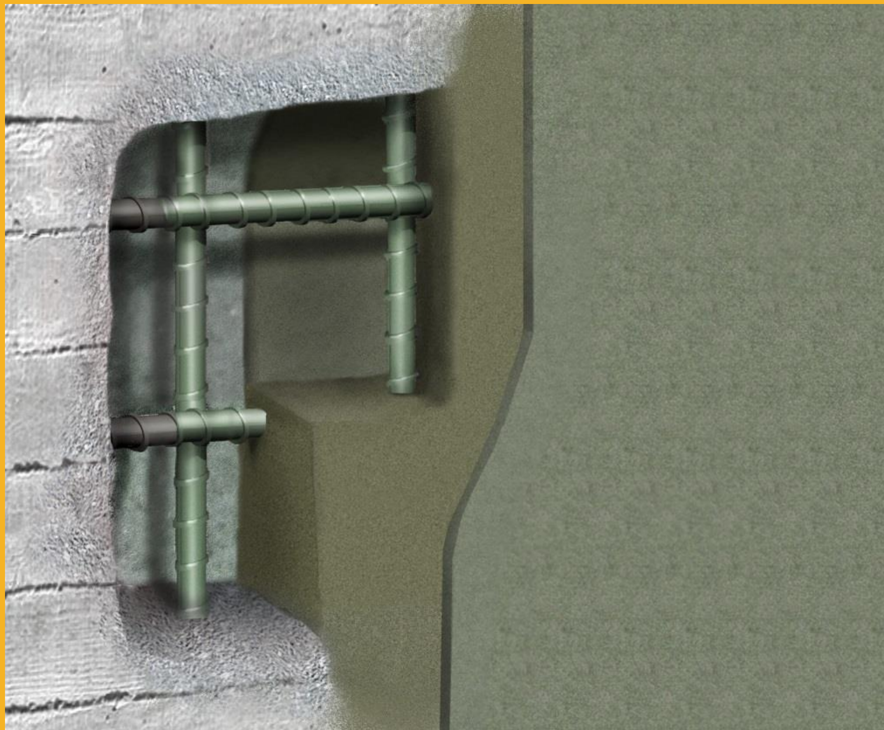


ADVANCED CONCRETE REPAIR MORTARS

AYDIN KHAJEPUR
SIKA PARSIAN/ TM REFURBISHMENT

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CONCRETE HAS TO WITHSTAND HARSH ENVIRONMENTS

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AND OFTEN CONCRETE NEEDS REPAIRING!

1. CONCRETE DAMAGES

IDENTIFICATION

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WHAT IS THE ISSUE WITH THIS CONCRETE?

WHAT HAS CAUSE THIS EFFECT TO THE SURFACE?

WHAT HAS CAUSED THIS SPALLING??

WHAT HAS CAUSED THIS DAMAGE?

WHAT HAS CAUSED THIS SURFACE DAMAGE?

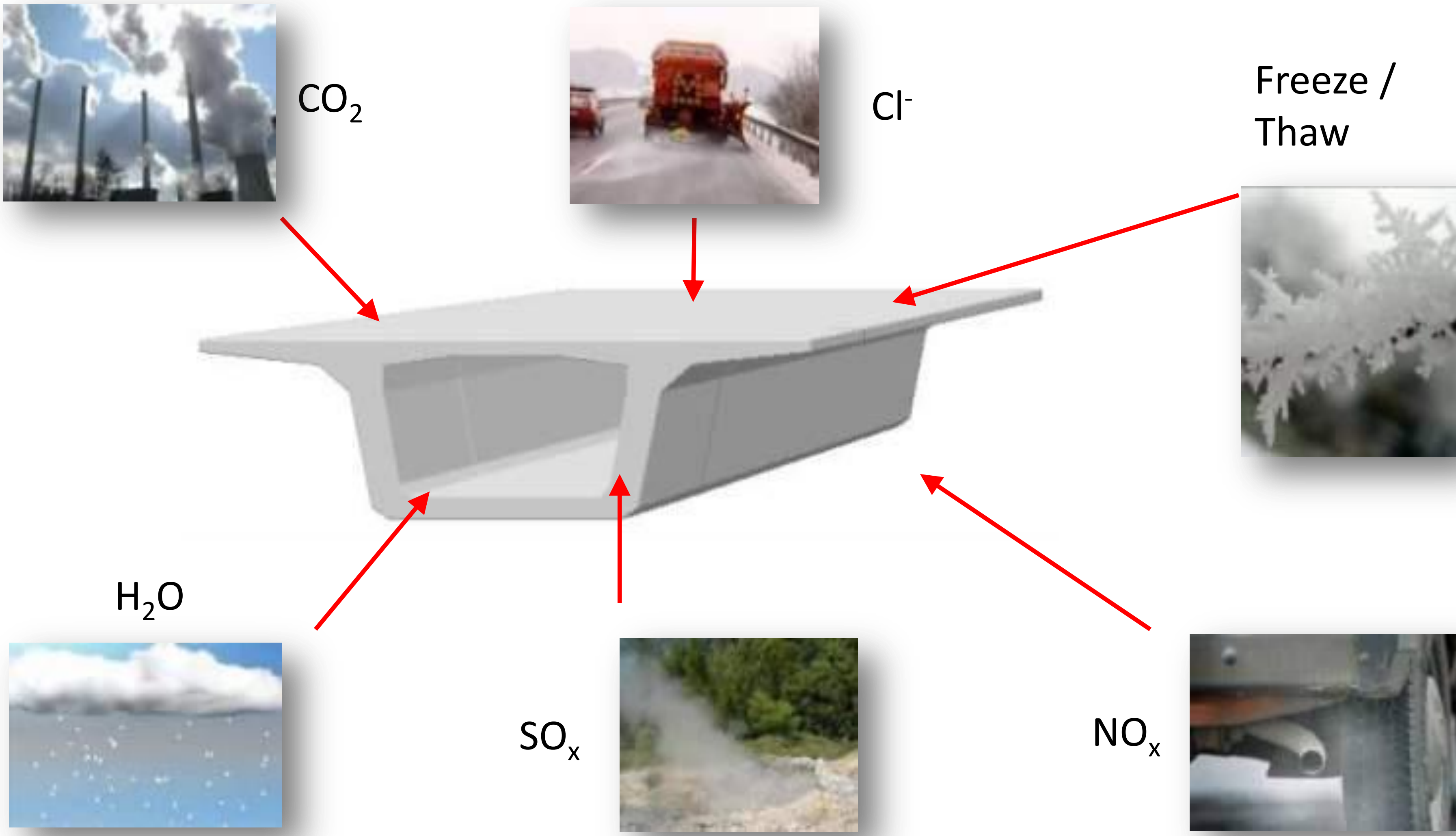
WHAT IS HAPPENING TO THE CONCRETE HERE?

FINALLY..... WHAT IS THE PROBLEM HERE?

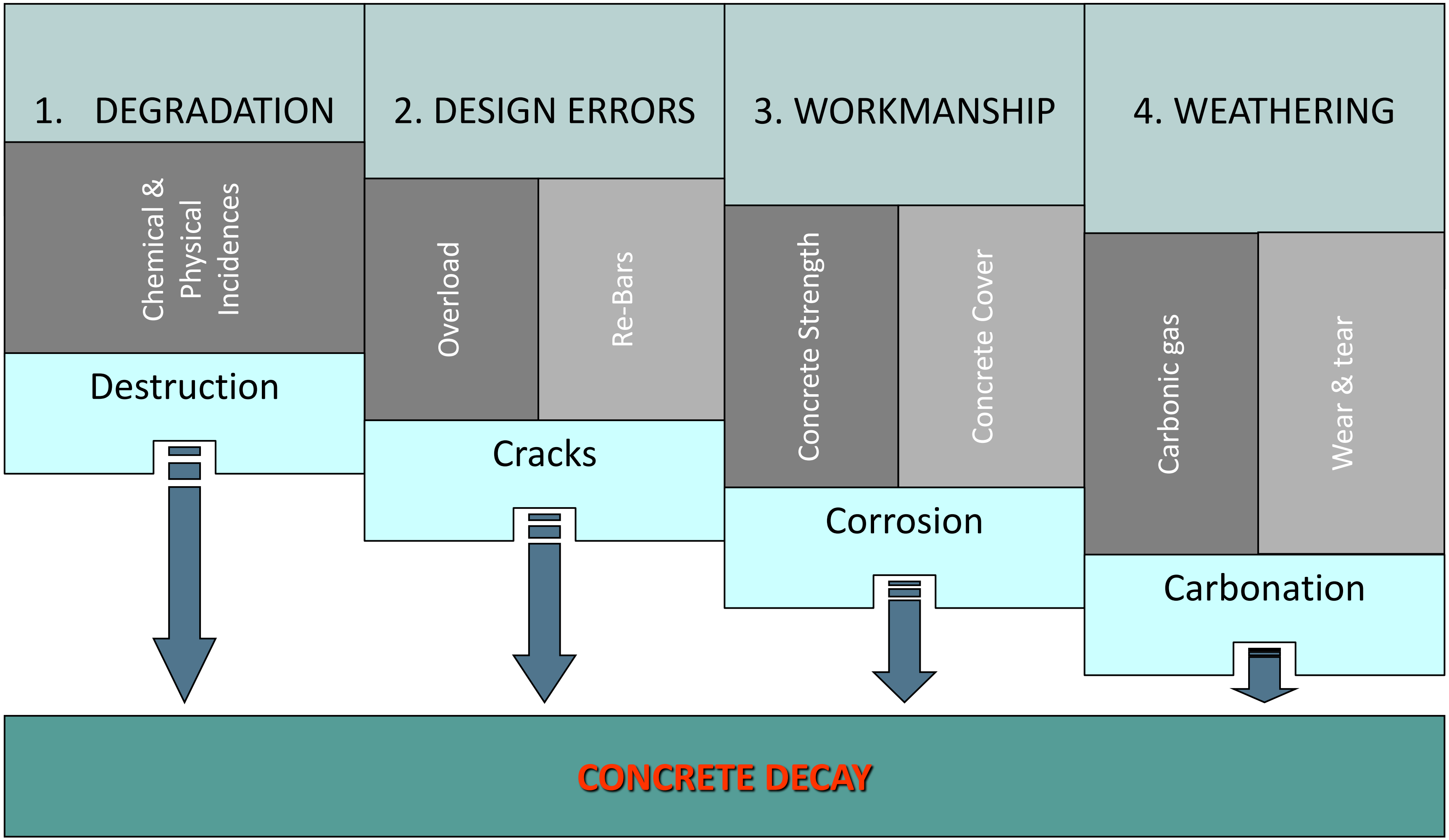
2. CAUSES OF CONCRETE DAMAGE

EXPOSURES
ROOT CAUSES
CORROSION
CARBONATION
CHLORIDE ATTACK

EXPOSURES ON REINFORCED CONCRETE



ORIGIN OF DECAY ARE MULTIPLE



ROOT CAUSES OF CONCRETE DAMAGE

MECHANICAL ATTACK

- Impact, overloading, movement
- Vibration, earthquake, explosion

PHYSICAL ATTACK

- Freeze-thaw, thermal movement, shrinkage
- Salt crystal expansion, erosion, abrasion, wearing

CHEMICAL ATTACK

- Alkali aggregate reaction, aggressive chemicals
- Bacterial, biolgical, efflorescence, leaching

REINFORCEMENT CORROSION

CHEMICAL ATTACK

- Carbonation
- Acids

CORROSIVE CONTAMINANTS

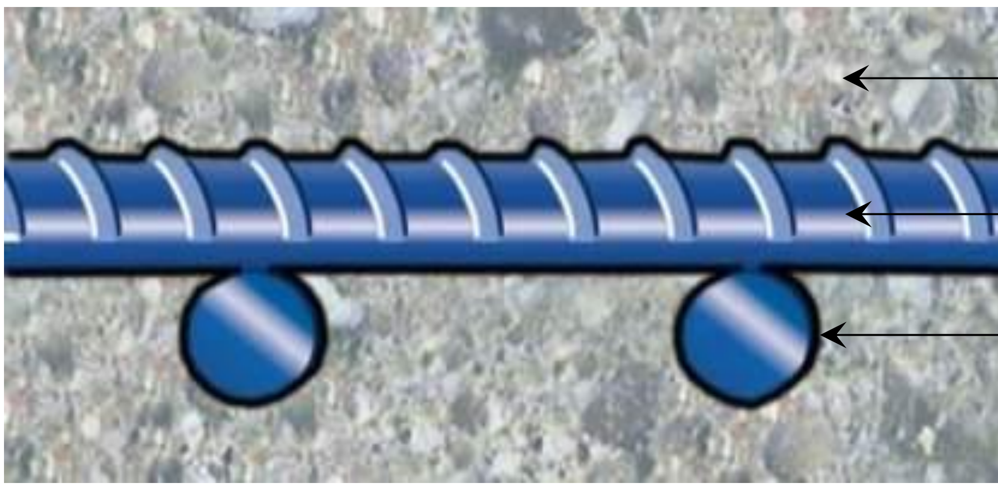
- Chlorides

STRAY ELECTRIC CURRENT

- Metals of different electro potential connected to each other
- From power supply or transmission works

PROTECTION OF STEEL IN CONCRETE

Alkaline environment protects reinforcing steel from corrosion

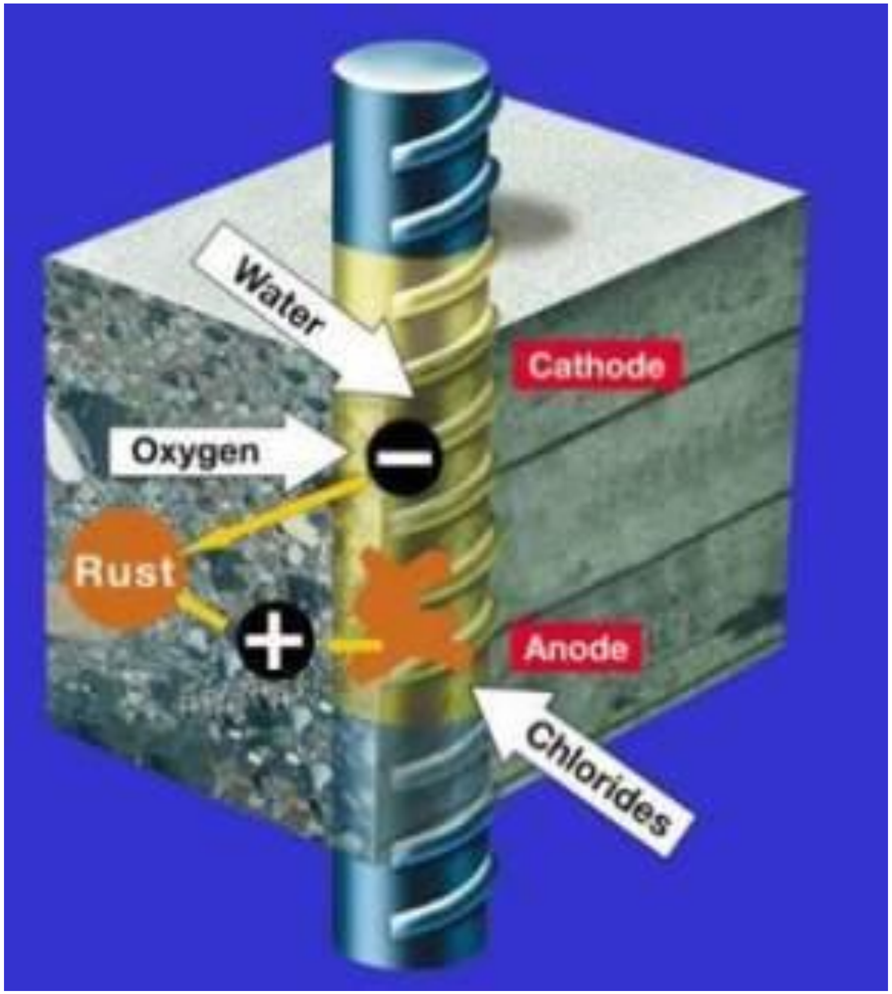


Concrete pH 12.5 - 13.5

Reinforcing steel

Passive iron oxides with max. layer thickness ~10Å (1.0 nm)

CONDITIONS FOR CORROSION OF STEEL IN CONCRETE



STAGE 1

Breakdown of the protective layer

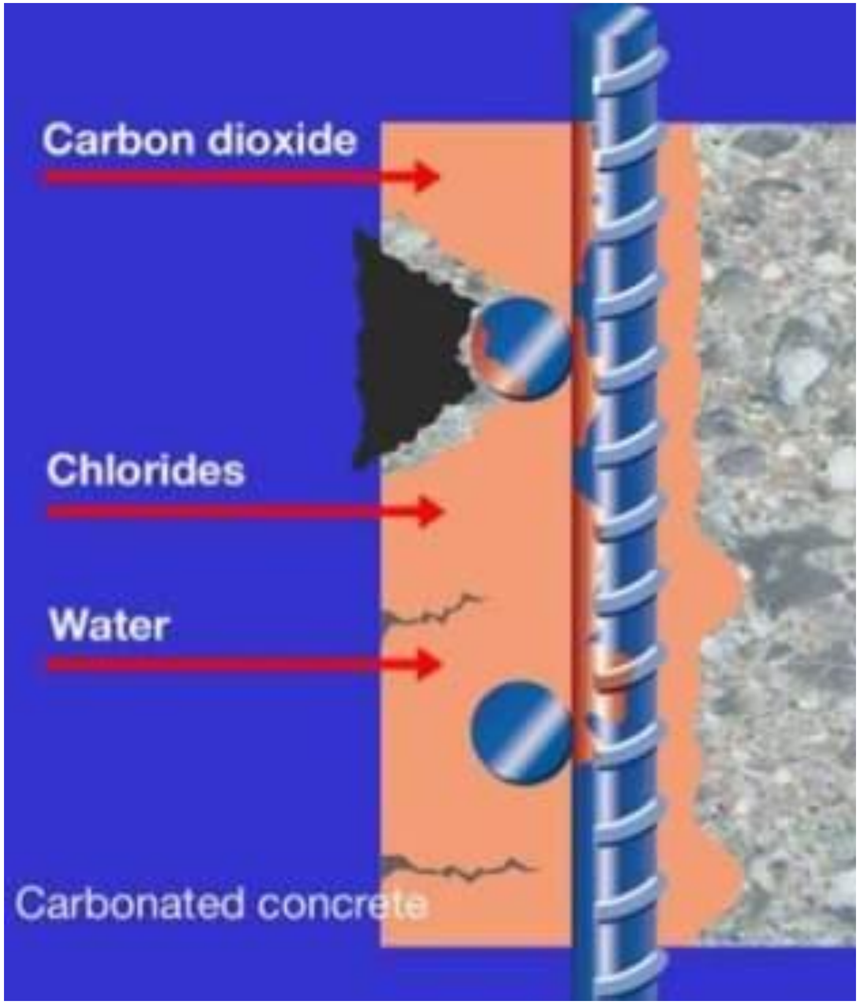
- By carbonation
- By chlorides

STAGE 2

Electrochemical process requires

- Electrolyte (moist concrete matrix)
- Anode
- Cathode

CORROSION OF STEEL IN CONCRETE



Concrete (pH = 12.5-13.5)
Steel is protected.

