



Concrete Facts

- **Concrete** is the **most** consumed **material on earth**, **second** only to **water**, with three tons per year **used** for every person.
- Twice as much **concrete** is **used** in construction as all **other** building **materials** combined.
- Approximately 5 billion cubic yards of concrete are produced each year.
- The concrete industry accounts for \$40 billion dollars annually
- Worldwide over 50 million employees work in concrete construction.
- 70% of the world's population lives in structures that contain concrete.
- One more fact??

The Euclid Chemical Company



EUCLID CHEMICAL

Concrete Cracks

Presented By: Matt Hansen

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Let's talk about 23 different kinds of cracks.

A diagram of a building floor plan with various types of cracks highlighted in red. The cracks include straight lines, zig-zags, and circular patterns, illustrating different crack types. The floor plan shows several rooms and corridors, with cracks appearing in different orientations and patterns across the surfaces.



Cracks in Concrete

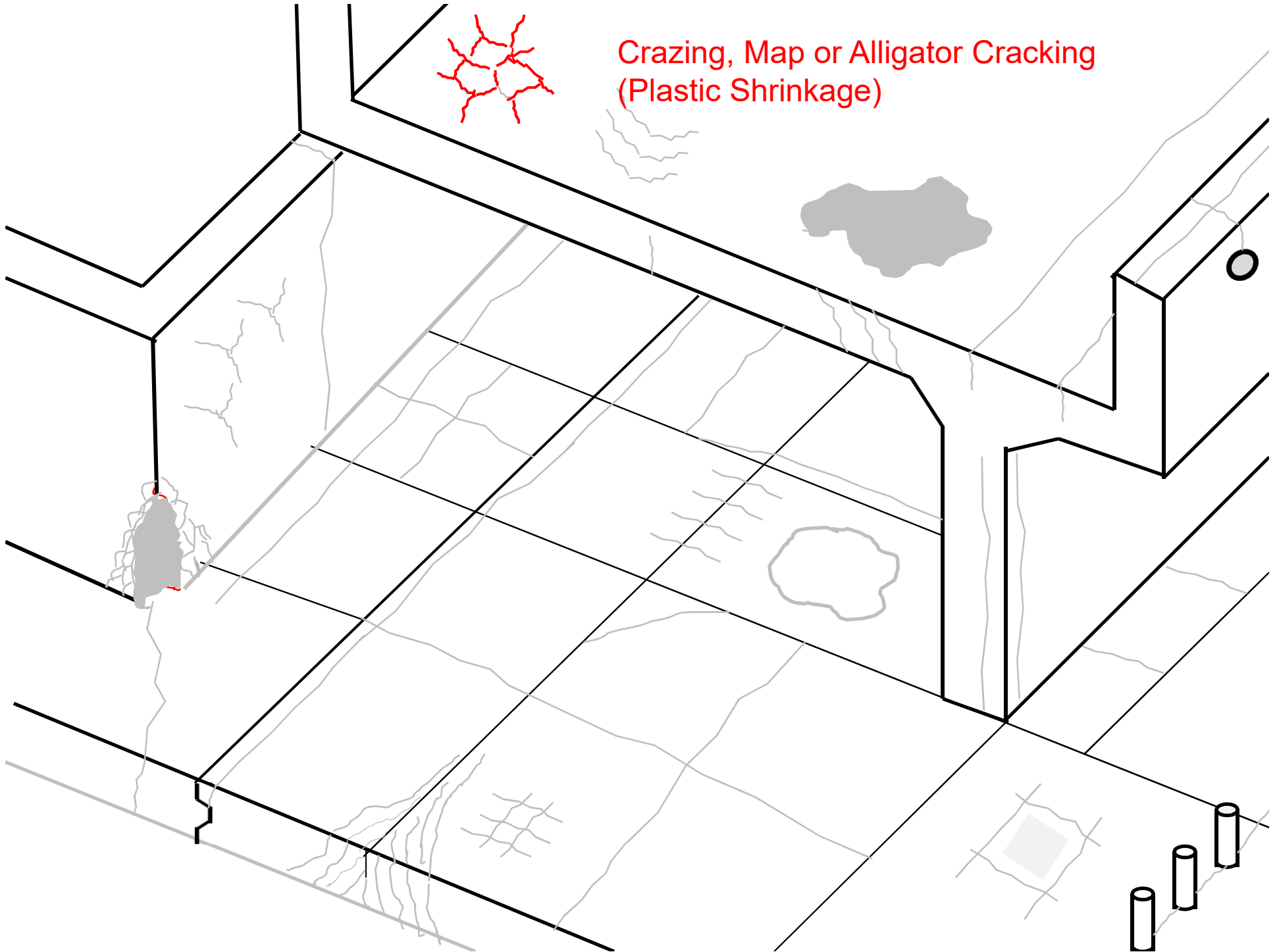
- How to identify them
 - What caused them
 - How they could have been prevented
 - How to repair them
- 

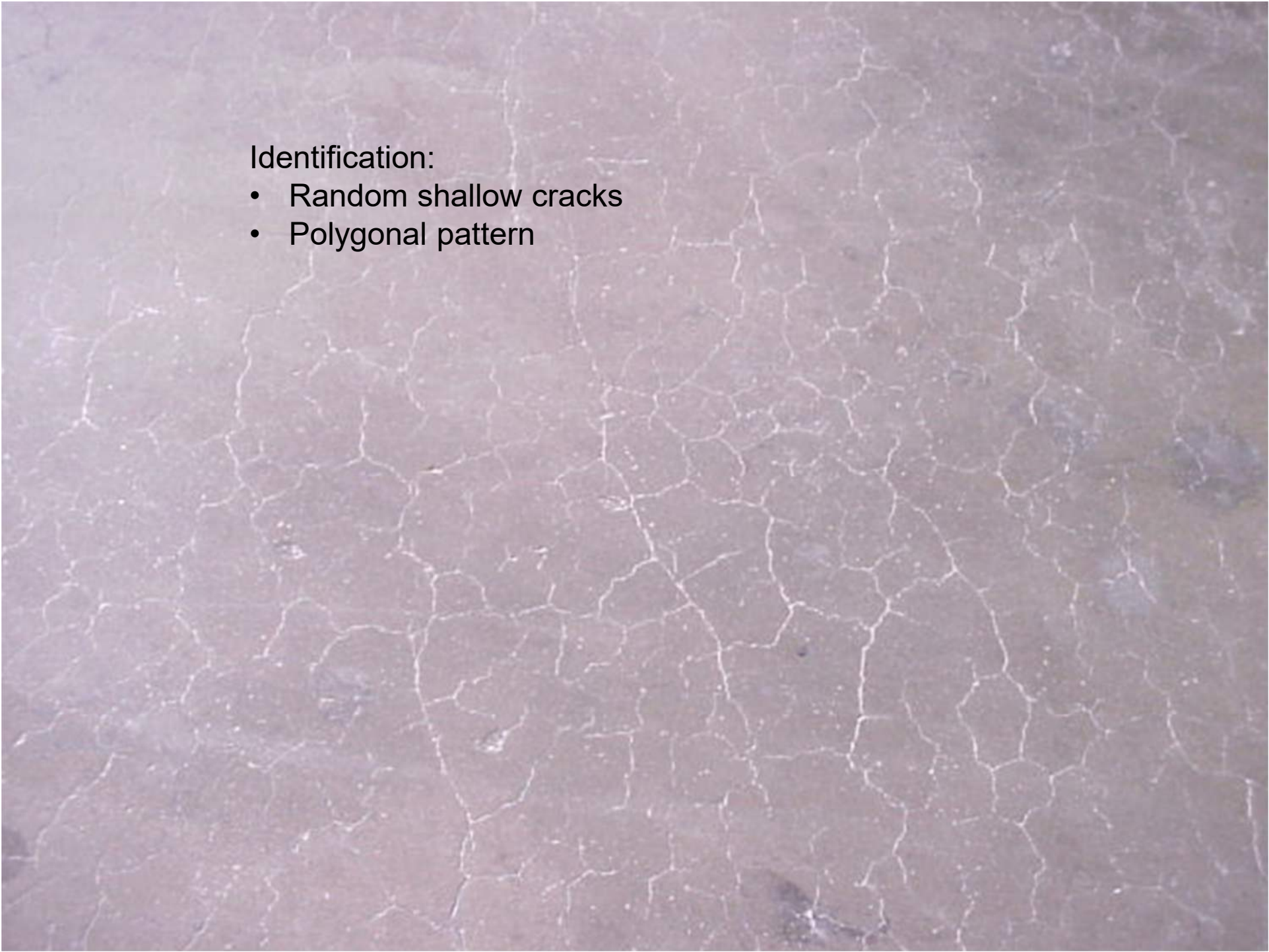


Crack Categories

- Plastic Concrete cracking takes place while concrete is still in plastic state.
- Hardened Concrete cracking takes place after concrete has hardened





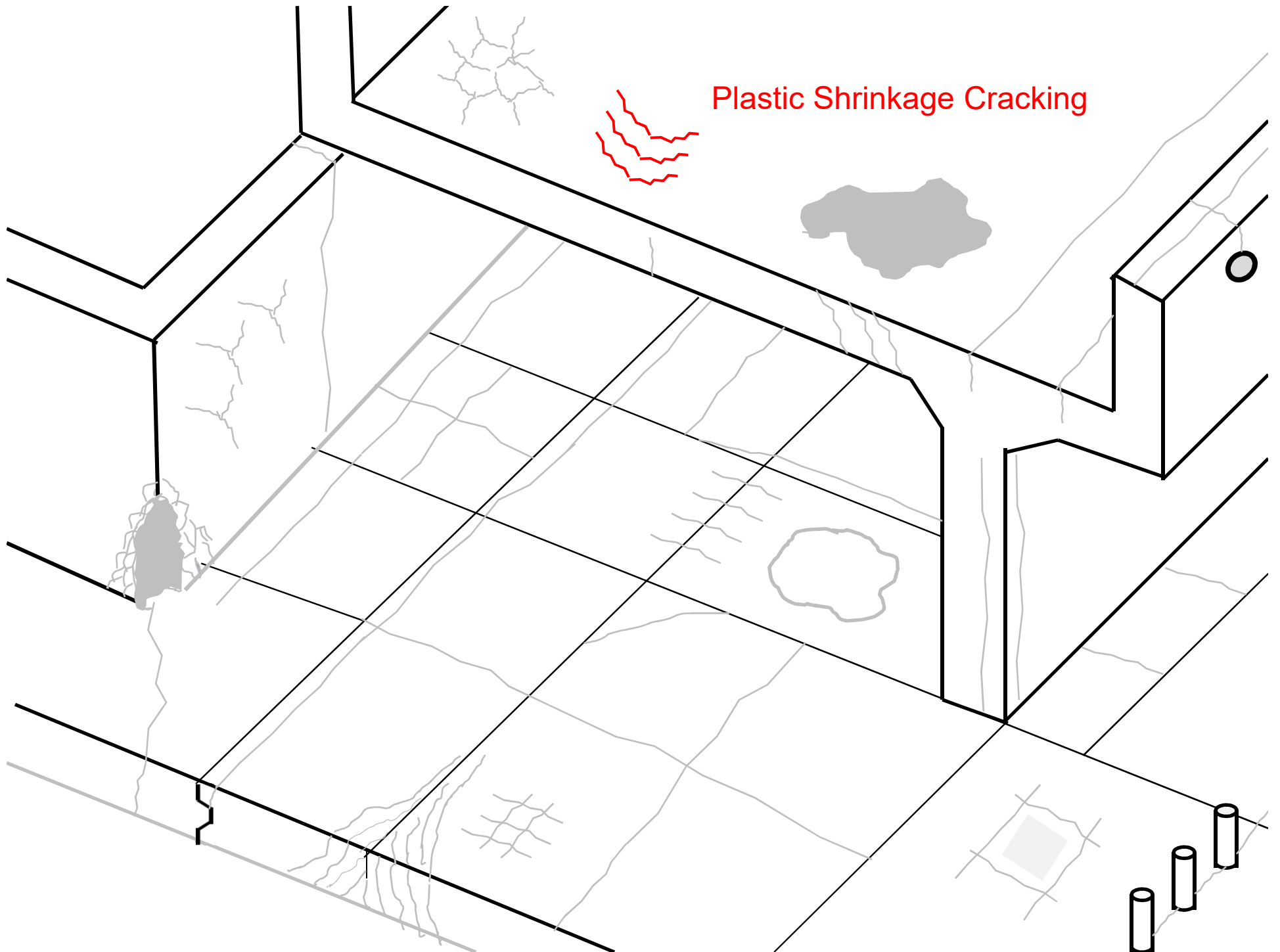


Identification:

- Random shallow cracks
- Polygonal pattern



Crazing is a network of fine superficial surface cracks due to minor surface shrinkage caused by moisture loss.



Plastic Shrinkage Cracking

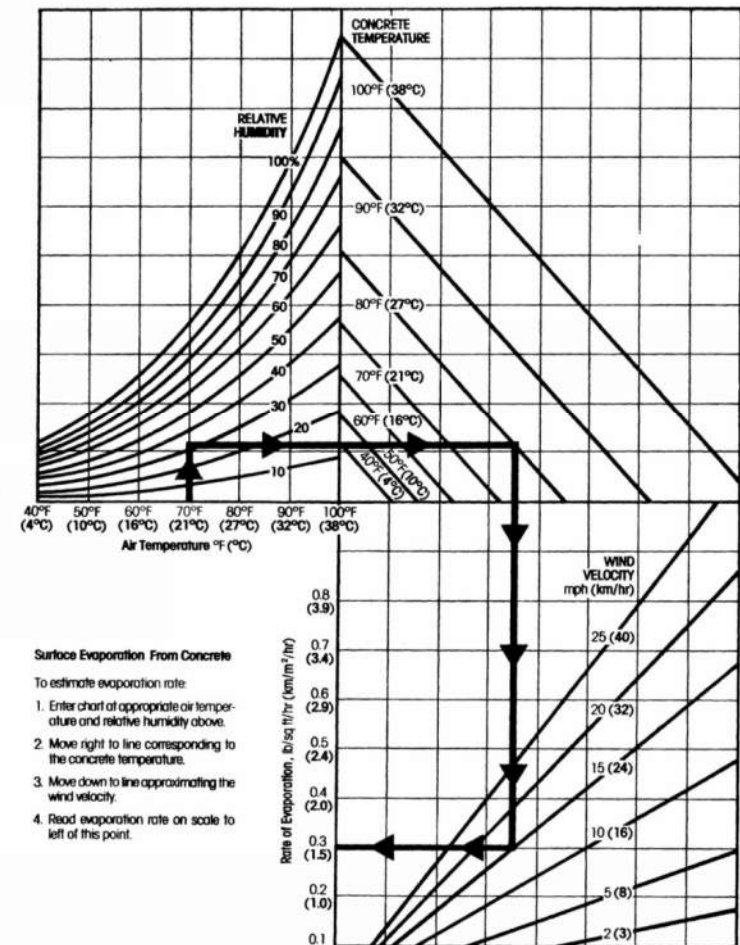
Identification:

- Random shallow cracks
- Running parallel to each other
- Fairly close together and short in length



Craze Cracking and Plastic Shrinkage Cracking

- **CAUSE:** Water evaporating from concrete
- Four contributing factors;
 - High Ambient Temps
 - High Concrete Temps
 - Low Humidity
 - High Winds





Plastic Shrinkage Cracks

PREVENTION

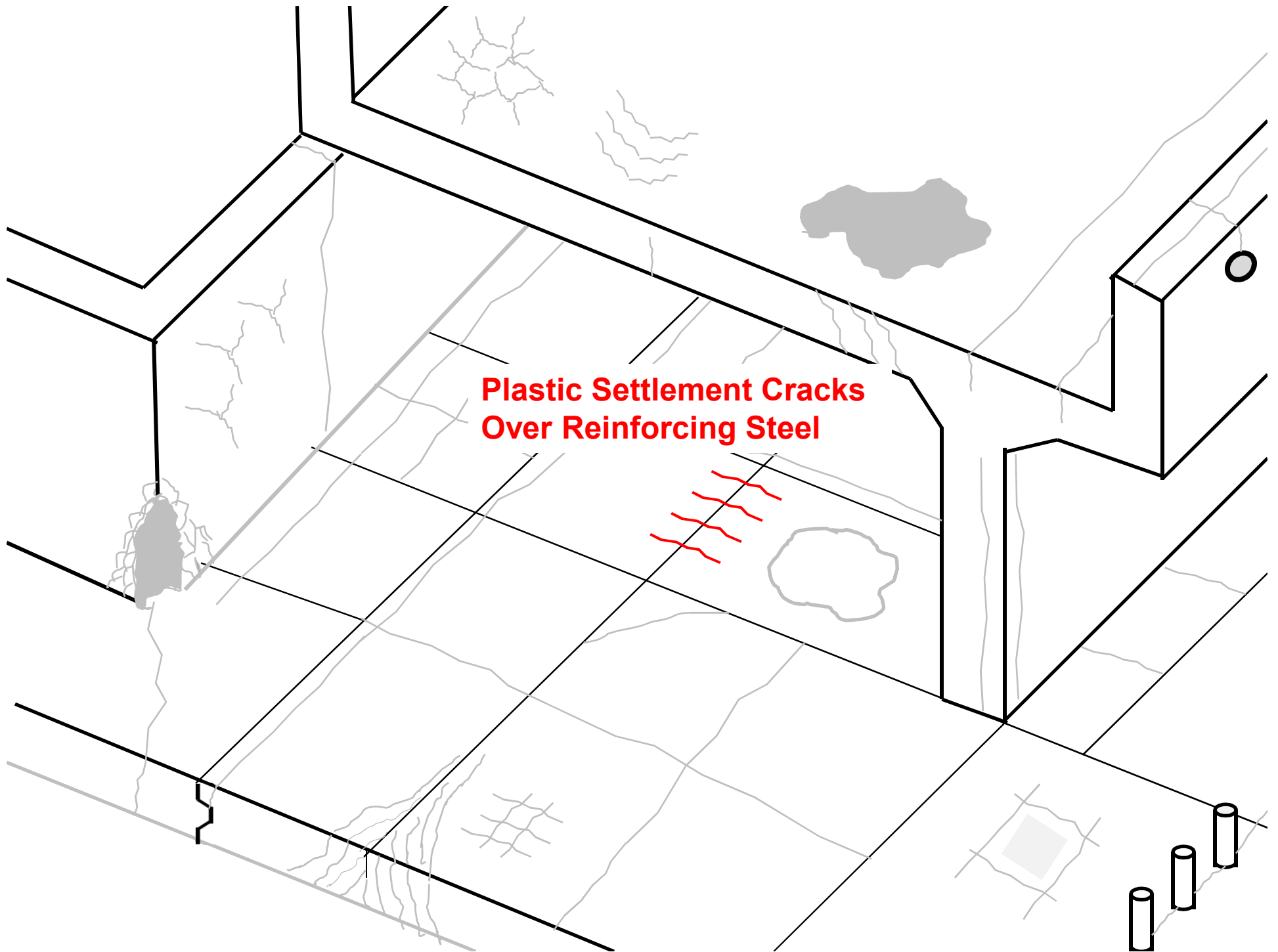
Plastic Shrinkage Cracking

- Fogging
 - Plastic Sheeting between finishing processes
 - **Evaporation Retarder**
 - Wind Breaks
 - Night Placement
 - **Micro Fiber Addition**
- 

REMEDY - Plastic Shrinkage Surface Cracking

- Treat with penetrating silane/siloxane sealer.





Identification:

- Cracks located directly over reinforcing steel



Plastic Concrete Settlement Cracks

CAUSES

- Increase with bar size
- Increasing Slump
- Decreasing Cover
- Insufficient Vibration
- Leaking or Highly Flexible Forms

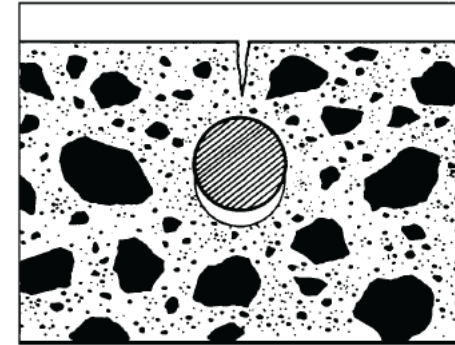


*Fig. 1.2—Crack formed due to obstructed settlement
(Price 1982).*

PREVENTION

- Add Fibers
- Proper Form Design
- Vibration
- Low Slump
- Increase Concrete Cover



Hardened Concrete Cracking

Restrained drying shrinkage

Thermal stresses

Chemical Reaction

Weathering (Freeze/Thaw)

