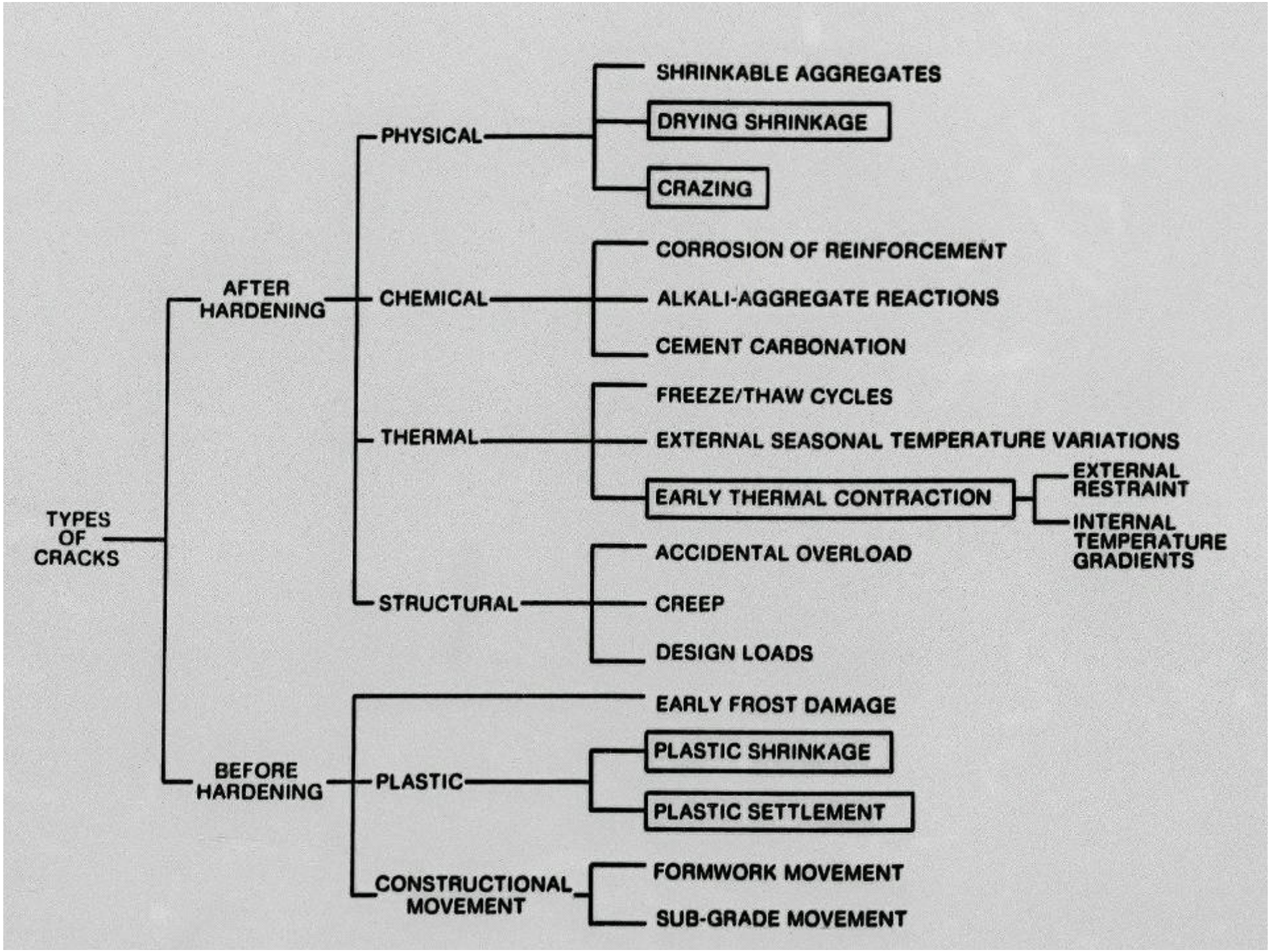
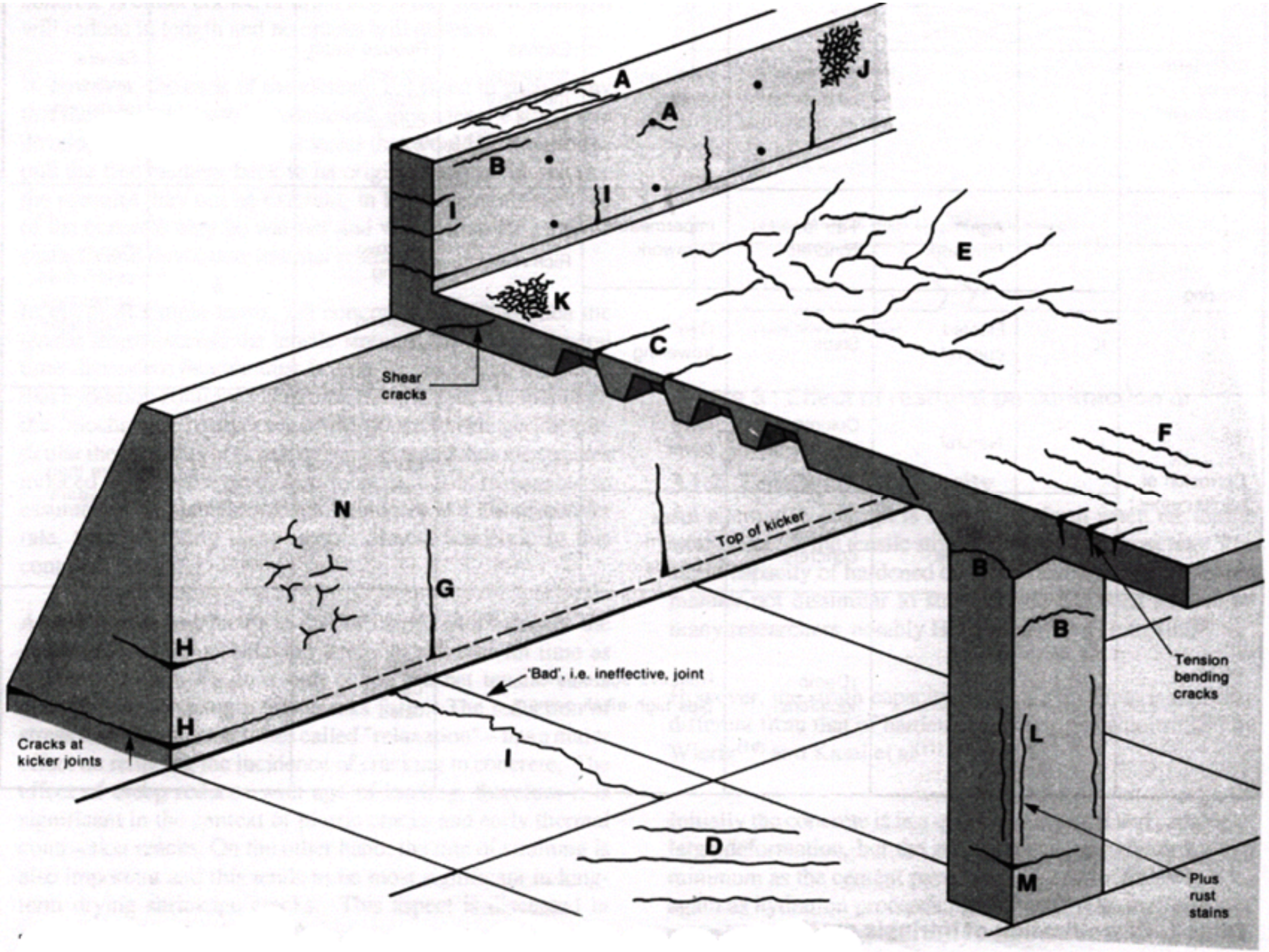
PCA

Concrete Technology and Codes

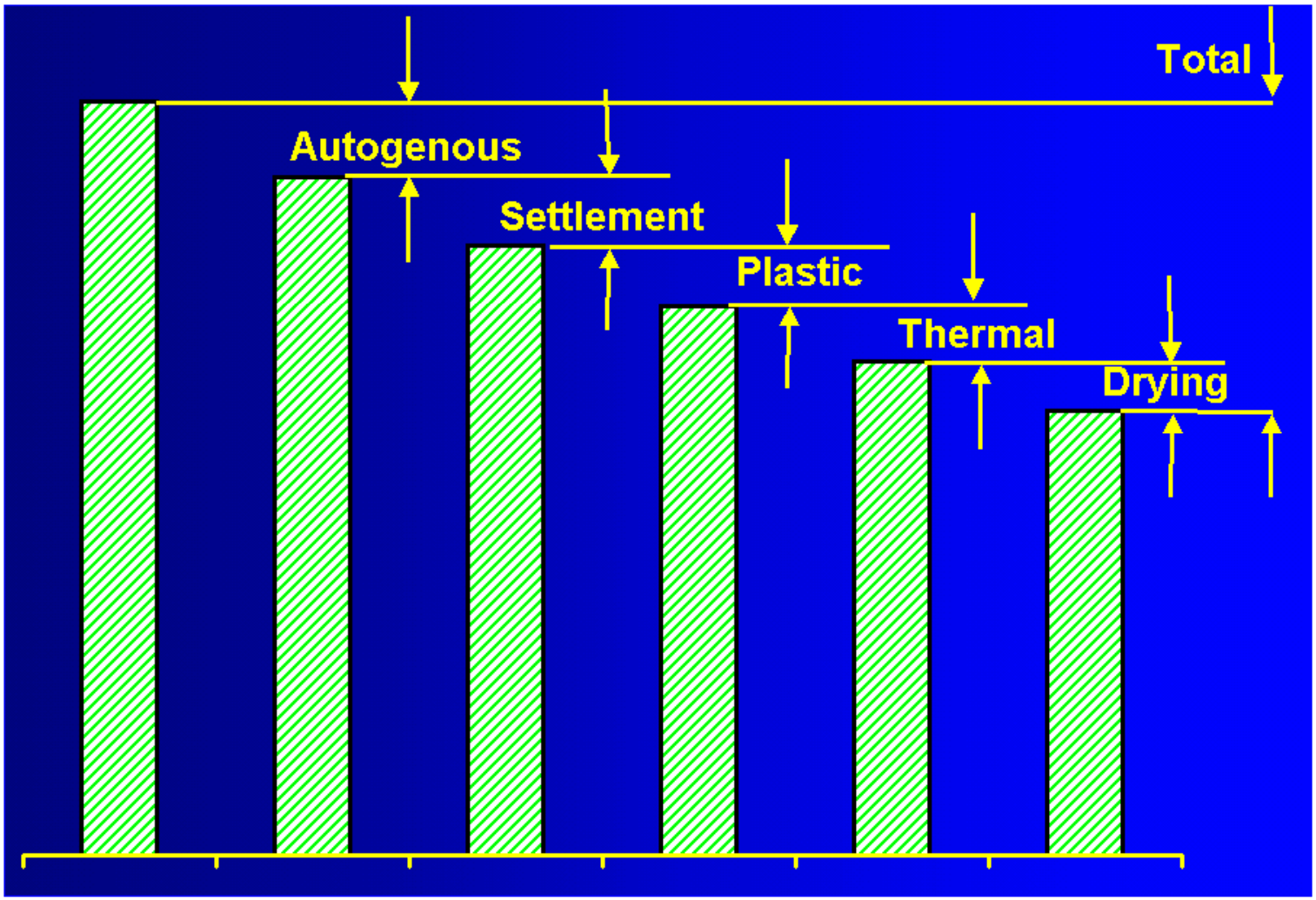
Non-structural Cracks in Concrete


TYPES OF CRACKS
AFTER HARDENING
BEFORE HARDENING
PHYSICAL
CHEMICAL
THERMAL
STRUCTURAL
PLASTIC
CONSTRUCTIONAL MOVEMENT
SHRINKABLE AGGREGATES
DRYING SHRINKAGE
CRAZING
CORROSION OF REINFORCEMENT
ALKALI-AGGREGATE REACTIONS
CEMENT CARBONATION
FREEZE/THAW CYCLES
EXTERNAL SEASONAL TEMPERATURE VARIATIONS
EARLY THERMAL CONTRACTION
EXTERNAL RESTRAINT
INTERNAL TEMPERATURE GRADIENTS
ACCIDENTAL OVERLOAD
CREEP
DESIGN LOADS
EARLY FROST DAMAGE
PLASTIC SHRINKAGE
PLASTIC SETTLEMENT
FORMWORK MOVEMENT
SUB-GRADE MOVEMENT


A
A
J
B
I
I
E
K
C
Shear cracks
F
N
Top of kicker
G
B
B
H
H
'Bad', i.e. ineffective, joint
Tension bending cracks
Cracks at kicker joints
L
I
D
M
Plus rust stains

Letter	Type of Cracking	Subdivision	Most Common Location	Primary Cause (excluding restraint)	Secondary Causes/Factors	Time of Appearance
A	Plastic settlement	Over reinforcement	Deep sections	Excess bleeding	Rapid early drying conditions	Ten minutes to three hours
B		Arching	Top of columns			
C		Change of depth	Trough and waffle slab			
D	Plastic shrinkage	Diagonal	Roads and slabs	Rapid early drying	Low rate of bleeding	Thirty minutes to six hours
E		Random	Reinforced concrete slabs			
F		Over reinforcement	Reinforced concrete slabs	Ditto plus steel near surface		
G	Early thermal contraction	External restraint	Thick walls	Excess heat generation	Rapid cooling	One day or two or three weeks
H		Internal restraint	Thick slabs	Excess temperature gradients		
I	Long-term drying shrinkage		Thin slabs (and walls)	Inefficient joints	Excessive shrinkage inefficient curing	Several weeks or months
J	Crazing	Against formwork	"Fair faced" concrete	Impermeable formwork	Rich mixes	One to seven days, sometimes much later
K		Floated concrete	Slabs	Over troweling	Poor curing	
L	Corrosion of reinforcement	Natural	Columns and beams	Lack of cover	Poor quality concrete	More than two years
M		Calcium chloride	Precast concrete	Excess calcium chloride		
I	Alkali-aggregate reaction		Damp locations	Reactive aggregate plus high-alkali cement		More than five years

Why does concrete shrink?



