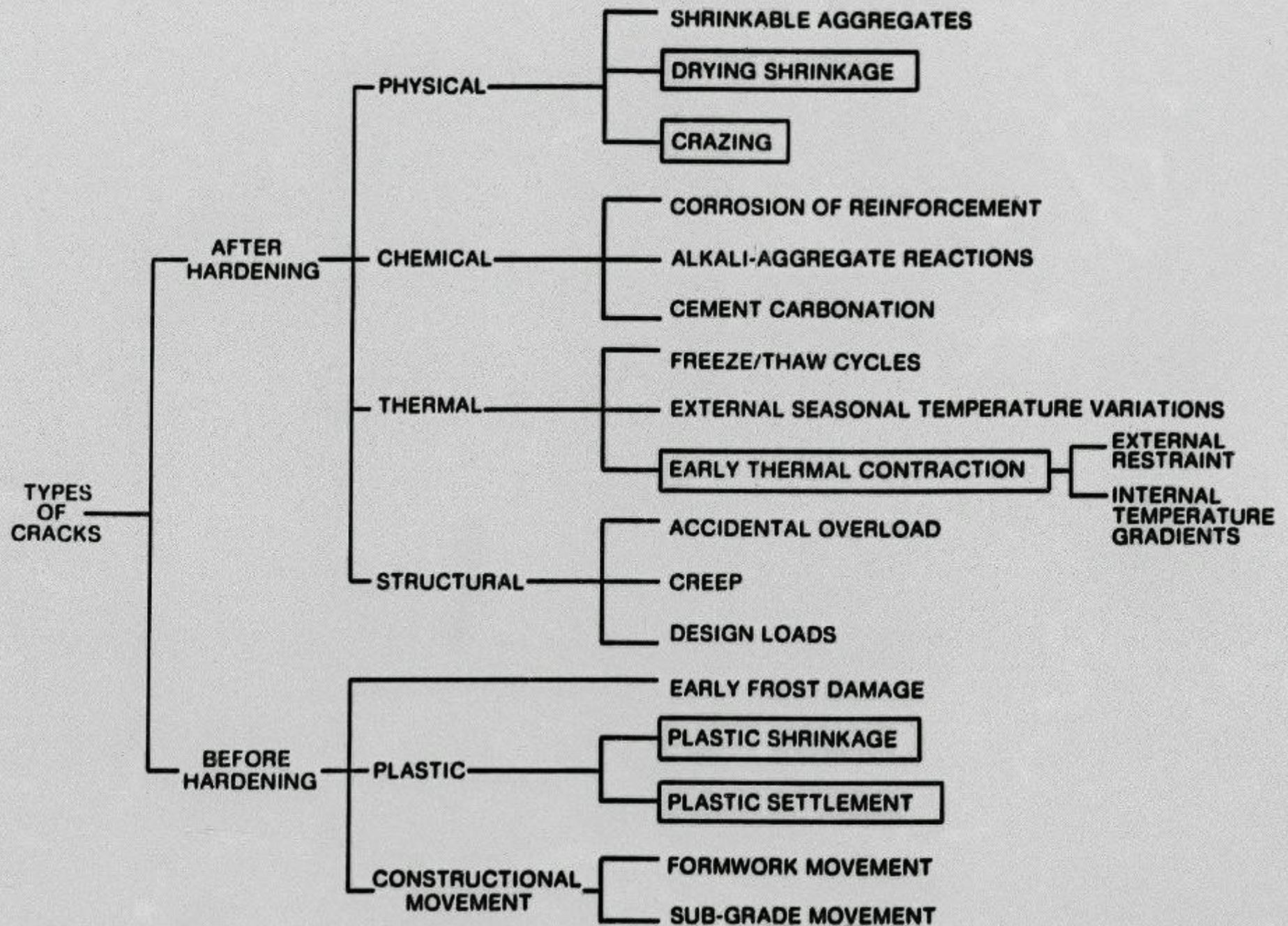
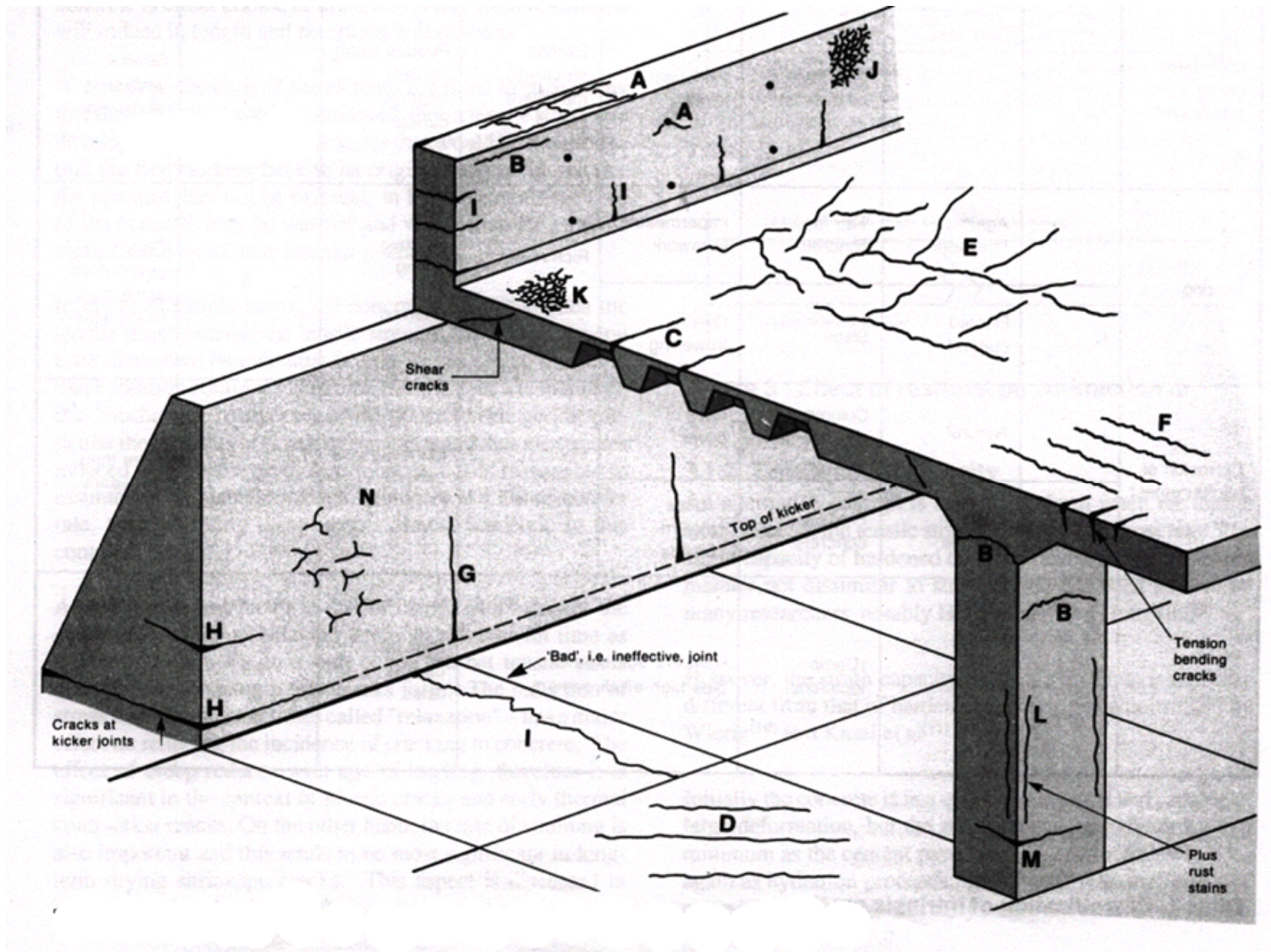

Non-structural Cracks in Concrete

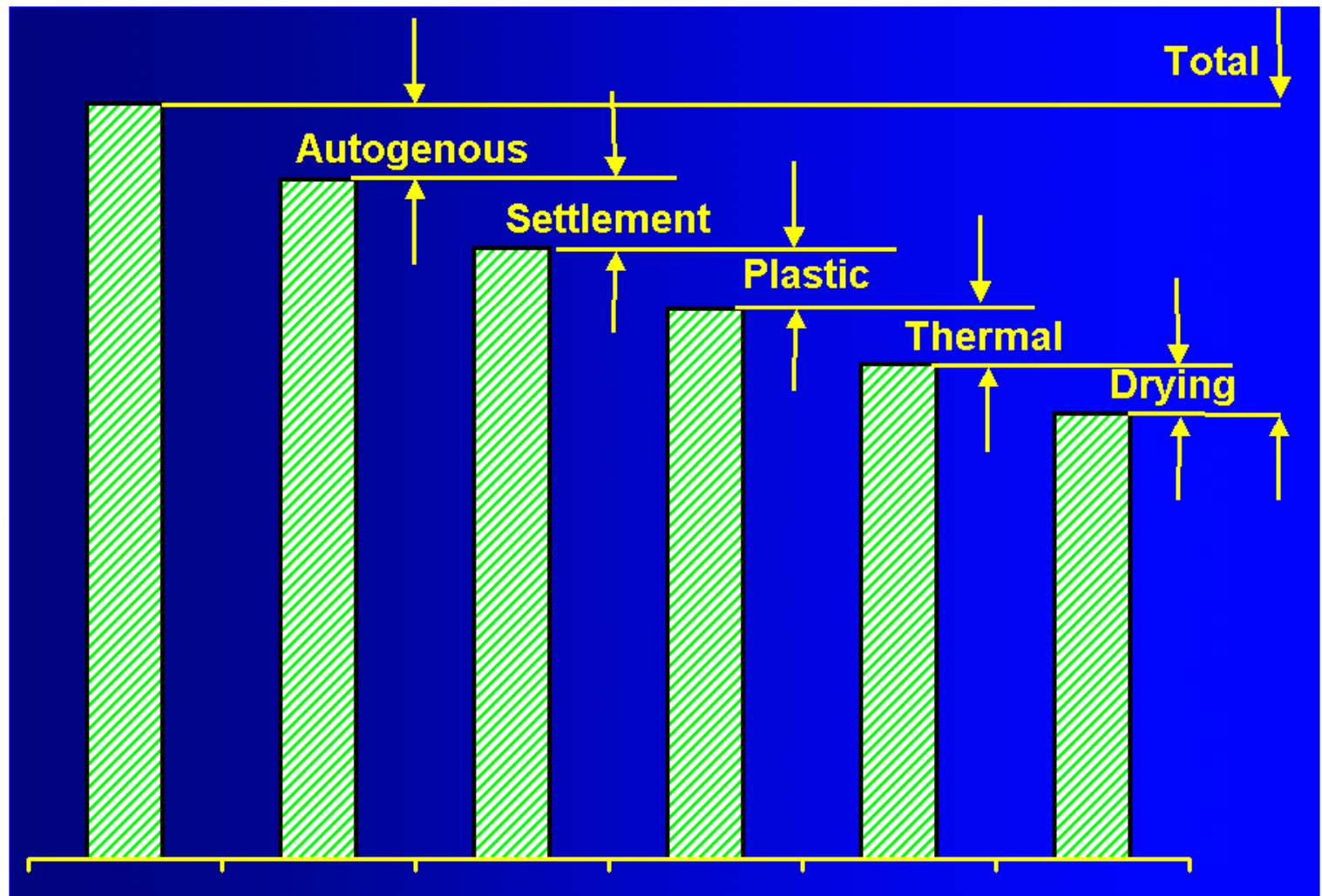






Letter	Type of Cracking	Subdivision	Most Common Location	Primary Cause (excluding restraint)	Secondary Causes/Factors	Time of Appearance
A	Plastic settlement	Over reinforcement	Deep sections	Excess bleeding	Rapid early drying conditions	Ten minutes to three hours
B		Arching	Top of columns			
C		Change 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?