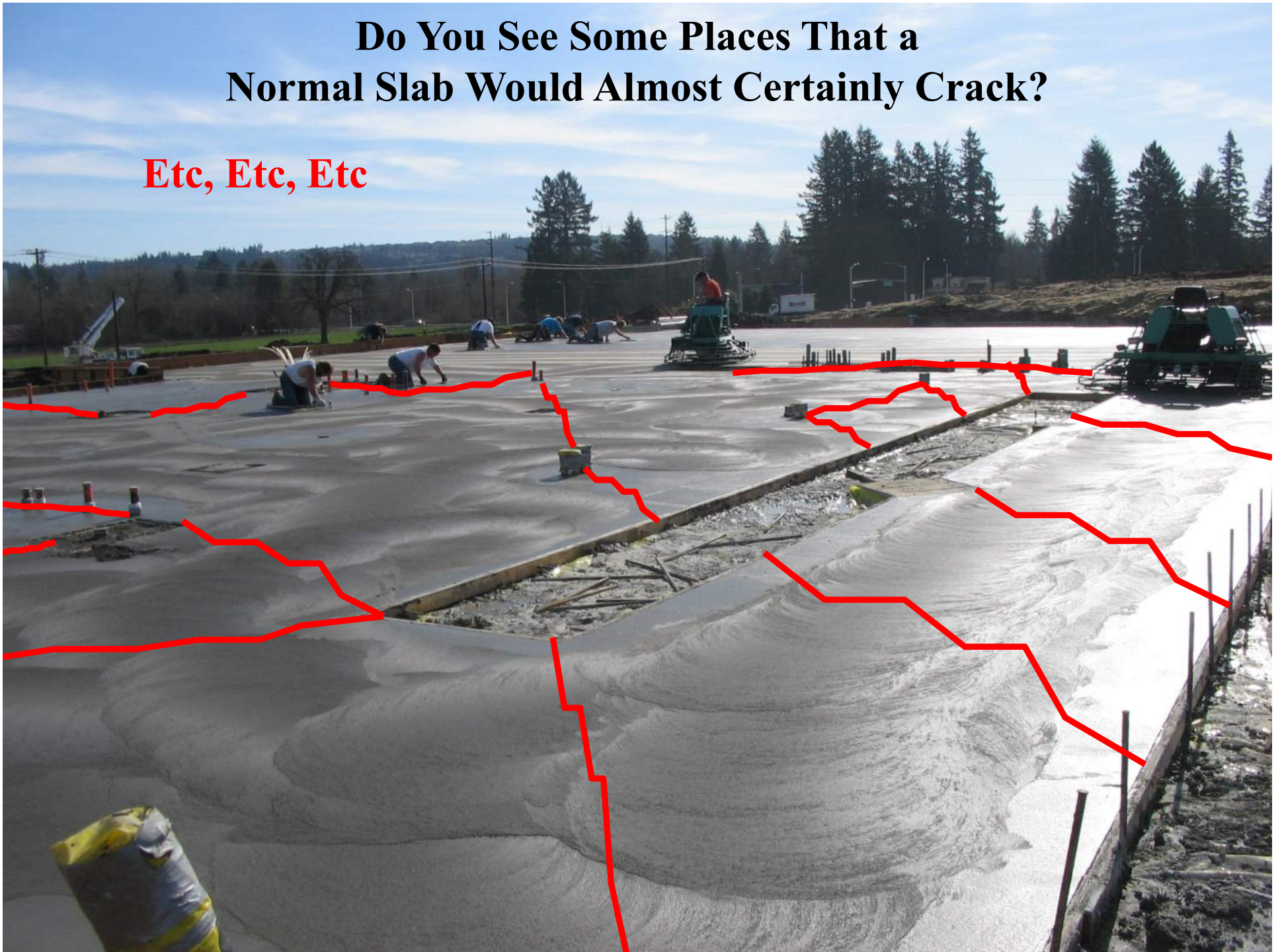
Corrosion of Reinforcing Steel

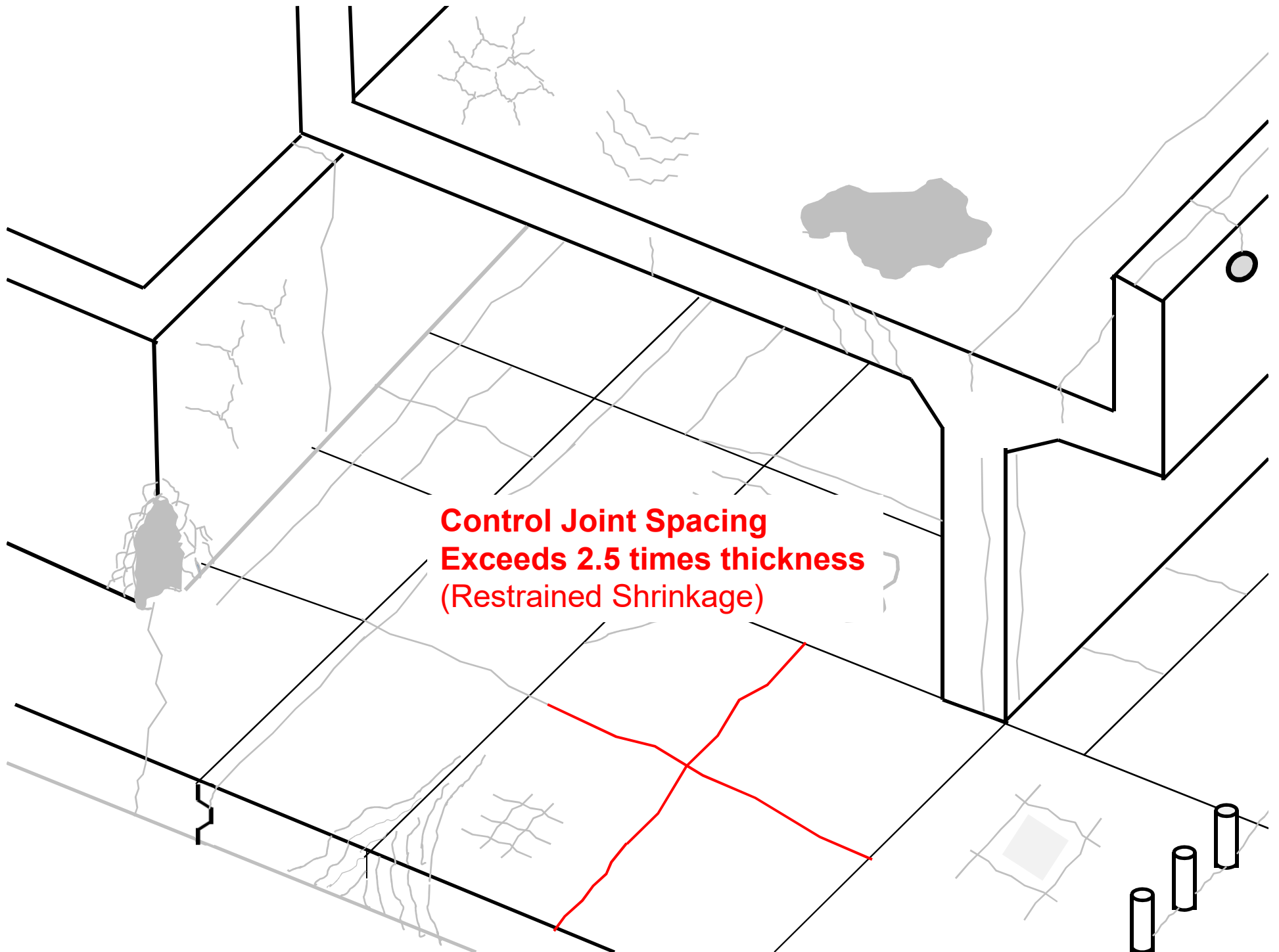
Structural Cracking



**Do You See Some Places That a
Normal Slab Would Almost Certainly Crack?**

Etc, Etc, Etc

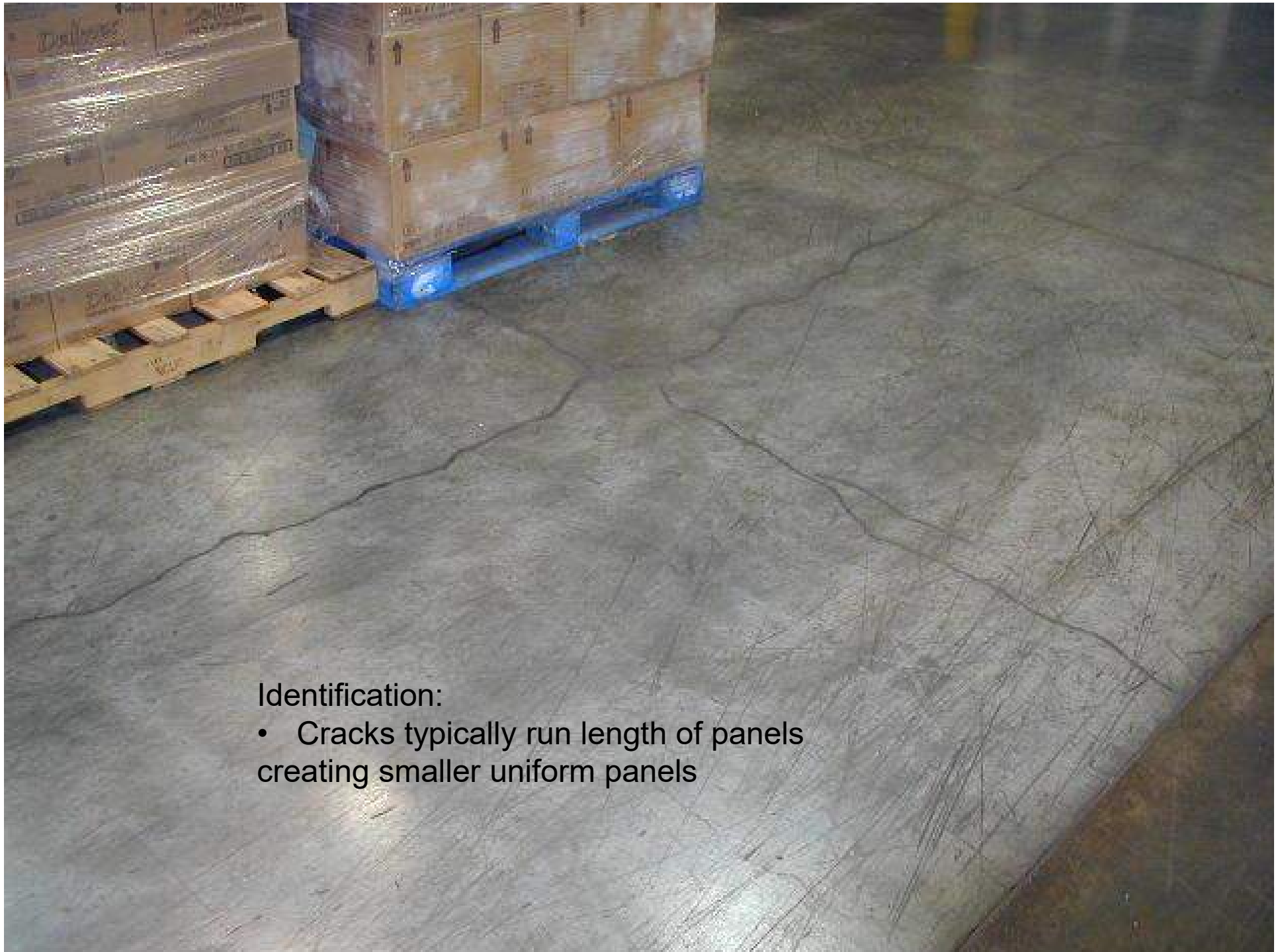




**Control Joint Spacing
Exceeds 2.5 times thickness
(Restrained Shrinkage)**

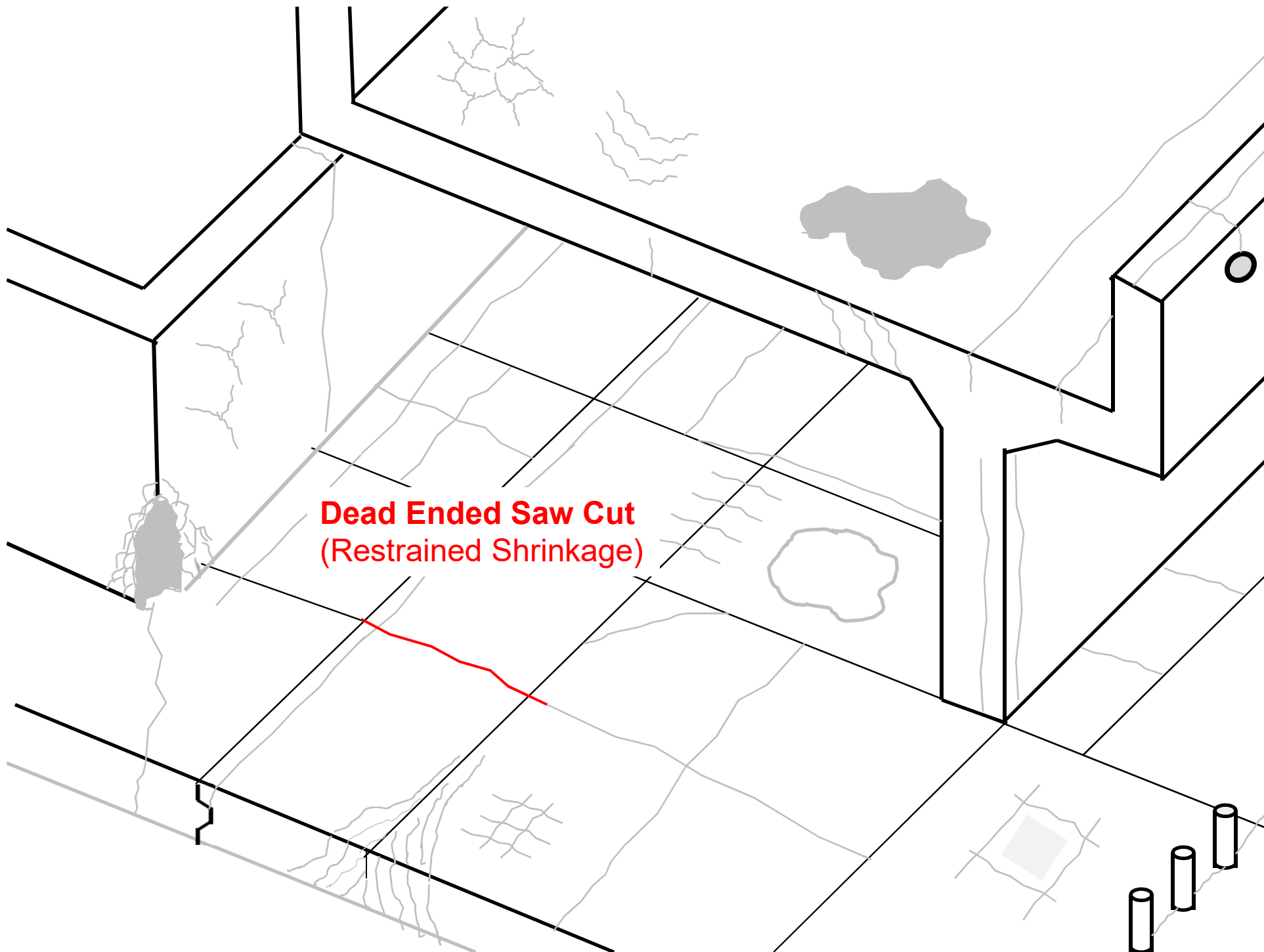
Control Joints





Identification:

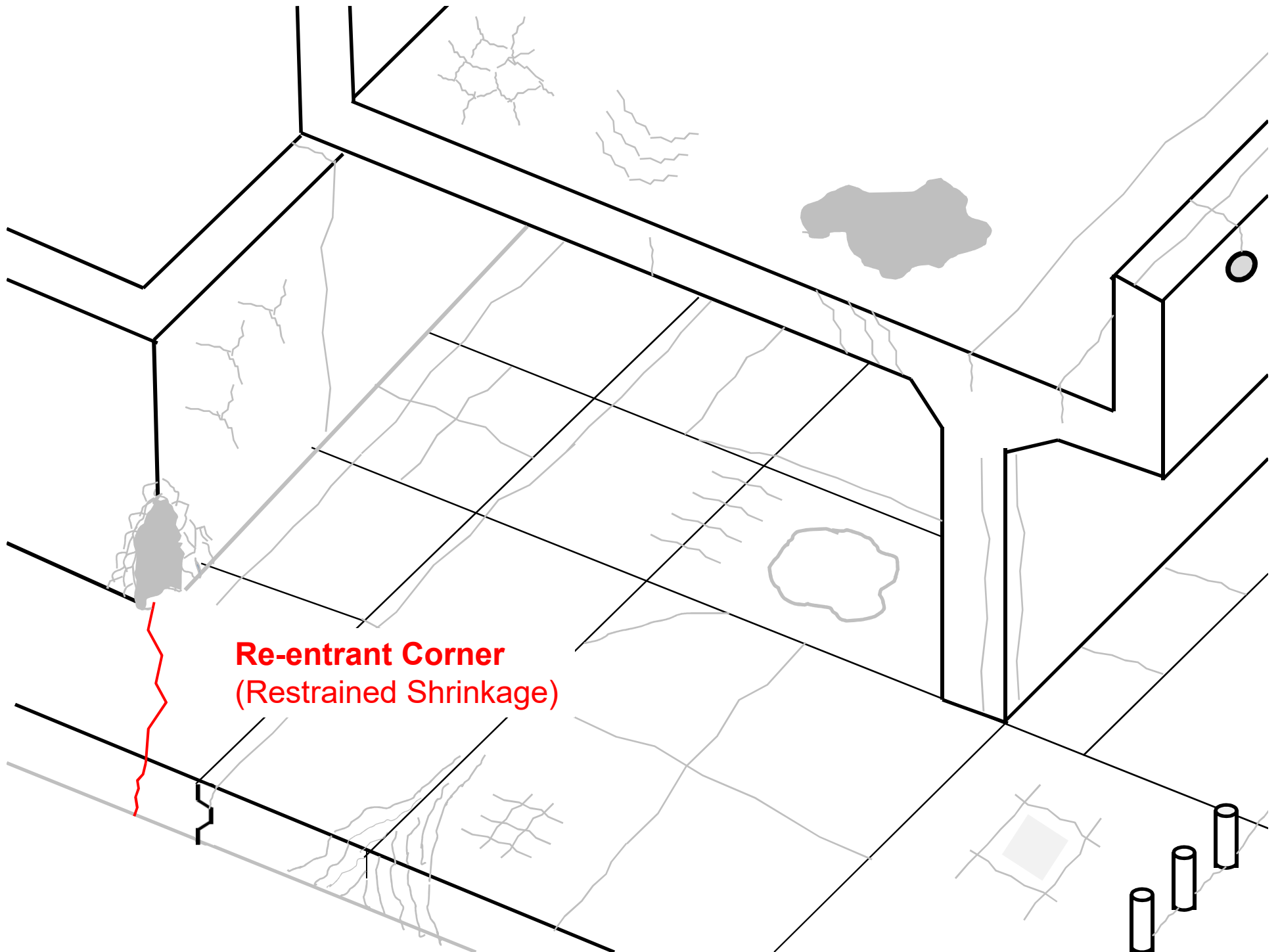
- Cracks typically run length of panels creating smaller uniform panels



Identification:

- Crack continues on from point of saw cut termination.





Identification:

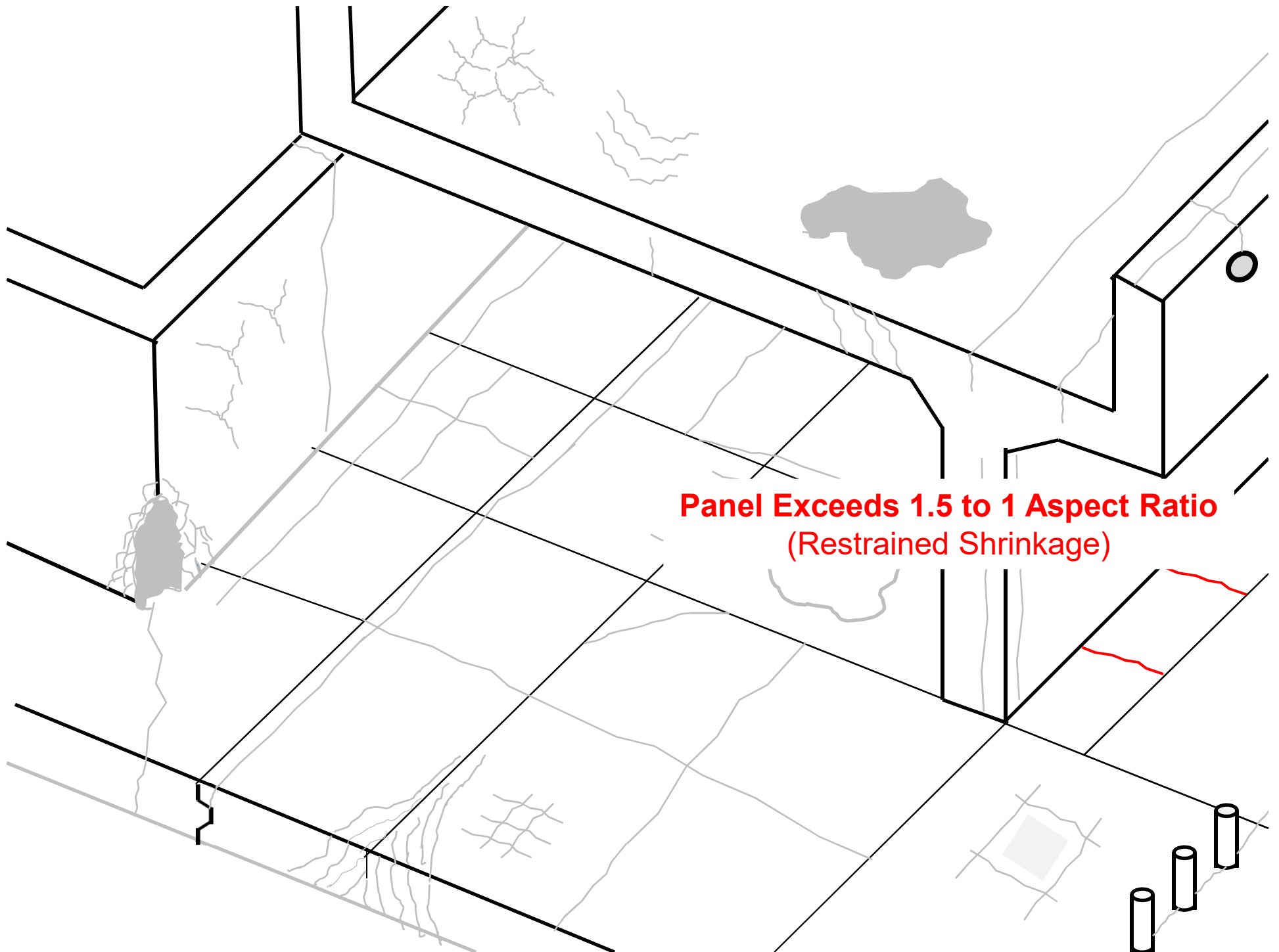
- Crack coming off of re-entrant corner



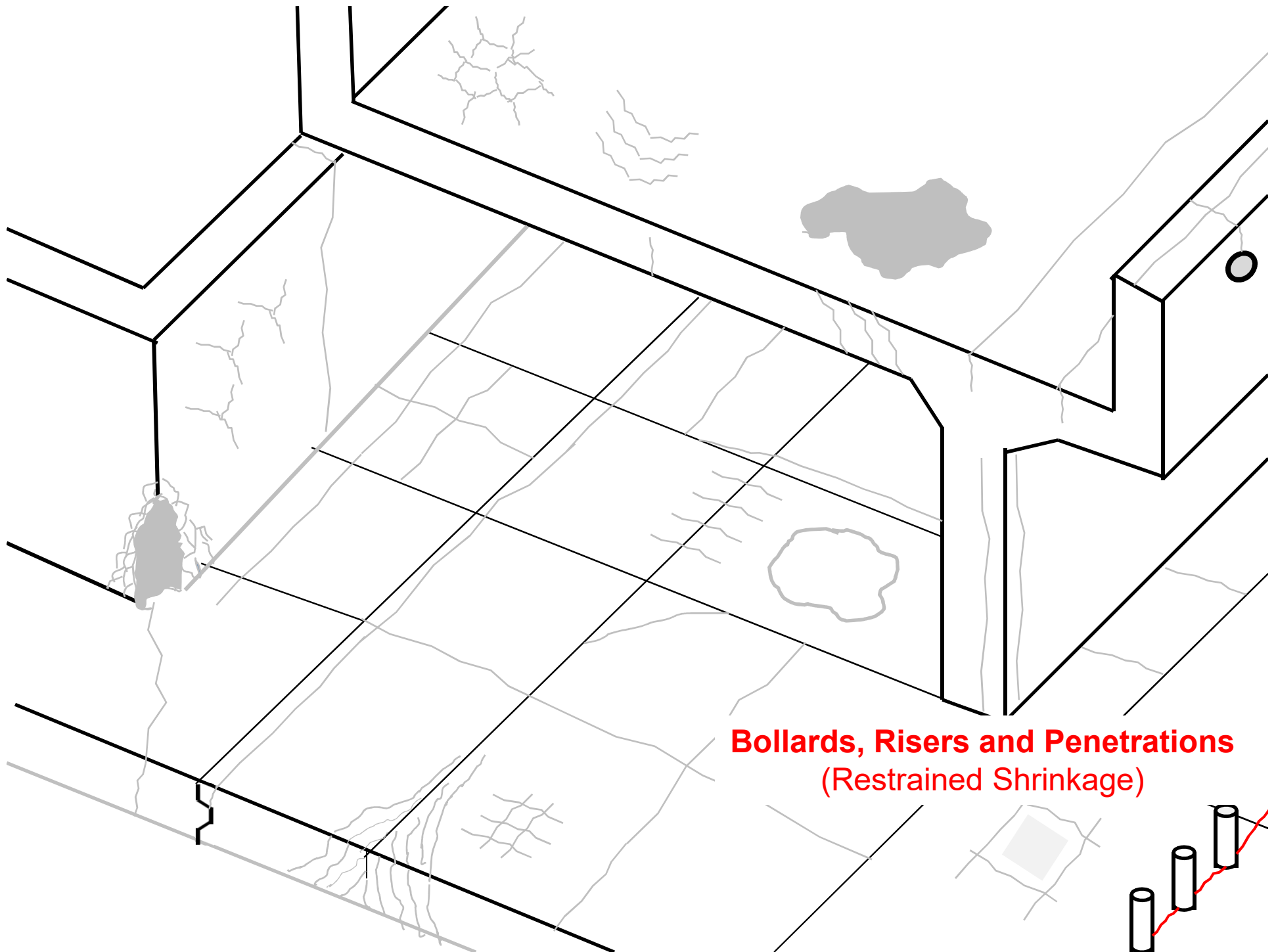


The Euclid Chemical



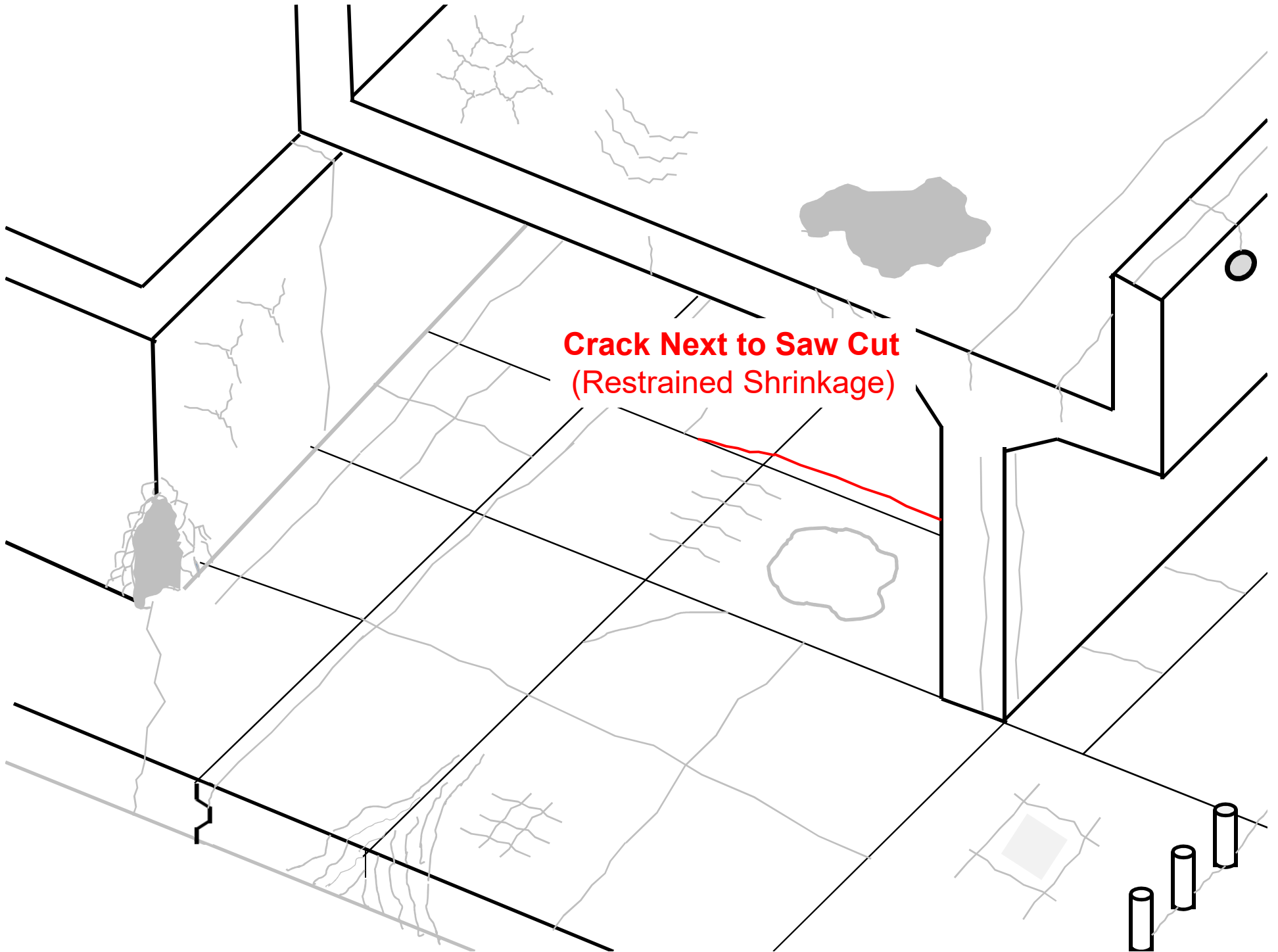






**Bollards, Risers and Penetrations
(Restrained Shrinkage)**

Crack Next to Saw Cut
(Restrained Shrinkage)



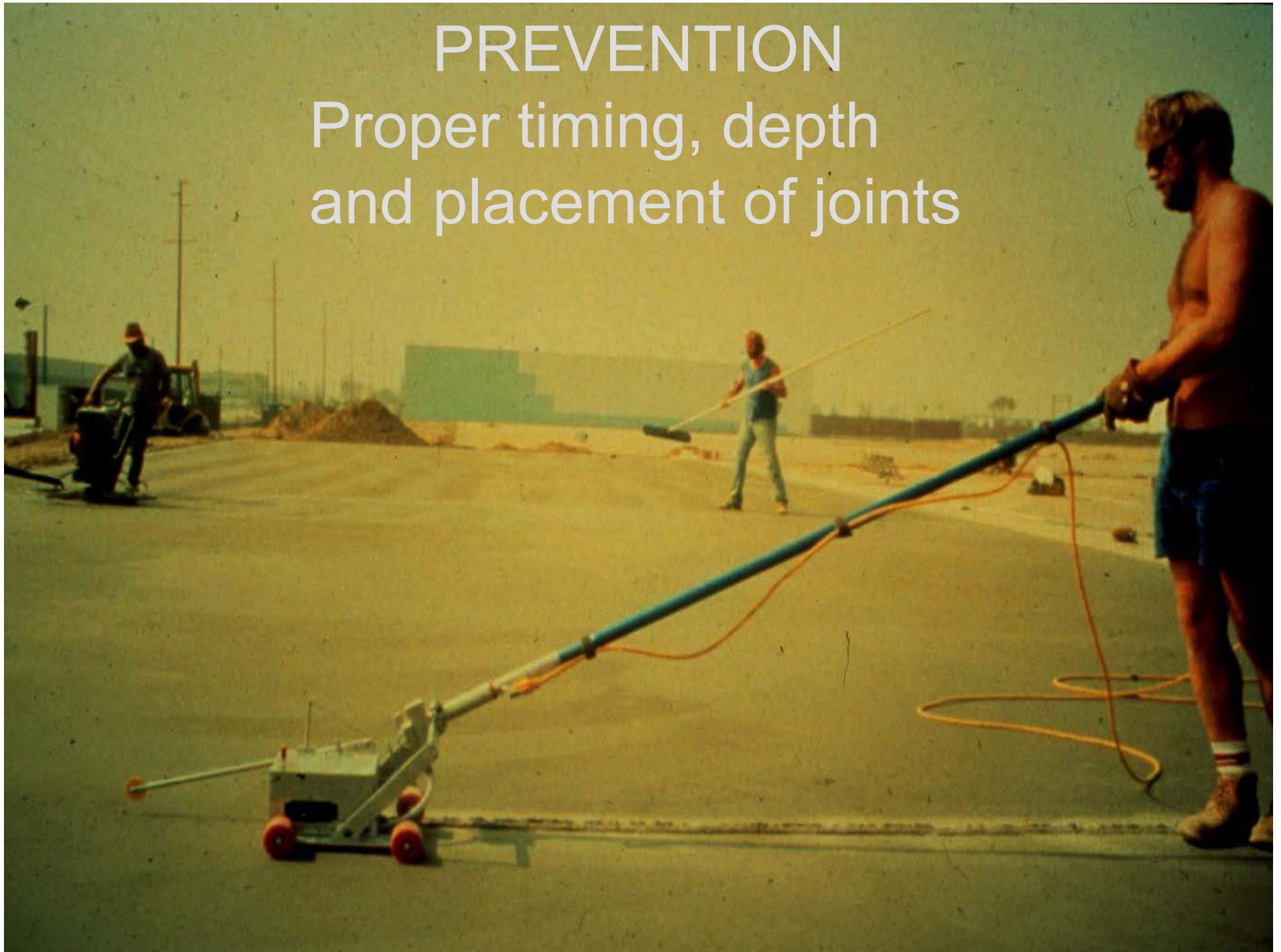






PREVENTION

Proper timing, depth
and placement of joints



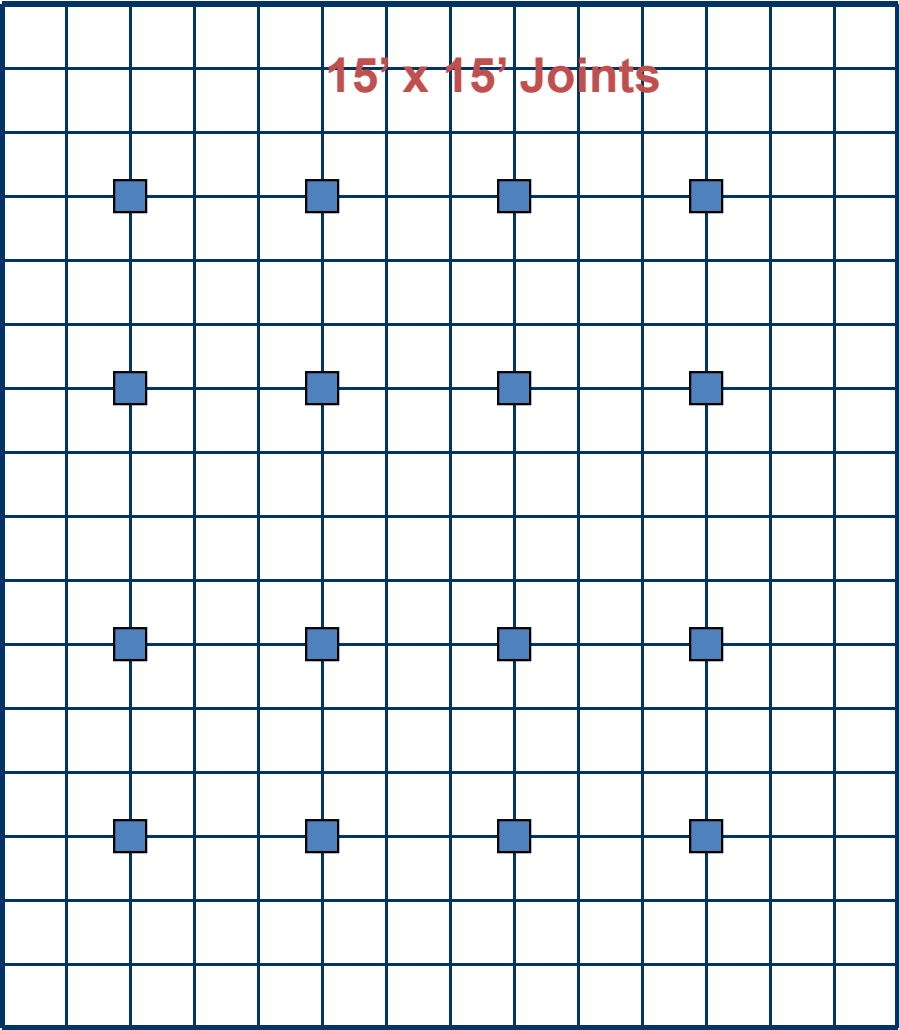
Restrained Shrinkage Crack - Prevention

1. Maximum joint spacing 24 to 30 times the thickness
2. Maximum length to width ratio 1.5 to 1
3. Joints at every re-entrant corner
4. No T's
5. Proper subgrade preparation
6. Expansion joints at penetrations
- 7. Lower Shrinkage Concrete**
- 8. Reinforcement**

