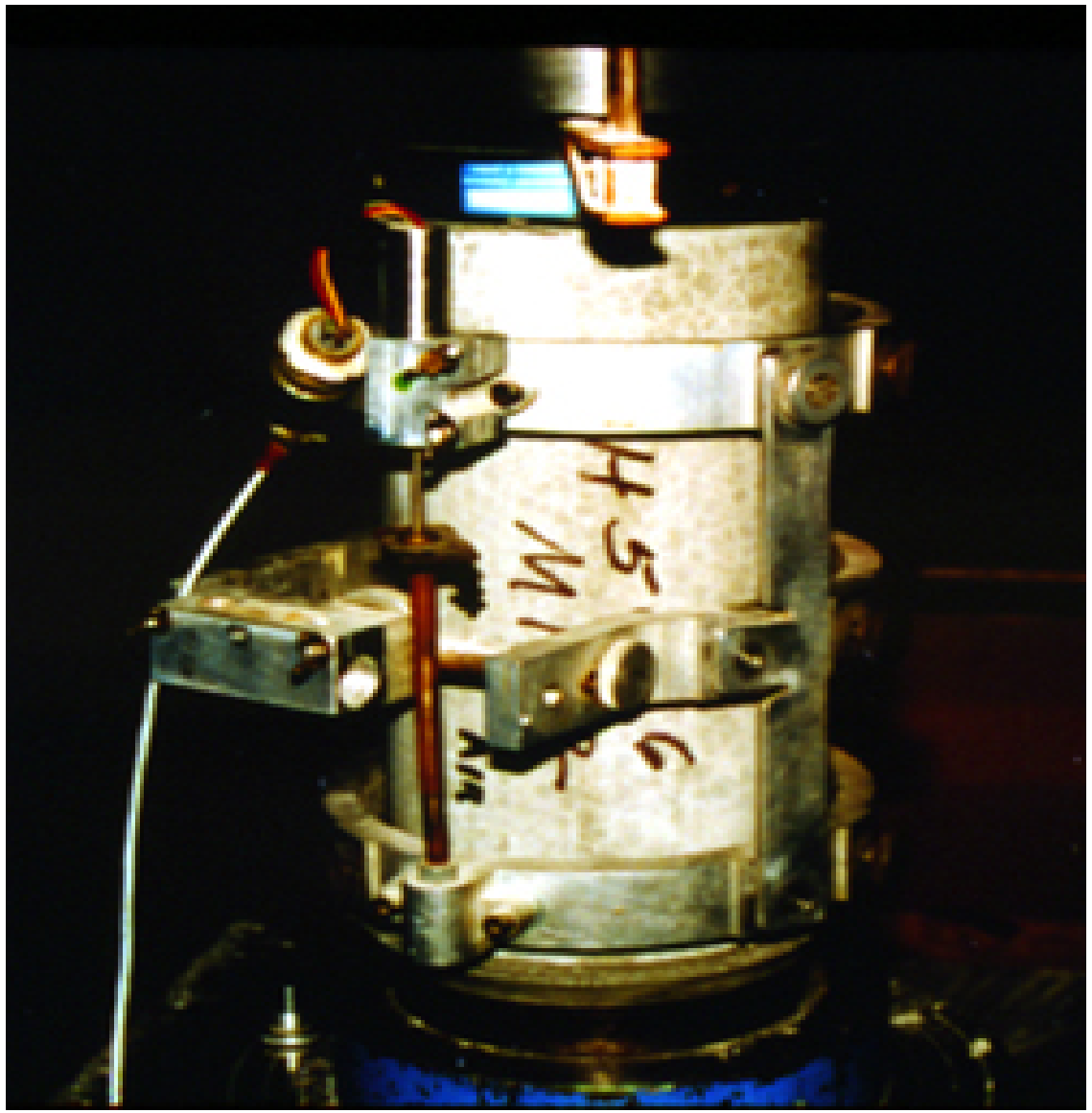
$$Stress = \frac{Load\,(lbs)}{Area\,(in.^2)} = psi$$

$$Strength = Maximum\ Stress$$

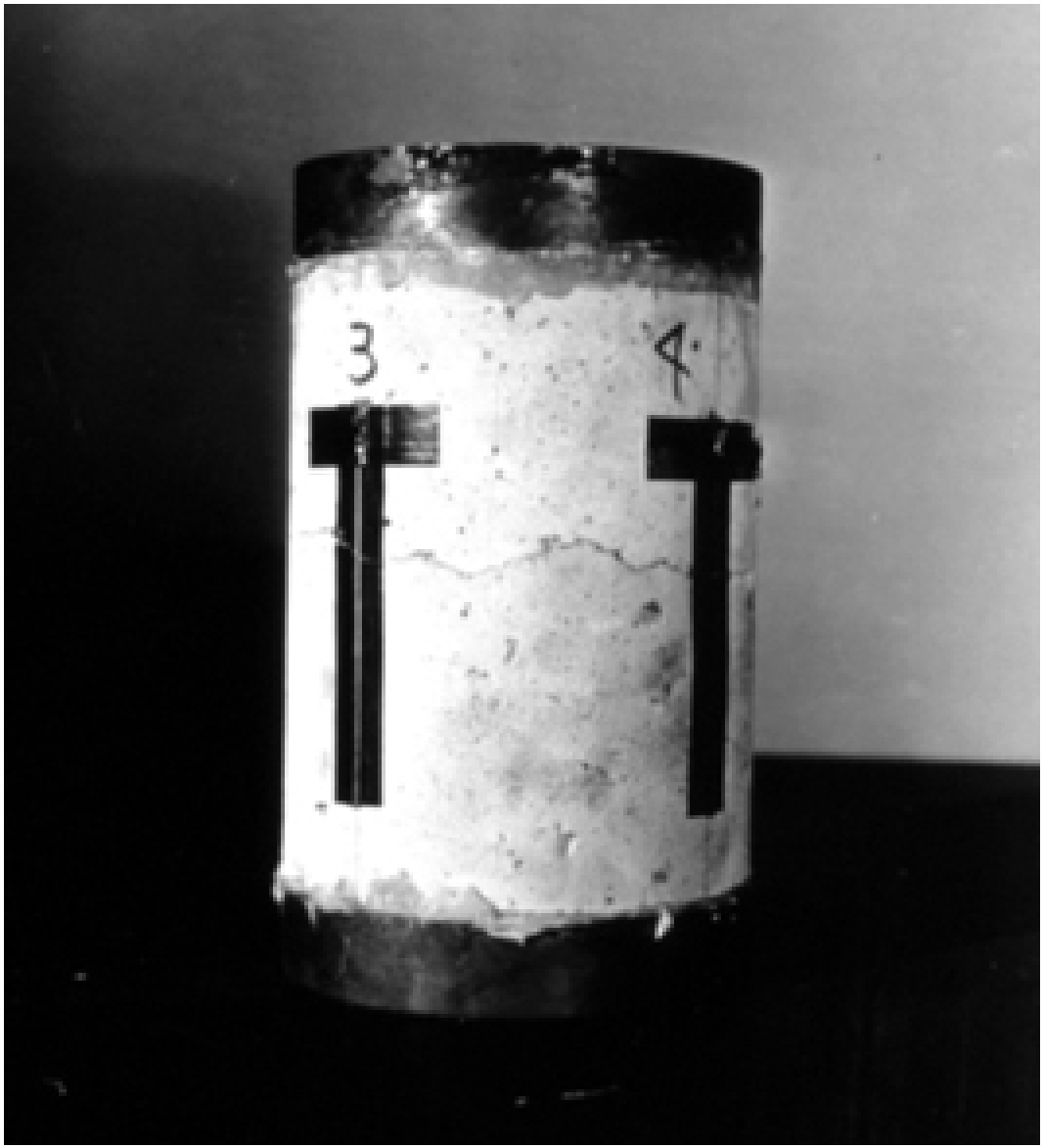
$$Strain = \frac{Deformation\,(in.)}{Original\ Length\,(in.)}$$