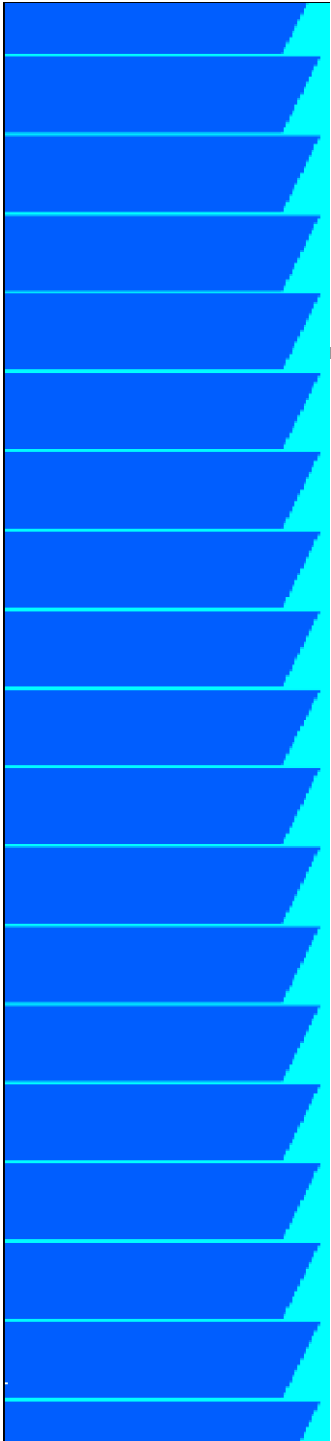
Non-structural Cracks

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



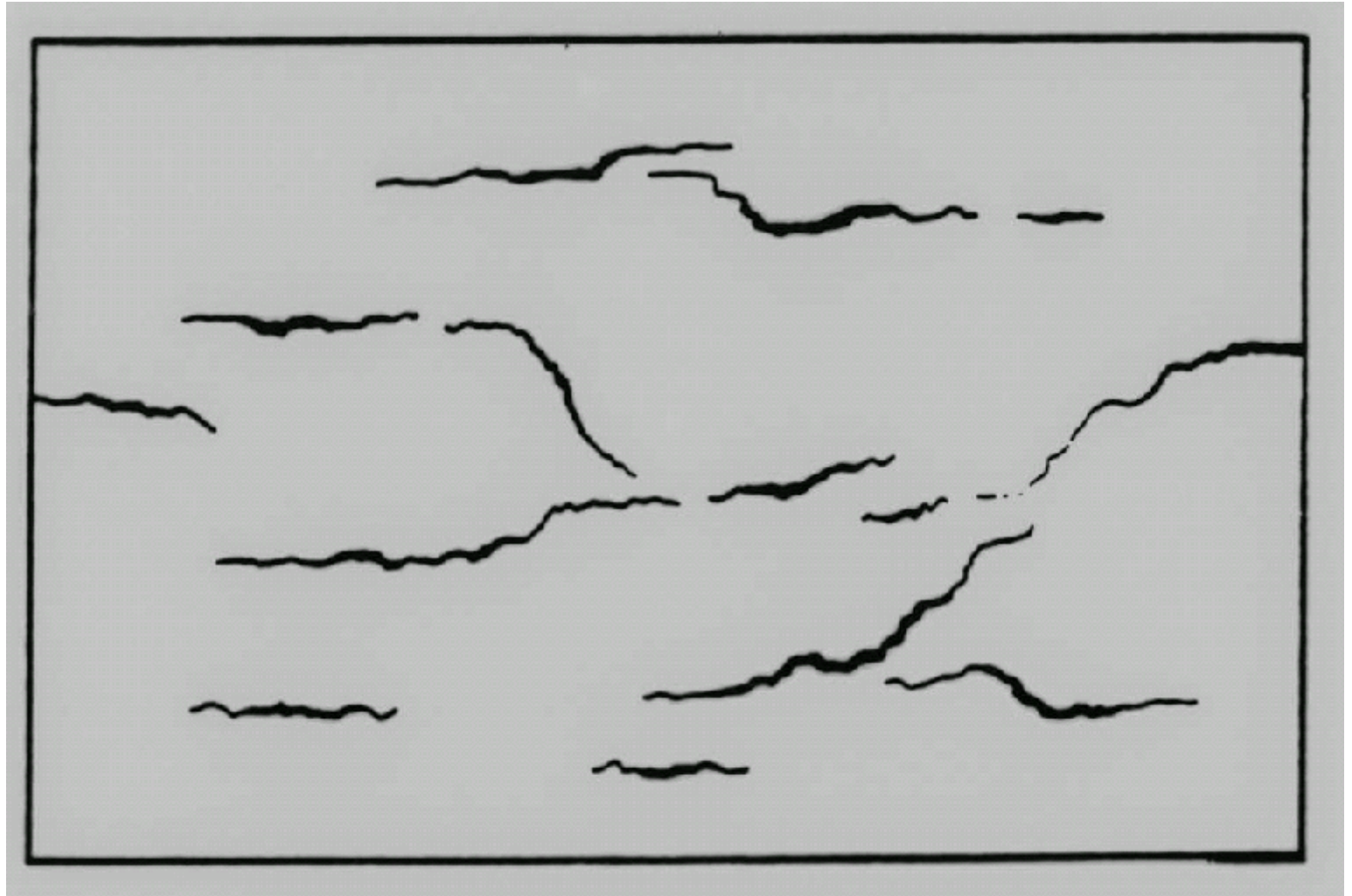
Before Hardening

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



PLASTIC SHRINKAGE CRACKING

Typical Plastic Shrinkage Cracking









DL
Densitometry
Technology
Laboratory

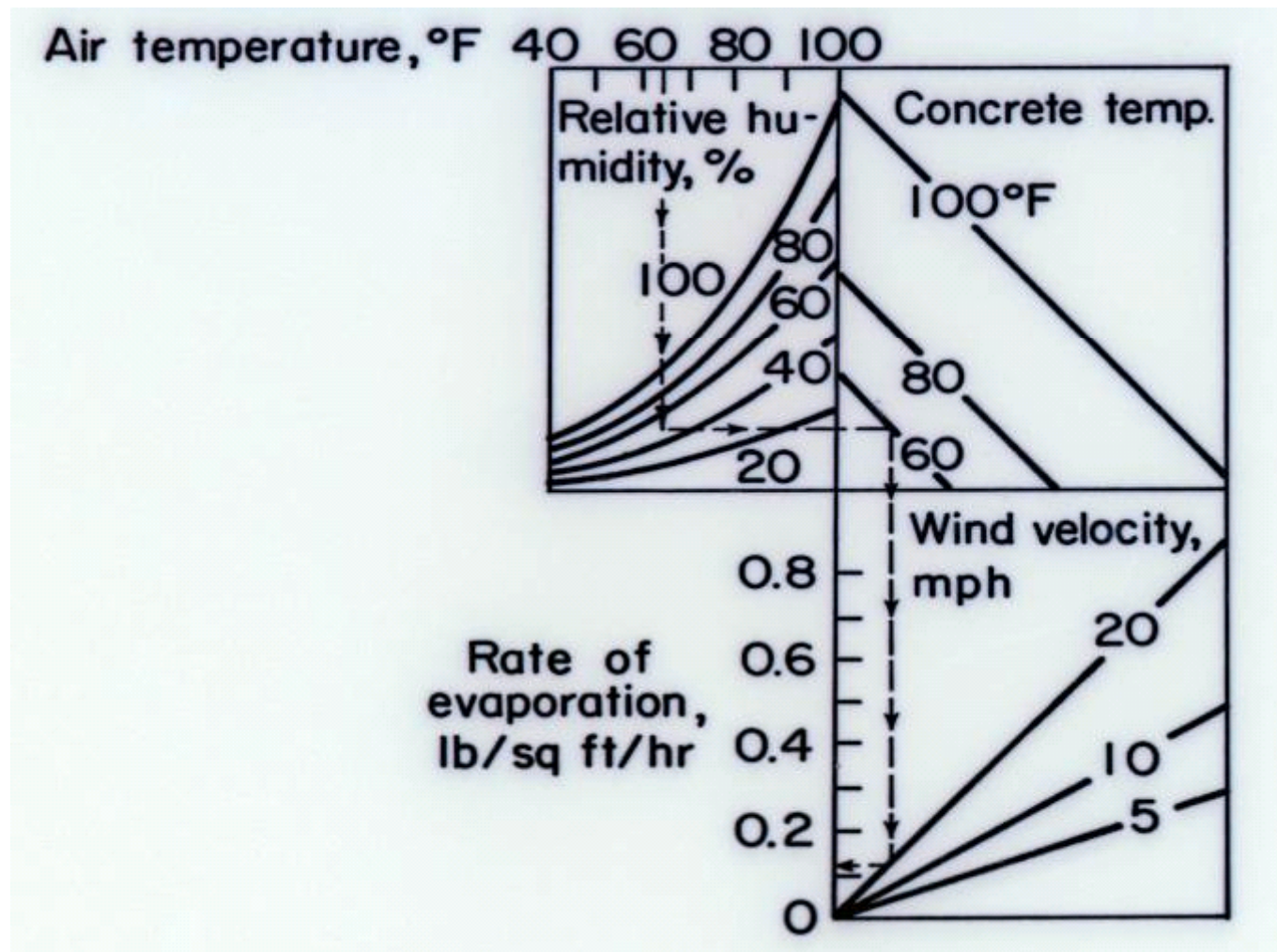
312/965-7500
Densitometry Project, 5000, 10000, 20000

0.0401
0.0950
0.1998
0.3360
0.5061
0.7343
0.9412
1.3146
1.6989
2.1314
2.6211
3.1412
3.7424
4.4761
5.3041
6.1886
7.1033
8.0329
9.0626
10.1673
11.3321
12.5421
13.7921
15.0771
16.3921
17.7321
19.0921
20.4721
21.8721
23.2921
24.7321
26.1921
27.6721
29.1721
30.6921
32.2321
33.7921
35.3721
36.9721
38.5921
40.2321
41.8921
43.5721
45.2721
46.9921
48.7321
50.4921
52.2721
54.0721
55.8921
57.7321
59.5921
61.4721
63.3721
65.2921
67.2321
69.1921
71.1721
73.1721
75.1921
77.2321
79.2921
81.3721
83.4721
85.5921
87.7321
89.8921
92.0721
94.2721
96.4921
98.7321
100.9921

