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ACADEMY

CPD SEMINAR CPD-CR-RP-01

Repairing Reinforced Concrete: Diagnosis, Principles and Materials

From site evidence to durable patch repairs, using EN 1504 and ISO 16311

1.0 LEU | AIA LU|HSW | 60 MIN | PRACTITIONER

RIBA core curriculum · Design, construction and technology · Legal, regulatory and statutory compliance



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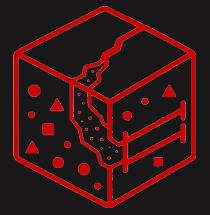
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Why this matters

Many concrete repairs fail within a few years, usually because the cause was misdiagnosed or the materials and workmanship did not suit the structure.

This seminar follows a repair from first inspection to final testing: how reinforced concrete deteriorates, how to investigate it, how to use the EN 1504-9 principles to choose a strategy, how to select compatible repair mortars, and how to specify preparation, application, curing and inspection.

FOR Structural engineers, architects, asset owners, specifiers and repair contractors



CREDIT

1.0 LEU · AIA LU|HSW

RIBA TOPIC

Design, construction and technology; Legal, regulatory and statutory compliance

LEVEL

Practitioner

FORMAT

Live, in-office or self-paced

ASSESSMENT

10 questions, 80% to pass

LEARNING OBJECTIVES

By the end of this course you will be able to

01

Diagnose

the causes of concrete deterioration, including carbonation, chloride attack, cracking and chemical attack, from site evidence and testing

HSW

02

Apply

the EN 1504-9 principles and methods to choose a repair and protection strategy

HSW

03

Select

repair mortars by structural class (R1 to R4) and compatibility with the parent concrete

04

Specify

surface preparation, reinforcement treatment, application, curing and inspection for repairs that last

HSW

AGENDA

How the next 60 minutes run

01	How concrete deteriorates	LO1	12 min
02	Investigation and diagnosis	LO1	10 min
03	The EN 1504-9 principles	LO2	11 min
04	Repair materials	LO3	11 min
05	Doing the repair	LO4	11 min
Q	Knowledge check and summary	LO1–LO4	5 min

01

MODULE 01 · 12 MIN · LO1

How concrete deteriorates

Passivity, carbonation, chlorides, cracking, chemical and physical attack

Alkalinity keeps reinforcement passive

12.5+

Typical pH of pore solution in sound, uncarbonated concrete

< 9

Approximate pH at which the passive film on steel breaks down

A thin oxide film forms on steel in highly alkaline concrete and protects it. Corrosion starts when that film is destroyed by carbonation or by chlorides.



How carbonation reaches the reinforcement

01	**CO2 diffuses in**	Atmospheric carbon dioxide enters through pores and cracks, fastest in moderately damp concrete
02	**Alkalinity is consumed**	It reacts with calcium hydroxide to form calcium carbonate, lowering pore-solution pH
03	**A front advances**	Depth grows roughly with the square root of time, so cover and quality govern the timing
04	**Steel depassivates**	When the front reaches the bar, general corrosion can start if moisture and oxygen are present

Where chlorides come from

Chlorides break the passive film locally, even when the concrete is still highly alkaline.

01

Marine exposure

Seawater, spray and airborne salt on coastal structures, worst in tidal and splash zones

02

Salt-laden ground

Saline groundwater and soils in hot, arid regions rise by capillary action and concentrate by evaporation

03

De-icing salts

Run-off on bridges and car park decks in cold climates, often concentrated at joints and drainage

04

Cast-in chlorides

Contaminated aggregates, unwashed sand, saline mixing water or old chloride-based accelerators

05

Hot, wet-dry cycles

High temperatures and repeated wetting and drying accelerate ingress and the corrosion rate

Carbonation versus chloride-induced corrosion

Carbonation

- Front advances evenly from the surface
- General corrosion along the bar
- Visible cracking and spalling tend to come early
- Phenolphthalein test shows the front clearly
- Often managed by restoring alkalinity and cover

Chlorides

- Ingress varies with exposure, cracks and joints
- Localised pitting can cut bar section quickly
- Serious section loss can hide behind sound concrete
- Needs chloride profiles from dust or core samples
- Contaminated concrete beyond patches stays active

Crack patterns and what they usually indicate

Crack type	Typical pattern	Usual timing and clue
Plastic shrinkage	Short, shallow, often diagonal on slab surfaces	Within hours of casting; hot, windy, poorly protected pours
Early thermal	Regular, through-thickness in restrained walls	First days to weeks; thick sections, high cement contents
Structural	Flexural or shear cracks related to load paths	Under load; width relates to stress and detailing
Corrosion	Along bar lines, with rust staining or spalling	Years; low cover, carbonation or chlorides at the bar
ASR or sulfate	Map or random cracking, sometimes with gel or exudation	Years; reactive aggregate or sulfate exposure, moisture

Cracks are symptoms. Record width, length, pattern, movement and moisture before deciding anything.