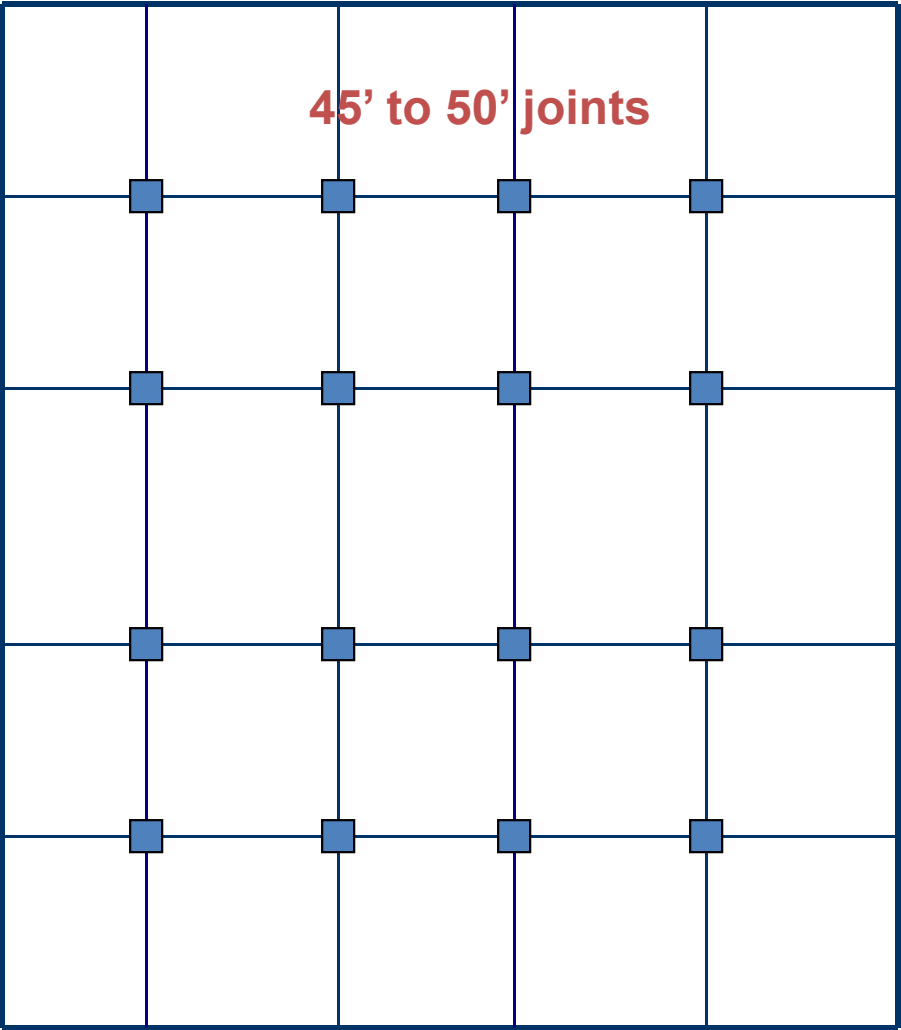
Corps of Engineers Concrete Shrinkage

Shrinkage %	Shrinkage / 100 lf	Probability of Random Cracking	Special Mix Design Requirements
0.08	1.00"	Almost Certain	None
0.06	0.75"	Very Probable	None
0.05	0.625"	Likely	None
0.04	0.50"	Probably Not Many	Optimize Aggregates
0.02	0.25"	Probable Very Few	Optimize Aggregates and add SRA/SCA
0.00	0.00"	Very Few if Any	Optimize Aggregates and add SRA/SCA

TYPICAL SLAB 6" 210' by 240' 50,400ft²



Standard Concrete
6270 lf of joints



<0.02% Shrinkage Concrete
1800 lf of joints

CONCRETE SHRINKAGE

Which Mix Will Have Less Shrinkage??

Mix A
0.50 w/c Ratio

Mix B
0.40 w/c Ratio

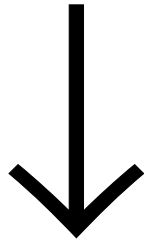


DON'T ANSWER YET!

Which mix has less water content??



**LOWEST SHRINKAGE
CONCRETE MIX**



LEAST PASTE



Top Size Aggregate Dictates Minimum Water Content

Table 9-5 (Inch-Pound Units). Approximate Mixing Water and Target Air Content Requirements for Different Slumps and Nominal Maximum Sizes of Aggregate

Slump, in.	Water, pounds per cubic yard of concrete, for indicated sizes of aggregate*							
	¾ in.	½ in.	¾ in.	1 in.	1½ in.	2 in.**	3 in.**	6 in.**
Non-air-entrained concrete								
1 to 2	350	335	315	300	275	260	220	190
3 to 4	385	365	340	325	300	285	245	210
6 to 7	410	385	360	340	315	300	270	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
1 to 2	305	295	280	270	250	240	205	180
3 to 4	340	325	305	295	275	265	225	200
6 to 7	365	345	325	310	290	280	260	—
Recommended average total air content, percent, for level of exposure:†								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate exposure	6.0	5.5	5.0	4.5	4.5	3.5	3.5	3.0
Severe exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

* These quantities of mixing water are for use in computing cement factors for trial batches. They are maximums for reasonably well-shaped angular coarse aggregates graded within limits of accepted specifications.

** The slump values for concrete containing aggregates larger than 1½ in. are based on slump tests made after removal of particles larger than

ACI 302.1R – 6.1 “Currently available water-reducing admixtures perform best when they are mixed with concrete that has enough water to produce a slump of **2 to 3 in.** (50 to 75 mm) if no admixture was added. If this “water slump” is not achievable without the admixture, setting time and finishability can vary when the concrete is subjected to normal variations of ambient temperature and time between batching and discharge (Harrison 2004)”

Top Size Aggregate vs Paste Content

1 1/2" Top size aggregate,

0.50 w/c – 4,000 psi 2" to 3" initial slump mix prior to addition of water reducers:

- **275 lbs water** - Dictated by top aggregate size.
- **550 lbs. of cement** – Dictated by w/c ratio spec and water demand.

275 lbs water

1 (relative density) x 62.4lbs/cf = 4.41 cu.ft.

550 lbs cement

3.15 (relative density) x 62.4 = 2.80 cu.ft.

Total Paste Content 7.21 cu.ft

Less Paste = Less Shrinkage

3/4" Top size aggregate,

0.50 w/c – 4,000 psi 2" to 3" initial slump mix prior to addition of water reducers:

- **315 lbs water** - Dictated by top aggregate size.
- **630 lbs. of cement** – Dictated by w/c ratio spec and water demand.

315 lbs water

1 (relative density) x 62.4lbs/cf = 5.04 cu.ft.

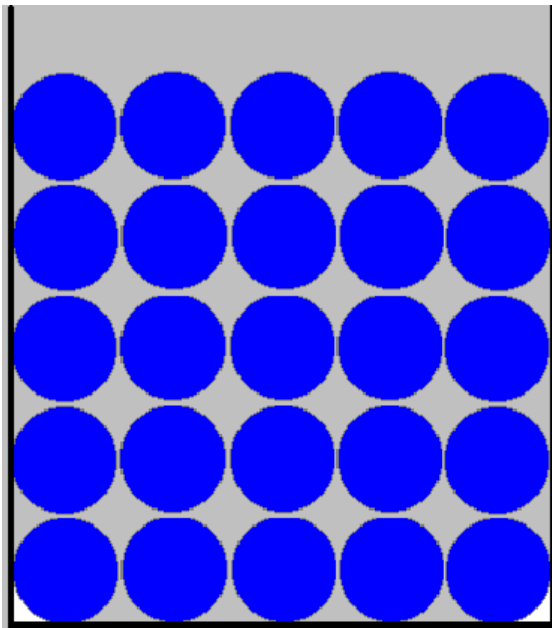
630 lbs cement

3.15 (relative density) x 62.4 = 3.20 cu.ft.

Total Paste Content 8.24 cu.ft

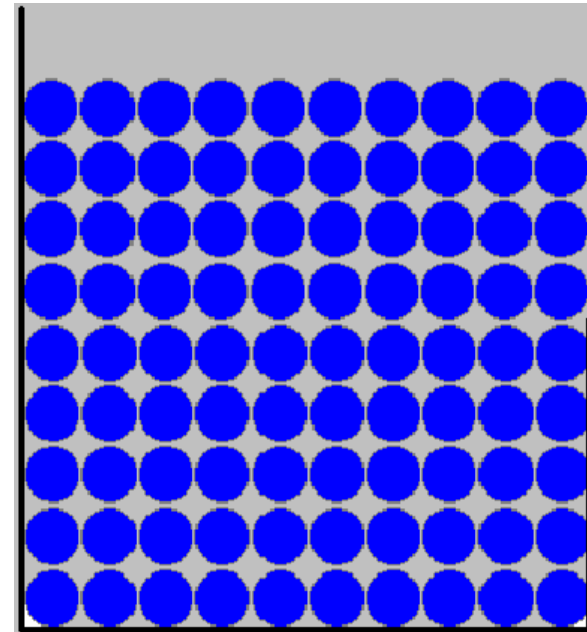
The Surface Area of 3/4 inch stone is 2 times greater than the Surface area of 1.5 inch stone - per unit volume

1.5" Stone



2 X

.75" Stone



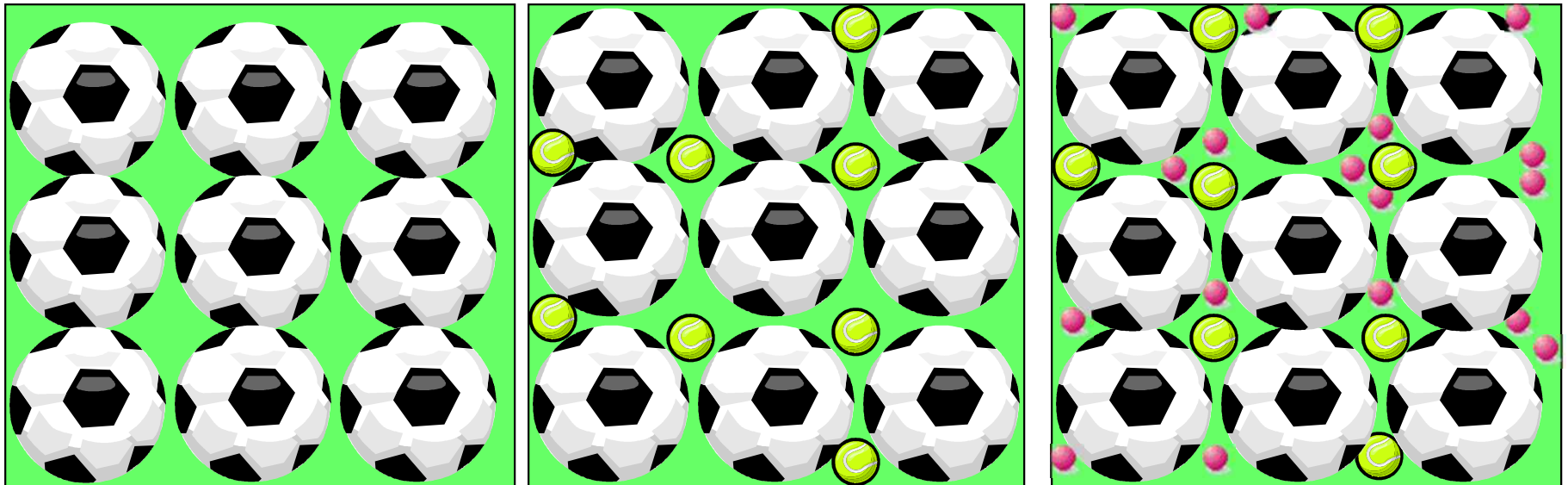
Reduce Concrete Shrinkage and Curli

Concrete Aggregates

Particle Size Distribution

Packing Theory:

Given a fixed volume and objects of the same size, there is a maximum number of objects that can fit in that volume





Section 5.4.3 – Combined Aggregate Gradation per ACI

- ◆ Gradation requiring between 8 percent and 18 percent for large top size aggregates (such as 1 1/2 in.) or 8 percent and 22 percent for smaller top size aggregates (such as 1 in. or 3/4 in.) retained on each sieve below the top size and above the No. 100 sieve have proven to be satisfactory in reducing water demand while providing good workability.
- 



Reinforcement



ACI 360

CHAPTER 7—DESIGN OF SLABS REINFORCED FOR CRACK-WIDTH CONTROL

7.1—Introduction

- Slabs-on-ground are designed and their thickness selected to prevent cracking due to external loading, as discussed in **Chapter 6. Slab thickness calculations are based on the assumption of an uncracked and unreinforced slab.** Steel reinforcement may be used in slabs-on-ground to improve performance of the slab under certain conditions. These include:
 - Limiting width of shrinkage cracks;
 - Use of longer joint spacings than unreinforced slabs; and
 - Providing moment capacity and stability at cracked sections.
- The use of reinforcement will not prevent cracking, but will actually increase crack frequency while reducing crack widths. **Properly proportioned and positioned, reinforcement will limit crack widths such that the cracks will not affect slab serviceability.**

ACI 360 Continued

7.5—Reinforcement location

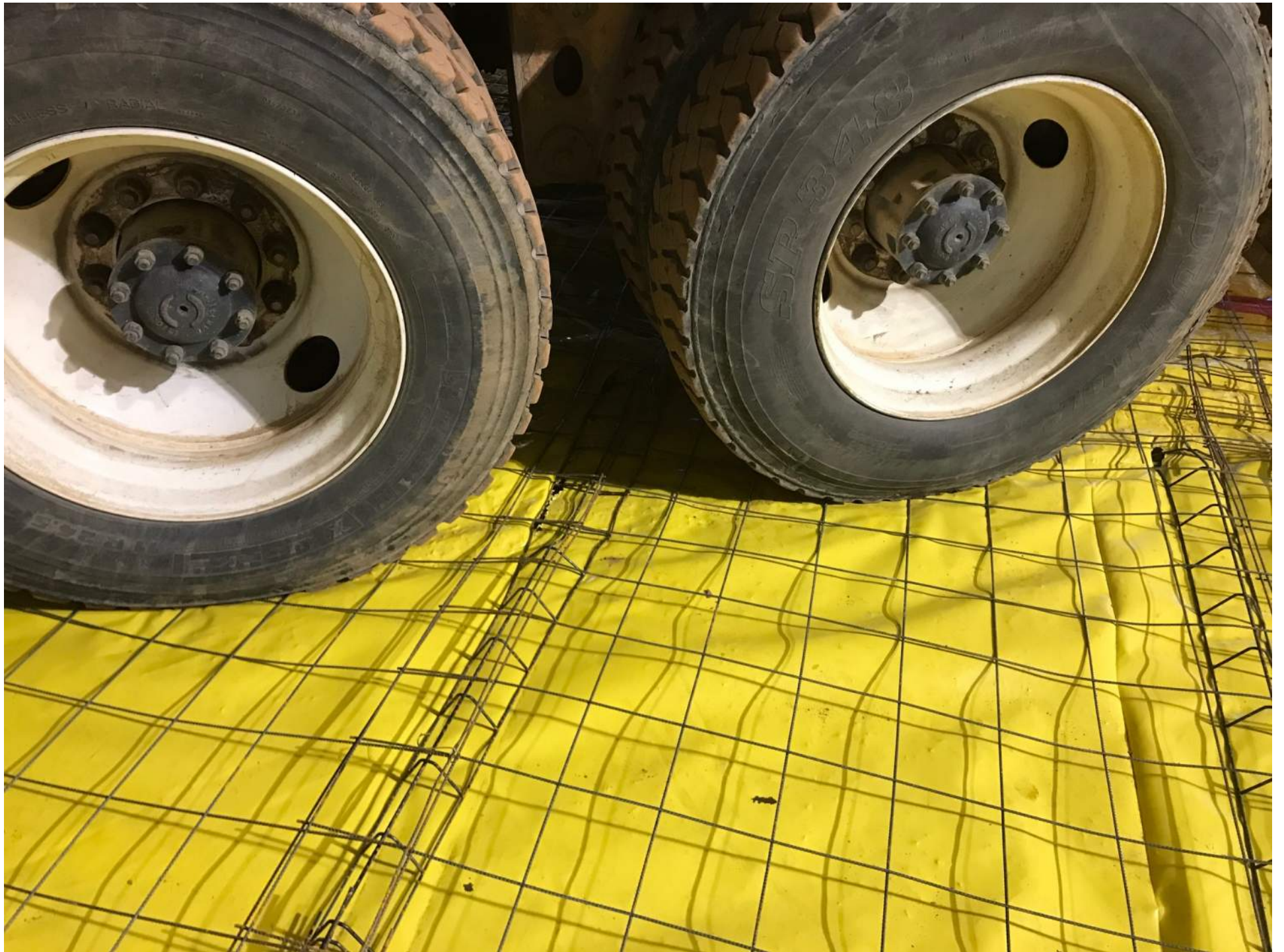
Reinforcement for crack-width control only should be at or above mid-depth of the slab-on-ground, never below mid depth.

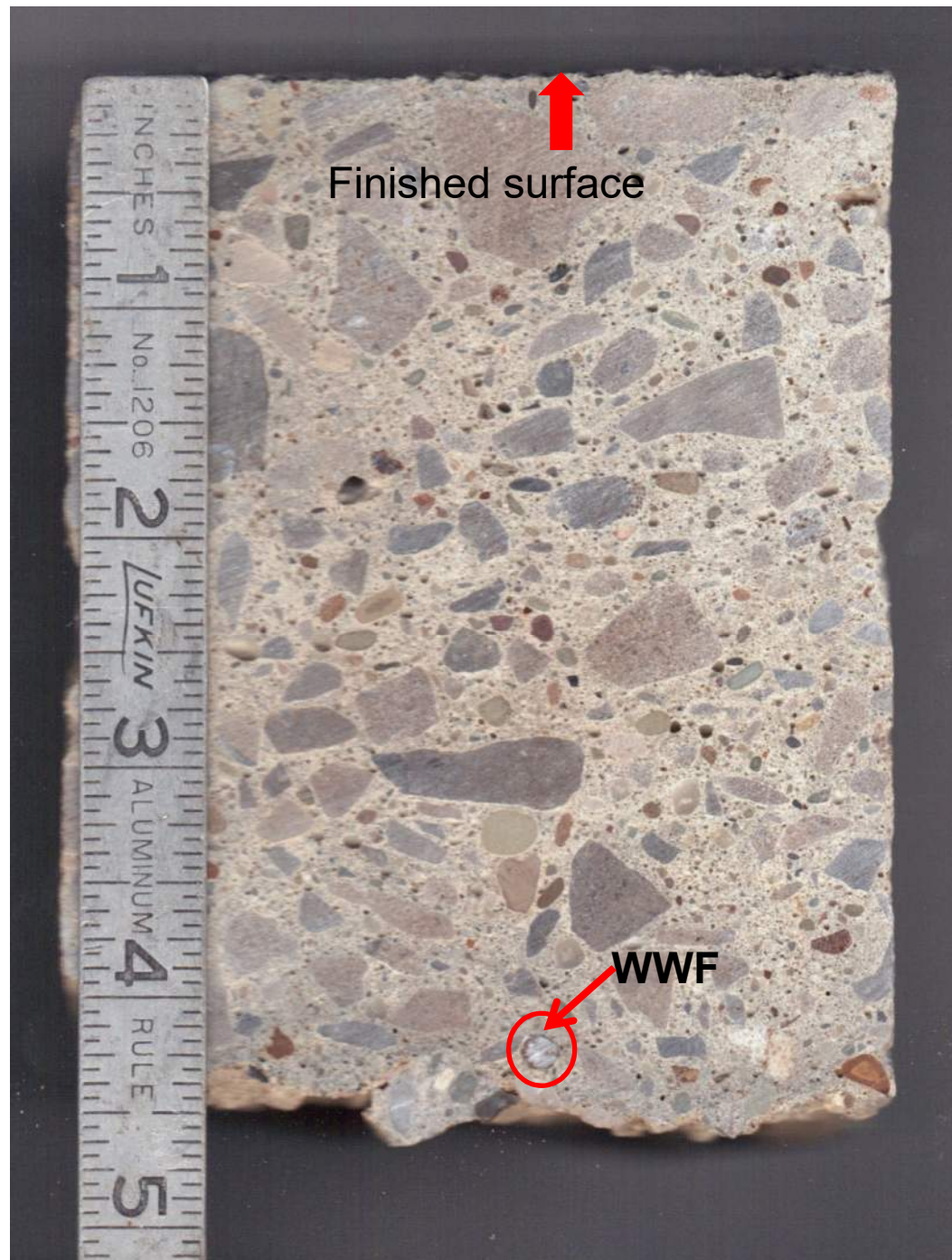
A common practice is to specify that the steel have 1.5 to 2 in. (38 to 51 mm) cover below the top surface of the concrete. Reinforcement for moment capacity should be at the centroid of the tensile area of the uncracked concrete section.

What is wrong with wire mesh?!









Finished surface

WWF



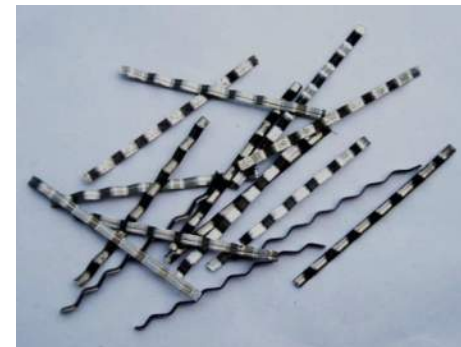


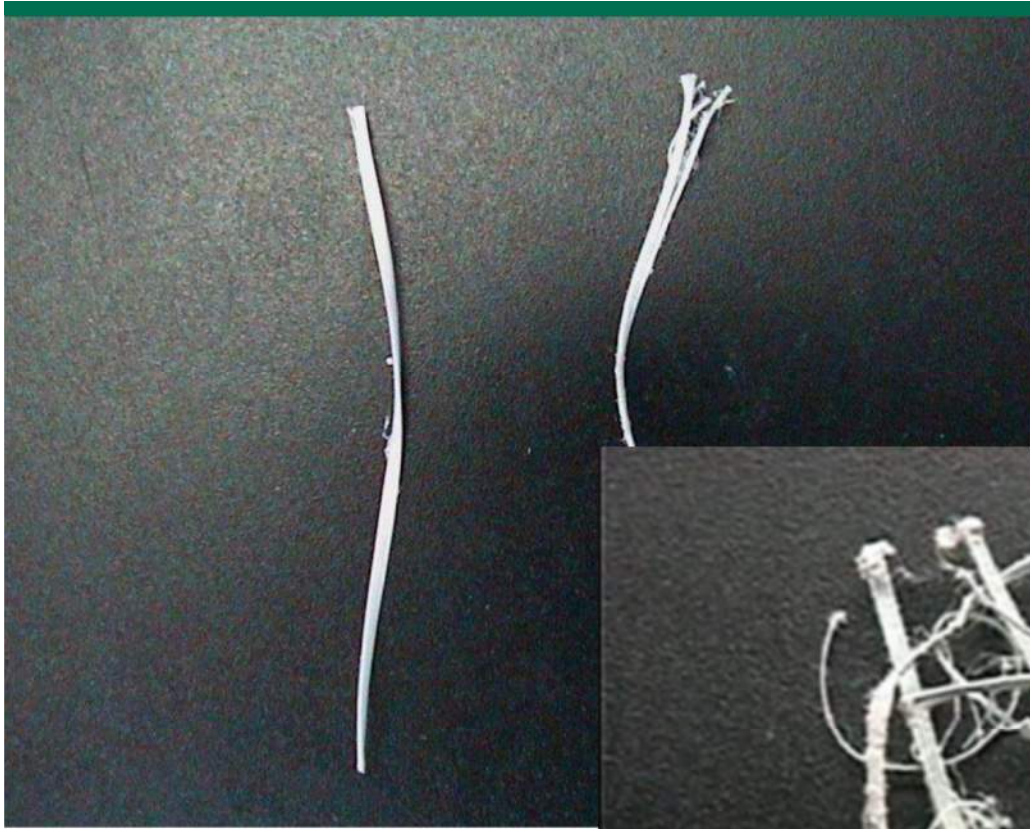
FIBER REINFORCEMENT



Types of Fibers

- **Synthetic micro fibers:** “secondary” reinforcement; shorter and finer strands, plastic shrinkage crack control only. They can be monofilament or fibrillated (0.5-1.5 pcy)
- **Synthetic macro fibers:** longer and coarser strands, shrinkage crack control and limited structural applications. Dosages should be calculated by engineering requirements and equations (3-20 pcy)
- **Steel fibers:** longer and coarser pieces, extended structural applications. Dosages should be calculated by engineering requirements and equations (15-100 pcy)





Application Potentials

- **Macro synthetic fibers can replace WWM and light steel rebar in applications such as:**
 - Slab on grade (parking, industrial, etc)
 - Pavement (road, driveway, etc)
 - Overlays (toppings)
 - Composite metal deck
 - Shotcrete (tunnels, slopes, pools, repair)
 - Precast (structural, hydraulic, decorative)
 - Supplementary seismic reinforcement



Where We Cannot Use Fibers (To Replace Steel)

- **Macro synthetic fibers cannot replace steel rebar in applications such as:**

- Two-way slabs
- Structural beams
- Structural columns
- Structural walls
- Shear walls



- **Note that we may be able to replace “some” portion of the structural steel with macro synthetic fibers to reduce congestion!**



Advantages of Fiber During Construction

- Reduced labor and costs
- Reduced construction time
- Increased safety
- Easier to construct
- Earlier completion



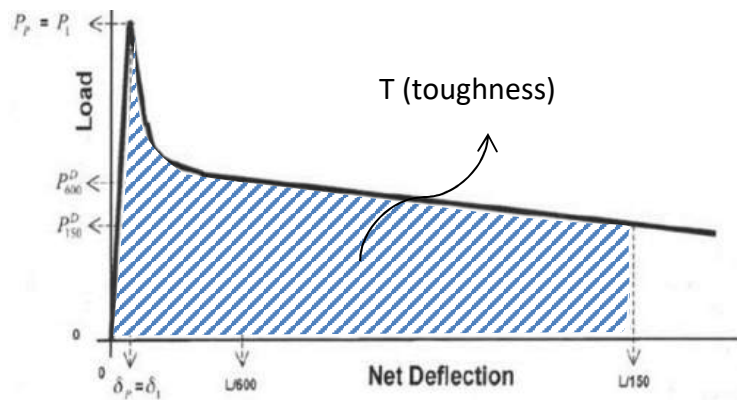


Performance Based Specifications

- Not all fibers are the same, that is why it is important to specify fibers based on their “performance” in “fiber-reinforced concrete (FRC)”.
 - Currently there are two main standard test methods used in North America: ASTM C1399 and ASTM C1609.
 - C1609 is the preferred method due to it’s more sophisticated and accurate procedure. Some labs use C1399 instead because it’s easier and less expensive to perform.
- 

Standard Test Methods for FRC: ASTM 1609

ASTM C 1609 can be used to find the performance of FRC in terms of residual strength. Closed-loop four-point bending test is required for proper data collection in post peak.