High-Strength Concrete

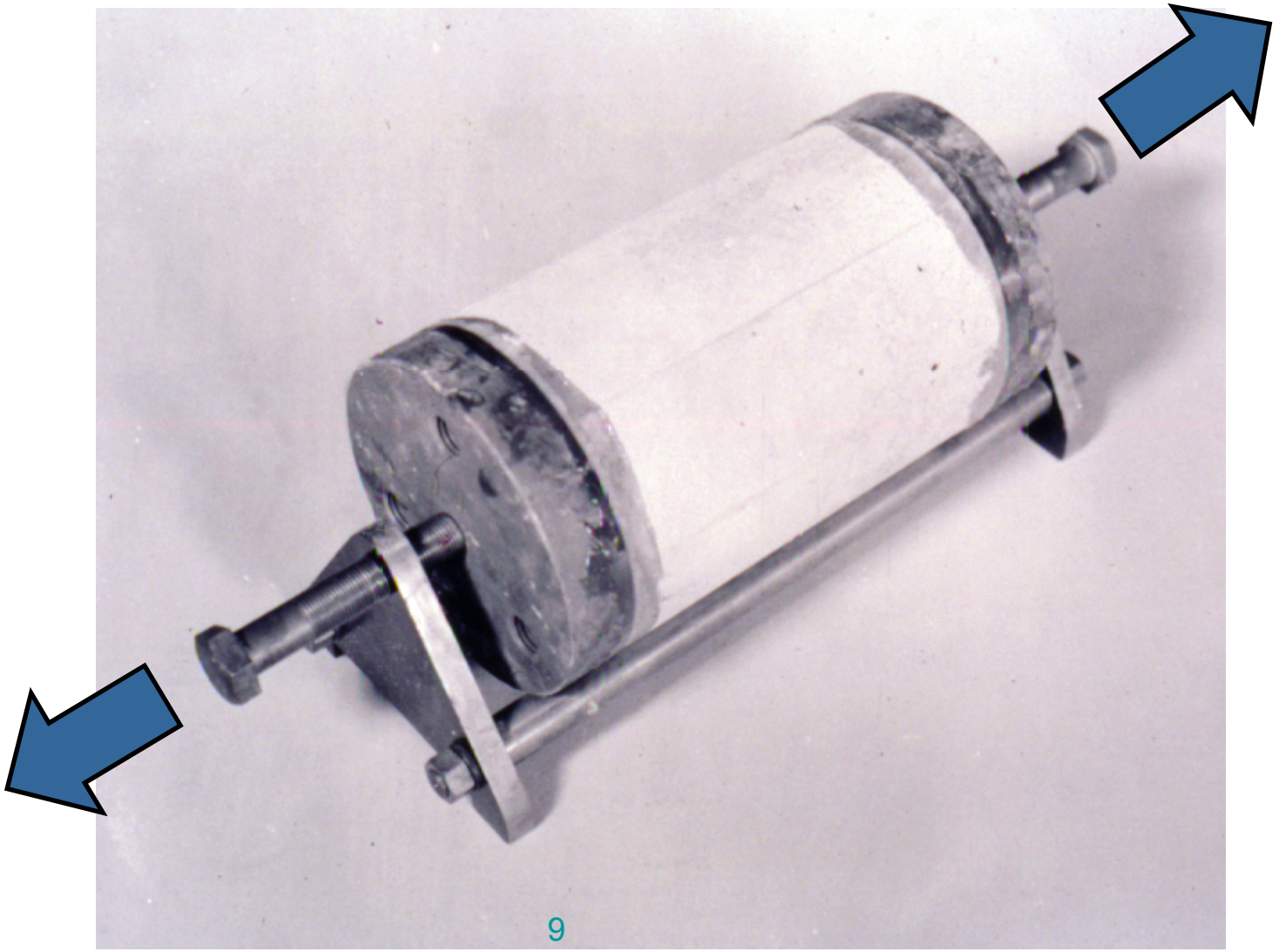
Compressometer



Strain Gage on Cylinder

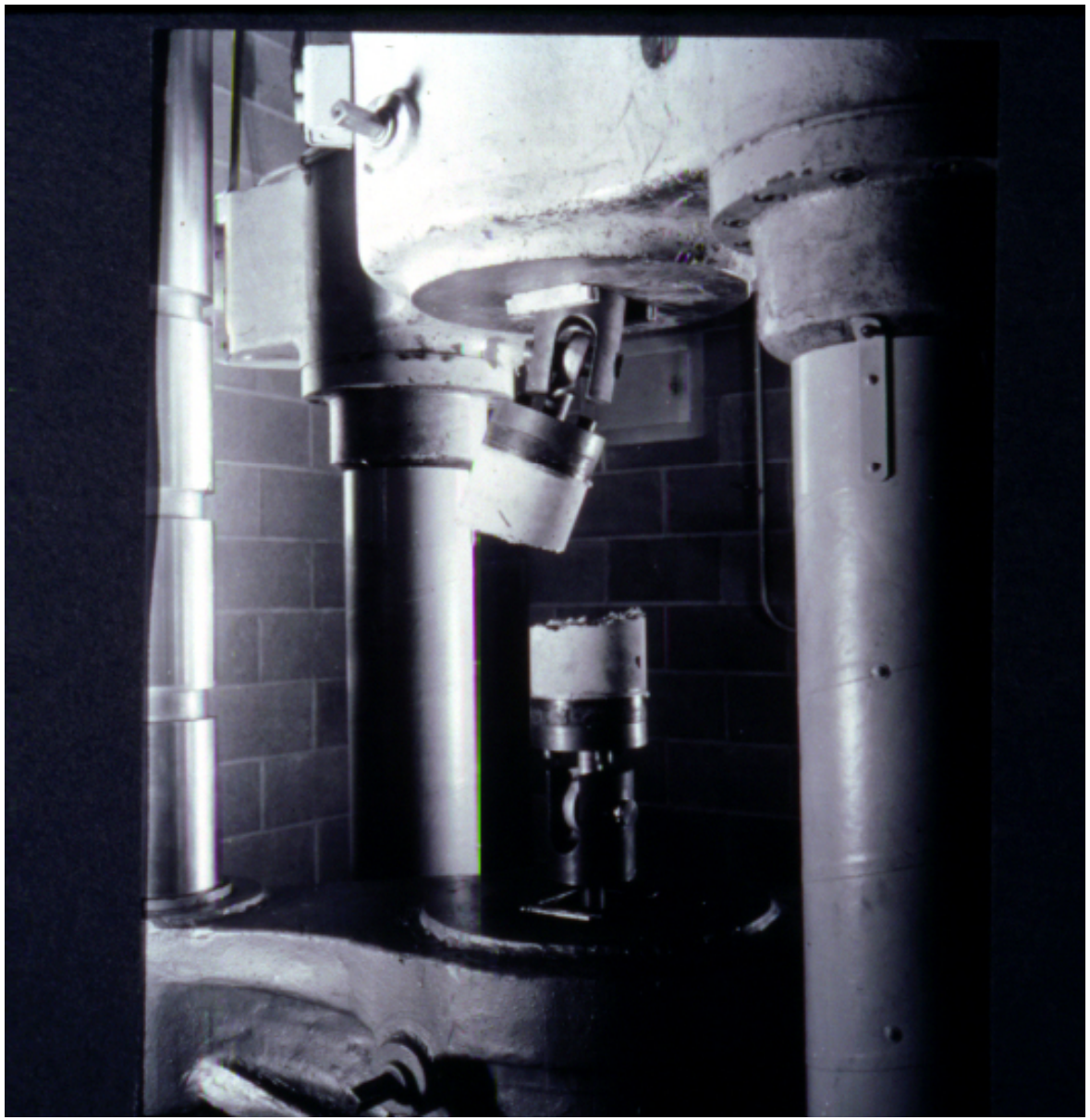


Direct Tension Test Specimen

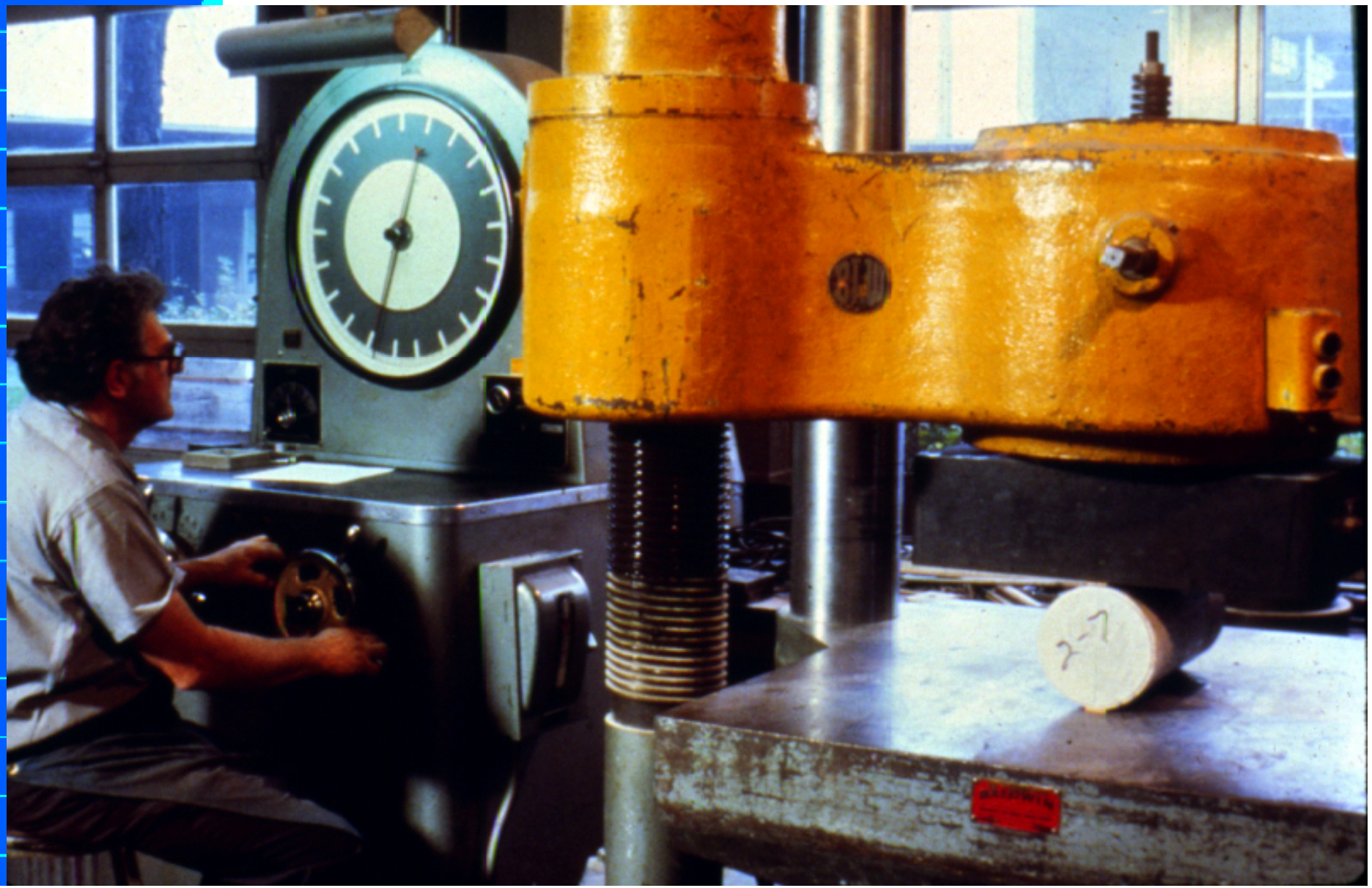


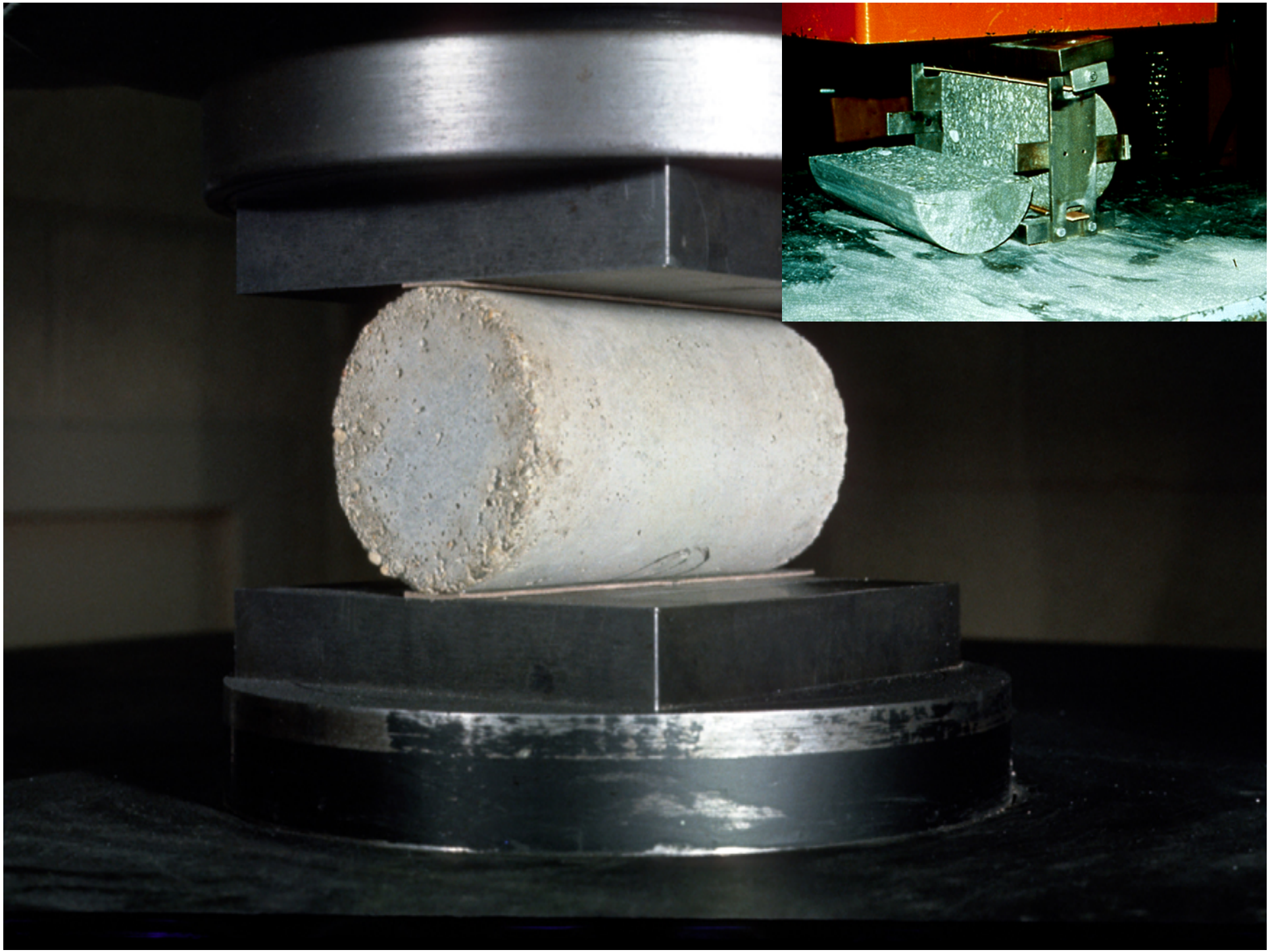
Direct Tension Test Setup

Direct Tension Failure



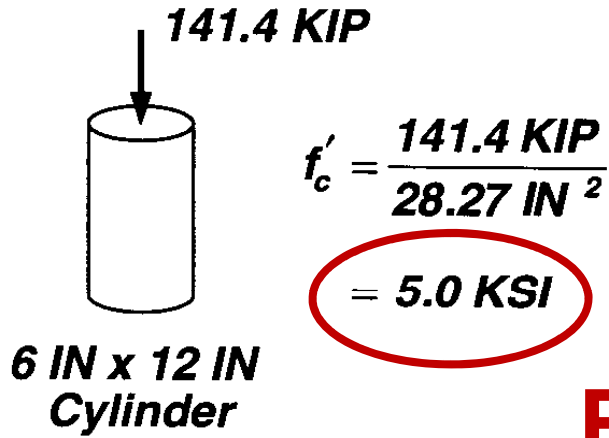
Splitting Tensile Test



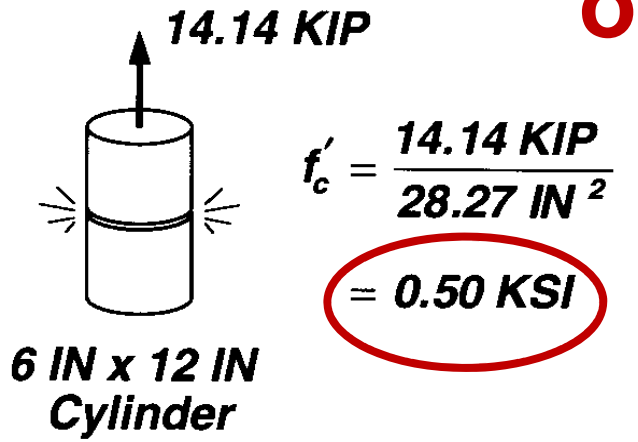


Characteristics of Concrete

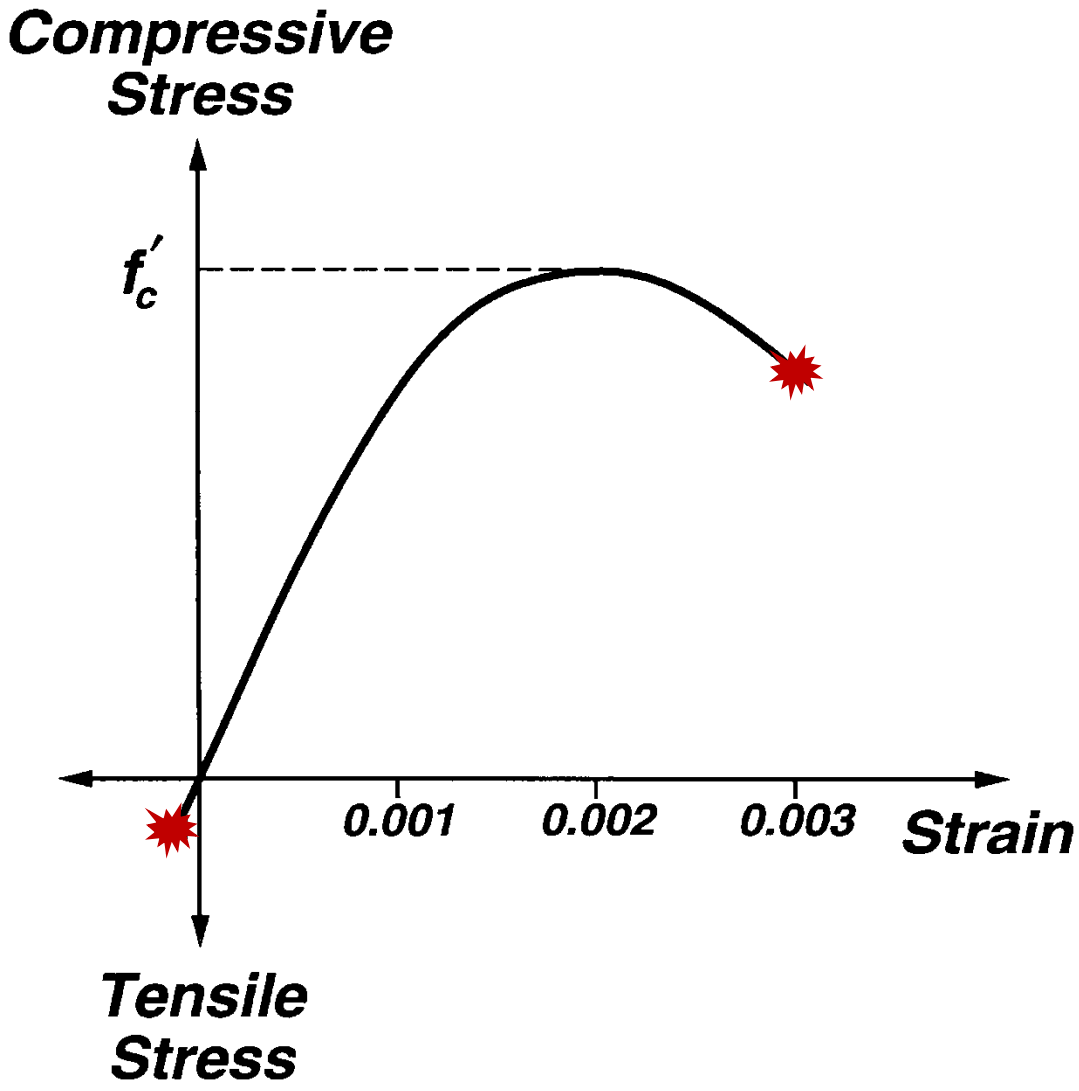
- Basic Concept
  - Strong in Compression
  - Weak in Tension



Factor of 10!!



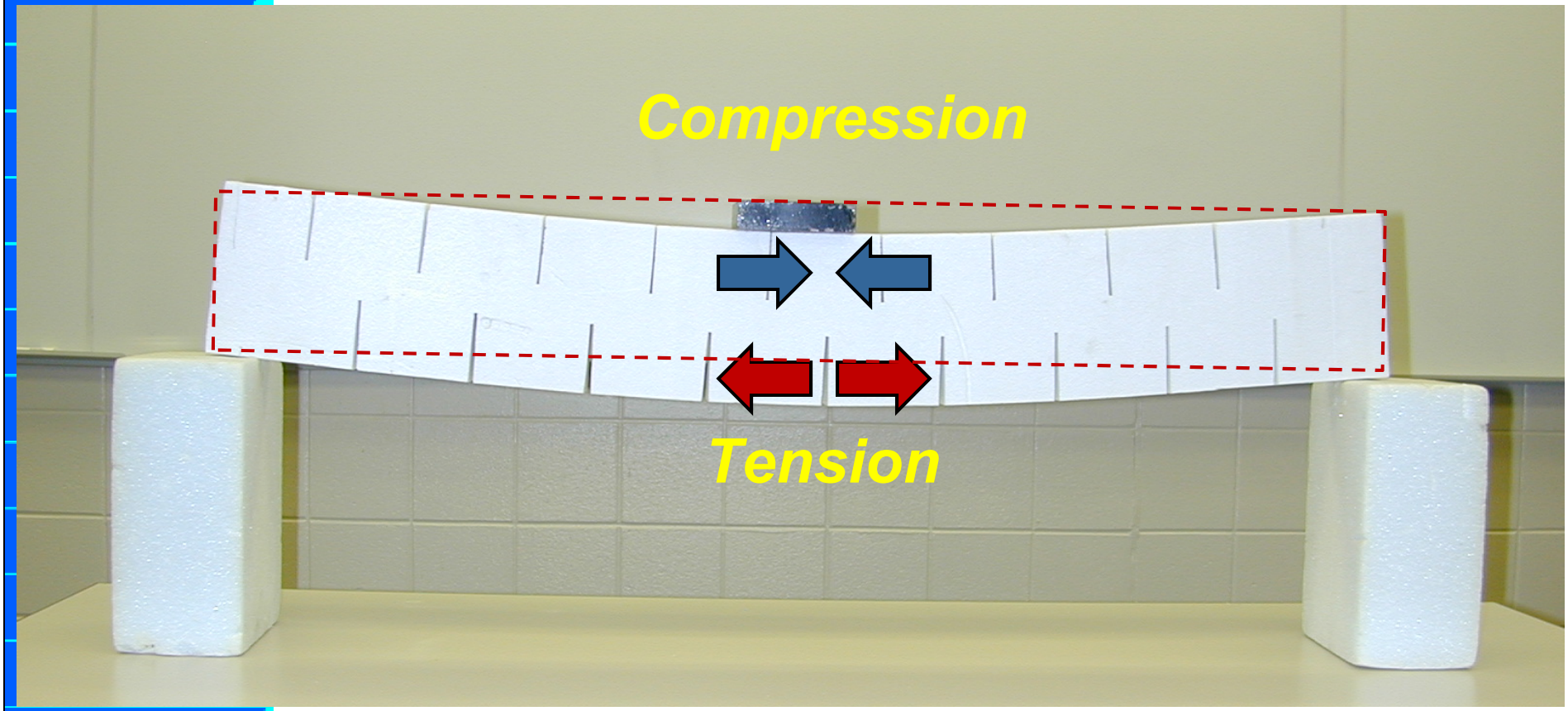
Load-Deformation Characteristics for Concrete