Chemical and physical attack

01

Alkali-silica reaction

Reactive silica in aggregate forms an expansive gel with alkalis and moisture, giving map cracking

02

Sulfate attack

Sulfates from soil or water form expansive products and can soften the paste, softening or spalling the surface

03

Acid attack

Acids dissolve cement paste, common in sewers, industrial floors and some agricultural settings

04

Freeze-thaw

Ice formation in saturated concrete causes scaling and surface breakdown in cold climates

05

Abrasion and erosion

Traffic, sliding loads, water-borne grit and cavitation wear away the surface

06

Fire and impact

Heat causes spalling and loss of strength; impact causes local fracture and exposed steel

From rust to structural risk

01	**Expansion**	Rust occupies several times the volume of the steel it replaces and pressurises the cover
02	**Cracking and spalling**	Cover cracks along the bar, then delaminates and falls, creating a hazard below
03	**Loss of bond and section**	Reduced bar area and anchorage lower the capacity of the member
04	**Accelerating damage**	Cracks let in more water, oxygen and chlorides, so deterioration speeds up

A coastal beam soffit shows small, deep pits on the bars but little cracking. Which mechanism is most likely?

A Carbonation of the cover concrete

B Plastic shrinkage during casting

C Chloride-induced pitting corrosion

D Freeze-thaw scaling of the soffit

QUICK CHECK · LO1 · ANSWER

A coastal beam soffit shows small, deep pits on the bars but little cracking. Which mechanism is most likely?

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C Chloride-induced pitting corrosion

D Freeze-thaw scaling of the soffit

WHY Chlorides break the passive film locally, producing pits that can lose section with little expansion. Carbonation gives more general corrosion and earlier cracking.

02

MODULE 02 · 10 MIN · LO1

Investigation and diagnosis

Survey, testing and structural assessment before any repair is designed

THE FIRST RULE OF REPAIR

Diagnosis before prescription

Never specify a repair until you know the cause, the extent and the rate of deterioration. A patch that treats the symptom and ignores the cause usually fails within a few years.



A staged investigation



01 Desk study

Drawings, specifications, past reports, exposure, age, loading and change of use

02 Visual survey

Map cracks, spalls, staining, damp, leaks and previous repairs on elevations

03 Non-destructive tests

Cover, hammer sounding, half-cell potential and resistivity on a grid

04 Sampling

Carbonation depth, chloride dust profiles and cores at representative locations

05 Laboratory work

Chloride, sulfate and cement content, strength, petrography where needed

06 Diagnosis and report

Cause, extent, rate, structural effect and options for the client

ISO 16311-2 and EN 1504-9 both place assessment ahead of repair design.

Common site tests and what they tell you

Test	What it measures	Practical note
Cover meter	Depth and position of reinforcement	Calibrate on exposed bars; congested steel reduces accuracy
Phenolphthalein	Depth of the carbonation front	Spray a freshly broken face; EN 14630 gives the method
Chloride profile	Chloride content at depth increments	Drilled dust or core slices; compare with level at bar depth
Half-cell potential	Probability of active corrosion	ASTM C876 method; needs electrical continuity of the steel
Hammer sounding	Hollow areas and delamination	Quick, cheap and essential before marking out repairs
Cores	Strength, density, depth of damage	EN 12504-1 for coring; also used for petrography

No single test is enough. Combine results so that each one confirms or questions the others.

Interpreting half-cell readings

> −200 mV

$Cu/CuSO_4$ electrode: typically a low probability of active corrosion

Between

−200 and −350 mV: uncertain; confirm with breakouts and other tests

< −350 mV

Typically a high probability of active corrosion

ASTM C876 guidance against a copper/copper sulfate electrode. Moisture, carbonation, coatings and oxygen supply shift readings, so map gradients matter more than single values.