Grain
Comparator

Technical Consulting

Evaporation of Surface Moisture from Concrete



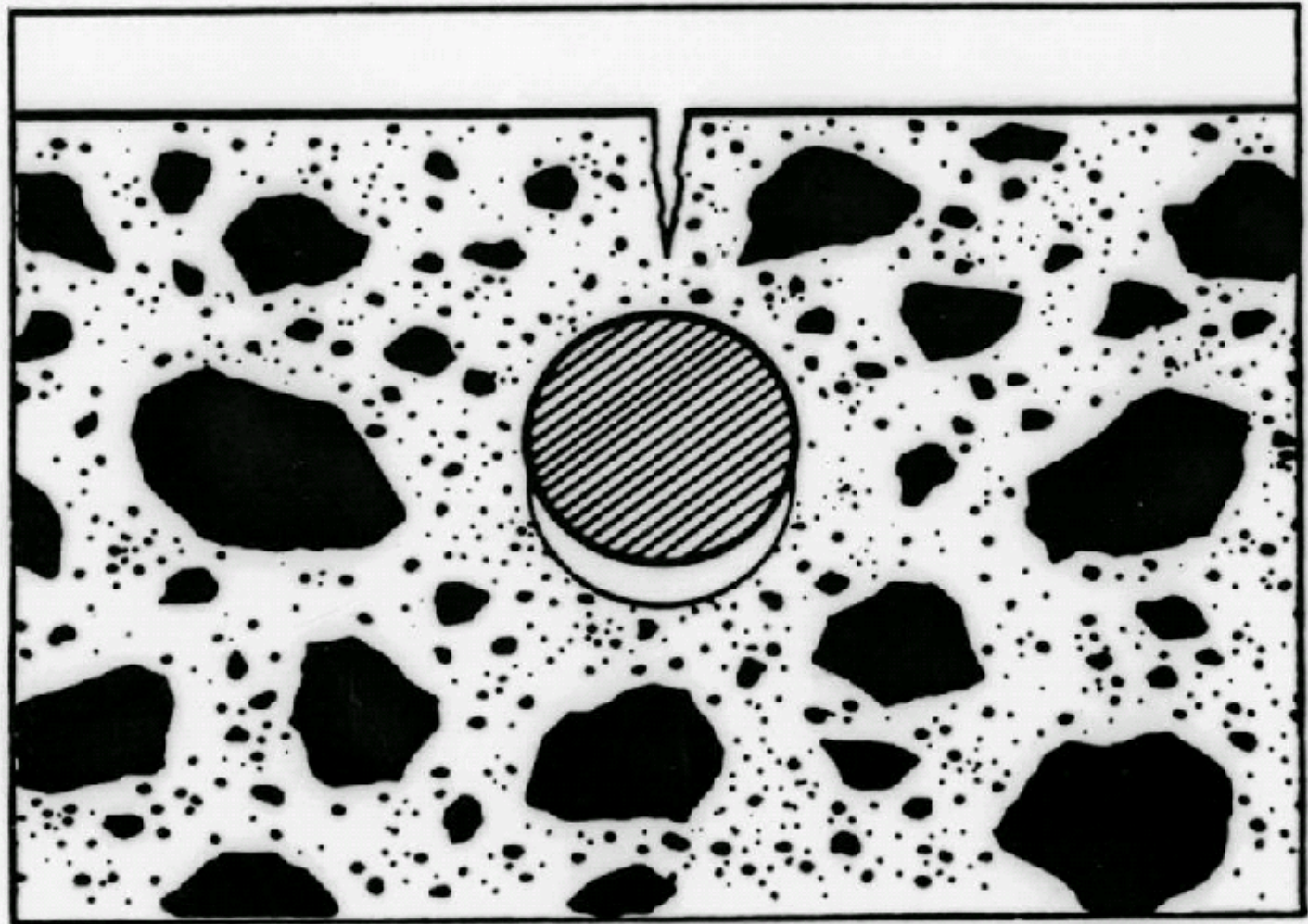




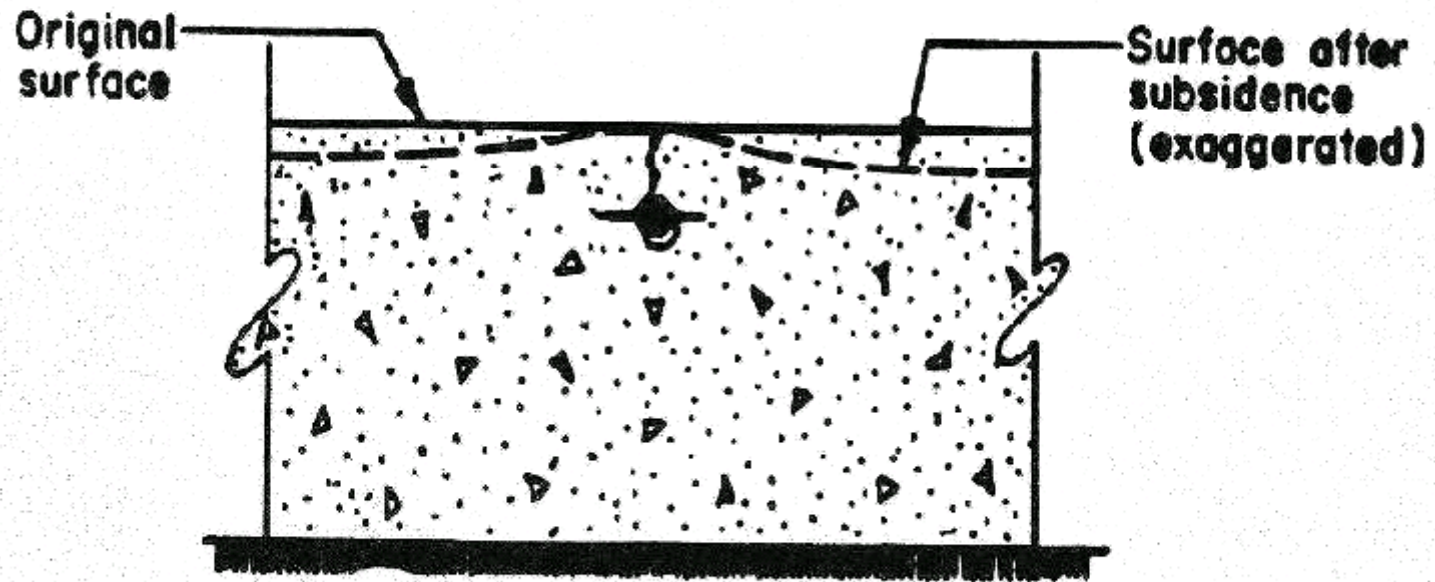


Plastic Settlement

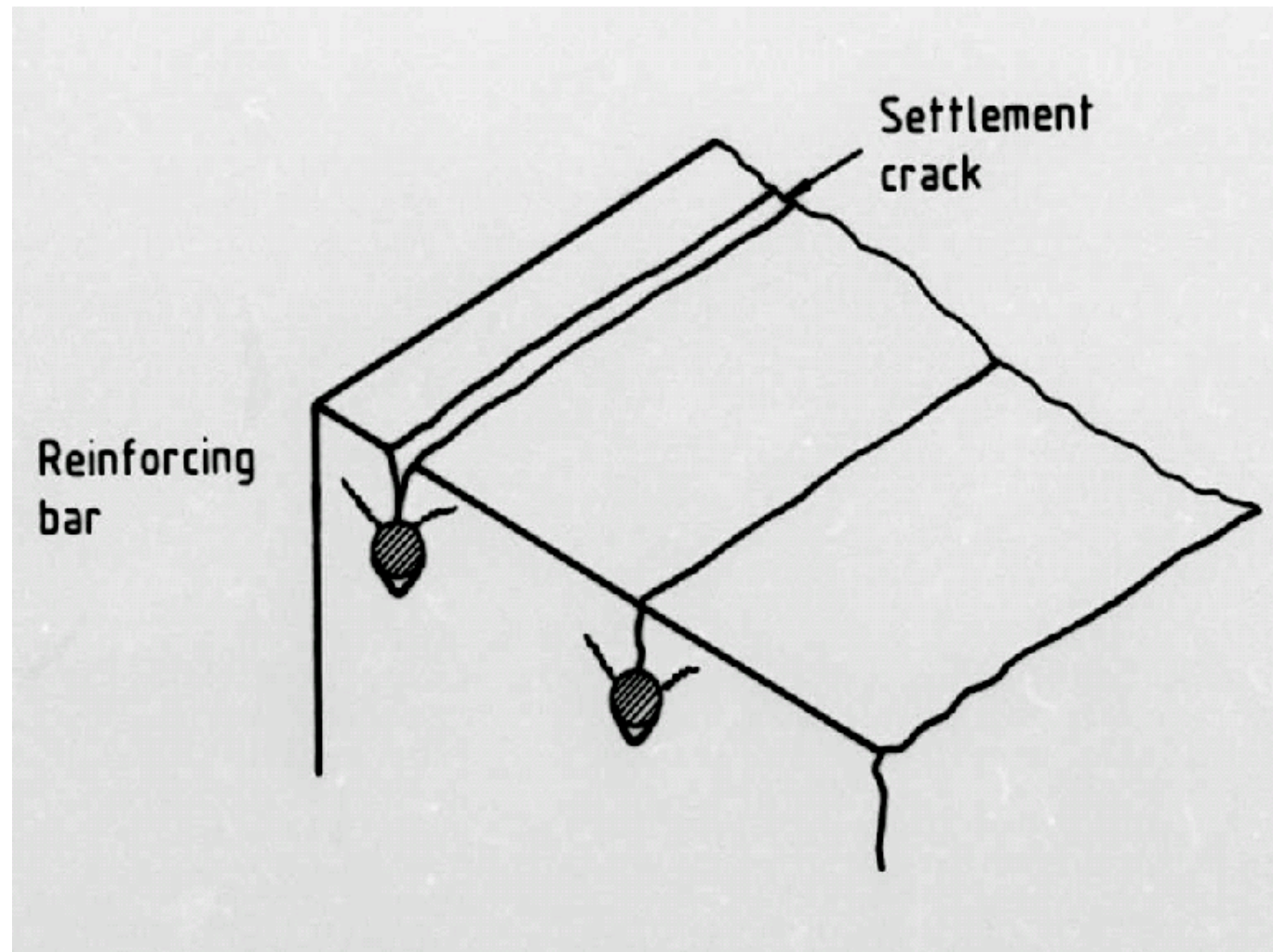
Subsidence Cracking



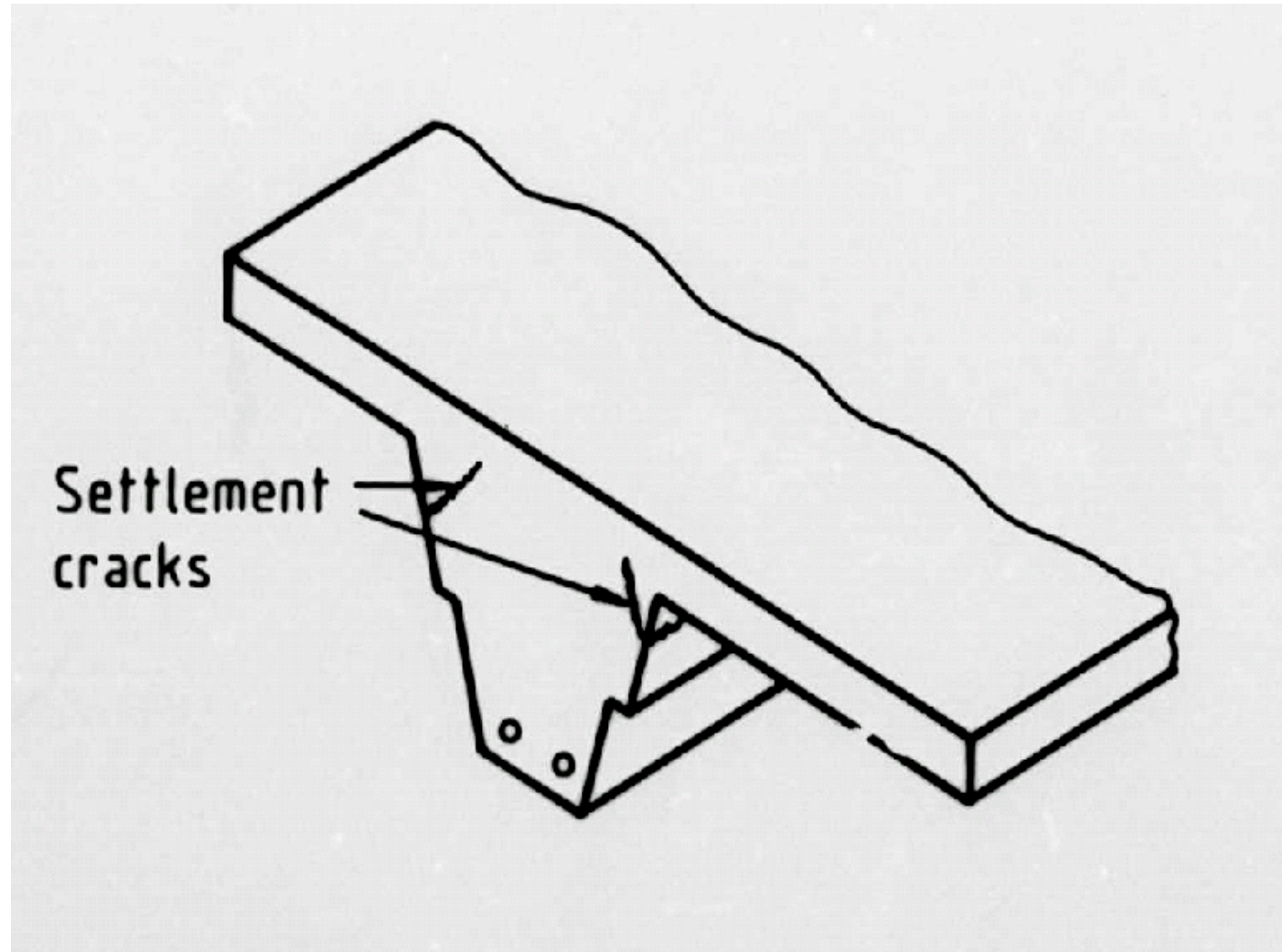
Resistance to subsidence by top reinforcement