Non-structural Cracks

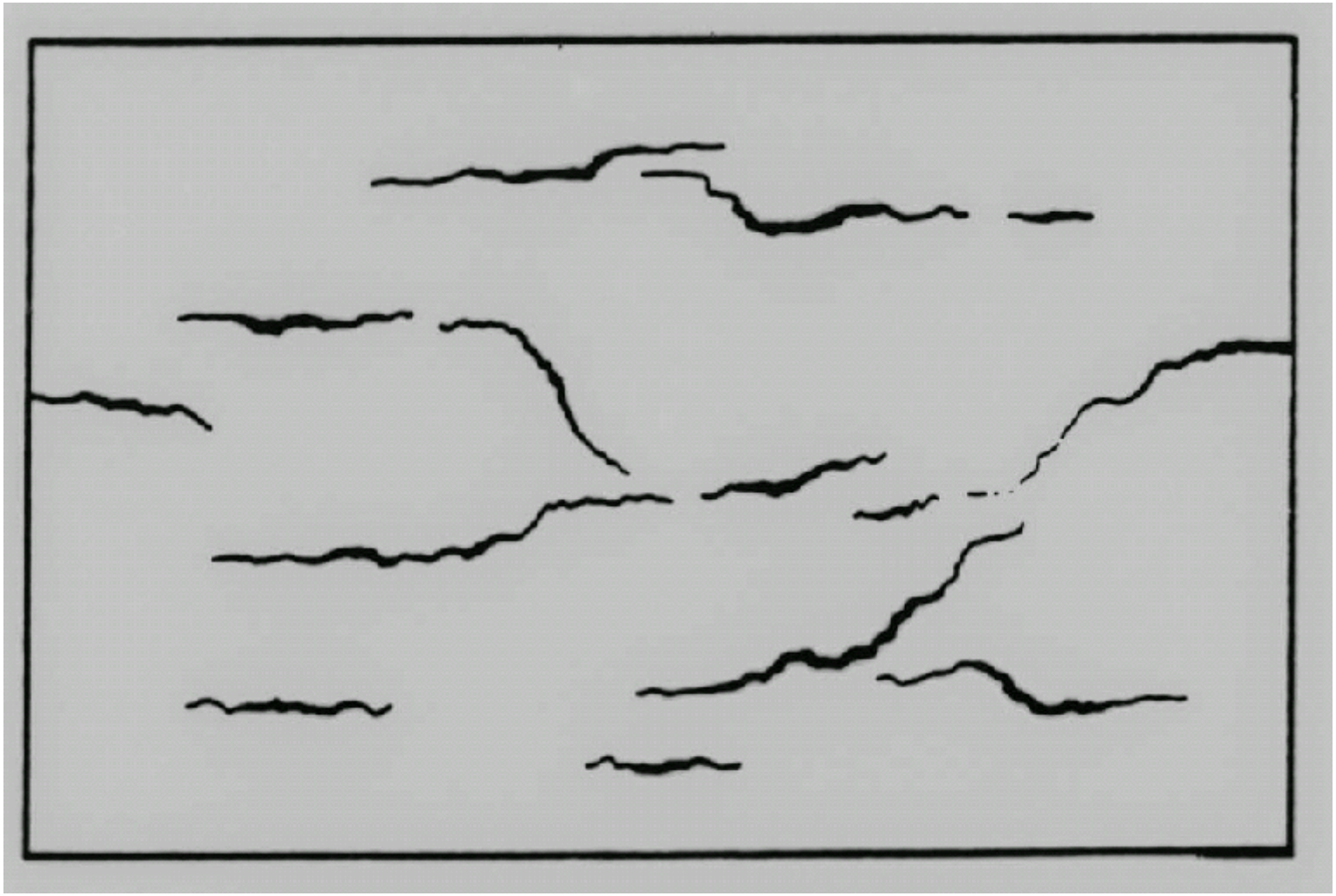
- Fresh
  - Settlement
  - Plastic shrinkage
- Hardened
  - Drying shrinkage
  - Thermal dilation

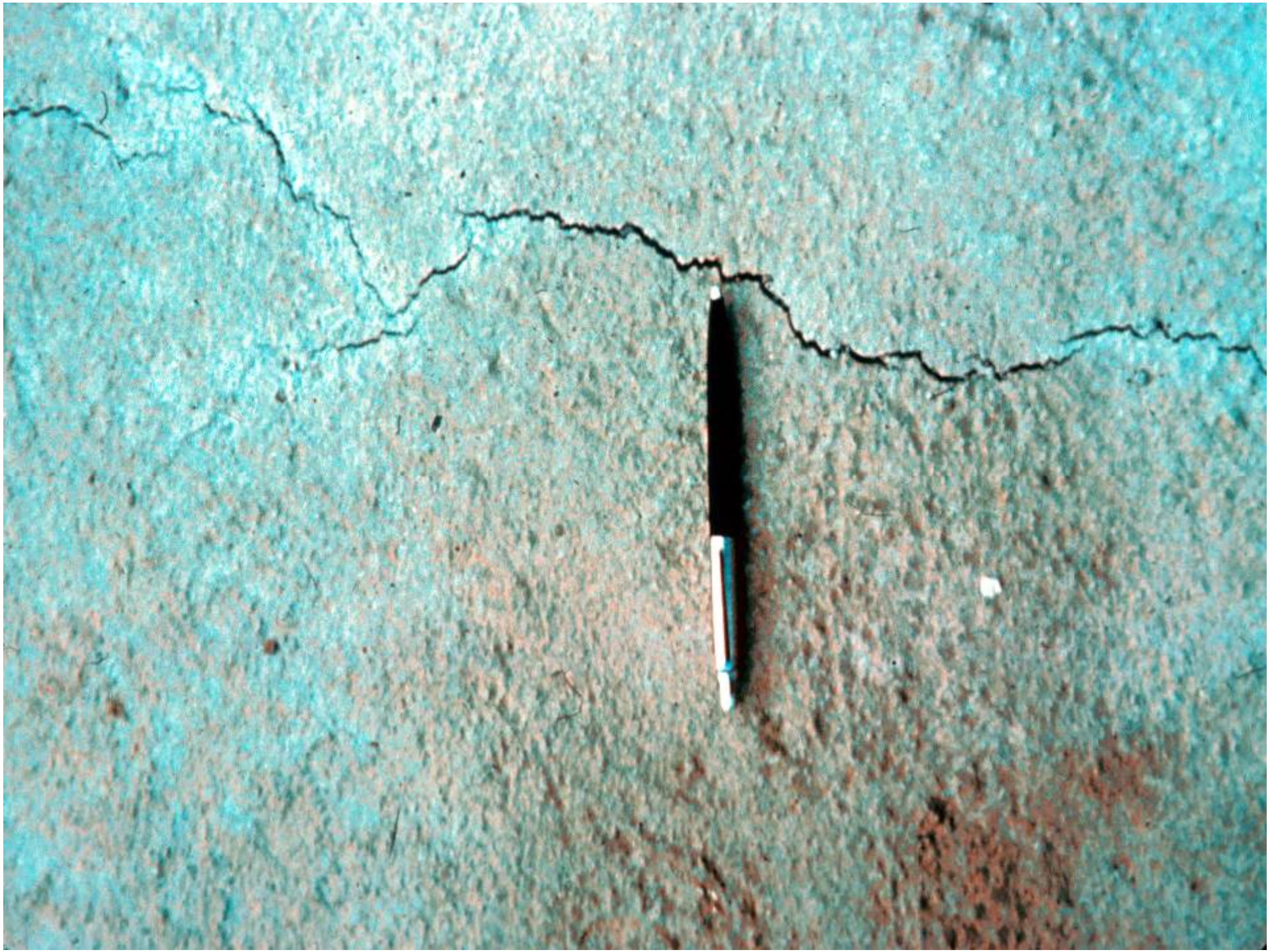
Before Hardening

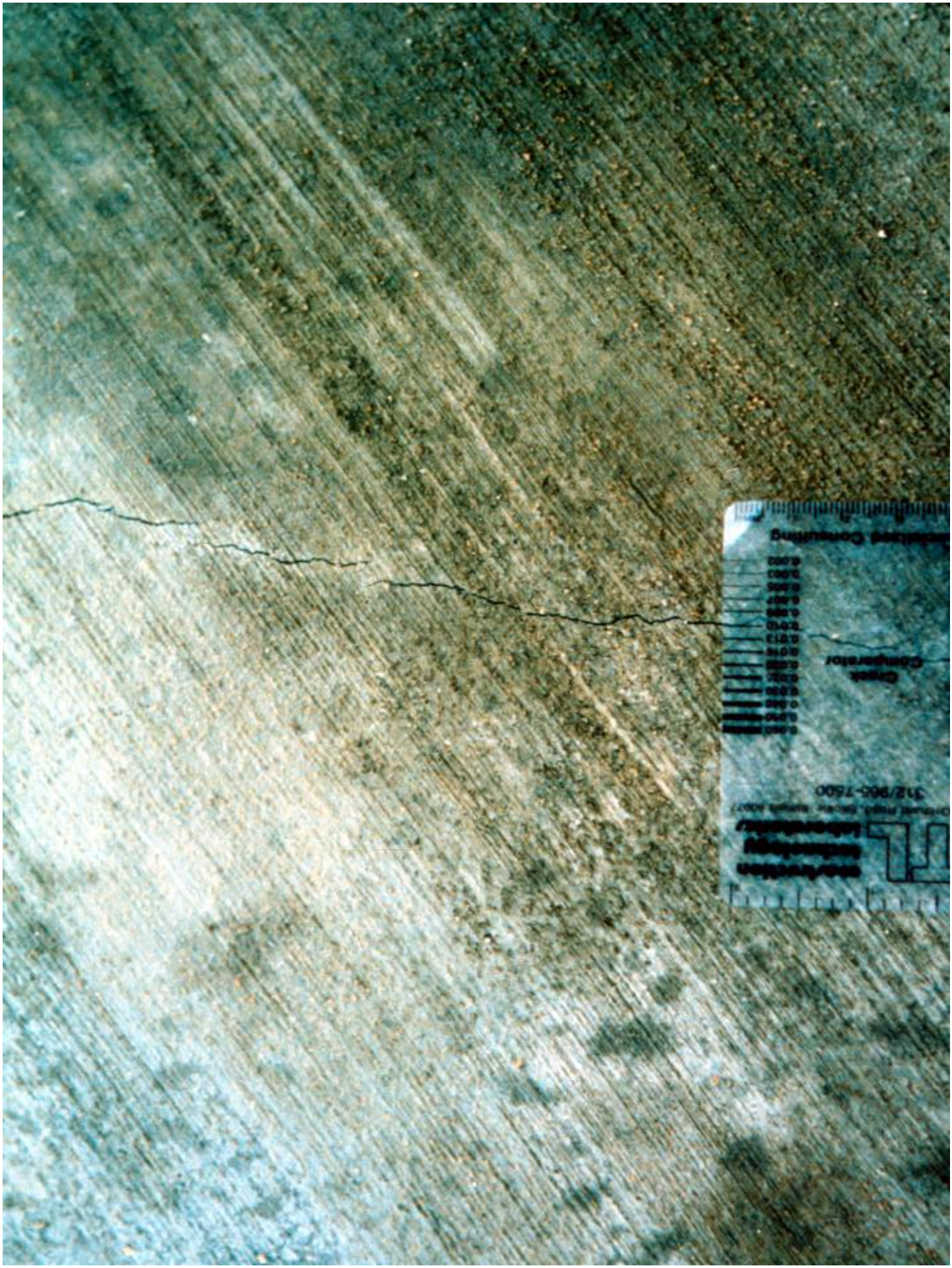
- Early frost damage
- Plastic
  - Shrinkage
  - Settlement
- Construction movement
  - Formwork
  - Sub-grade

