Early-Age Properties of Repair Binders
(Lab, Field and Test Methods)
Tuesday, April 16, 4:00 PM - 6:00 PM, C-101 D

Early-Age Repair Material Properties
&
Early Age Repairs

Fred Goodwin
Fellow Scientist
BASF Construction Systems

Early-Age Repair Material Properties

Repairs Performed at Early Ages

Early Age Material Properties

What is Concrete?

- Concrete is economical with a long life & low maintenance
- Concrete does not rot, corrode, or decay.
- Concrete can be molded or cast into almost any desired shape.
- Concrete is fire-safe & able withstand high temperatures.
- Concrete is resistant to wind, water, rodents, and insects.
- 12 BILLION cu meters per year globally
- ~1 cu yd / person / year in USA
- >70 Billion cu meters placed in USA since 1930 with ~10 Billion cu meters > 20 years old

CONCRETE

Wood Age →

Stone Age→

Masonry Age →

Steel Age →

Improved Construction Technology

Concrete Age

HOWEVER……….

- The cost to owners for concrete repair, protection, and strengthening in US is $18 to $21B /yr (2004)

  http://www.concrete.org/members/CRB04_Emmons-Sordyl.pdf

- The cost of corrosion of concrete reinforcement is > $125B / yr

  http://www.corrosioncost.com/infrastructure/highway/index.htm

- A 7 year infrastructure investment of $3.6 trillion is needed to return to quality of 1988 infrastructure C→D+

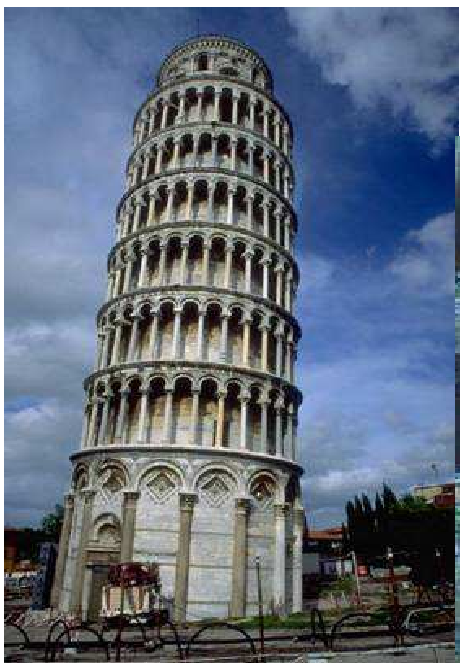
  http://www.infrastructurereportcard.org/




Why does concrete fail?

Concrete requires repair and strengthening due to the 3 D’s

- Design and Construction Errors
- Deterioration
- Damage

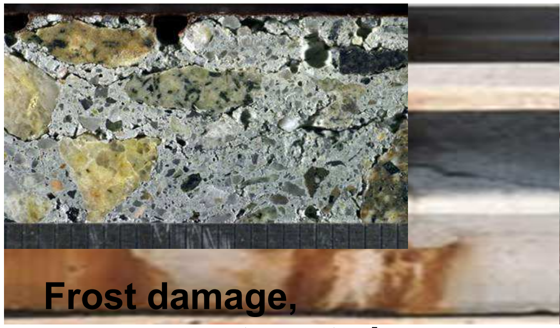


Why does concrete fail?

- **Concrete has (compared to other building materials)**
- **-low tensile strength** (~10% of compressive strength),
- **-low ductility** (it's brittle),
- **-low strength-to-weight ratio** (it's heavy),
- **-responds to environment** (it changes with time)
- **-has permeability**(ingress of deleterious materials)
- **-is susceptible to chemical attack**(acids, AAR, etc.)
- **-and it cracks.**
- **Steel corrodes**
  - Chloride, carbonation, and polarization interaction
  - Rust expands, causing cracking, spalling, and eventual failure

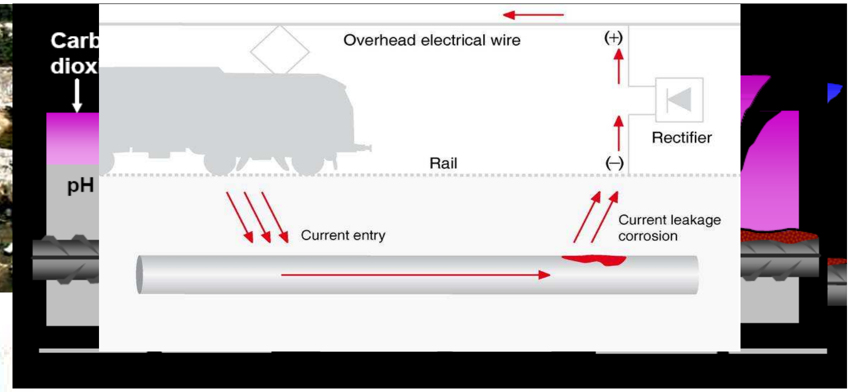
ALL of these properties change as the concrete ages.

How does concrete fail?