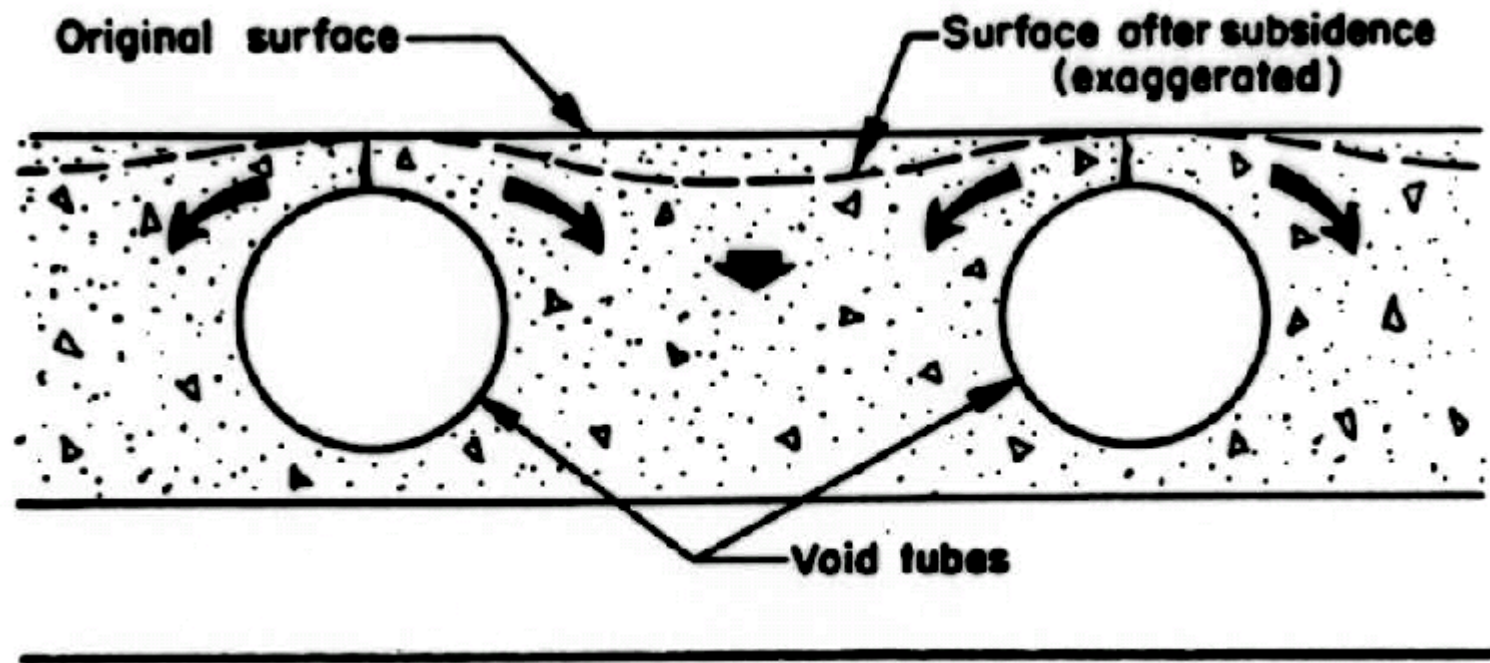
Cracks usually appear along
reinforcement bars...



..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

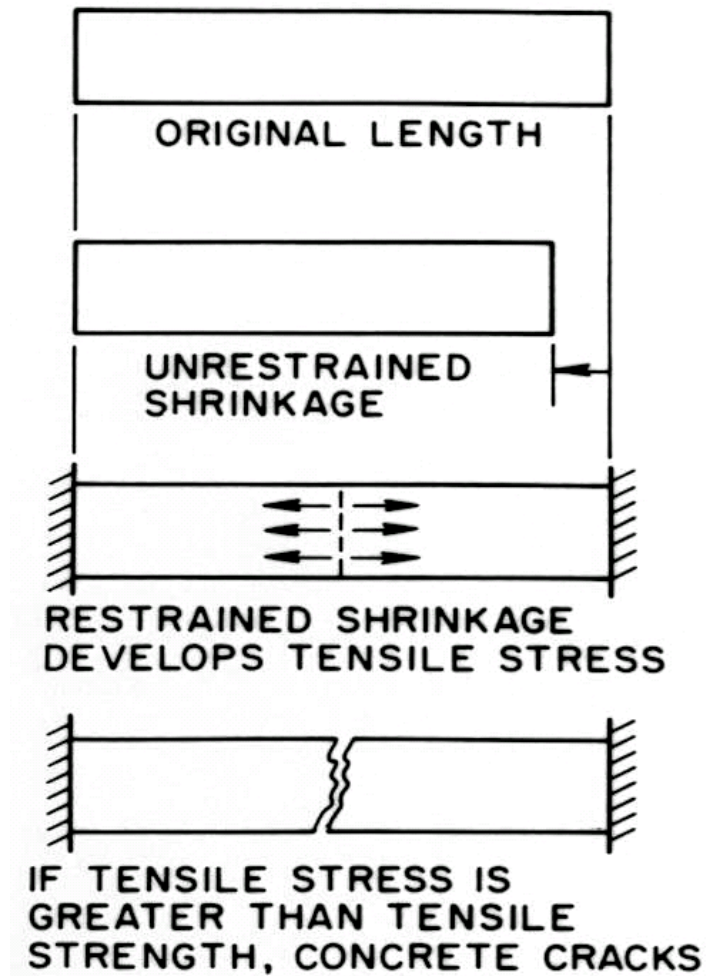
- ◆ Design loads

Drying Shrinkage Cracking

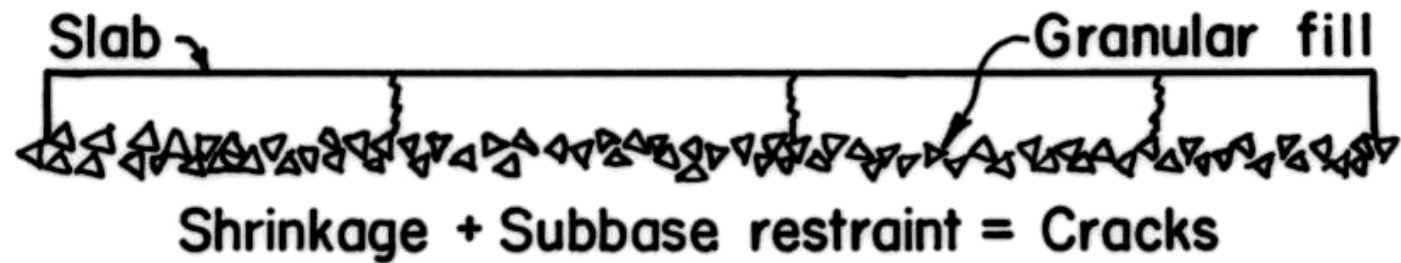
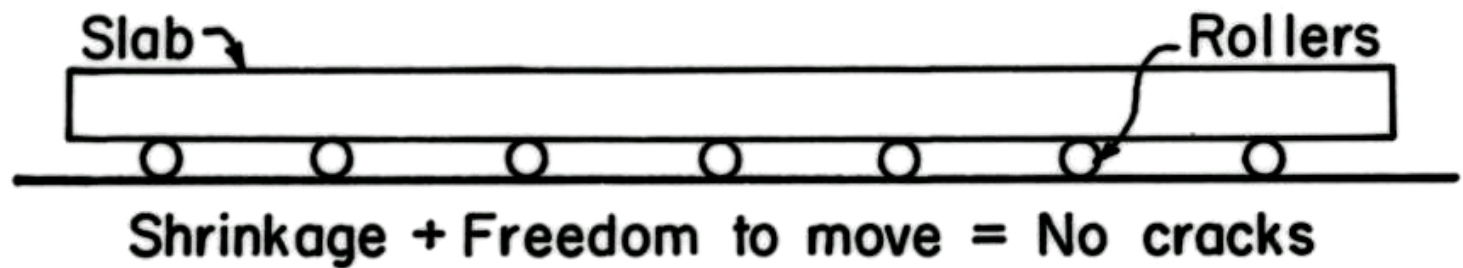