INITIATION PHASE

Destroying passive layer..
Carbon dioxide/chlorides enter.
pH reduces.   Steel unaffected

PROPOGATION PHASE

Steel Corrosion..
Moisture and oxygen
causes corrosion of steel

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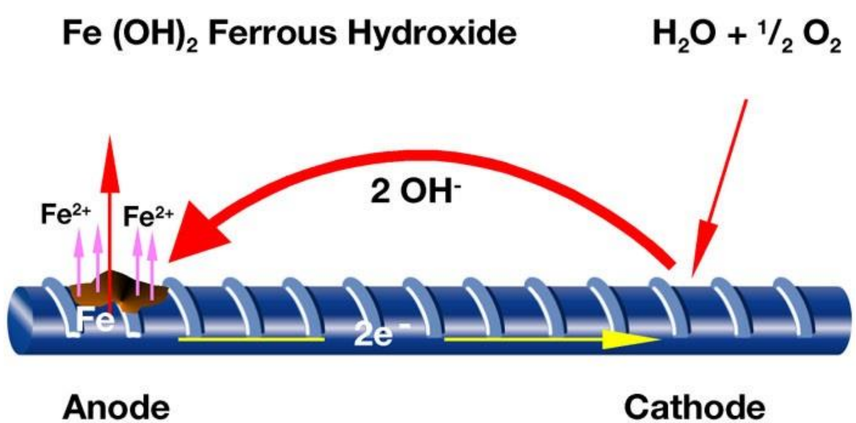
CORROSION PROCESS

corrosion = Redox reaction

$Fe + ½ O_2 + H_2O \rightarrow Fe^{2+} + 2 OH^-$



Oxidation

$Fe + 2 OH^- \rightarrow Fe(OH)_2 + 2e^-$

Reduction

$½ O_2 + H_2O + 2e^- \rightarrow 2 OH^-$

1. Electrical current flows between the anode and cathode
2. Iron(Fe) oxidised into Iron Hydroxide $Fe(OH)_2$
3. Results in increase in metal volume

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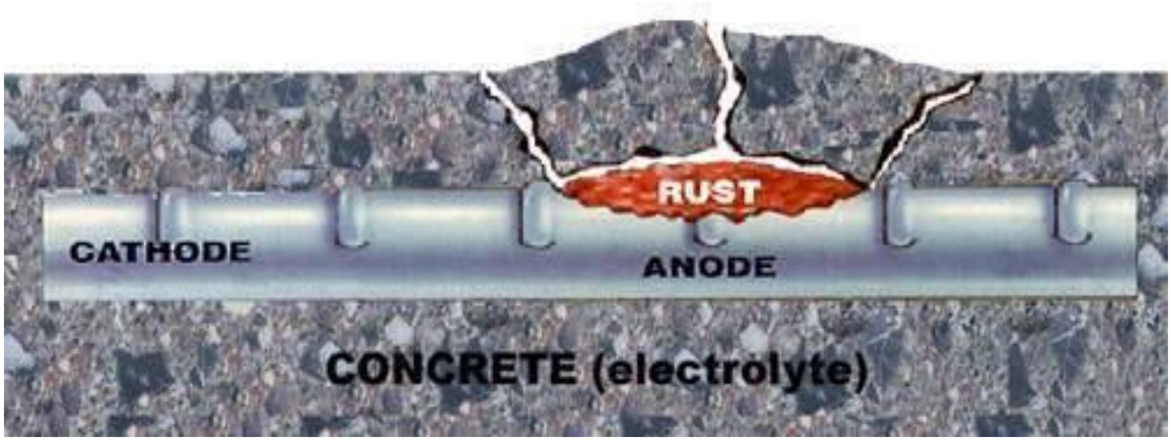
RESULT OF STEEL CORROSION IN CONCRETE

Volume of corrosion product is approx. 2,5 times bigger than black steel → delaminating load → spalling!



PROBLEM OF STEEL CORROSION

There is no "early warning system" for steel corrosion

It is the physical degradation of the steel reinforcement itself indicating the structure is exhibiting signs of distress

"Reactive" corrosion monitoring

INFLUENCES OF STEEL CORROSION IN CONCRETE

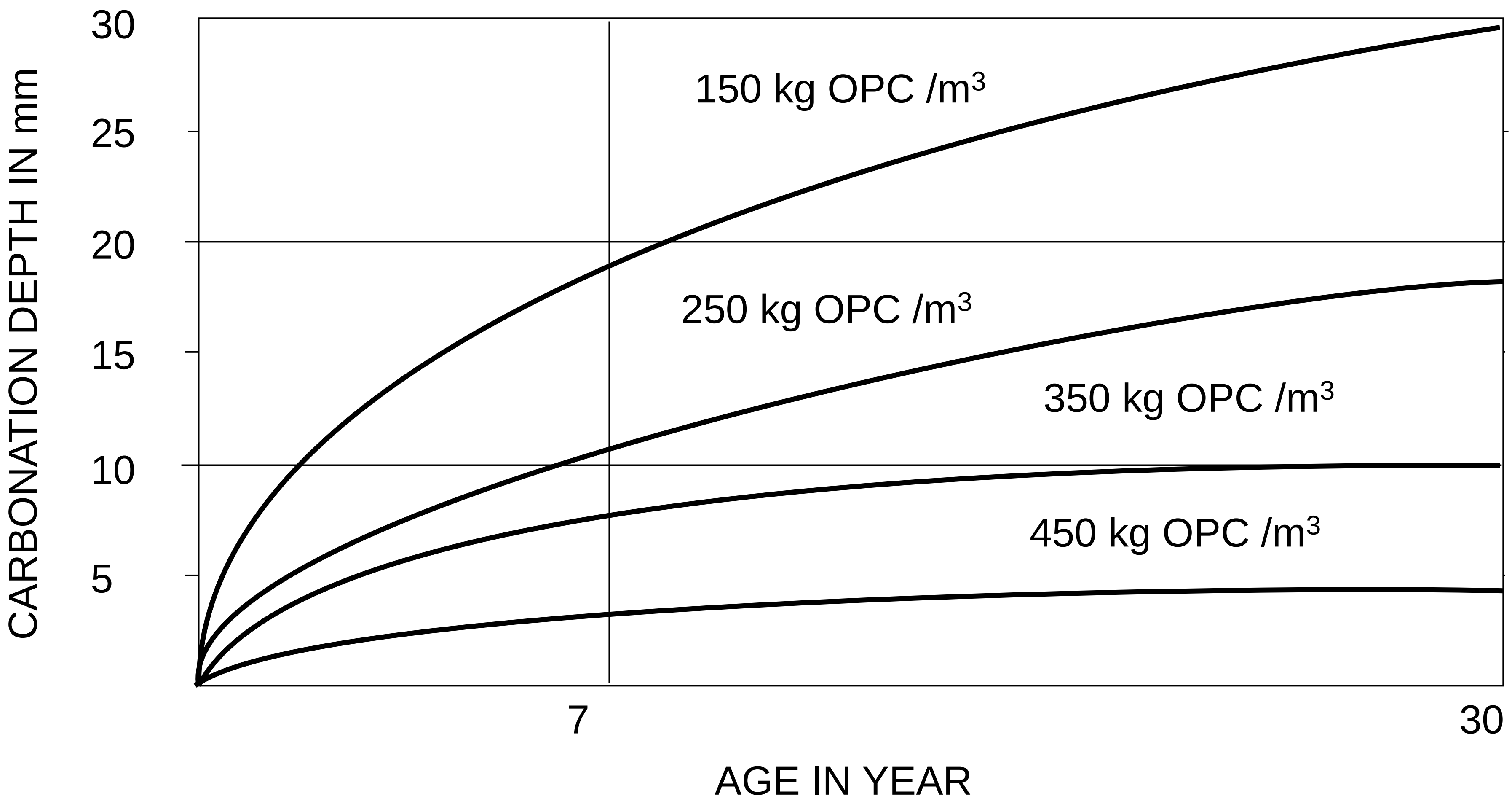
INDIRECT INFLUENCES

- Design - joints, cover
- Concrete – cement, type & content, water cement ratio, mixed
- Application - cracks, gravel nests, curing, surface finishing
- Conditions - humidity 50-70%, exposure conditions

DIRECT INFLUENCES

- Chlorides, atmospheric acidic gas, chemical attack

INFLUENCE OF CONCRETE QUALITY



CARBONATION OF CONCRETE STRUCTURE

Acidic gasses in atmosphere reacting cement hydration

CARBONATION DEFINITION

Reaction of the free Calcium-Hydroxide **$Ca(OH)_2$** in concrete with cardon-dioxide **CO_2**

Calcium-Hydroxide **$Ca(OH)_2$** = slaked lime; reaction of cement clinker and water

Calcium Carbonate **$CaCO_3$** = Limestone

Chemical equation:

$$Ca(OH)_2 + CO_2 \xrightarrow{\text{in } H_2O} CaCO_3 + H_20$$

(pH ca. 12.5 - 13.5) → **(pH < 9)**

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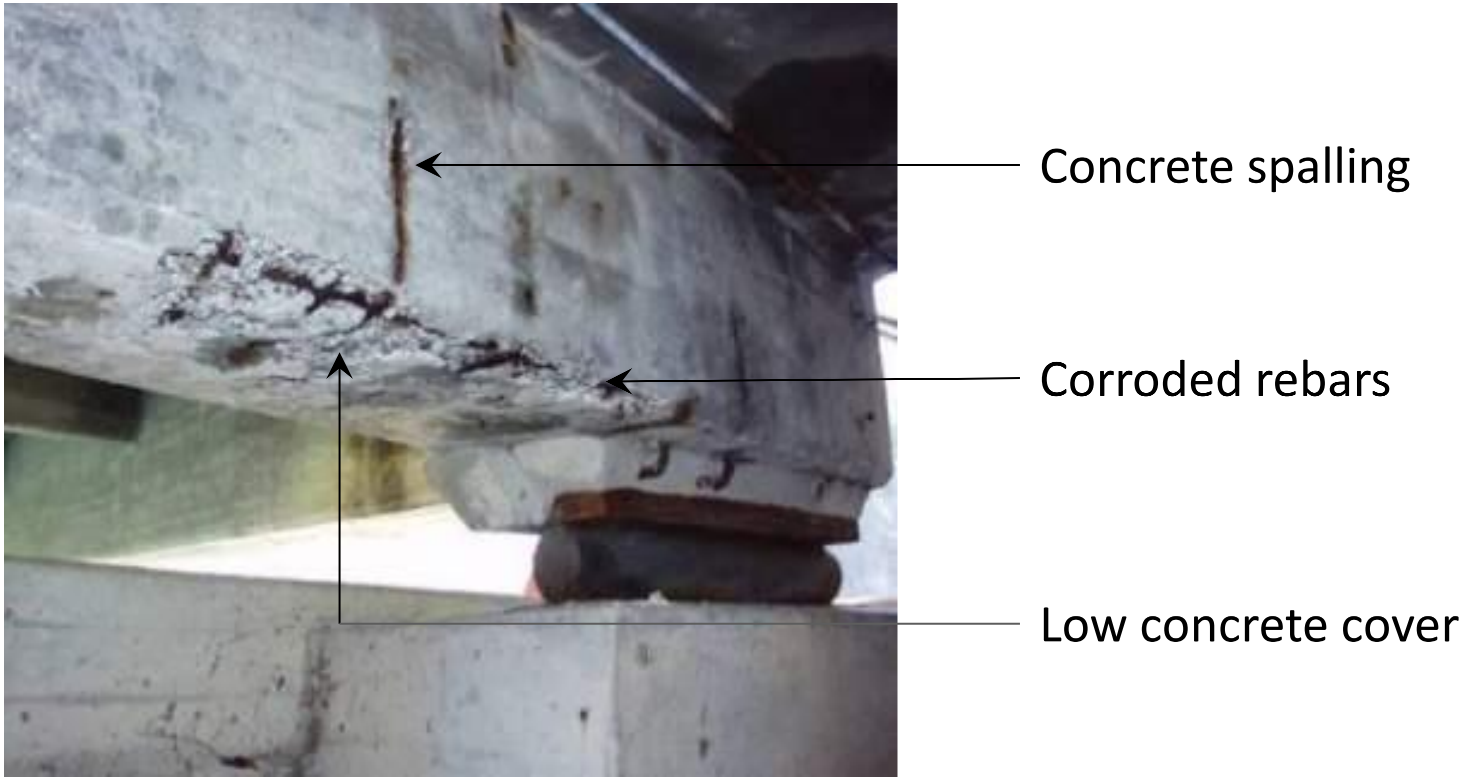
CORROSION DUE TO CARBONATION PROCESS

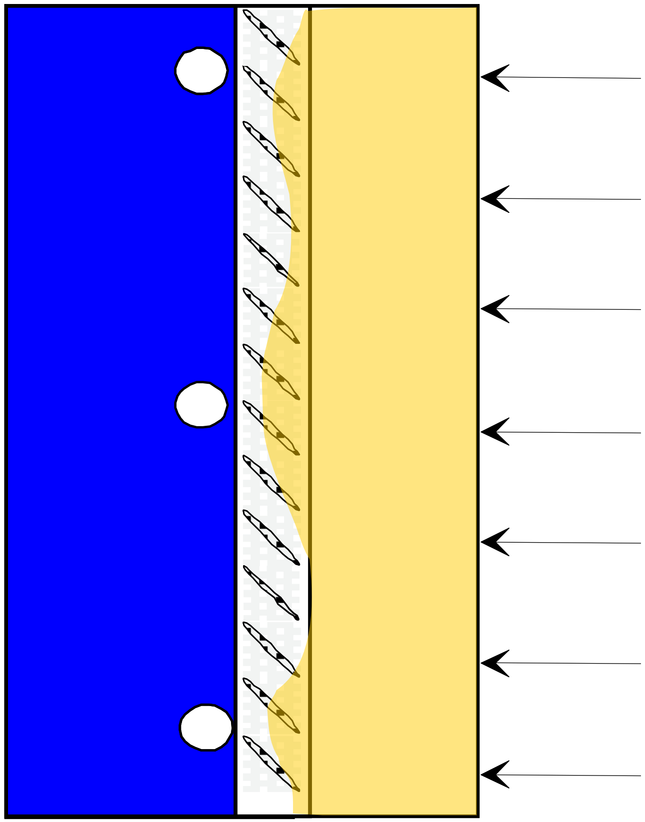


Reduction of rebar: approx. $^{2}/_{100}$ to $^{2}/_{10}$ mm per year

CHLORIDE ATTACK

- De-icing salt
- Sea water
- Industry salt (softening agent)
- Edible salt (cheese dairy, food production)
- Swimming pool (saline bath, water treatment, etc.)
- Magnetite floors ($MgCl_2$)
- Combustion of PVC

CHLORIDE INGRESS



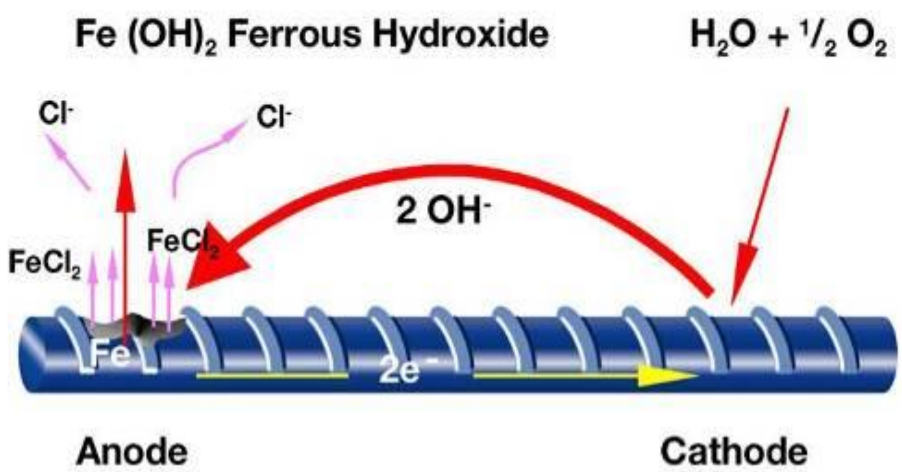
INFLUENCES

- Amount of chloride
- Concrete permeability
- Degree of moisture present

CONSEQUENCE

- Destroy passivity around steel
- Cause steel corrosion
- Concrete cracks and delaminates

PINHOLE CORROSION CAUSED BY CHLORIDES



Electrolyt: pore solution

<u>Particulars</u>

- Small surface of Anode ; large surface of Cathode
- Enrichment of chlorides
- Acceleration (catalyst) of reaction. Acid ambience.

→ Fast, local reduction of cross-section

CORROSION DUE TO CHLORIDE

Pinhole corrosion (localised)

De-icing salt (chlorides)

CORROSION OF REBARS DUE TO CHLORIDE

Reduction of rebar: approx. 1 to 10 mm per year!!

OTHER ATTACKS ON CONCRETE

- Frost Damage
- Alkali Aggregate Reaction (AAR) (Full Wiki Page in Connections)
- Chemical attack
- Sulphate attack – External (free) or internal (DEF)
- Leaching
- Etc..

FROST DAMAGE

- Mainly occurs in saturated concrete
- When approximately **91%** of pores are filled with water
- The freezing ice occupies ~ 9% more volume than water
- If there is no room for the water to expand, then it can distress concrete
- Commences with first freeze thaw-cycle
- Continues over successive winters
- Sometimes difficult to diagnose
- Hand in hand with other mechanisms (e.g. AAR)
- Then difficult to diagnose the initial damage mechanism

FROST DAMAGE RECOGNITION

Indications (if other mechanisms are excluded)

- Spalling and scaling of the surface
- Large chunks breaking off
- Exposing of aggregate
- Possible un-cracked exposed aggregate
- Parallel surface cracking
- Possible gaps around aggregate

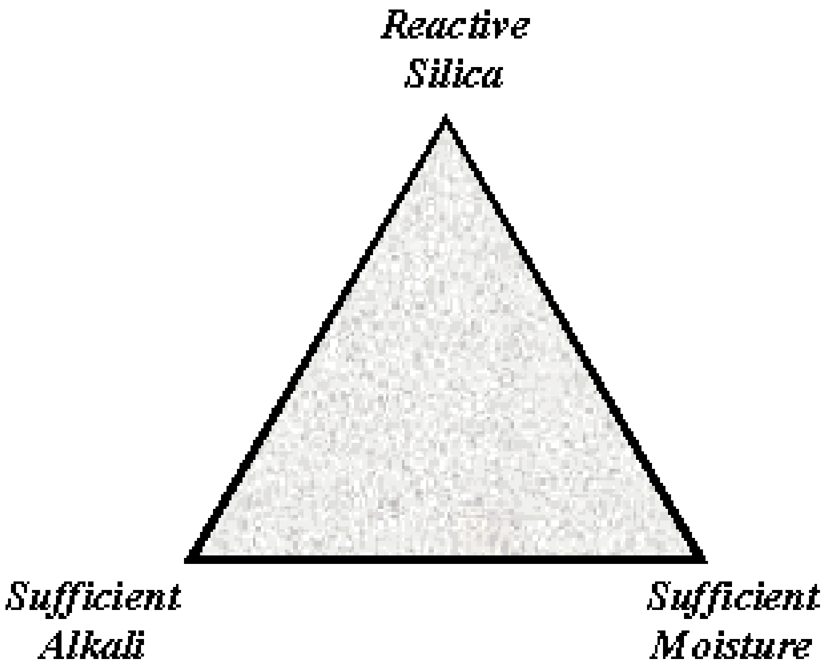
ALKALI AGGREGATE REACTION (AAR)

Certain natural aggregates react chemically with alkalis present in Portland cement

ALKALI-SILICATE REACTION

Three essential components:

- Reactive silica (from aggregates)
- Sufficient alkalis (mainly Portland Cement)
- Sufficient moisture



Eliminating any one will effectively prevent ASR damage

AAR DAMAGE

Unrestrained concrete element crazing cracking

- Uniform expansion in all directions

Restrained cracking mainly in direction of main reinforcement bars

EROSION BY CHEMICAL ATTACK

Concrete is alkaline therefore susceptible to acid attack

Dissolution of calcium hydroxide

Acidic environments can result in deterioration of exposed concrete surfaces

Depends on concrete porosity, concentration of acid, solubility of acid salts and migration through concrete

TYPES OF ACID

SULPHURIC ACID

- Very damaging as it combines an acid attack (soluble salt) and a sulphate attack

VERY AGGRESSIVE – Resulting salt easily soluble in water

- Nitric acid
- Hydrochloric acid
- Acetic acid

OTHERS – Resulting salt with low solubility (blockage of reaction)

- Phosphoric acid
- Humic acid

FREE - SULPHATE ATTACK

Sulphate solutions which react with calcium hydroxide and calcium aluminates, (C_3A)

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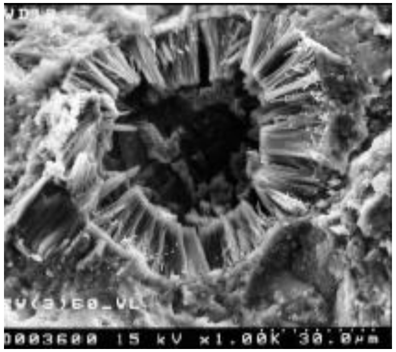
SULPHATE – ETTRINGITE FORMATION



- Sulphate is present in cement
- Early ettringite formation normally occurs in mortar

$$C_3A + 3(CaSO_4\ 2H_2O) + 26\ H_2O \longrightarrow C_3A\ 3C\bar{S} \cdot H_{32}$$

- Ground gypsum reacting with calcium aluminate and water
- Additional, sulphate-based expansive agents for shrinkage compensation

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3. STANDARDS & TEST METHODS

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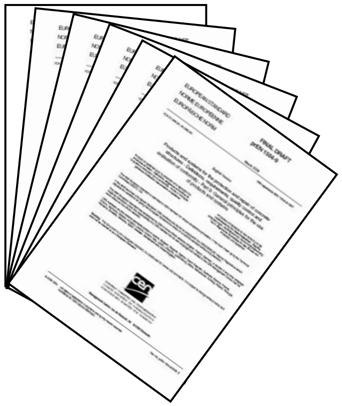
STANDARDS AND REQUIREMENTS

Europe: EN 1504

The EN 1504 consist of 10 main parts (EN 1504-1 to EN 1504-10) which covers about 65 standards for test methods for atmospherically exposed, buried and submerged concrete structures.