Frost damage, concrete not air entrained

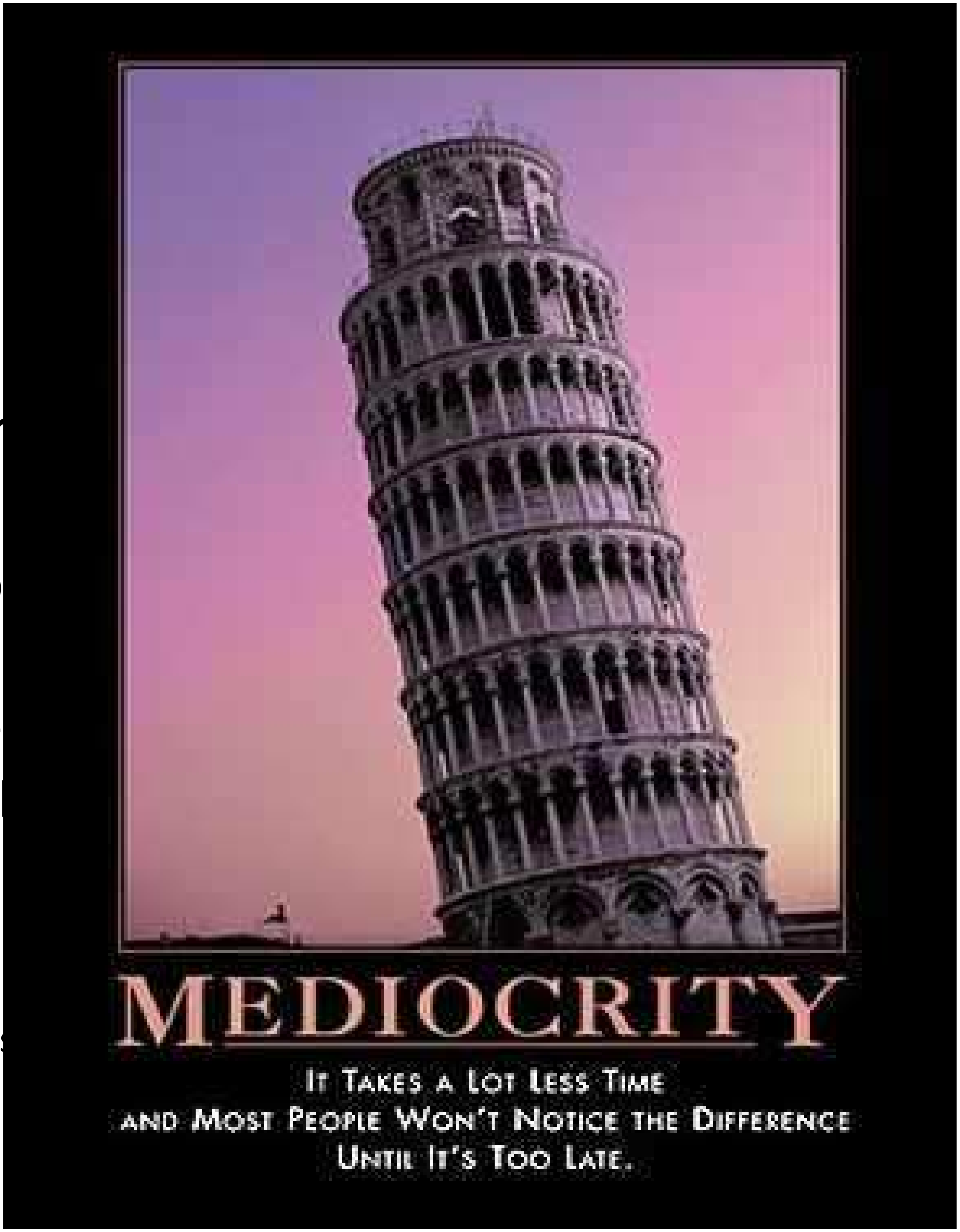
Concrete Matrix



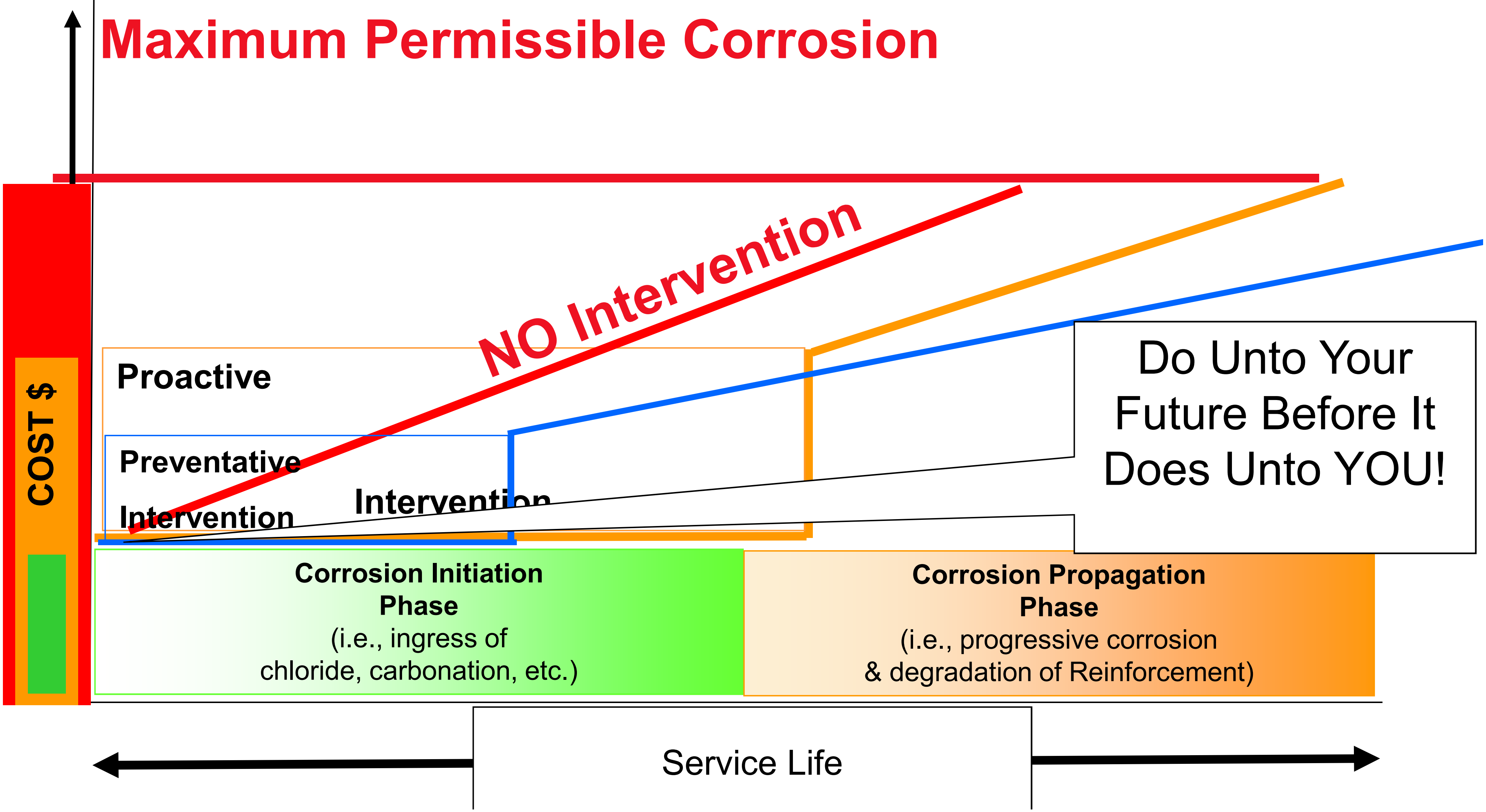
What to Do?

New Construction

- Usually you inherit the pr
    - Design!!!
    - Place reinforcement with p
    - Use low W/CM
    - Use appropriate admixture
    - Proper consistency and wel
    - Properly cure the concrete
    - i.e., good trade practice
        - **Details,** Details, Detail



Tuutti Diagram



What is the biggest ROI for concrete repair?

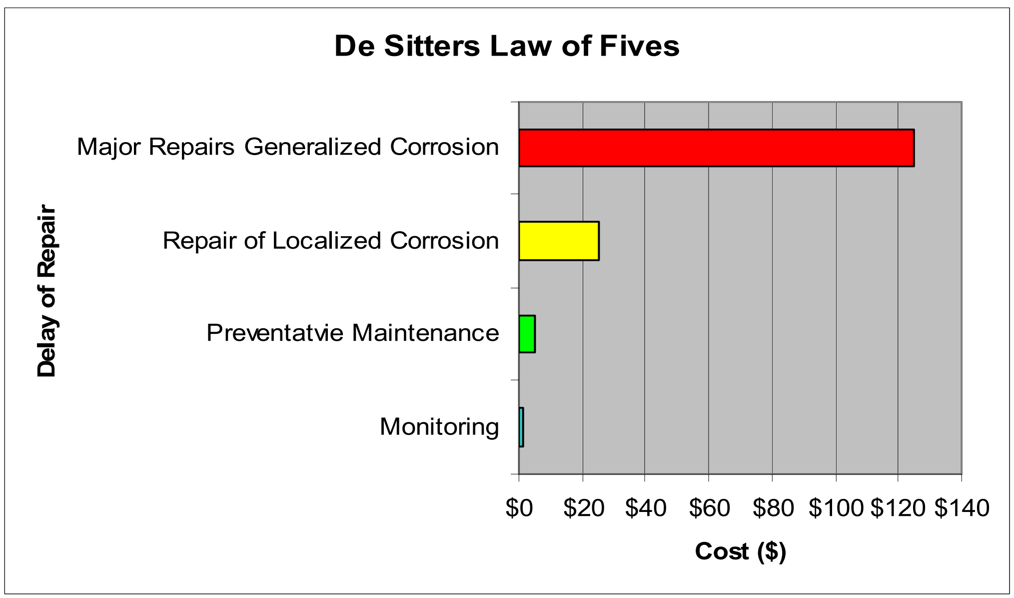
De Sitter's Law of Fives

$1 spent on Monitoring =

$5 spent on Preventative Maintenance Before Corrosion Initiation =

$25 spent on Repair and Maintenance after Corrosion Initiation =

$125 spent on Repair & Replacement after Generalized Corrosion Propagation



Pay Me NOW

OR

Pay Me LATER

BRE Client report number Oct. 02 Draft
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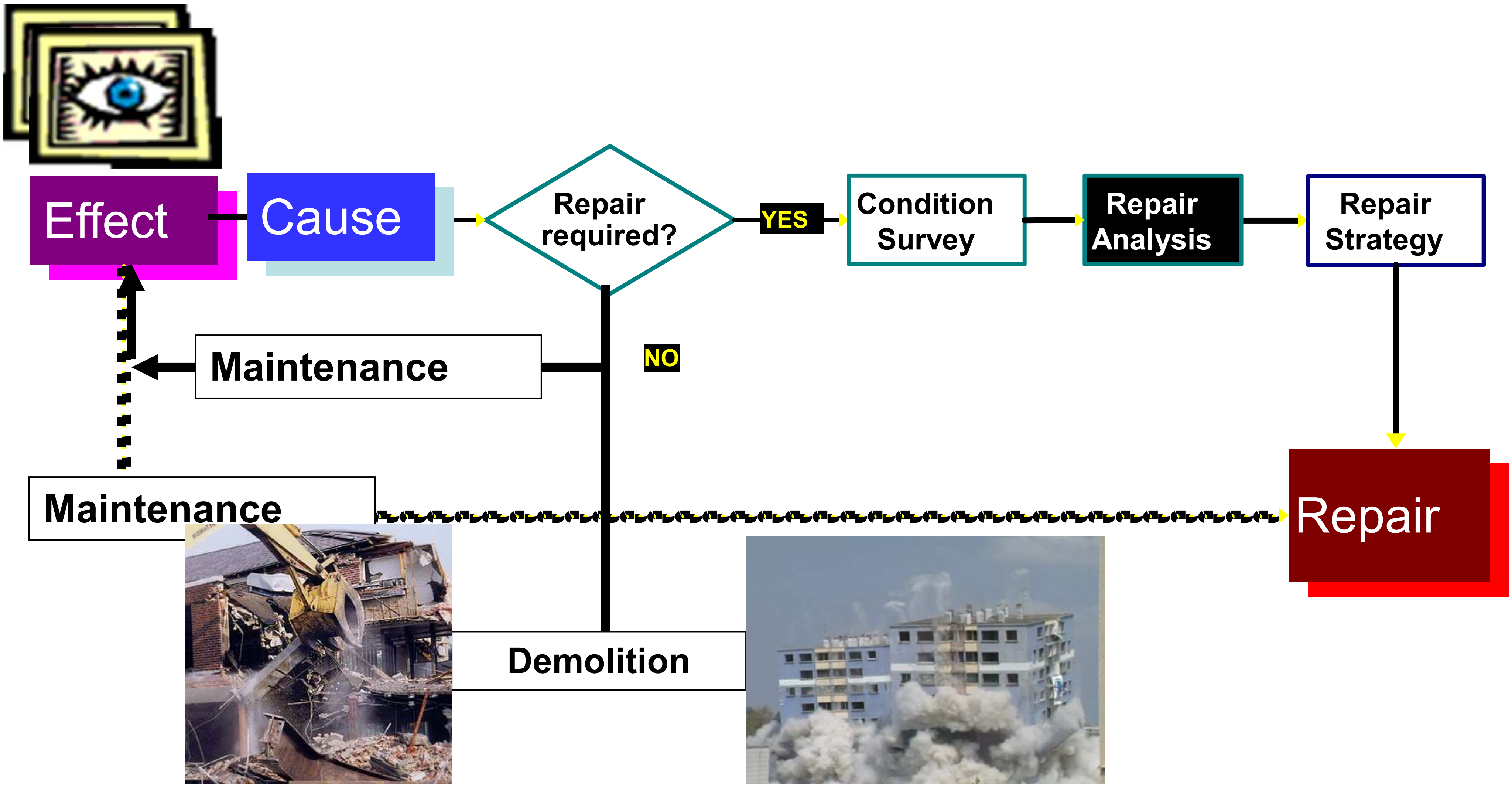
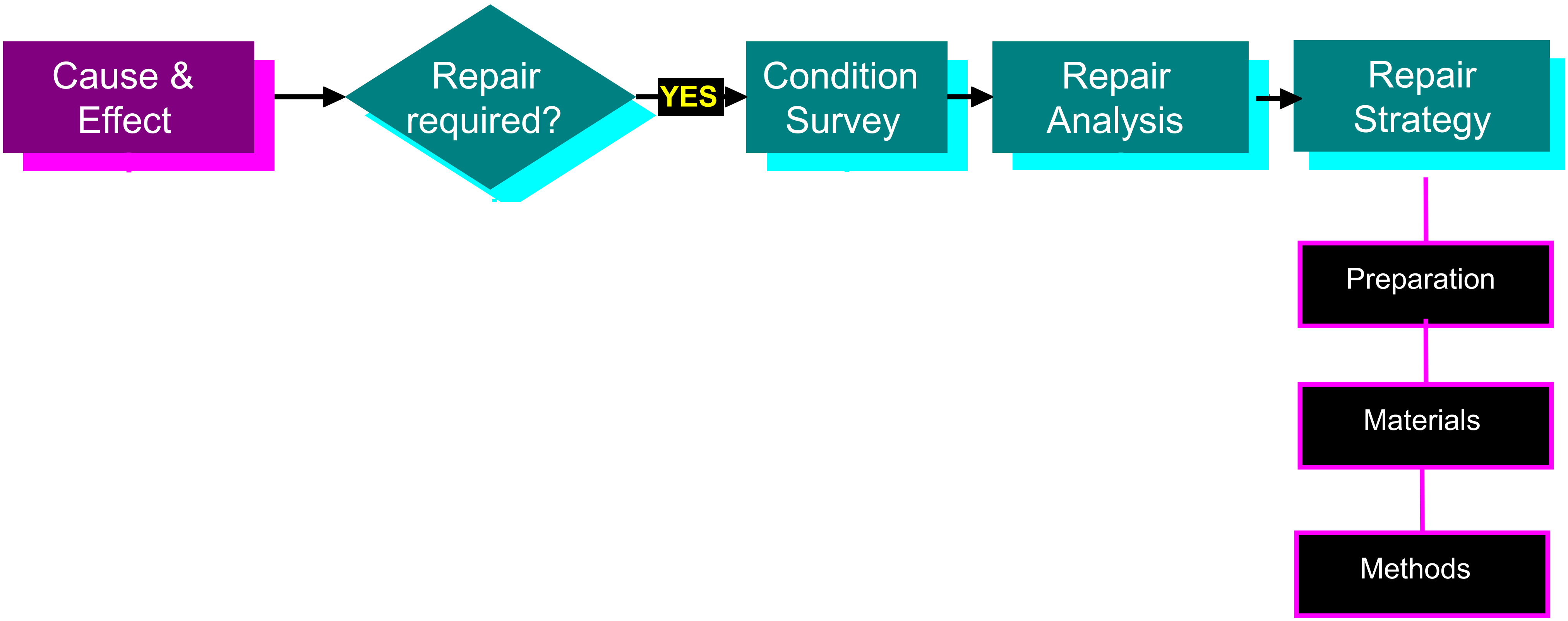
http://irc.nrc-cnrc.gc.ca/pubs/fulltext/nrcc44300.pdf