PLASTIC SHRINKAGE CRACKING

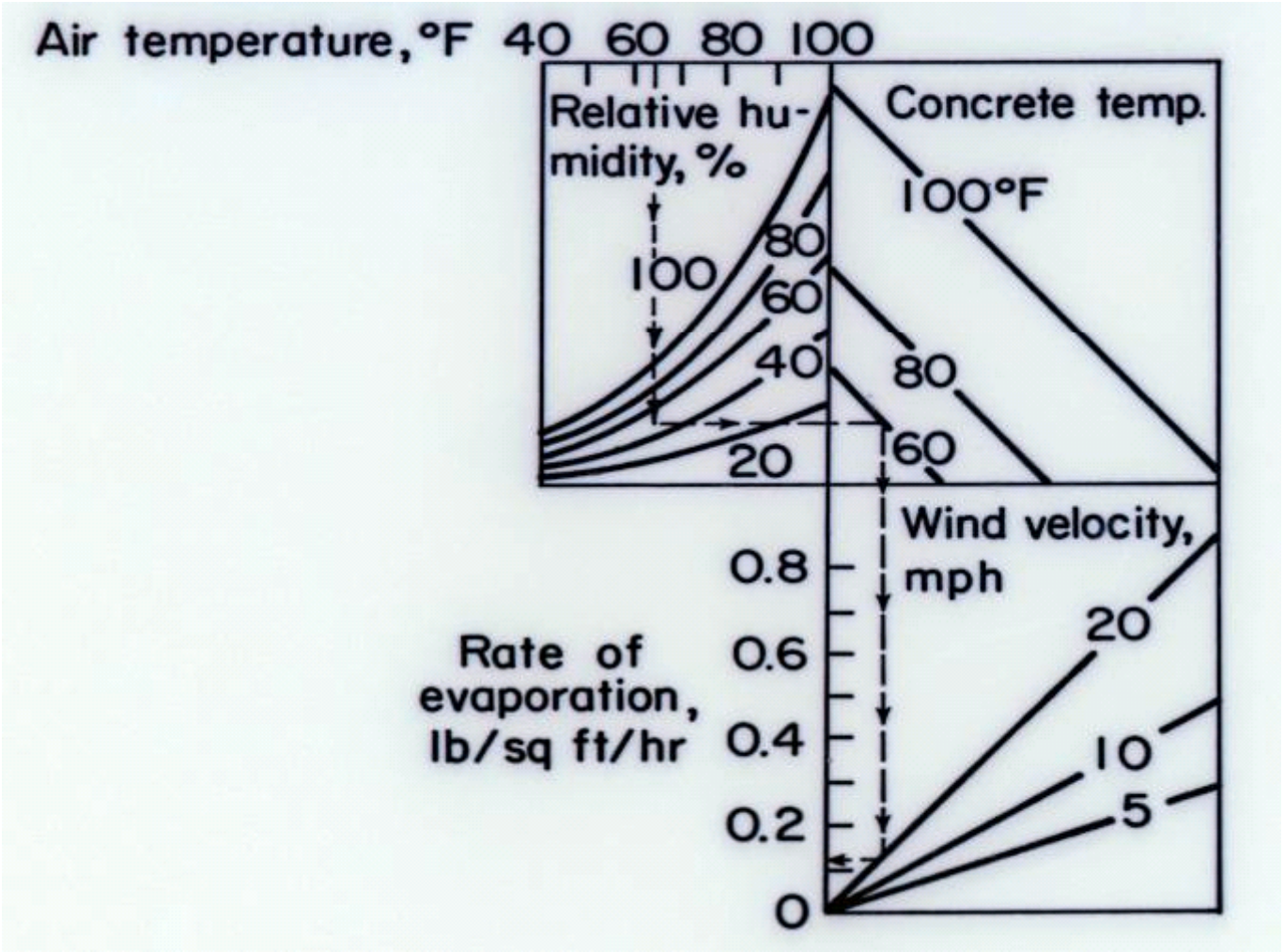
Typical Plastic Shrinkage Cracking







Evaporation of Surface Moisture from Concrete



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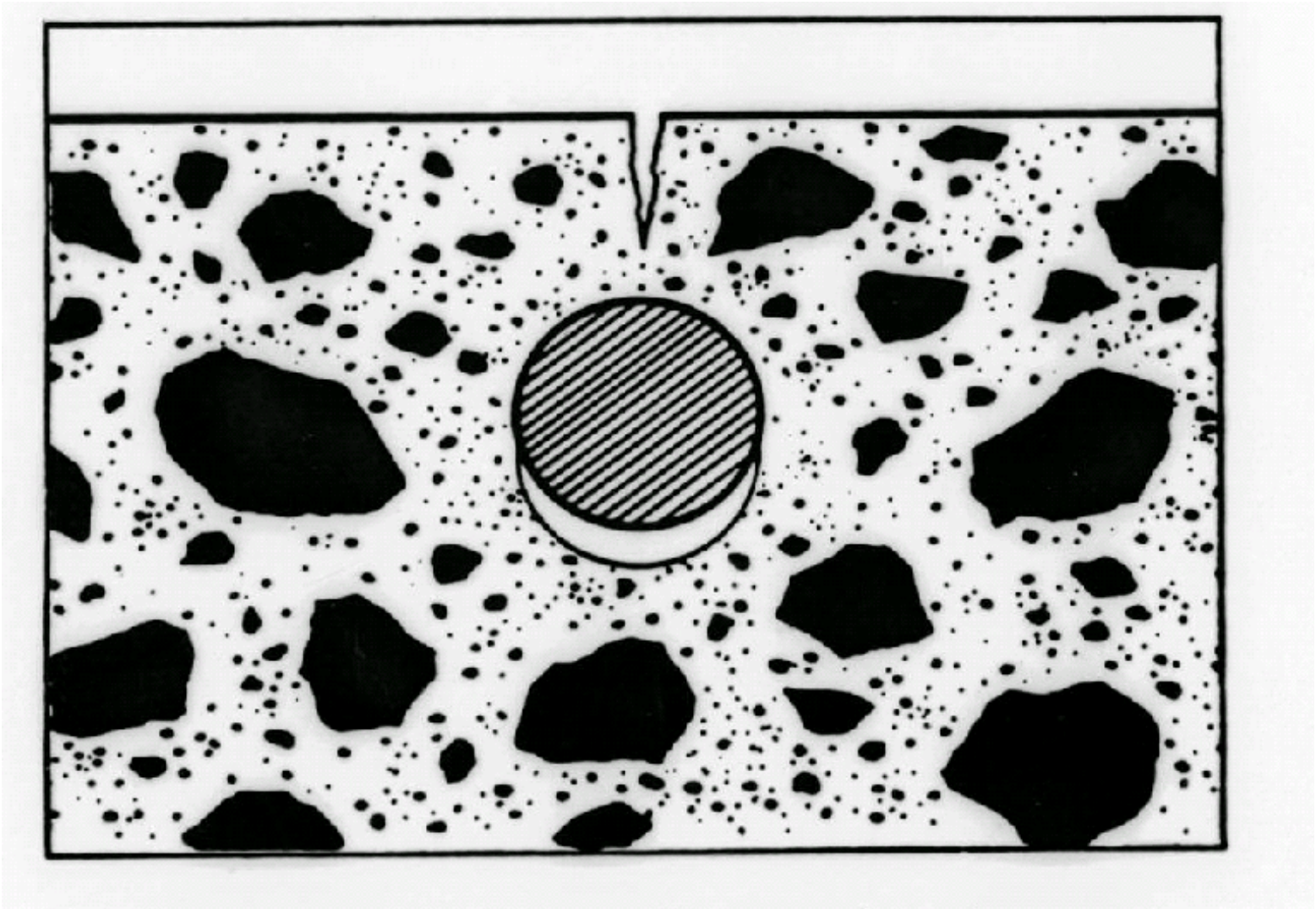
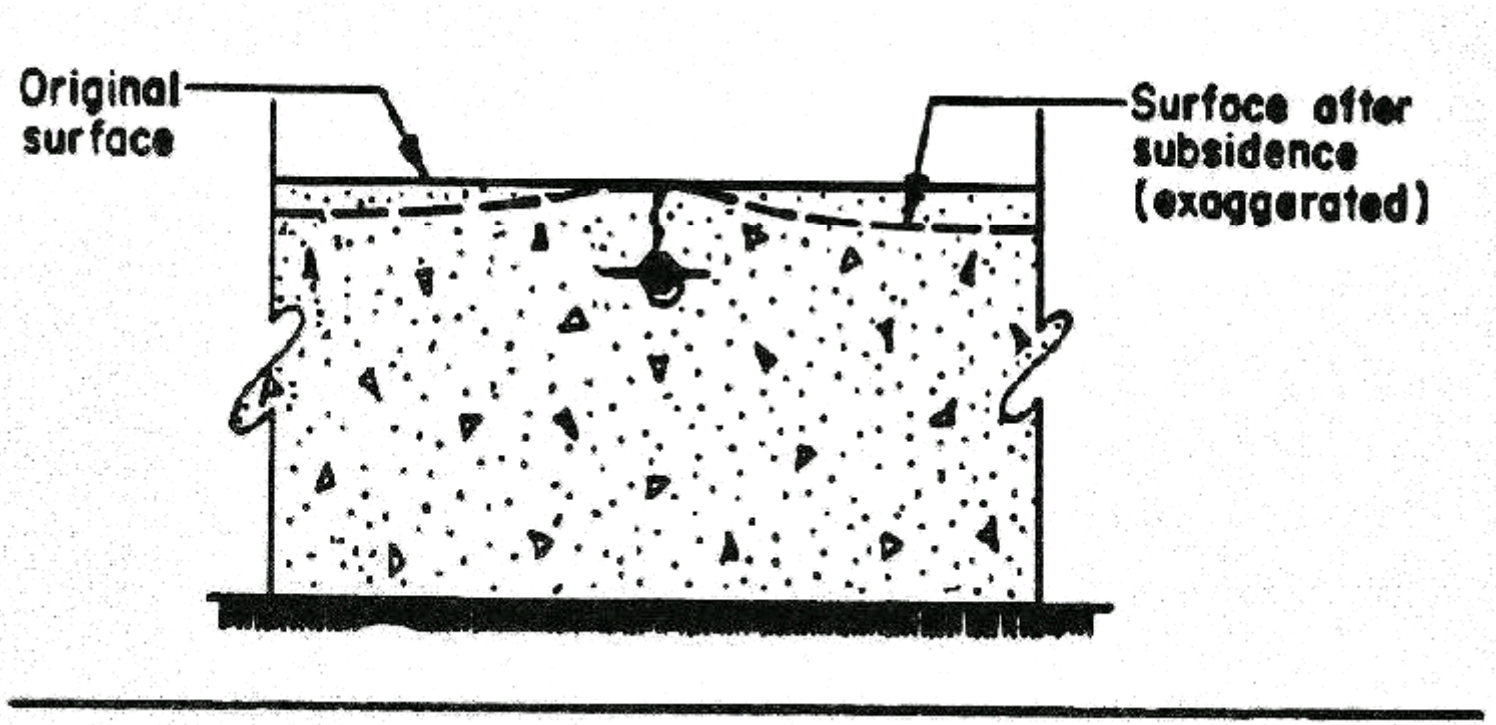
Concrete Technology and Codes

