# Conservation of a 100-year old steel reinforced lime-concrete system in a Class-I heritage building using galvanic anode cathodic protection

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Courtesy: Some images are sourced from the internet

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## Cost of corrosion

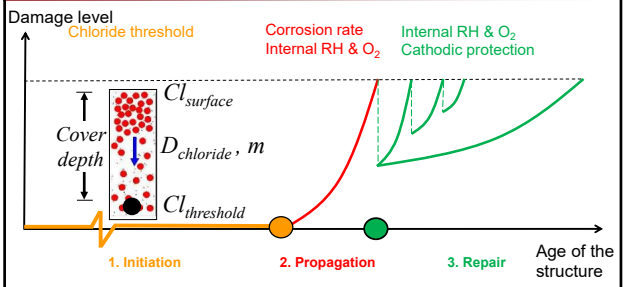



Cost of corrosion is about 3-5% of GDP or more…

We need to keep them safe and usable for long period (say, several decades) without much maintenance and repair.

2

## Service life of S-C systems



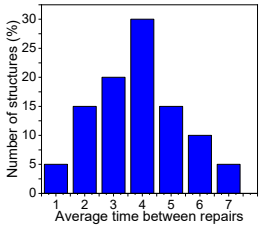

Durability is essential for achieving sustainability.
Need focus on carbon foot-print over the life cycle of structure.

3

## Conventional repairs are failing very fast

- Patch repair and concrete replacement
- Repair of repair ($n^{th}$ time?)
  - Data from 20 structures without CP

Frequency of major repairs is just about 4 to 5 years !




Krishnan, N., Kamde, D. K., Veedu, Z. D., Pillai, R. G., Shah, D., and Velayudham, R. (2021). "Long-term performance and life-cycle-cost benefits of cathodic protection of concrete structures using galvanic anodes", Journal of Building Engineering.

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## Repeated repairs

Courtesy: Vector Corrosion Technologies

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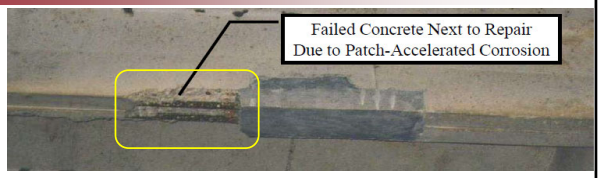
## Repeated repairs

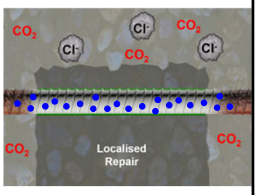
Courtesy: Vector Corrosion Technologies

6

## Why conventional repair fails so fast?




- Hidden corrosion continues
  - Differential chemistry
    - Dark and light grey regions
  - Halo/Ring effects
    - Brown rust
  - Residual chloride effects
    - Blue circles




David Whitmore, Vector Corrosion; https://structuraltechnologies.com/wp-content/uploads/2017/10/halo-effect-concrete.png

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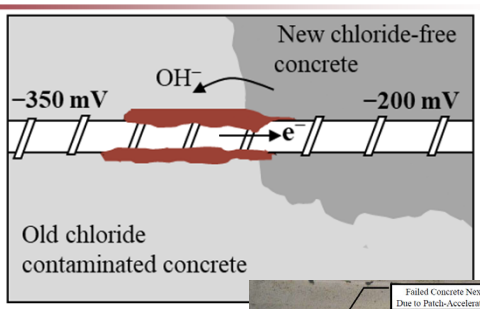
## "Halo" or "Ring" effect




David Whitmore, Vector Corrosion; https://structuraltechnologies.com/wp-content/uploads/2017/10/halo-effect-concrete.png

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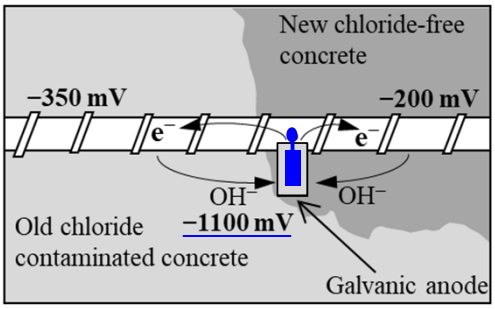
## Effect of embedded galvanic anode
- zinc sacrifices/corrodes & protects the steel