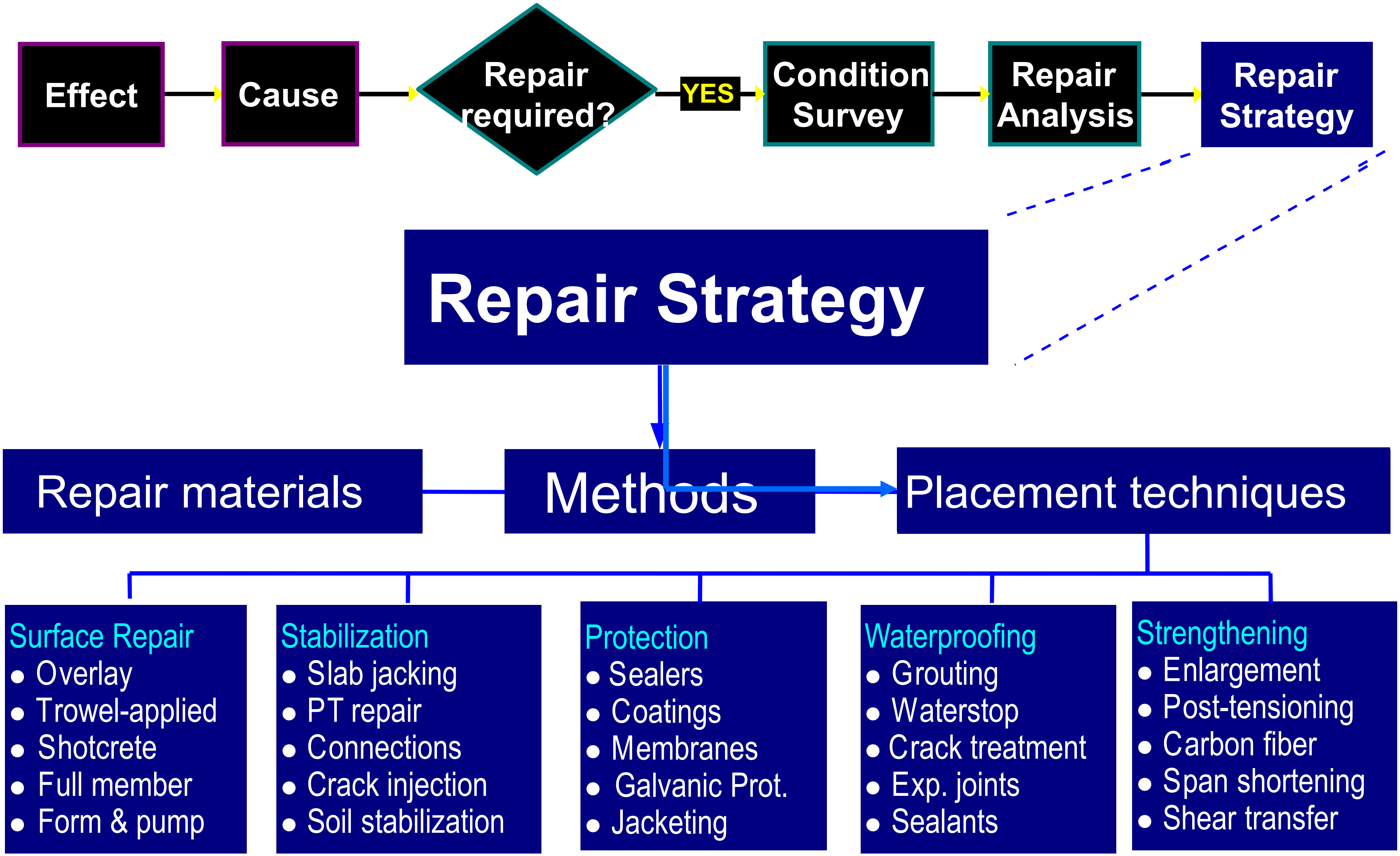
Concrete Repair Process

Evaluation, Analysis, & Strategy



Concrete Repair Process

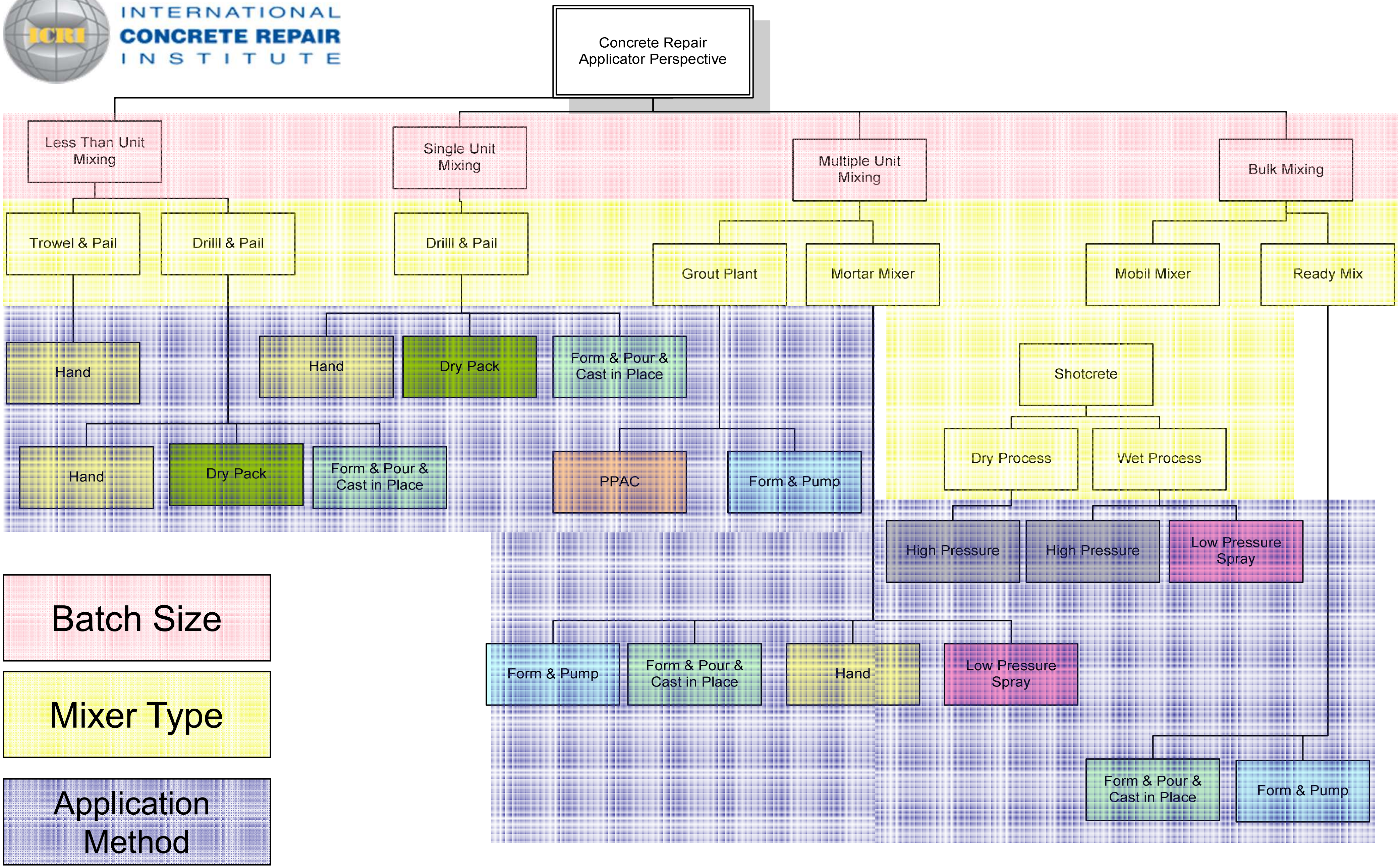


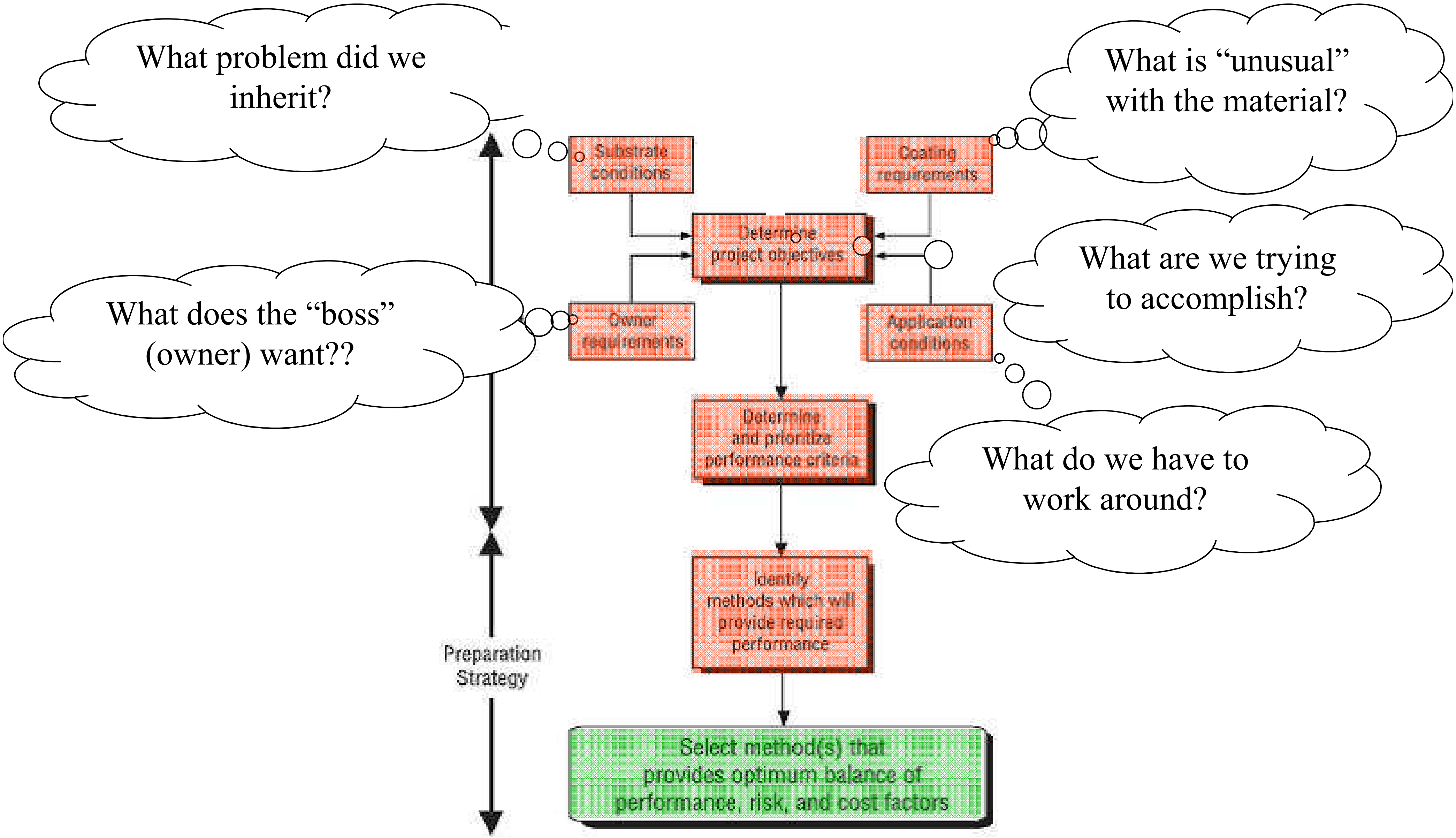

Effect
Cause
Repair required?
YES
Condition Survey
Repair Analysis
Repair Strategy
Repair Strategy
Repair materials
Methods
Placement techniques
Surface Repair
Overlay
Trowel-applied
Shotcrete
Full member
Form & pump
Stabilization
Slab jacking
PT repair
Connections
Crack injection
Soil stabilization
Protection
Sealers
Coatings
Membranes
Galvanic Prot.
Jacketing
Waterproofing
Grouting
Waterstop
Crack treatment
Exp. joints
Sealants
Strengthening
Enlargement
Post-tensioning
Carbon fiber
Span shortening
Shear transfer

Repair Materials

- Ordinary Concrete
- Preplaced Aggregate Concrete
- Fiber Reinforced Concrete
- Ferrocement
- Low Slump Dense Concrete
- Dry Pack
- Conventional Concrete & Mortar
- Shotcrete
  - Wet Process
    - High Pressure
    - Low Pressure
  - Dry Process
- Silica Fume Concrete
- Sulfur Concrete
- Cement-Based Grout