Plastic Settlement

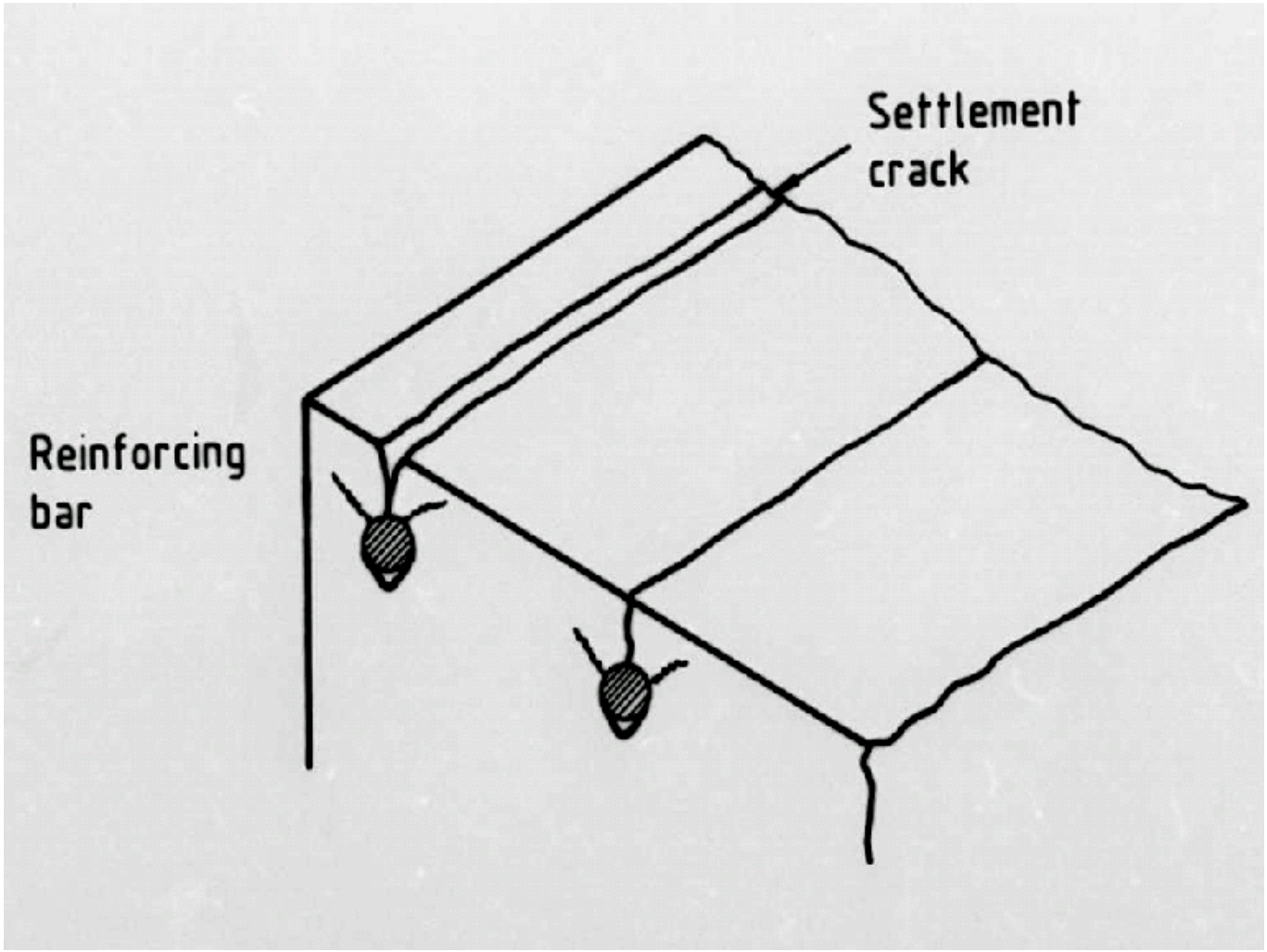
Subsidence Cracking



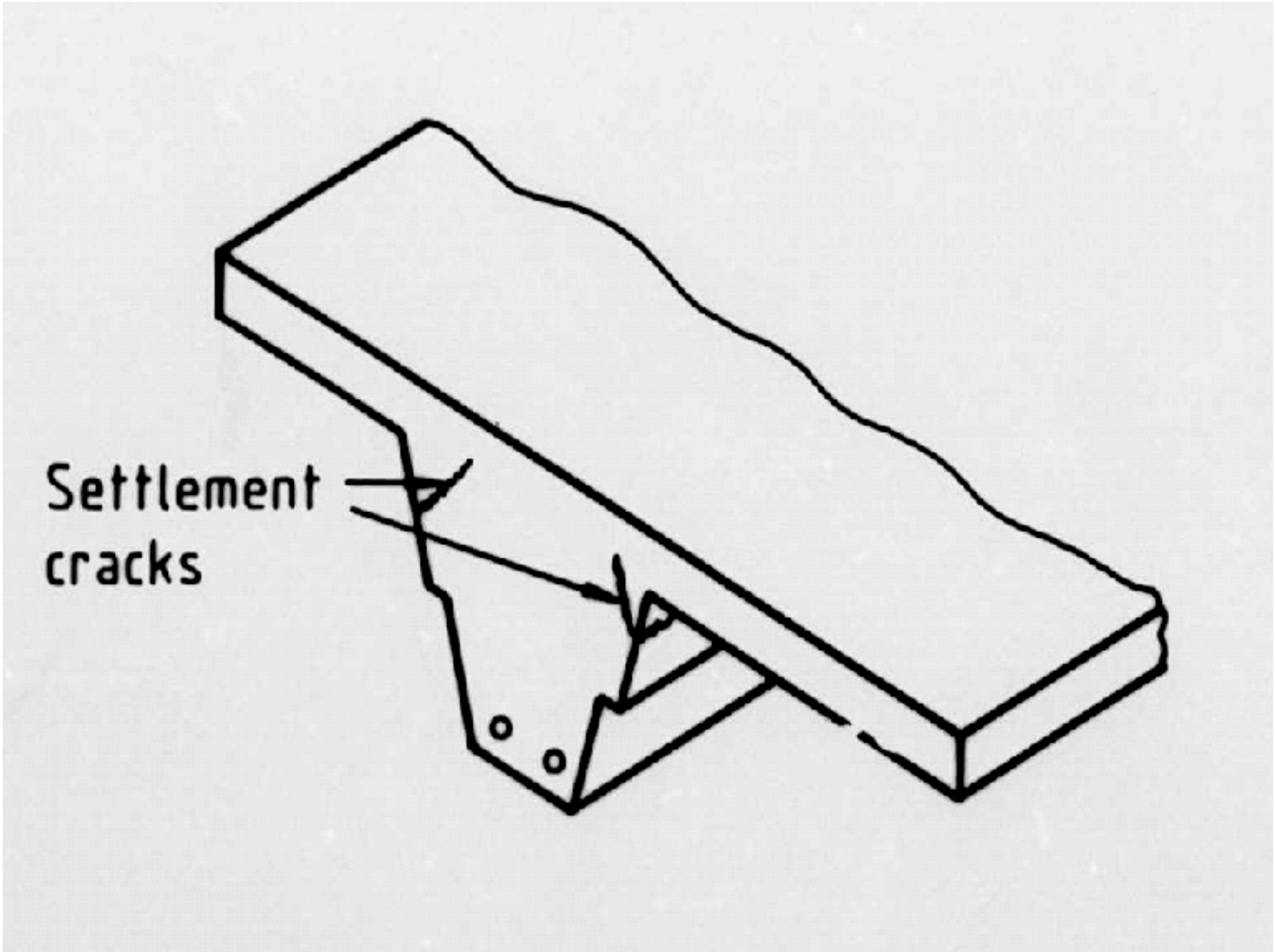
Resistance to subsidence by top reinforcement



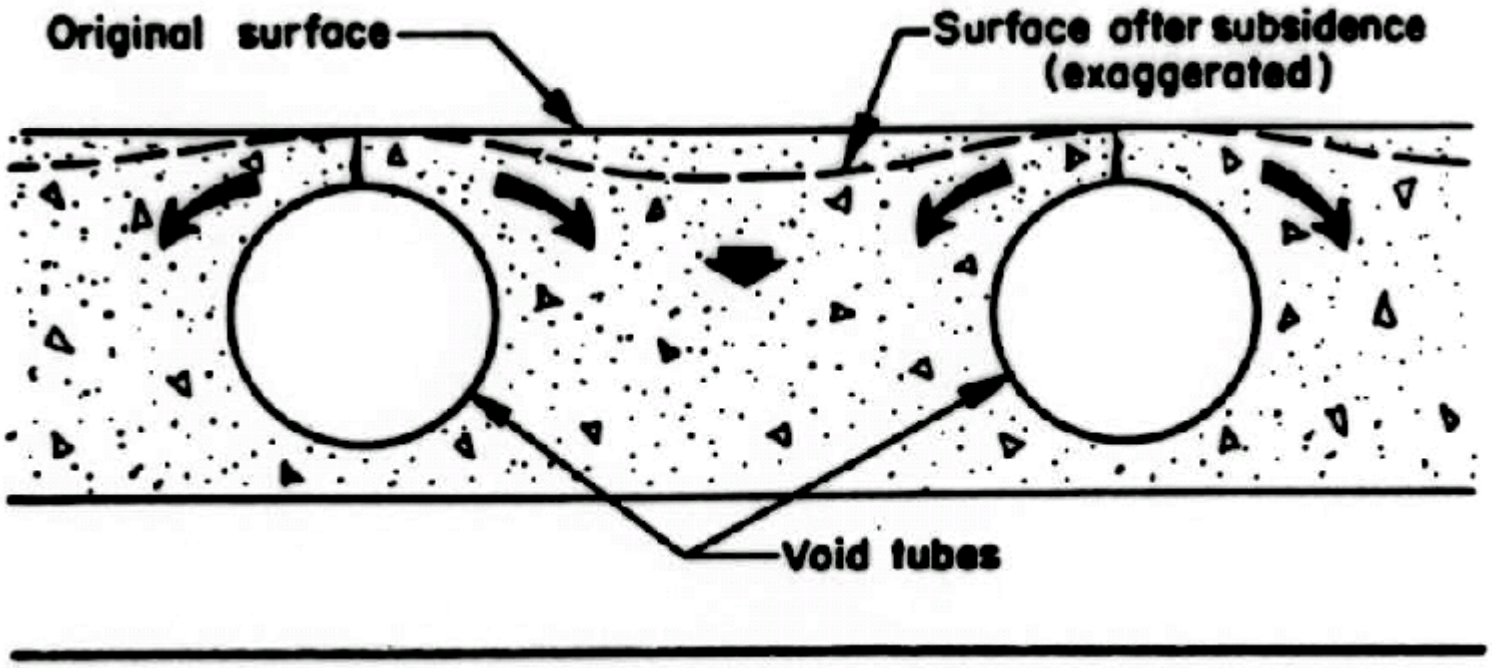
Cracks usually appear along reinforcement bars…



..but can also form from differential settlement



Resistance to subsidence by void tubes in hollow core



After Hardening

- Physical
  - Shrinkable aggregates
  - Drying shrinkage
  - Crazing
- Chemical
  - Corrosion of rebar
  - Alkali aggregate reaction
  - Carbonation

After Hardening

- Thermal
  - Freeze – thaw cycles
  - External seasonal temperature variations
  - Early thermal contraction
    - External restraint
    - Internal temperature gradients
- Structural
  - Accidental overload
  - Creep
  - Design loads

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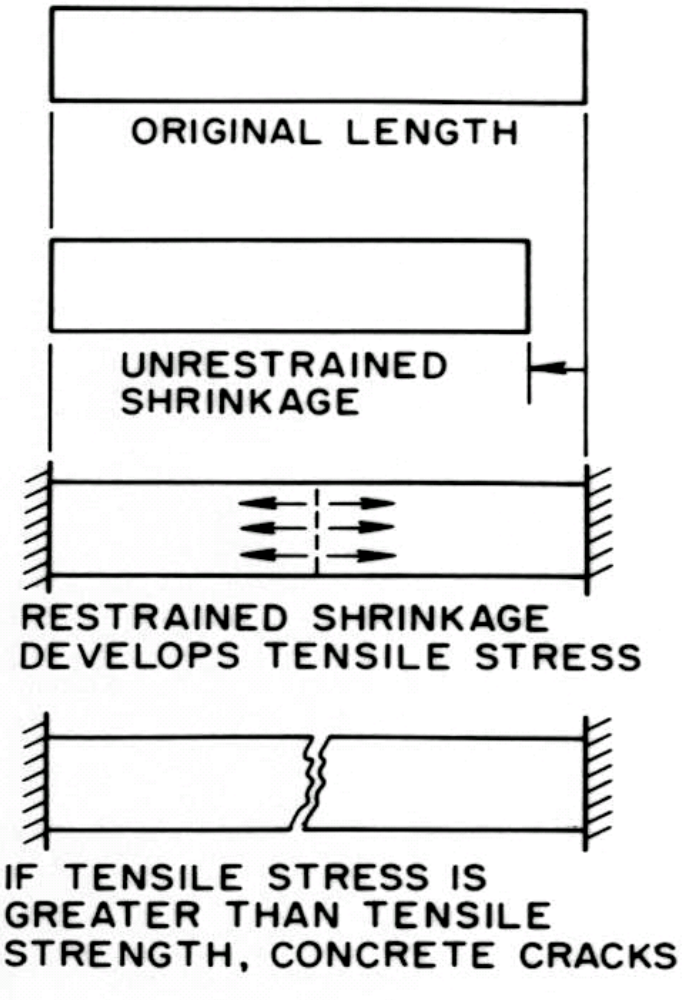
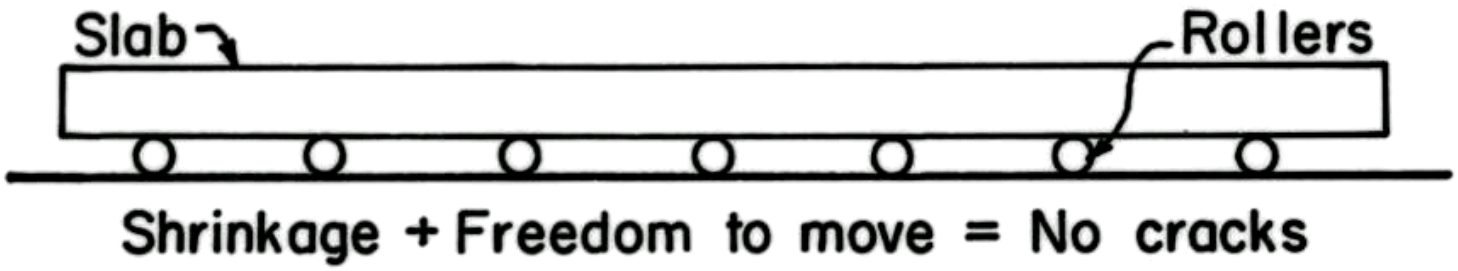
Concrete Technology and Codes