Reading carbonation and chloride data

01 **Compare front with cover**

If carbonation depth meets or exceeds cover, the steel is, or soon will be, depassivated

02 **Check chloride at bar depth**

Compare with a threshold, typically 0.2 to 0.4% by mass of cement, set by the engineer

03 **Read the profile shape**

Falling with depth means ingress from outside; uniform means chlorides were cast in

04 **Project forward**

Use the data to estimate when sound-looking areas will start to corrode



Questions the engineer must answer

01

Is it safe now?

Check falling concrete risk and whether temporary propping or exclusion zones are needed

02

How much steel is left?

Measure section loss at breakouts and assess the effect on bending, shear and anchorage

03

Is the damage moving?

Monitor live cracks and deflections before choosing rigid repairs

04

Can it be broken out?

Removing concrete around bars temporarily reduces capacity; plan sequence and support

05

What life is needed?

Remaining design life and future use drive how far the repair must go

Symptom-led versus cause-led investigation

Symptom-led	Cause-led
Lists visible spalls and cracks only	Maps hidden delamination and active corrosion
Repairs are sized to what can be seen	Quantifies carbonation and chloride extent
Cause and rate of attack stay unknown	Separates active areas from at-risk areas
New damage appears around old patches	Supports a strategy, not just a patch list

The extra testing in a cause-led survey is usually small compared with the cost of repeat repairs.

Chloride content is roughly constant from the surface to bar depth. What does this most likely indicate?

A Chlorides were cast into the concrete mix

B Recent ingress from seawater spray

C Carbonation has released bound chlorides

D The samples were taken too close together

QUICK CHECK · LO1 · ANSWER

Chloride content is roughly constant from the surface to bar depth. What does this most likely indicate?

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WHY A flat profile points to chlorides added with the materials. Ingress from outside gives a profile that falls with depth, so surface protection alone will not help here.

03

MODULE 03 · 11 MIN · LO2

The EN 1504-9 principles

Management options, eleven principles and choosing a strategy

The owner's options

EN 1504-9 asks the designer to consider the full range of options, not only repair.

01

Do nothing for now

Monitor and reassess at a set interval, with safety measures where needed

02

Reassess and downgrade

Re-analyse capacity; restrict loads or change the use if repair is not justified

03

Prevent further damage

Slow deterioration without restoring the structure, for example by protection

04

Repair and strengthen

Restore all or part of the structure, adding capacity where needed

05

Replace or demolish

Reconstruct elements, or the whole structure, when repair is not viable

Concrete-related principles

Principle	Aim	Typical methods
1 Protection (PI)	Stop ingress of water, chlorides, CO2 and other agents	Impregnation, coatings, crack bridging, membranes
2 Moisture control (MC)	Keep concrete within a target moisture range	Hydrophobic impregnation, coatings, cladding
3 Concrete restoration (CR)	Replace damaged concrete to original profile	Hand-applied mortar, recasting, spraying, replacement
4 Strengthening (SS)	Increase or restore load-carrying capacity	Added bars, bonded plates or fibre composites, overlays
5 Physical resistance (PR)	Resist abrasion, impact and freeze-thaw	Overlays, coatings, impregnation
6 Chemical resistance (RC)	Resist chemical attack	Coatings, overlays, impregnation

Principle 3 is the familiar patch repair. It rarely solves a durability problem on its own.

Reinforcement-related principles

01	**7 Preserving passivity (RP)**	Add cover, replace contaminated concrete, realkalise or extract chlorides
02	**8 Increasing resistivity (IR)**	Dry the concrete to slow corrosion, usually with impregnation or coatings
03	**9 Cathodic control (CC)**	Limit oxygen at cathodic areas, for example by saturation or surface coating
04	**10 Cathodic protection (CP)**	Apply an electrical potential to make the steel cathodic
05	**11 Control of anodic areas**	Active or barrier coatings on bars, or corrosion inhibitors

From diagnosis to repair strategy



Confirm the cause

Carbonation, chlorides, ASR, sulfate, physical damage or a combination

Define the extent

Separate active damage from contaminated but sound-looking concrete

Set the objectives

Required life, safety, appearance, access limits and future maintenance

Pick the principles

Combine concrete- and reinforcement-related principles to address the cause

Select the methods

Choose methods and products meeting the relevant EN 1504 part

Record the reasoning. EN 1504-9 expects the basis of the design choice to be documented.