David Whitmore, Vector Corrosion; https://structuraltechnologies.com/wp-content/uploads/2017/10/halo-effect-concrete.png

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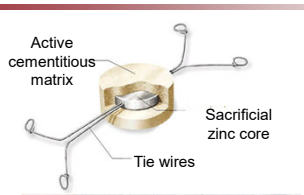
## Embedded galvanic/sacrificial anodes




www.vectorcorrosiontechnologies.com

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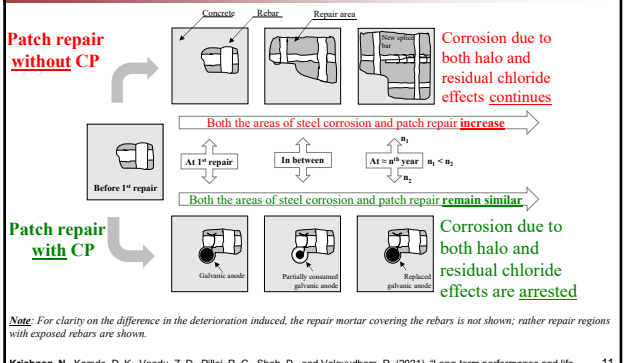
## Effect of repairs with and without galvanic anodes




*Note: For clarity on the difference in the deterioration induced, the repair mortar covering the rebars is not shown; rather repair regions with exposed rebars are shown.*

**Krishnan, N.,** Kamde, D. K., Veedu, Z. D., Pillai, R. G., Shah, D., and Velayudham, R. (2021). "Long-term performance and life-cycle-cost benefits of cathodic protection of concrete structures using galvanic anodes", Journal of Building Engineering. 11

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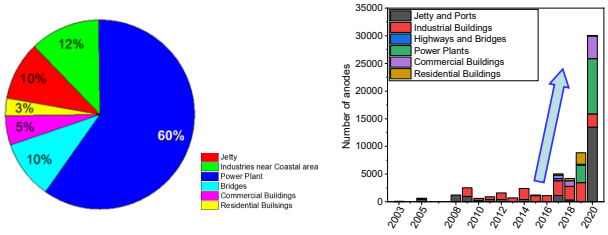
## Usage of CP in concrete structures

- North America (US, Canada) - USD 40 Million
- Rest of the World - USD 80 Million
- India (till date) < USD 1 Million (INR 500 Lakhs)




**Cathodic protection in India**

Courtesy: Vector corrosion technologies

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## Prevailing concerns regarding CP in India

- Industry Problems
  - Lack of CP knowledge
  - Initial costs is very high – a myth?
  - CP experts are not locally/widely available
  - Complexity in repair
  - Burden of maintenance
  - Challenges with quality control and monitoring
- Engineering Problems
  - Lack of consideration of long-term performance
  - High resistivity of repair materials
  - Rational design procedures?

Polder & Willy, 2018

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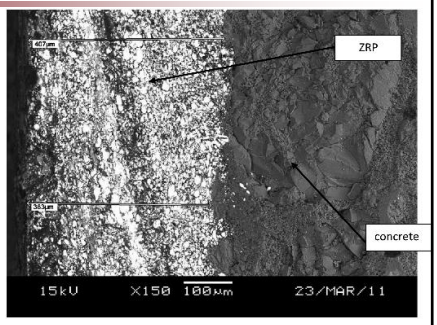
## Cathodic protection – Zinc coating on concrete surface




About 400 µm thick coating

https://metallisation.com/applications/cathodic-protection-of-steel-in-concrete/

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## Cathodic protection – Zinc coating on concrete surface



- No disturbance to traffic
- Long-term protection
- Large cover depth?
- Highly resistive concretes?

https://www.metallisation.com/applications/cathodic-protection-of-steel-in-concrete/

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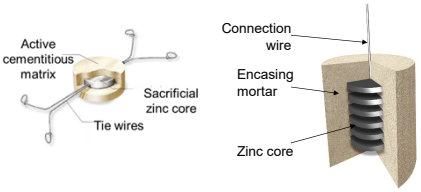
## Design parameters for cathodic protection

- Resistivity of concrete
- Steel density
  - Ratio of area of steel to concrete
- Exposure condition
  - More the concrete is contaminated with chloride, the more is the current demand.