Why cracks form



Shrinkage and Cracking

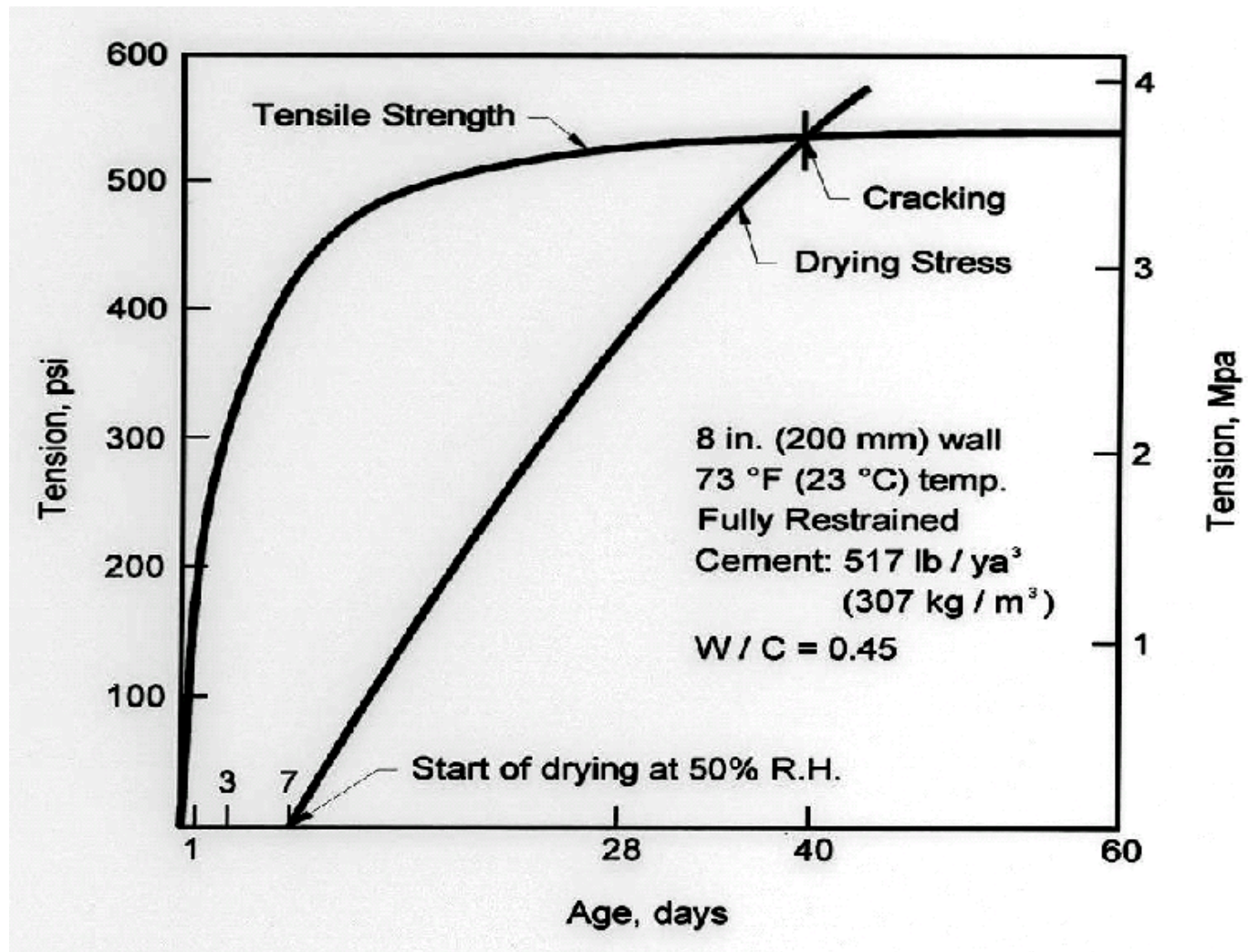




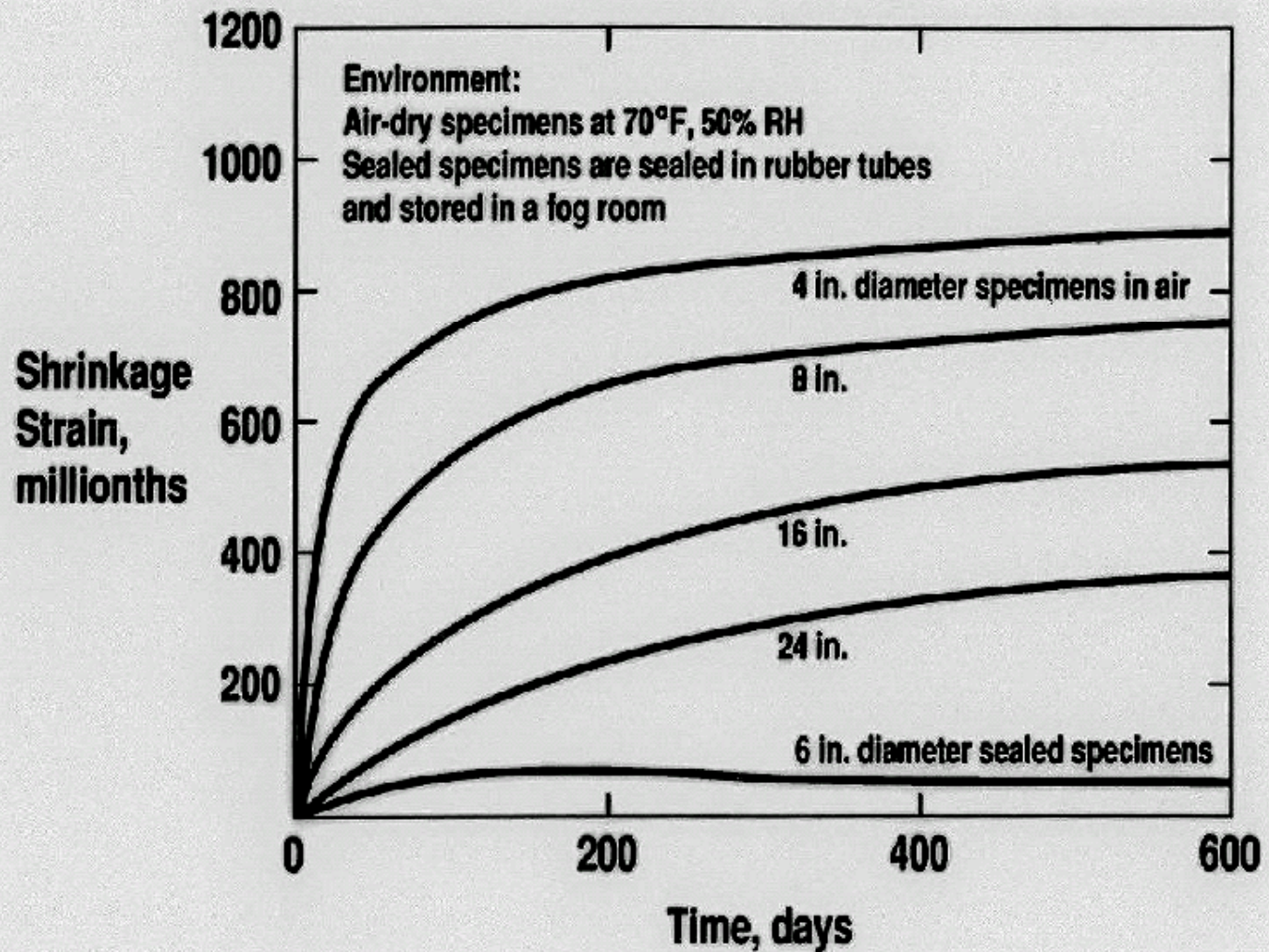
Drying Shrinkage Cracks

- 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

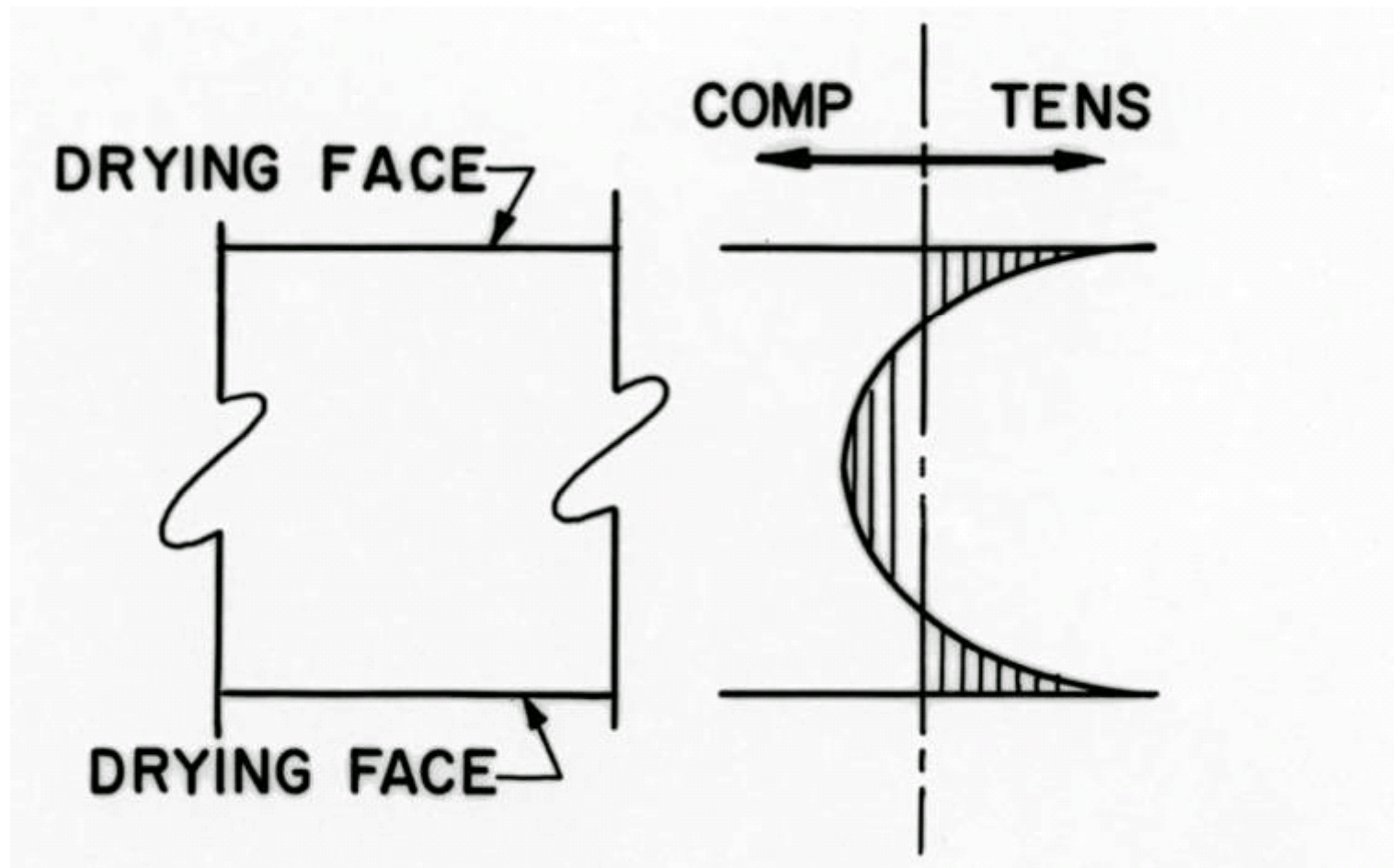
Cracking tendency depends on many factors



Shrinkage is Size Dependent



Theoretical Shrinkage Stresses





Mitigation of Drying Shrinkage Cracks

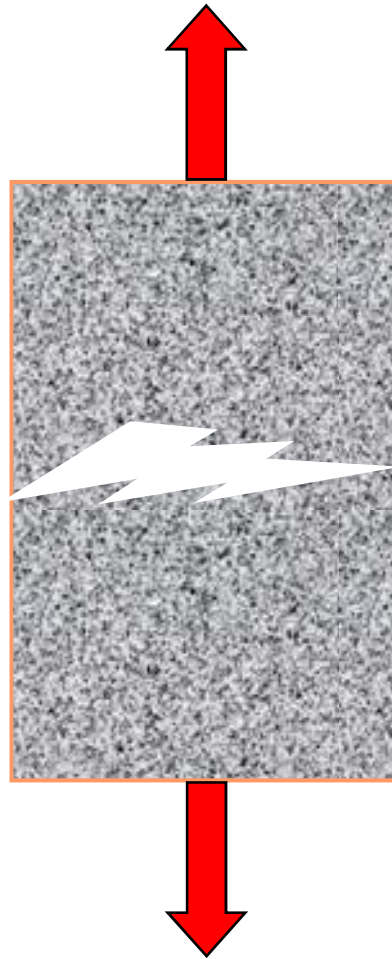
- Aggregate
 - ◆ Content
 - ◆ Size
- Workability
 - ◆ Ease of placement
 - ◆ Consolidation
- Admixtures
 - ◆ Chemical
 - ◆ Mineral
- Curing
- Eliminate external restraints by allowing joint movement
- Provide crack control steel distribution



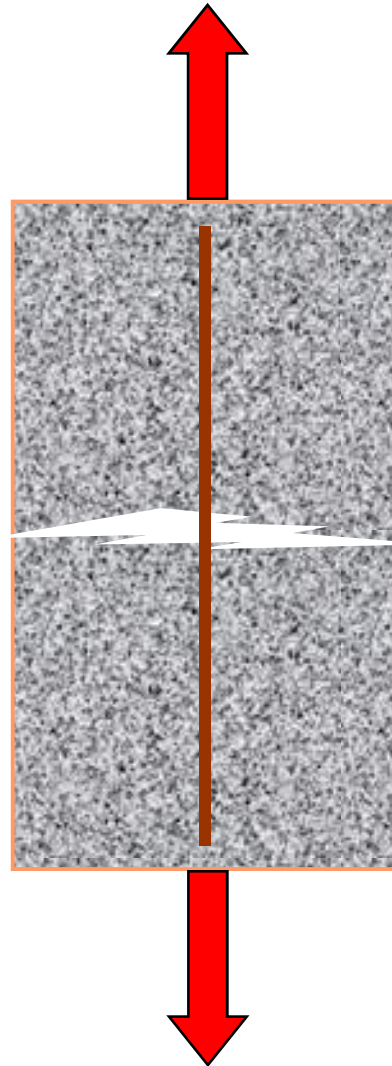
The role of fibers...