Demonstration

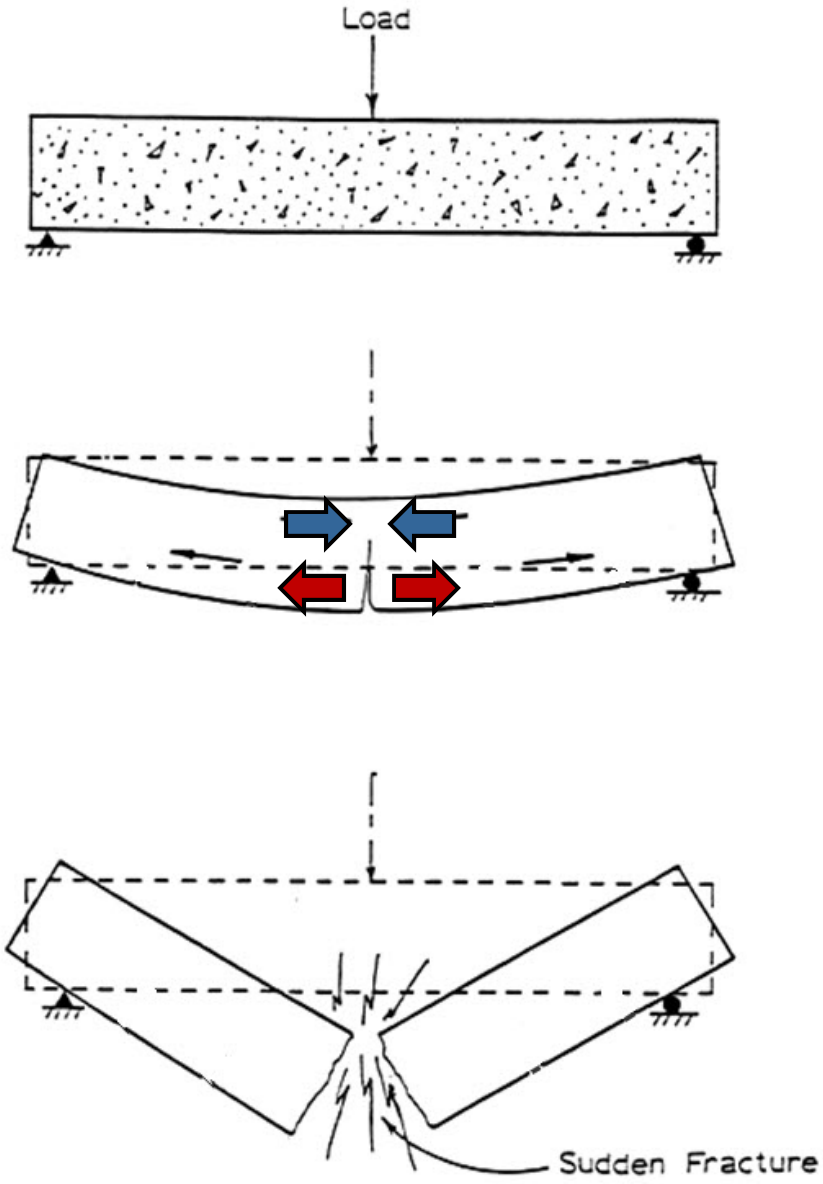
- Slotted Styrofoam Model
- Model Beams

Styrofoam Beam - Loaded

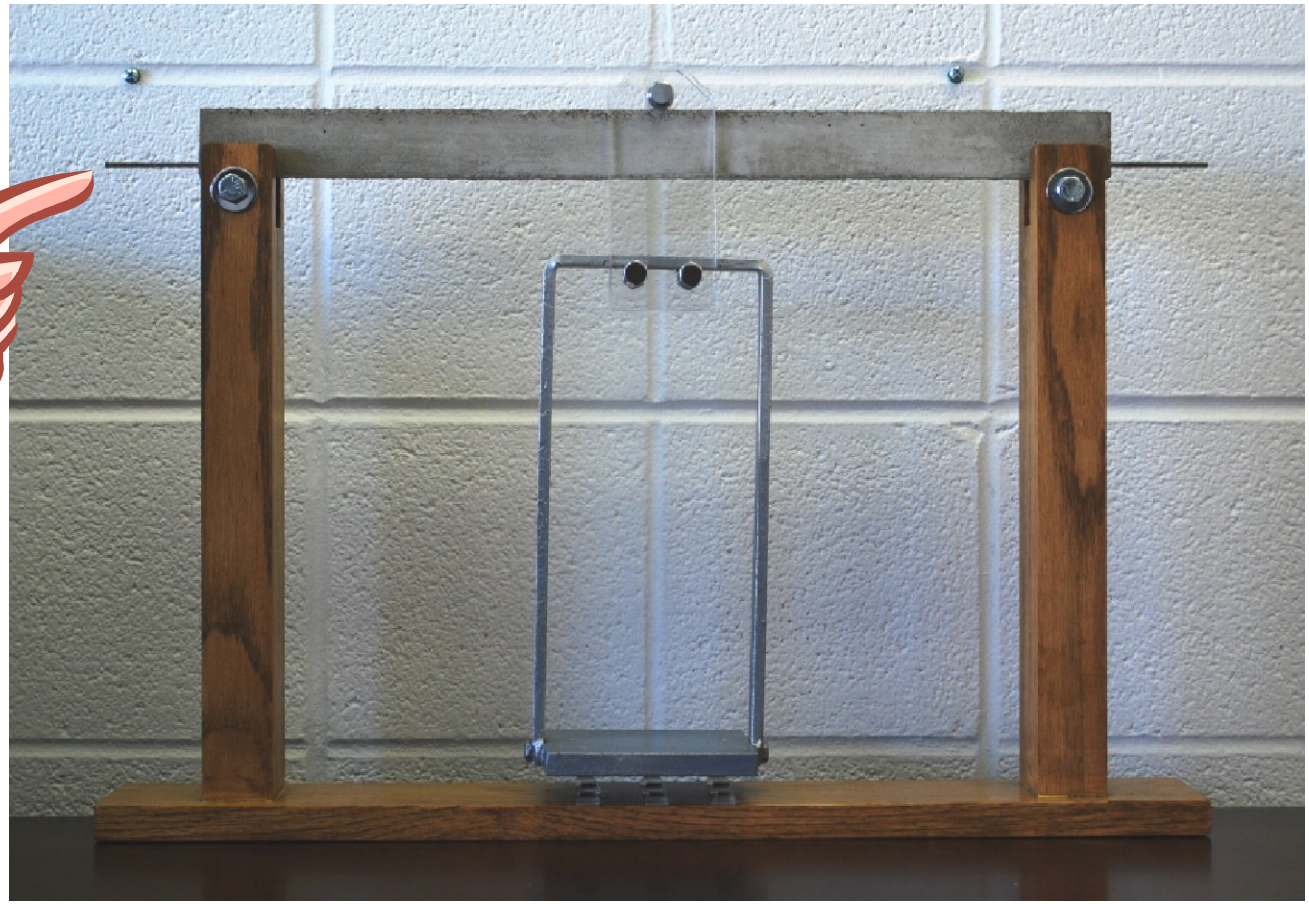


Plain Concrete Beam (no rebar)

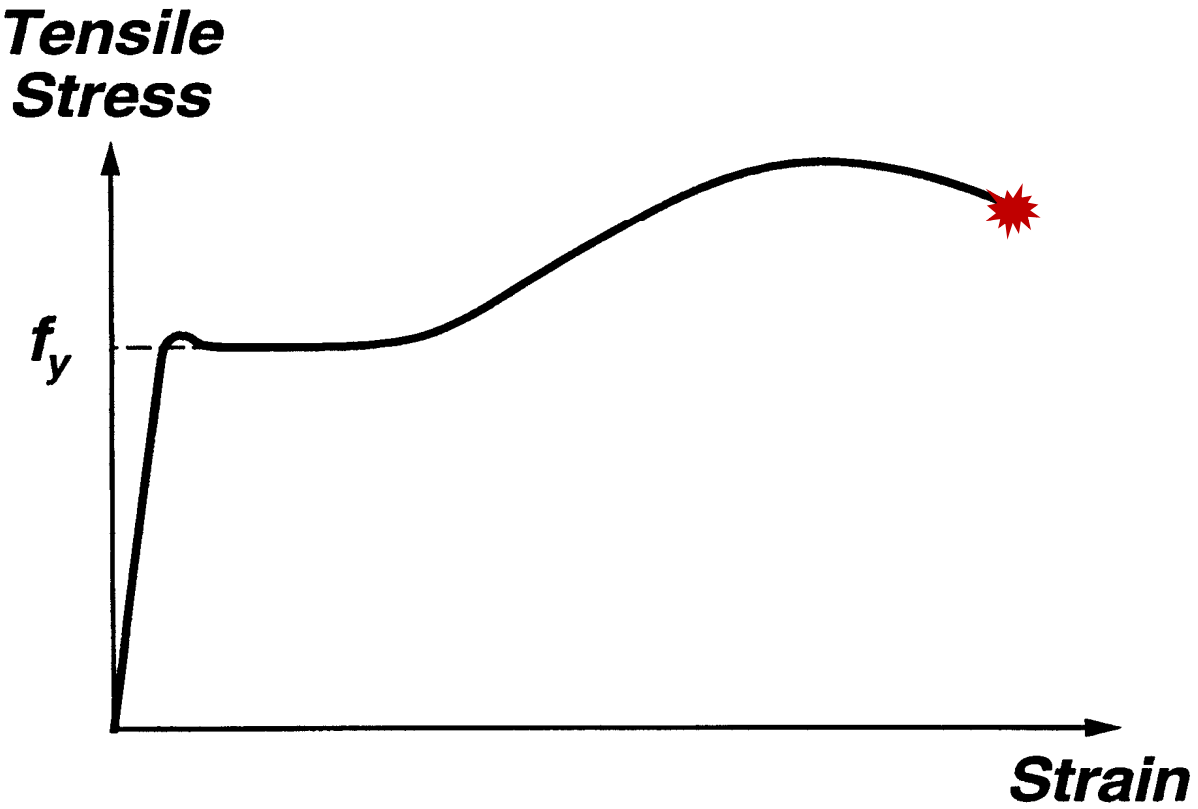
Plain Concrete Beam



Reinforced Concrete Beam



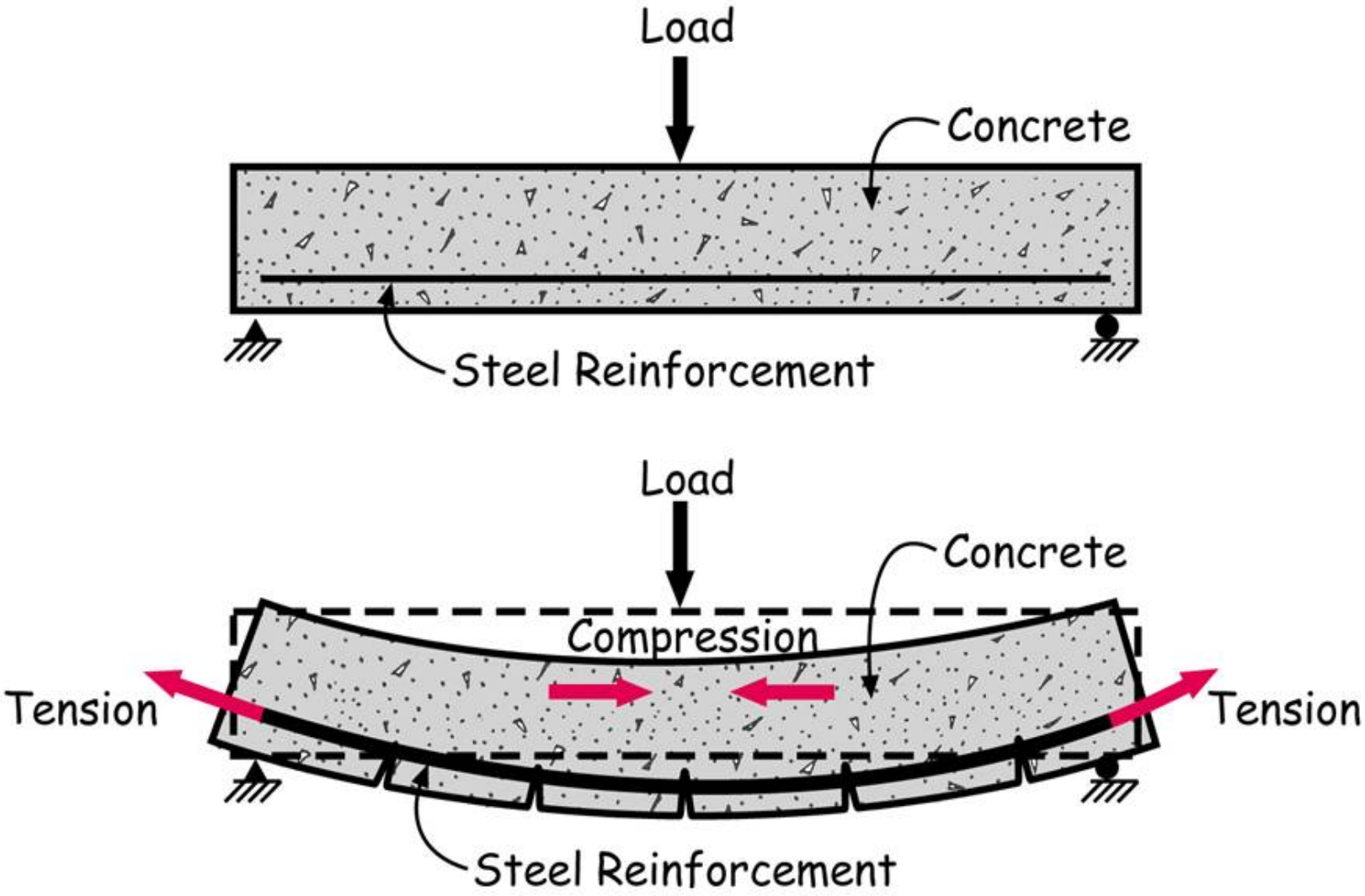
Load-Deformation Characteristics for Reinforcing Steel



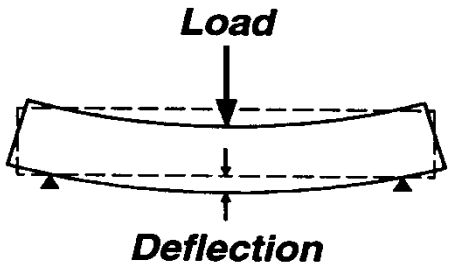
Why Steel?