Courtesy: George Sergi, Vector Corrosion Technologies

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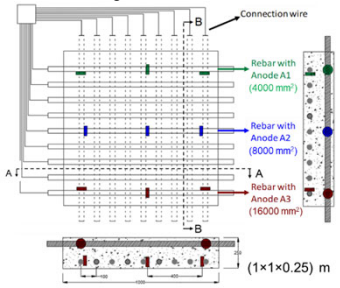
## Laboratory study – Four 12-year-old slabs

- Specimens were cast by Dr. George Sergi of Vector Corrosion Technologies (about a decade ago)
- Now being monitored in the Concrete Lab at IIT Bombay





Kamde et al (2019); Courtesy: Vector Corrosion Technologies

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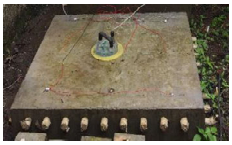
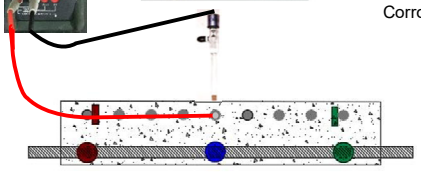
## Corrosion potentials and rates were measured for about 12 years

Multimeter

Corrosion measurements being taken



Kamde et al (2019)

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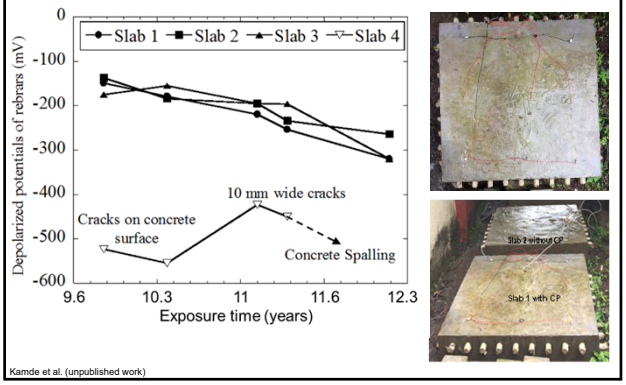
## Depolarized potentials - at the end of 12 years of exposure




Kamde et al. (unpublished work)

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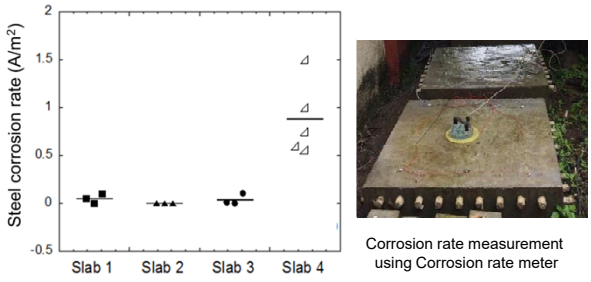
## Steel corrosion rate - at the end of 12 years of exposure




Corrosion rate measurement using Corrosion rate meter

Sacrificial anodes could suppress the corrosion rate of reinforcement embedded in concrete

Kamde et al. (unpublished work)

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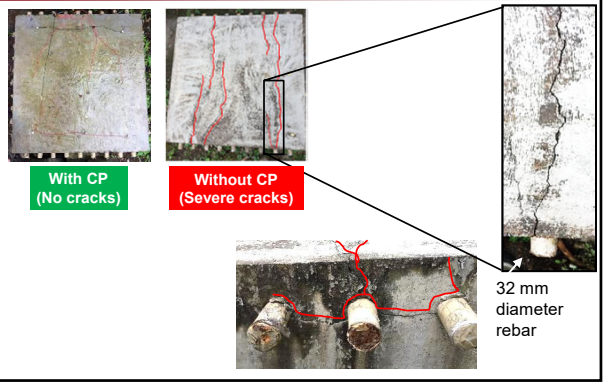
## Slab without CP exhibited severe cracks - at the end of 12 years of exposure

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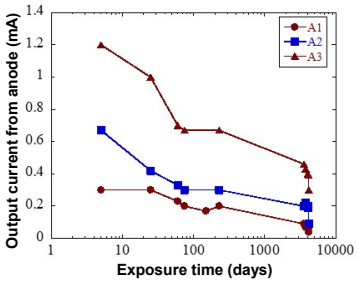
## Output current from EACH anode




Surface areas of A1, A2, and A3 are 4000, 8000, 16000 mm², respectively.