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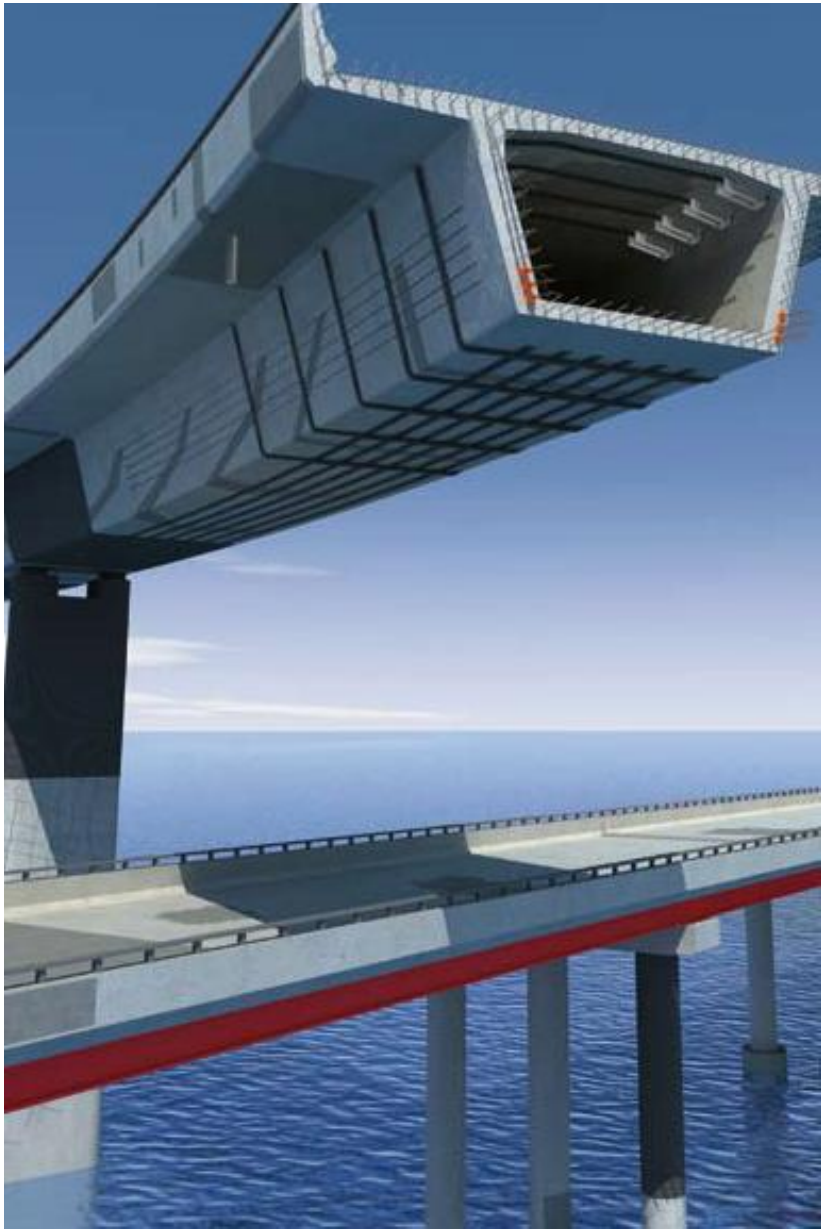
EN 1504

Products And Systems For The Protection And Repair Of Reinforced Concrete

- Definitions
- Requirements
- Quality Control
- Evaluation Of Conformity



EN 1504 - BACKGROUND

- International – all EU countries since 2009
- Most comprehensive repair specification in the world
- Covers:
  - Material specifications and quality
  - Repair and maintenance principles
  - Site investigation
  - Refurbishment strategies
  - Site application

IN-SCOPE

- EN 1504 *is about*
  - Environment and mechanical attack
  - Corroding reinforcement
  - Preventive maintenance
  - Most of the repair and refurbishment projects Sika are involved in

OUT-SCOPE

- EN 1504 *is not about*
    - Fire damaged structures
    - Modification due to change of use
    - Aesthetic improvements such as floor screeds, renders and plasters
    - Post tensioned structures

DEFINED PROJECT PHASES

- Information about the structure
- Process of assessment
- Maintenance strategy
- Design of repair work
- Repair work
- Acceptance of the works

THE 10 PARTS

Part	Content
Part 1	Definitions
Part 2	Surface protection systems
Part 3	Concrete repair with mortars
Part 4	Structural bonding
Part 5	Concrete injection
Part 6	Products and systems for grouting anchor reinforcement
Part 7	Reinforcement corrosion protection
Part 8	Quality control and evaluation of conformity
Part 9	General principles for use of products and system
Part 10	Site application of products and systems and quality control of the works

EN 1504-9 - PRINCIPLES

- Different types of damage and the root causes existed for many years
- The correct repair and protection methods have also been established
- This knowledge summarized by 11 Principles in Part 9
- Systematic approach to repair
  - Principles 1 to 6 relate to defects in the concrete
  - Principles 7 to 11 relate to damage due to reinforcement corrosion

PRINCIPLES AND METHODS

Principle	Description	Method
Principle 1 (PI)	**Protection against ingress.** Reducing or preventing the ingress of adverse agents, e.g. water, other liquids, vapour, gas, chemicals and biological agents.	1.1 Hydrophobic Impregnations 1.2 Impregnations 1.3 Coatings 1.4 Surface bandaging of cracks 1.5 Filling of cracks 1.6 Transferring cracks into joints 1.7 Erecting external panels 1.8 Applying membranes
Principle 2 (MC)	**Moisture control.** Adjusting and maintaining the moisture content in the concrete within a specified range of values.	2.1 Hydrophobic impregnations 2.2 Impregnations 2.3 Coatings 2.4 Erecting external panels 2.5 Electrochemical treatment
Principle 3 (CR)	**Concrete restoration.** Restoring the original concrete to the originally specified profile and function. Restoring the concrete structure by replacing part of it.	3.1 Hand applied mortar 3.2 Recasting with concrete or mortar 3.3 Spraying concrete or mortar 3.4 Replacing elements

Principle 4 (SS)	**Structural strengthening.** Increasing or restoring the structural load bearing capacity of an element of the concrete structure.	4.1 Adding or replacing embedded or external reinforcing bars 4.2 Adding reinforcement anchored in pre-formed or drilled holes 4.3 Bonding plate reinforcement 4.4 Adding mortar or concrete 4.5 Injecting cracks, voids or interstices 4.6 Filling cracks, voids or interstices 4.7 Prestressing (post-tensioning)
Principle 5 (PR)	**Physical resistance.** Increasing resistance to physical or mechanical attack.	5.1 Coatings 5.2 Impregnations 5.3 Adding mortar or concrete
Principle 6 (RC)	**Resistance to chemicals.** Increasing resistance of the concrete surface to deteriorations from chemical attack.	6.1 Coatings 6.2 Impregnations 6.3 Adding mortar or concrete

PRINCIPLES AND METHODS

Principle	Description	Method
Principle 7 (RP)	**Preserving or restoring passivity.** Creating chemical conditions in which the surface of the reinforcement is maintained in or is returned to a passive condition.	7.1 Increasing cover with additional mortar or concrete 7.2 Replacing contaminated or carbonated concrete 7.3 Electrochemical realkalisation of carbonated concrete 7.4 Realkalisation of carbonated concrete by diffusion 7.5 Electrochemical chloride extraction
Principle 8 (IR)	**Increasing resistivity.** Increasing the electrical resistivity of the concrete.	8.1 Hydrophobic impregnations 8.2 Impregnations 8.3 Coatings
Principle 9 (CC)	**Cathodic control.** Creating conditions in which potentially cathodic areas of reinforcement are unable to drive an anodic reaction.	9.1 Limiting oxygen content (at the cathode) by saturation or surface coating
Principle 10 (CP)	**Cathodic protection.**	10.1 Applying an electrical potential
Principle 11 (CA)	**Control of anodic areas.** Creating conditions in which potentially anodic areas of reinforcement are unable to take part in the corrosion reaction.	11.1 Active coating of the reinforcement 11.2 Barrier coating of the reinforcement 11.3 Applying corrosion inhibitors in or to the concrete

Sika MonoTop®-412 N

R4 Structural Repair Mortar

Product Description Sika MonoTop®-412 N is a 1-component, fibre reinforced, low shrinkage structural repair mortar meeting the requirement of class-R4 of EN 1504-3.

Uses

- Suitable for restoration work (Principle 3, method 3.1 & 3.3 of EN 1504-9). Repair of spalling and damaged concrete in buildings, bridges, infrastructure and superstructure works.
- Suitable for structural strengthening (principle 4, method 4.4 of EN 1504-9). Increasing the bearing capacity of the concrete structure by adding mortar.
- Suitable for preserving or restoring passivity (principle 7, method 7.1 and 7.2 of EN 1504-9). Increasing cover with additional mortar and replacing contaminated or carbonated concrete.
- Tested application under live dynamic loading

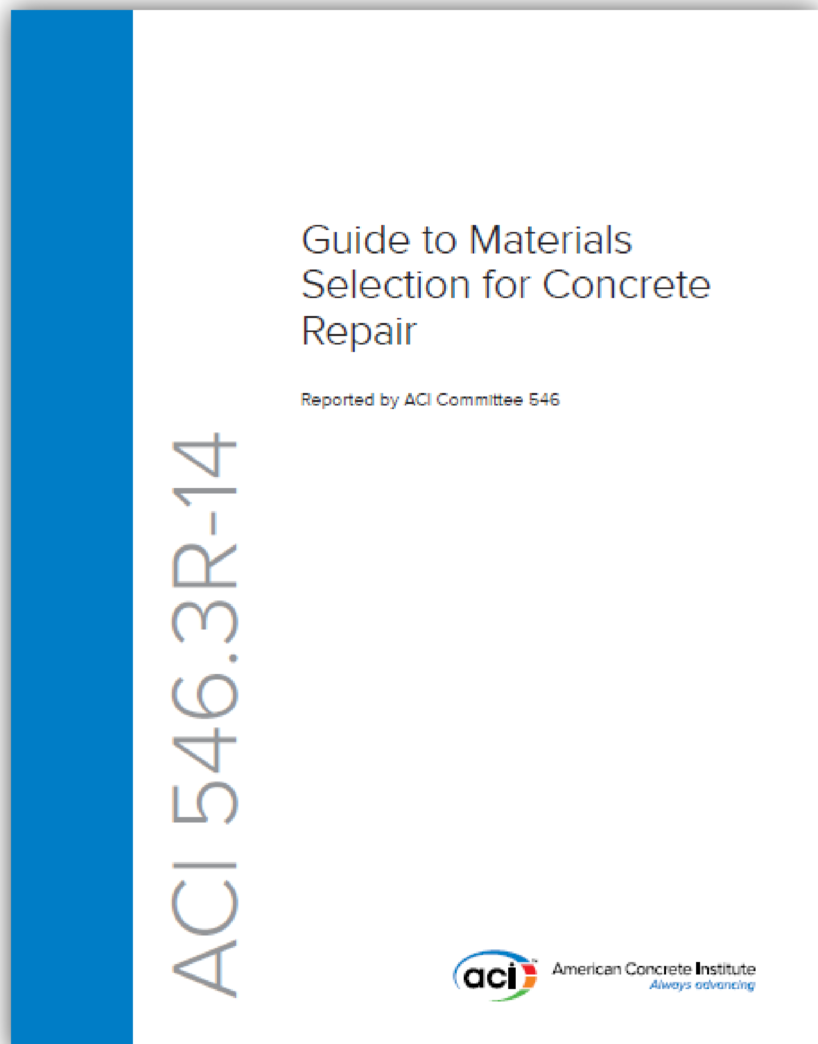
Example Product Data Sheet

DURATION EUROPEAN TEST METHODS

Test Method	Approximate Total Test Duration
Compressive Strength	During 28 days up to 91 days
Chloride Ion Content	~0.5 day
Adhesive Bond	After 28 days
Restrained Shrinkage Expansion	During 28 days up to 91 days
Carbonation Resistance	~3 months
Elastic Modulus	After 28 days
Thermal Compatibility	~5.5 weeks (freeze-thaw)
Coefficient of Thermal Expansion	After 28 days
Capillary Absorption	~1.5 weeks

According to test methods Table3 EN 1504-3

NORTH AMERICAN GUIDELINE


Guide to Materials Selection for Concrete Repair

Reported by ACI Committee 546

ACI 546.3R-14

American Concrete Institute
Always advancing

AMERICAN CONCRETE INSTITUTE

ACI 546.3R-14

Guide to Materials Selection for Concrete Repair

EUROPEAN AND ACI COMPARISON

Performance Characteristic	European Test Method	ASTM Test Method
Compressive / Flexural Strength	Y	Y
Tensile strength	No requirement EN 1504-3	Y
Chloride Ion Content	Y	Y
Adhesive Bond	Y	Y
Slant shear bond	No requirement EN 1504-3	Y
Restrained Shrinkage Expansion / Length change	Y	Y
Carbonation Resistance	Y	
Elastic Modulus	Y	Y
Freeze Thaw	Y	Y
Scaling resistance	No European test method*	Y
Coefficient of Thermal Expansion / Thermal Expansion	Y	Y
Skid / Abrasion Resistance	Y	Y
Capillary Absorption	Y	Y
Creep	Certain uses (anchoring)	Y
Rapid chloride permeability	No European test method*	Y
Alkali aggregate reaction	No requirement EN 1504-3	Y
Sulphate resistance	No requirement EN 1504-3*	Y

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NORTH AMERICAN APPROACH TO DURABILITY

Service Conditions	Related Characteristics	Standard Test Method
Climate: Temperature fluctuations Ambient Moisture	Thermal expansion/contraction Freezing and thawing resistance	Freeze-Thaw – ASTM C666 Proc A &B
Exposure: Applied salts/salt water, Aggressive chemicals	Chloride permeability Scaling resistance Chemical resistance	Chloride Perm. – ASTM C1202 Scaling Resistance – ASTM C672
Loads: Traffic, wind, earthquake	Abrasion resistance Creep/shrinkage Strength Modulus of elasticity	Abrasion – ASTM C 944 Creep – ASTM C 512 Shrinkage - ASTM C 157 Elasticity - ASTM C 469 Strength - ASTM C39

RAPID CHLORIDE PERMEABILITY

DETERMINATION OF ELECTRICAL CONDUCTANCE

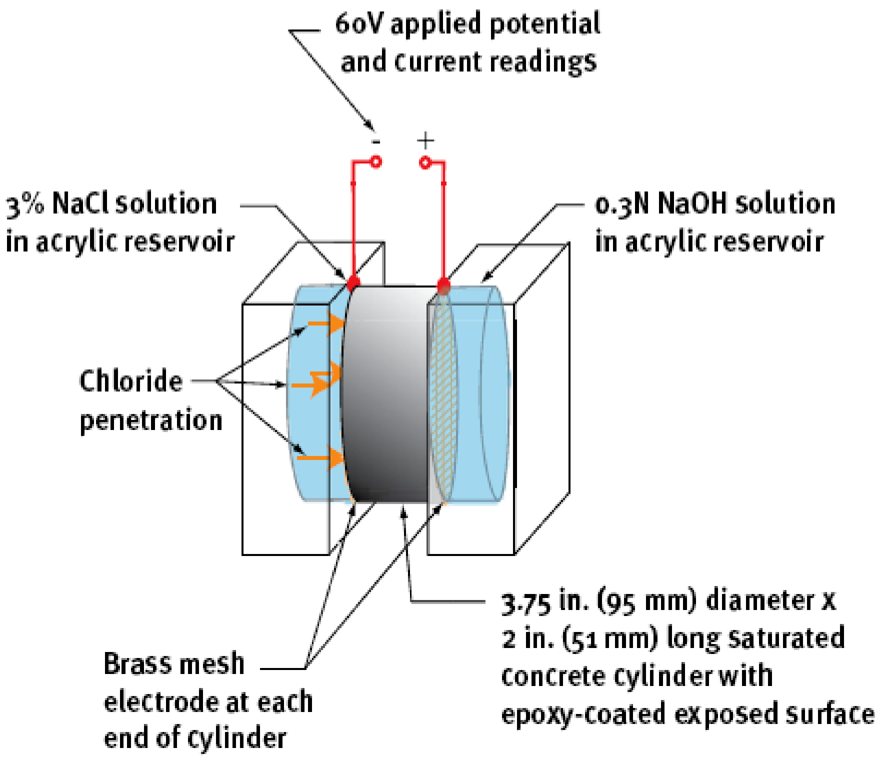


Fig. 1: Schematic of rapid chloride permeability test setup

- ASTM 1202
- Concrete core
- Coated epoxy
- Vacuum saturated with water
- Remove & expose one end to Sodium Chloride (NaCl) the other end Sodium Hydroxide (NaOH)
- Apply 60 V potential
- Measurements every 30 minutes for 6 hours

RATING SYSTEM

Chloride ion penetrability based on charge passed

Charge passed, coulombs	Chloride ion penetrability
>4000	High
2000 to 4000	Moderate
1000 to 2000	Low
100 to 1000	Very low
<100	Negligible

As chlorides penetrate deeper pore solution becomes more conductive and current readings increase