Drying Shrinkage Cracking

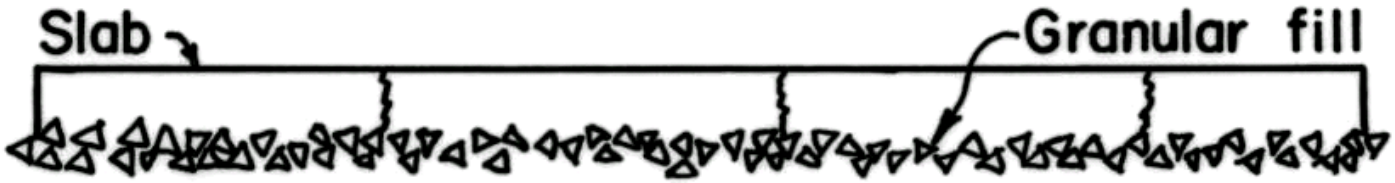
Why cracks form



Shrinkage and Cracking



Shrinkage + Freedom to move = No cracks

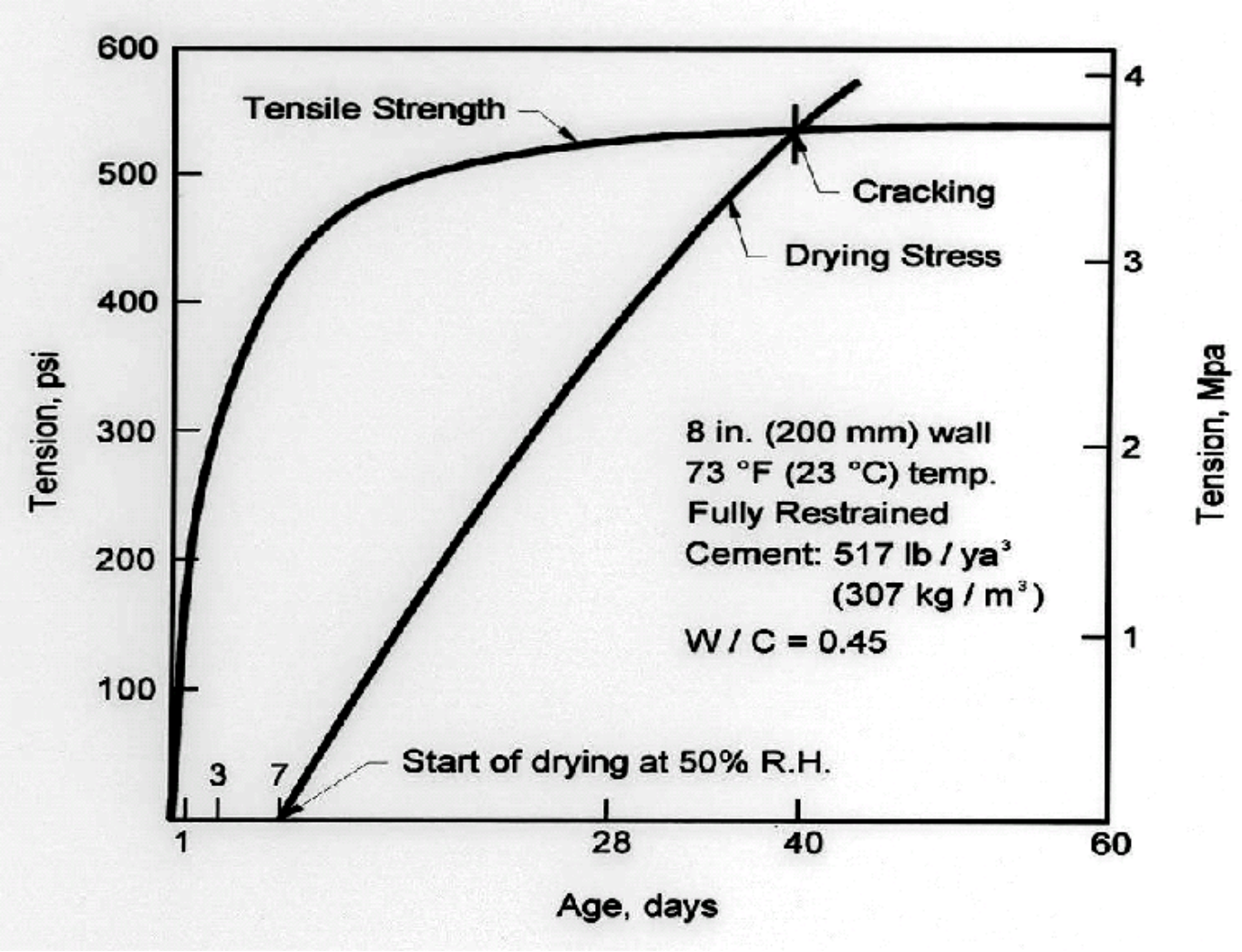


Shrinkage + Subbase restraint = Cracks

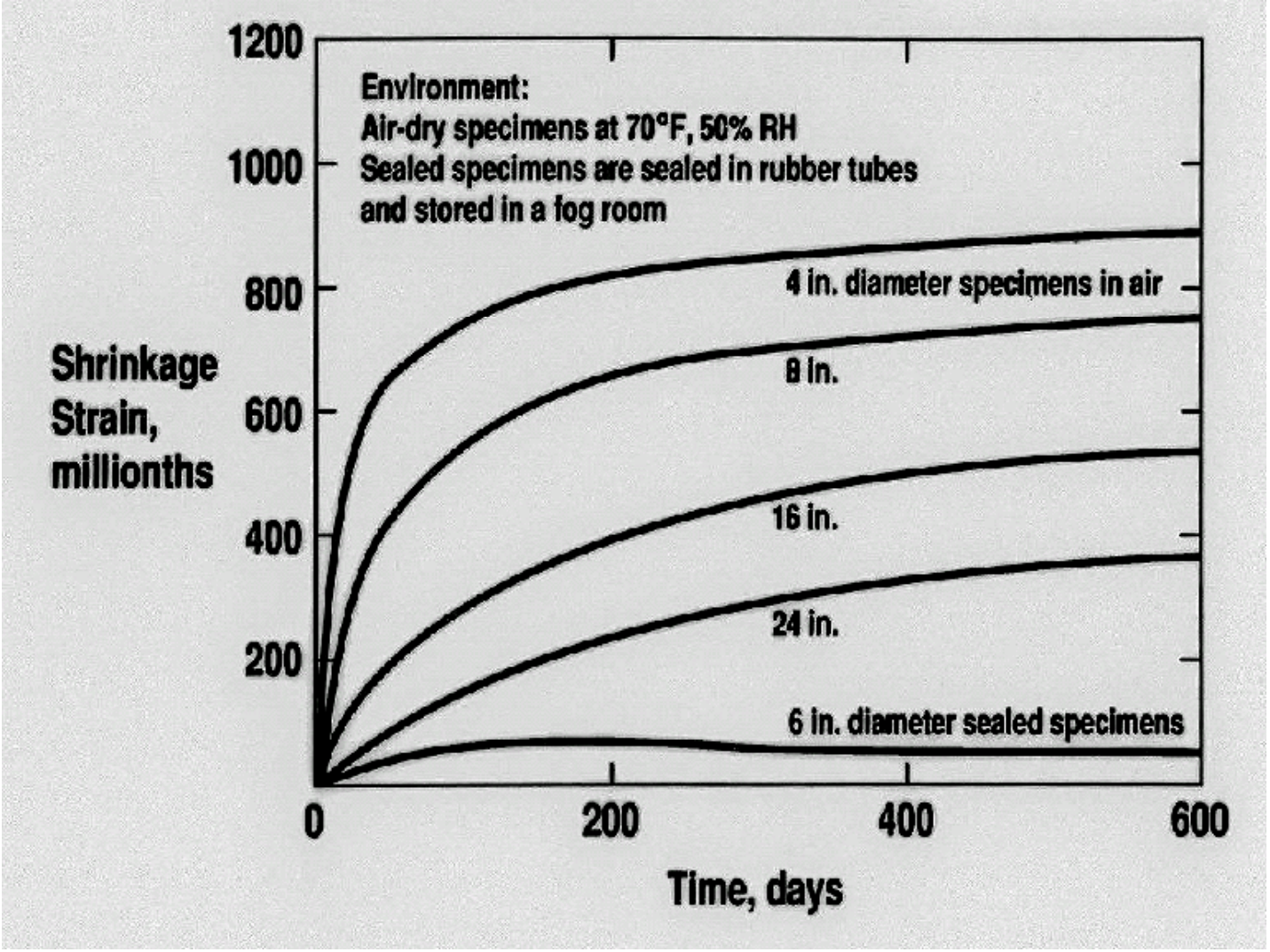
Drying Shrinkage Cracks

- Occur: In thin sections (low V/S ratio)
- When: Several weeks after casting
- Causes:
  - Excess water in mix
  - High paste content
  - Inefficient joints
  - Poor curing
- Remedies:
  - Reduce water content of mix
  - Improve curing

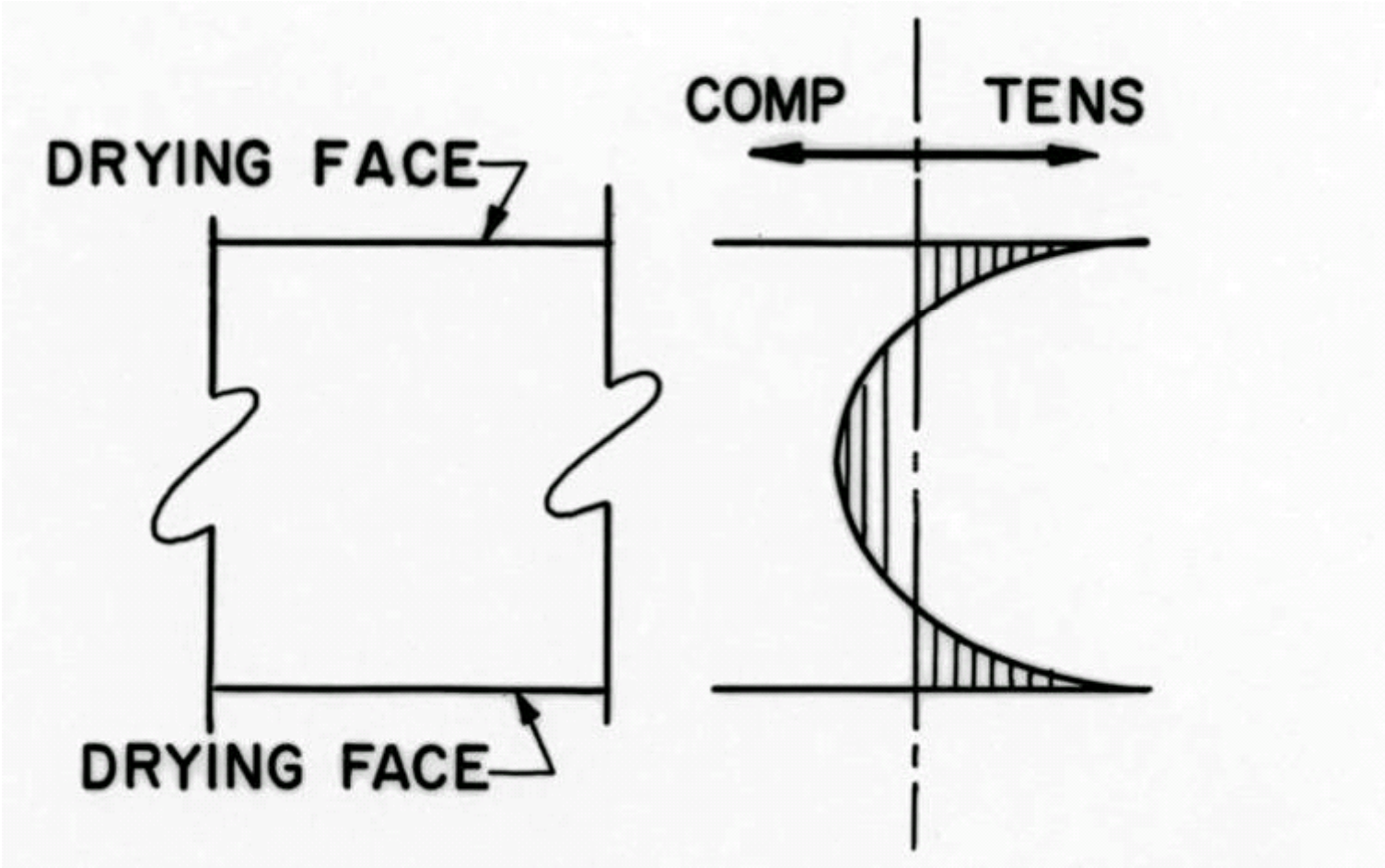
Cracking tendency depends on many factors