- Proprietary Repair Mortars
- Rapid Setting Cementitious
- Magnesium Phosphate
- Polymer Based
  - Epoxies-mortars, adhesives, coatings
  - Polyurethanes-sealants, coatings
  - Polyureas-sealants, coatings
  - Methacrylates-mortars, injection, coatings
  - Polyesters-mortars, coatings
  - Silicones-sealants
- FRP Strengthening

Repair Application Guide (developmental ICRI 320.1 M&M)





From ICRI 320.1

Compromises

Cracking Resistance
- Creep
- Tensile Strength
- Modulus
- Bond Strength
- Length Change
- Thermal Expansi
- Flexural Strength

Durability
- Cracking Resistance

Economics
- Repair or Replace?
- rial Cost
- lled Cost

Application Constrai
- Environmental Con
- Utilities
- Surface Preparatio
- Access
- Return to Service T
- Orientation of App
- Volume of Materia

re Intrusion
on Resistance
bility

CODES
and
SPECIFI

Design and
Maintain Concrete
to Prevent
Repairing
It!

Etc.

Early-Age Repair Material Properties

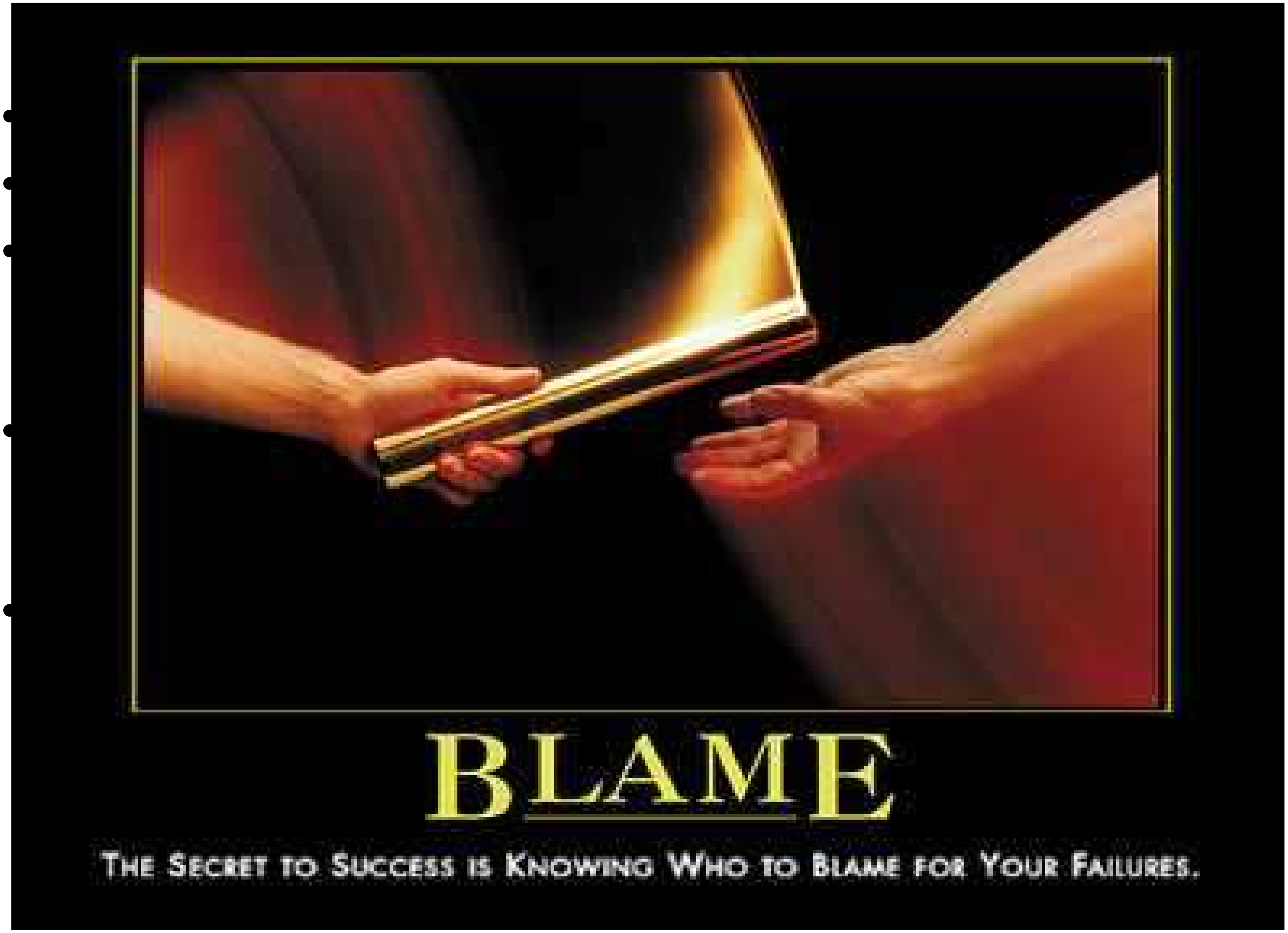
Repairs Performed at Early Ages

Early Age Material Properties

What to Do?