Flexural strength
(psi)

$$f_r = P \cdot \frac{L}{bd^2}$$

Example: 600 psi

Residual Strength
Ratio (%)

$$R_{e,3} \text{ or } R_{T,150} = \frac{150T}{\sigma_b bd^2} \times 100\%$$

Example: 35% psi

Implies what % of the load can be carried by the fibers after cracking

Jeb Bush
Governor



John O. Agwunobi, M.D., M.B.A.
Secretary

January 23, 2004

Mr. Michael Mahoney
Euclid Chemical Company
19218 Redwood Road
Cleveland, Ohio 44110-2799

Dear Mr. Mahoney:

We received your letter dated **January 12, 2004** requesting approval of the **TUF-STRAND SF Structural Synthetic Fiber** for use in onsite sewage treatment receptacles in the State of Florida. We have reviewed the test lab report from ISIM Group of Dalhousie University regarding the testing of **TUF-STRAND SF Structural Synthetic Fiber** in accordance with ASTM C 1399-Test Method for Obtaining Average Residual Strength of Fiber-Reinforced Concrete.

We are pleased to inform you that the **TUF-STRAND SF Structural Synthetic Fiber** is approved for use in onsite sewage treatment concrete receptacles at a minimum of **3.0 lbs per cubic yard**. The test indicates that the:

- **3.0 lbs per cubic yard** matrix will produce an average residual strength (ARS) of **141 psi**
- **4.0 lbs per cubic yard** matrix will produce an average residual strength (ARS) of **217 psi**
- **5.0 lbs per cubic yard** matrix will produce an average residual strength (ARS) of **243 psi**

Supplier	Approved product name	Minimum acceptable weight:	Average Residual Strength (ARS)
W. R. Grace & Co.-Conn 62 Whittemore Avenue Cambridge, MA 02140 Phone: (877) 423-6491 Fax: (617) 498-4313 Website: www.graceconstruction.com	Grace Structural Fiber (GSF) Grace Structural Fiber (GSF) Grace STRUX 85/50 Grace STRUX 85/50 Grace STRUX 90/40 Grace STRUX 90/40	4.0 lbs per cubic yard 5.0 lbs per cubic yard 4.0 lbs per cubic yard 5.0 lbs per cubic yard 3.0 lbs per cubic yard 4.0 lbs per cubic yard	160 psi 230 psi 160 psi 200 psi 159 psi 207 psi
Forta Corporation 100 Forta Drive Grove City PA 16127-6399 Phone: (800) 245-0306 Fax: (724) 458-8331 Website: www.fortacorp.com	FORTA FERRO™ FORTA FERRO™ II FORTA FERRO™ II FORTA FERRO™ II FORTA® Econo-Net® FORTA® Econo-Net®	4.5 lbs per cubic yard 3.5 lbs per cubic yard 4.0 lbs per cubic yard 4.5 lbs per cubic yard 3.5 lbs per cubic yard 3.1 lbs per cubic yard	155 psi 144 psi 148 psi 168 psi 156 psi 118 psi
Durafiber, Inc. 2802-A Foster Avenue Nashville, TN 37210-5310 Phone: (800) 844-3880 Fax: (615) 333-9882 Website: www.durafiber.com	Durafiber DFCFP Durafiber SF-57	3.1 lbs per cubic yard 16.25 lbs per cubic yard 25.00 lbs per cubic yard	133 psi 160 psi 248 psi
PGI Fibersource Formerly: PGI Performance Concrete Fibers 701 East Avenue A P.O. Box 517 Kingman, KS 67068 Phone: (800) 821-4391 Fax: (620) 532-2571 Website: www.pgifibers.com	1.5" Performax™ Synthetic Macro Fiber Formerly: Genesis SF Fiber	3.0 lbs per cubic yard 5.0 lbs per cubic yard	155 psi 228 psi
Propex Concrete Systems (Formerly SI Concrete Systems) 6025 Lee Highway, Suite 425 PO Box 22788 Chattanooga, TN 37422 Phone: (800) 621-1273 Fax: (423) 899-5005 Website: www.fibermesh.com	Fibercast 500 Novocon XR Fibercast 510 Fibercast 510 ENDURO 600 ENDURO 600	4.0 lbs per cubic yard 20 lbs per cubic yard 5 lbs per cubic yard 7.5 lbs per cubic yard 5 lbs per cubic yard 7 lbs per cubic yard	154 psi 205 psi 215 psi 250 psi 175 psi 245 psi
TRICO International, Inc. 5303 4 th Avenue West Bradenton, FL 34209 Phone: (941) 747-9021 Fax: (941) 747-3064 Website: www.abcfibers.com	ABC F75-1500 Fibrillated Fibers	4.0 lbs per cubic yard	136 psi
Nycon, Inc. 101 Cross Street Westerly, RI 02891 Phone: (800) 456-9266 Fax: (401) 596 4242 Website: www.nycon.com	NyconXL	3.5 lbs per cubic yard 4.0 lbs per cubic yard 5.0 lbs per cubic yard	115 psi 127 psi 134 psi
The Euclid Chemical Company 19218 Redwood Road Cleveland, Ohio 44110-2799 Phone: (800) 321-7628 Fax: (216) 531-9596	TUF-STRAND SF	3.0 lbs per cubic yard 4.0 lbs per cubic yard 5.0 lbs per cubic yard	141 psi 217 psi 243 psi

Performance Based Specification

PART 2 PRODUCTS

2.0 FIBER REINFORCEMENT

- A. Polypropylene/polyethylene synthetic macro fiber complying with ASTM C 1116 Type 3, minimum 2 inch length, aspect ratio 50 to 90.

1. Basis of Design:
 - a. Euclid Chemical Company (The); Tuf-Strand SF;
www.euclidchemical.com
 - b. Or approved equal

2.0 CONCRETE MIXES

Submit fiber manufacturer's documentation indicating that proposed fiber dosage will provide a minimum F_{e3} value of **<Insert value>** psi in accordance with ASTM C 1609. Under no circumstances shall dosage rate be less than 3.0 LBS per cubic yard of concrete.

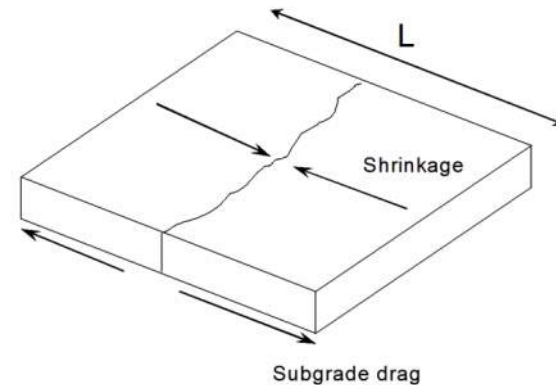
- 1) F_{e3} shall be defined as the R_{T150}^D/R_{e3} (as determined through ASTM C1609 testing) multiplied by the flexural strength (F_r) of the concrete tested .
 - a) $F_{e3} = R_{T150}^D \times F_r$

TEMPERATURE AND SHRINKAGE STEEL CALC

$$A_s = \frac{F_f L W}{2 F_{ws}}$$

$$F_{steel} = \frac{A_s F_y F_{ws}}{\phi_s b d}$$

- F_{steel} = contribution of steel in direct tension, psi
 A_s = area of steel per unit cross sectional area, in²/ft
 F_y = yield strength of steel reinforcement, psi
 F_{ws} = working stress for steel reinforcement (typically 0.67 – 0.75 F_y)
 ϕ_s = material safety factor for steel
 b = unit width of concrete section, in
 d = depth of concrete section, in
 F_f = coefficient of sub-grade friction (typically 1.5 – 2.0)
 L = slab length between joints
 W = dead weight of slab (typically 12.5 lbs per sq.ft. per inch of slab thickness)



Testing methods to evaluate the post-crack strength of FRC in direct tension are not directly available. However, it can be inferred from existing standardized flexural testing. In the analysis, it is assumed that the percentage of the post-crack load carrying capacity to the flexural modulus of rupture of concrete, derived from flexural testing according to ASTM C 1609, *Flexural Performance of Fiber Reinforced Concrete (using beam with third point loading)*, divided by a factor of 2.7, will represent the post-crack direct tensile capacity of the FRC at a given dosage.

$$F_{steel} = 0.37 F_{e3}$$

TEMPERATURE AND SHRINKAGE STEEL CALC

For temperature stresses, the flexural stress can be calculated based on the thickness and temperature gradient, as well as the concrete properties. Temperature gradient can be considered to be approximately 1.5 – 2.5°F for every inch of concrete slab.

$$\sigma_T = \frac{C \cdot E \cdot \alpha \cdot \Delta T}{2}$$

σ_T : stress from temperature gradient (in flexure)

C : coefficient (0.8 for granular base and 0.65 for stabilized base)

E : concrete modulus of elasticity ($E = 57,000$ multiplied by the square root of (f'_c))

α : coefficient of thermal expansion

Δ_T : temperature gradient (top surface to bottom surface)

Slab on Grade - Design Example (Non-Structural)

Slab on Grade project is currently using a single layer of #4 @ 12" c.c. reinforcing placed near the top of an 6" (150 mm) thick slab. Concrete strength is 5000 psi (35 MPa), with an approximate tensile strength of 575 psi (4MPa). Steel reinforcing strength is Imperial Grade 60 (410 MPa).

The contractor would like to replace this steel with fibers. What fiber dosage would be applicable? – kg/m³ (lbs/yd³)



TEMPERATURE AND SHRINKAGE STEEL CALC

6" Slab On Grade: Reinforcing at mid depth: #4's @ 12" OCEW; 4000 psi Concrete (Exterior)

The following calculations show the reinforcement by steel and the fiber dosage required to provide the same performance. $A_s = 0.196 \text{ in}^2/\text{ft}$ and $F_y = 60 \text{ ksi}$. Assume 12°F temperature differential (between top and bottom surfaces) and a granular sub base.

$$F_{steel} = \frac{(0.196 \cdot 60000 \cdot 0.67)}{(1.15 \cdot 12 \cdot 6)}$$

$$\sigma_T = \frac{C \cdot E \cdot \alpha \cdot \Delta T}{2}$$

$$F_{steel} = 95.15 \text{ psi in tension}$$

$$\sigma_T = \frac{0.8 \cdot (4.0 \cdot 10^6) \cdot (5.5 \cdot 10^{-6}) \cdot 12}{2}$$

$$F_{steel} = 0.37 F_{e3}$$

$$\sigma_T = 105.6 \text{ psi}$$

$$F_{e3} = 95.15 \text{ psi (tension)} \div 0.37$$

$$\sigma_T = F_e^3 = 105.6 \text{ psi}$$

$$F_{e3} = 257 \text{ psi (flexural)}$$

TEMPERATURE AND SHRINKAGE STEEL CALC

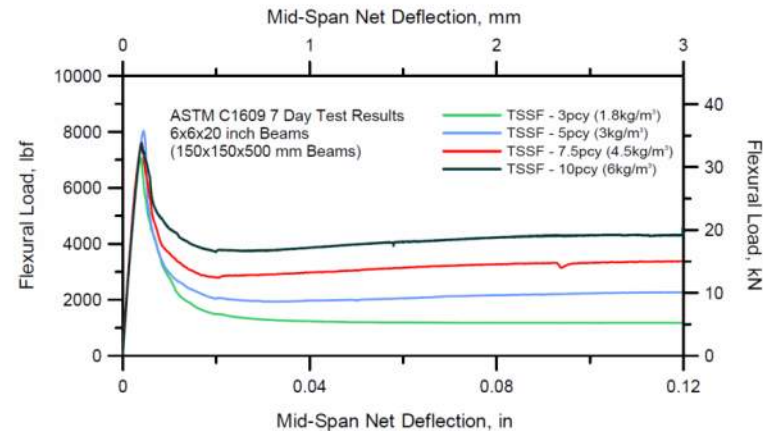
ASTM C1609 Test Results on Fiber-Reinforced Concrete

Comparative Evaluation of Synthetic Fibers

Dosage Rate: As shown

Date: March, 2015

Concrete Strength: 4,500 psi (30 MPa)



*Approx 40 to 60 lbs/cy
Steel Fiber*

AVG± SD	f_3 (psi)	f_{e3} (psi)	R_{e3} (%)
Tuf-Strand SF-3pcy	104±10	128±10	22±3
Tuf-Strand SF-5pcy	190±18	203±8	30±1
Tuf-Strand SF-7.5pcy	285±27	288±25	44±5
Tuf-Strand SF-10pcy	365±28	354±32	54±5

Statistical Correlations:

$$f_{e3} = 32.4 (\text{Dosage}) + 37$$

$$\text{Dosage} = 0.03 (f_{e3}) - 1.1$$

$$R_{e3} = 4.7 (\text{Dosage}) + 7.6$$

$$\text{Dosage} = 0.21 (R_{e3}) - 1.5$$

Solving for TUFSTRAND SF Dosage = $0.03 (f_{e3}) - 1.1$

TUFSTRAND SF Dosage Based on Statistical Correlation (See attached testing)

TUFSTRAND SF Dosage = $0.03 (f_{e3}) - 1.1$

TUFSTRAND SF Dosage = $0.03 \cdot 257 - 1.1$

Minimum Required TUFSTRAND SF Dosage = 6.61 lbs per cubic yard

Design Concepts (Suspended Sections)

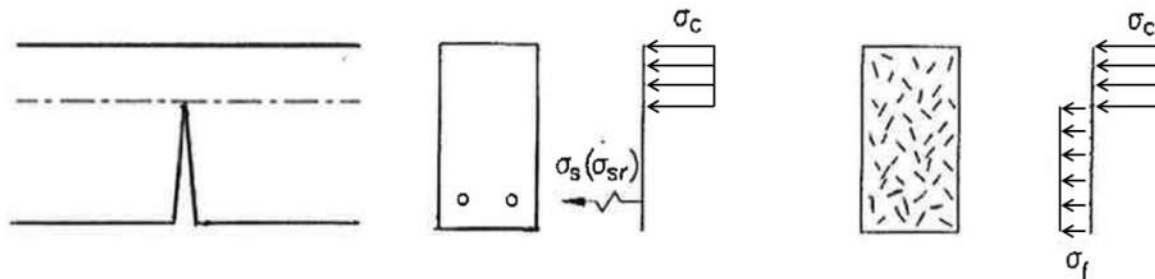
ACI 318 method for calculating moment capacity (in a cracked beam):
If fibers are substituted for steel rebar, the flexural stress is carried by fibers, called “residual stress”. The residual strength capacity of fiber-reinforced concrete may be obtained using:

Bending moment:
$$M = \phi \cdot A_s \cdot F_y \cdot \left(d - \frac{a}{2} \right)$$

Bending (flexural) strength:
$$\sigma_b = \frac{M \cdot y}{I}$$

Residual strength of FRC:
$$\sigma_{frc} = ARS \quad or \quad R_{e,3} \times f_r / 100$$

Set the two equal
(with safety factor)



Design Example (Bending Moment)

Design a 6" slab section, $f'_c=4,000$ psi with #4 rebar @16" o.c. at 3" depth. How much fiber do we need for the same flexural performance?

$$A_s = 0.147 \text{ in}^2 / \text{ft} \quad (\rho = 0.21\%)$$

$$a = \frac{A_s \cdot f_y}{0.85 f'_c \cdot b} = \frac{0.147 \times 60}{0.85 \times 4 \times 12} = 0.22"$$

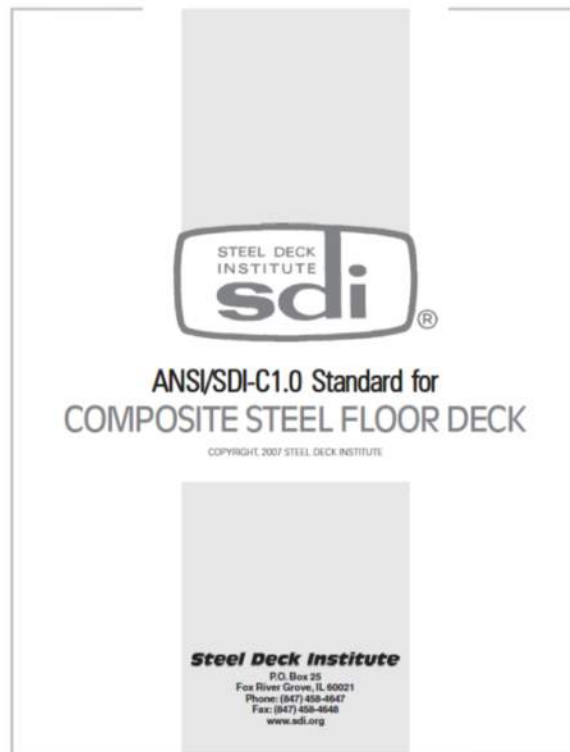
$$\phi M_{n-RC} = \phi \cdot A_s \cdot F_y \cdot \left(d - \frac{a}{2} \right) = 0.9 \times 0.147 \times 60,000 \times \left(3 - \frac{0.22}{2} \right) = 22,940 \text{ in-lb}$$

$$f_{e3} = \frac{6M}{\phi \cdot b \cdot h^2} = \frac{6 \times 22940}{0.9 \times 12 \times 6^2} = 354 \text{ psi}$$

To find the fiber dosage rate, refer to ASTM C1609 test data.

Codes and Guides

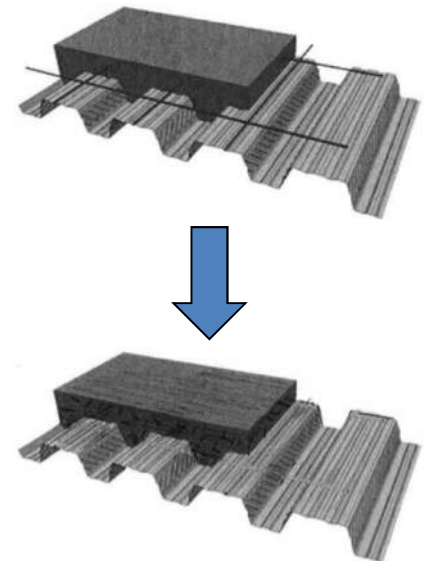
Steel Deck Institute (SDI C-1.0.) allows for using macro fibers in composite metal deck to replace wire mesh. IBC 2015 will include fiber reinforcement of this kind.



6. Reinforcement:

- a. Temperature and shrinkage reinforcement, consisting of welded wire fabric or reinforcing bars, shall have a minimum area of 0.00075 times the area of the concrete above the deck (per foot or meter of width), but shall not be less than the area provided by 6 x 6 – W1.4 x W1.4 welded wire fabric.

Fibers shall be permitted as a suitable alternative to the welded wire fabric specified for temperature and shrinkage reinforcement. Cold-drawn steel fibers meeting the criteria of ASTM A820, at a minimum addition rate of 25 lb/cu yd (14.8 kg/cu meter), or macro synthetic fibers "Coarse fibers" (per ASTM Subcommittee C09.42), made from virgin polyolefin, shall have an equivalent diameter between 0.4 mm (0.016 in.) and 1.25 mm (0.05 in.), having a minimum aspect ratio (length/equivalent diameter) of 50, at a minimum addition rate of 4 lb./cu yd (2.4 kg/m³) are suitable to be used as minimum temperature and shrinkage reinforcement.



UL Approval (Fire Resistance)

several steel and synthetic macro-fibers are now UL/ULC approved for D900 Series deck design: 2 hour un-restrained fire rating

What does this mean?

- approved material for replacement of WWF in elevated deck systems requiring a UL approval
- Applications: schools, hospitals, government, mixed-use, banks, etc.



Finishing

With proper finishing equipment, fiber reinforced slabs can be prepared as well as a conventionally reinforced slab.







Beautiful fiber floors

Exposed Floors



Design Software for FRC (steel equivalent)

SOG, CMD

TUF-STRAND SF
Tensile Strength Conversion Sheet for Slab on Grade Fiber Dosage Calculations

Instructions: Select the desired **Units of Measurement** from the "pull-down" menu. Fill in the required information in the "yellow" shaded blocks.

Note: This spreadsheet is only valid for VvM and steel designs where the thickness of the slab will support the loading conditions and the steel is located in the top half of the slab only.

Units of Measurement
Imperial/Unit (US)

Required Information: Project Description: slab on grade construction
Reinforcing Details: $\sqrt{2.9}$ VvM on 4" slab mid depth

bar diameter: 0.1943 in
bar spacing: 6.0 in
Slab Thickness, t: 3.0 in
concrete compressive strength, f'_c : 3000 psi
typical steel strength, f_s : 70000 psi

Unit width of measure, b: 12 in
Area of steel provided, A_s : 0.093 in²/ft
Steel reinforcing ratio, ρ : 0.185 %

Required Volume of TUF-STRAND SF to match: 4.1 lbs/yd

Cost Estimator: Area of slab: 405 ft²
Price of TUF-STRAND SF (installed): \$ 4.00 /lb
Estimated cost of TUF-STRAND SF solution: \$ 0.16 /ft²

TUF-STRAND SF
Bending Moment Conversion Sheet for Thin Wall & Pre-Cast Fiber Dosage Calculations

Instructions: Select the desired **Units of Measurement** from the "pull-down" menu. Fill in the required information in the "yellow" shaded blocks.

Note: This spreadsheet is only valid for VvM and steel designs where the wall or pre-cast element will undergo one-way bending only and the reinforcing is placed at mid-depth.

Units of Measurement
Imperial/Unit (US)

Required Information: Project Description: pre-cast burial vaults
Reinforcing Details: $\sqrt{2.9}$ VvM in 2.5" wall

bar diameter: 0.224 in
bar spacing: 6.0 in
Wall Thickness, t: 3.0 in
concrete compressive strength, f'_c : 4000 psi
typical steel strength, f_s : 60000 psi
depth to reinforcing (mid-depth): 1.5 in

Unit width of measure, b: 12 in
Area of steel provided, A_s : 0.078 in²/ft
Steel reinforcing ratio, ρ : 0.219 %
Gross Moment of Inertia: 27 in⁴

Required Volume of TUF-STRAND SF to match: 6.8 lbs/yd

Cost Estimator: height of wall or pre-cast product: 3 ft
Price of TUF-STRAND SF (installed): \$ 4.00 /lb
Estimated cost of TUF-STRAND SF solution: \$ 0.75 /linear ft

**Residential walls,
precast,
shotcrete**



TUF-STRAND **SF**

Slab Design Parameters

Units: **Imperial (US)** Metric

Bar Diameter	W2.9
Bar Spacing	6
Slab Thickness	6
Concrete Strength	4000
Steel Strength	60 (Most Common)

Submit

Instructions Slab Design Wall Design

Bar Diameter W2.9
Bar Spacing 6
Slab Thickness 6
Concrete Strength 4000

Required Volume of TUF-STRAND SF to match:

3.0 lbs/yd

Close

TUF-STRAND **SF**

Slab Design Parameters

Units: **Imperial (US)** Metric

Bar Diameter	#4
Bar Spacing	12
Slab Thickness	6
Concrete Strength	4000
Steel Strength	60 (Most Common)

Submit

Instructions Slab Design Wall Design

Bar Diameter #4
Bar Spacing 12
Slab Thickness 6
Concrete Strength 4000

Required Volume of TUF-STRAND SF to match:

5.8 lbs/yd

Close

Design Software for FRC (full design)

Euclid Chemical Company: New Project [C:\Documents and Settings\allusers\My Documents\Euclid\TUF-STRAND...

File Edit Project View Help

SI Imp

New Project

- Loading Zone 1
 - Vehicle Load

Find Dosage

Compressive Strength [f_c]: 4500.00 psi

Ultimate Flexural Strength [F_f]: 484.73 psi

Modulus of Elasticity [E]: 3427543.84 psi

Subgrade Modulus [k]: 200.00 pci

Friction Coefficient: 1.60 Gravel

Load Factor: 1.2

Dynamic Factor: 1.4

Pour Conditions: ☒ Interior ☐ Exterior

Concrete Shrinkage Strain:
 RH > 80% 65% 50% 35% RH < 20%
 Typical Outdoor Typical Indoor

Average Relative Humidity (RH) Level:

Thickness of Slab [t]: 11.00 in

Column Spacing: 1000.00 ft

Contraction Joint Spacing: 25.00 ft

Temperature Difference: 9.00 F

Vehicle Load

Wheel Configuration: Single Axle Quad

Axle Load [P]: 150000.00 lb

Axle Distance [S]: 144.00 in

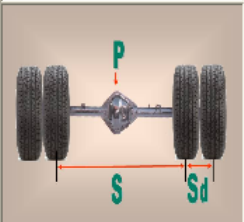
Contact Pressure: 188.00 psi

✓ Corner/Edge Check?

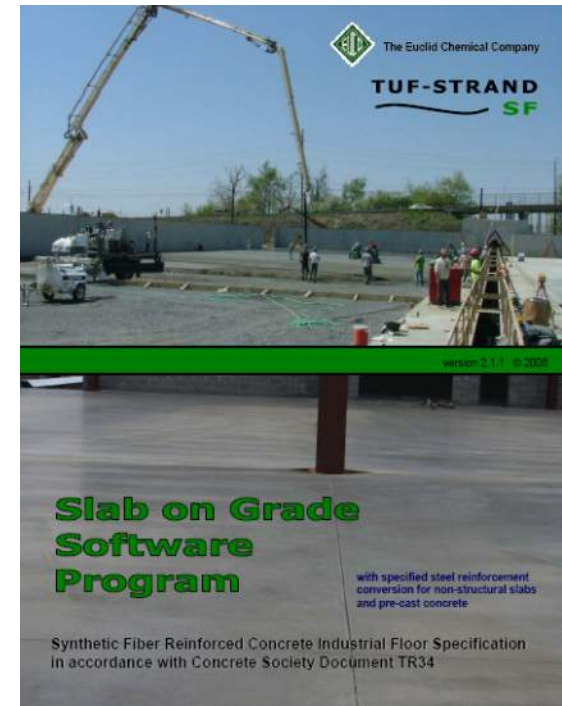
Sd: 30.00 in

Contact Area: 823.61 in²

SLAB



Offered for free, will be available online soon!