WORKED EXAMPLE

Coastal jetty crosshead beams

THE BRIEF

Structure

Reinforced concrete jetty, 25 years old, splash zone exposure

Symptoms

Spalling on soffits and sides; rust staining at bar lines

Tests

Cover 30 to 40 mm; chloride at bars up to 0.8% by mass of cement

Half-cell

Large areas more negative than −350 mV, beyond visible spalls

Life needed

Owner needs a further 25 years with planned maintenance

01 **Diagnose**

Chloride-induced corrosion, active well beyond the visible damage

02 **Restore concrete**

Principle 3: break out and replace delaminated concrete with sprayed mortar

03 **Tackle the chlorides**

Principle 10: cathodic protection, as patching alone would leave active steel

04 **Reduce future ingress**

Principle 1: coating where compatible with the protection system

Patch only versus patch with a strategy

Patch only

- Treats visible damage, not the cause
- Leaves carbonated or chloride-laden concrete
- Can trigger new corrosion beside patches
- Low first cost, high repeat cost

Patch with a strategy

- Matches principles to the diagnosed cause
- Deals with contamination beyond the patches
- Adds protection to slow future attack
- Higher first cost, lower whole-life cost

A façade has carbonation reaching the steel in most areas but only a few small spalls. Which strategy fits best?

A Patch the spalls only and leave the façade uncoated

B Apply cathodic protection to the whole façade

C Remove and replace all cover concrete across the façade

D Repair the spalls, then apply an anti-carbonation coating

A façade has carbonation reaching the steel in most areas but only a few small spalls. Which strategy fits best?

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WHY Restoring damaged areas (principle 3) and protecting the rest against CO2 and moisture (principles 1, 2 and 8) treats both damage and cause at proportionate cost.

04

MODULE 04 · 11 MIN · LO3

Repair materials

EN 1504-3 classes, compatibility, application types and bar coatings

Repair mortar classes R1 to R4

Class	Compressive strength	Typical use
R4 structural	≥ 45 MPa	Load-bearing repairs in high-strength members, columns, beams
R3 structural	≥ 25 MPa	Load-bearing repairs in normal-strength concrete
R2 non-structural	≥ 15 MPa	Cosmetic and profile repairs, non-load-bearing areas
R1 non-structural	≥ 10 MPa	Thin levelling and cosmetic work only

Classes also set limits for bond, chloride content, shrinkage and, for R3 and R4, modulus and carbonation resistance.

STRUCTURAL CLASS LIMITS

Some EN 1504-3 requirements for R4

≥ 2.0 MPa

Adhesive bond for R4 (R3 requires ≥ 1.5 MPa)

≥ 20 GPa

Elastic modulus for R4 (R3 requires ≥ 15 GPa)

≤ 0.05%

Chloride ion content of the repair product, all classes

Values are minimum performance requirements from type testing. Site bond strength depends on preparation and workmanship, so it must be verified on the job.

COMPATIBILITY

Match the repair to the parent concrete

Strength alone does not make a durable repair. The repair and substrate must work together.

01

Elastic modulus

Similar stiffness lets the repair share load; too stiff attracts stress, too soft sheds it

02

Thermal movement

Similar thermal expansion limits stress at the bond line under daily temperature swings

03

Shrinkage

Low, controlled shrinkage stops cracking and debonding around the patch edges

04

Strength

Close to the parent concrete; much stronger is not automatically better

05

Permeability

Low enough to protect steel, but avoid trapping moisture behind dense layers

Hand-applied, sprayed or flowable

Hand-applied

- Small, scattered repairs and difficult access
- Applied in layers to set thicknesses
- Thixotropic for vertical and overhead work
- Labour-intensive on large areas

Sprayed

- Large areas, soffits and long elevations
- Wet or dry process, high output
- Good compaction with skilled nozzlemen
- Rebound and overspray need managing

Flowable

- Deep repairs and congested reinforcement
- Poured or pumped into sealed formwork
- Self-compacting, no vibration needed
- Formwork must be tight and vented

Select the product and method together: a mortar formulated for spraying may not suit hand application.