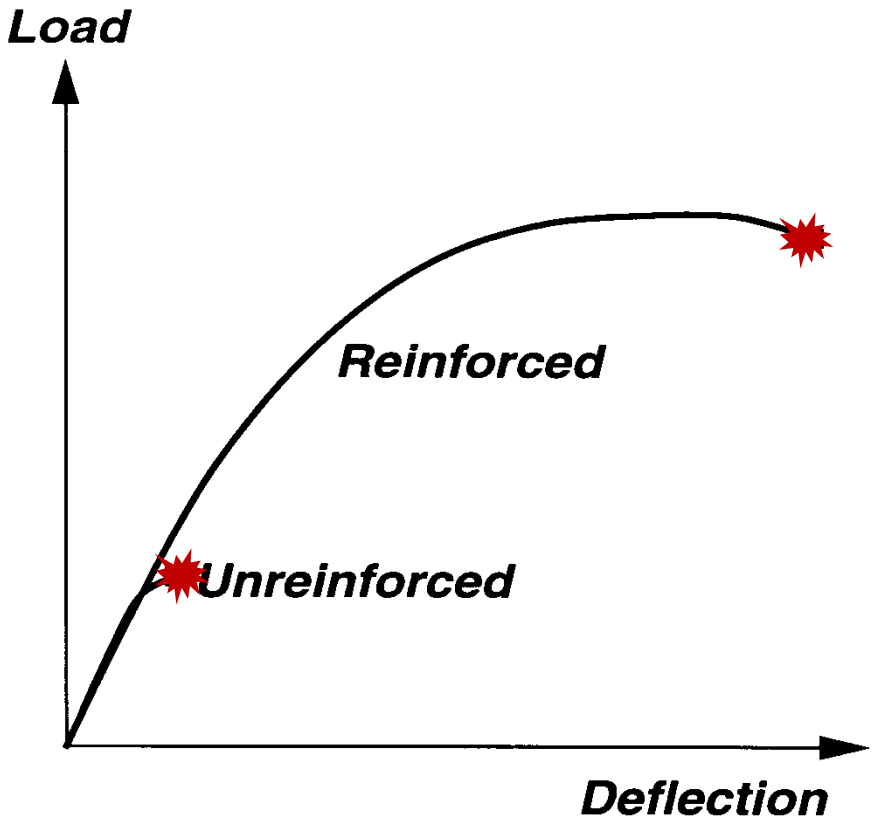
- Strong in tension
- Does not react with concrete
- Compatible thermal expansion and contraction
- Ductile
- Bond strength

Reinforced Concrete Beam

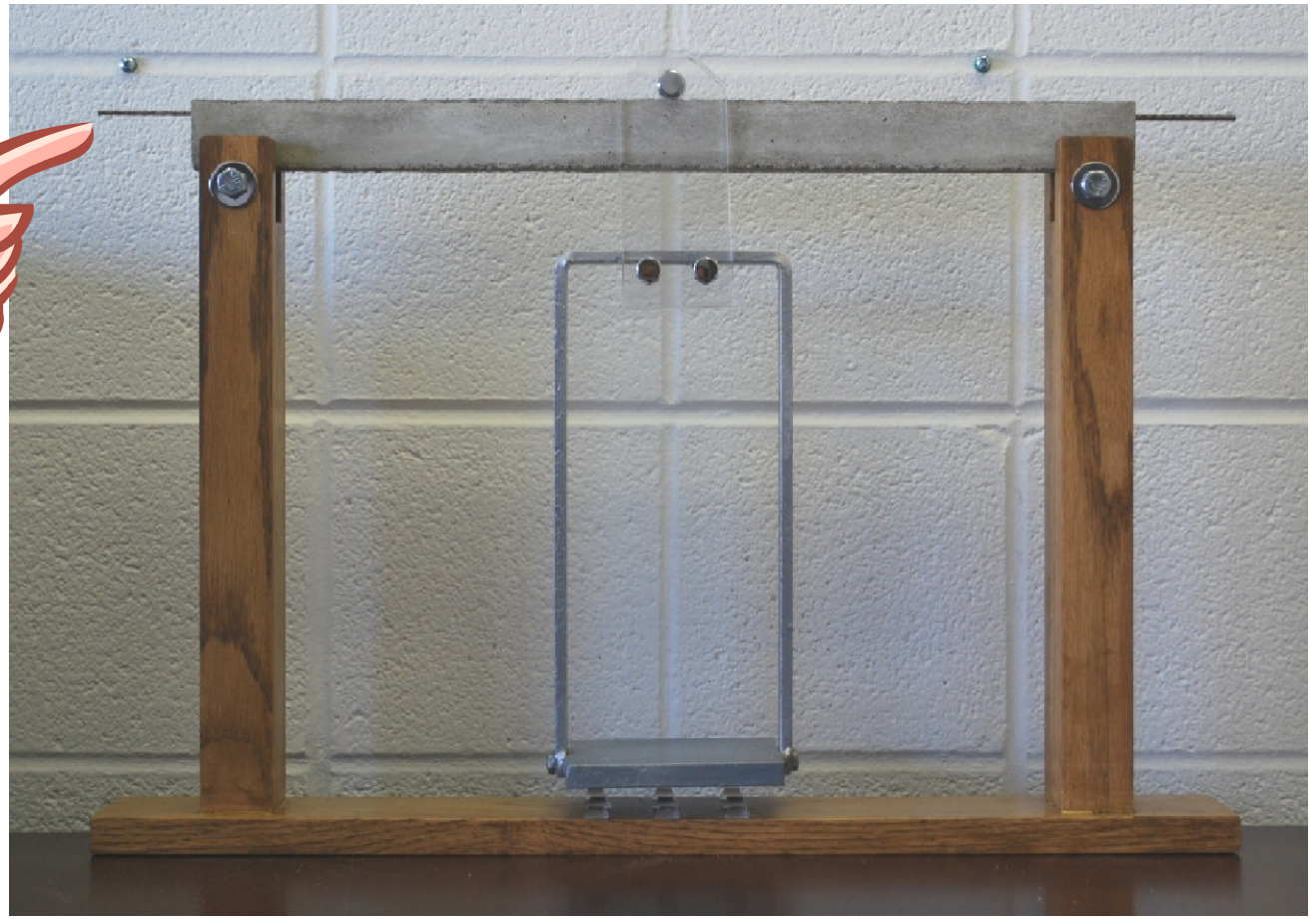


Load-Deformation for Plain and Reinforced Beams

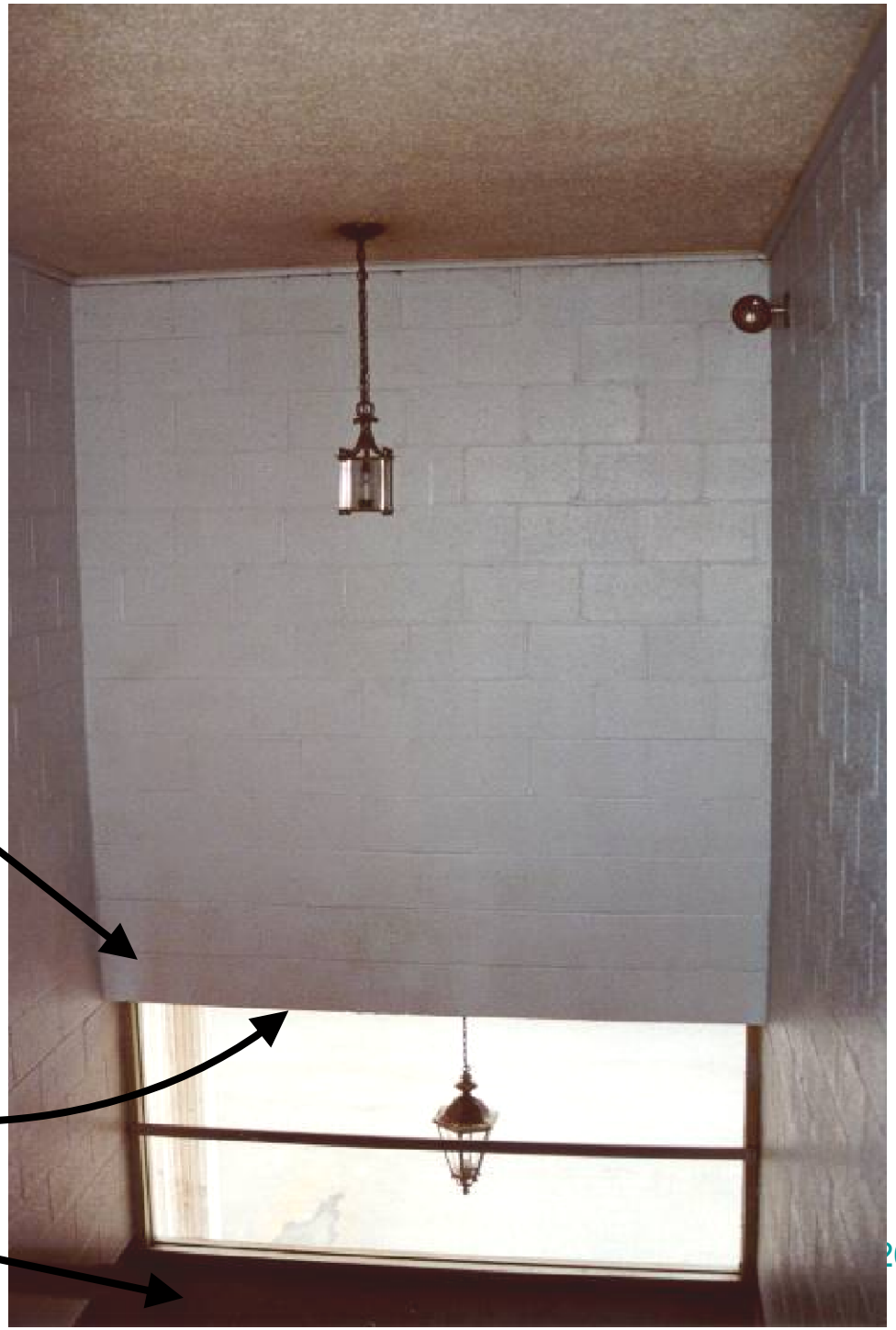




Reinforced Concrete Beam (steel at top)



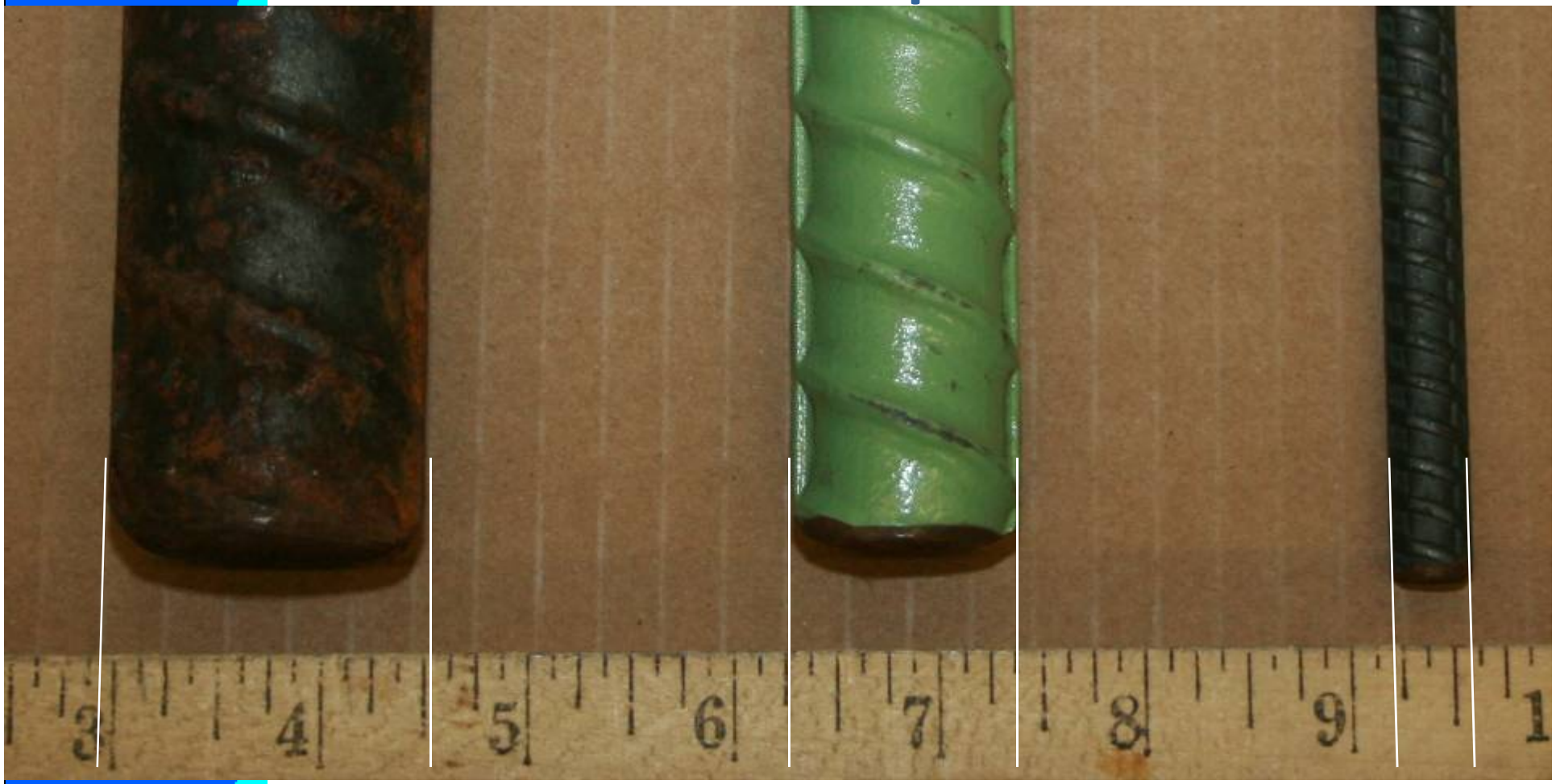
Case Study


Pair of Precast Ledger Beams
If you look underneath….
Stairway Landing

Case Study

Remember, this is from underneath!