Existing construction

- Ok,



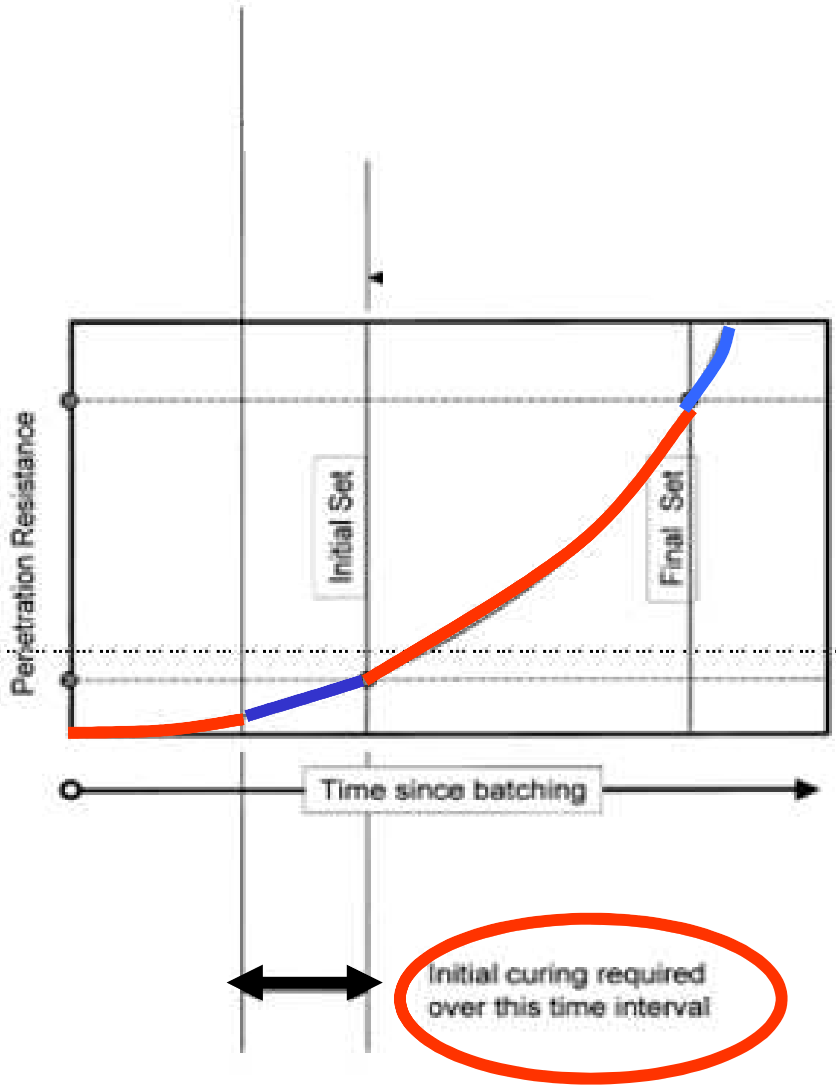


Fig. 1.6(b)—Bleed water disappears and surface drying commences at some time before beginning finishing. Initial curing is required to minimize moisture loss before and during finishing operations.

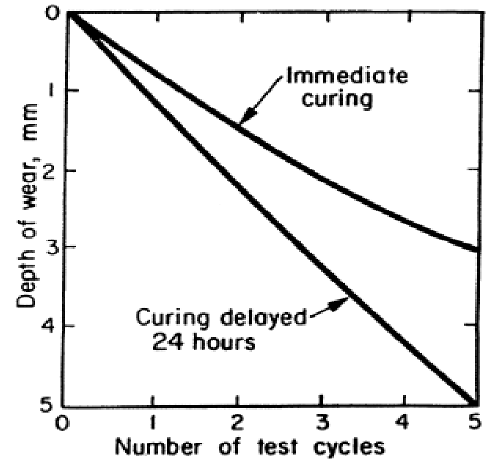
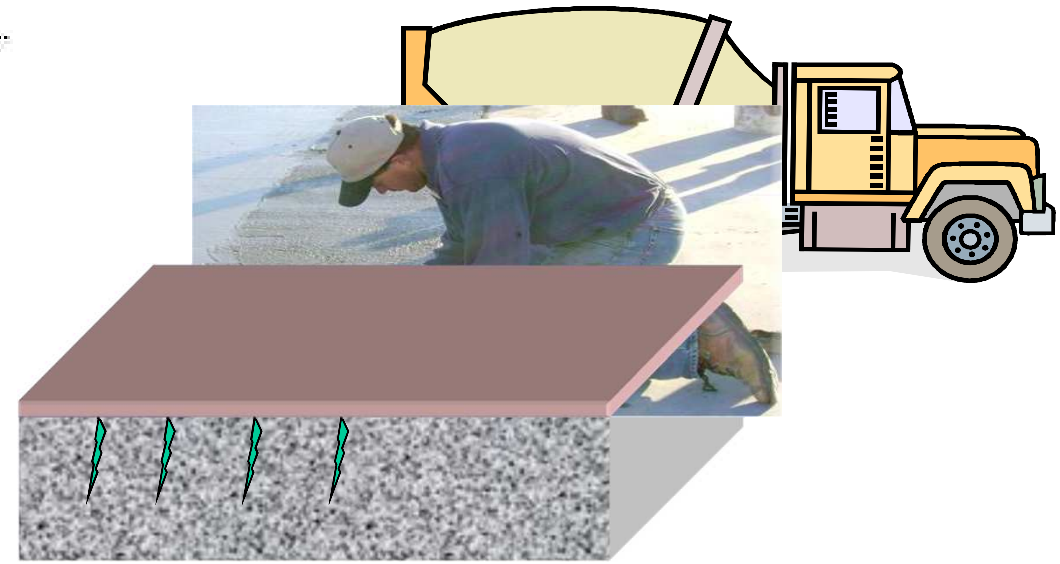


Fig. 1.13—Sawyer (1957) demonstrated the effects of delaying curing on abrasion resistance (1 mm = 0.04 in).



Typical Conditions

ACI 308

Cement + Water = granular solid + water = Fluid of more or less stability

Cement Grains = granular solid + air = Free flowing powder

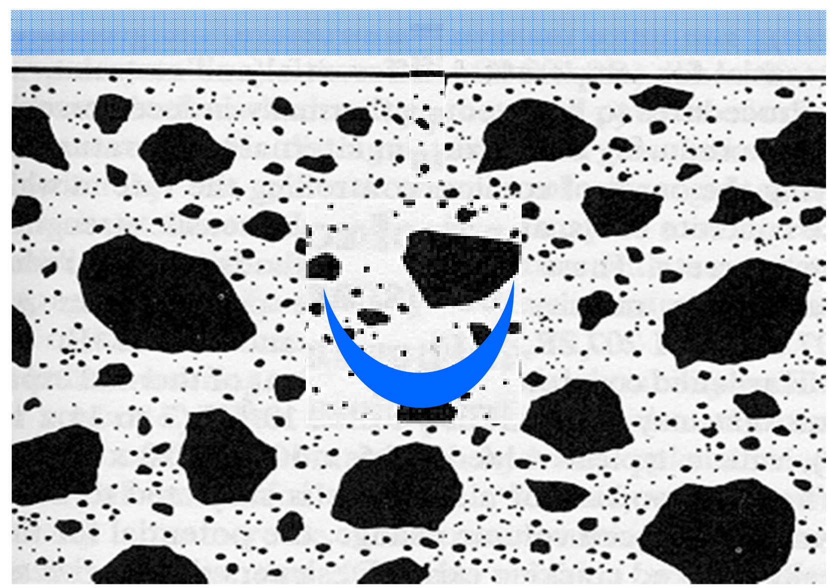
Settlement Shrinkage

Occurs within the concrete paste as air voids collapse and aggregates wet out

Cracks may form over areas of restraint (i.e., rebar)

Settlement may also create pockets under rebar and aggregates.