Corresponding output current density

A1 = 0.0175 μA/cm²

A2 = 0.0125 μA/cm²

A3 = 0.0187 μA/cm²

Sacrificial anodes were found active even after 12 years in the slabs with premixed chloride

Kamde et al. (unpublished work)

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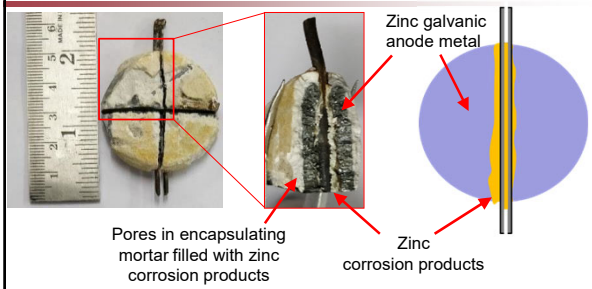
## Corrosion of zinc at its interface with tie wire




Tie wires should be well separated and die-cast into the molten zinc metal.

Karthikeyan, IIT Madras

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## Different types of galvanic anodes are available


Courtesy:George Sergi;
Christian Christodoulou and Chris Goodier, 2018
https://5.imimg.com/data5/VK/XU/MY-1740911/galvashield-500x500.jpg
https://www.vector-corrosion.com/uploads/gallery/fullsize/Picture%20019.jpg, https://cp-tech.co.uk/wp-content/uploads/2019/06/duoguard-how-it-works.jpg ;

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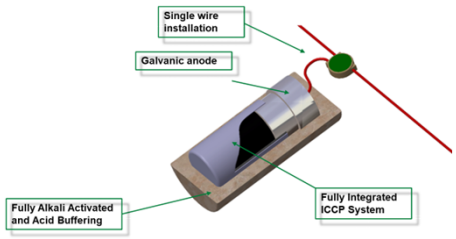
## Combination of ICCP and SACP systems for accelerated corrosion protection

- Corroded rebar surfaces
- Need of stopping corrosion on an urgent basis

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## A 100+ year old heritage building with reinforced lime concrete weather shade

- Rashtrapathi Bhavan

Severe corrosion due to low pH

- Premature failure of patch repair → Repeated repairs
- Recommended pilot study on representative locations using discrete galvanic anode CP system

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## Corrosion condition

Before delamination survey

After

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## A 100+ year old heritage building with reinforced lime concrete weather shade

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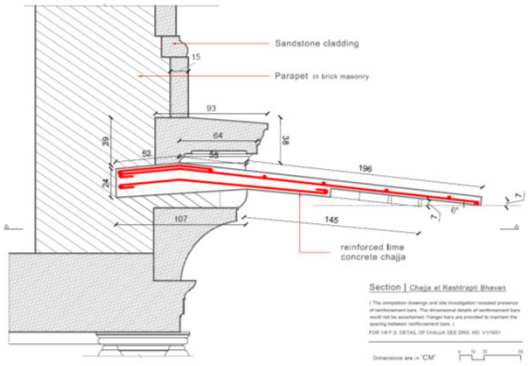
## A 100+ year old heritage building with reinforced lime concrete weather shade

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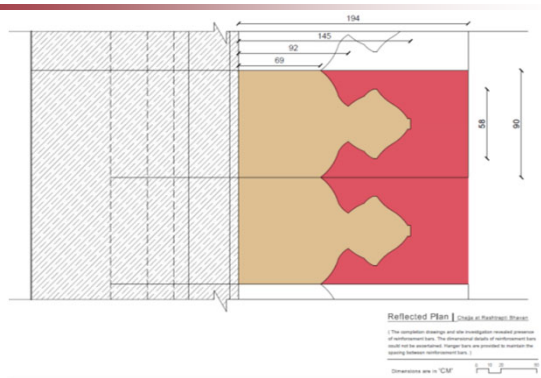
## A 100+ year old heritage building with reinforced lime concrete weather shade

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## A pilot study on a stretch of 10 m was conducted using two types of galvanic anodes