Rebar Development

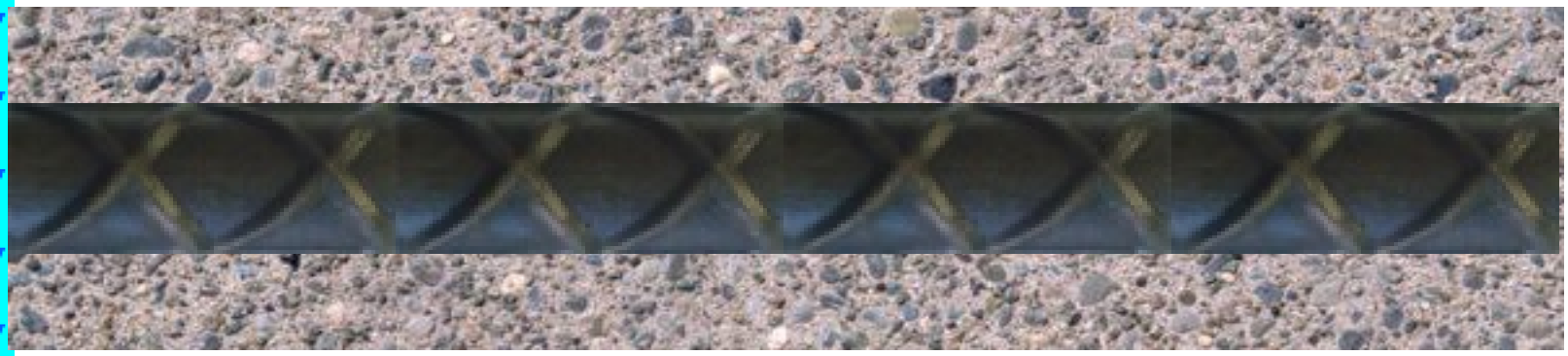


~ 1 3/8”
#14

9/8”
#9

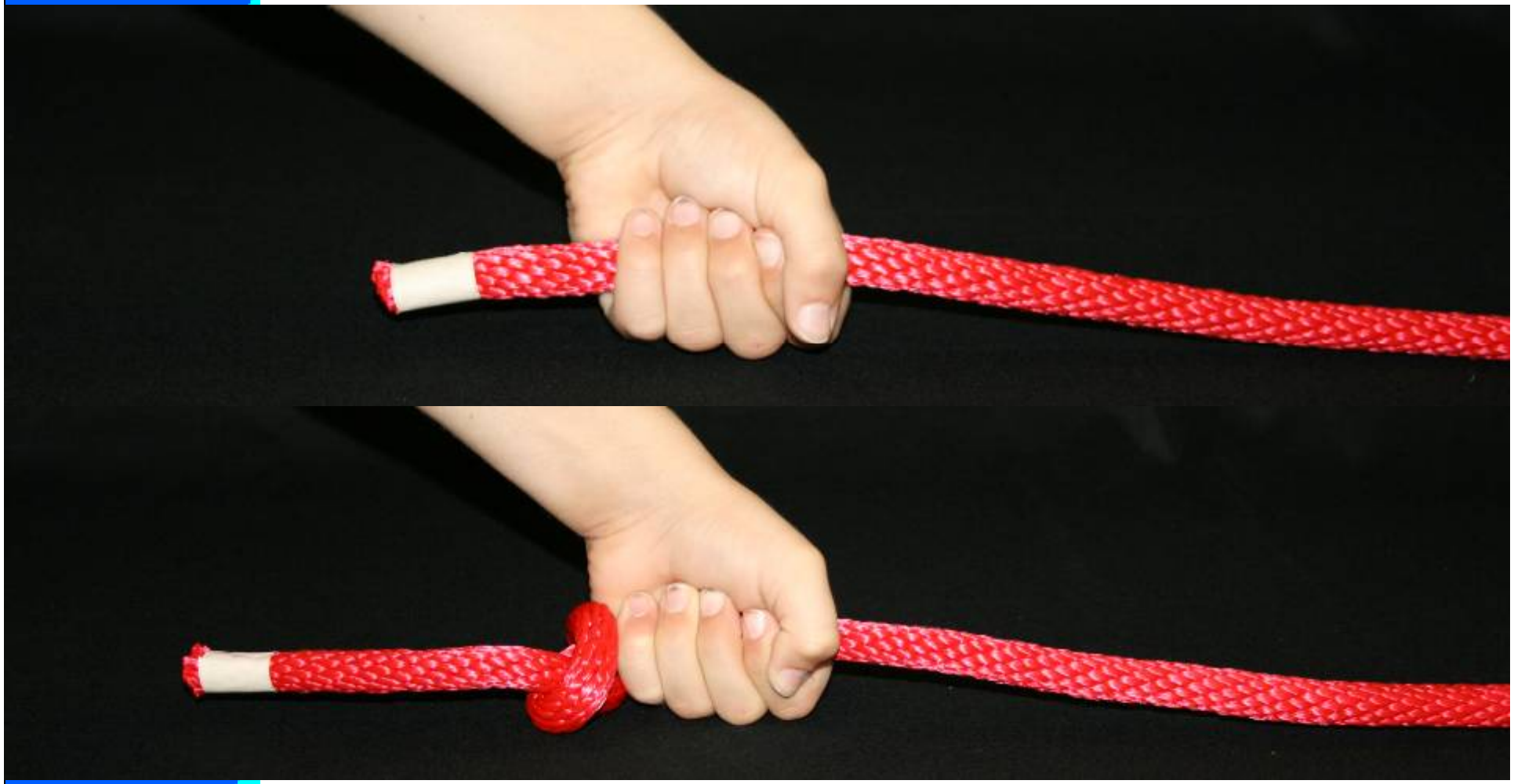
3/8”
#3

Rebar Development



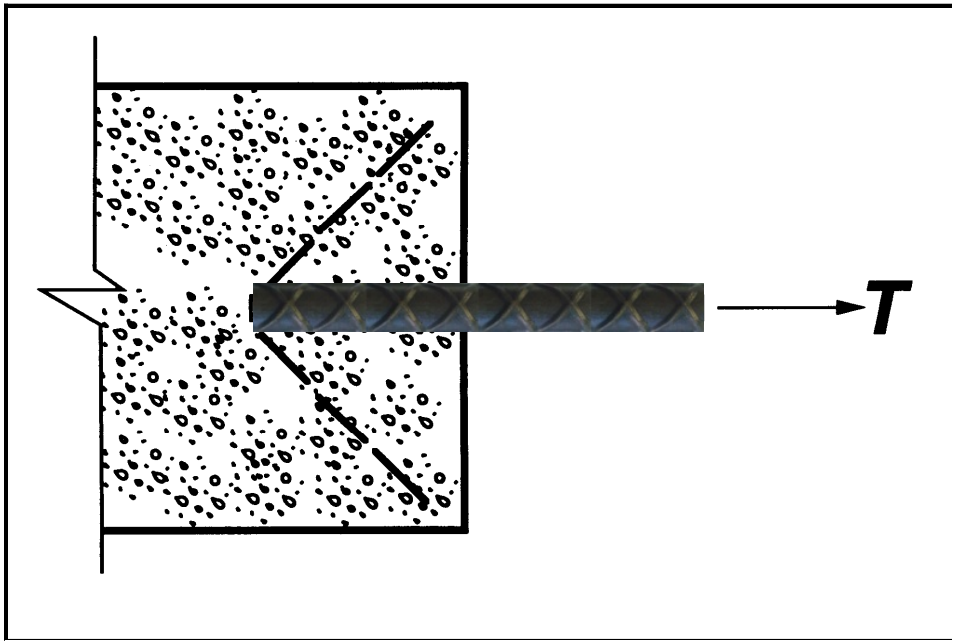
Why the ribs?

Rebar Development

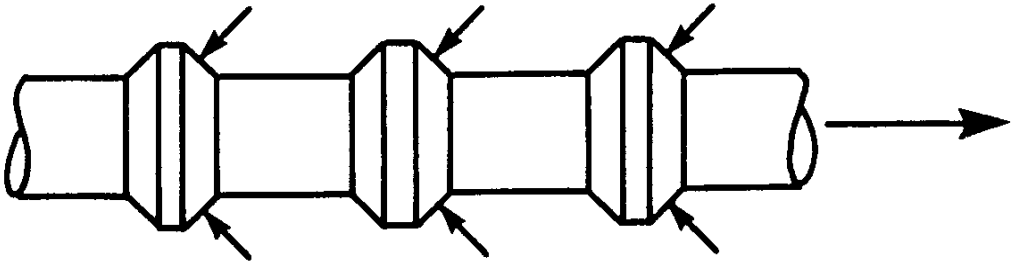
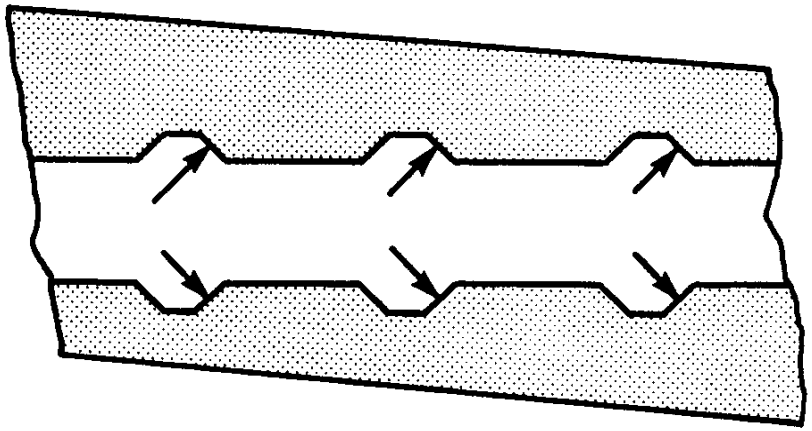