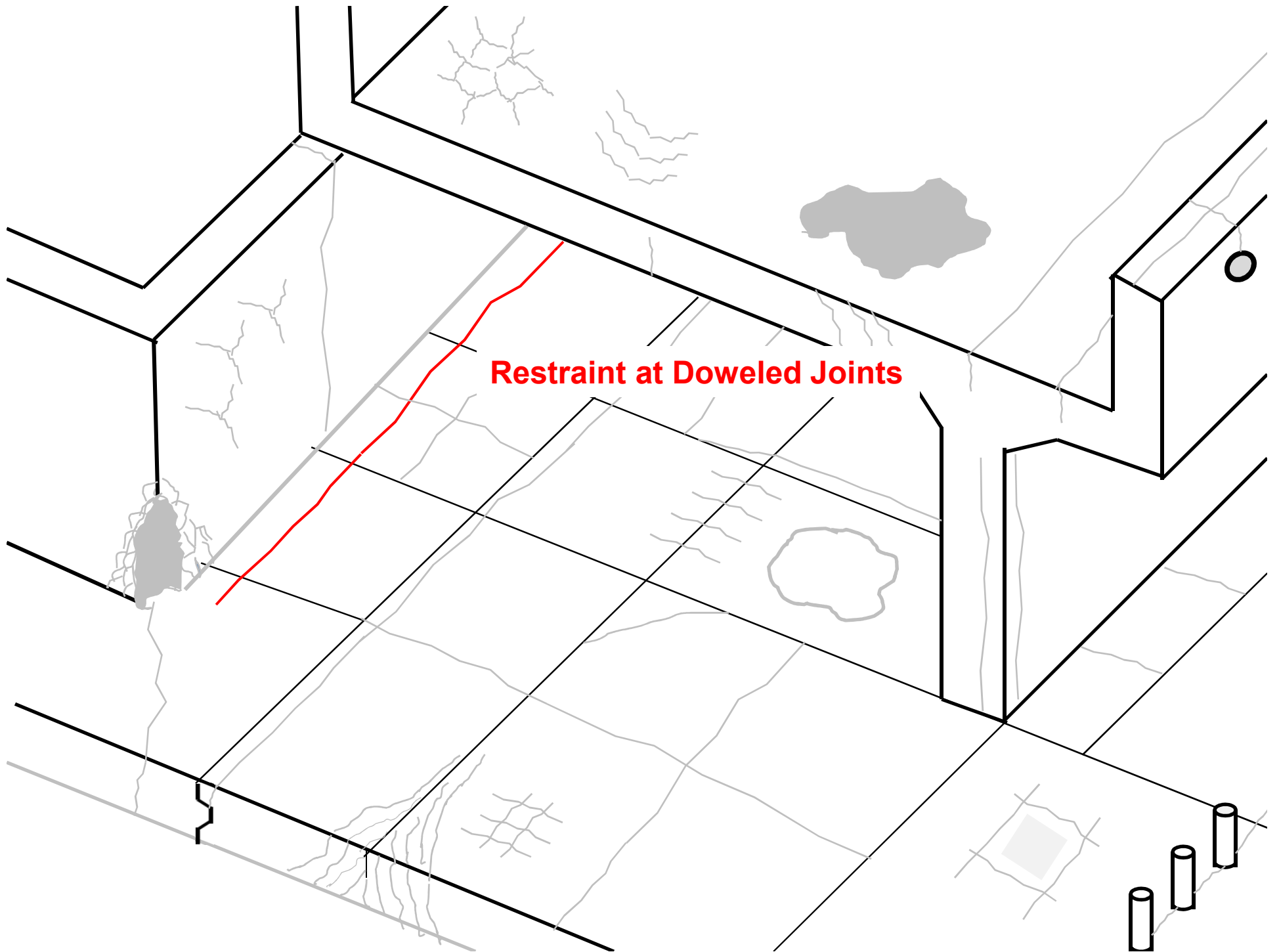
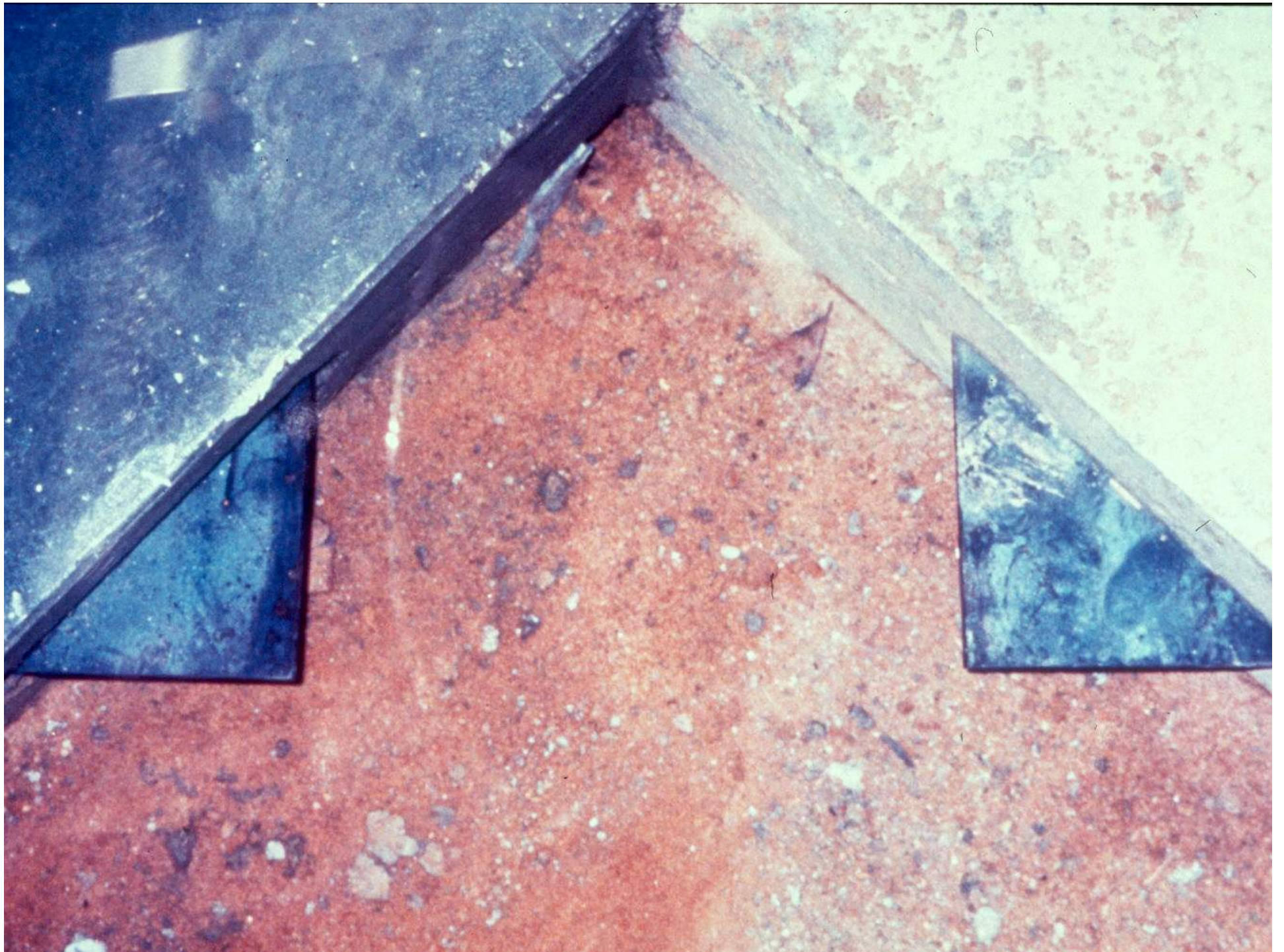
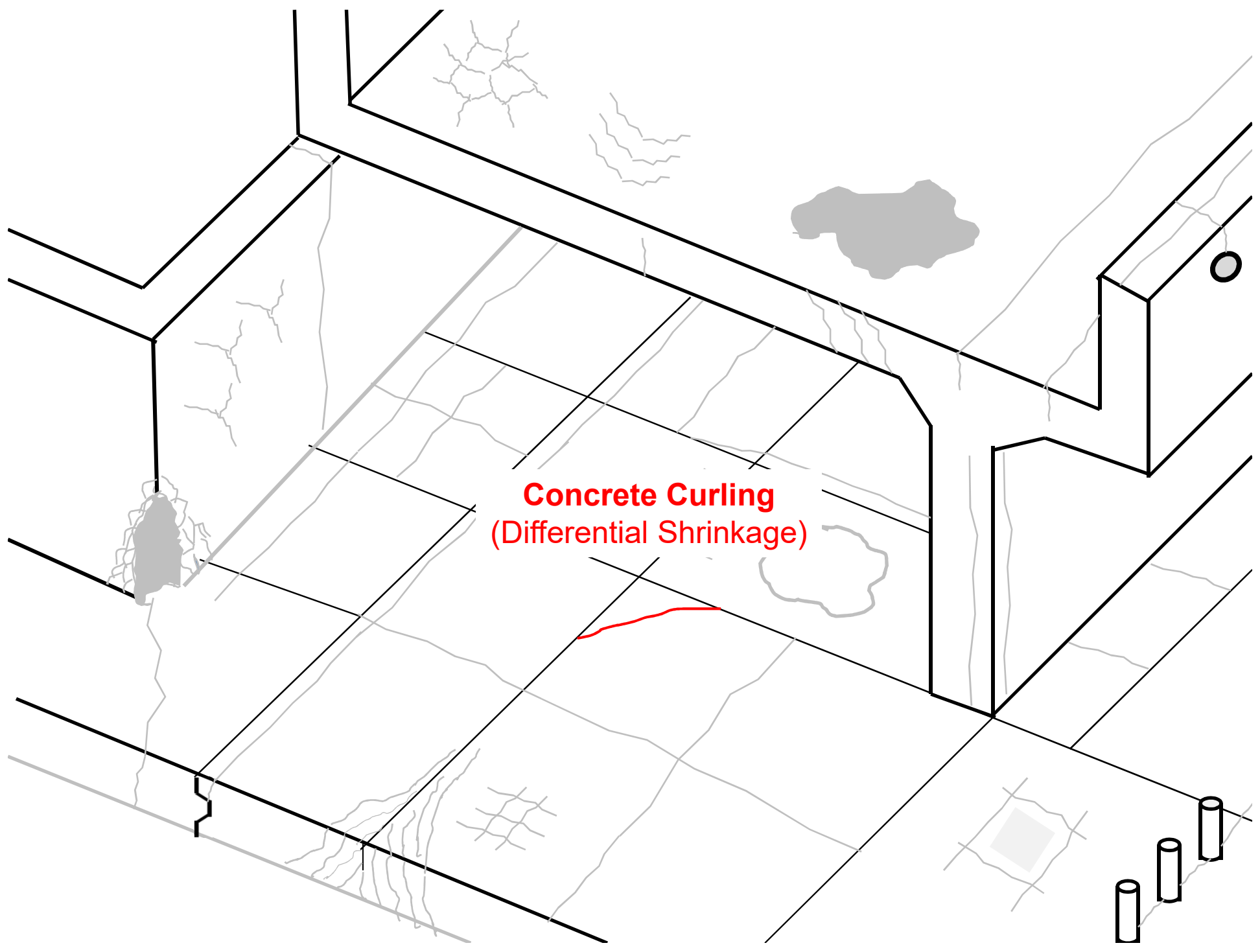




PLATE DOWELS LOAD TRANSFER







Concrete Curling
(Differential Shrinkage)

Identification:

- Typically located near joint intersections





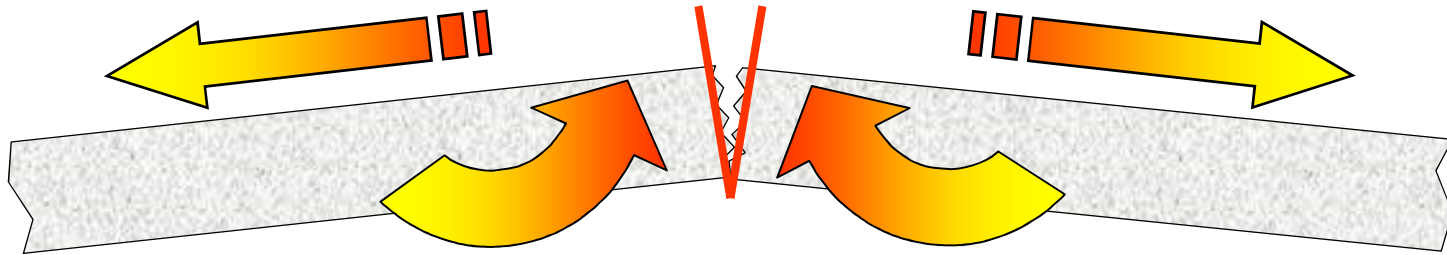




Curling

Caused by differential shrinkage

Panel edges lift resulting in cracking and uneven joints

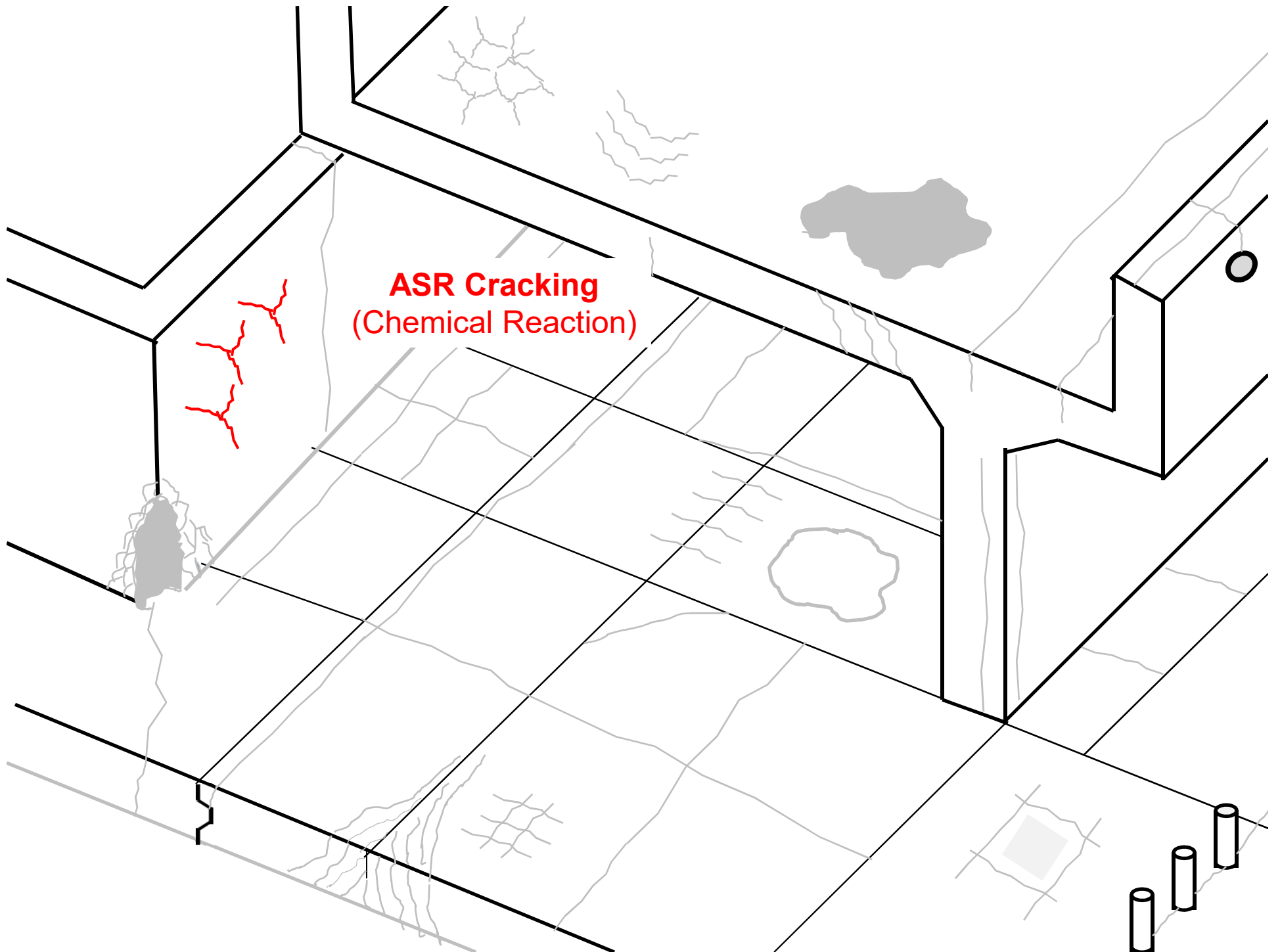


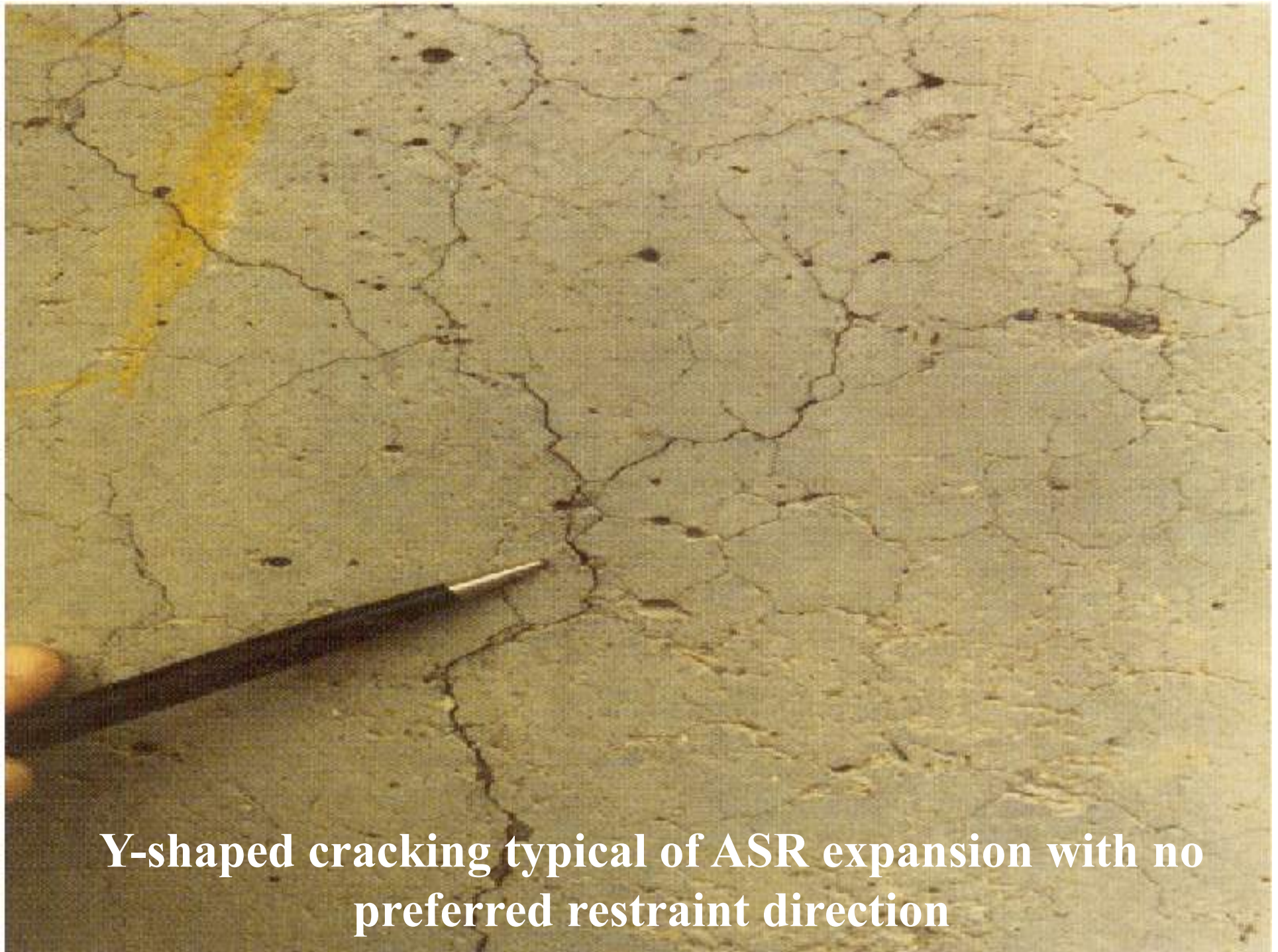
Prevention

- Reduce shrinkage
- Reduce differential shrinkage

Remedy

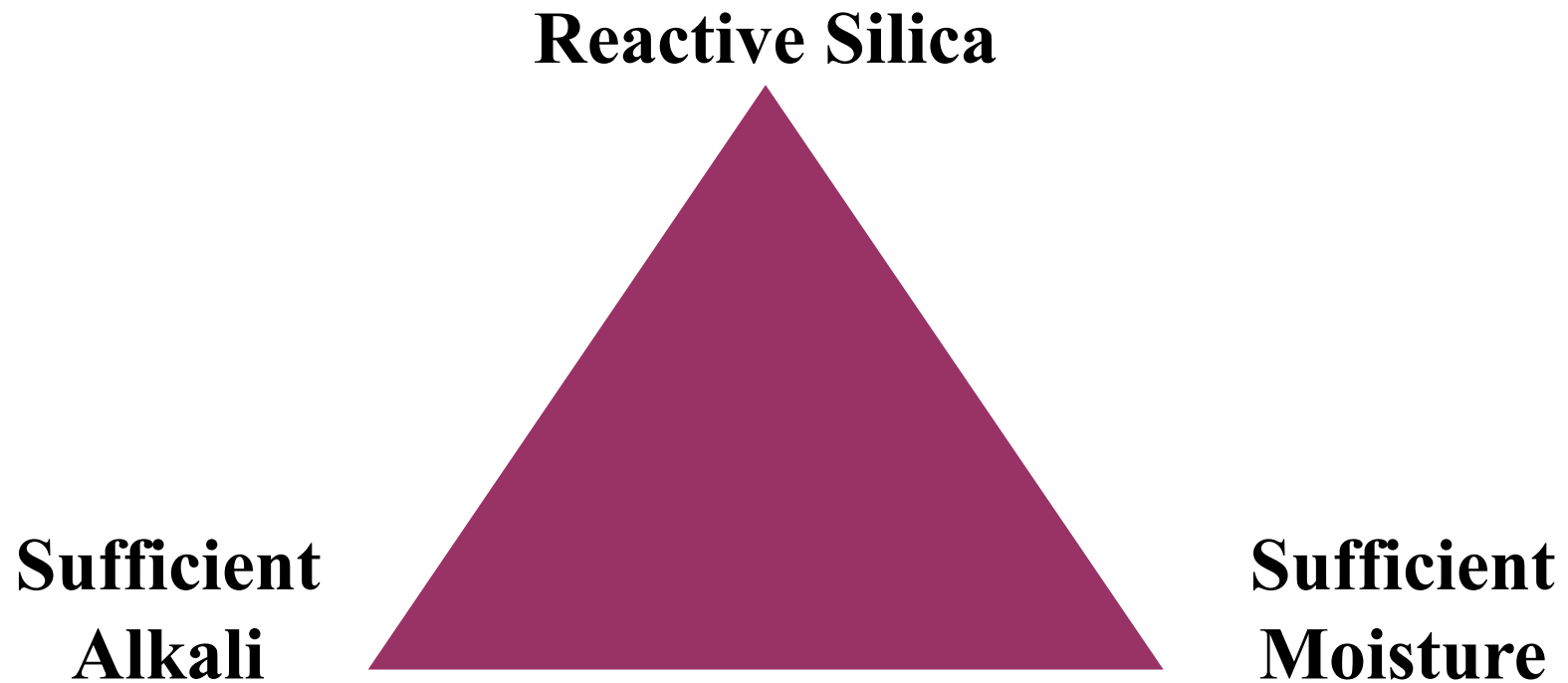
- Grinding
- Grout jacking



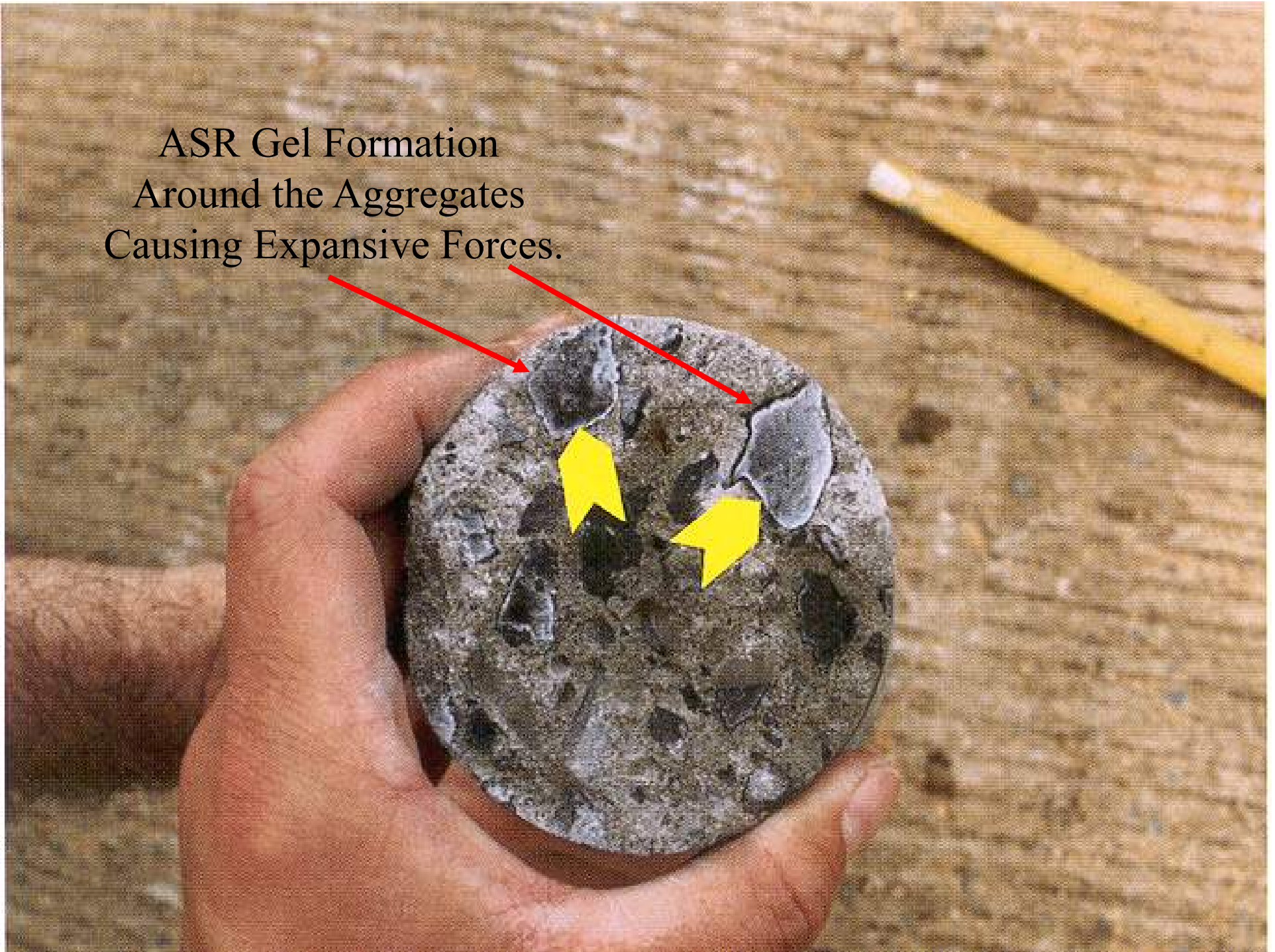


Y-shaped cracking typical of ASR expansion with no preferred restraint direction

Three Necessities of ASR



ASR Gel Formation
Around the Aggregates
Causing Expansive Forces.