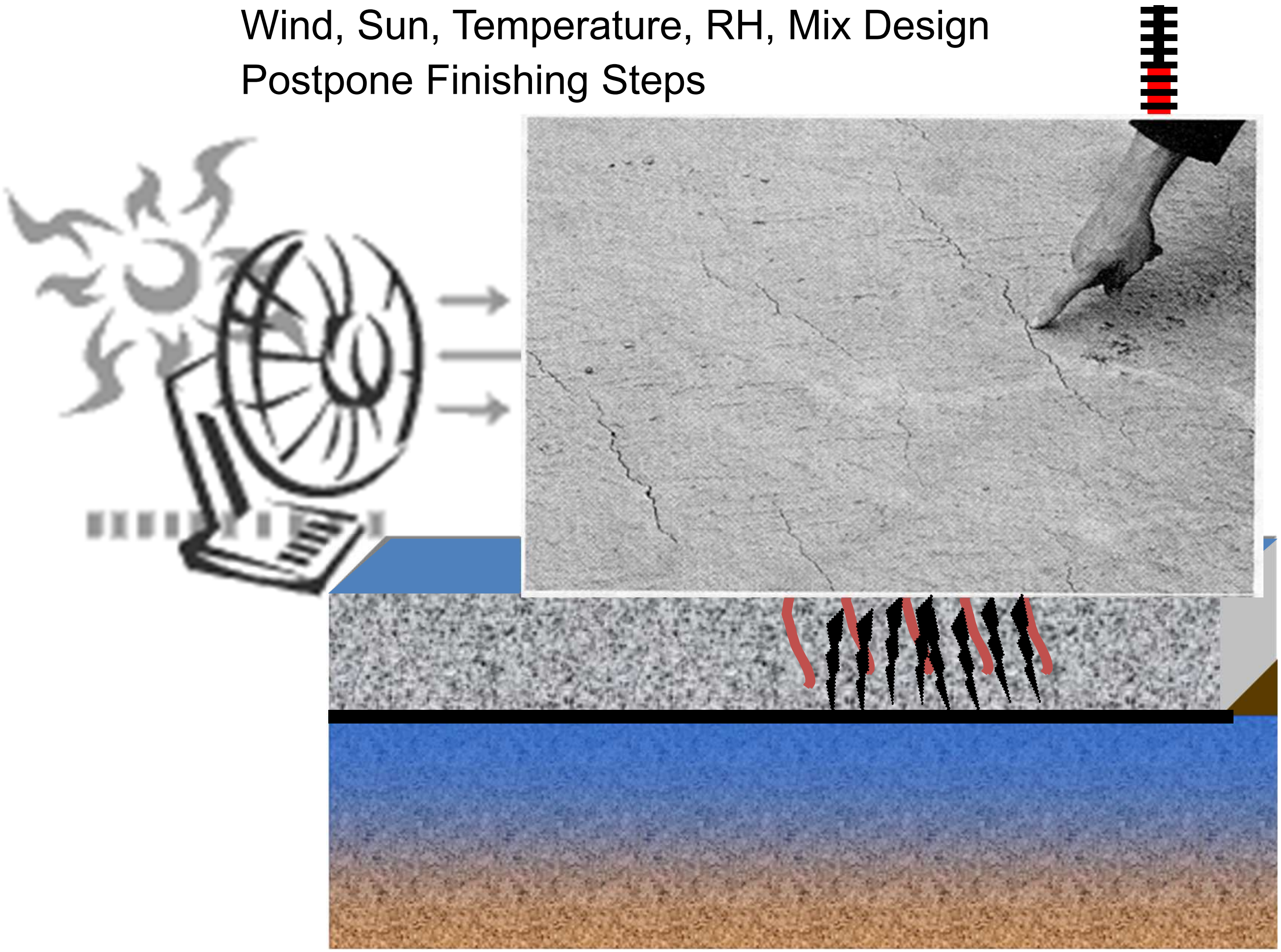
Bleeding is also settlement

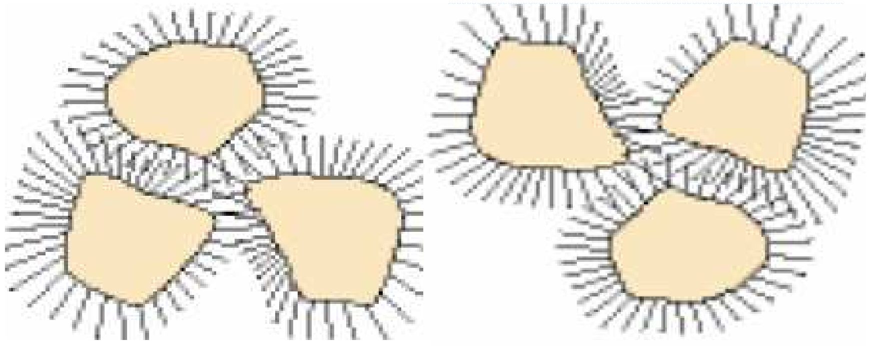


Early Cracking

- Plastic Shrinkage

Dampen Base if No Vapor Retarder
Avoid Use of Under Slab Vapor Retarder
Use Moisture Retaining Coverings/Evaporation Retarders/Fibers
Wind, Sun, Temperature, RH, Mix Design
Postpone Finishing Steps





Cement Hydrates

Hydrates begin to interlock.

Setting begins

Finishing occurs

Shearing will weaken concrete after setting

Hydration continues

Consumption of water, hydrate rims form.

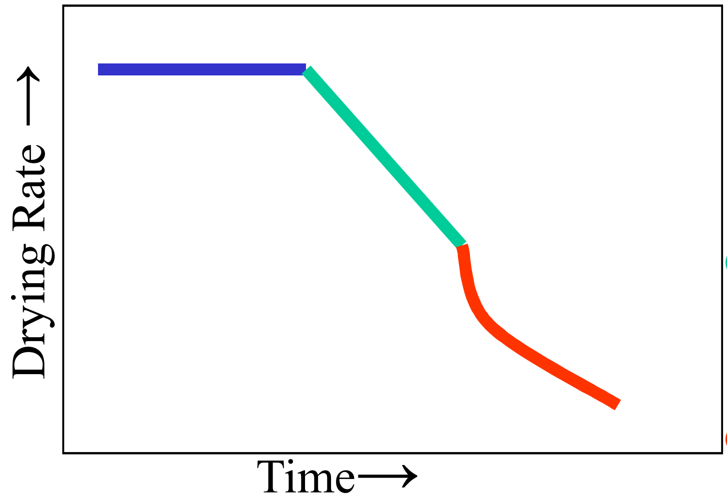
Increase in viscosity.

Shearing that occurs can be repaired by new hydration.

At Early Ages

- **Creep is high**
- **Shrinkage is high**
- **Porosity is high**
- **Strength is low**
- **Cement exotherms = Thermal stress**

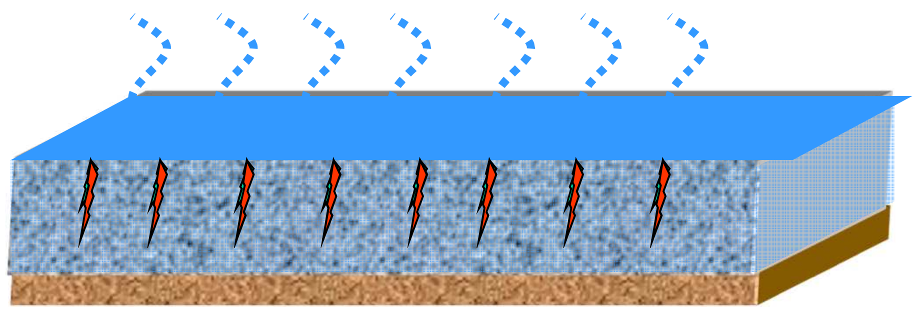
Drying of Concrete- One Side



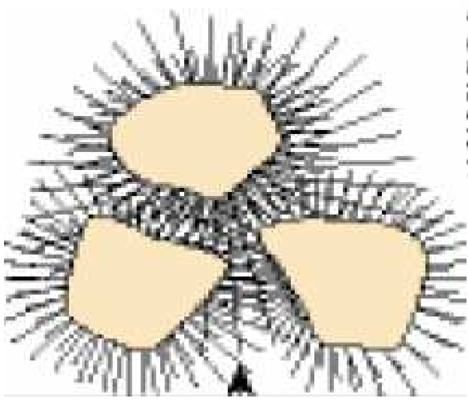
Stage 1 Bleed water on surface evaporates

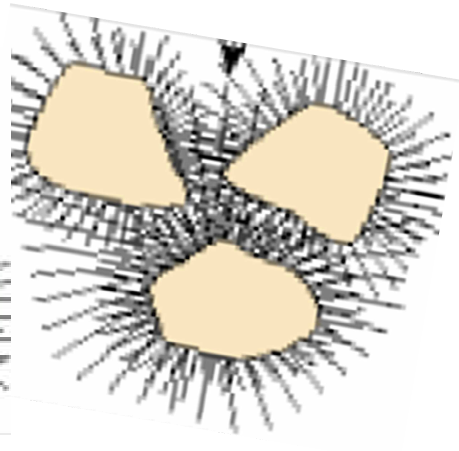
Stage 2 Water evaporates from pores refilled from within concrete = settlement & plastic cracking

Stage 3 Water evaporates from within as vapor = drying shrinkage

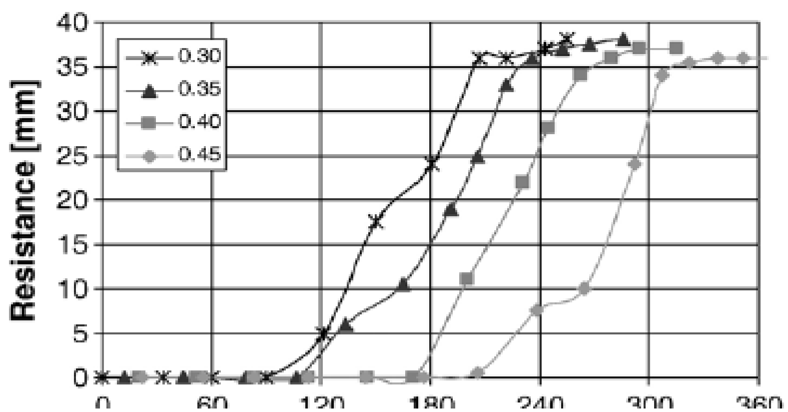


Kanare, H. Concrete Floors & Moisture, Eng. Bulletin #119 PCA/NRMCA, 2005





Hydration continues
Porosity decreases
Pore water may be consumed or evapor
=
Curing Required
Drying shrinkage begins
Freezing will destroy concrete.