Bond and Development Length

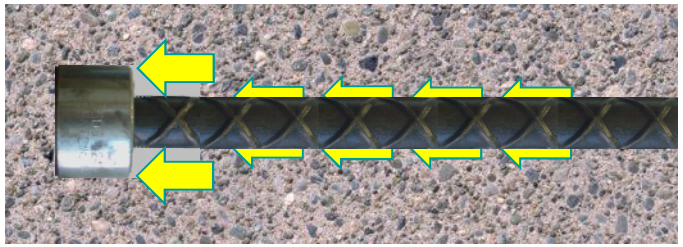
- Mechanical Bond
- Adhesion Bond



Mechanical Bond

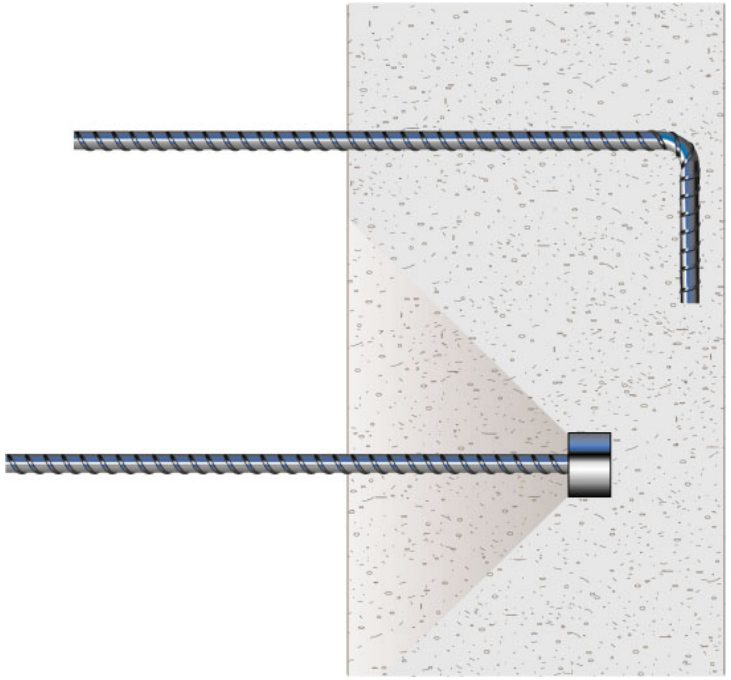
Forces on bar	
Forces on concrete	

Headed Bars in Tension



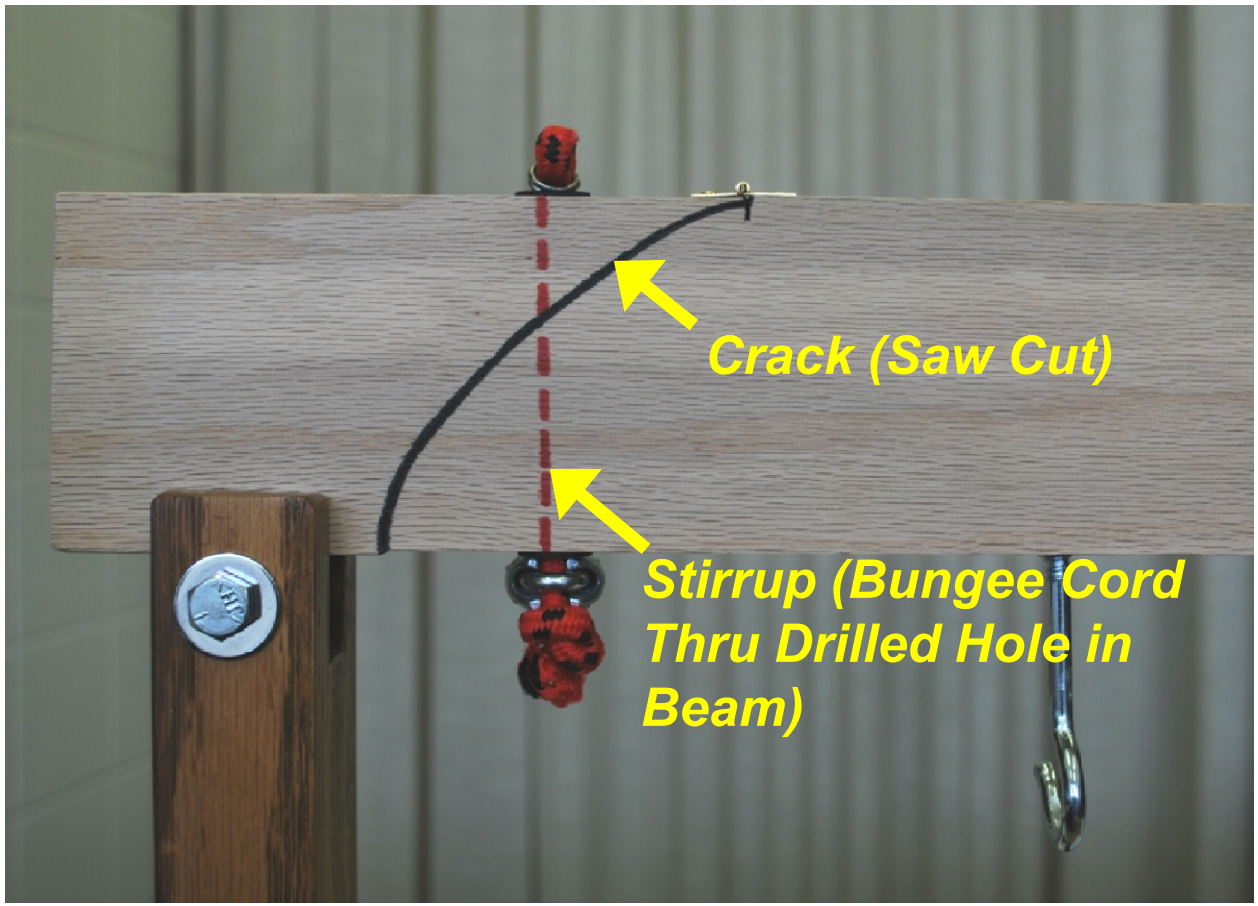
Headed Bars Can Reduce Rebar Congestion

Trump Tower Chicago

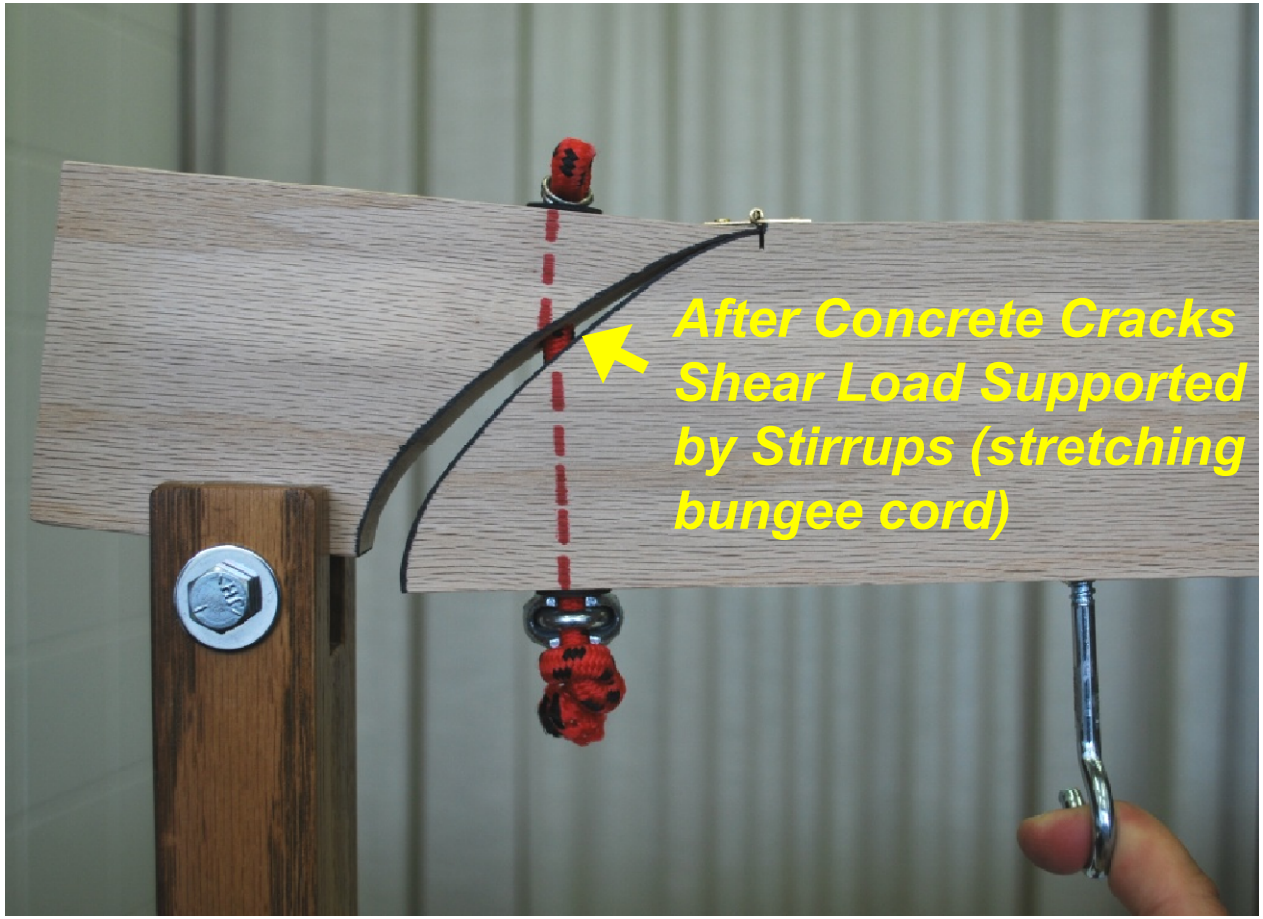


Courtesy ERICO

Shear and Stirrups

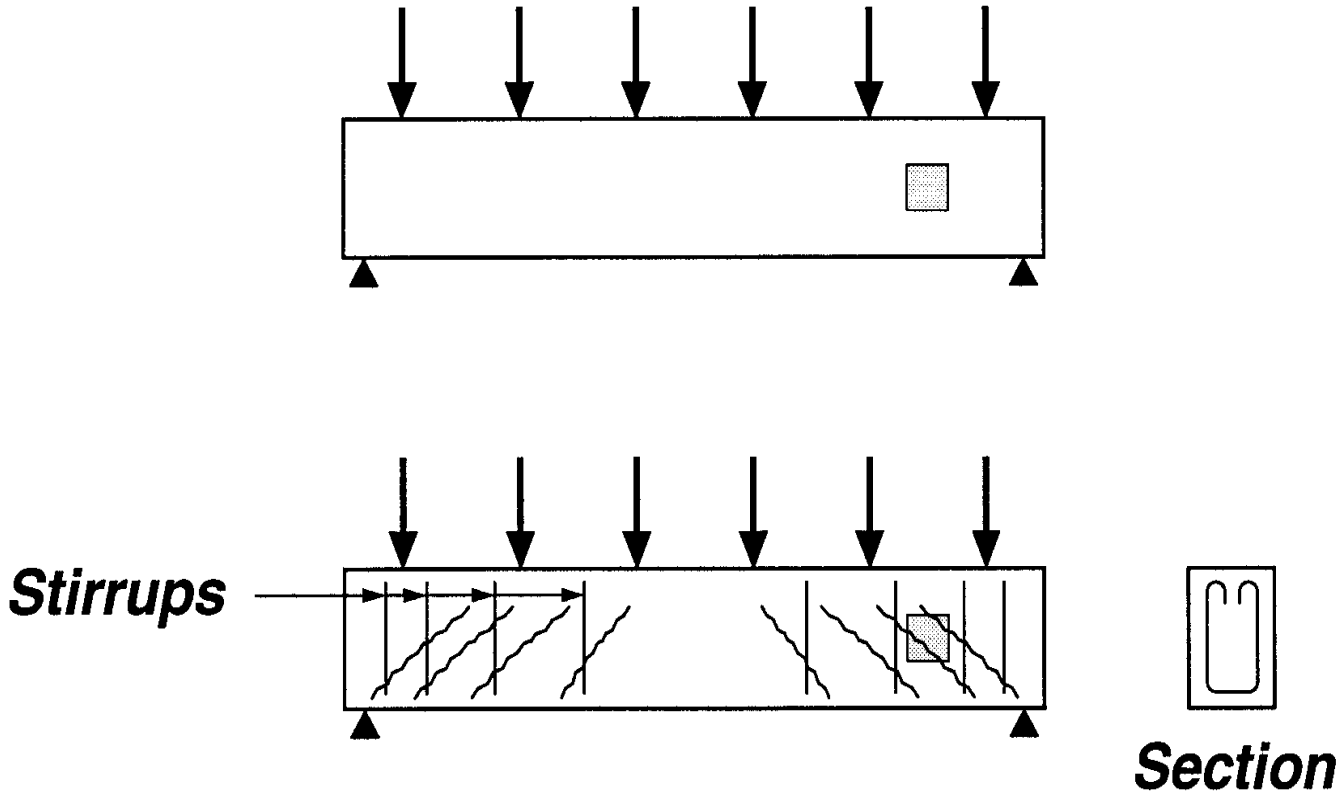


Shear and Stirrups

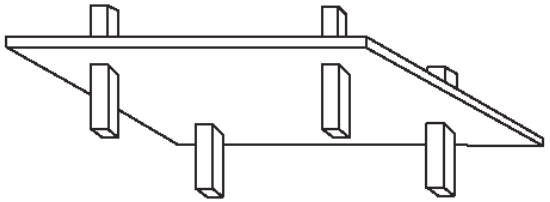


Held Together by "Stirrup"

Diagonal Tension Due to Shear



Headed Shear Stud Reinforcement



Courtesy of Hai Dinh, Univ. of Michigan

Creep and Shrinkage

"The Rocket Science of Structural Concrete"

Short-term Elastic Behavior Superimposed over Long-term Inelastic Behavior

Creep and Shrinkage

Determine the Important Parameters

Use Analogy of Inflatable Mattress

Creep and Shrinkage

Short-term Loads = Elastic

Creep and Shrinkage

Long-term Loads = Inelastic

Creep and Shrinkage

Important Parameters

Scale of Element

Creep and Shrinkage

Important Parameters

Scale of Element

Creep and Shrinkage

Important Parameters

Size of “Openings” = Age and Strength of Concrete

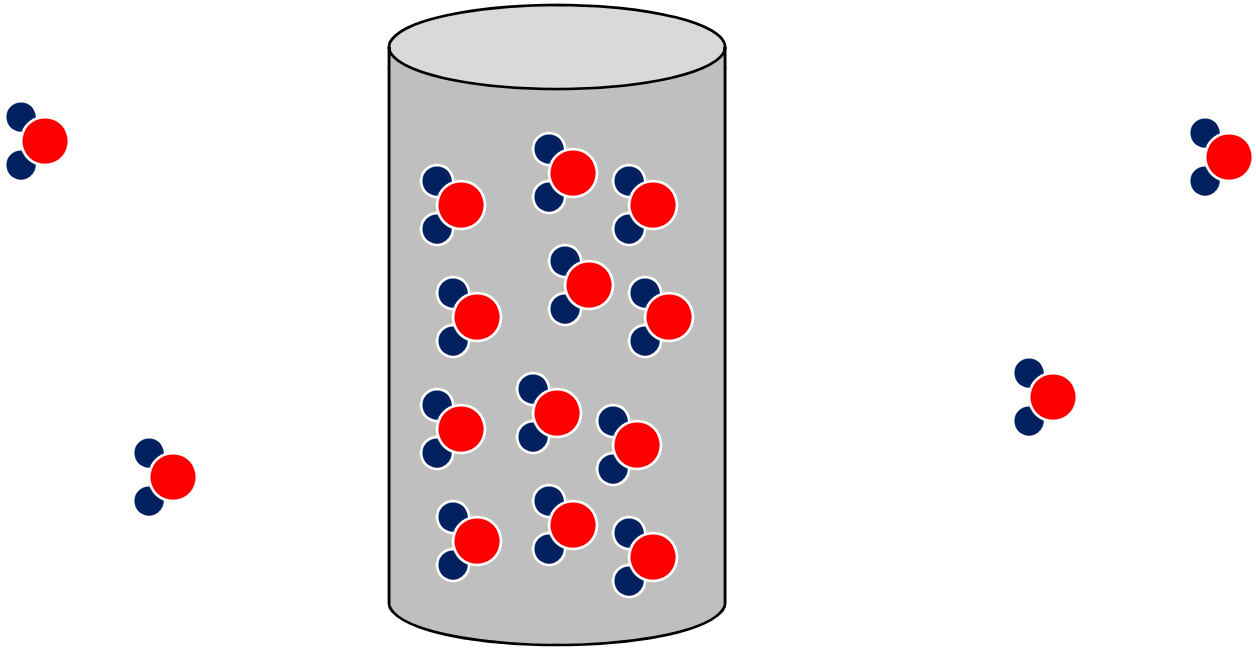
Creep and Shrinkage

Important Parameters

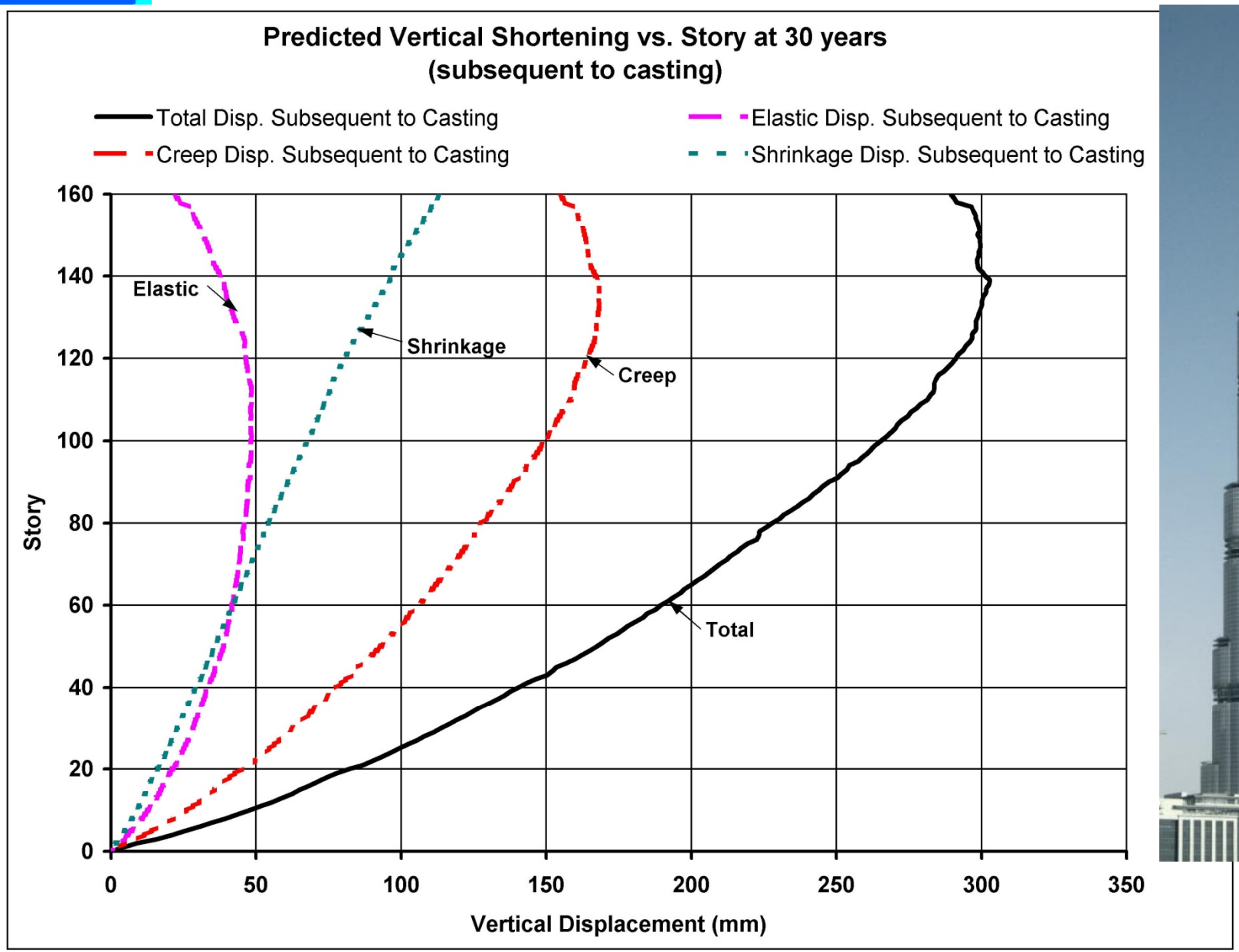
Pressure Differential

Creep and Shrinkage

Pressure Differential = Relative Humidity



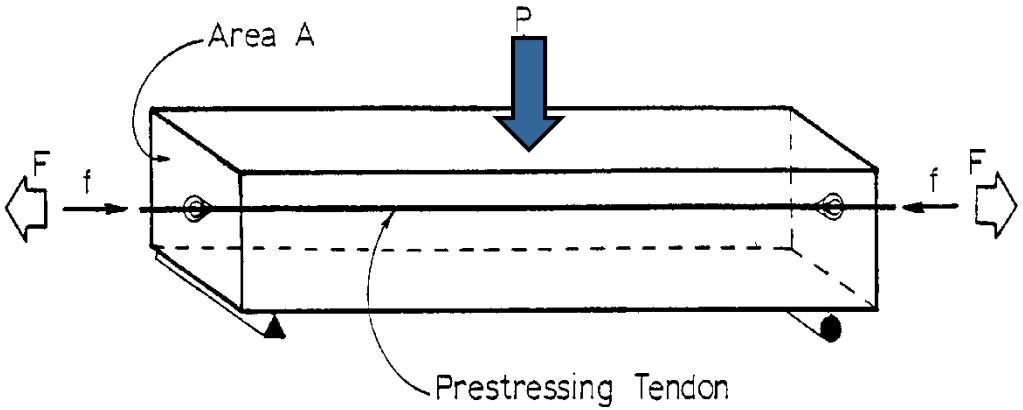
Predicted Vertical Shortening vs. Story at 30 Years

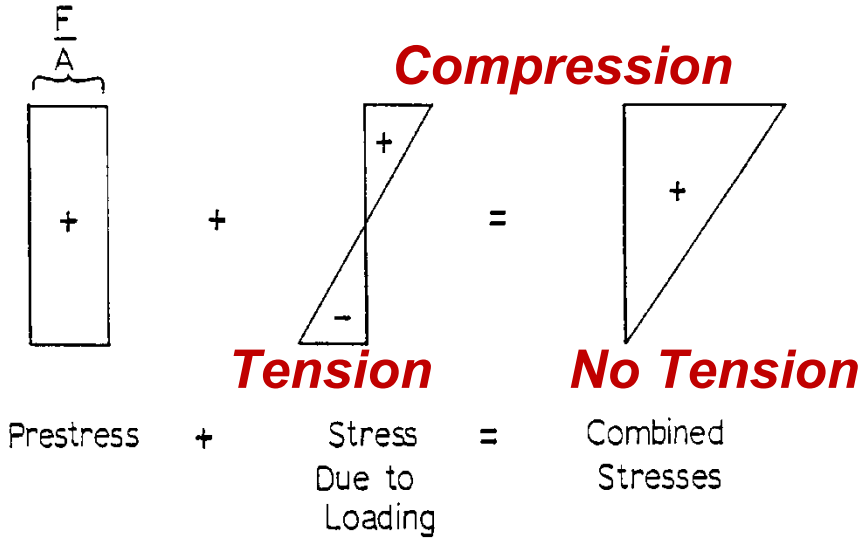


Demonstration

- Styrofoam Blocks (Prestressed)