Where resin mortars fit, and their limits

01

Good for

Small, thin or rapid repairs, early strength and some chemical-resistant situations

02

Thermal mismatch

Thermal expansion is typically several times that of concrete, stressing larger patches

03

No alkalinity

They do not re-passivate steel, so reinforcement protection relies on the barrier

04

Temperature sensitive

Properties change with heat; check behaviour at service and fire temperatures

05

Moisture barrier

Dense resin patches can trap moisture and shift corrosion to surrounding concrete

Reinforcement coatings and the incipient anode

01	**Active coatings**	Cementitious or zinc-bearing coatings that help keep the steel passive
02	**Barrier coatings**	Resin coatings that isolate steel; gaps or damage leave weak points
03	**Incipient anode effect**	Repaired steel turns cathodic, so corrosion can start in contaminated steel nearby
04	**Limit the risk**	Remove contamination widely, add galvanic anodes or use cathodic protection

What a good repair mortar clause states

01

Class and standard

EN 1504-3 class, with declared properties from type testing

02

Compatibility values

Modulus, shrinkage and thermal properties suited to the parent concrete

03

Method and thickness

Hand, sprayed or flowable; minimum and maximum layer thickness

04

System components

Bar coating, primer or bond coat and finish from one compatible system

05

Climate limits

Substrate and air temperature range and curing needs for the site

A load-bearing column repair in 40 MPa concrete is being specified. Which mortar is most appropriate?

A R2 mortar, because lower stiffness reduces cracking

B R4 cementitious mortar with a compatible modulus

C Epoxy mortar, because it has the highest strength

D R1 mortar applied in a single thick layer

A load-bearing column repair in 40 MPa concrete is being specified. Which mortar is most appropriate?

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C. Epoxy mortar, because it has the highest strength

D. R1 mortar applied in a single thick layer

WHY A structural repair in a loaded column needs a structural class. R4 suits 40 MPa concrete, and a compatible modulus lets the repair share load with the parent concrete.

05

MODULE 05 · 11 MIN · LO4

Doing the repair

Preparation, bar treatment, application, curing, testing and protection

The patch repair sequence

01	02	03	04	05	06
Mark out	**Break out**	**Clean**	**Treat steel**	**Apply**	**Cure and test**
Sound and test to find the full extent of defective concrete; mark simple shapes	Remove defective concrete, exposing the full corroded length of bar	Remove rust and contamination from steel and laitance from the substrate	Assess section loss, add bars if needed, apply reinforcement coating	Prepare the substrate moisture, prime as the system requires, place mortar	Cure fully, then inspect, sound and pull-off test before protection

Agree hold points for inspection after break-out, after cleaning and after application.

Getting the break-out right

01 **Go behind the bars**

Typically 15 to 20 mm clearance, or more for the mortar's aggregate size

02 **Chase the corrosion**

Extend along the bar until clean, uncorroded steel is reached

03 **Cut square edges**

Saw-cut perimeter, typically 5 to 10 mm deep; avoid feathered edges

04 **Protect the structure**

Avoid heavy breakers that micro-crack the substrate; prop if required



Preparing the steel and the substrate

01

Steel cleanliness

Blast to Sa 2 or power-tool clean to St 2 to ISO 8501-1, or better if the system requires

02

Chloride residues

Pitted bars may retain salts; high-pressure washing helps remove them

03

Section loss

Measure remaining diameter; the engineer decides on lapping or added bars

04

Substrate

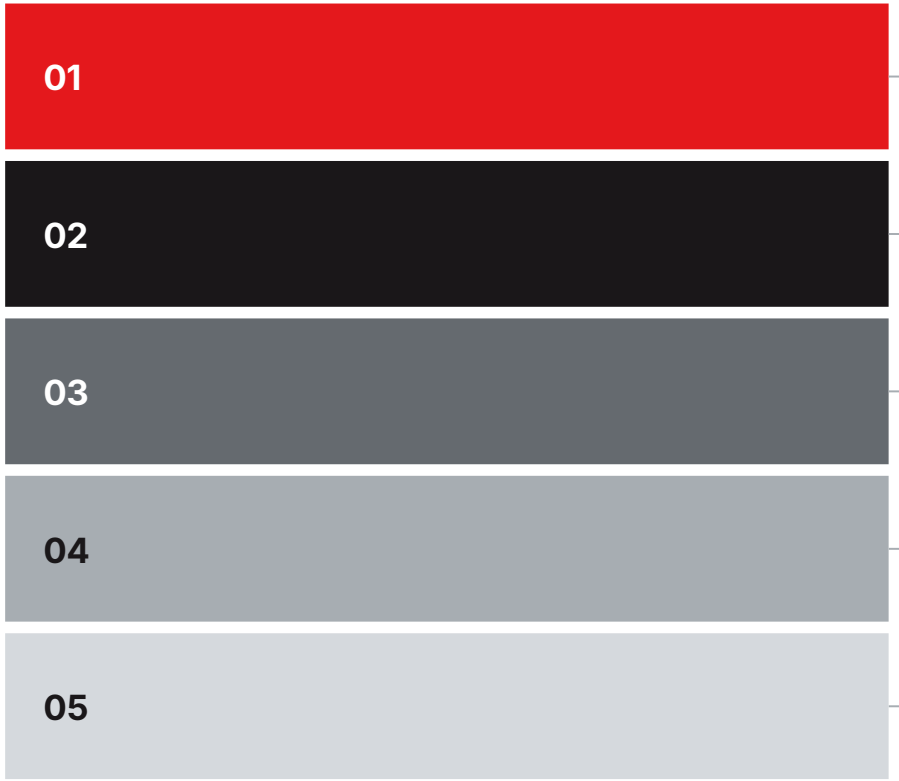
Sound, rough and free of dust, laitance, oil and loose particles