Area under graph of time vs. current gives charge passed, Coulomb

Does not measure depth or rate of chloride penetration

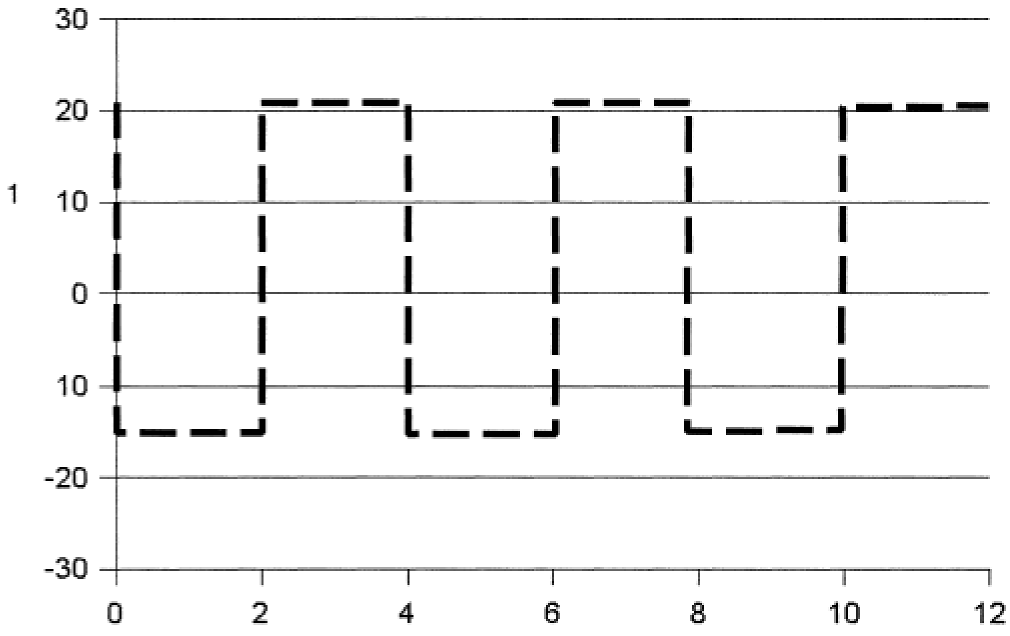
DURABILTY TESTING

FREEZE-THAW TEST METHODS

- 50 cycles - European – EN 13687-1
- ~300 cycles North American – ASTM C666

  ASTM C672 Scaling
- 200 (EN 13687-1) cycles - Polish Standard
- 400 cycles Swiss Standard - BEII

EUROPEAN FREEZE-THAW TEST



THERMAL COMPATIBILITY

EN 13687-1

- Samples 300 x 300 test plates
- Apply and cure 6d under water
- 21 day in controlled conditions
- Inspect surface
- Store x2 under water 24 hours
- Begin shock FT cycle

- 2h immersed vertically in sodium chloride (-15 ±2) deg
- 2h stored in water tank vertically (+21 ±2) deg
- 50 cycles
- Inspection every 10 cycles, record cracks flacking etc
- Performance related to pull off strength EN 1542
- Classify according T.3 EN 1504-3

SCALING

Apart from steel corrosion, the repeated action of de-icing chemicals has the potential to cause scaling, pitting and spalling of concrete surfaces.

THEORY

1. De-icing chemicals melt the ice
2. The concrete thaws
3. Melt water is absorbed by concrete
4. The concrete surface becomes more saturated
5. If concrete surface freezes, it undergoes a freeze-thaw cycle

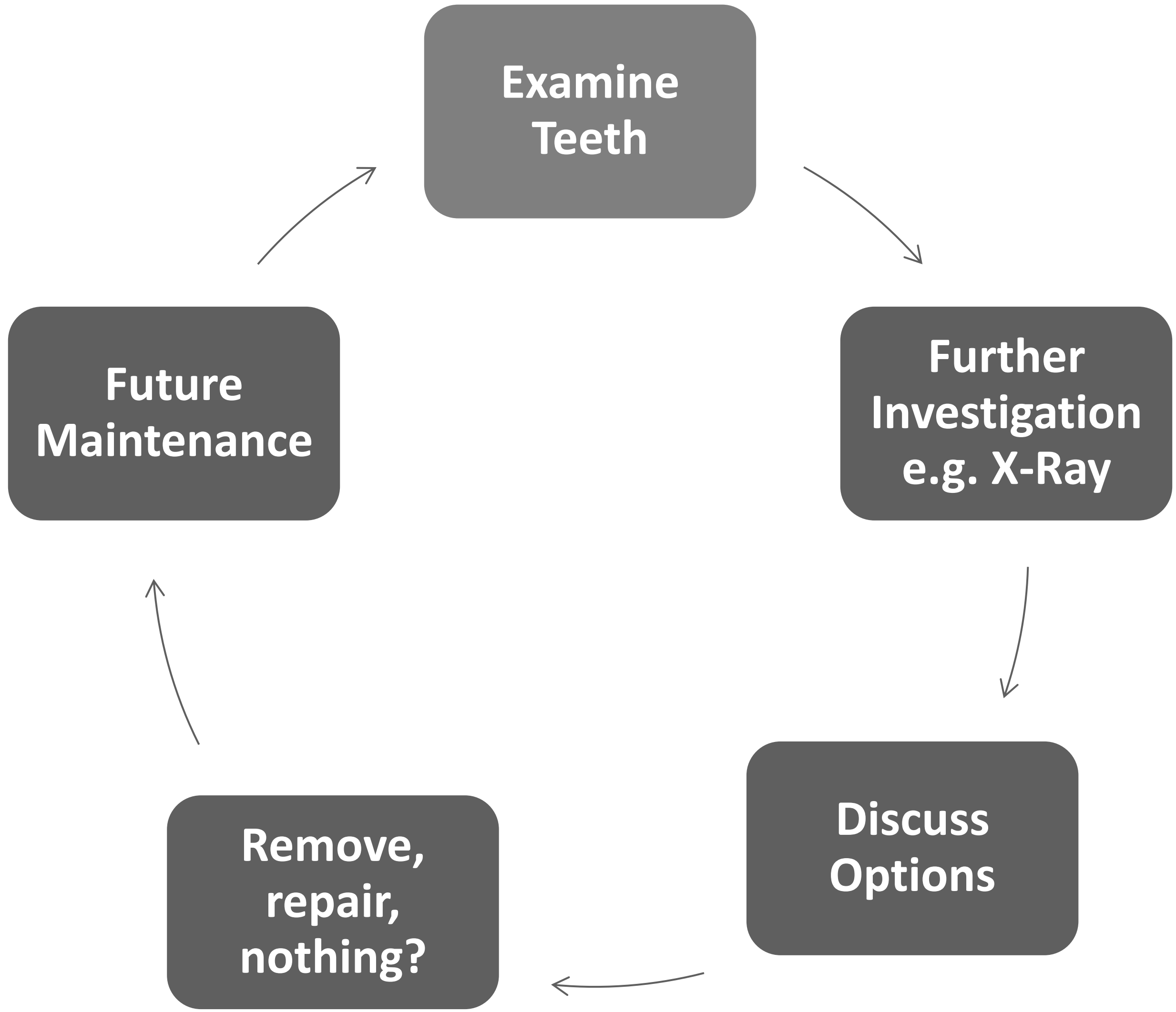
The surface would not undergo a freeze thaw cycle had it remained frozen.

4. THE REPAIR PROCESS

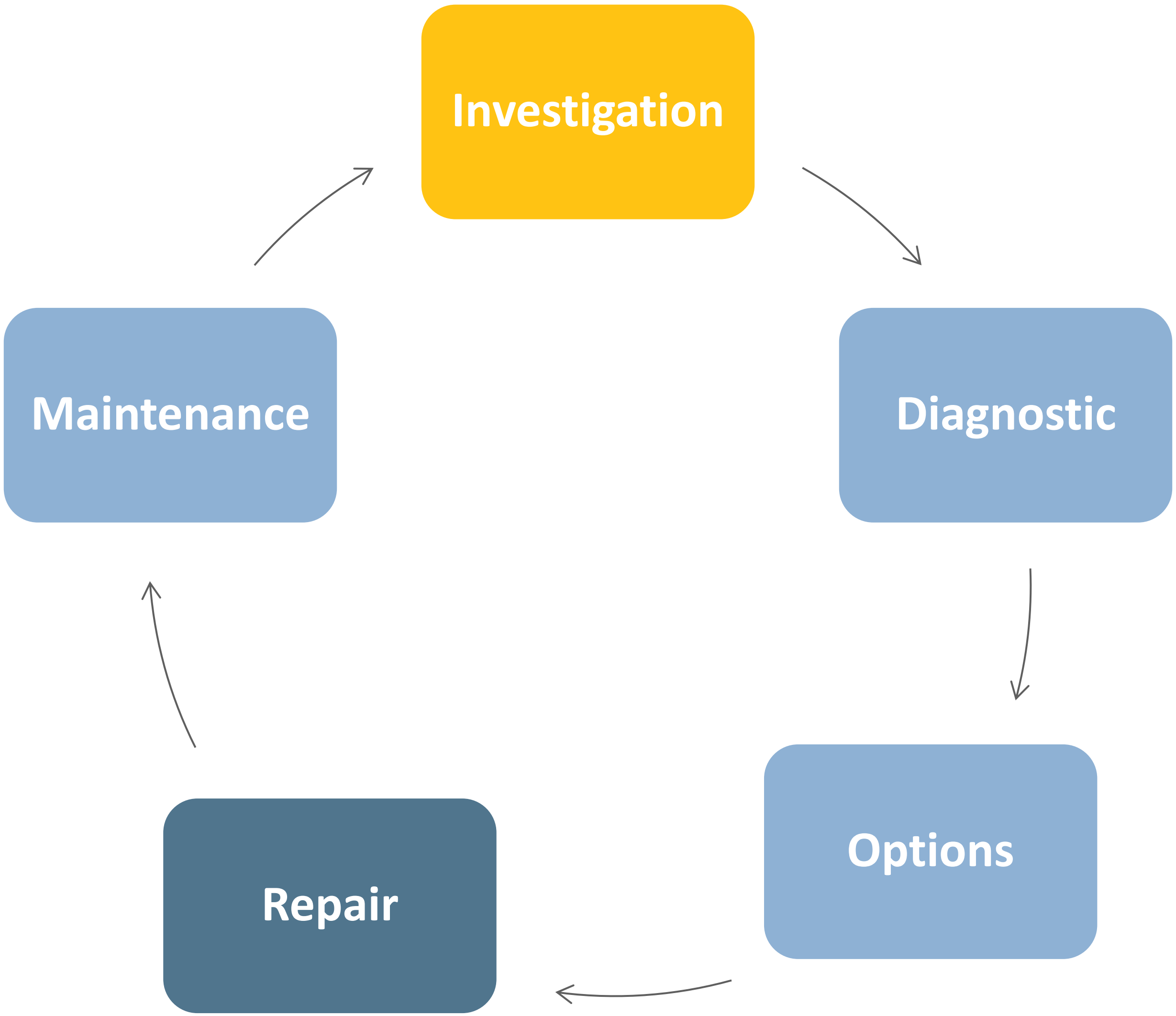
AT THE DENTIST

Repairing concrete is very much like going to the dentist

KEY STAGES AT THE DENTIST



5 KEY STAGES IN CONCRETE REPAIR



INTERVENTION STRATEGY

PROACTIVE

- **Ideally** - early warning system but;
  - Inability to monitor steel corrosion;
  - Would be costly

- **Ideally**, a monitoring strategy
  - Owner's responsibility
  - Planned maintenance schedule
  - Budget to cover costs

REACTIVE

- The **reality**
- Indication by physical degradation
  - Often too late, damage is done
  - Time lapse to actual repair
  - Sometimes no survey
  - Sometimes no planning
  - Lead to unsuccessful repair
  - Ultimately, costly

SURVEY/MONITORING

AIM OF INVESTIGATION/MONITORING

Determine the **effect**

Identify the **cause**

What is the **consequence?**

KEY STAGES

STAGE 1 – VISUAL INSPECTION

- Review past, current & future use
- Visual aspects

STAGE 2 - DIAGNOSTIC

- Non-destructive testing
- Destructive test or probing
- Laboratory analysis

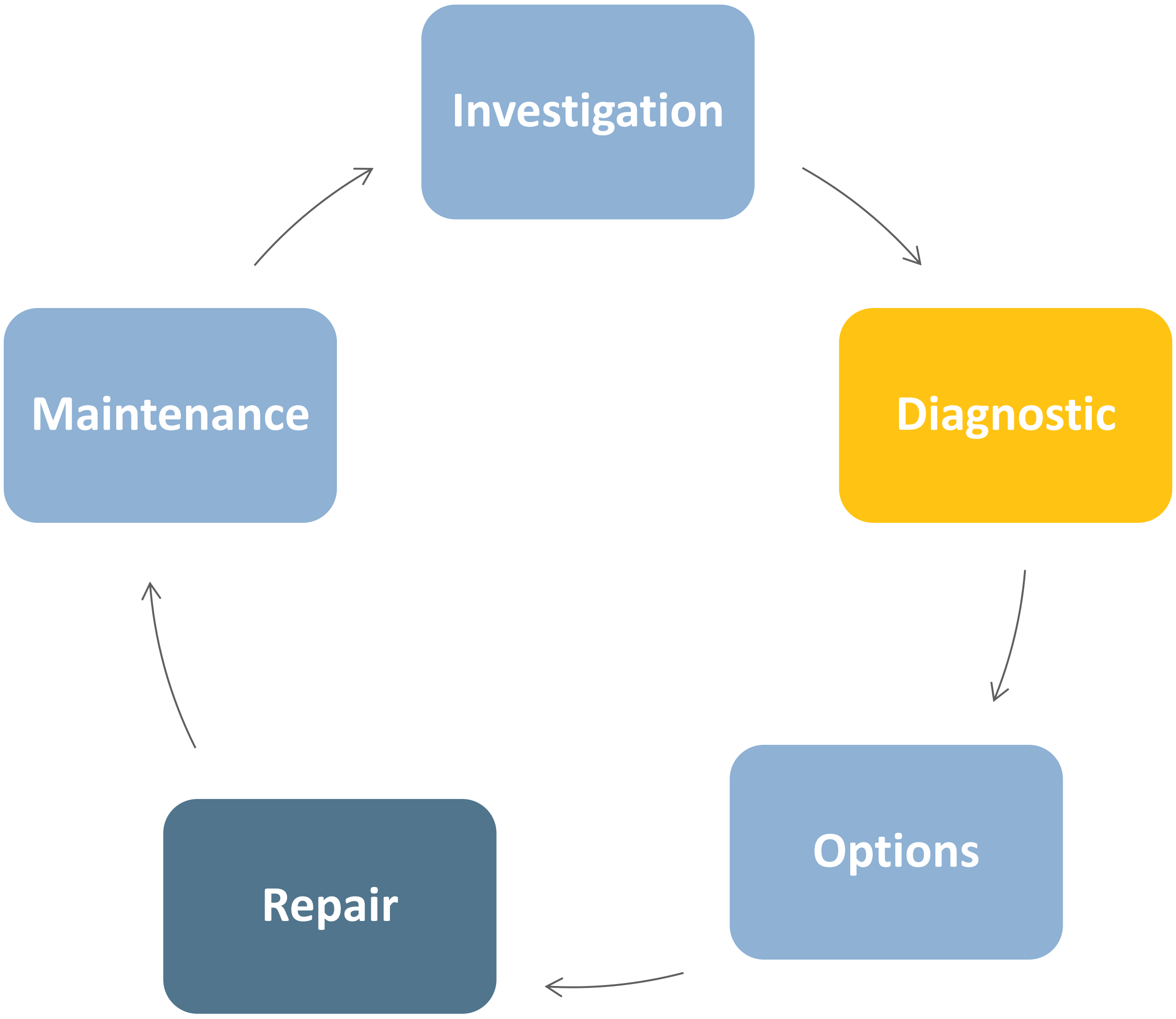
STAGE 1 – VISUAL INSPECTION
LOOKING FOR THE OBVIOUS

- Environmental influences
- Service influences
- Visual damages

REPORTING
VISUAL INSPECTION

- Service conditions
- Cracks
- Spalling concrete
- Bar corrosion
- Discolouration
- Damp patches
- Efflorescence
- Cavities
- Surface texture
- Etc.

5 KEY STAGES IN CONCRETE REPAIR



KNOWN ROOT CAUSES OF CONCRETE DAMAGE

MECHANICAL ATTACK

PHYSICAL ATTACK

CHEMICAL ATTACK

MECHANICAL PROPERTIES

i. SURFACE HARDNESS TESTING

ii. WINDSOR PROBE

iii. CYLINDRICAL CORE TESTING

iv. SURFACE TENSILE STRENGTH

v. ULTRASONIC PULSE VELOCITY (UPV) TEST

I. REBOUND HAMMER

- EN 12504
- ASTM C805

- Determines **surface** hardness
- Shows general uniformity
- Identifies potential problems
- It is NOT compressive strength

I. HAMMER SOUNDING

Tapping a concrete surface to determine the presence of delaminating or bonding problems

e.g. ASTM C803

II. WINDSOR PROBE

Can determine compressive strength of hardened concrete

e.g. EN 12390-1

III. CYLINDRICAL CORE TESTING

Cores drilled out of concrete can determine

1. Compressive strength
2. Static E-Modulus
3. Carbonation depth
4. Density

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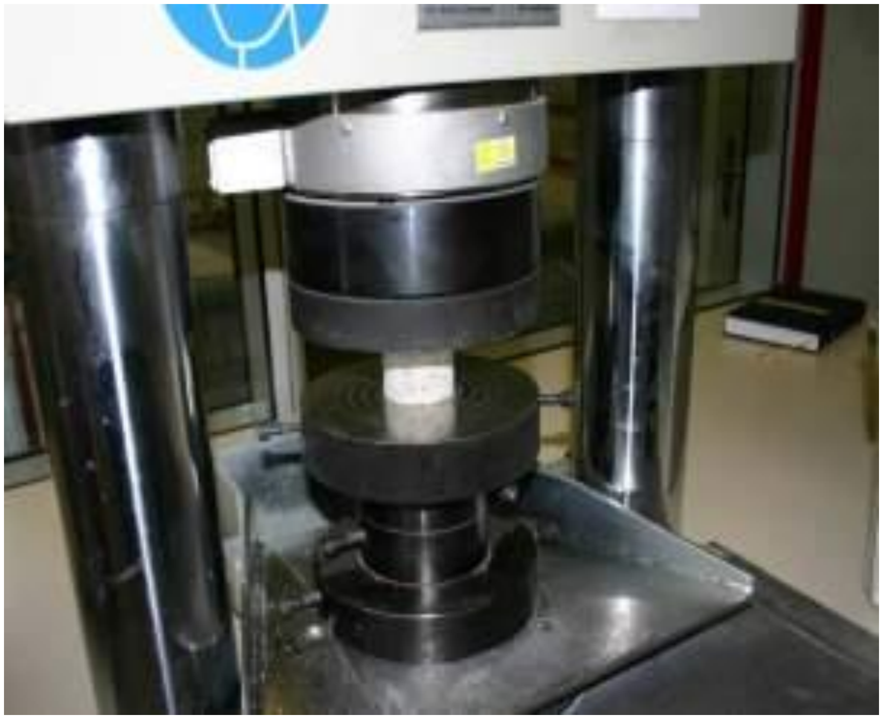
e.g. EN 12504-1