**This Airport concrete was approximately
14 years old when it had to be removed
and replaced due to ASR**





ASR PREVENTION

- Utilize Non-Reactive Aggregates
 - Fly Ash to Reduce Alkalis in Concrete Mix
 - ASR Admixture
 - Lithium Nitrate based
 - Effective control of ASR when aggregate sources are determined to be reactive
 - The Lithium Nitrate combines with/neutralizes the alkalis making them unavailable to react
 - Prevent Moisture Penetration
- 



ASR Remedies

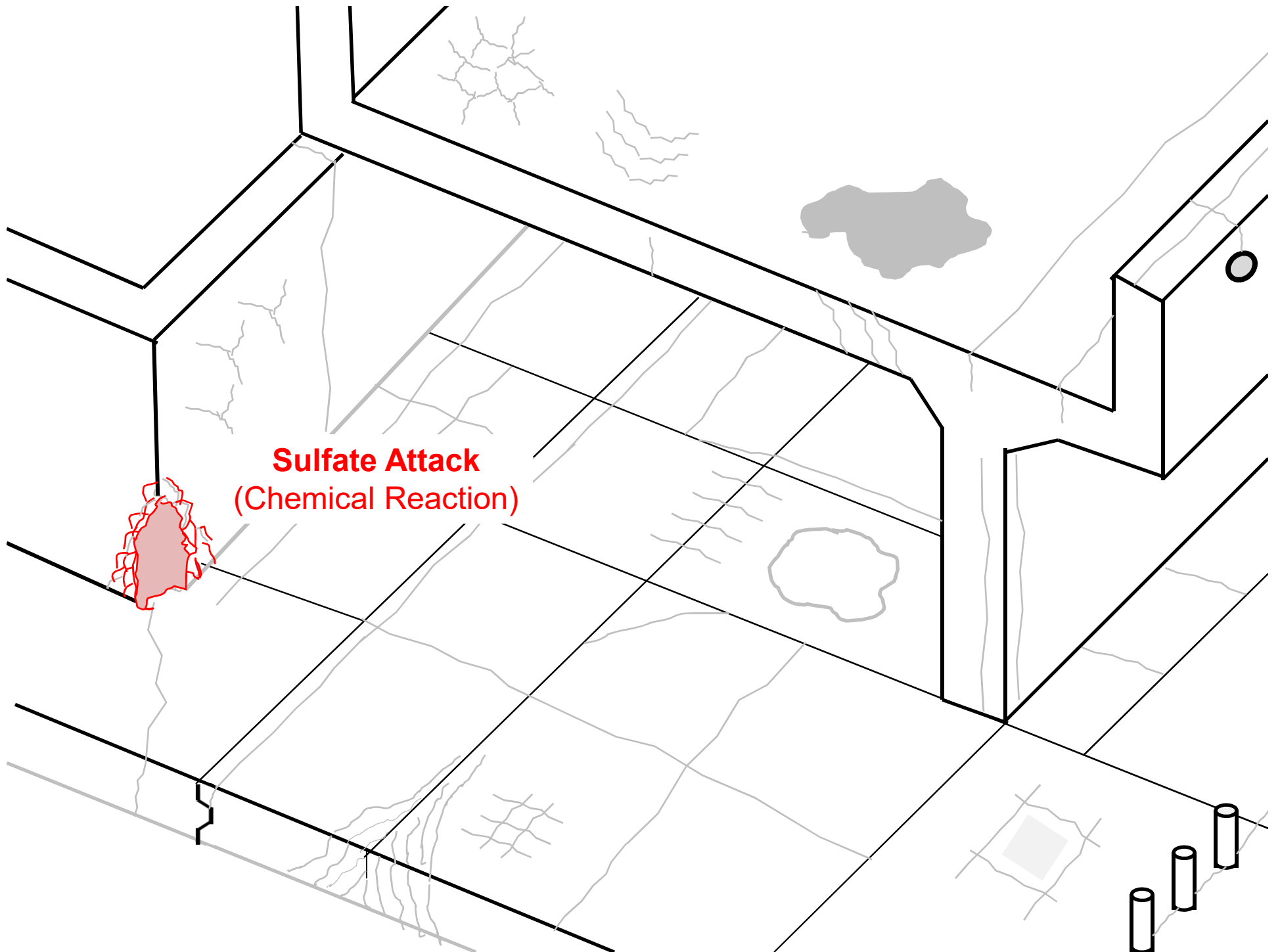
- **Determine through petrographic analysis**
- **Very difficult to remedy**
- Reduce or eliminate moisture intrusion to stop reaction
 - Sealers and Coatings
- Topically Applied Lithium Nitrate



ASR REMEDY



- Determined through petrographic analysis
- Surface Preparation
- Typically Applied Lithium Nitrate
- Bonding Agent
- Repair Material – Sloped to Edges
- Curing/Sealing Compound

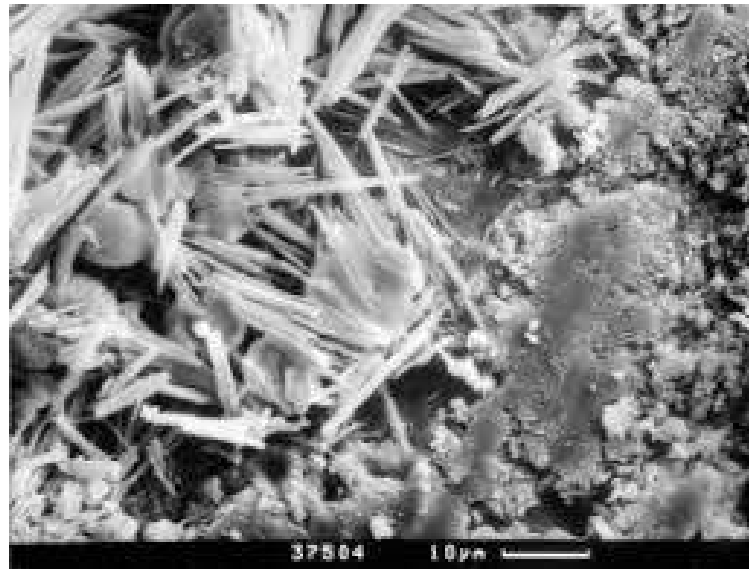




Sulfate attack is often evidenced by bloom of sulfate sodium sulfate salts on surface.

Sulfate Attack on Concrete

- **Cause**
 - Sulfates come into contact with hydrated calcium aluminate in hydrated cement paste and react to form calcium sulfoaluminate resulting in expansive forces within concrete paste.



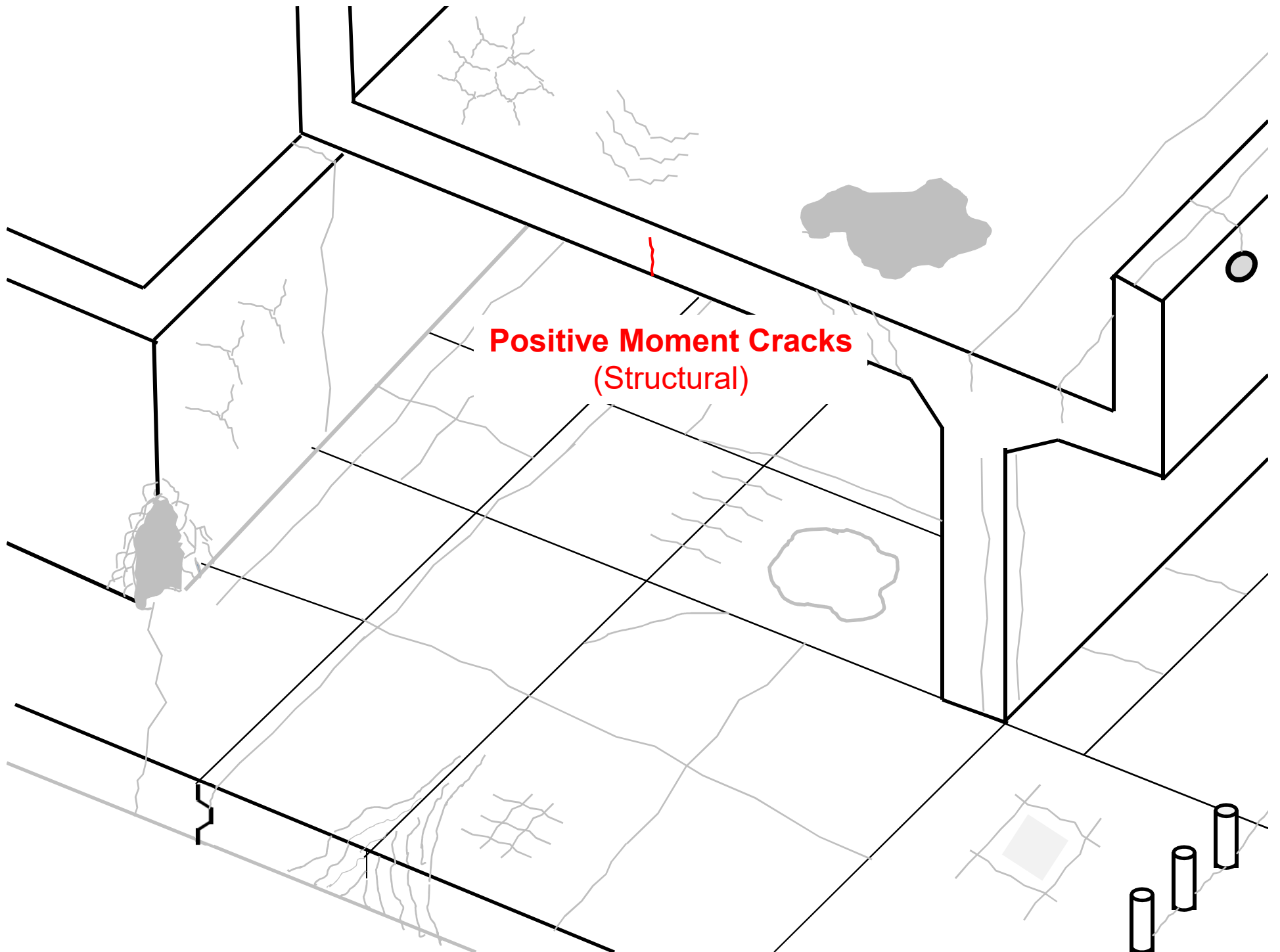
Sulfate Attack on Concrete

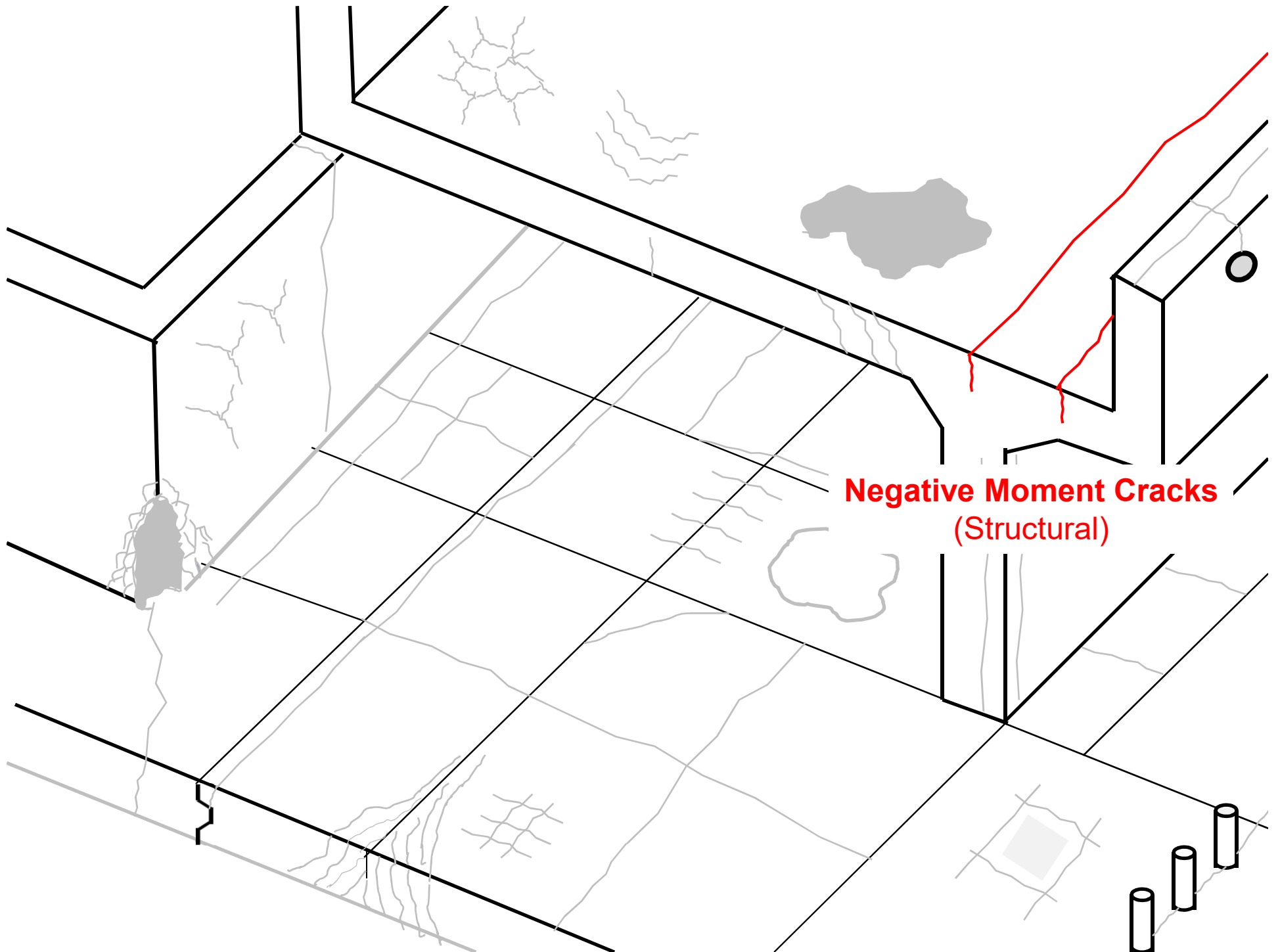
- **PREVENTION:**

- Utilize types II or V portland cement which are low in tricalcium aluminate. Reduces formation of calcium sulfoaluminate.
- Protect concrete from sulfate exposure with chemical resistant coatings such as epoxy

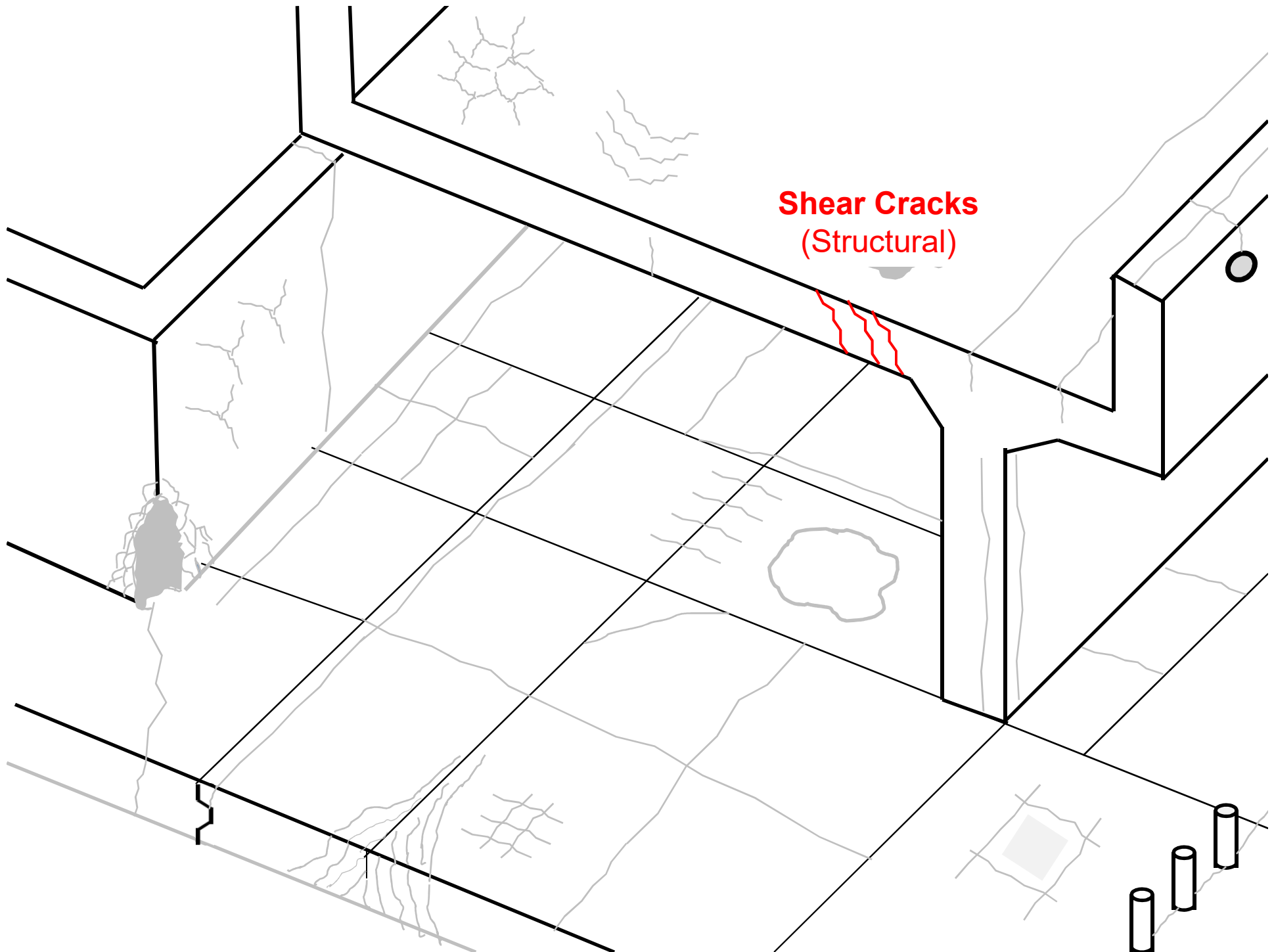
- **REMEDIES:**

- Repair with sulfate resistant repair mortars and protect with chemical resistant coatings





Negative Moment Cracks
(Structural)









<https://www.eeri.org/wp-content/uploads/Shear-cracks-in-beam-near-main-stairways.jpg>

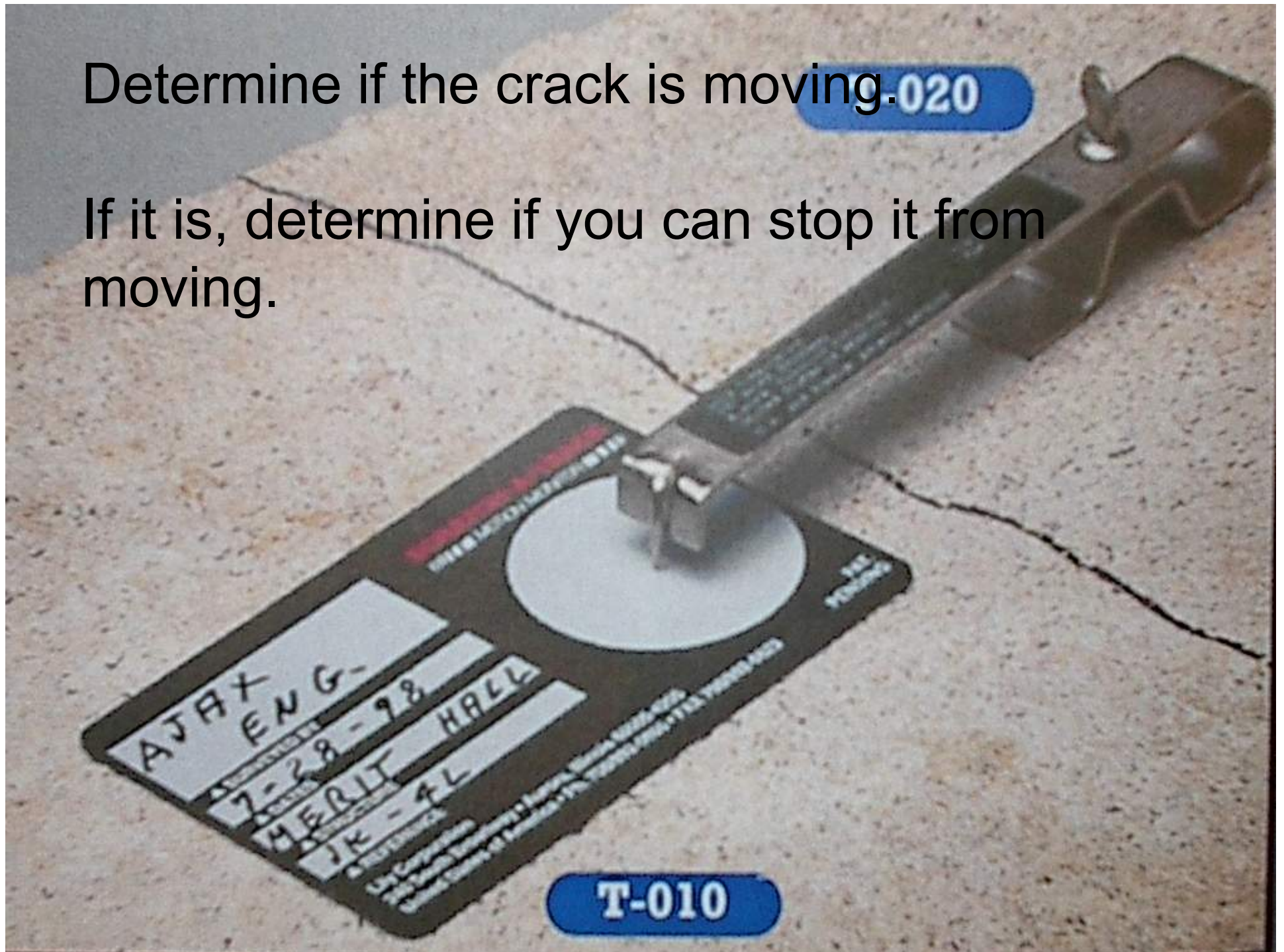
05.09.2012 15:27

Causes of Cracks Due to Overload

- Loads Exceed Design Strengths of Members
- Loads Applied Before Concrete Reaches Design Strength
- Improper Transport and Placement (Precast)
- Construction Overloads
 - Heavy Equipment
 - Storage of Materials

Determine if the crack is moving.020

If it is, determine if you can stop it from moving.





Epoxy Crack Injection

CARBON FIBER WRAP

**Carbon
Fiber**

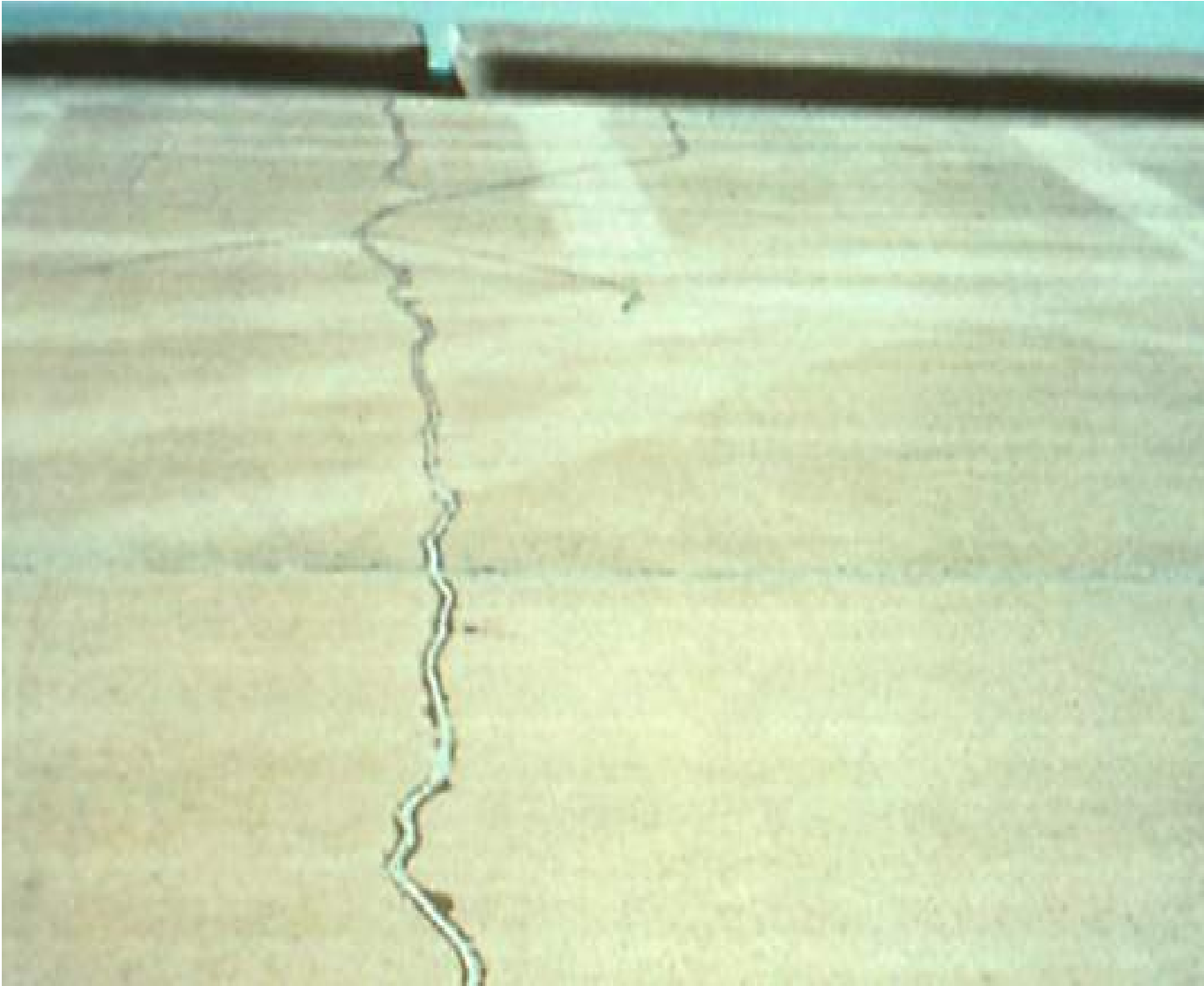




This is not Carbon Fiber Wrap!!



MOVING CRACK REMEDY



Flexible sealants and crack fillers are used to seal against intrusion of foreign materials and liquids.