- 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!

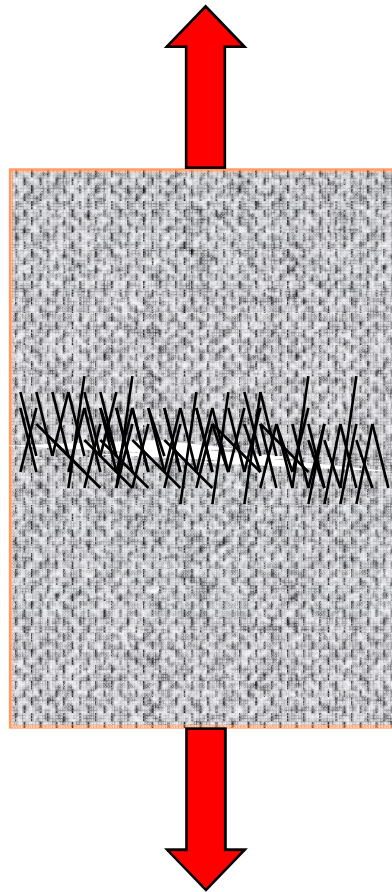
Tensile Deformation Plain Concrete



Tensile Deformation Steel Reinforced Concrete



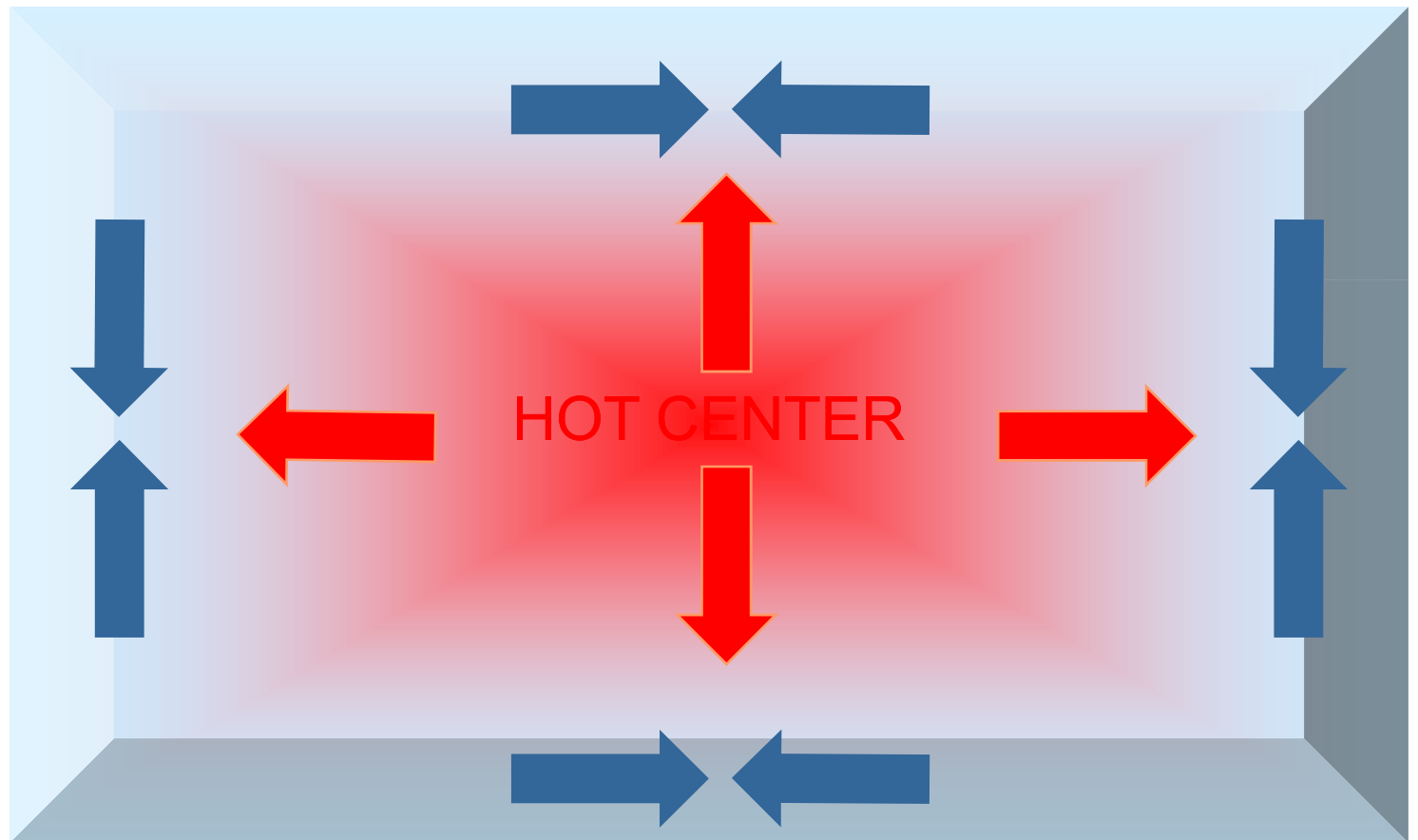
Tensile Deformation Fiber Reinforced Concrete