COMPRESSIVE STRENGTH

ASTM C39 / C42



Core test to determine compressive strength of the concrete

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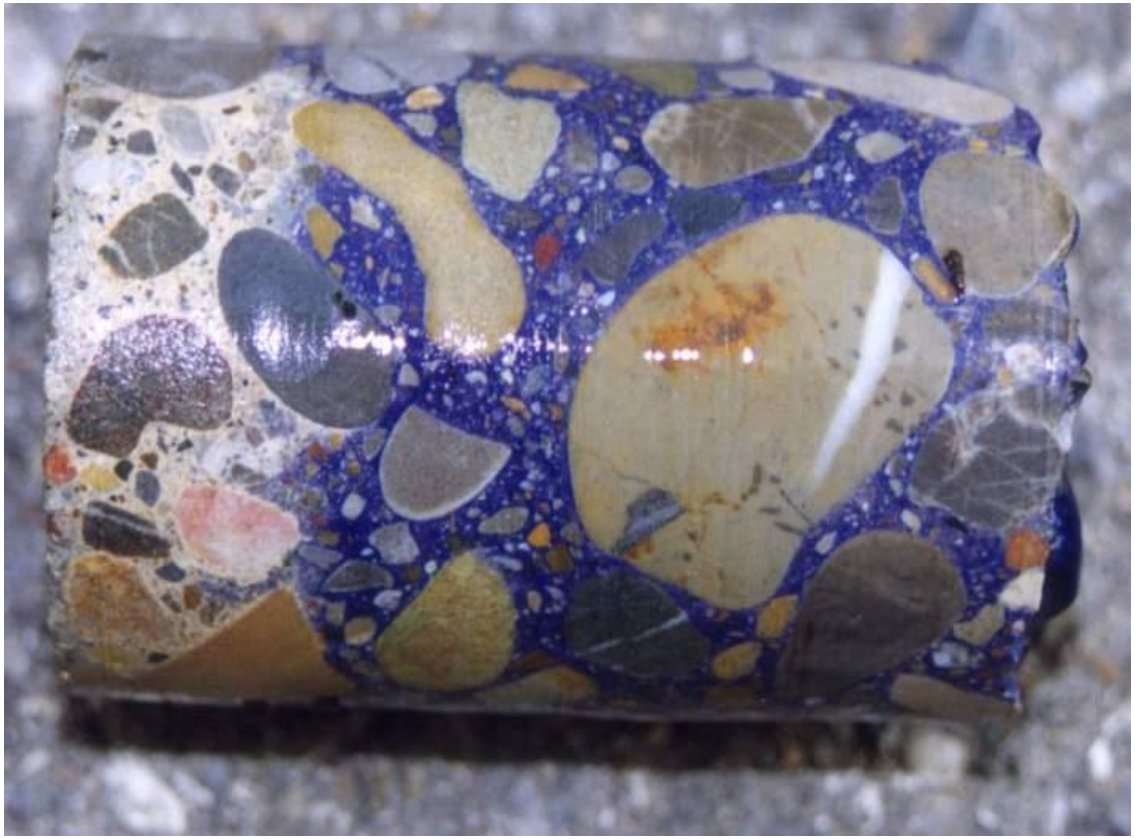
STATIC E-MODULUS IN COMPRESSION

e.g. ASTM C469
ISO 6784

Test on drilled core sample to determine static modulus of elasticity in compression

TEST FOR CARBONATION DEPTH



IV. SURFACE TENSILE STRENGTH

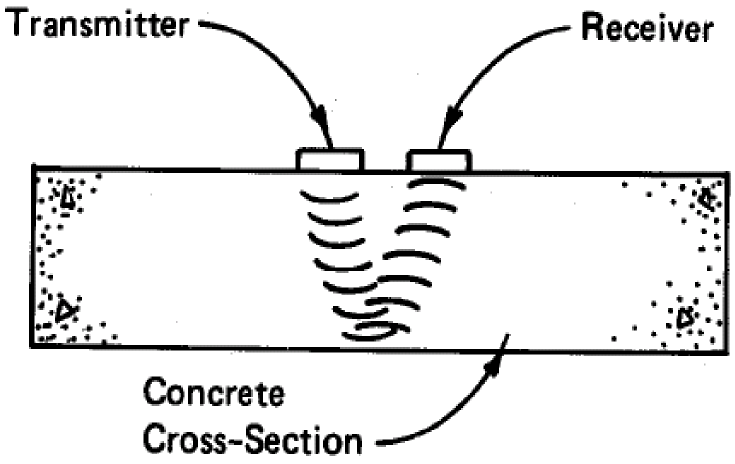
Indication of concrete strength by pull off measurement

e.g. EN 12504-2

V. ULTRA PULSE VELOCITY

Transmit a wave of fixed frequency through a transmitter and receiver

USES OF ULTRA PULSE VELOCITY



- Concrete uniformity
- Presence of voids, cracks etc
- Layer thickness
- Monitoring

PHYSICAL PROPERTIES

i. CONCRETE COVER SURVEY
ii. PERMEABILITY TEST
iii. GAS DIFFUSION TEST
iv. SORPTIVITY TEST

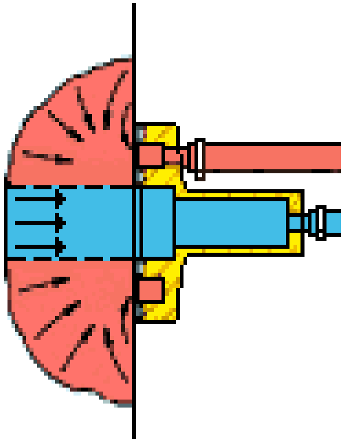
VI. CONCRETE COVER SURVEY

Can measure location, bar size and depth of reinforcement embedment

Simple location using magnets

FERROSCAN

VII. CONCRETE PERMEABILITY



Vacuum cell

Determine permeability of a concrete surface e.g. BS 1881-208

VIII. GAS DIFFUSION TEST

Determines initial surface absorption of concrete

Rate of flow of water into concrete surface subjected to 200 mm constant head

BUILDING TRUST

e.g. DIN 1045

IX. ABSORPTION TEST

Measuring water penetration depth after subjected to a specified bar water pressure for 3 days

CHEMICAL TESTING

i. CARBONATION TESTING
ii. CHLORIDE CONTENT TESTING
iii. PETROGRAPHY TEST
iv. CORROSION SURVEY (HALF CELL POTENTIAL)
v. CORROSION SURVEY (LINEAR POLARISATION)

e.g. EN 14630

X. CARBONATION TESTING

Acid based indicator indicates parts of concrete which are not carbonated (purple) e.g. EN 14629

XI. CHLORIDE TESTING

Chloride test kit

Dust samples collected from concrete for analysis of free chloride content

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XII. PETROGRAPHY ANALYSIS

MICROSCOPY TECHNIQUE

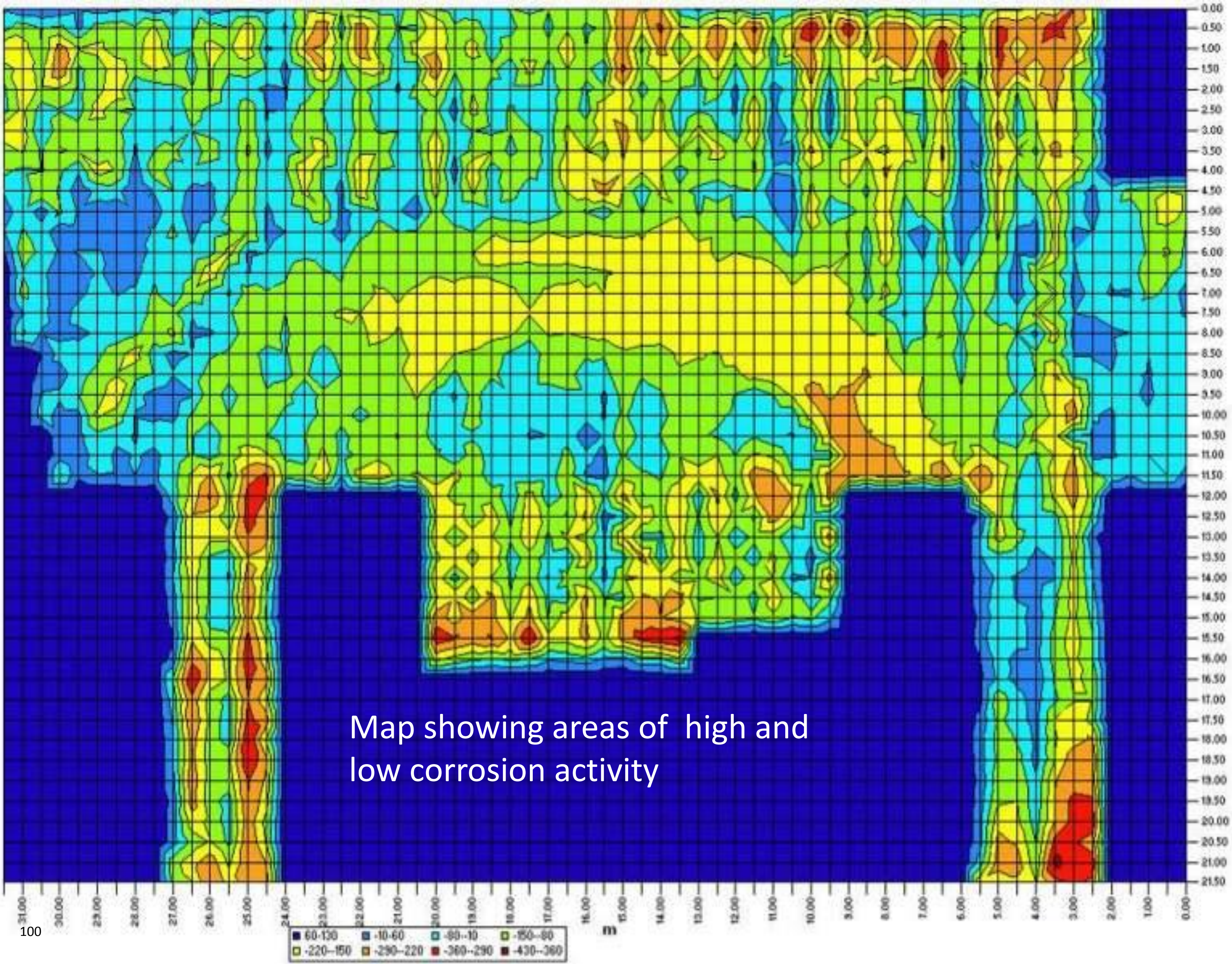
- Detailed examination of concrete
- Evaluation of distressed concrete
- Quality and quantity of material
- Nature and causes of deterioration

e.g. ASTM C876-87

XIII. HALF CELL POTENTIAL

- Measures potential corrosion activity
- Identify corrosion risk at early stage
- Does not determine corrosion rate
- Does not determine degree of corrosion


6



Map showing areas of high and low corrosion activity

FURTHER REFERENCES

ACI 201.1R-08 – Guide for Conducting a Visual Inspection of Concrete in Service

ACI 364.1R-07 - Guide for Evaluation of Concrete Structures before Rehabilitation

ACI 228.2R-98 – Non-Destructive Test Methods for Evaluation of Concrete in Structures

ICRI - Guideline N° 210.4-2009 Guide for Non-Destructive Evaluation Methods for Condition Assessment, Repair and Performance Monitoring of Concrete Structures

THE CONCRETE SOCIETY– Diagnostic of Deterioration in Concrete Structures

BUILDING RESEARCH ESTABLISHMENT (UK) – Digest 444 Part 1 Corrosion of Steel in Concrete, Durability of Reinforced Concrete Structures

- Digest 434 Corrosion of Reinforcement in Concrete, Electrochemical Monitoring

FURTHER REFERENCES

EUROPEAN STANDARD - EN 1504-9
General Principles for the Use of Products and Systems

YOUR COUNTRY?

5. MATERIAL TECHNOLOGY

MATERIAL TECHNOLOGY

European Standard EN 1504 defines three main groups of mortars

CC	Cement Concrete
PCC	Polymer modified cement concrete
ECC	**Sika Speciality Modified Epoxy (EpoCem)**
PC	Polymer Concrete

CEMENT CONCRETE (CC)

~50-70 %

Filler
(Sand and/or Aggregates)

~0.4 -0.45 w/c

Water
(potable)

~25-30 %

Binder
(Cement)

When mixed together sets by hydration reaction

CC mortars contains additives to modify properties

POLYMER CEMENT CONCRETE (PCC)

~50 - 70 %

Filler
Sand and/or Aggregates

~0.4 – 0.45 w/c

Water
(Potable)

~1 - 3 %

Re-dispersible
Polymer / Additives

~25 - 30 %

Binder
(Cement)

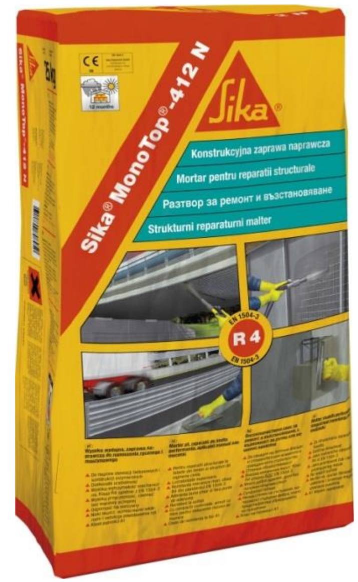
When mixed together sets by hydration reaction

Polymer may be added 5 – 15 % by weight of cement

POLYMER DISPERSIONS

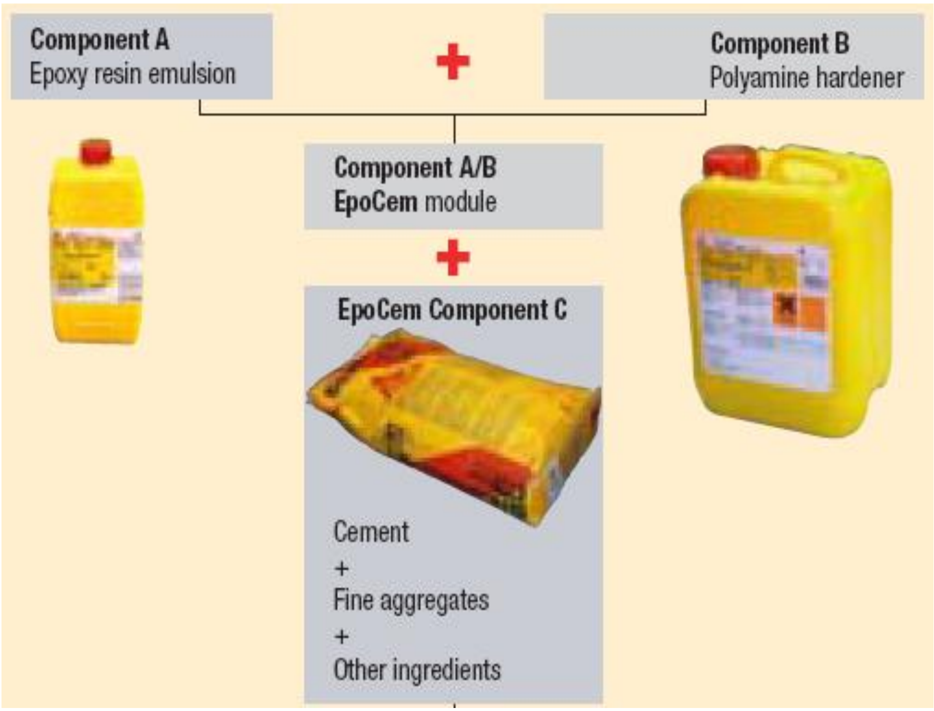
Polymers form films and adds binding domains within the cement pore system

Polymer Dispersion
(Liquid State)



Re-dispersible Polymer Powder

EPOXY CEMENT CONCRETE (ECC)



Combining the physical properties of the cement with the positive chemical properties of a water based epoxy resin

20 years best experiences and references, worldwide.

EpoCem

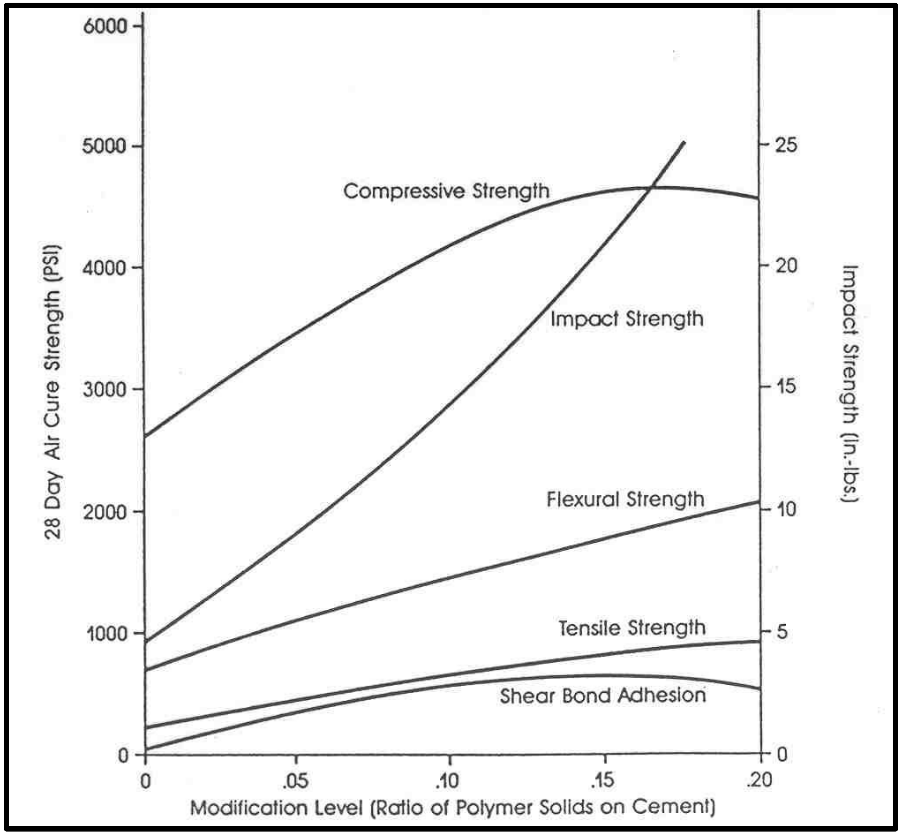
SHRINKAGE

PLASTIC SHRINKAGE	DRYING SHRINKAGE	CHEMICAL SHRINKAGE	AUTOGENIOUS SHRINKAGE	THERMAL SHRINKAGE
Evaporation of Water		Reaction	Self desiccation	
Drying out of concrete surface **BEFORE** it has set	Drying out of concrete surface **AFTER** it has set	Volume of fresh material is greater than volume of hardened material	Water consumption from cement hydration at low water-cement ratio	Temperature gradient causing strains
FACTORS INFLUENCING SHRINKAGE				
• Grading curve • Wind • Temperature • Solar radiation • Curing • W/C ratio • Shrinkage reducer • Accelerators	• Wind • Temperature • Solar radiation • Curing • W/C ratio • Shrinkage reducer • Accelerators	Natural occurrence	• Grading curve • Shrinkage reducer • Accelerators • Internal curing	• Structural thickness • Hydration temperature • Fast cooling of surface

DISADVANTAGES OF UNMODIFIED MORTARS

- High water demand for workability
- Potentially incomplete hydration (especially thin sections)
- Poorer adhesion
- Poorer chemical resistance
- Lower freeze/thaw stability
- Lower durability
- Higher brittleness
- Lower tensile and flexural strength
- Lower abrasion resistance
- Lower impact resistance