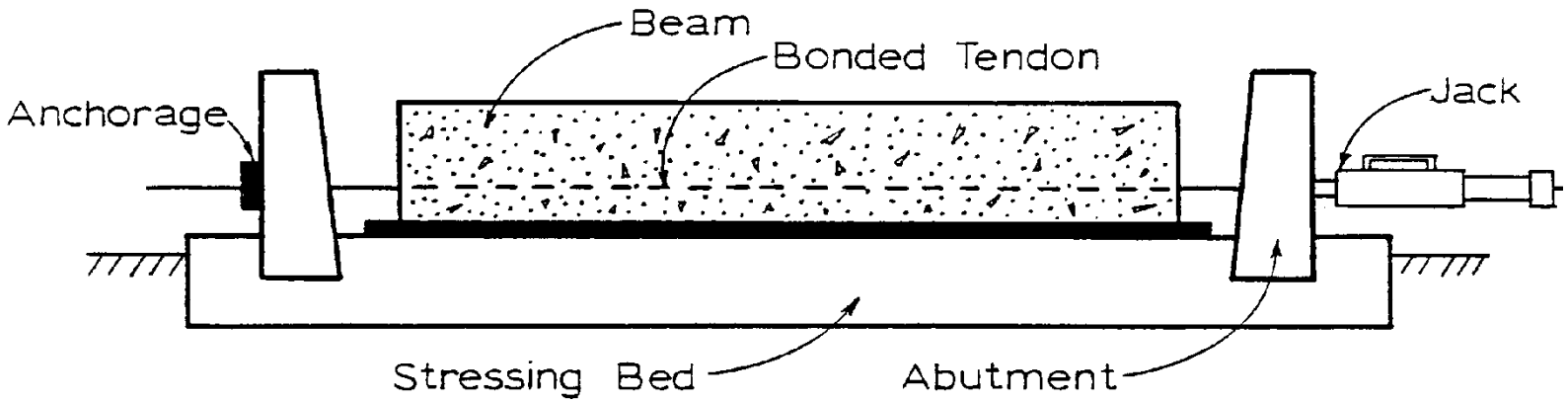
Prestressed Concrete: General Principles



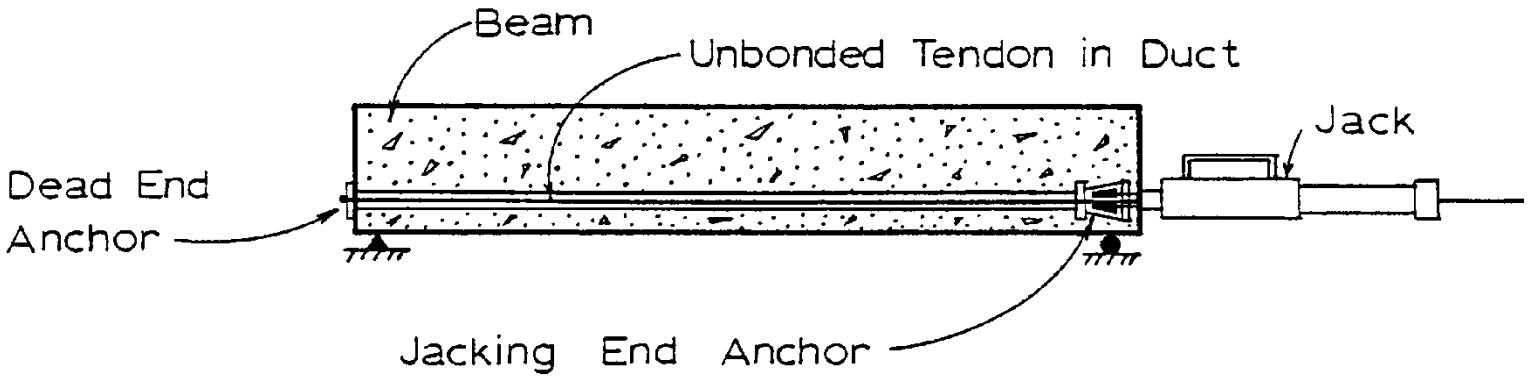


Methods of Prestressing Concrete Members

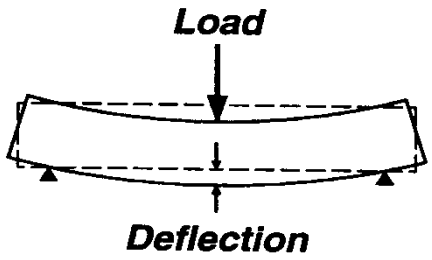
- ***Pretensioning***

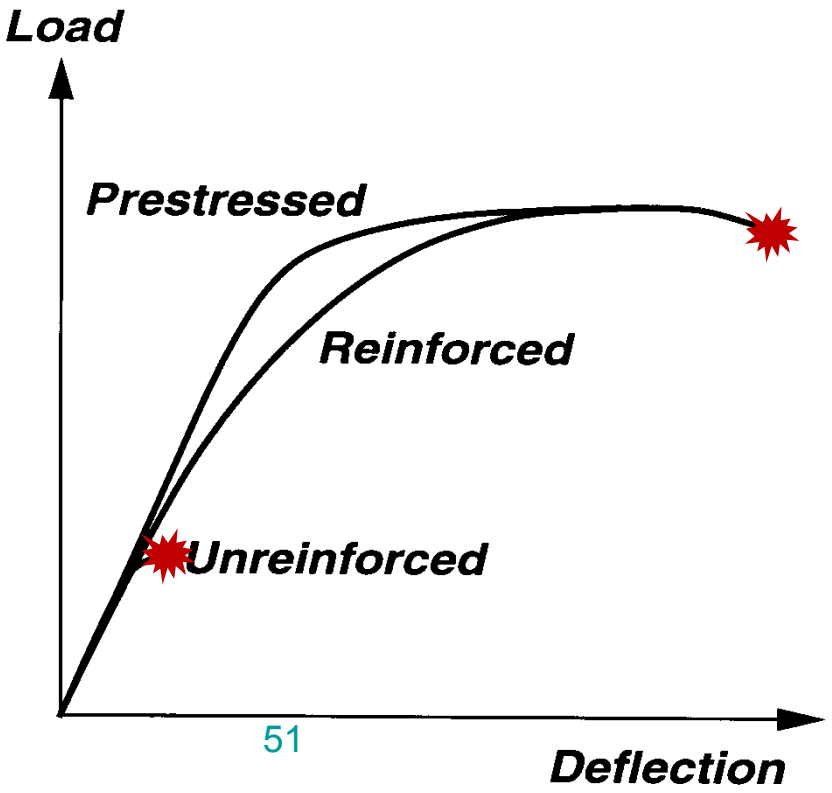


- ***Post-Tensioning***

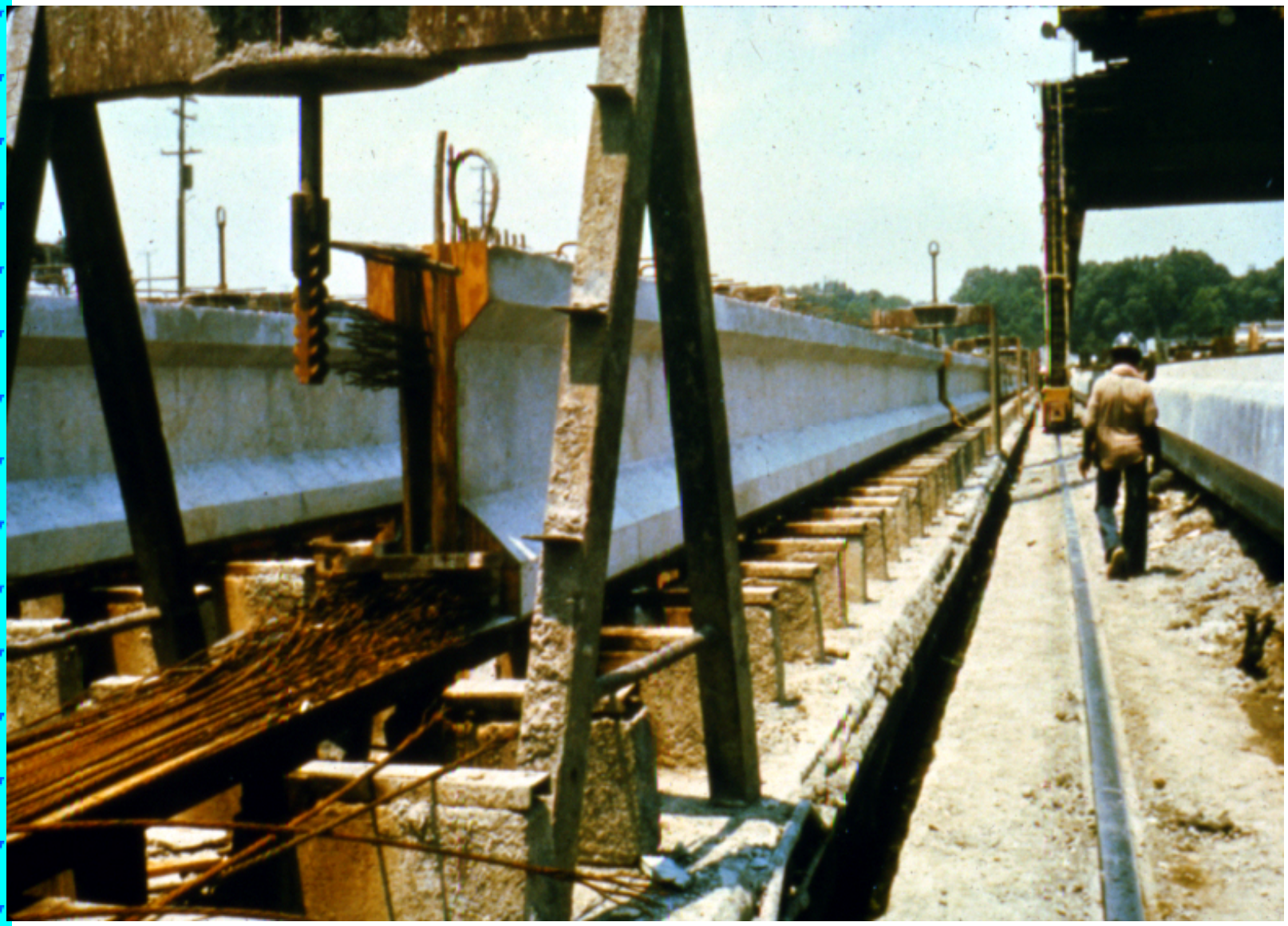


Prestressed Concrete Beams





Precast Girders After Detensioning

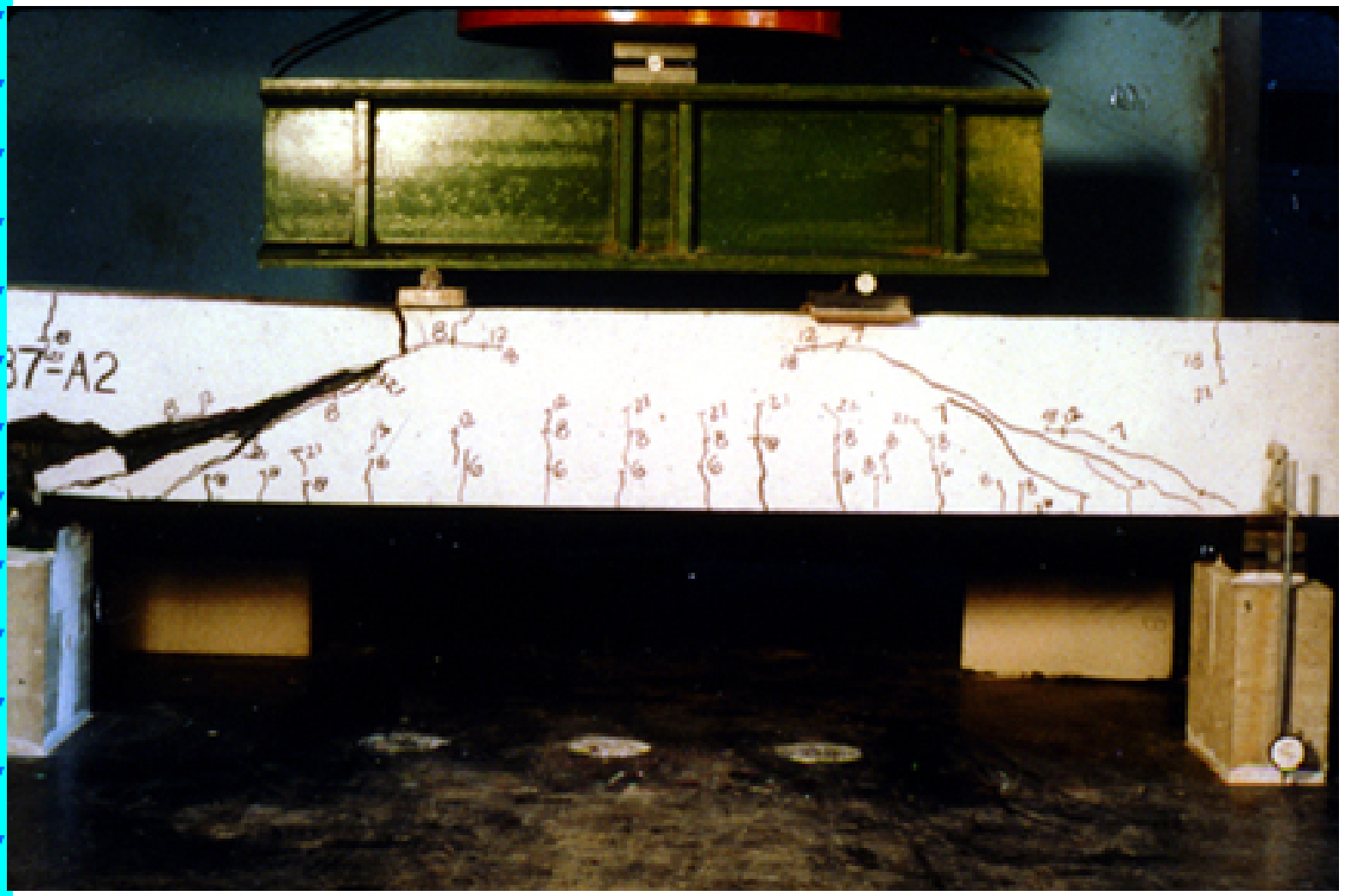


Unloading Girders from Flat Bed Rail Car

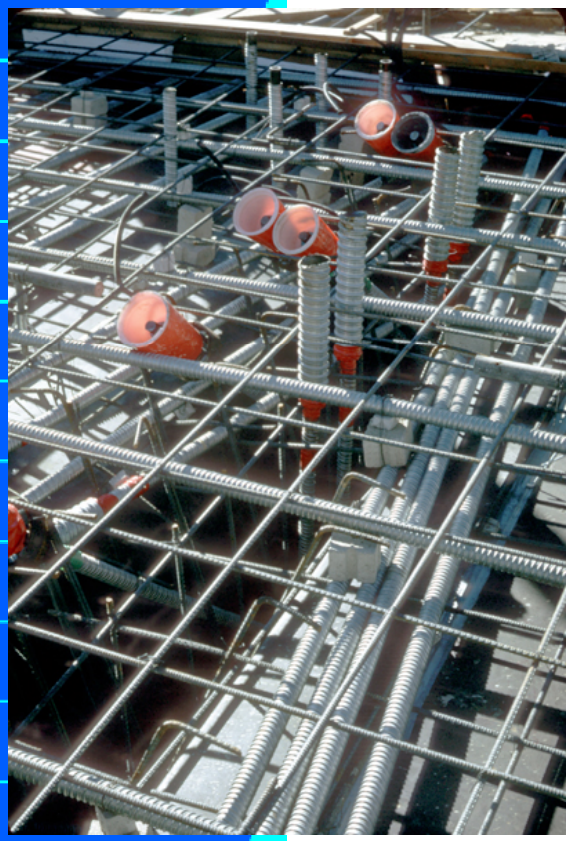
Test to Destruction

Flexural Cracks

Sudden Shear Failure - No Shear Reinforcement



Advantages of Post-tensioned Structures



- Reduced structural depth for lower story heights and reduced dead load
  - Additional savings in labor and material for M/E/P, elevator and cladding
- Long economical spans
- Wide flexibility and variation in design
- Reduced cracking
- However, additional inspections are required