Type I
Conventional

Type II
Hybrid

Both anodes were installed on the sunshade

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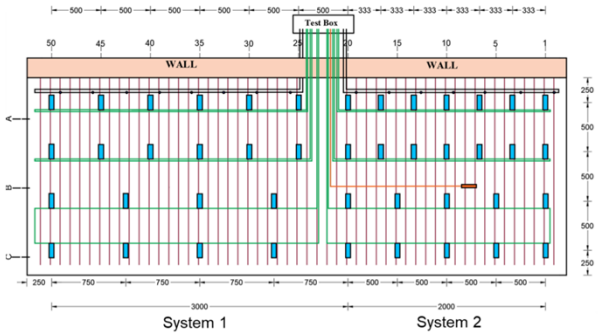
## Anode layouts

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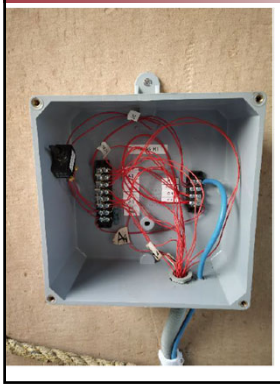
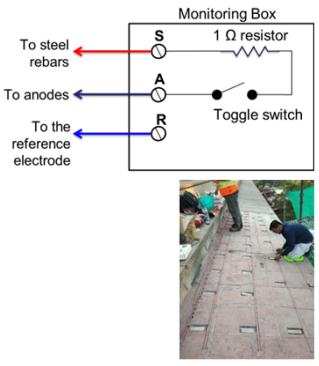
## The performance of the anodes was assessed by using monitoring box



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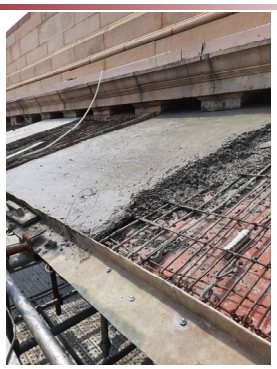
## Photos during and after repair



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## Photos during and after repair

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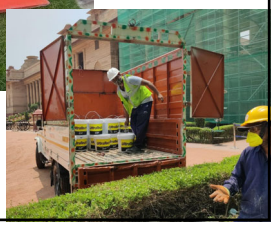
## Photos during and after repair



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## Photos during and after repair

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## Photos during and after repair

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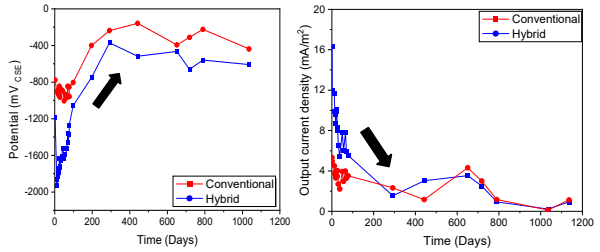
## Data from each anode system was collected for about 3 years




- Significant increase in $E_{ON}$ potential → Reduction in potential of steel or anode
- $I_{out}$ ≈ 2 mA/m² → Decreased corrosion rate of the steel rebars
- Both Type I and II anodes are performing well and protecting the steel

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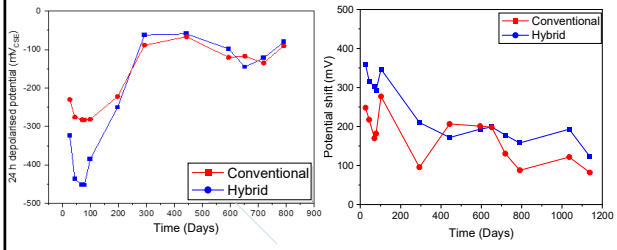
## Depolarization data were collected at every six months




- Significant increase in 24 h depolarized potential → Repassivation of steel
- 100 mV potential criteria
  - Type – I hybrid anode satisfies even after 800 days
  - Type – II anodes failed to satisfy after 750 days (possible "False Negative" result)

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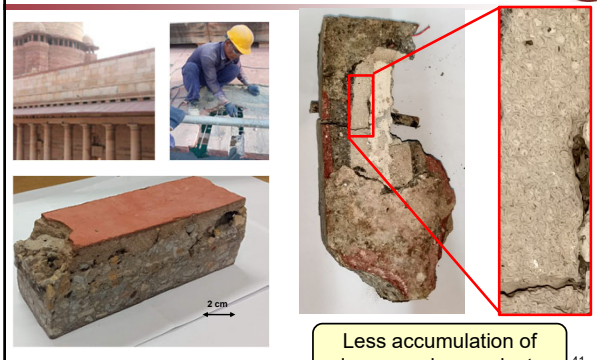
## After 3 years, anodes from the pilot study region were extracted and autopsied




Less accumulation of zinc corrosion products.