POLYMER EFFECTS

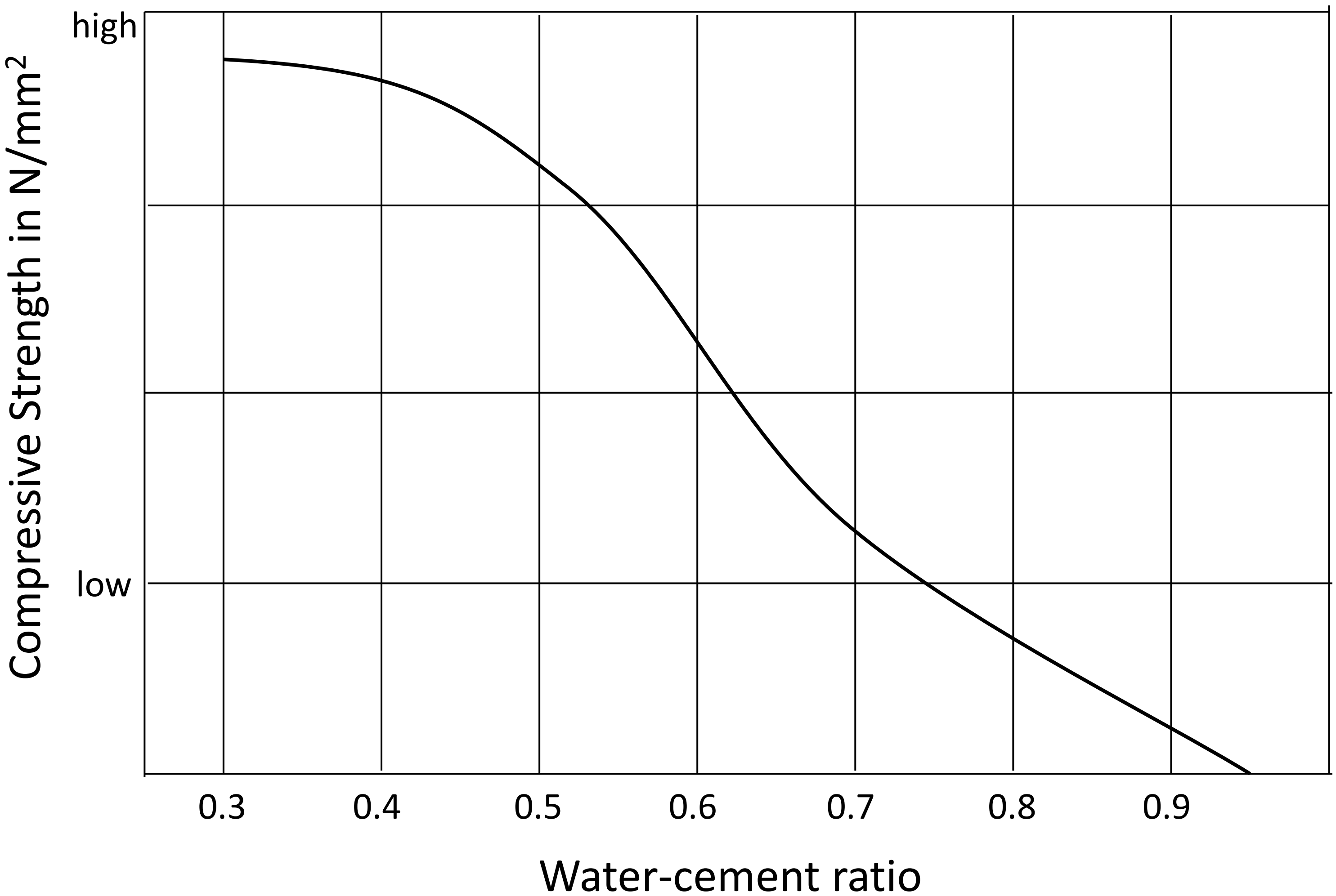


- Increase flexural strength
- Increase bond strength
- Reduced permeability
- Increase protection against corrosion

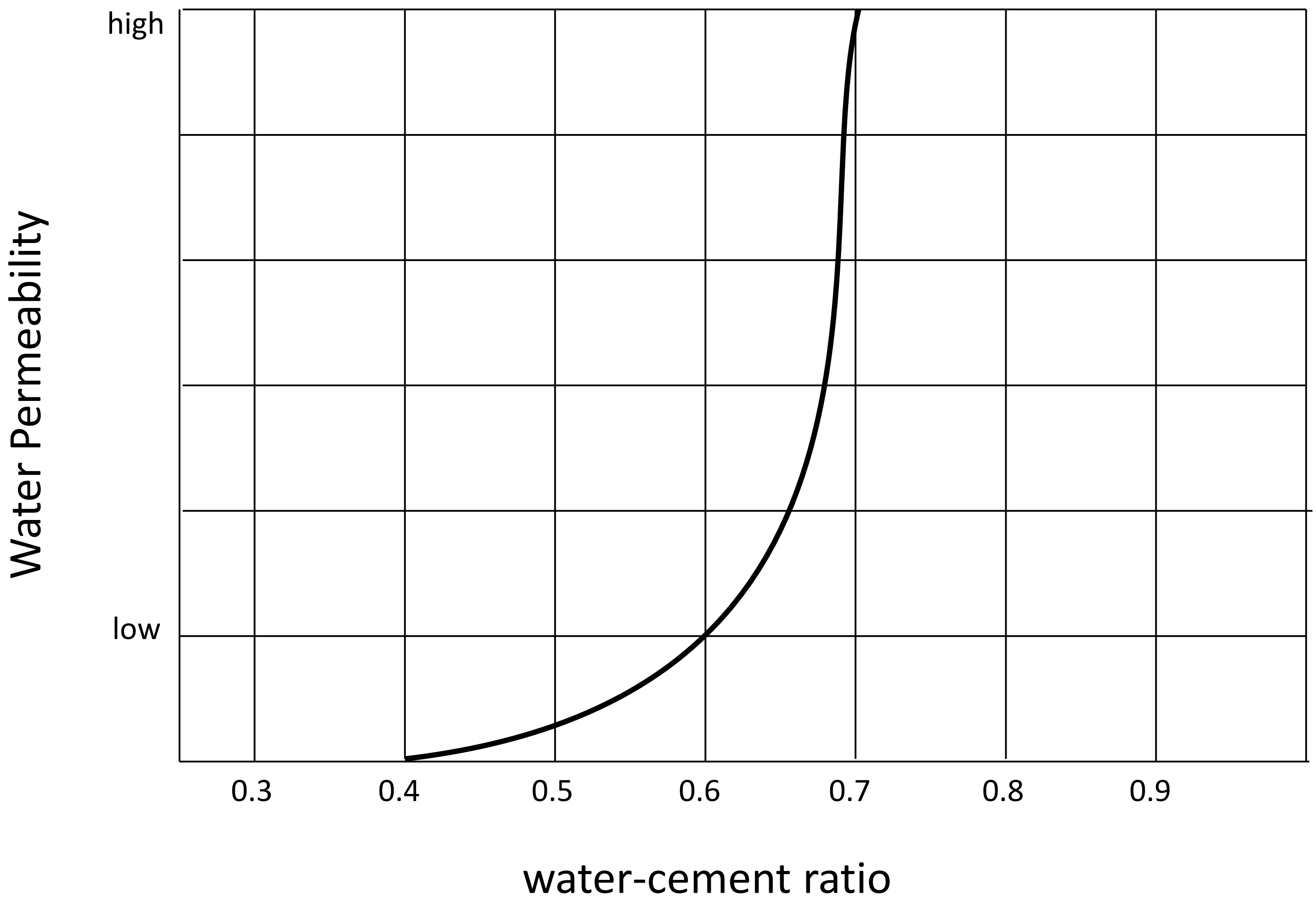
MORTAR TECHNOLOGIES

- Mechanical strengths
- Physical resistance (Freeze/Thaw action, shrinkage, etc.)
- Chemical resistance
- Abrasion resistance
- Fast hardening and setting time
- Workability
- Application at low / high temperatures
- Etc…

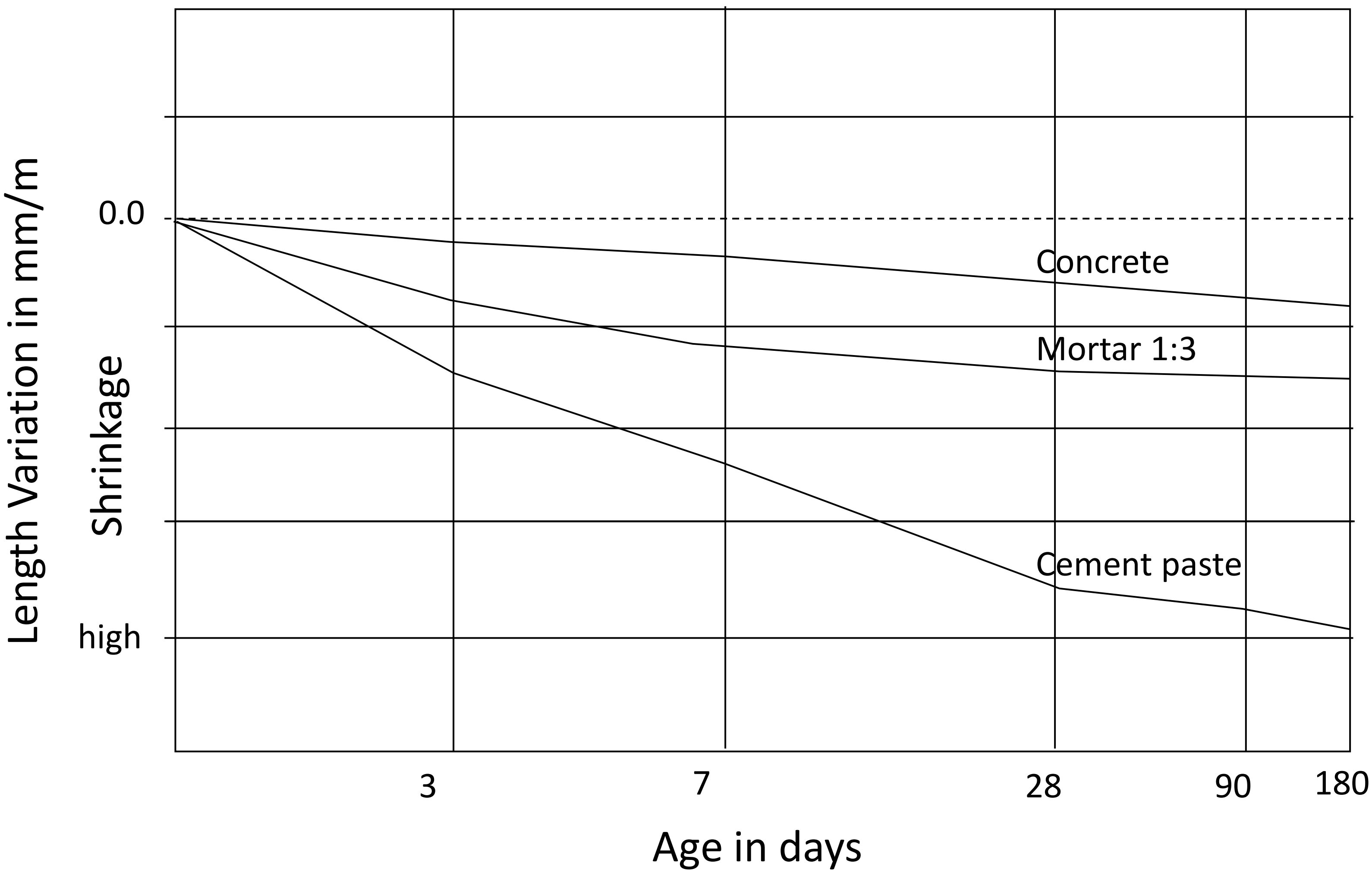
COMPRESSIVE STRENGTH AND WATER CEMENT RATIO



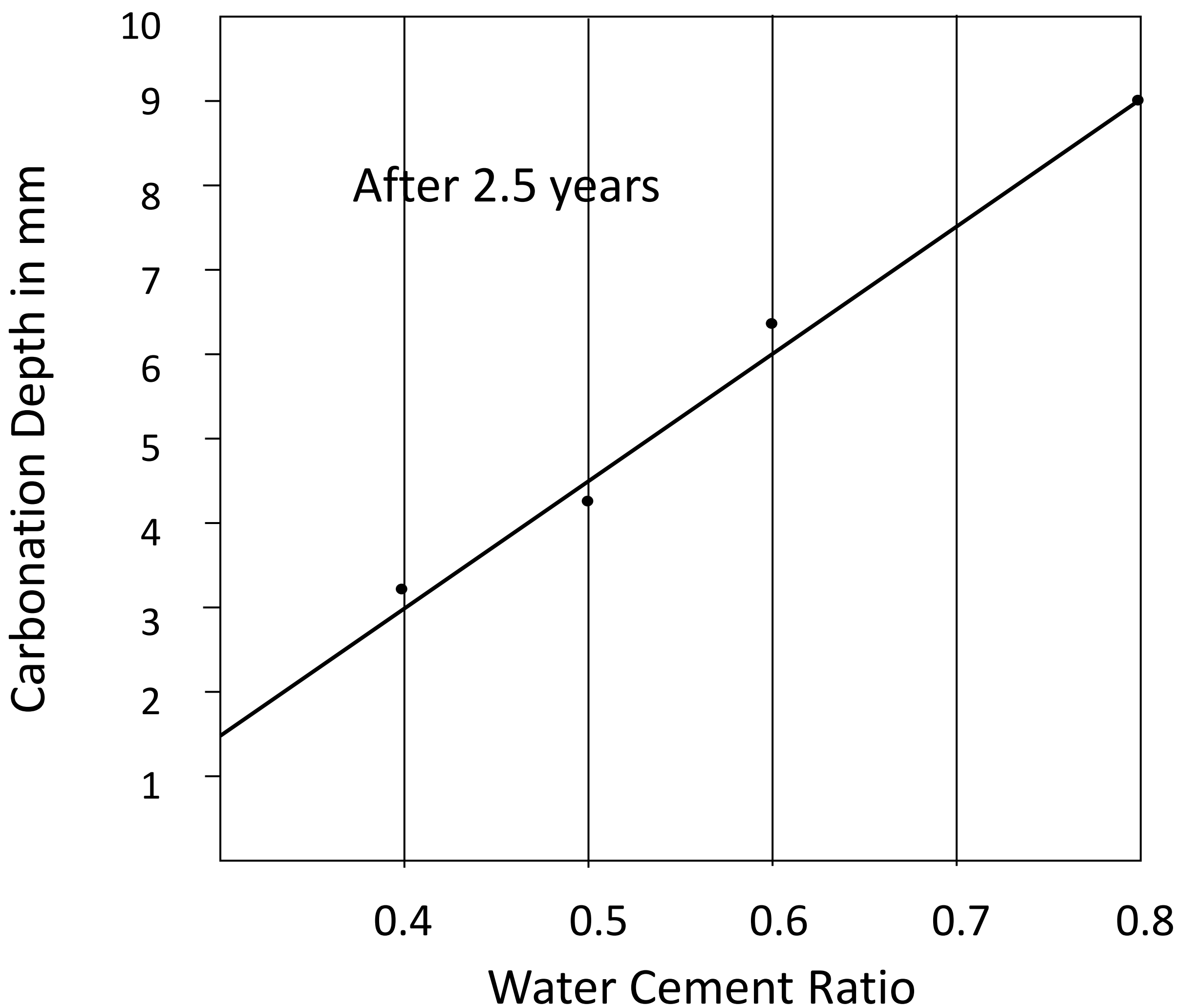
WATER PERMEABILITY & W/C RATIO



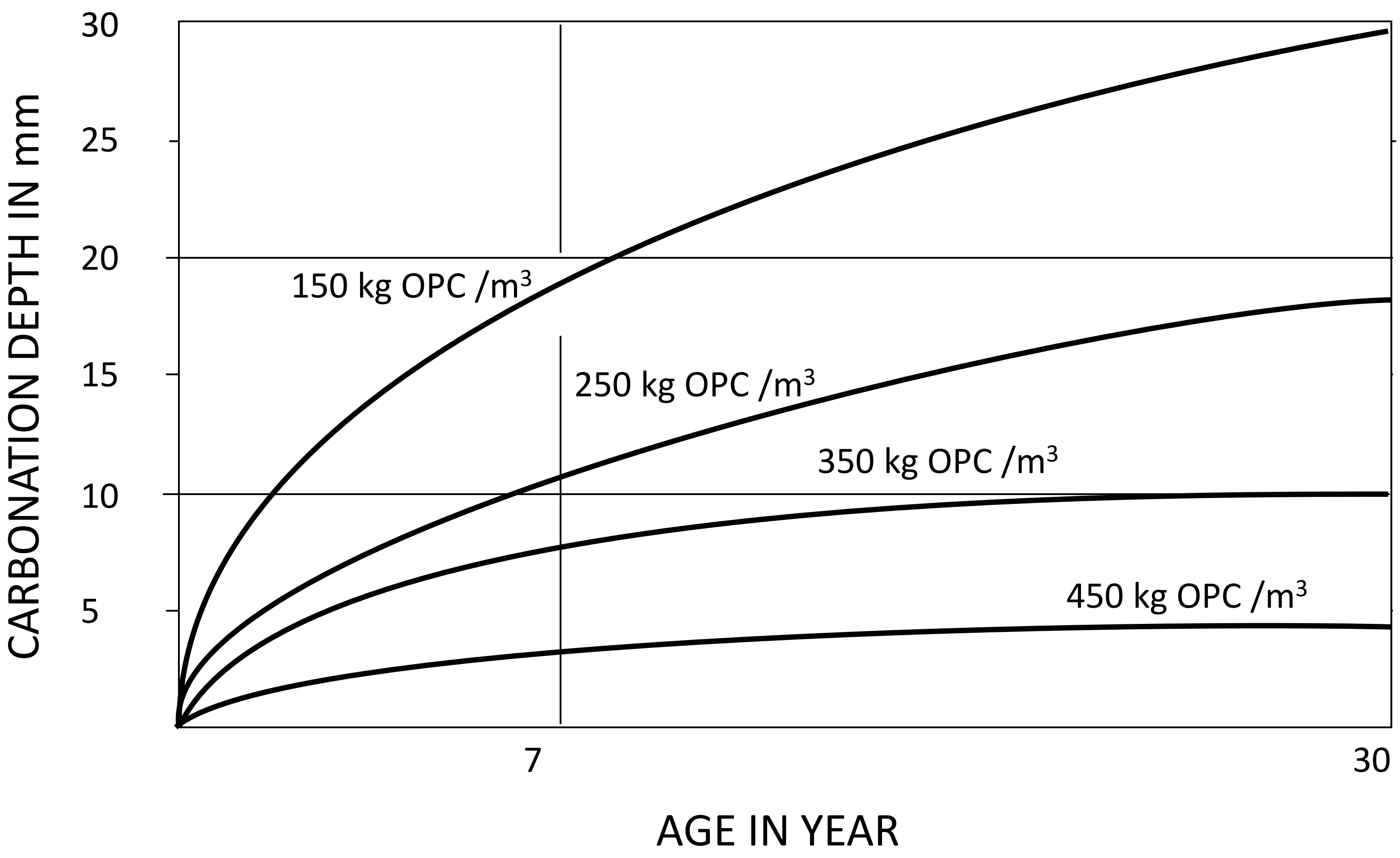
SHRINKAGE OF CONCRETE, MORTAR & CEMENT PASTE



W/C INFLUENCE ON CARBONATION (STANDARD MORTAR)