Shrinkage is Size Dependent



Theoretical Shrinkage Stresses



Mitigation of Drying Shrinkage Cracks

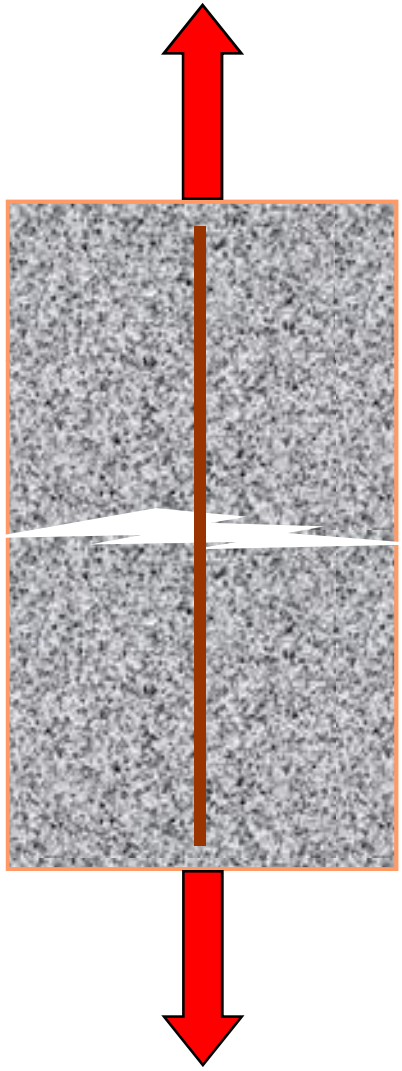
- Aggregate
  - Content
  - Size
- Workability
  - Ease of placement
  - Consolidation
- Admixtures
  - Chemical
  - Mineral
- Curing
- Eliminate external restraints by allowing joint movement
- Provide crack control steel distribution

The role of fibers…

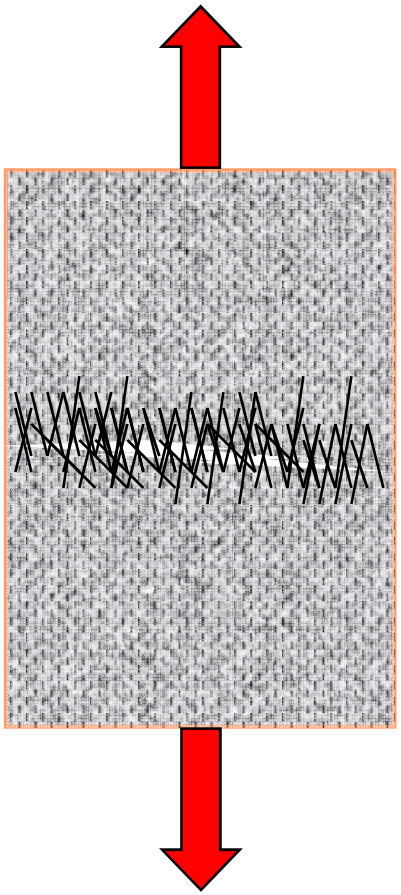
- Fibers will:
  - Reduce plastic shrinkage cracking
  - Reduce bleeding
- What about other types of cracking?
  Fibers can:
  - Bridge cracks
  - Distribute stresses and limit crack widths
  - Volume is critical!

Tensile Deformation Plain Concrete

Tensile Deformation
Steel Reinforced Concrete



Tensile Deformation
Fiber Reinforced Concrete



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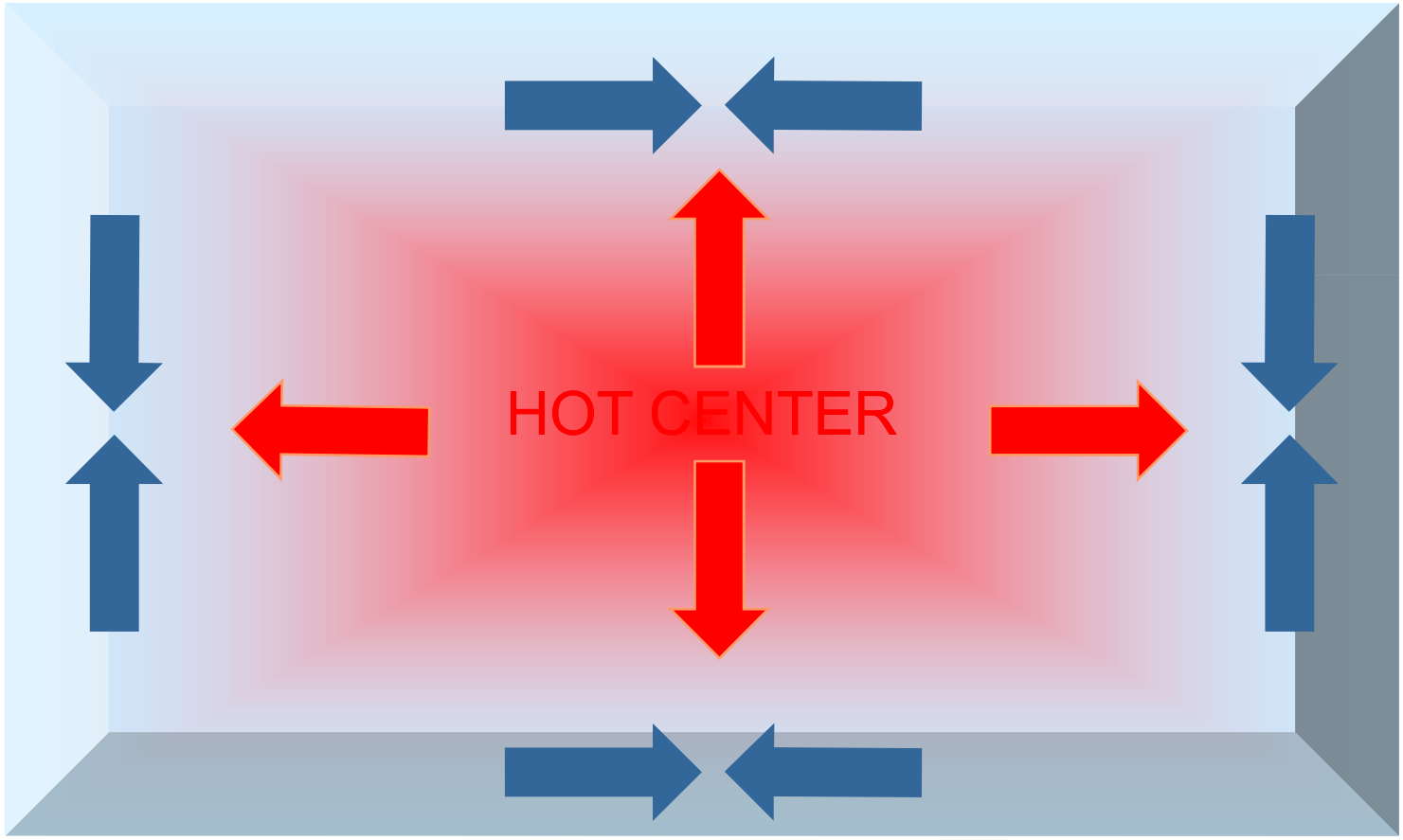
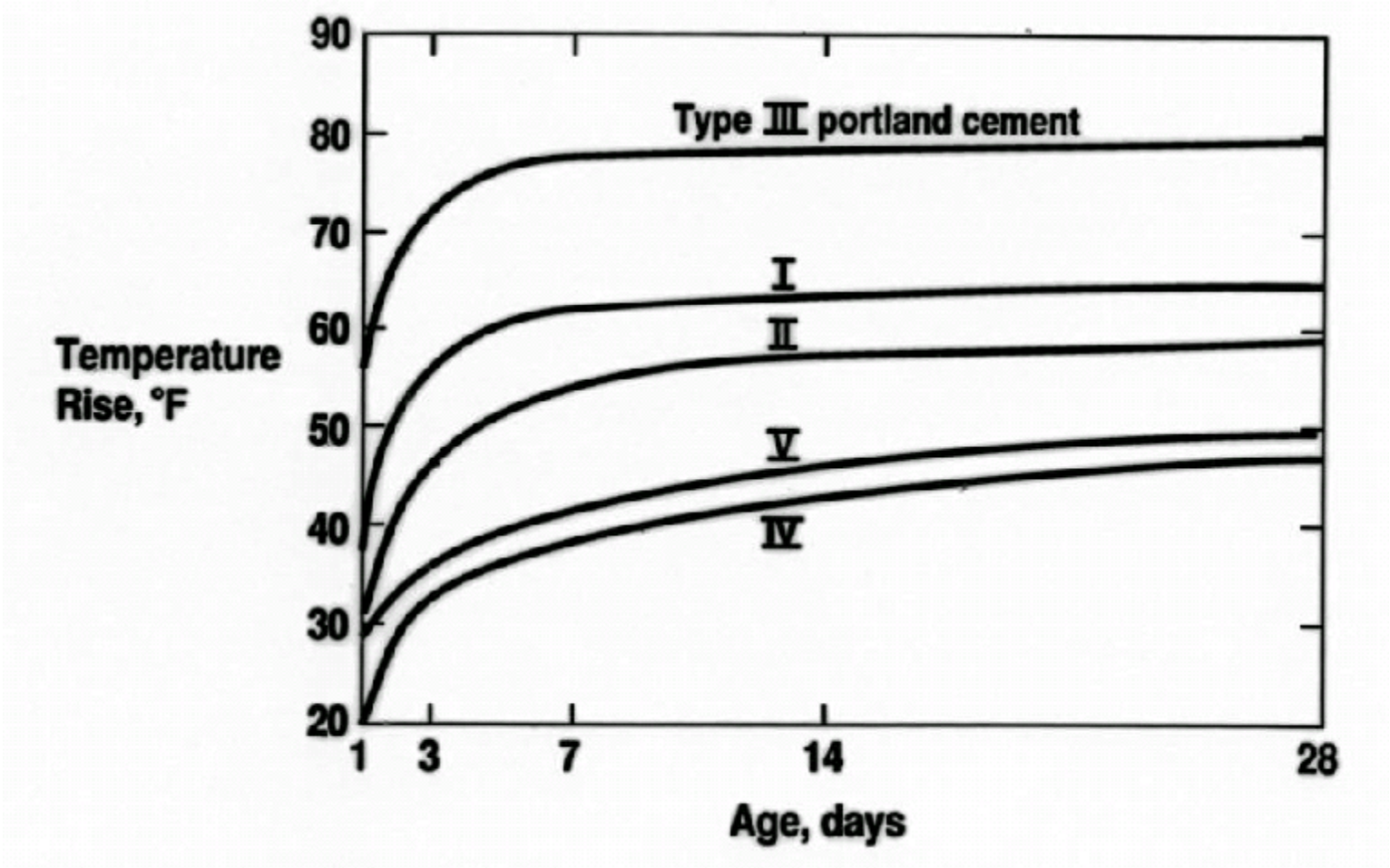
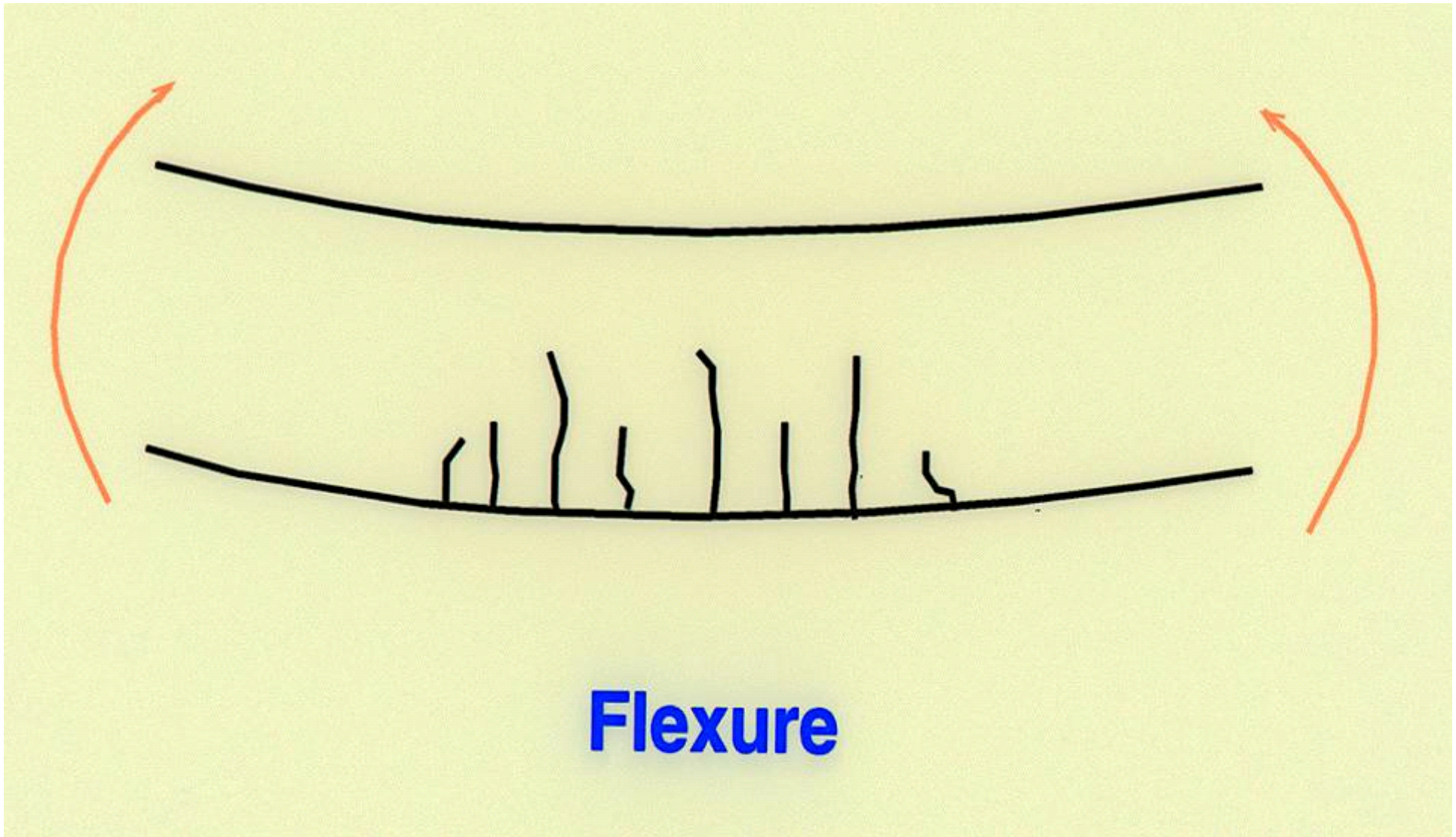
Thermal Cracking