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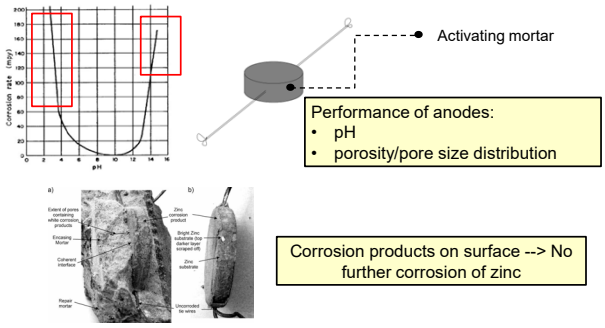
## Importance of activating mortar in galvanic anodes




Performance of anodes:
- pH
- porosity/pore size distribution

Corrosion products on surface --> No further corrosion of zinc

https://www.researchgate.net/figure/The-corrosion-rate-of-zinc-as-a-function-of-the-pH-of-the-environment_fig6_237621276
https://onlinelibrary.wiley.com/doi/10.1002/maco.201005707

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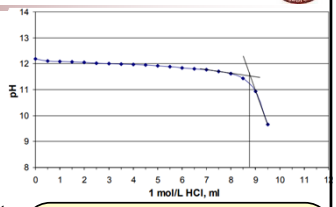
## How to measure the approximate pH of activating mortar?

- pH should be > 14
- Usual pH meters cannot measure pH > 14
- Predominant species responsible for high pH is $LiOH.H_2O$
- pH due to $Li^+$ is determined by acid-base titration against 1M HCl, since the amount of Li is difficult to detect with characterization methods




If the obtained concentration of LiOH is lesser than its solubility i.e., 10.9 g / 100 mL of water, then pH is calculated by adding the log [Li] to 14, if it is greater than the solubility, then pH is buffered to 14.4

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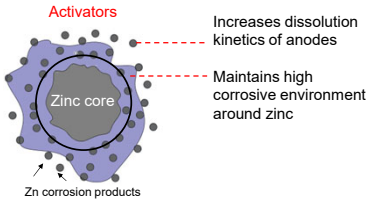
## Maintaining high-pH at the fresh zinc surface for long-term…a challenge




- LiOH, KOH and NaOH --> high pH
- With time → activator gets consumed → performance of anodes

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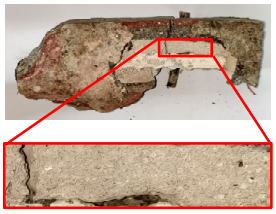
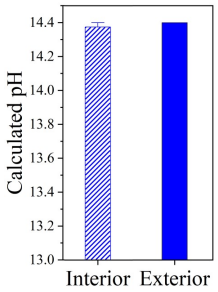
## Calculated pH in encapsulating mortar






At the end of 3 years
- NO reduction in pH
- Enough LiOH

Reference region in activating mortar

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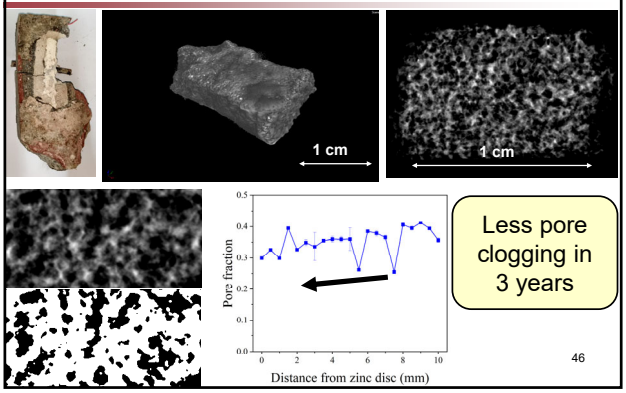
## Evolution of porosity in 3 years