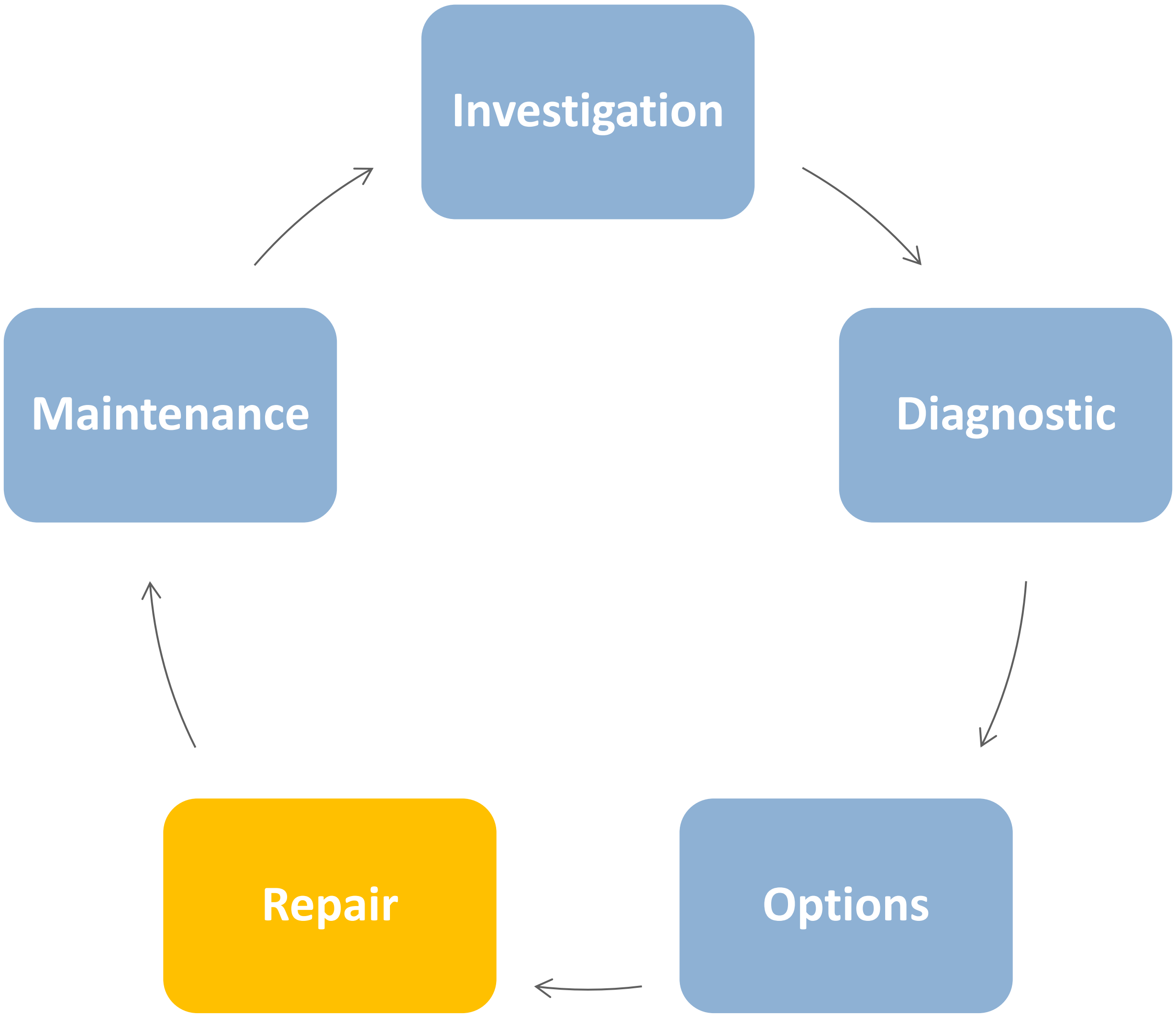


INFLUENCE OF CONCRETE QUALITY ON CARBONATION



6. CONCRETE REPAIR SYSTEM

5 KEY STAGES IN CONCRETE REPAIR



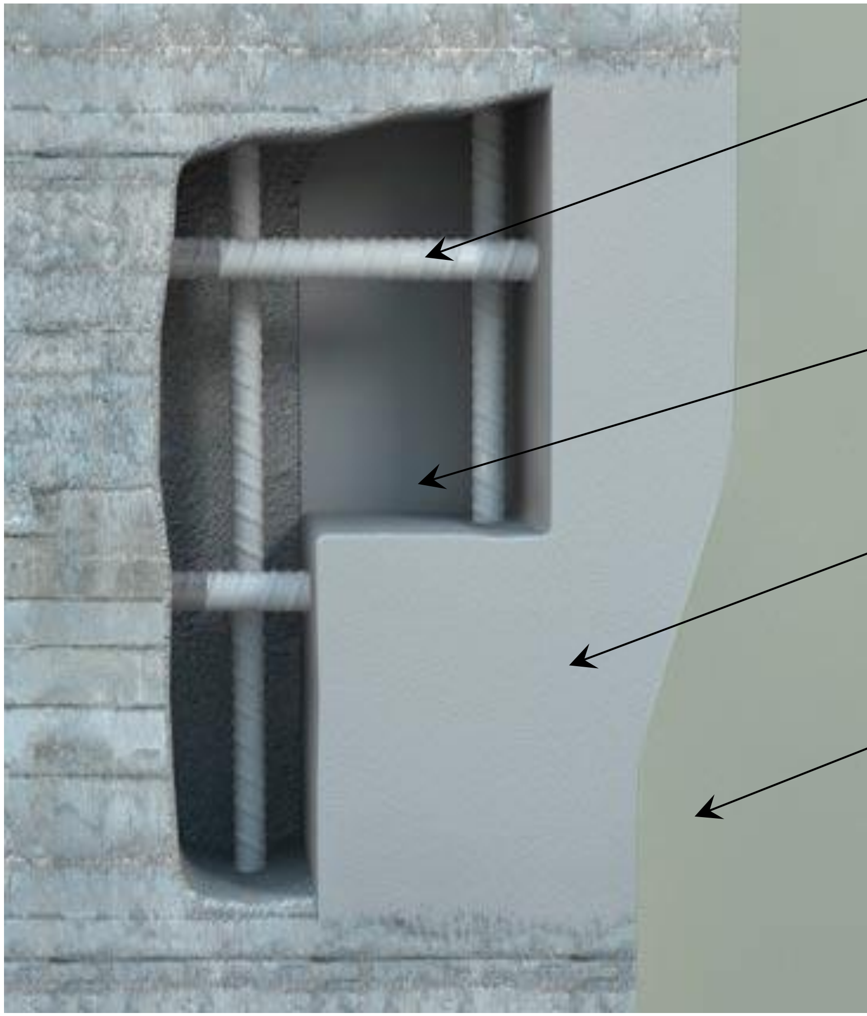
METHODS OF REPAIRING CONCRETE

- Conventional patch repair
  - Mostly necessary
- Electrochemical techniques
  - Cathodic Protection (CP)
    - Galvanic Cathodic Protection (GCP)
    - Impressed Current Cathodic Protection (ICCP)
  - Electrochemical Chloride Extraction (ECE) or Chloride Extraction (CE)
  - Electrochemical Realkalisation
- Corrosion inhibitors
- Surface treatments

OBJECTIVES OF CONCRETE REPAIR

- Replace defective concrete
- Restore structural integrity
- Restore aesthetic appearance
- Restore geometric appearance
- Restore durability

CONCRETE REPAIR SYSTEM



Step 1: Reinforcement Corrosion Protection

Step 2: Bonding Primer

Step 3: Repair Mortar

Step 4: Smoothing / Levelling Mortar

Step 5: Protection system

APPLICATION TECHNIQUES

Traditional by Hand

Spray Techniques

Form and Pour

DEMONSTRATION KIT

SHOW CONCRETE REPAIR

- No power-point
- No pictures
- Something practical
- Something to touch

KEY STAGES OF CONCRETE REPAIR

REMOVAL DAMAGED CONCRETE

SUBSTRATE AND STEEL PREPARATION

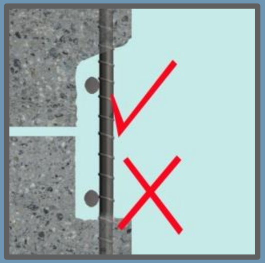
APPLICATION OF REPAIR MORTAR

FINISHING

BEST DEMONSTRATED PRACTICES

1-COMPONENT MIXING

REINFORCEMENT & SUBSTRATE DETAILS



REINFORCEMENT CORROSION PROTECTION

Repair mortar applied wet on dry

BONDING PRIMER

Repair mortar applied wet on wet

BEST DEMONSTRATED PRACTICES

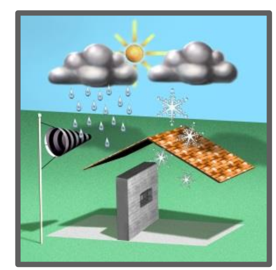
HAND APPLICATION

SPRAY TECHNIQUE

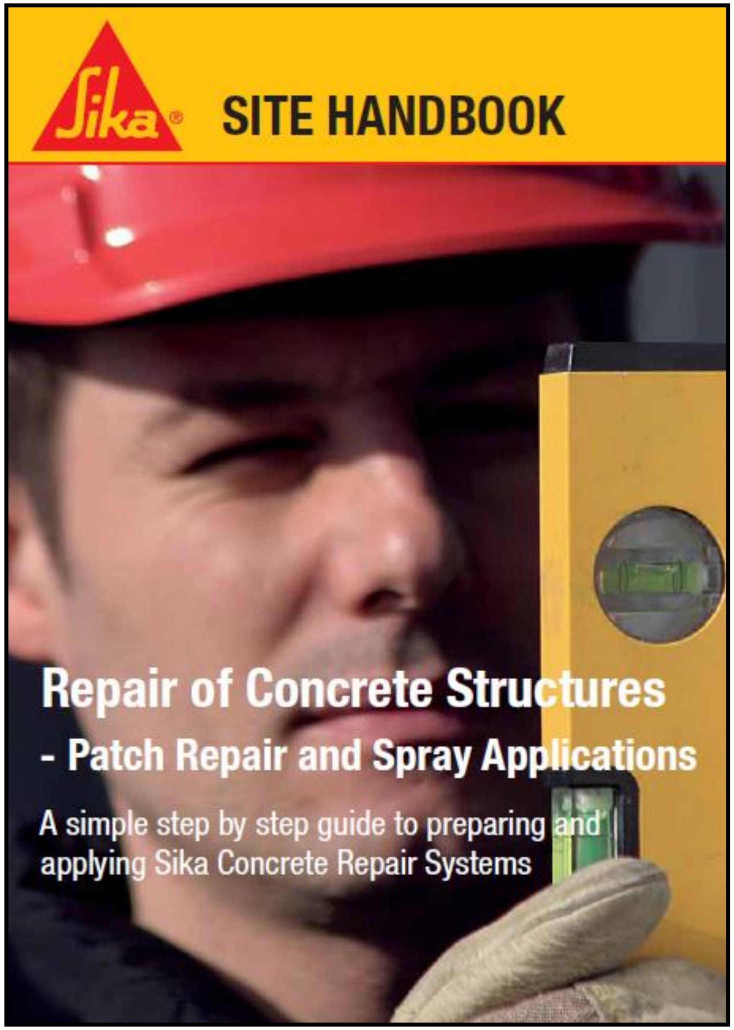
Experienced Contractors only

LEVELLING MORTARS

OTHER

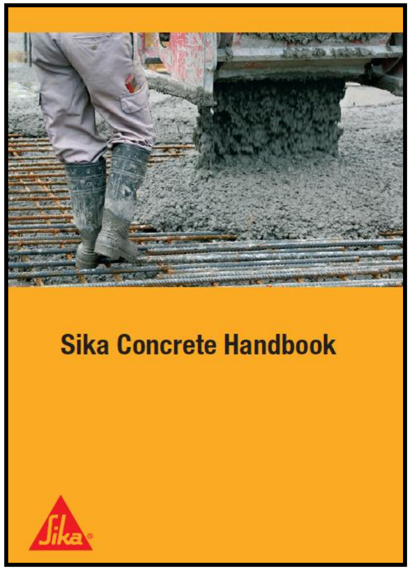


HANDBOOKS



PATCH REPAIRS

- Step by step application procedure
- Pictures with minimal text



CONCRETE TECHNOLOGY

- Recommended

PLANNING

- Quantity and size of repairs
- Permanent or temporary repair
- Availability of repair materials
- Service environment
- Time available
- Access
- Noise, dust and vibration
- Waste disposal

REMOVAL OF CONTAMINATED CONCRETE

Shall not effect the structural integrity

SURFACE ROUGHNESS

Exposing the aggregate and roughen ~2mm

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PROBLEM 1: WRONG MIXING

Damages due to wrong mixing ratio:

- cracks
- low adhesion to substrate
- increased porosity

The amount of mixing water can be varied within the limitations stated by the material supplier. Reasons:

- Environmental conditions (temperature, humidity, etc.)
- Type of application (hand, spray application)
- Position of application (horizontal, vertical, over head)

PROBLEM 2: INSUFFICIENT MIXING

Effects of insufficient mixing:

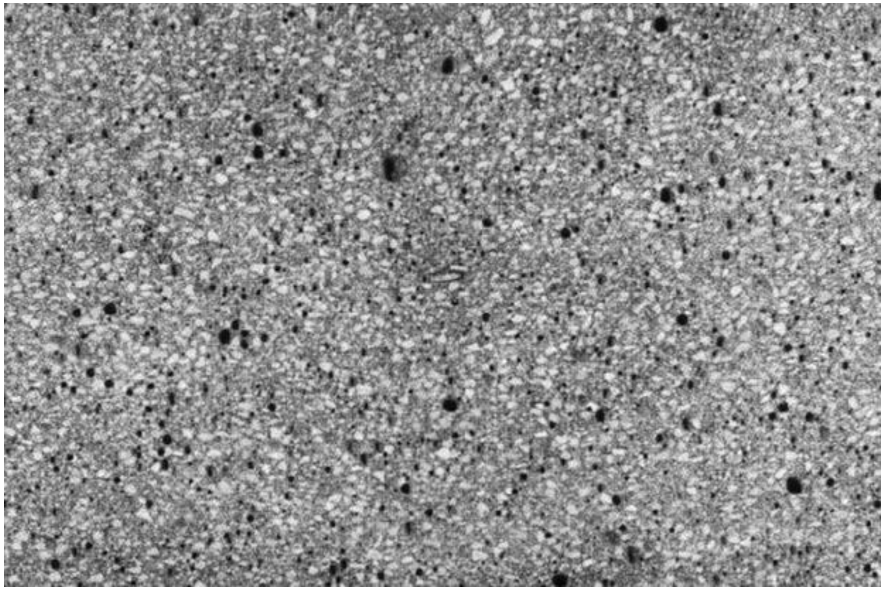
- reduced workability
- shortened set-time
- increased air content, reduced density
- increased shrinkage, crack formation
- reduced strength, etc.

Insufficiently mixed material results in poor material!

PROBLEM 2: INSUFFICIENT MIXING

- ➔ right mixing equipment (no ordinary concrete mixer)
- ➔ mixing time according to supplier recommendation (2-3 minutes)
- ➔ ~400 rpm (additional air entraining results in „whipped cream“)
- ➔ suitable size mixing container for the intended amount of mortar

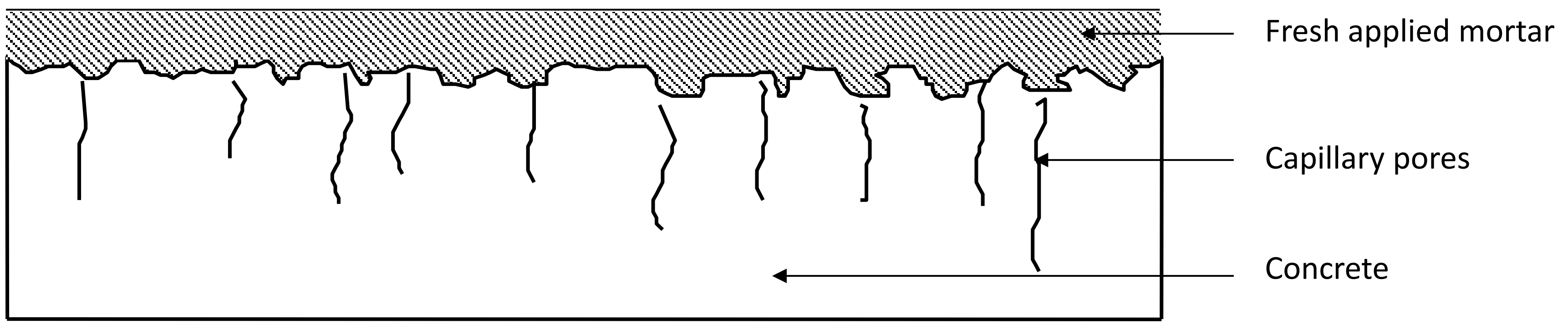
PROBLEM 3: APPLICATION BY HAND



Effects of insufficient compaction:

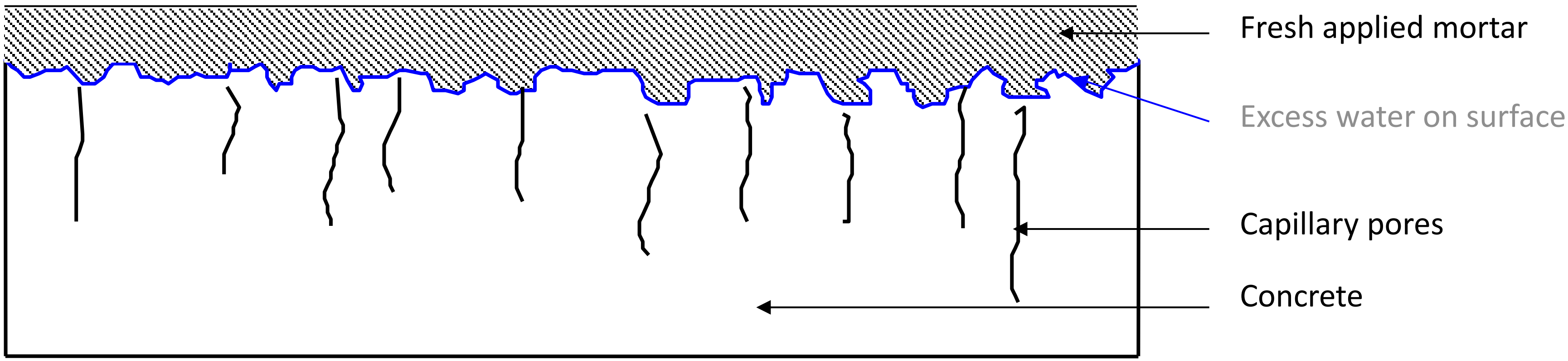
- insufficient adhesion to the substrate
- reduced strengths (tensile and bond strength)
- increased water absorption
- increased CO_2-diffusion rate

PROBLEM 4: NO PRE-WETTING



- Concrete extract water from fresh repair material
- Cement particles in the interface zone cannot hydrate completely
- Insufficient hydration results in reduction of bonding behaviour