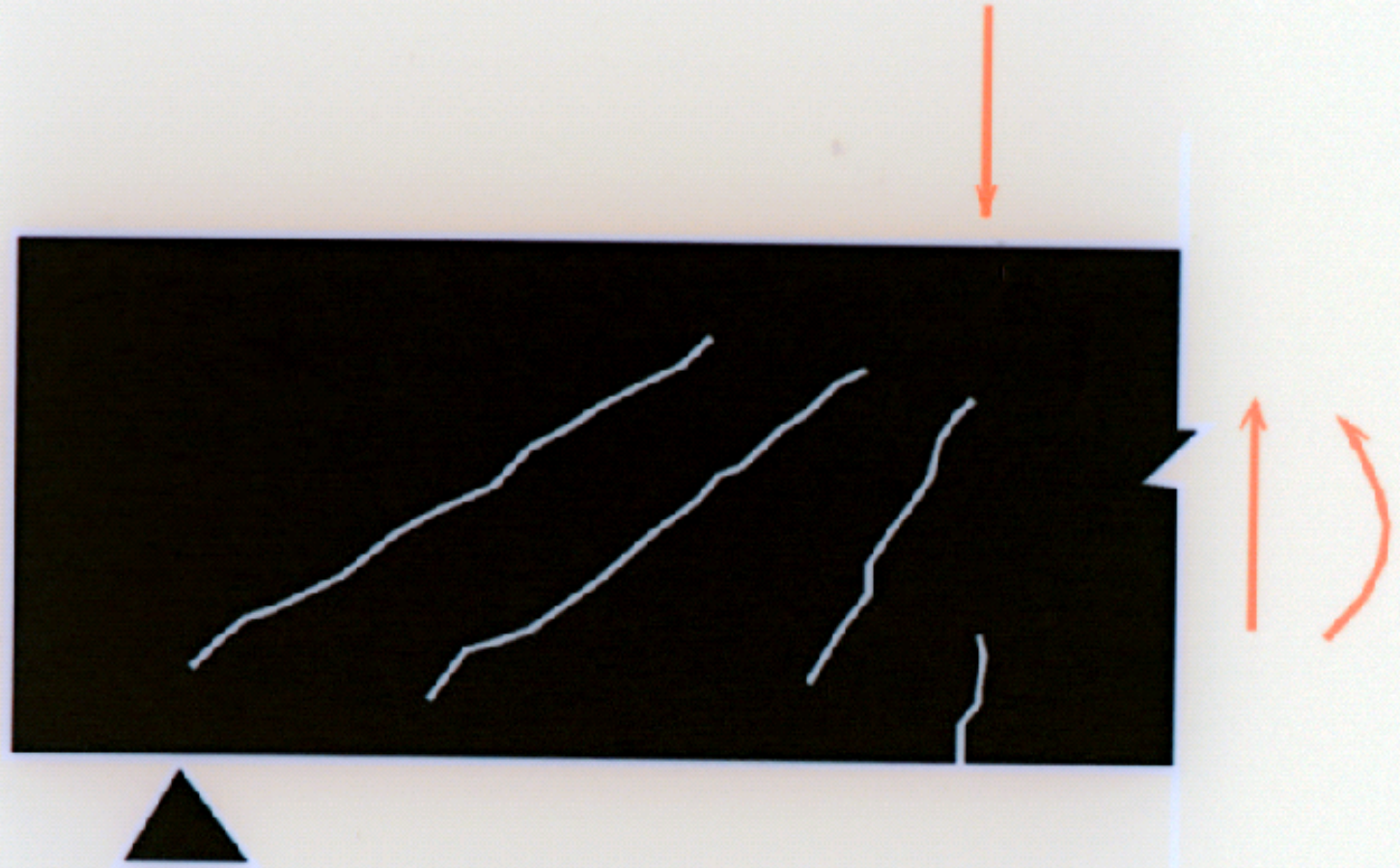
Internal Thermal Restraint



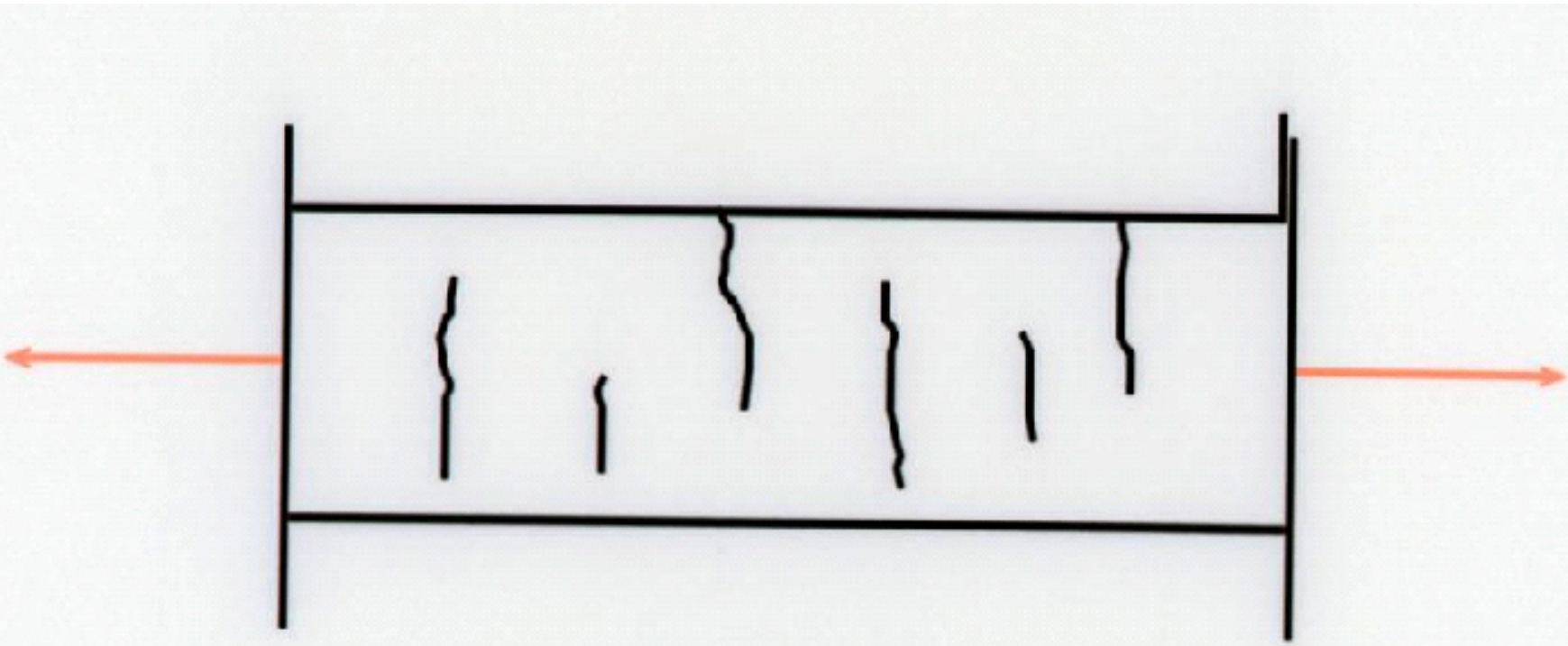
Temperature Rise and Cement Type



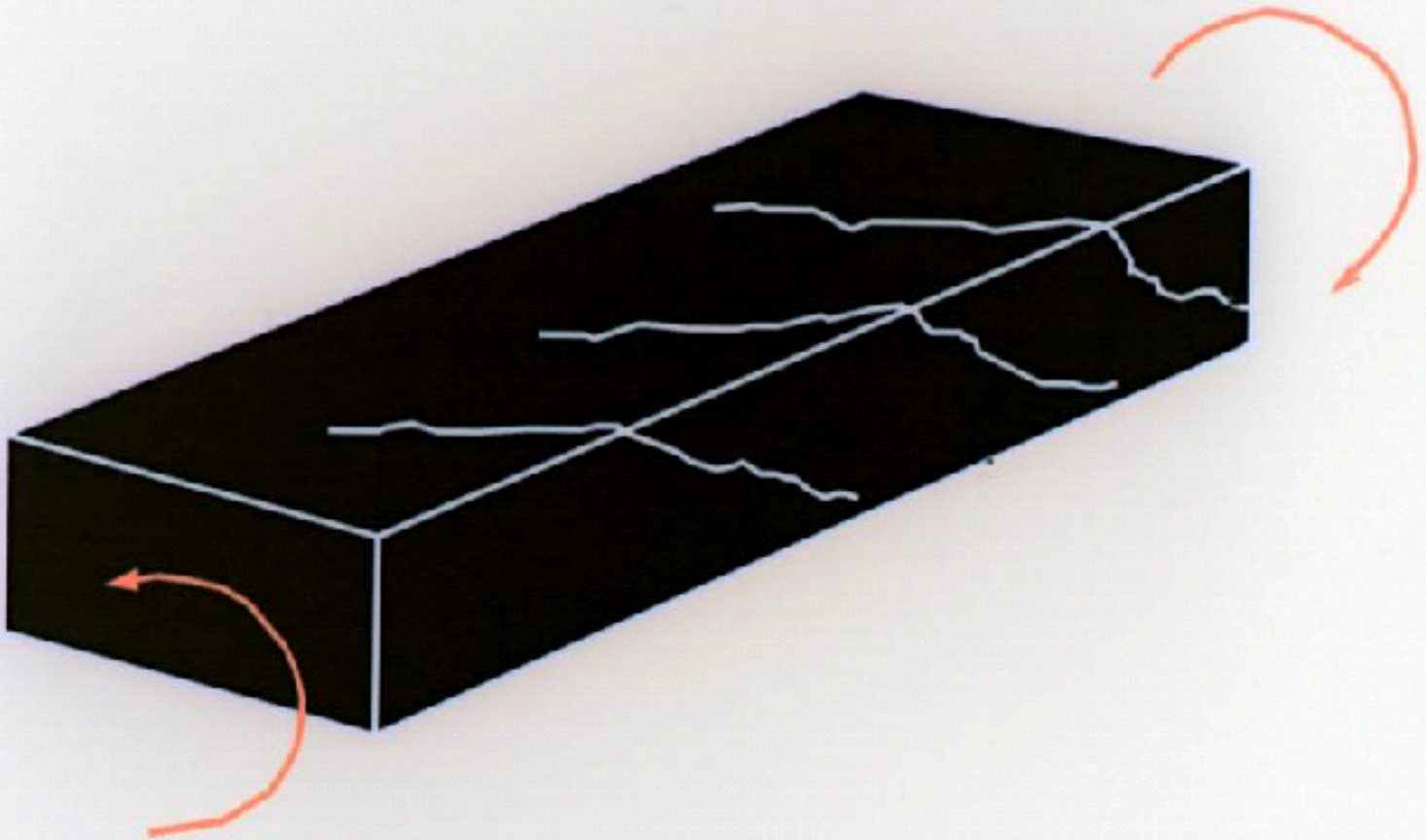

Flexure



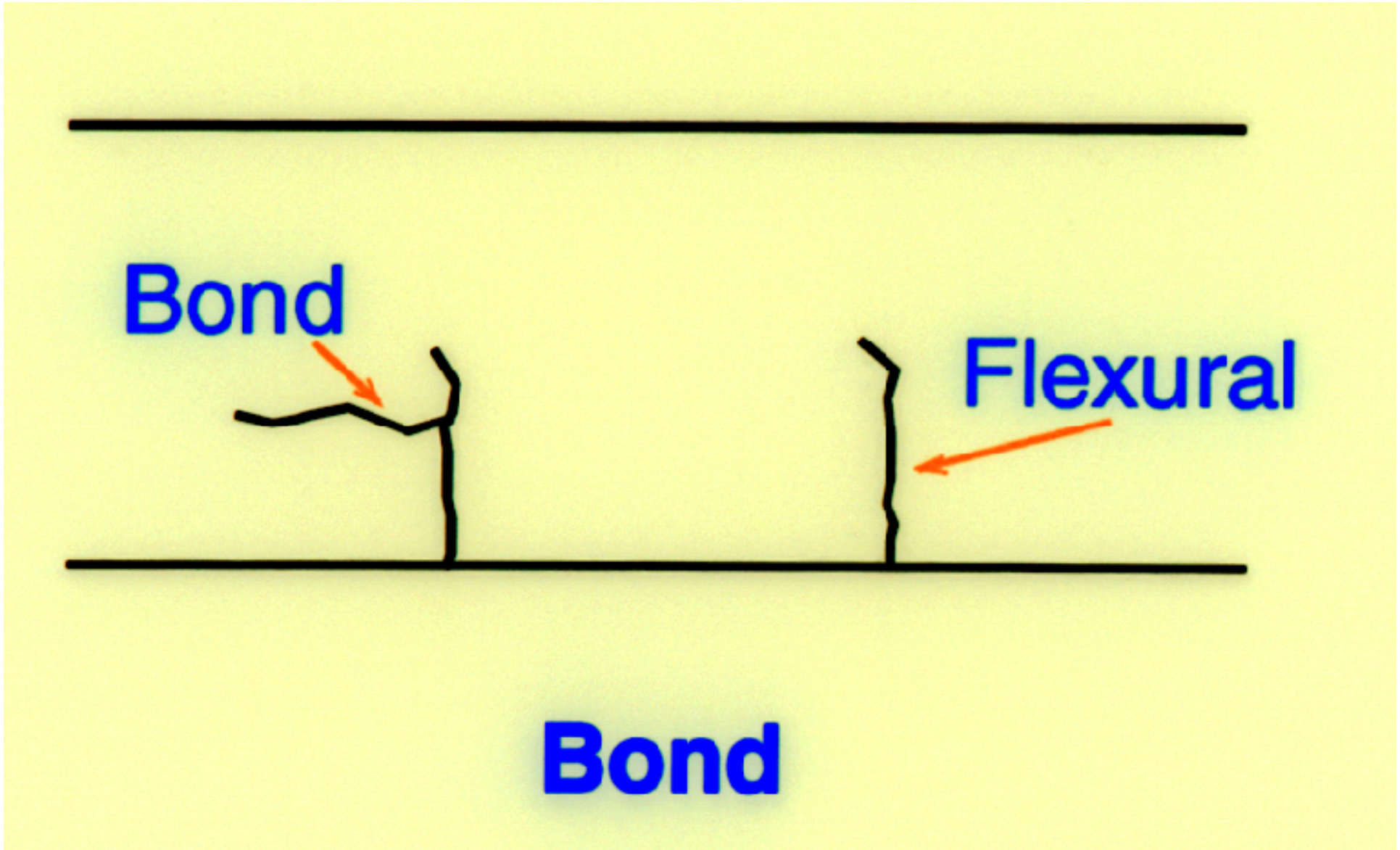
Shear



Tension



Torsion


Bond
Flexural
Bond

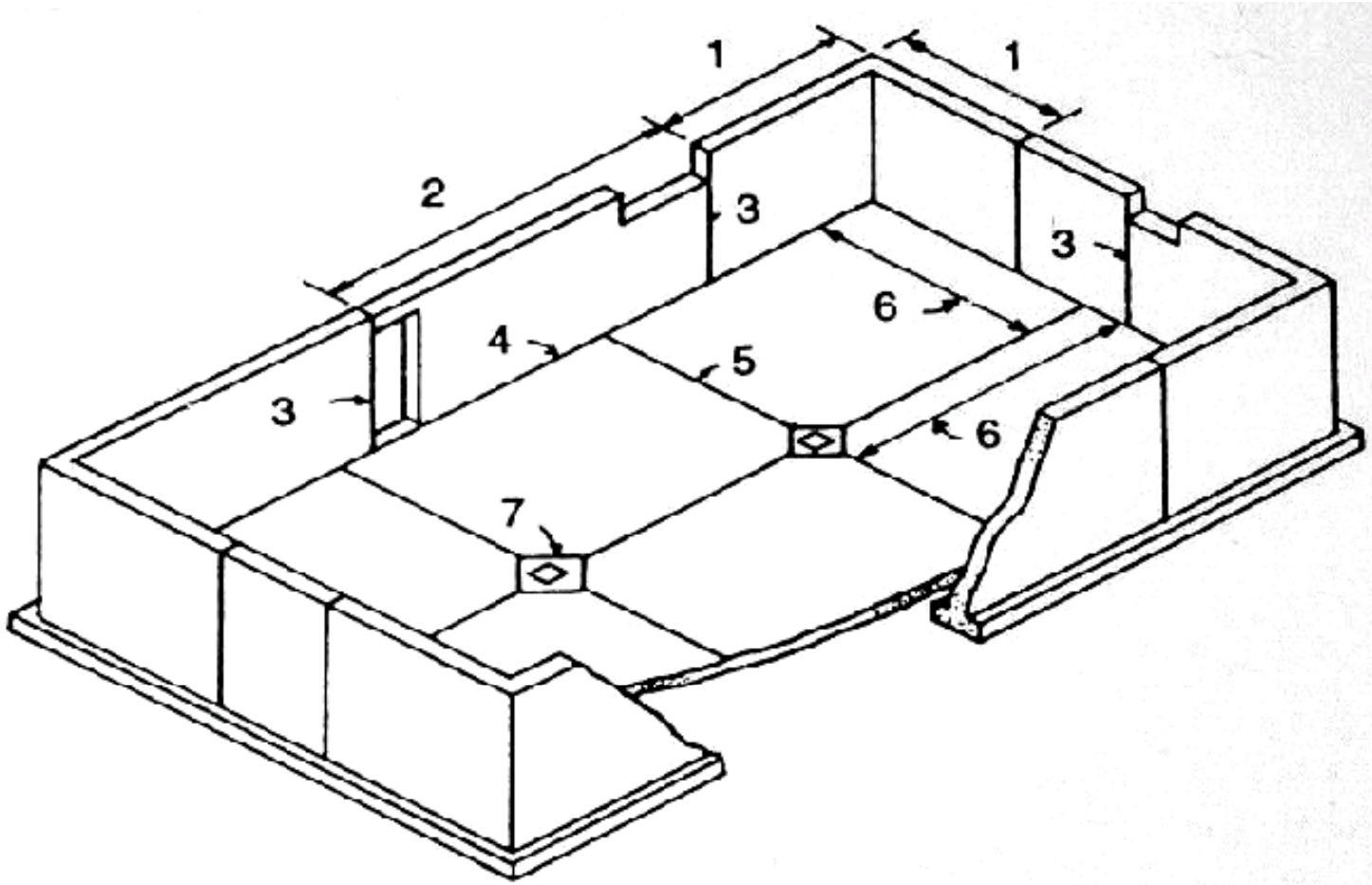
ACI 224
Tolerable Crack Widths

Exposure condition	Tolerable crack width, in.
Dry air or protective membrane	0.016
Humidity, moist air, soil	0.012
Deicing chemicals	0.007
Seawater and seawater spray; wetting and drying	0.006
Water-retaining structures	0.004

Crack Control

Control of Cracking

- Joints
  - Isolation
  - Contraction
  - Construction
- Reinforcement
  - Cover
  - Size of crack
  - Frequency (numerous tight cracks)
  - What's allowable (crack width)



1. CONTRACTION JOINTS WITHIN 10 TO 15 FEET OF CORNERS
2. SPACING OF JOINTS 20 FOOT MAXIMUM