Less pore clogging in 3 years

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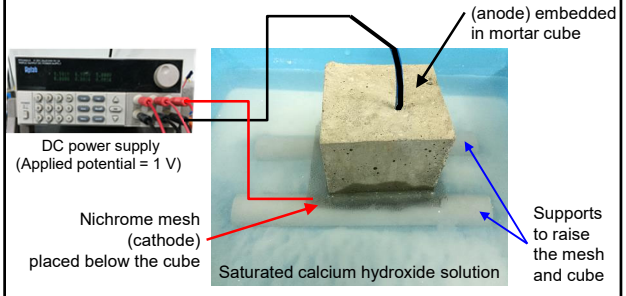
## Galvanic Anode Performance (GAP) test setup

- Developed at IIT Madras

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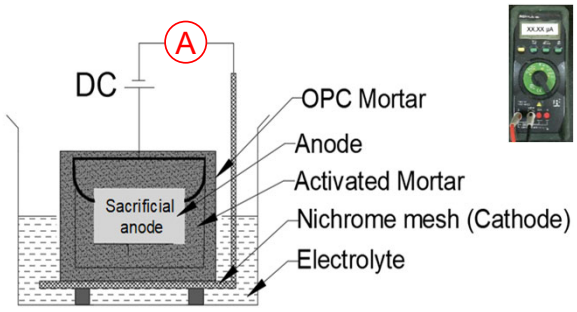
## GAP test – Output current from anode is measured using a multimeter




GAP test was developed at IIT Madras

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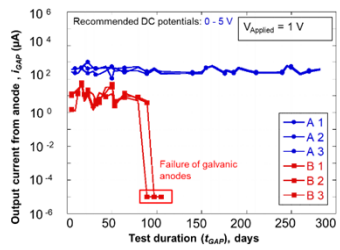
## GAP test - Performance of Anode 'A' and 'B'




Long-term performance of multiple galvanic anode systems in the Indian market are being evaluated.

Charge passed during the short-term GAP test is equal to the total charge passed during its long-term service in concrete structure

$$[i_{GAP} \times t_{GAP} = i_{required} \times t_{GA\ service\ life}]$$

GAP test was developed at IIT Madras

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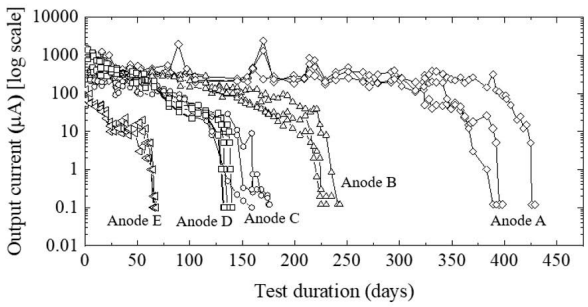
## Performance of different anode as per the GAP test results

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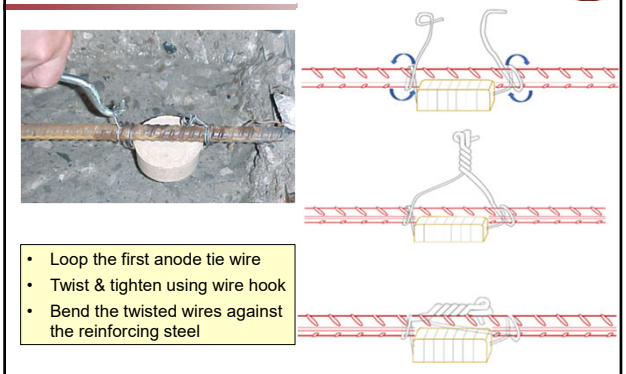
## Installation of anodes – Good electrical connection is essential



- Loop the first anode tie wire
- Twist & tighten using wire hook
- Bend the twisted wires against the reinforcing steel

https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcQWcIuWc2ngL5WtxRxZ9vdgWRohZy2rbNTXTFwVfYuyArXP3-YR&s

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## POOR practice in the installation of anodes - Avoid this

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## POOR practise in the installation of anodes - Avoid this

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## Anode installation Continuity check – (BS EN ISO 12696)