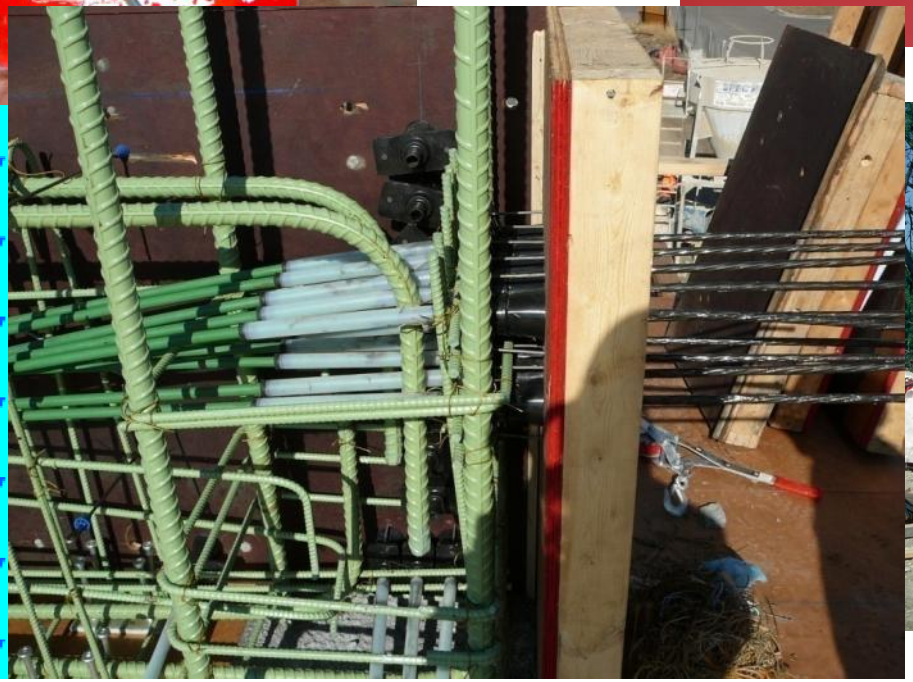
Unbonded Tendons

- The prestressing strand is prevented from bonding, and is free to move, relative to the surrounding concrete
  - 7-wire strands (0.5” dia.)
  - Sheathing
  - Anchor

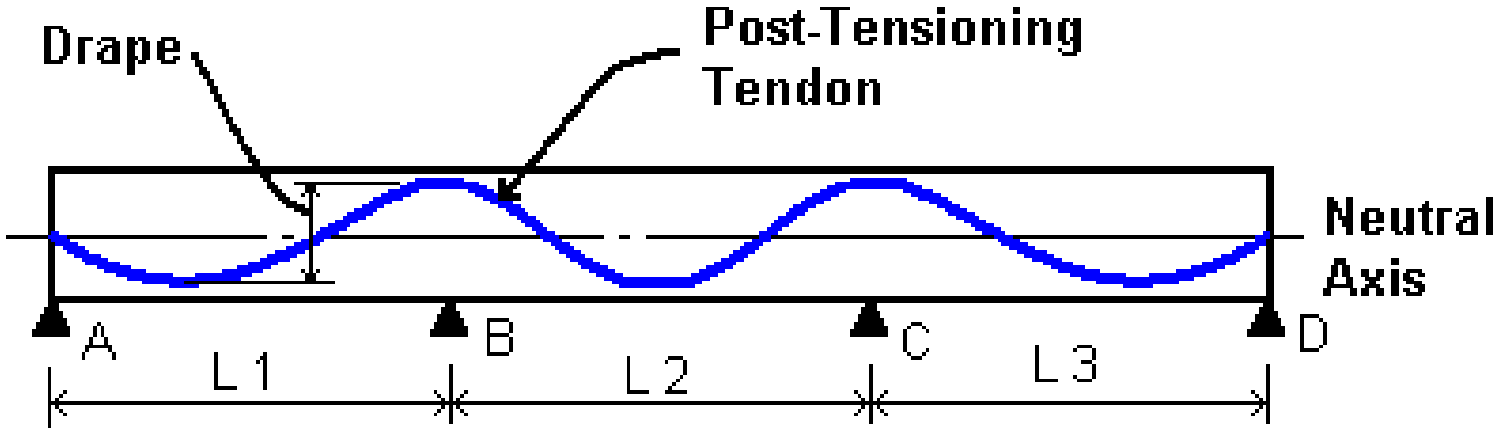
Unbonded Tendons

- Prestressing force can only be transferred to the concrete through the anchorage
  - Casting: 5” x 2 ¼” typical
  - Wedges

Unbonded Tendons



Typical Tendon Profile



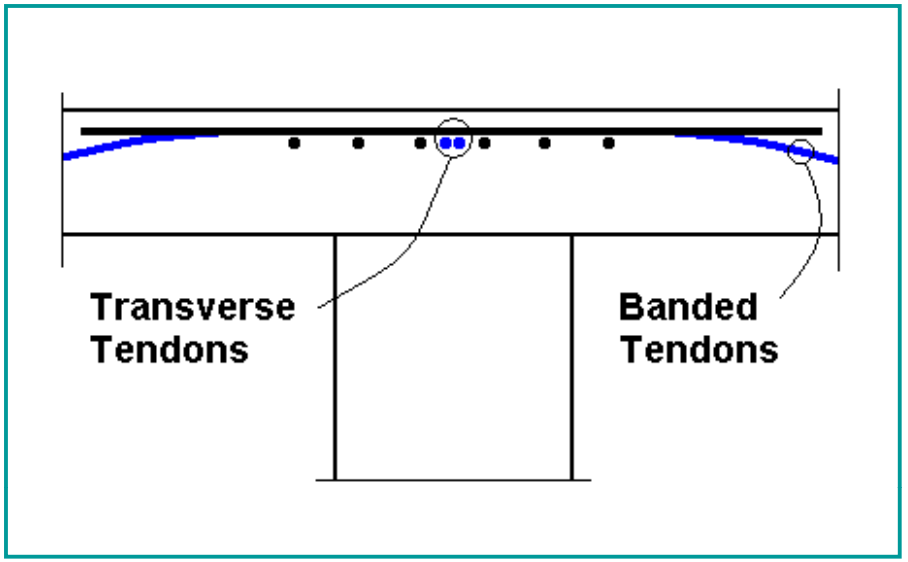
Continuous Post-Tensioned Beam

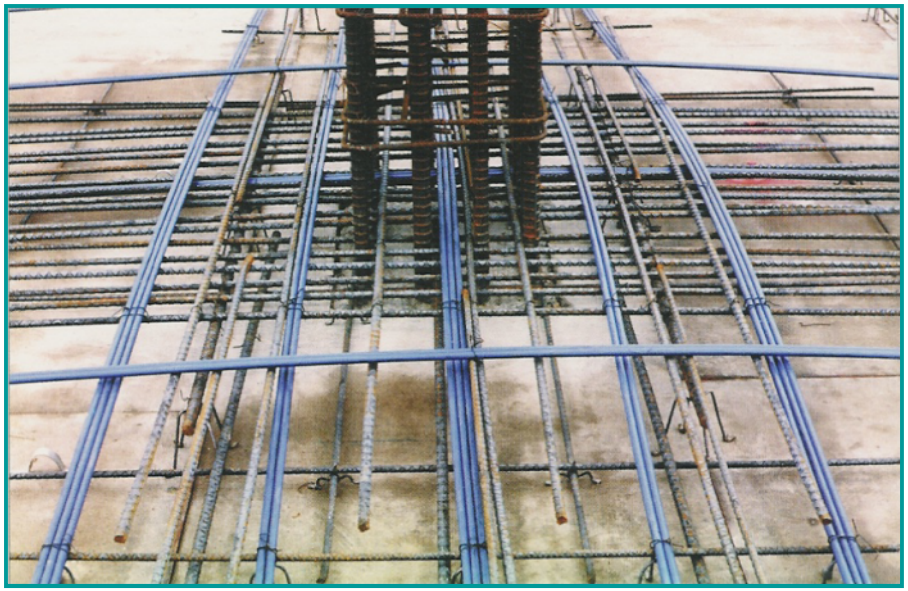
Banded Tendon Distribution

- Resembles a one-way slab (uniform tendons) supported by an embedded beam (banded tendons) along column lines
- Tendons grouped in flat bundles of 4 to 5
- Accommodates column

Placement at Column

- #4 bars, typical to match tendon diameter
- Place transverse reinforcing steel below the banded reinforcing steel





Curving Banded Tendons

Extreme Curves

Extreme Curves

Curves in Plan Cause:

- **Increased Losses**
- **High Internal Forces**
- **Cracking at Openings**

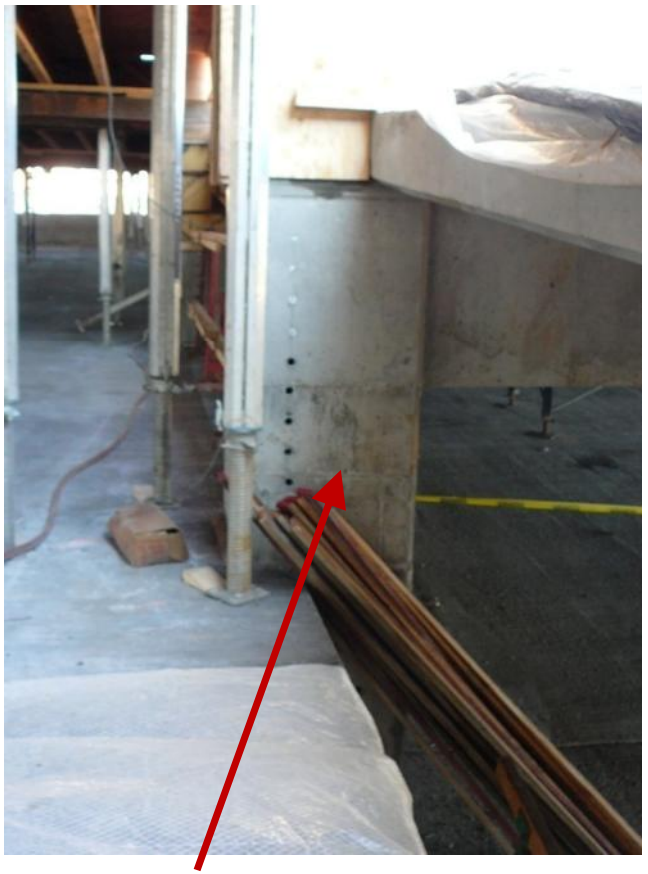
Extreme Curves

Corrected Layout

Punching Shear

- Detail with tendon group running directly through column core
- 2 minimum required per ACI Code
- Headed shear stud reinforcement

Short Column Effect in Ramps



Crack in Column

Improper Conduit

Acceptable Conduit

Beam Column Joint - Interior

- Tendons and beam top steel compete for placement at top of beam

Beam Column Joint - Exterior

- Beam hooked tops bars compete for space with PT anchorages

Beam Column Joint - Corner

- Two beams framing in at a corner column have even more congestion issues

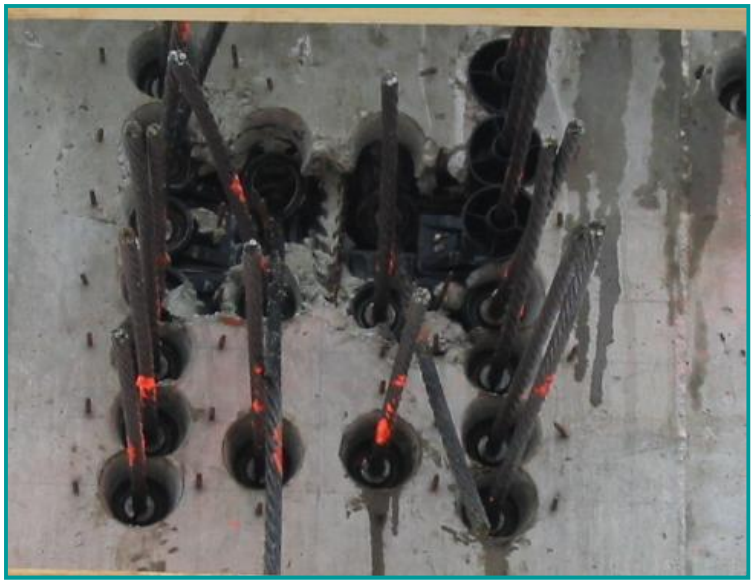
- Coordinate Coordinate Coordinate!

Anchorage Zones

- Beam-column connections have limited space for anchoring tendons
  - Wider columns for ease of construction
  - Consider column vertical steel configuration

Beam Column Joint - Exterior

- Congestion + Poor consolidation
  = Problems



Beam Column Joint - Exterior

- Congestion + Poor consolidation = Problems

Consolidation at Anchors

Blow Out Prevention

- One tendon exerts ~33,000 pounds of force at the anchor or about the weight of 10 cars
- Remove penetrations near the anchorage zone
- Proper concrete consolidation is crucial

Restraint Crack

Restraint Crack

Special Inspections

- Pre-Pour
  - Verify PT c.g.s off structural drawings

    Supports, midspan, anchors
  - Verify minimum number of tendons intersect center of column in both directions
  - Remove conduit, penetrations, etc., by the anchors

Special Inspections

- Pre-Pour
  - Look for tendons with extreme bends, reverse curvature, or odd configurations
  - Inspect for damage to sheathing

Special Inspections

- During and after stressing operation
  - Inspection of the stressing operation is to be continuous, NOT periodic
  - A deputy inspector is required for each stressing crew (each jack)
  - Measurement of strand tails

Elongation Record

MONOSTRAND STRESSING RECORD

Date: 7/25/2005

Stessing Date: 7/11/05 (Tendon 79&80 7/23/05

16 of 17

Project:

Job No: 1053-05-042

GC:

Pour No. 1

Building:

Location: Lobby Level Area B

Weather: sunny/warm

Jack Ser. No: 249

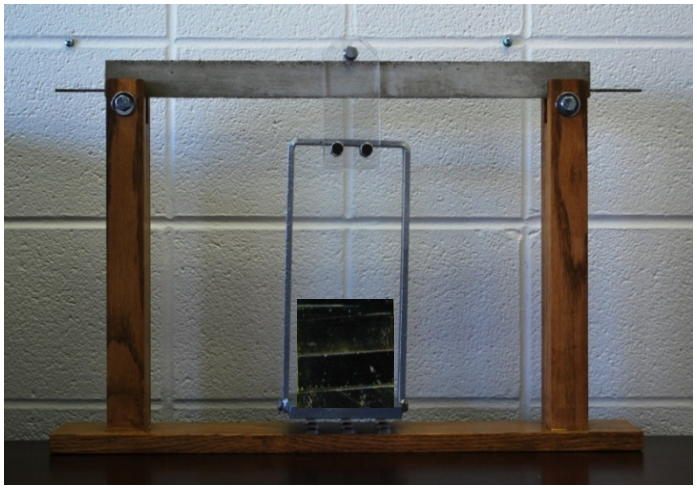
Gauge No: 249

Cal Date: 6/21/2005

Stressed by:

Tendon No.	Gauge Reading	Jacking Force	Calc. Elong.	Measured Elongations			% Deviation
				End 1	End 2	Total	
79a	5600	33040	5.750	5.75		5.75	0.00%
79b	5600	33040	5.750	6		6	4.35%
79c	5600	33040	5.750	5.875		5.875	2.17%
80a	5600	33040	5.750	5.875		5.875	2.17%
80b	5600	33040	5.750	6		6	4.35%
80c	5600	33040	5.750	6		6	4.35%
81a	5600	33040	3.750	4		4	6.67%
81b	5600	33040	3.750	3.75		3.75	0.00%
81c	5600	33040	3.750	3.5		3.5	-6.67%
82a	5600	33040	3.750	3.75		3.75	0.00%
82b	5600	33040	3.750	3.5		3.5	-6.67%
82c	5600	33040	3.750	3.5		3.5	-6.67%
83a	5600	33040	3.750	3.625		3.625	-3.33%
83b	5600	33040	3.750	3.75		3.75	0.00%
83c	5600	33040	3.750	3.75		3.75	0.00%
84a	5600	33040	3.750	3.75		3.75	0.00%

Building is Human Nature



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