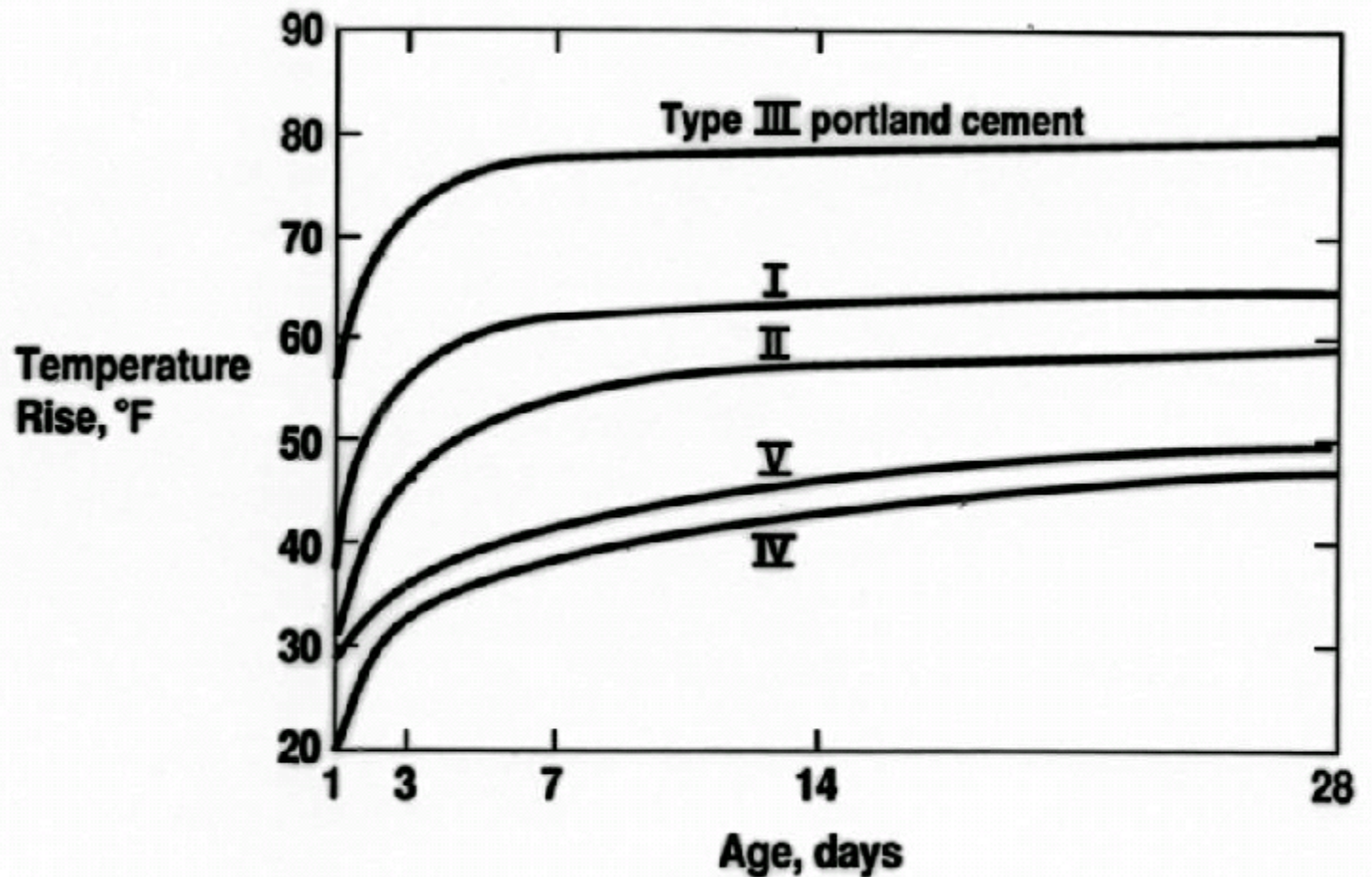
Thermal Cracking

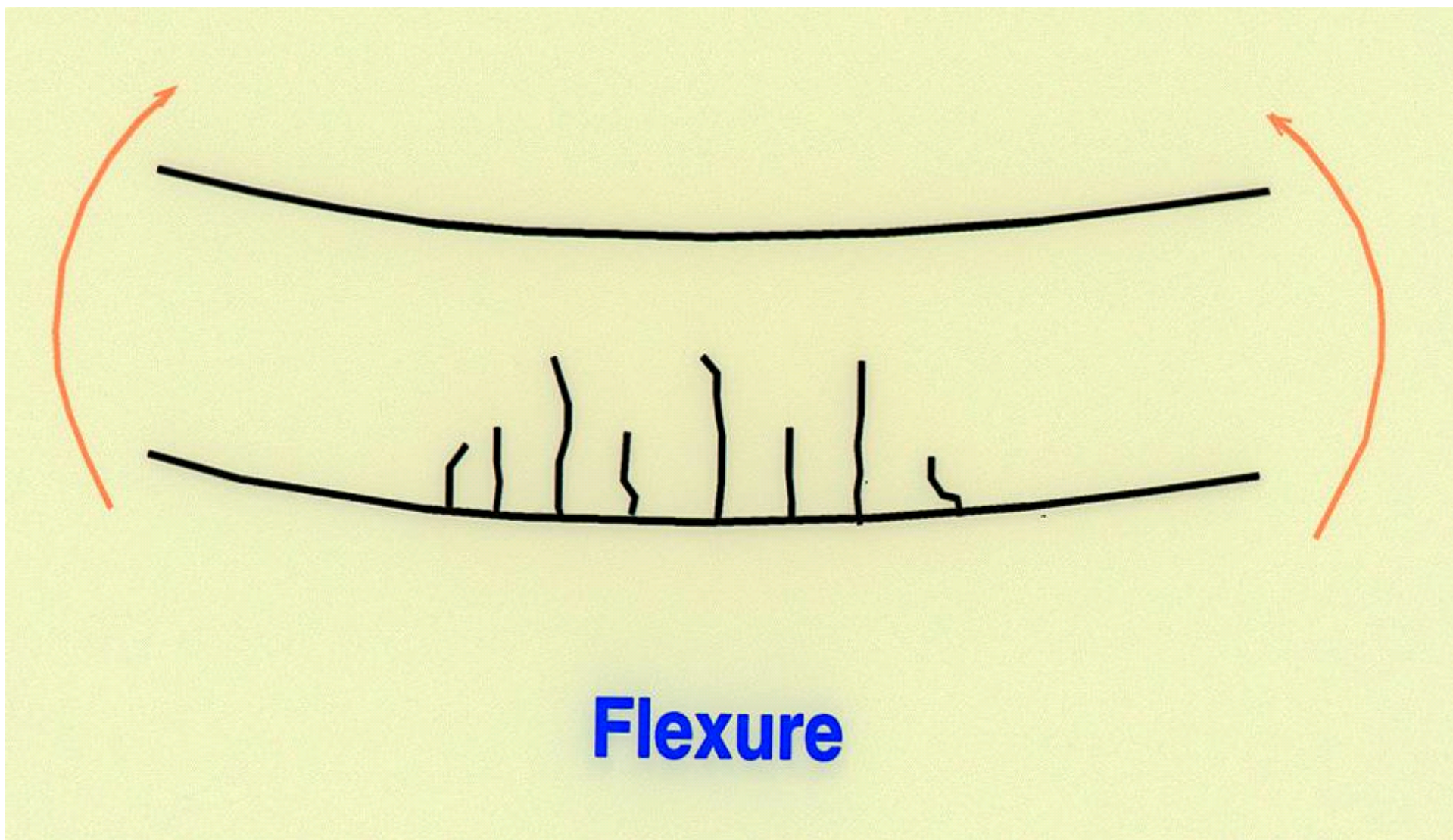


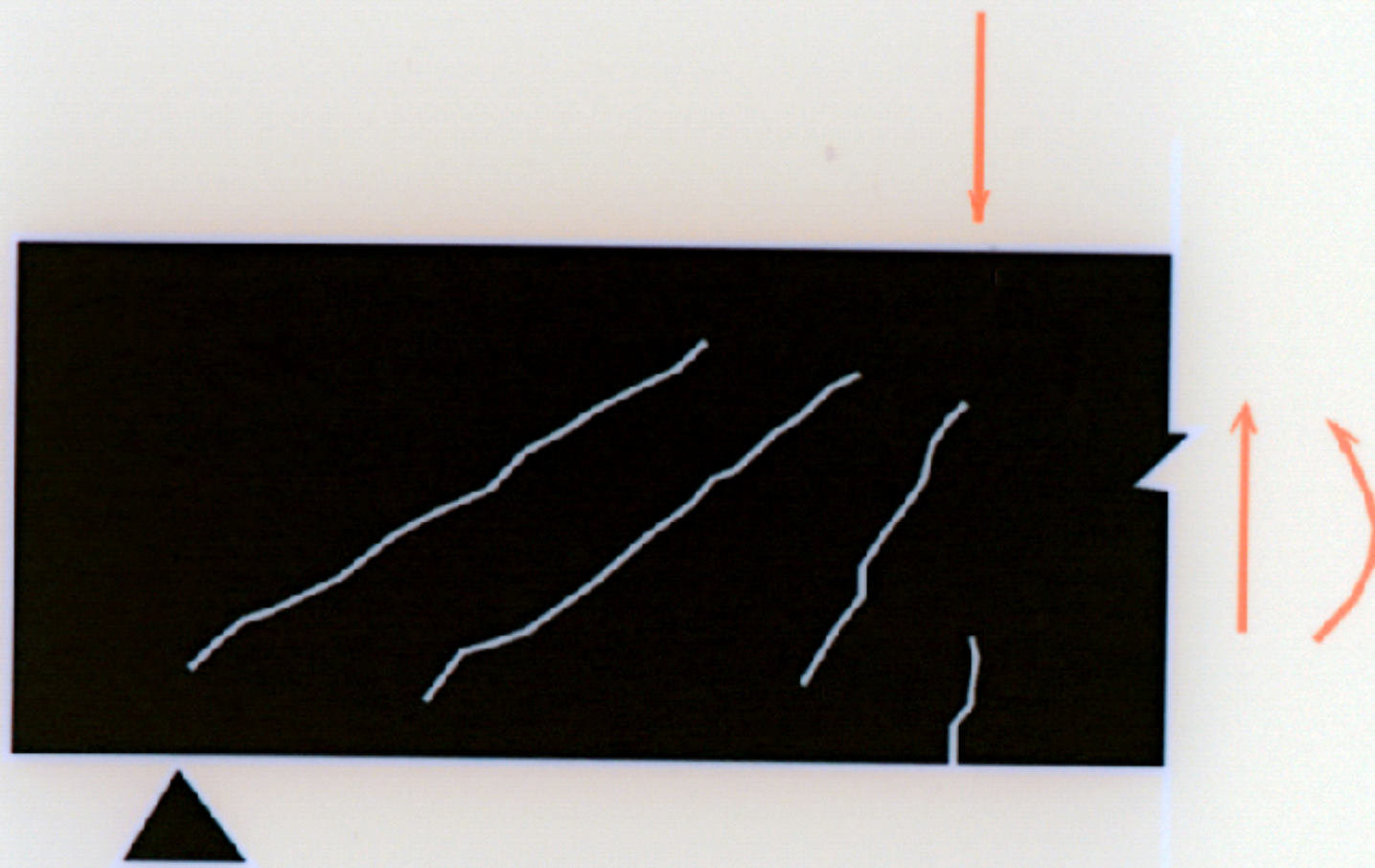
Internal Thermal Restraint



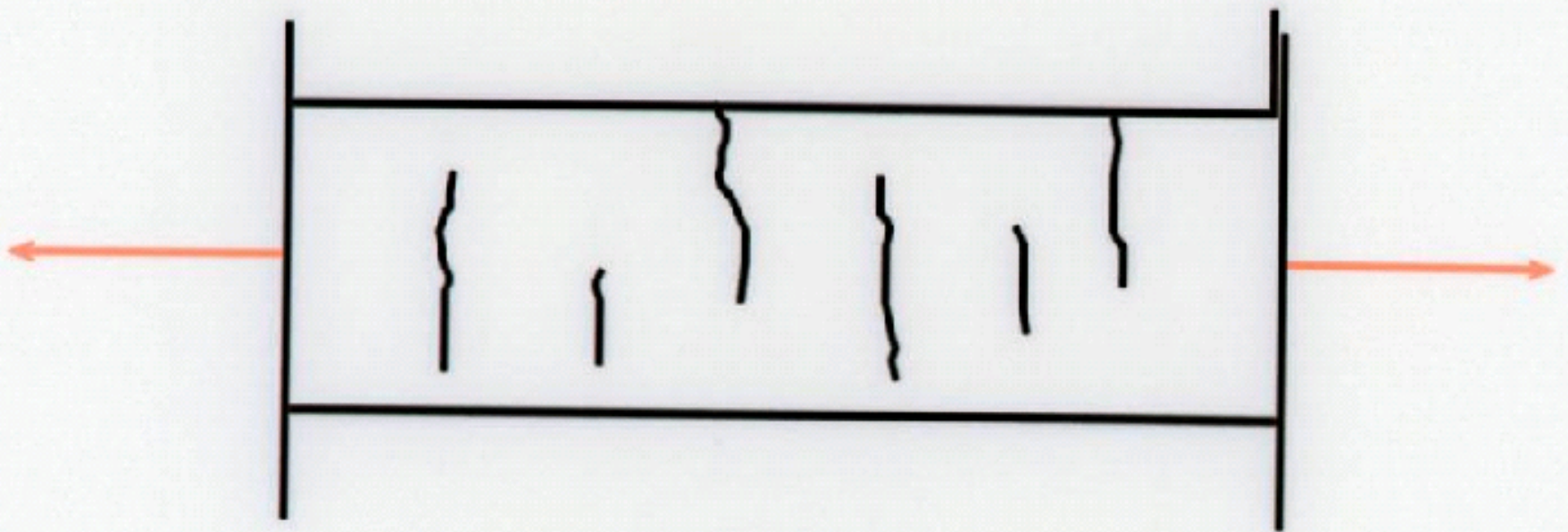
Temperature Rise and Cement Type



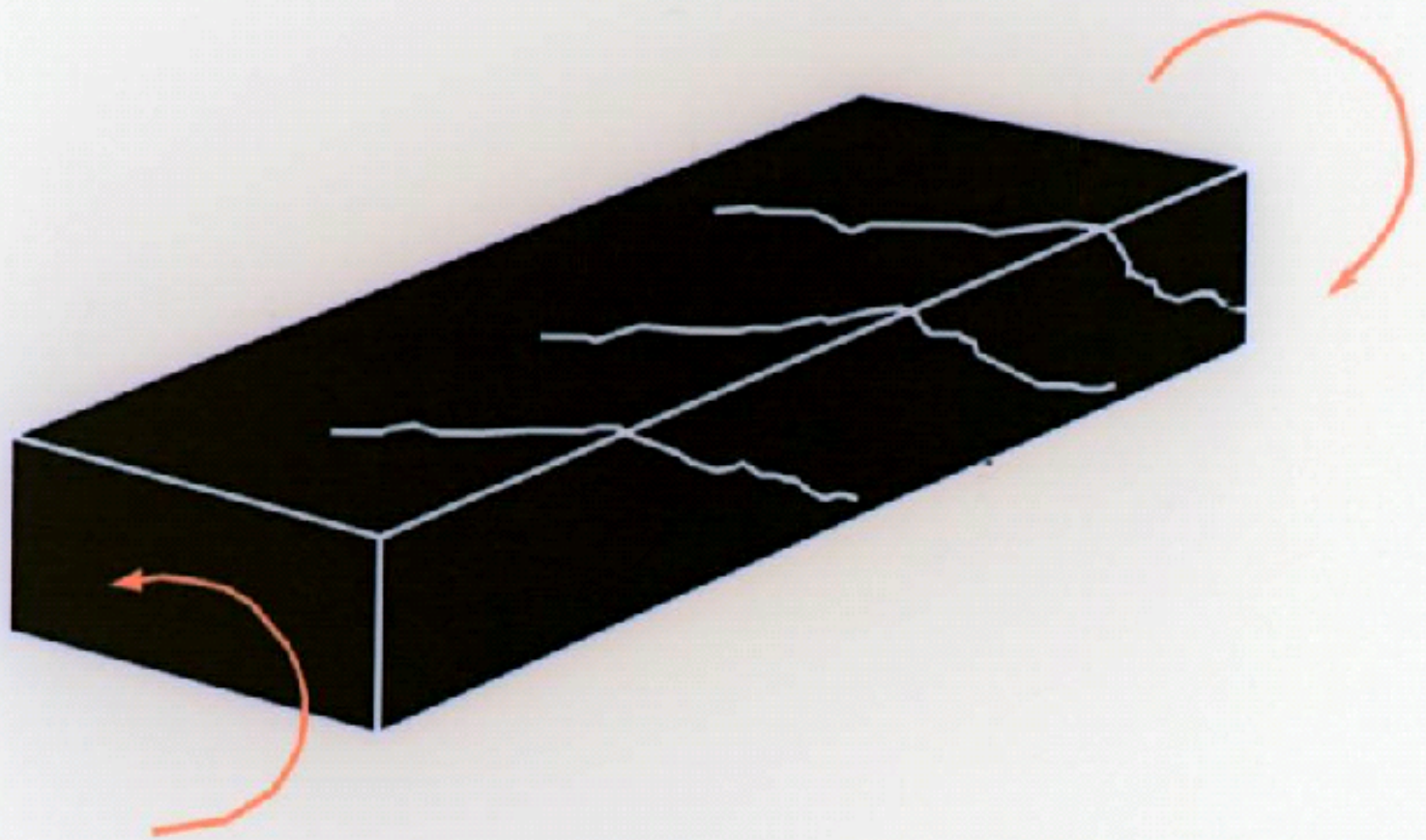




Shear



Tension

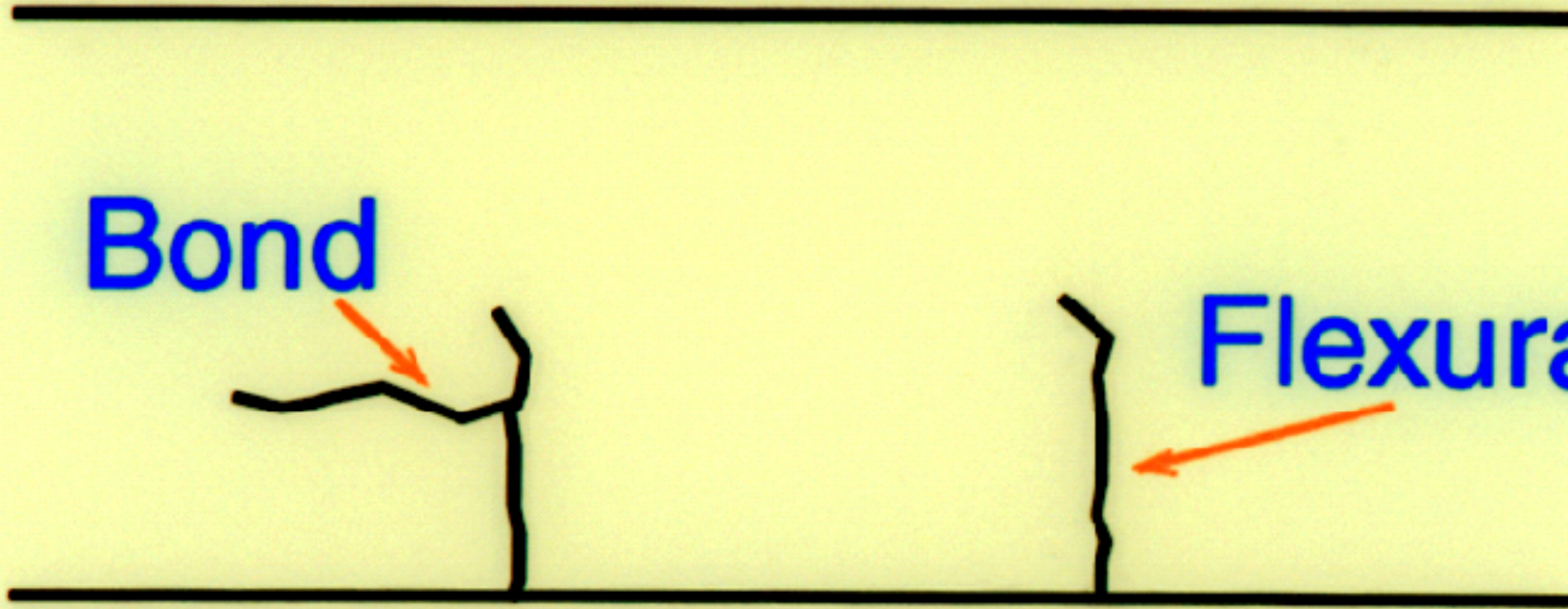


Torsion

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