- Between
  - every rebar
  - rebar & anode connections
  - all anode connections
    - when connected using additional wires

**GOOD connection**
< 1 Ohm resistance or
< 1 mV DC voltage

https://www.youtube.com/watch?v=aC-9OsMU-4A

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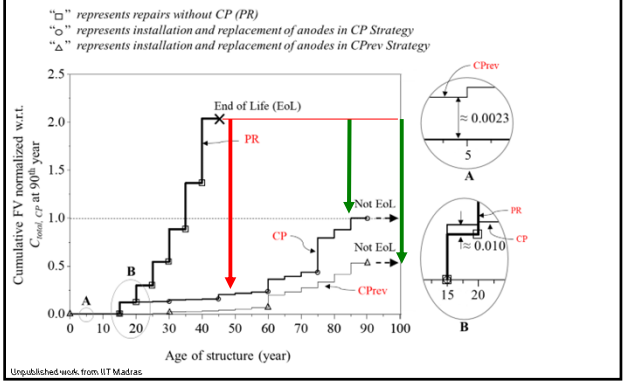
## Life-cycle cost of repair - CR, CP, and CPrev

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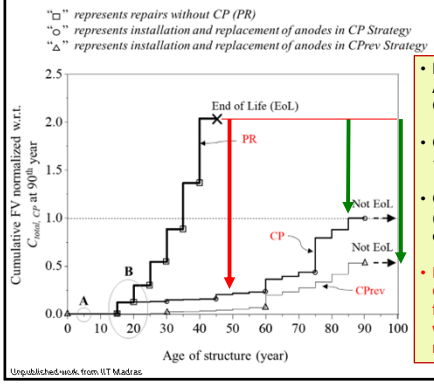
## Life-cycle cost of repair - CR, CP, and CPrev




- Patch Repair (PR) → About 10 times the LCC of CP option
- Cathodic Protection (CP) → 90% savings
- Cathodic Prevention (Cprev) → most economical
- For existing structures, CP is probably the only feasible and economic way to achieve durable repair, in most cases.

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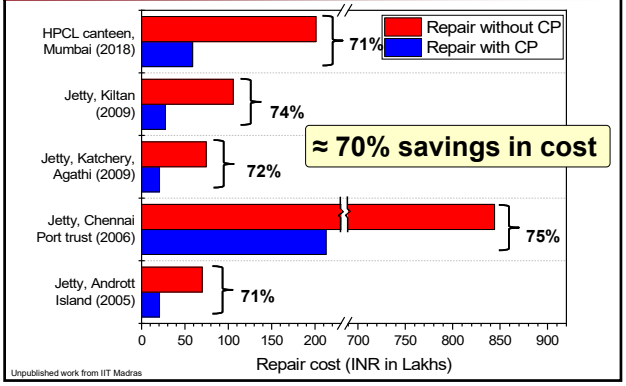
## Some other case studies…

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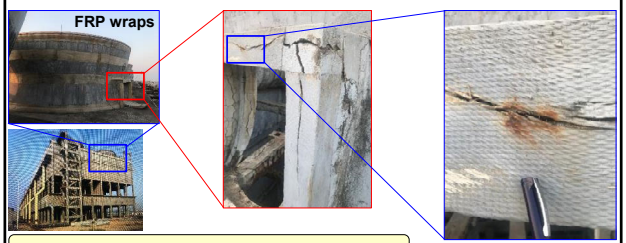
## Arresting the ongoing corrosion is essential for long-term performance of OTHER repairs

- FRP Wrapping + Cathodic Protection would have been a better choice of repair/strengthening




Cathodic protection helps other repair systems to work effectively

Cooling tower in a power plant

In about 3 years, FRP laminates were torn due to continued steel corrosion & expansive stresses from inside

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## Summary

- State of concrete repair industry
  - Frequency of repeated repairs
- Development and mechanisms of CP systems
- Field implementation and performance of galvanic anodes
- Galvanic Anode Performance (GAP) test
  - for assessing service life of anodes
- Cathodic protection is not a competitor rather an augmenter for the other repair systems
- Reduced life cycle cost and increased service life

Ask the consultants, engineers, and contractors for
**a service life of quarter century for concrete repair works**

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Where there is a will, there is a way!

# Thank You

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Courtesy: Prof. Devanshu Pandit

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