05

Coat promptly

Apply bar coating soon after cleaning, before flash rust forms

Layers of a typical cementitious repair



Protective coating
Anti-carbonation or anti-chloride coating, or impregnation, over the finished area

Repair mortar
EN 1504-3 class mortar placed in layers to the original profile

Bond coat or primer
Where the system requires it, applied to the substrate just before mortar

Reinforcement coating
EN 1504-7 coating on cleaned steel, covering the full circumference

Prepared substrate
Sound, rough, clean concrete at saturated surface-dry condition

Use one tested system. Mixing primers, coatings and mortars from different systems can compromise bond.

Applying and curing in hot, arid conditions

Do

- Work in the cooler part of the day
- Shade the work and the stored materials
- Use cool mixing water within system limits
- Start curing as soon as the surface allows
- Keep curing for the period the system states

Avoid

- Hot substrates in direct sun
- Adding extra water to restore workability
- Leaving fresh mortar exposed to drying winds
- Patches thicker than the layer limit
- Coating before the repair has cured

Inspection and testing for lasting repairs

Stage	Check	Method
After break-out	Depth, clearance behind bars, edges, extent	Visual inspection and measurement at a hold point
After cleaning	Steel grade, section loss, substrate condition	ISO 8501-1 visual standards, calipers
During application	Temperatures, moisture, layer thickness, curing	Site records, thermometers, wet-film gauges
After curing	Hollowness and cracking	Hammer sounding of every repair
Bond verification	Adhesion to the substrate	Pull-off test to EN 1542 on trial and sample areas

Agree acceptance criteria and test frequency before work starts, not after a failure.

Repair restores; protection preserves

A patch repair restores the profile. Protecting the whole element with coatings or impregnation slows the next cycle of deterioration and is usually where the long-term value lies.

Pull-off tests on new patches show low strength with failure at the bond line. What is the most likely cause?

A The parent concrete is weaker than the repair

B The protective coating was applied too early

C Poor substrate preparation or moisture control

D The repair mortar class was set too high

Pull-off tests on new patches show low strength with failure at the bond line. What is the most likely cause?

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WHY Low strength at the interface points to the bond itself: dust, laitance, a dry or wet substrate, or a missed primer. A weak substrate would fail within the parent concrete.

SUMMARY

Four things to take away

LO1 Find what destroyed the steel's passivity, and where, before choosing any repair

LO2 Use EN 1504-9 to combine concrete and reinforcement principles that address the cause

LO3 Choose R3 or R4 for structural repairs and match modulus, shrinkage and thermal movement

LO4 Specify break-out, cleaning, curing, hold points and EN 1542 pull-off testing in the contract

EARN YOUR CREDIT

Complete the online assessment

10

questions drawn at random from the four objectives

80%

to pass; two attempts, reshuffled each time

1.0

LEU and AIA LU|HSW on your certificate

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Standards and references

EN 1504-9

Protection and repair of concrete structures: general principles for the use of products and systems

EN 1504-3

Protection and repair of concrete structures: structural and non-structural repair

EN 1504-7

Protection and repair of concrete structures: reinforcement corrosion protection

EN 1504-10

Protection and repair of concrete structures: site application and quality control of the works

EN 1542

Protection and repair of concrete structures, test methods: measurement of bond strength by pull-off

EN 14630

Test methods: determination of carbonation depth in hardened concrete by the phenolphthalein method

ASTM C876

Standard test method for corrosion potentials of uncoated reinforcing steel in concrete

ISO 16311 (Parts 1 to 4)

Maintenance and repair of concrete structures: principles, assessment, design and execution

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THANK YOU FOR ATTENDING

Questions?

Kashif Aijaz
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This concludes The American Institute of Architects Continuing Education Systems course.