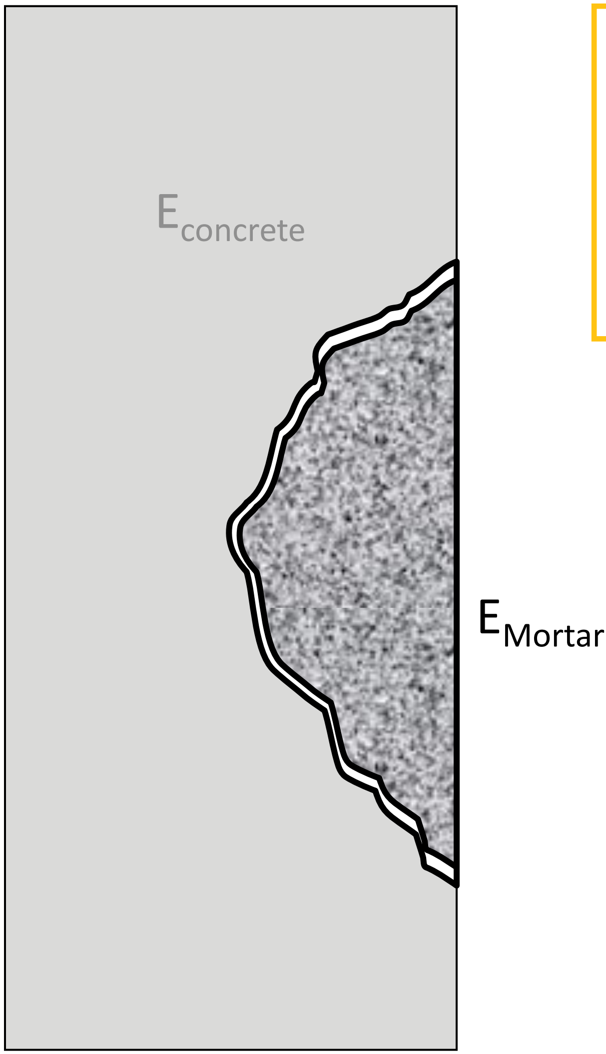
PROBLEM 5: EXCESS WATER ON SUBSTRATE



- Excess water on surface cannot absorbed by concrete
- Too much water results in higher Water/Cement ratio and creates pores in the interface layer and the reduce the bonding surface
- This results in reduction of bonding behaviour
- Water layer on surface: 0.1 mm → 0.1 l water per m^2
- New W/C ratio by additional 0.1 l per m^2: 0.61

➔Increasing of W/C ratio: +42%

PROBLEM 6: WRONG REPAIR MATERIAL

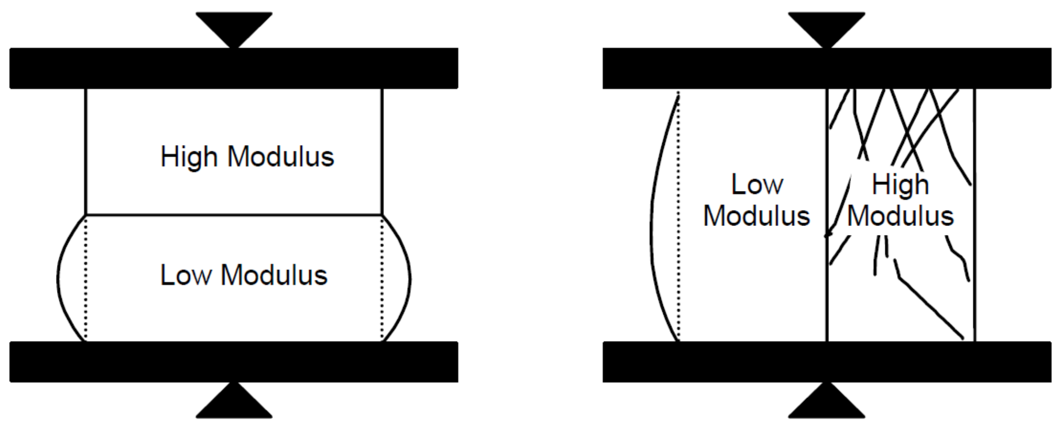


$$\sigma = \varepsilon \times E$$

Tension = Elongation x Modulus of Elasticity

Repair not intended to share load → $E_{Mortar} \leqq E_{Concrete}$

Repair to share load → $E_{Mortar} = E_{Concrete}$



BUILDING TRUST

PROBLEM 8: WRONG CUTTING

- Remove excess mortar with a sharp steel plate. Do not use a wooden bar!
- Cut the mortar carefully without moving repair material too much → result in less bonding behavior

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PROBLEM 9: WRONG FINISHING

- Start with finishing process if repair mortar are setting (approx. 40 minutes @ 20° C)
- Close pores and small voids with humid but not wet sponge
- Smoothing surface with metal trowel

INCIPIENT ANODE

Incipient meaning just in the beginning or earliest stages of development

- High alkaline patch repairs
- Re-passivated steel bars
- Surrounding concrete still contaminated
- In suitable conditions
- Electrochemical activity
- New anode can form

JOB SITE ISSUES…….

PREPARATION

No safety equipment
No training/ no PDS
No Investigation/diagnostic
Weak or too strong substrate
Wrong material
Incorrect material storage
Expired material
No material (late delivery)
Insufficient material
Missing or wrong tools
No water/pressure or electricity
No surface preparation, roughen
Not removed contamination
Prep too strong, micro cracks
Bars not cleaned
No cleaning or pre-wetting
No edge preparation
Exceeds min/max layer thickness

APPLICATION

No training
Wrong tools
Inadequate mixer or bowel
Part or wrong mixing
Inadequate mixing time
Too much/little mixing water
Adding water after pot time
Outside ambient conditions
Contaminated surface
Exceed max layer thickness
Exceed open time
Substrate too wet
No scratch coat
No layer build up
Over working material
Low application pressure
Not filling behind bars
No preparation between layers
No pre-wet between layers

AFTER APPLICATION

No training
No curing
Wrong curing material
Wrong finishing tools
Premature drying
Exposure to sun/wind/frost
Over finishing surface
Adding more water/raining
Service conditions (vibration)
Loaded to soon

DRY SPRAY PROCESS

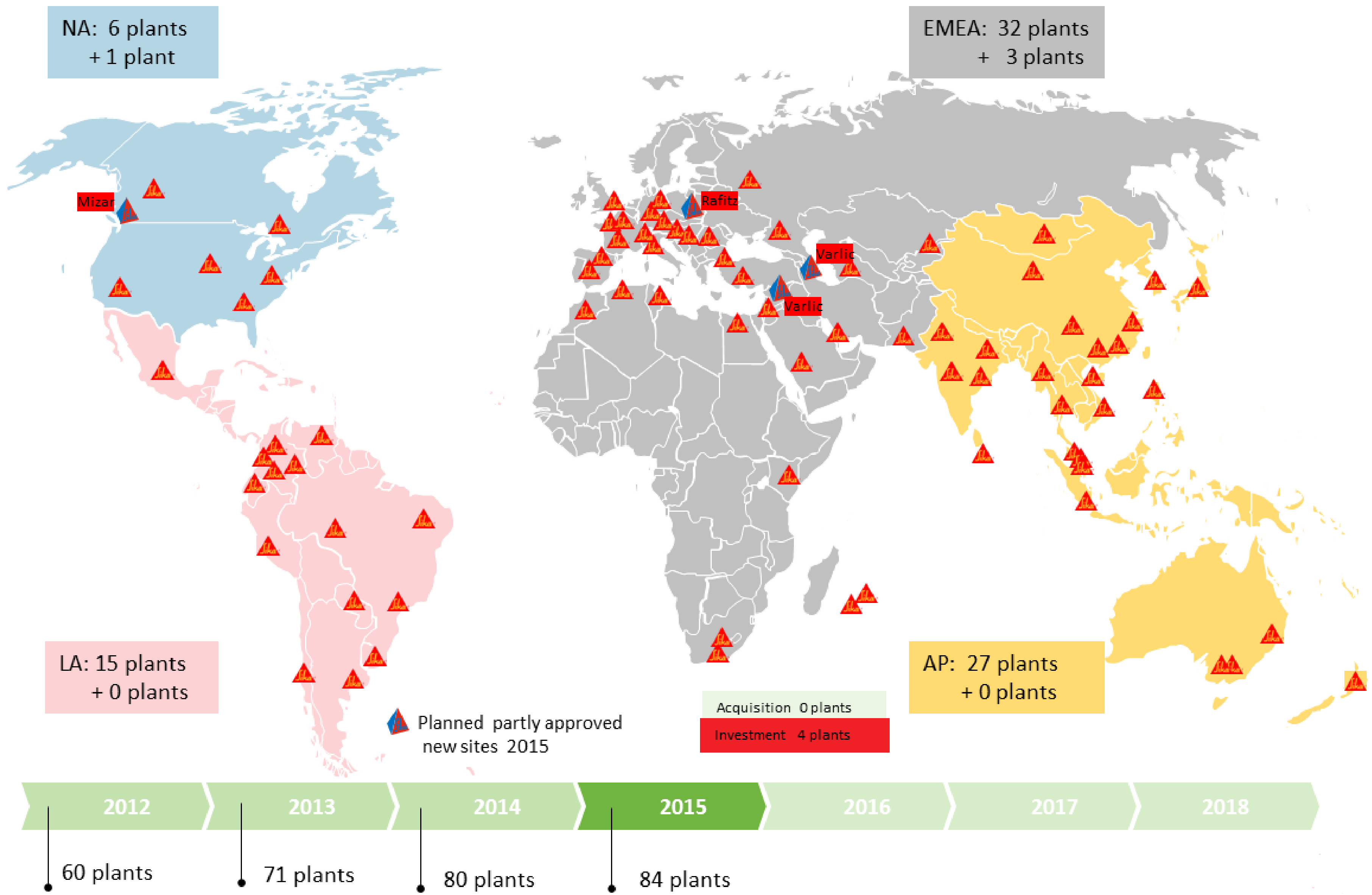
- Highest output
- Rarely equipment blockages
- Less cleaning of equipment
- Long equipment life
- No premixing required
- Higher early strengths
- Long feed distances
- Frequent stop/start sequences are easy
- Thicker layers in a single operation

WET SPRAY PROCESS

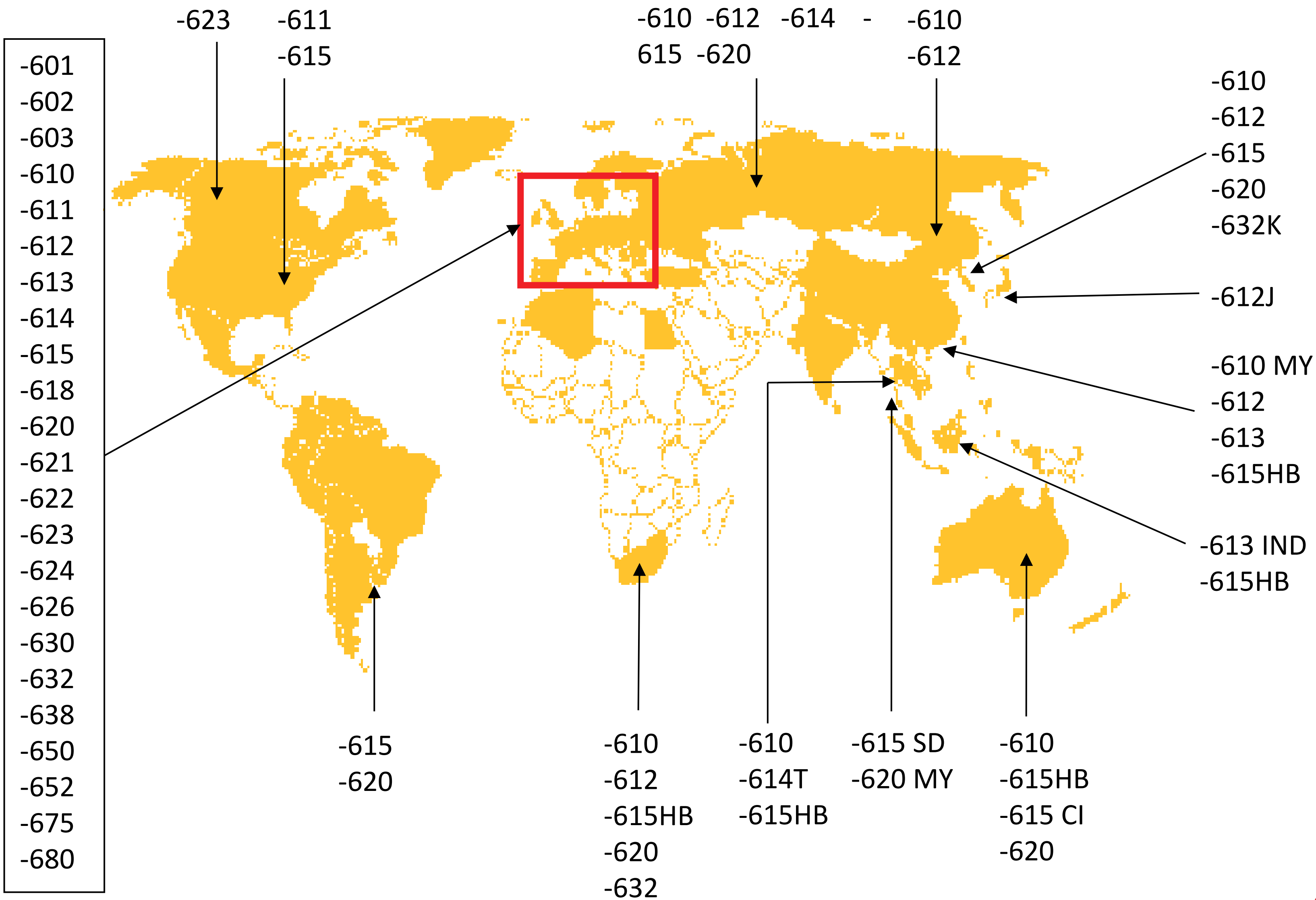
- Better yield
- Minimal rebound
- Minimal site protection required
- Suitable in confined spaces
- Easy trowel finishing
- Easier QC-procedures
- Reduced dust generation
- Constant mortar consistency

7. PRODUCT RANGE

NAMING
POSITIONING


NA: 6 plants
+ 1 plant
EMEA: 32 plants
+ 3 plants
Mizar
Rafitz
Varlic
Varlic
LA: 15 plants
+ 0 plants
AP: 27 plants
+ 0 plants
Planned partly approved
new sites 2015
Acquisition 0 plants
Investment 4 plants
2012
2013
2014
2015
2016
2017
2018
60 plants
71 plants
80 plants
84 plants

SIKA MONOTOP®-600 SERIES IN 2009

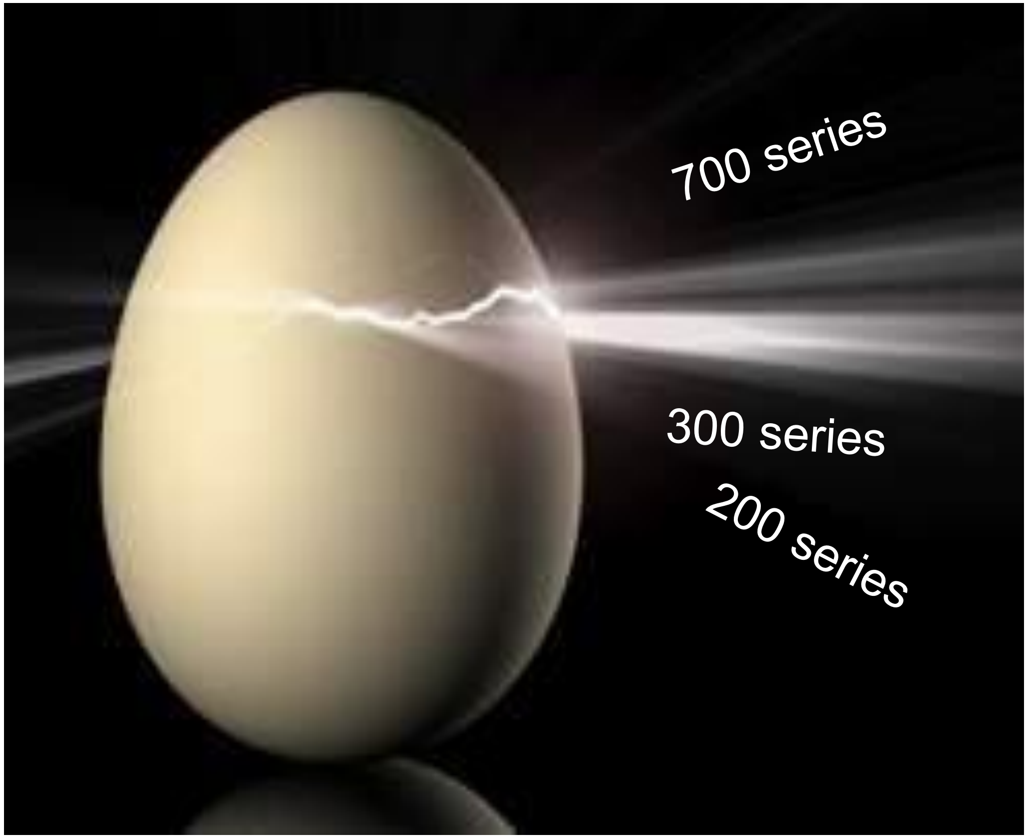


GLOBAL PROJECTS WITH GLOBAL CUSTOMERS

THE OPPORTUNITY

- New harmonised European Standard EN 1504-3
- Attestation of Conformity
- Quality Control
- CE Marking

IMPROVED SIKA MONOTOP® SYSTEM



"the harmonised global generation of concrete repair "

FORMULATION IMPROVEMENTS

- Latest cement technology
- New additives
- Optimised grading
- Dense mortar structure
- Improved workability
- New shrinkage technology

MARKET REQUIREMENTS

- Choice normal or slow setting mortars
- Polymer or non-polymer modified
- Structural or non-structural application
- Rapid setting mortars
- Lightweight mortars
- Pourable mortars

NAMING SYSTEM

Sika MonoTop® -412 NFG

Registered brand name for 1-component ready to use mortars

Strength classification **4**xx, **3xx** or **2xx** (related to EN 1504-3 table 3)

x**1**x: number of plasticity/application typ

1	thixotropy, hand/machine applied
2	soft/semifluid
3	Pourable
4	Multi purpose
5	Light weight

xx**2**: number of max. grain size

Additional term:

S	slow setting
N	normal setting
R	fast setting
SFG	slow setting, FerroGard-Inhibitor
NFG	normal setting, FerroGard-Inhibitor
RFG	fast setting, FerroGard-Inhibitor

CORPORATE PRODUCT OVERVIEW

PRODUCT	SUMMARY
Sika MonoTop-910 N	1C PCC cement slurry, applied by hand or spray as a coating; carbon dioxide and water vapour diffusion resistant, EN1504-7; 25kg & 2x5kg bags
SikaTop Armatec-110 EpoCem	3C epoxy modified cement - EpoCem technology; A+B liquid and dry powder C component. Long open time even at high temperatures. Passes EN1504-7. Hand or spay applied.
Sika MonoTop-412 NFG	1C PCC thixotropic repair mortar, BEII; corrosion inhibitor; 6-50mm layers; A1 fire rating; low rapid chloride permeability (ASTM)
Sika MonoTop-412 N	1C CC; 6-50mm layers
Sika MonoTop-352 NFG	1C PCC; lightweight mortar; corrosion inhibitor 4-75 mm layers; low rapid chloride permeability (ASTM)
Sika MonoTop-352 N	1C CC;lightweight mortar; 4-75 mm layers
Sika MonoTop-211 RFG	1C PCC; fast setting; corrosion inhibitor; 4-60mm layer; low rapid chloride permeability (ASTM)
Sika MonoTop-723 N	1C; R3 to EN1504:3; A1 fire rating : French sulphate and sea water resistance NF P 18837
Sikagard-720 EpoCem	R4 to EN1504:3; EpoCem technology; TMB, chemical resistant

FROM KNOW IT…….. TO DO IT

IF YOU NEED A DENTIST FOR CONCRETE REPAIR, ASK A SIKA SPECIALIST

THANK YOU FOR PARTICIPATING

BUILDING TRUST