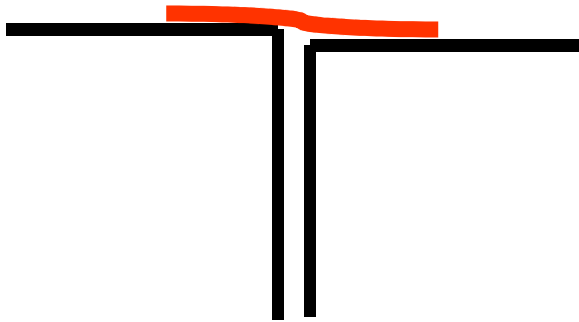
Moving Joint/Crack Tape

1. Surface preparation
2. Cover joint with bond breaking tape
3. Apply first layer epoxy adhesive
4. Remove bond breaking tape
5. Press tape into the fresh adhesive
6. Apply a second layer of bond breaking tape
7. Apply covering layer of adhesive
8. Remove bond breaking tape
9. If necessary, cover tape with protective material

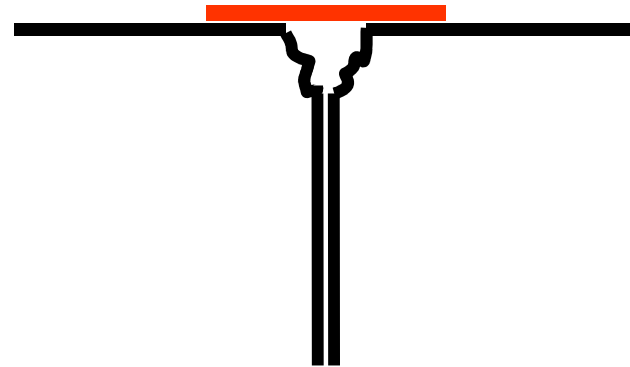


Moving Joint/Crack Tape - Typical Applications

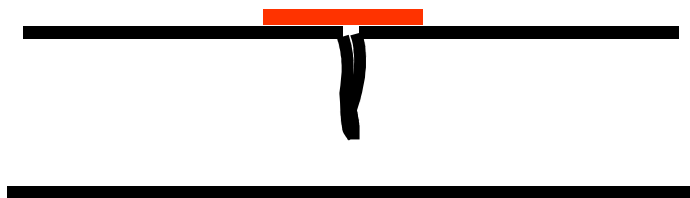
uneven joints/cracks



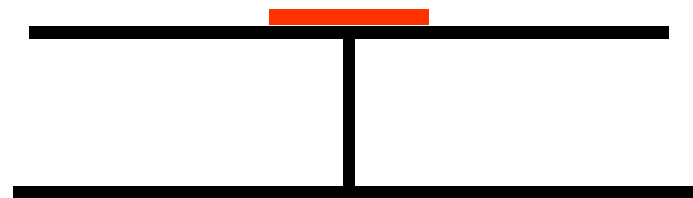
broken joints/cracks



cracks

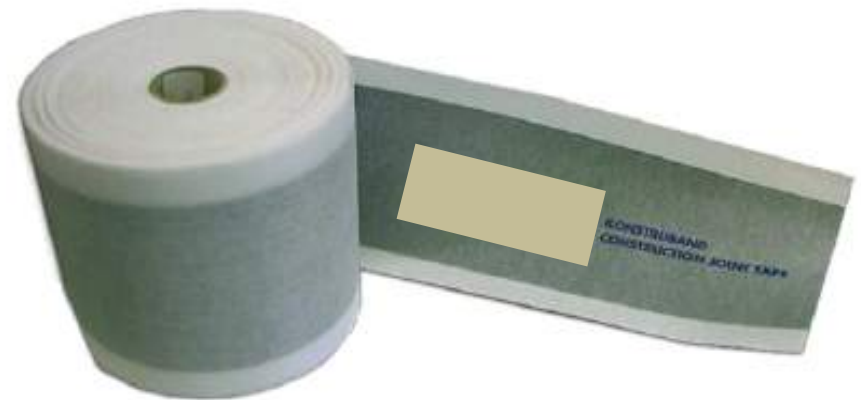


construction joints

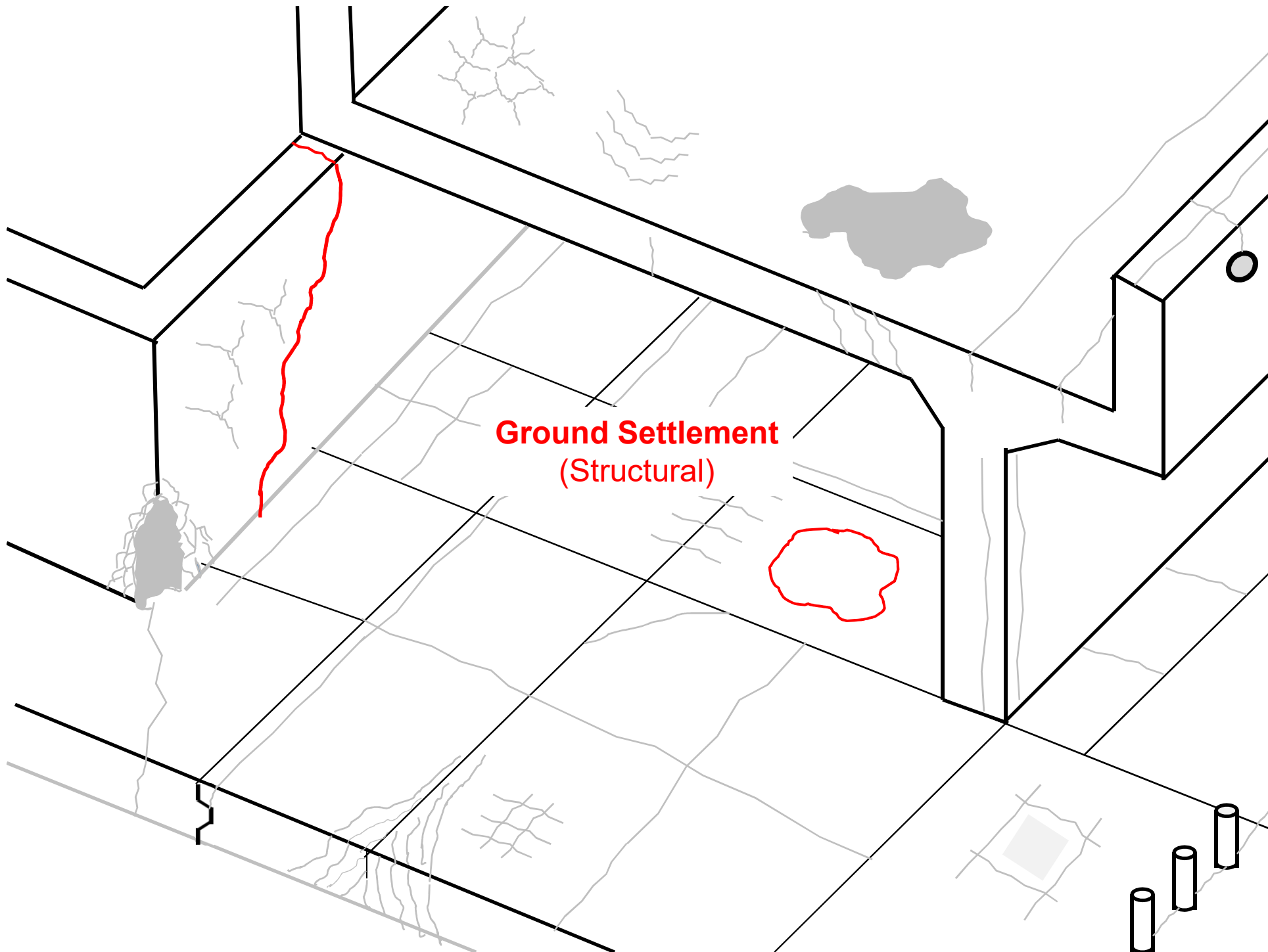




Over 500 lf of tape was installed over cracks to waterproof this pool in Tucson and then it was covered with pool plaster.



PS: It costs considerably less than epoxy crack injection.





(C) 2007 Daniel Friedman www.inspect-ny.com

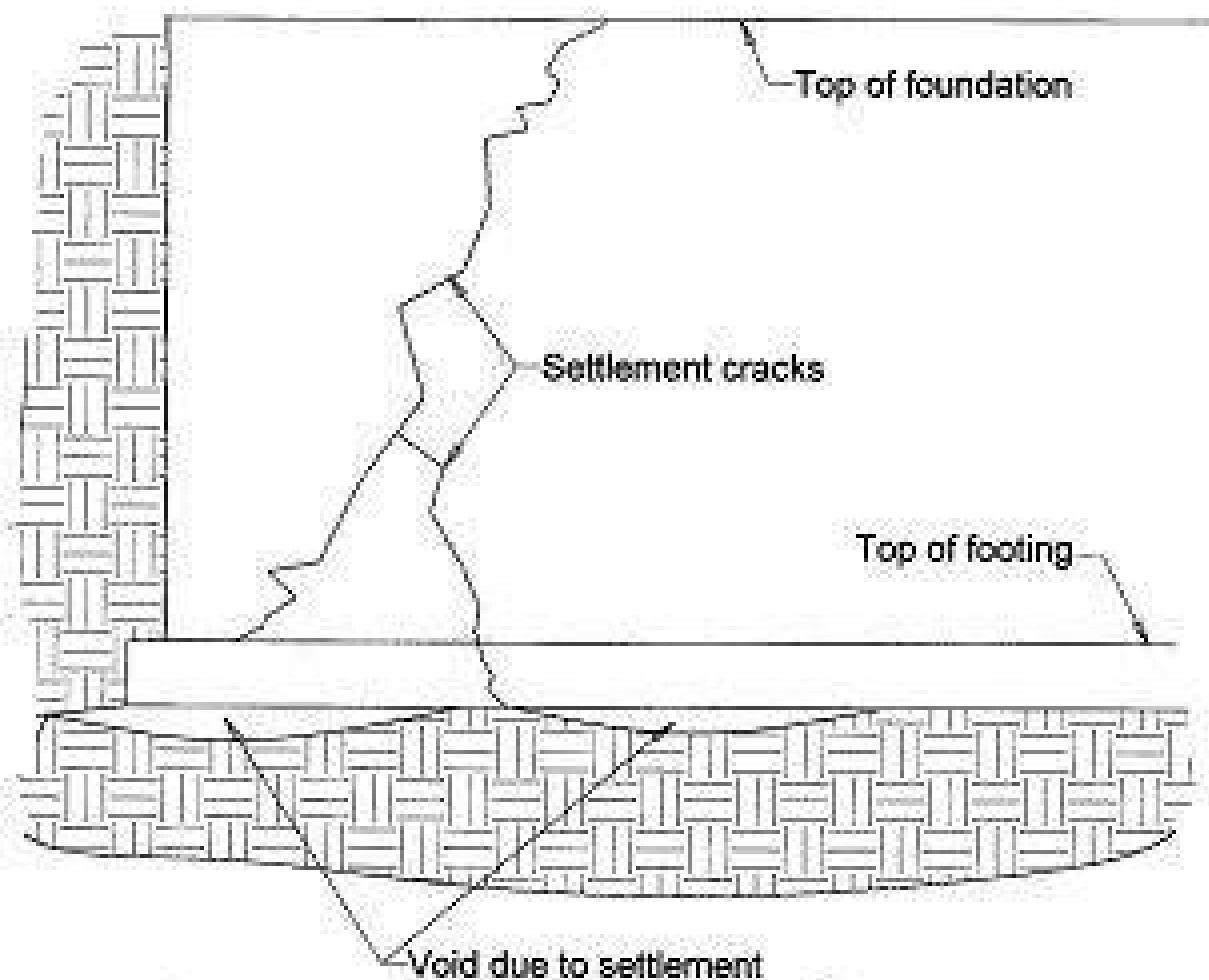
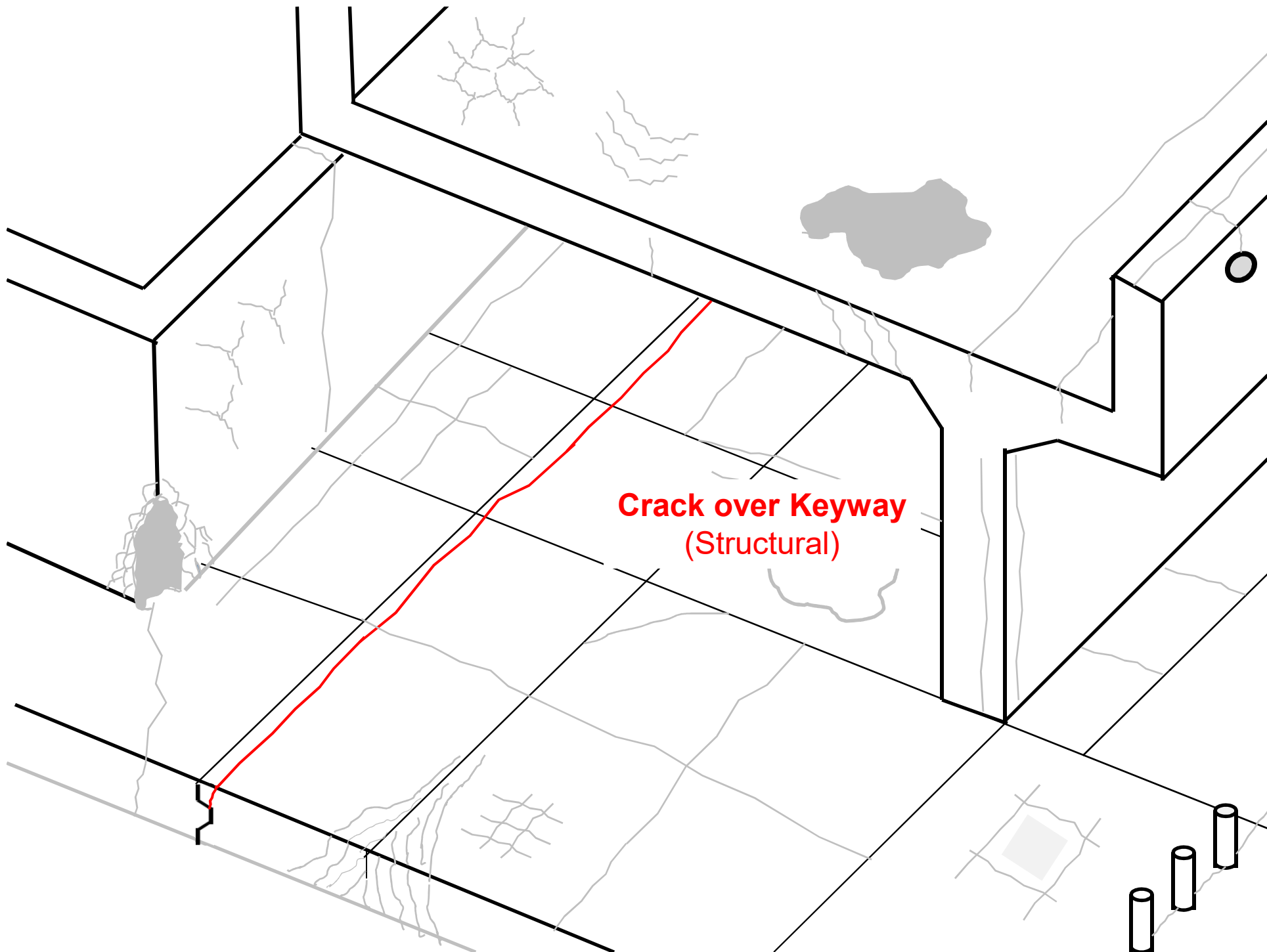


FIGURE 22

© all-concrete-cement.com



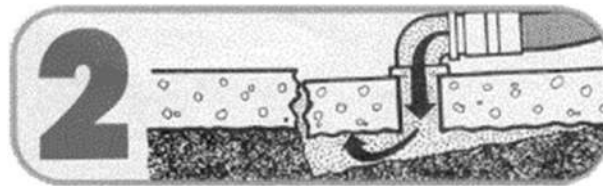
Settlement Cracks

- **PREVENTION:**

- Properly compacted substrate
- Proper design

- **REMEDIES:**

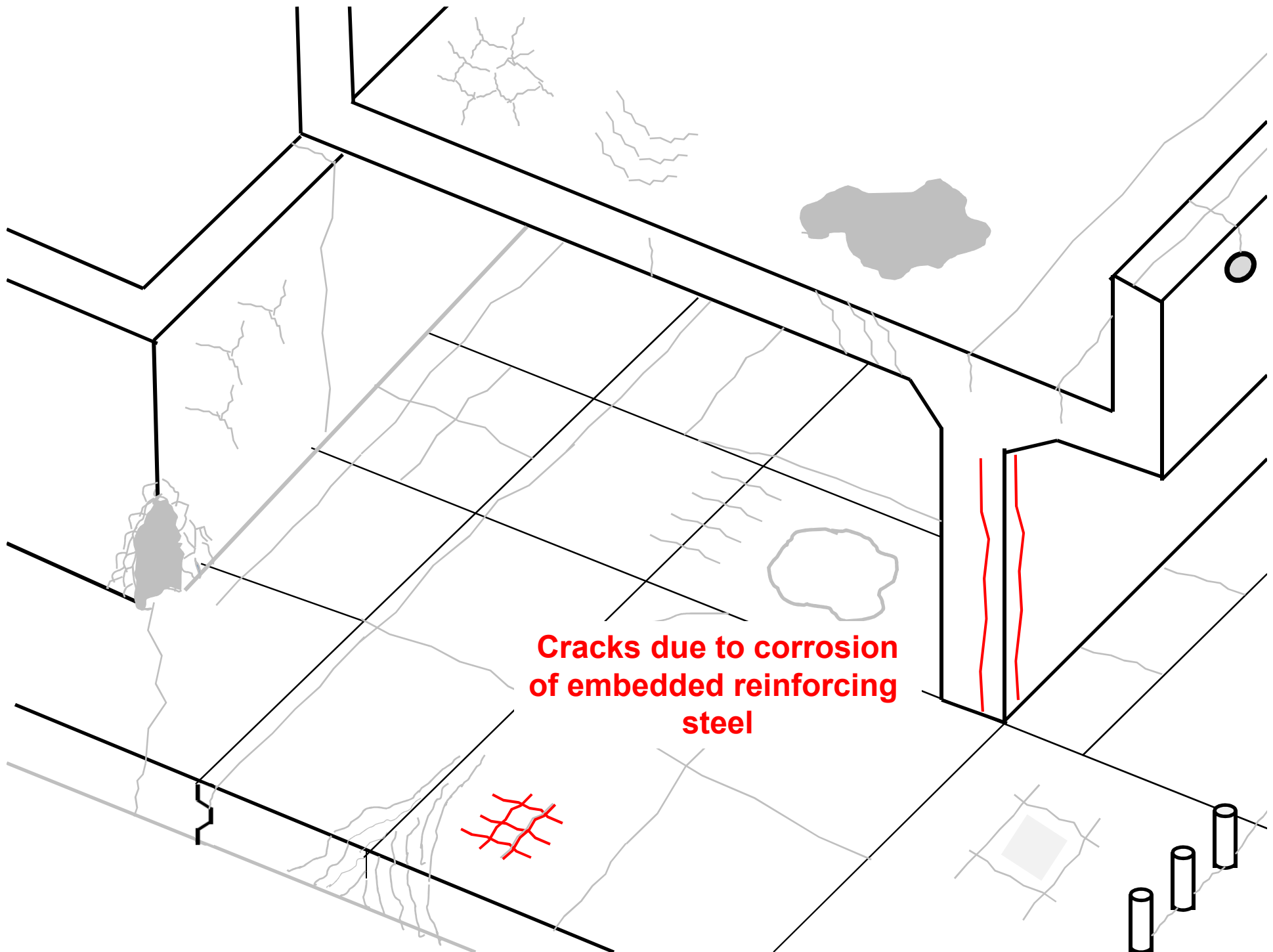
- Gravity feed epoxy or epoxy injection combined with “Slab Jacking” or “Soil Grouting”



REMEDY

**Aesthetic
crack, gouge,
and small
spall repairs**







Corrosion of Concrete Reinforcing Steel

Expands 400% to 900%

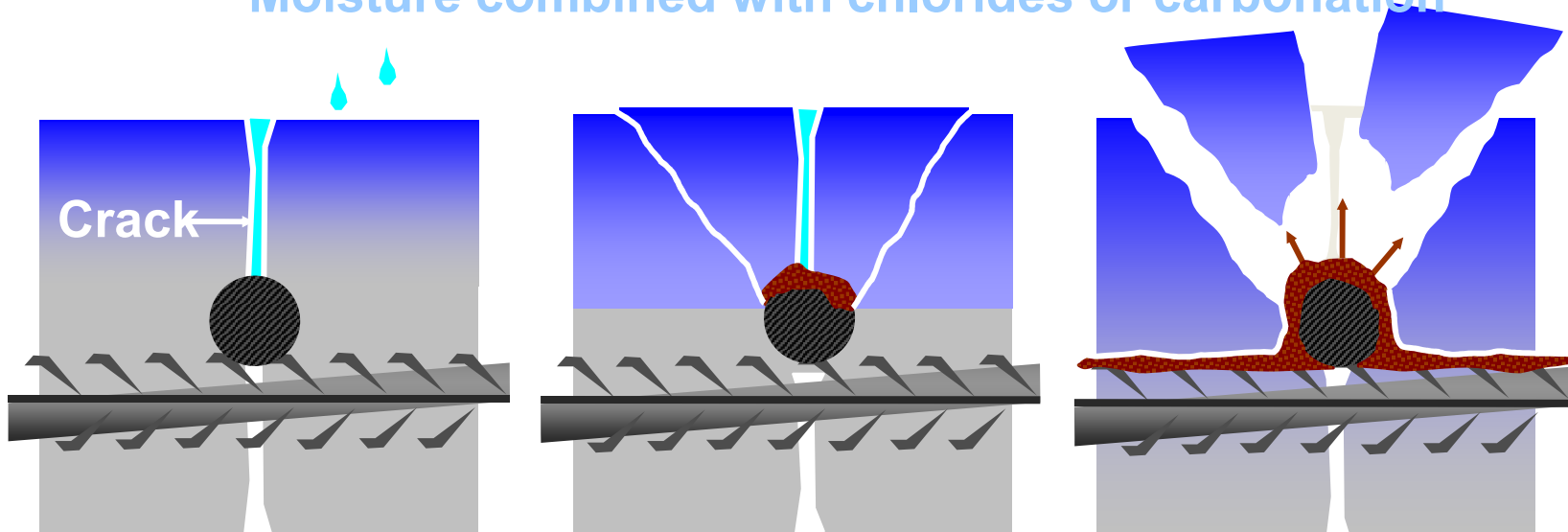
Lose bond

Delamination

Lose cross sectional area

Lose load bearing capacity

Moisture combined with chlorides or carbonation





Prevention of Cracking Due to Corrosion

- Low Permeability Concrete
 - Adequate Concrete Cover
 - Sealers and Coatings
 - Corrosion Inhibiting Admixtures
- 

Prevention of Corrosion

Corrosion Inhibiting Admixtures:

Calcium Nitrite at 2-6 gal/yd³ reacts

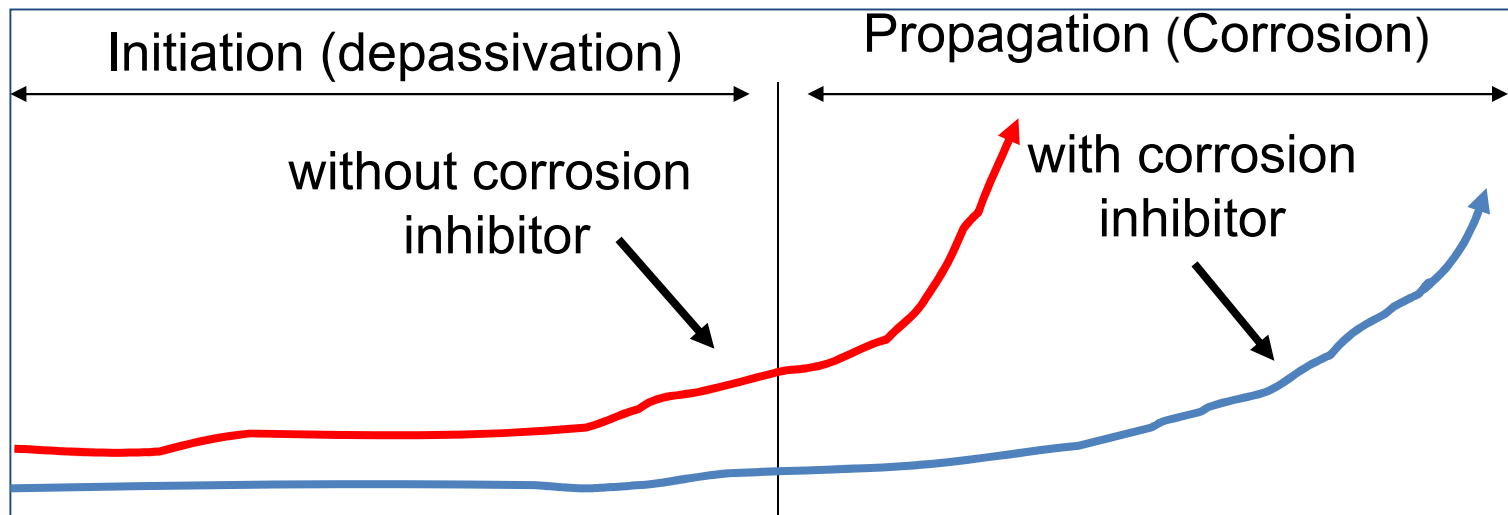
Creates a passive layer

Prevents reactions with the ferrous ions

Delays onset of corrosion

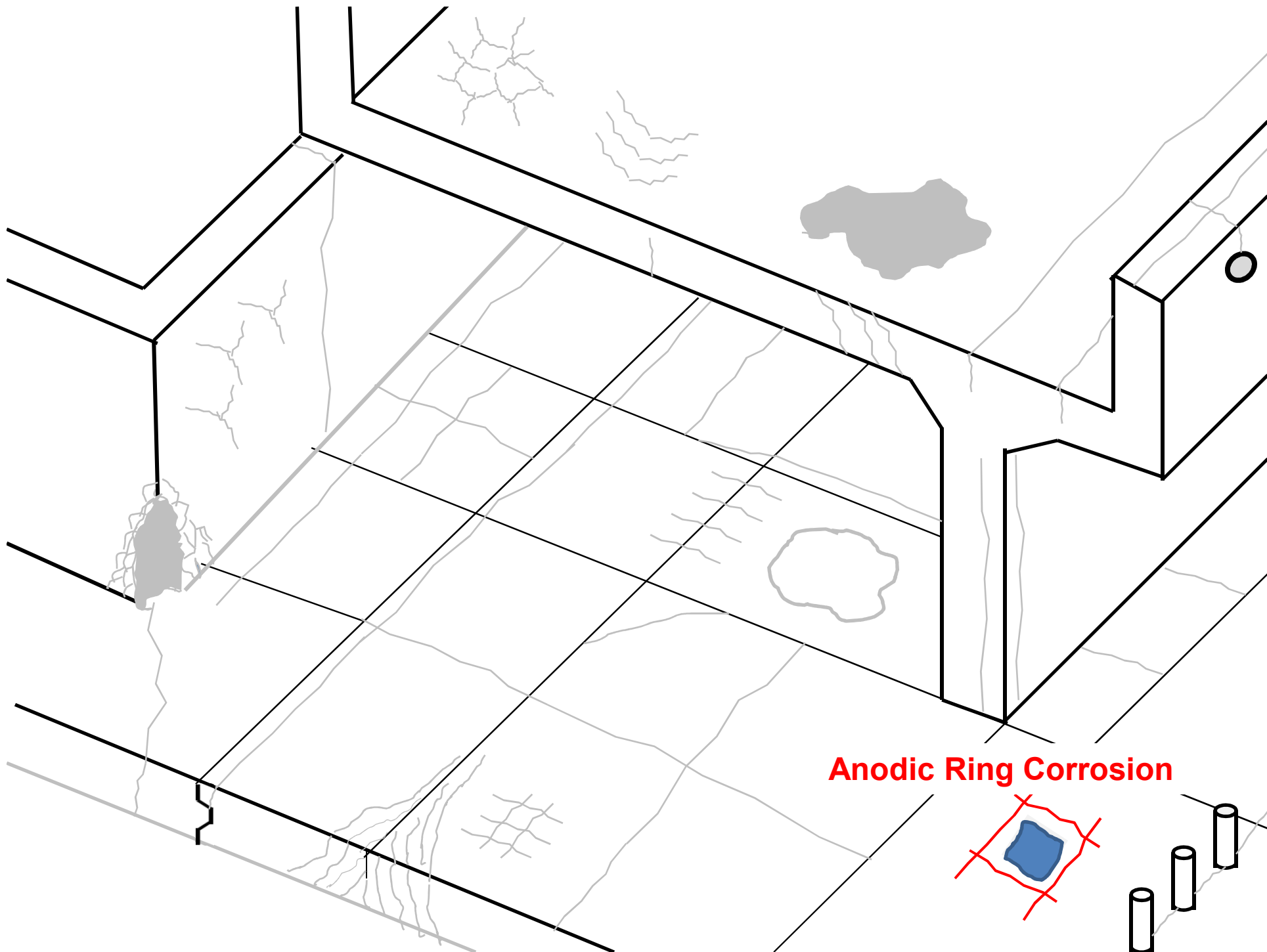
Decreases rate of corrosion

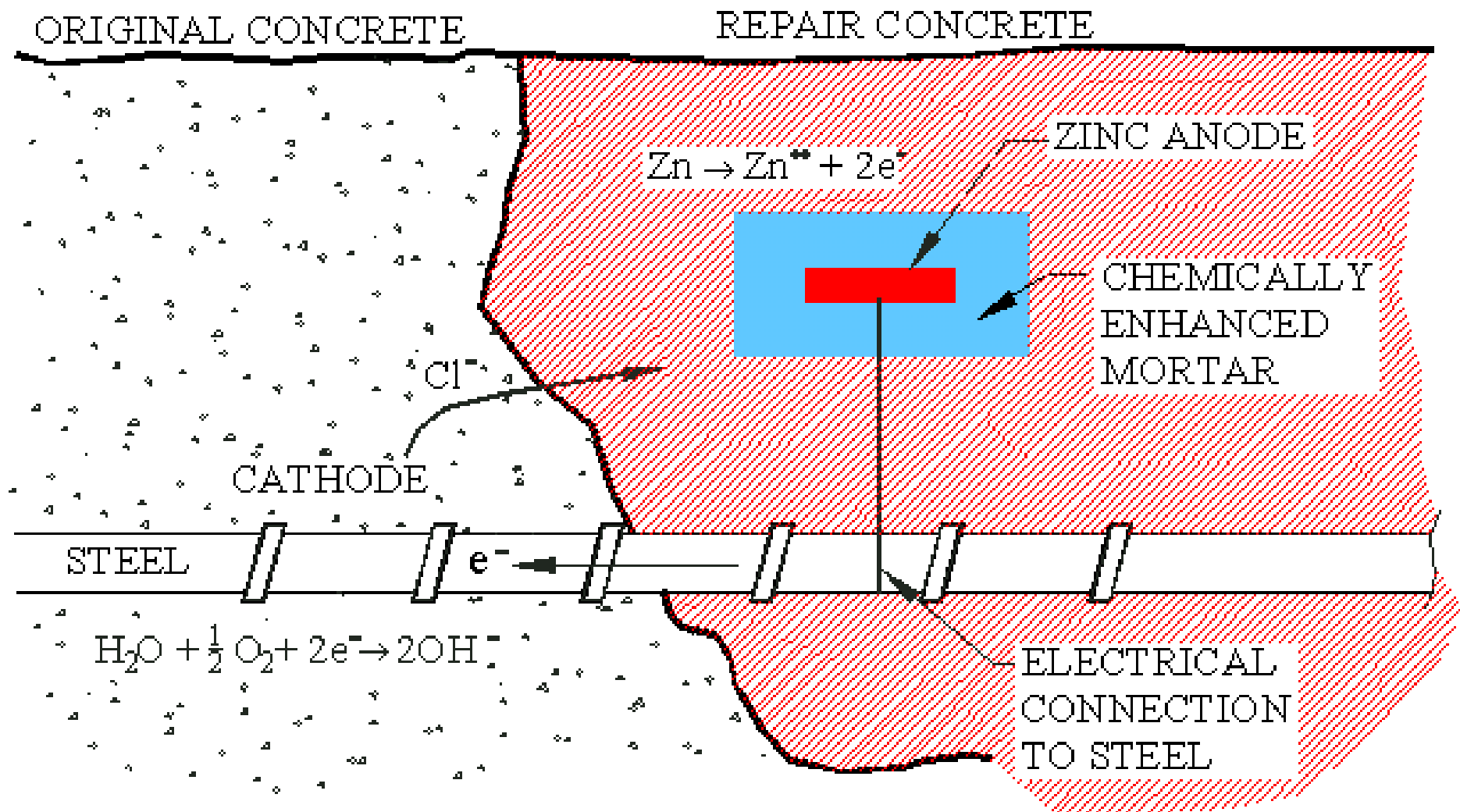
Increases svc life of structure



REMEDY

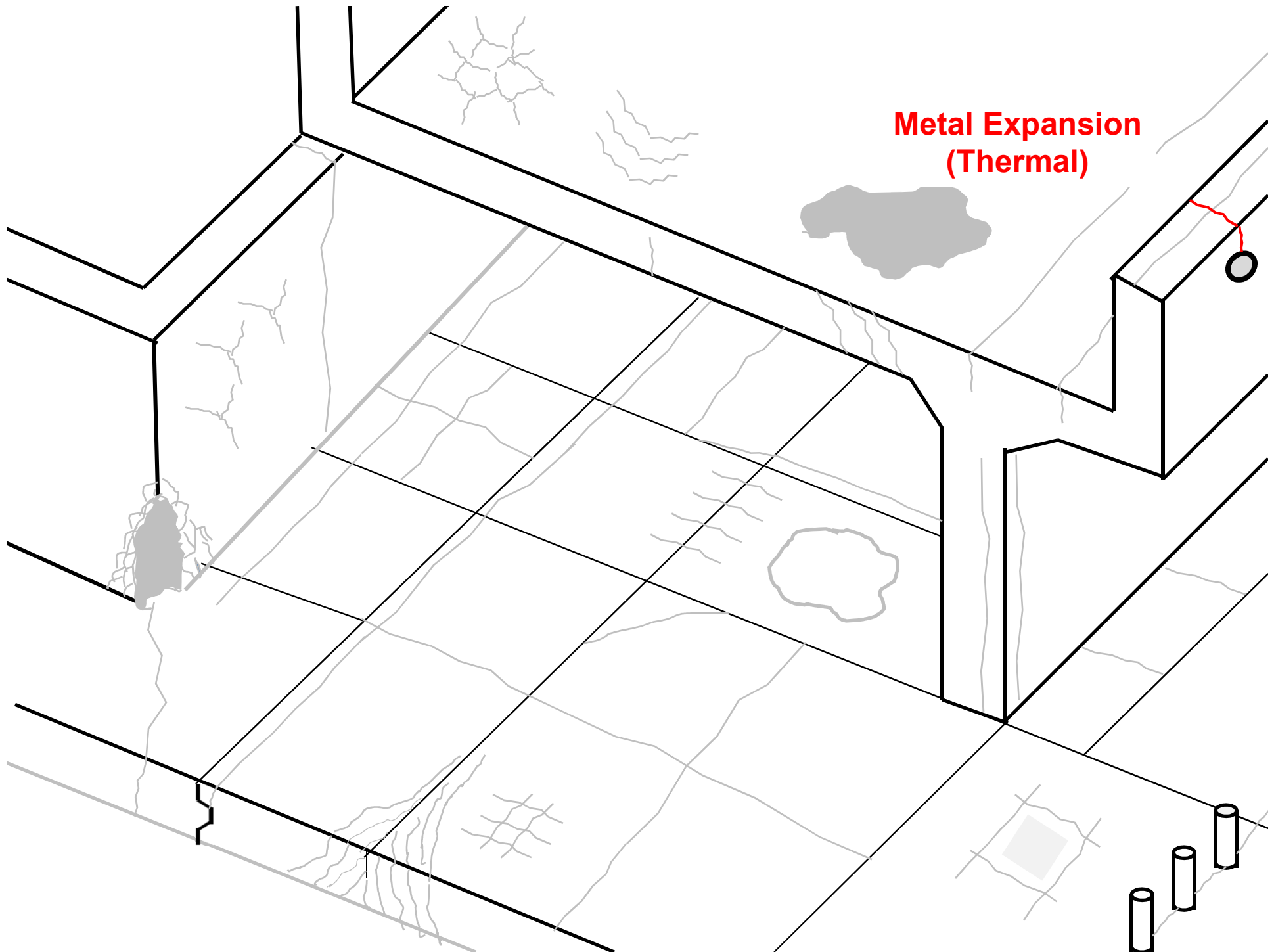






Embedded Zinc Anode for Repairs

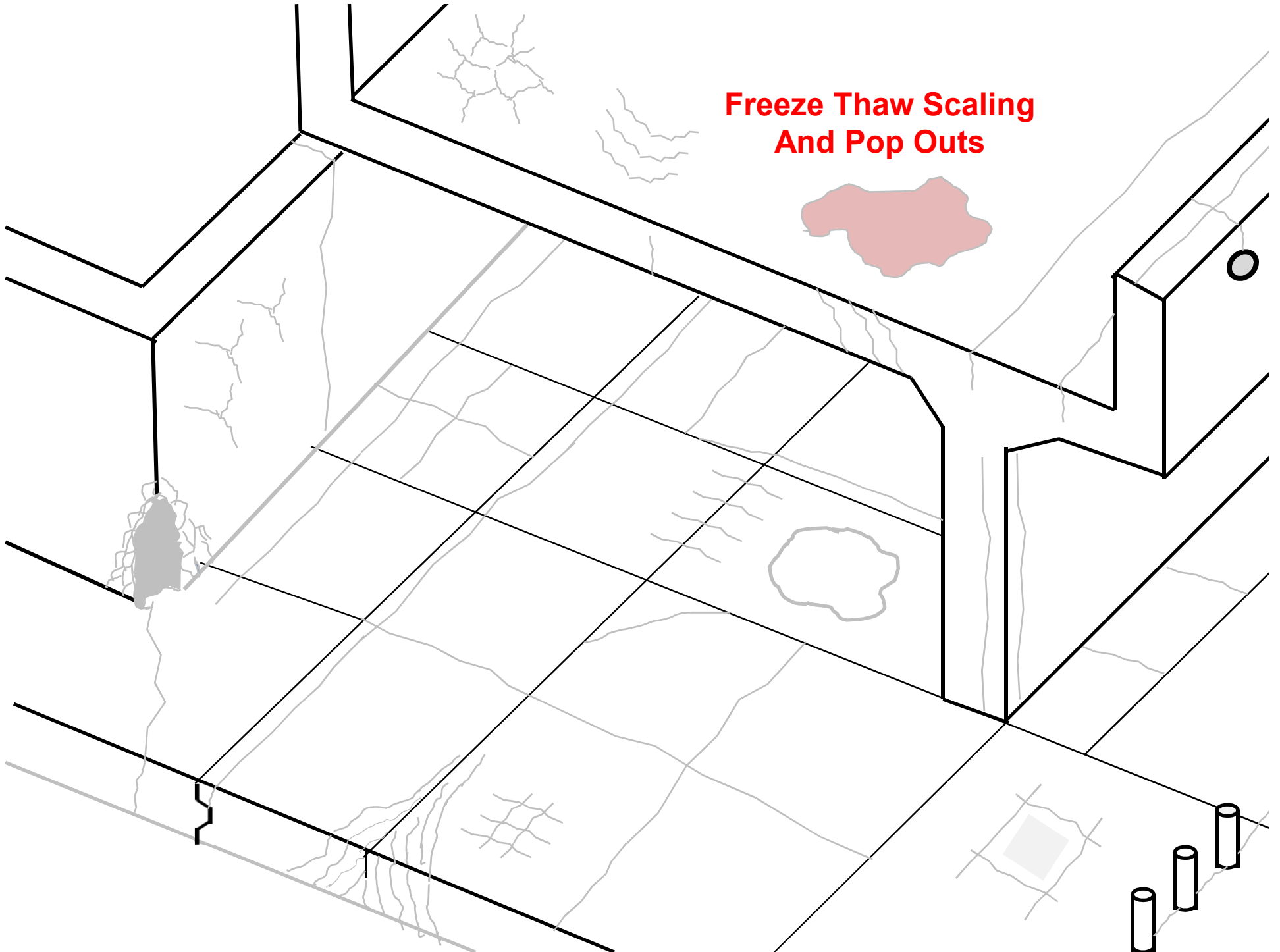




**Repair the
concrete leaving
space for the steel
tube to expand.**



Freeze Thaw Scaling And Pop Outs



Freeze Thaw Scaling

- **Causes:**

- Laminar cracking due to freeze thaw stresses.
- Improper Air Content

- **Prevention:**

- Proper air content
- Proper w/c ratio
- Proper cure
- Protect surface with cure and seal or penetrating sealer

- **Remedy:**

- Re-Surface
- Tear Out



Aggregate Pop Outs

CAUSE:

- Soft absorbent aggregate at surface becomes saturated. Freeze thaw stresses cause fracturing of aggregate.

PREVENTION:

- Specify quality aggregates per ASTM C33. Designate Class 4S or 5S.
- Utilize cure and seal or penetrating sealer to reduce absorption.

REMEDY:

- Excavate aggregate and patch hole.



POP-OUTS

Symptoms:

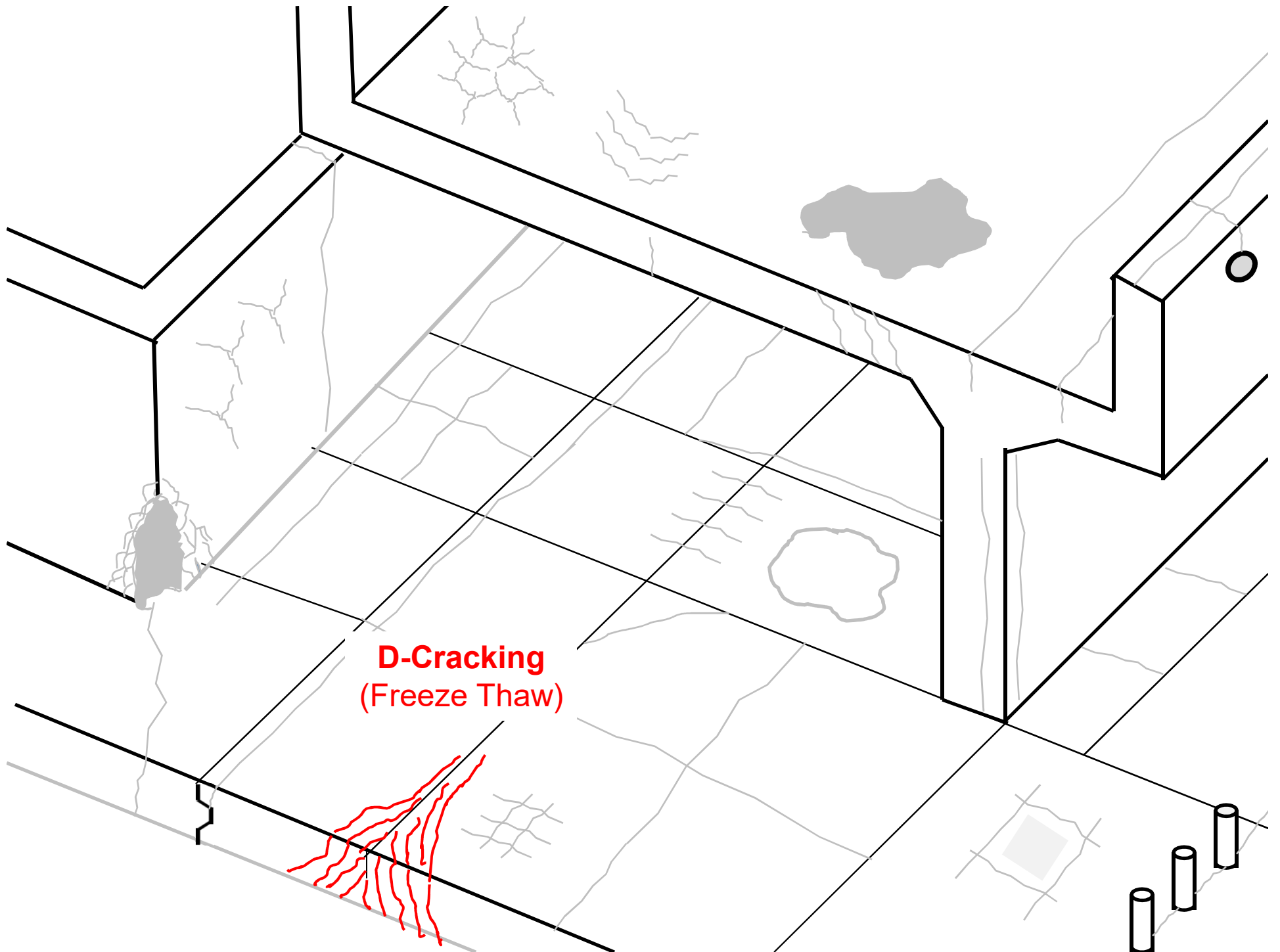
- “Pop” or “Chip” in the concrete surface of exterior concrete, leaving a piece of porous aggregate exposed.

Cause:

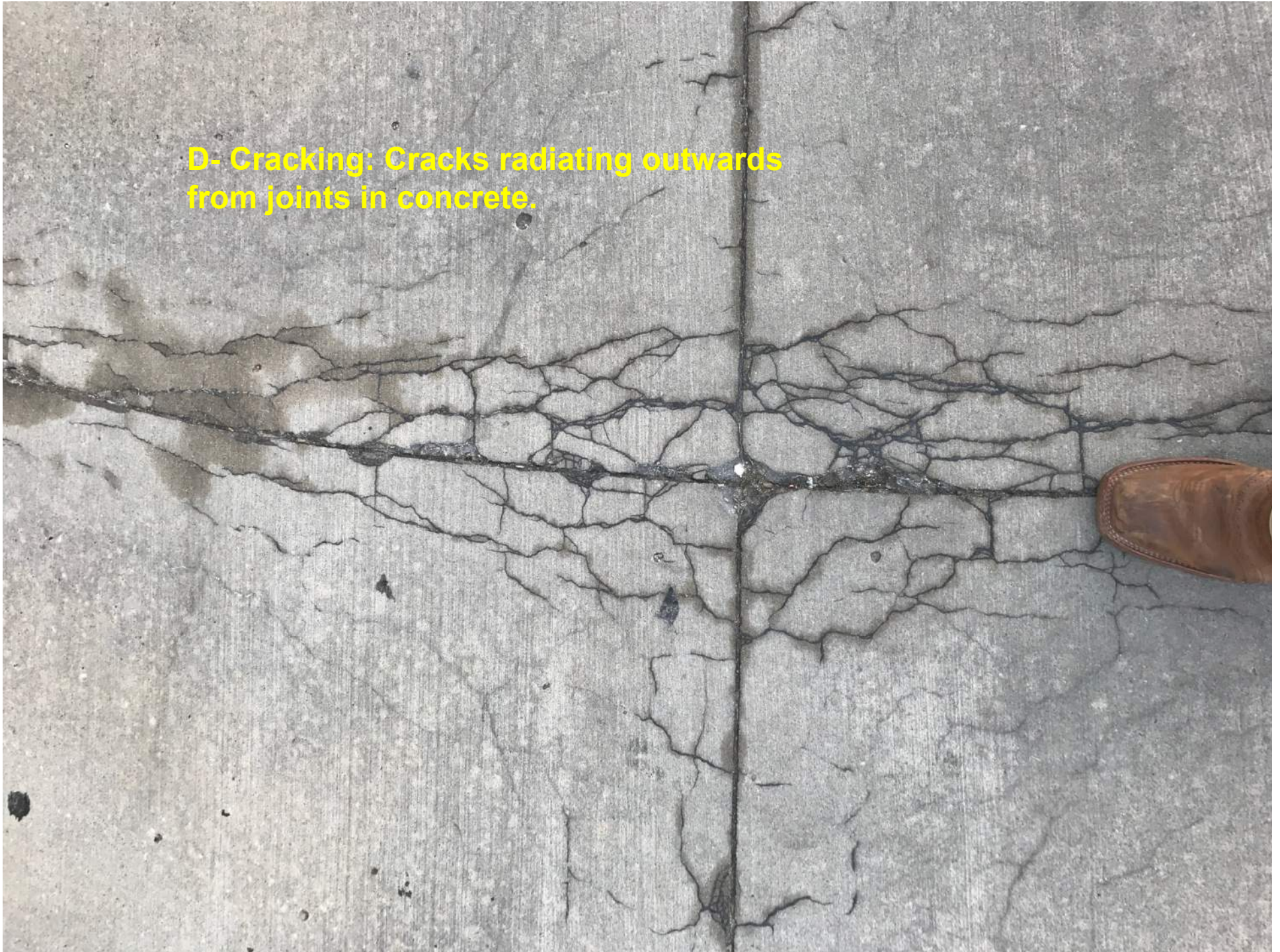
- Soft aggregates, within the concrete surface, absorb moisture. This moisture freezes, causing expansive stresses that fracture the concrete surface.

Remedy:

Excavate soft aggregate and repair with mortar.
Protect from moisture intrusion



**D- Cracking: Cracks radiating outwards
from joints in concrete.**

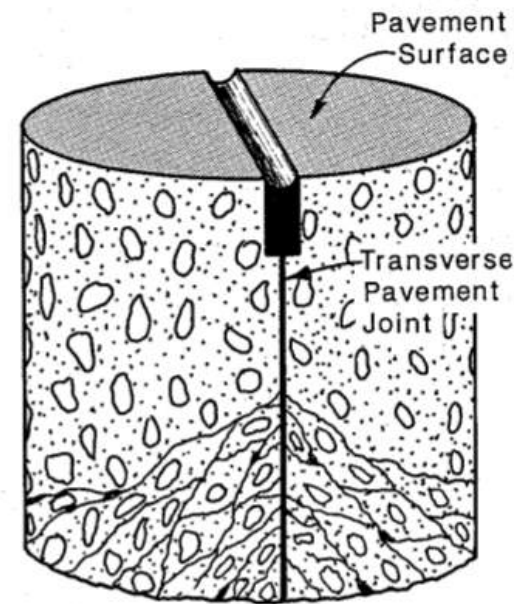




D - Cracking

CAUSE:

- Coarse aggregate that is susceptible to absorption and cracking.
- Ground water saturates aggregates
- Freeze thaw stresses fracture aggregates
- Poor drainage
- Unsealed joints



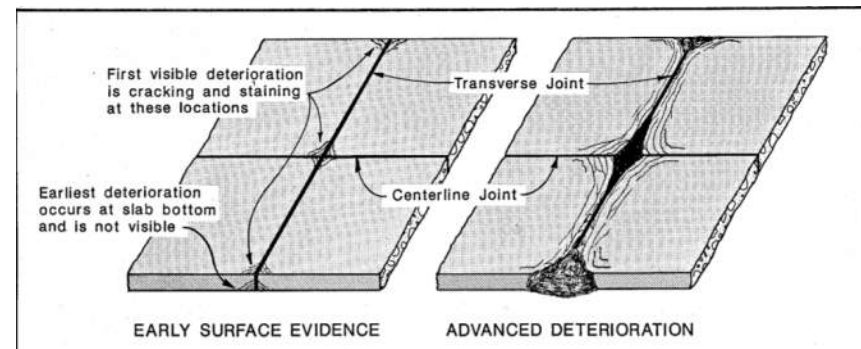
D-Cracking

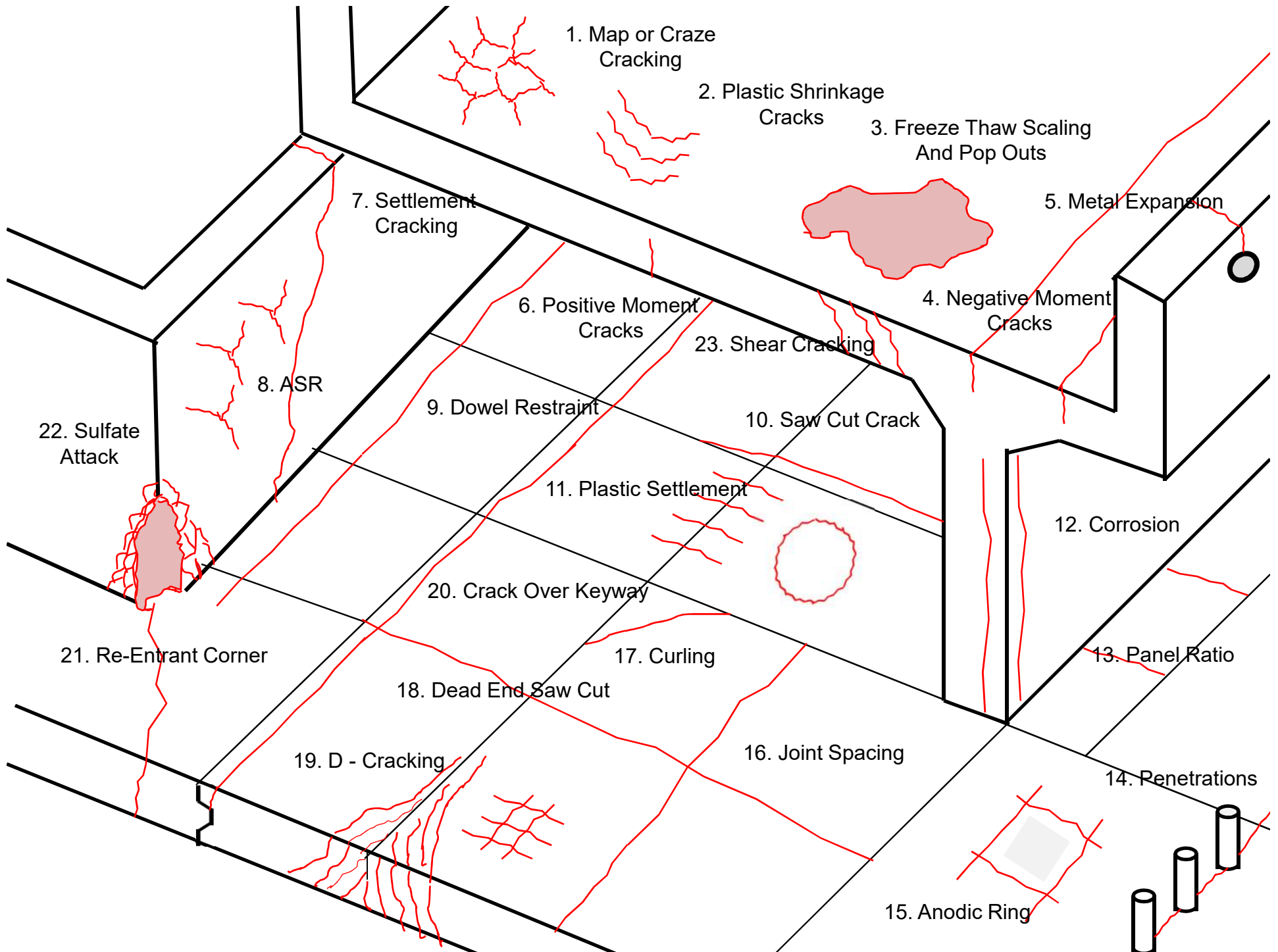
PREVENTION:

- Specify quality aggregates per ASTM C33. Designate Class 4S or 5S
- Provide proper drainage
- Seal joints
- Prevent moisture intrusion
- Watch for symptoms and try to catch it early.

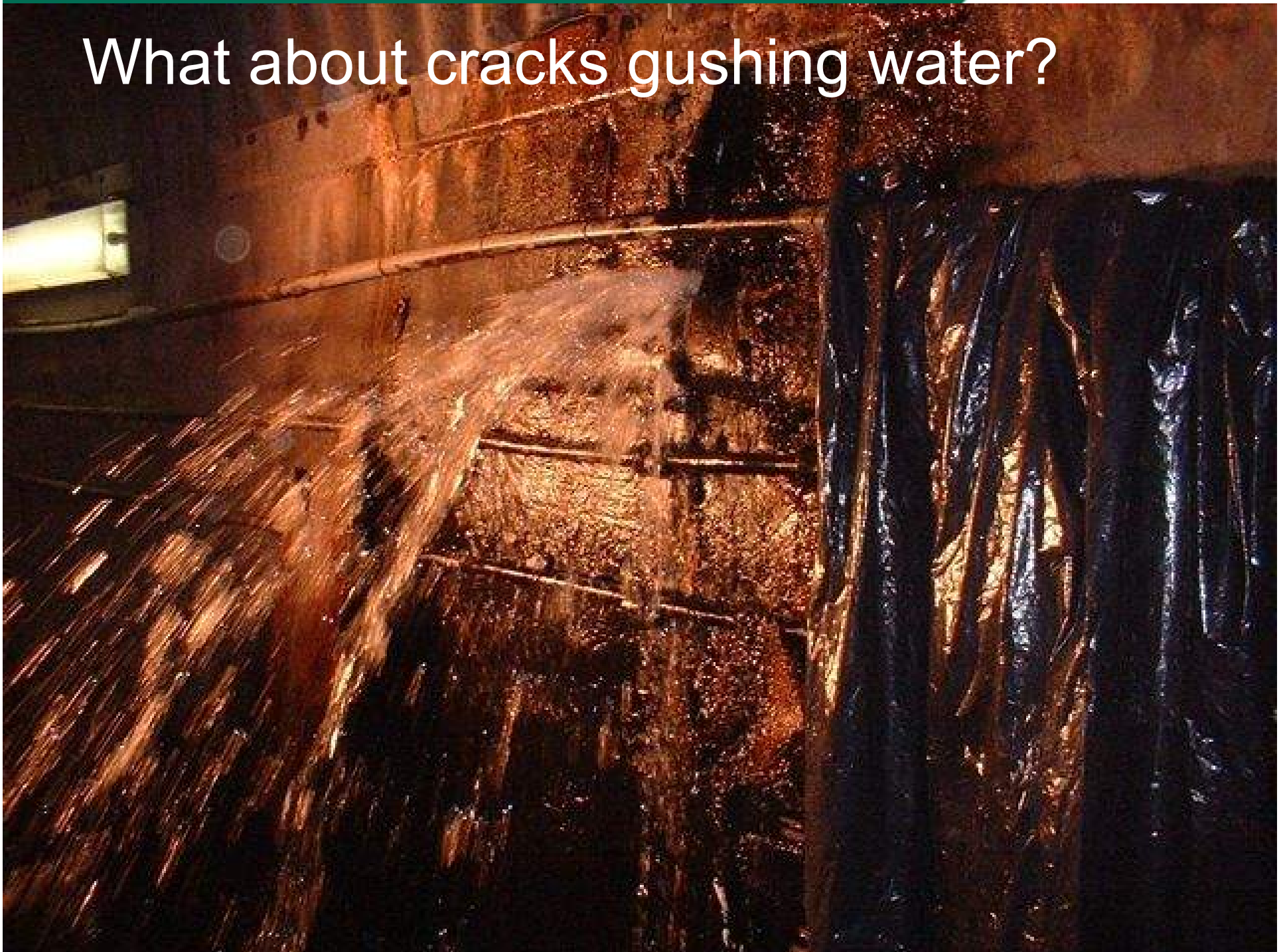
REMEDY:

- No real remedy. Take actions to slow deterioration.





What about cracks gushing water?







The Euclid Chemical Company



EUCLID CHEMICAL

Questions??

Matt Hansen

Euclid Chemical

952-567-1563

mhansen@euclidchemical.com