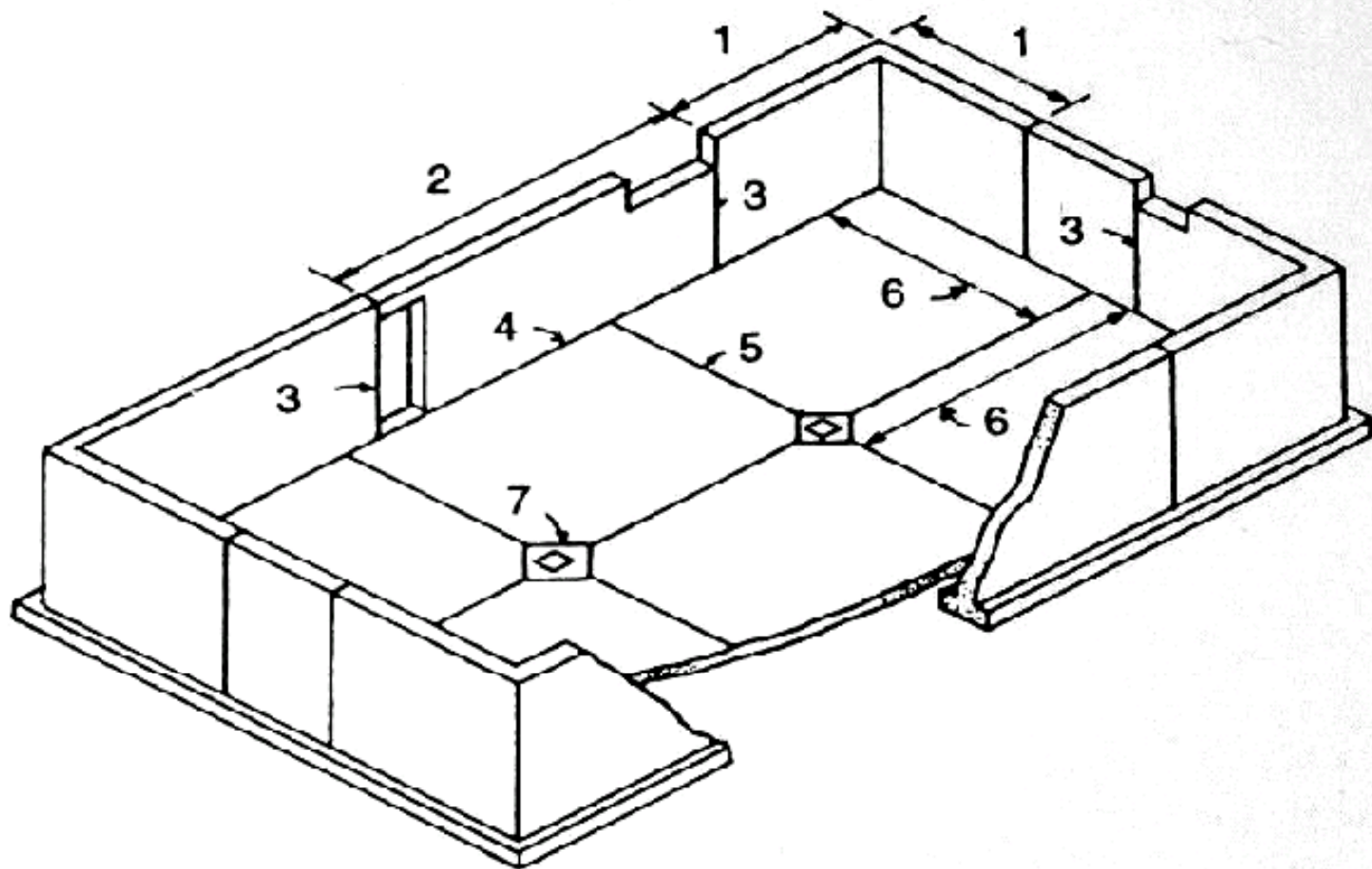
Crack Control





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
- $\alpha = 6 \times 10^{-6}$ in/in/°F
- Approximately 0.7"/100'/100°F



Result...

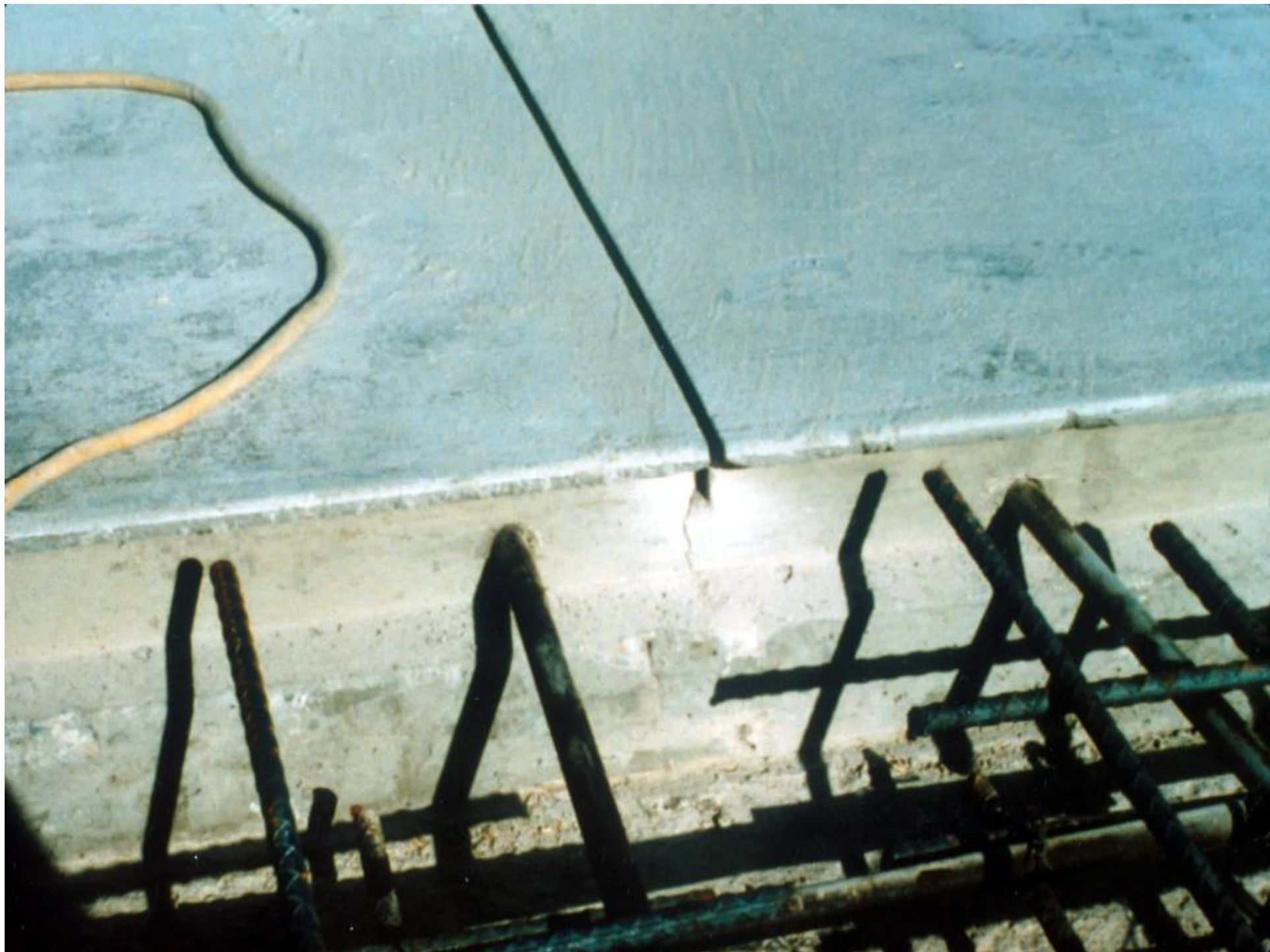
- Omission of full depth isolation /expansion joint
- Expansion of adjacent pavement results in cracking and buckling of concrete sidewalk





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

Questions?