3. JOINTS AT SIDE OF OPENINGS
4. ISOLATION JOINT BETWEEN FLOOR AND WALL
5. CONTRACTION JOINTS IN FLOOR SLAB
6. CONTRACTION JOINT SPACING 30t MAXIMUM
   t = SLAB THICKNESS
7. ISOLATION JOINT AROUND COLUMN FOOTINGS

Take an example…

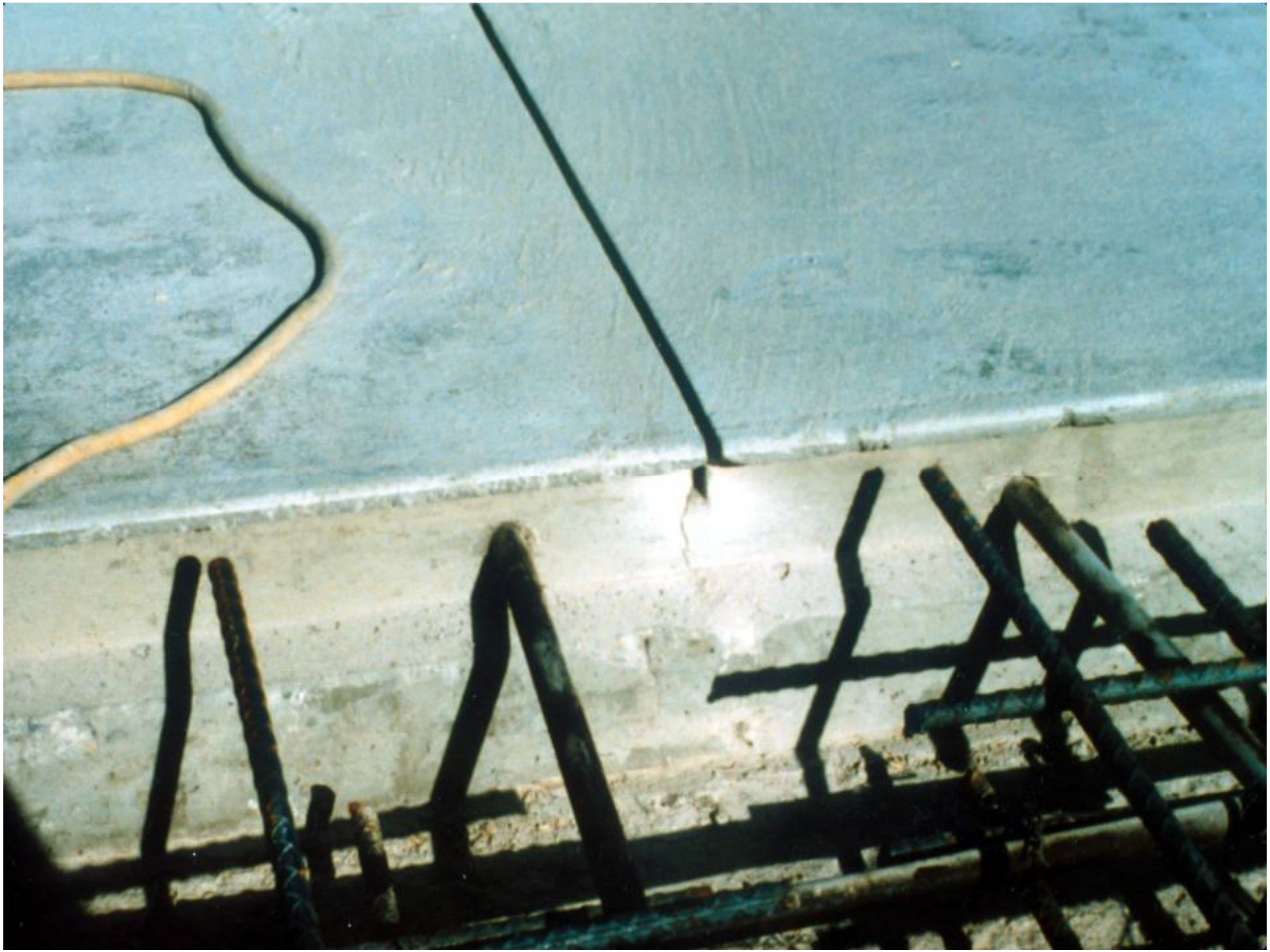
- Sidewalk set above pavement
- 500 ft long pavement strips
- $\alpha = 6x10^{-6}$ in/in/°F
- Approximately 0.7”/100’/100°F

Result…

- Omission of full depth isolation /expansion joint
- Expansion of adjacent pavement results in cracking and buckling of concrete sidewalk


TRUCKERS
ENTRANCE

Mid-Panel Cracking



Crack Repair

- Fix large cracks prior to exposure

Use:

  - MMA
  - Epoxy injection
  - Sealers
  - Routing and sealing
- Effect of cover
- Importance of curing on cracking

Summary

- Many forms of cracking
- Concrete is weak in tension
- Shrinkage!
- Jointing

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Questions?