Penetration resistance vs. time with different W/C

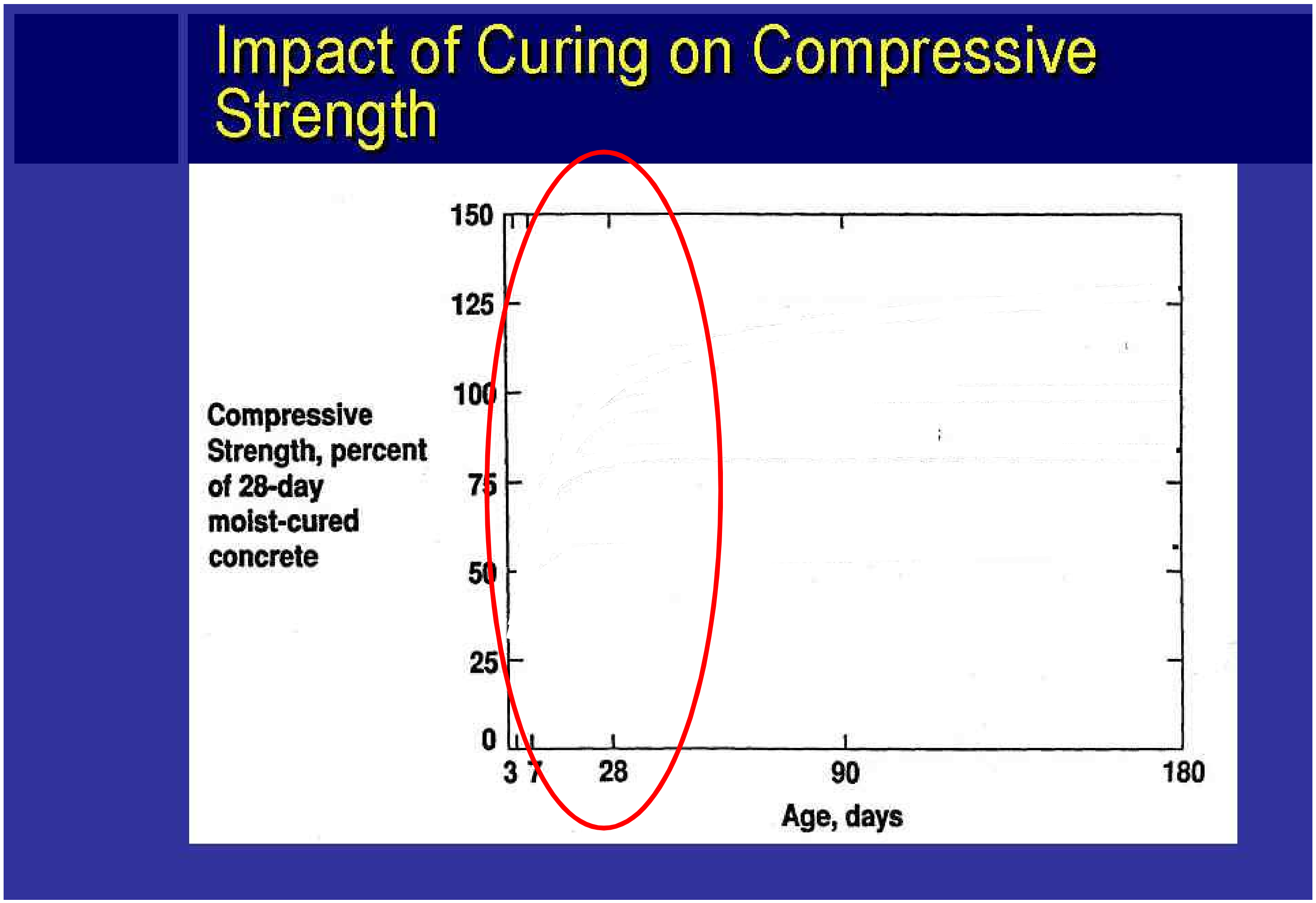
Porosity decrease vs. time with different W/C

A review of early-age properties of cement-based materials
D.P. Bentz

Rate of Strength Development is Much Faster at Early Ages

Up to 50% Strength Improvement if Properly Cured

Curing Induced Strength Variations



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Water Permeability vs Curing for Different W/C

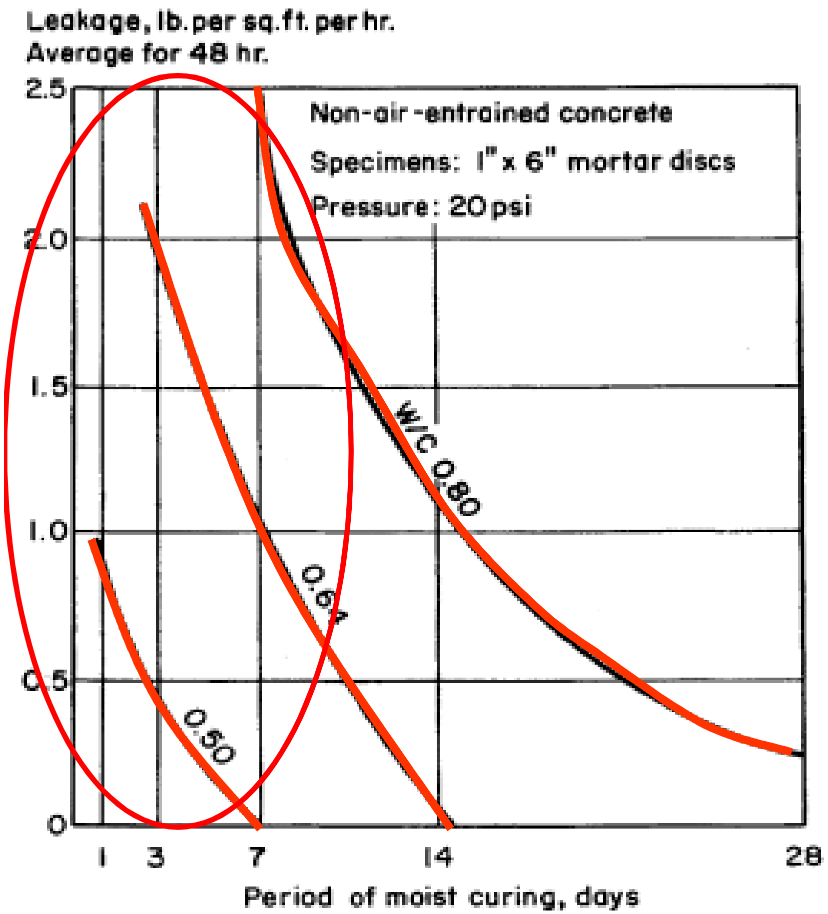
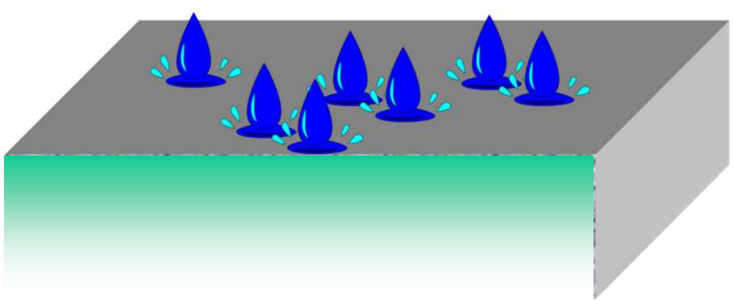


Fig 1.5—Influence of curing on the water permeability of mortar specimens (Kosmatka and Panarese 1988).



With Water Permeability Comes:

- •Chloride Ingress (Steel Corrosion)
- •F/T Deterioration
- •AAR
- •Sulfate Attack
- •ETC

Permeability Rate is HIGH at Early Ages

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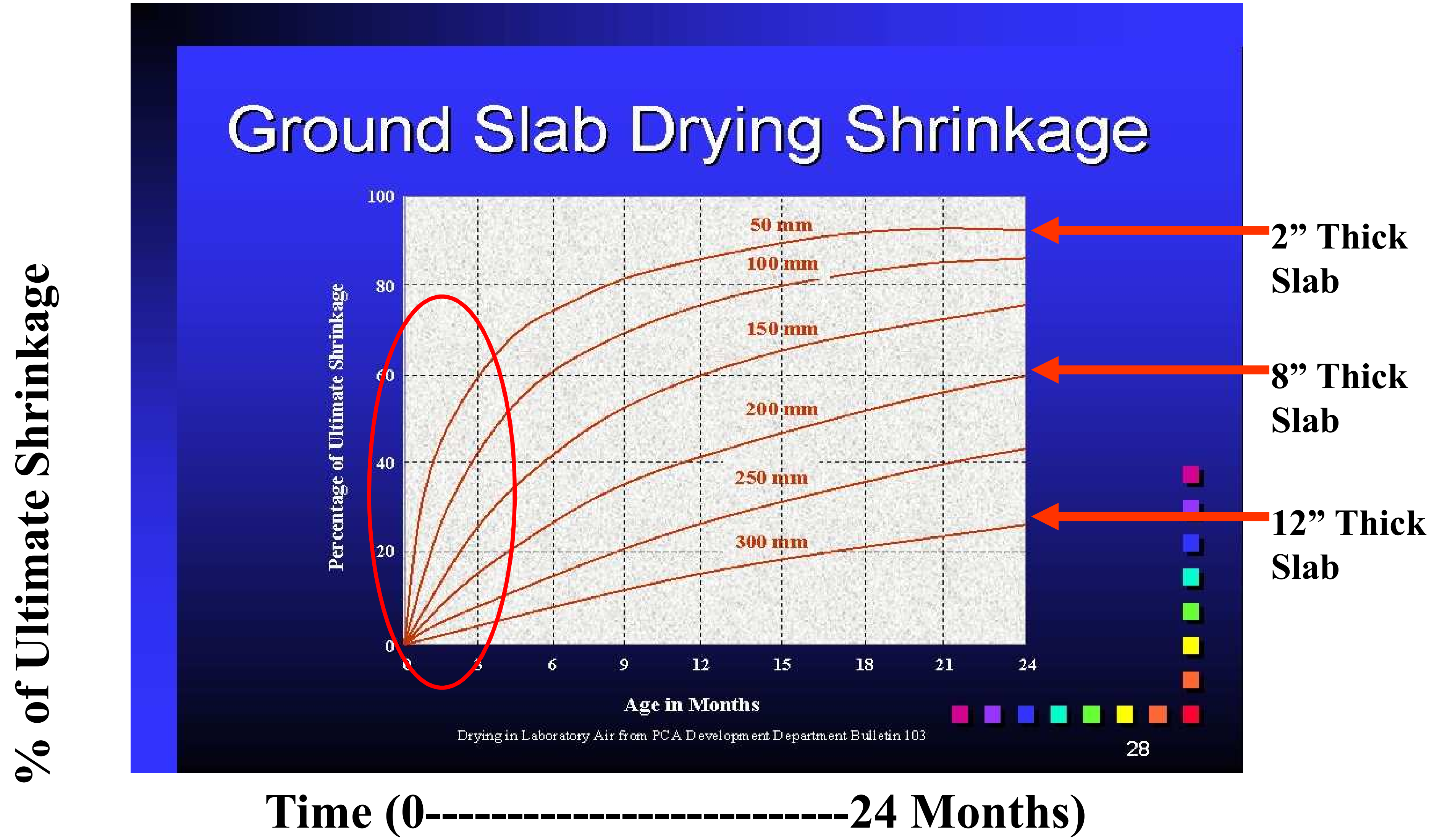
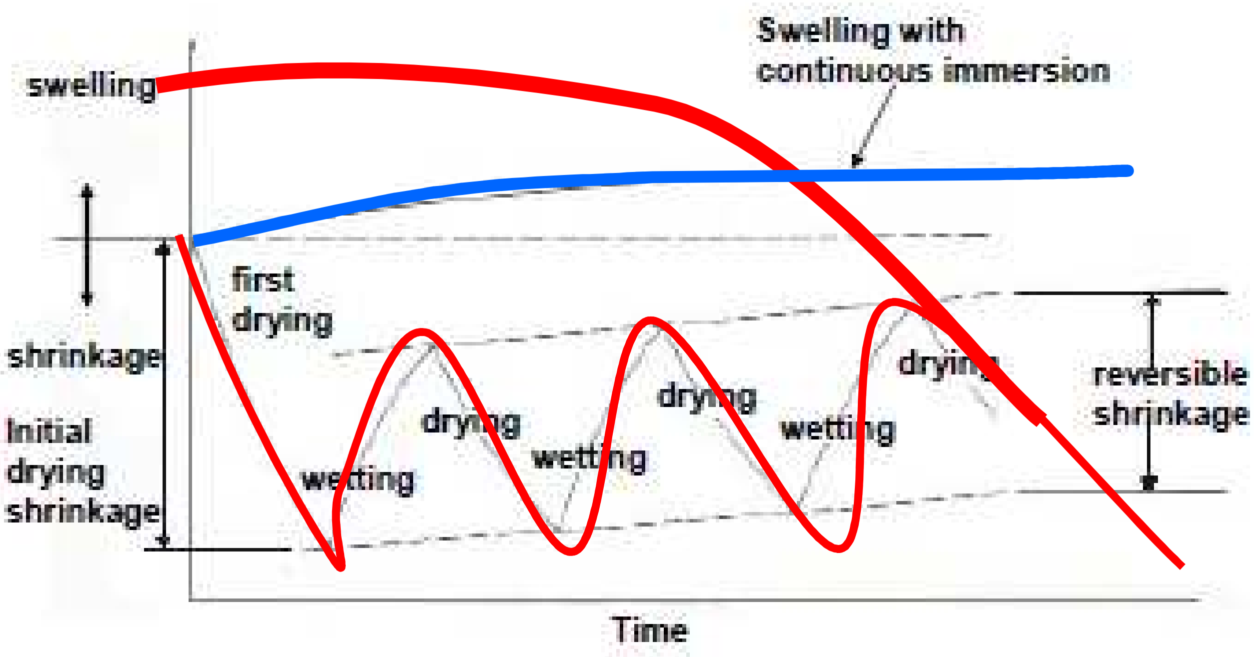
Drying Shrinkage:

Shrinkage is FASTER at Early Ages
Thinner sections dry (and shrink) faster



Concrete becomes a
Hard
Wet
Sponge



Degree of Hydration vs. Internal RH

Volume change vs. wet + dry cycles

Boğaziçi University Dept. of Civil Engineering Lecture Notes 3

A review of early-age properties of cement-based materials
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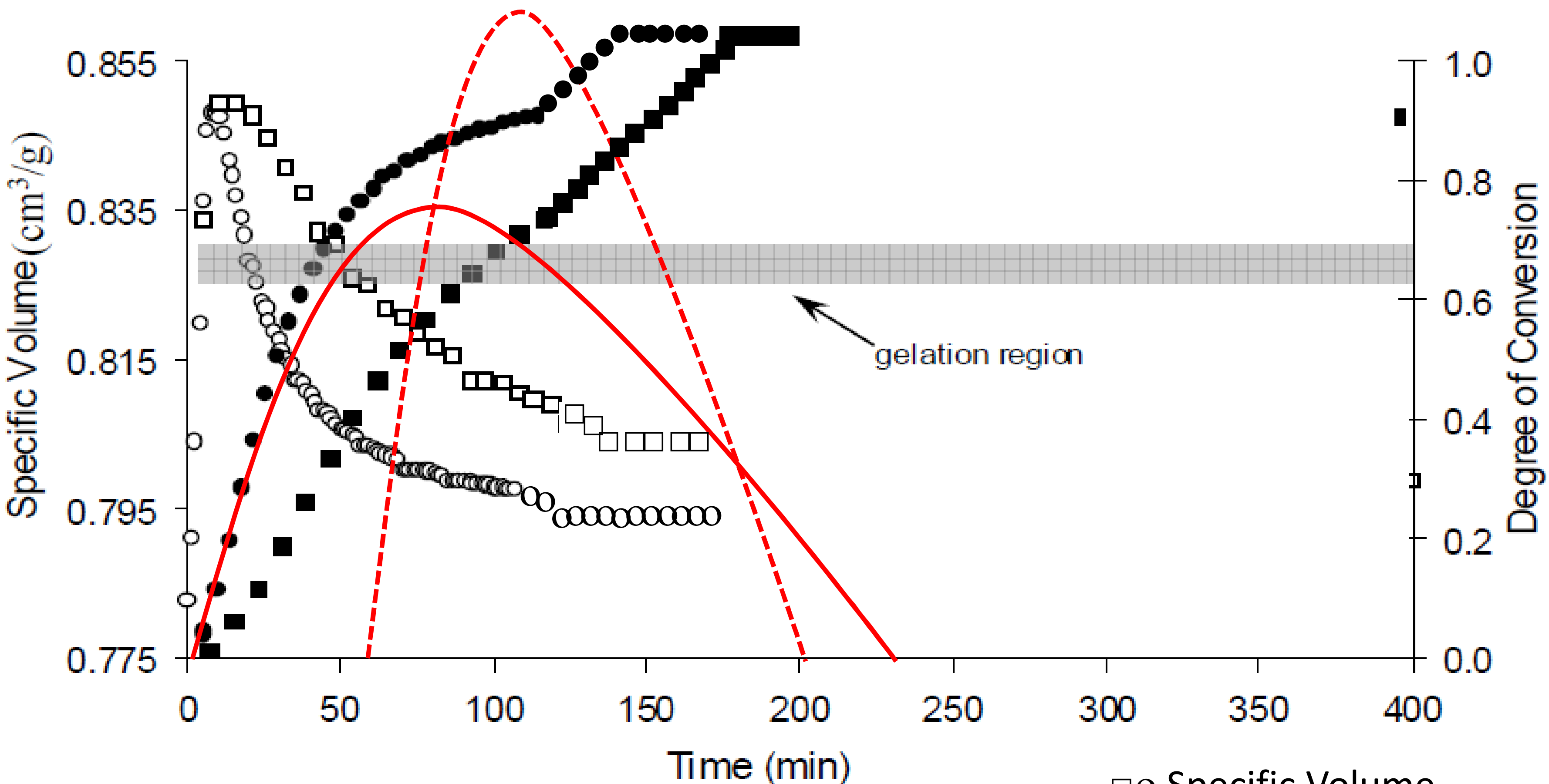
  - Polyesters-mortars, coatings
  - Silicones-sealants

?

- FRP Strengthening

Polymer Binder Curing Example (epoxy)



Epoxy degree of reaction vs. volume change

[Investigation of cure induced shrinkage in unreinforced epoxy resin](#)

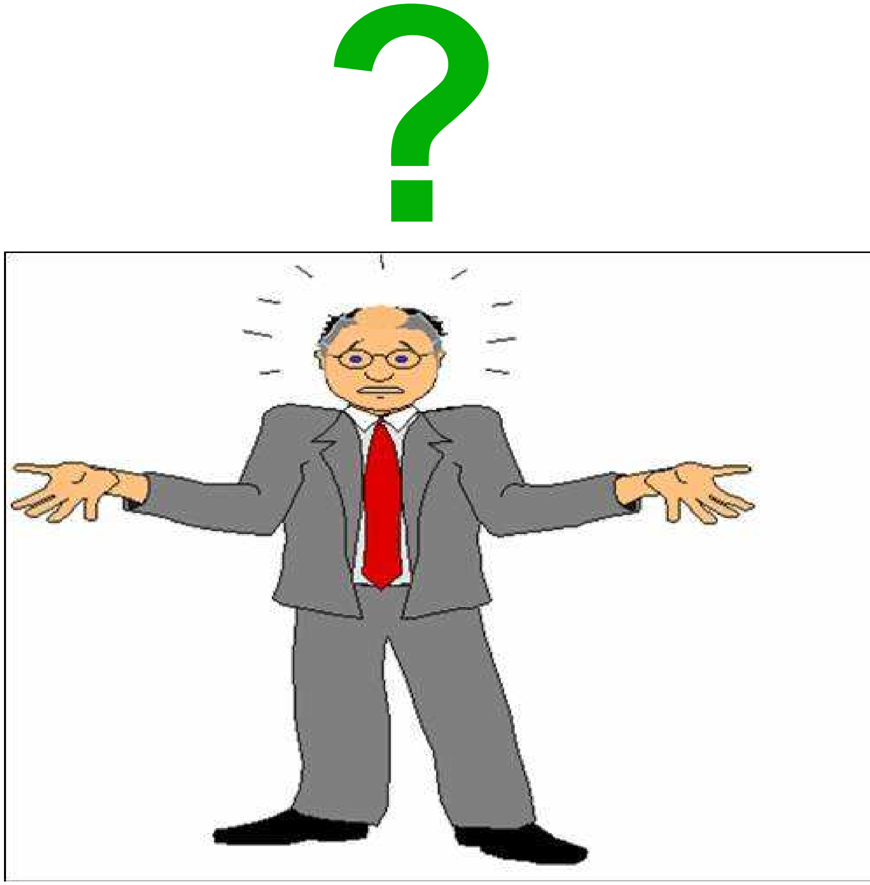
[Zarrelli, Skordos, Partridge](#)

□o Specific Volume

●■ Degree of Conversion

Exotherm temperature

Post cure



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Thank You!

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Fred Goodwin, Fellow Scientist