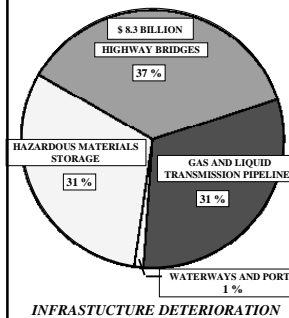


# Rehabilitation of Concrete Structures Affected by Corrosion

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## CORROSION COSTS AND PREVENTIVE STRATEGIES IN THE U.S.



- total direct annual cost of corrosion = \$ 276 billion
- 3.1% of U.S. gross domestic product
- \$ 22.6 billion estimated for infrastructure
- 15% of nations bridges are structurally deficient due to corrosion
- \$ 8.3 billion needed for bridges
  - \$ 3.8 billion to replace
  - \$ 4.5 billion for maint.
- indirect cost = 10 times the corrosion costs

## FDOT CONSTRUCTION PROGRAM

FY 2001 - 2002

- FDOT CONSTRUCTION PROGRAM = \$ 2.1 billion
- 14 BRIDGE STRUCTURES REPLACED
- 185 BRIDGE STRUCTURES REPAIRED

## SIGNIFICANCE OF CORROSION IN FLORIDA

- 6,200 EXISTING BRIDGES
- SUBTROPICAL CONDITIONS
- LARGE COASTAL AREA
- HIGH DENSITY POPULATION
- CONTINUOUSLY EXPANDING INFRASTRUCTURE TO ACCOMMODATE LOCAL AND VISITING TRAFFIC

## FDOT DESIGN PERSPECTIVE

### I. CORROSION PREVENTION FOR NEW STRUCTURES

- A. HIGH PERFORMANCE CONCRETES AND BETTER CONSTRUCTION PRACTICES
  - > STANDARD SPECIFICATION 346
  - > STANDARD SPECIFICATION 400
- B. CONCRETE COVER AND CLASS OF CONCRETE BASED ON CORROSION CLASSIFICATION OF STRUCTURE SITE
  - > STRUCTURES DESIGN GUIDELINES FOR LOAD AND RESISTANCE FACTOR DESIGN (LRF) – CHAPTER 2

## FDOT DESIGN PERSPECTIVE

Cont'd

### II. CORROSION CONTROL FOR EXISTING STRUCTURES

- > CATHODIC PROTECTION
- > CONCRETE REPAIR MATERIALS WITH CORROSION INHIBITORS

## Dificuldades



## Por quê?

**Alteração das características iniciais do concreto**

- *Perda da passivação*
- *Corrosão eletroquímica*

## Por quê?

### **Diagnóstico:**

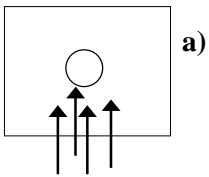
- origem;
- agentes causadores;
- sintomas;
- mecanismo.

## Por quê?

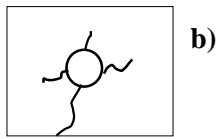
- **cloretos**
- **carbonatação**

*húmus, fungos, fissuras, lixiviação, retração*

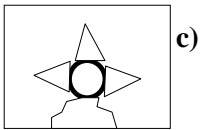
Deterioração progressiva devida a corrosão de armaduras



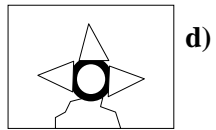
a)



b)

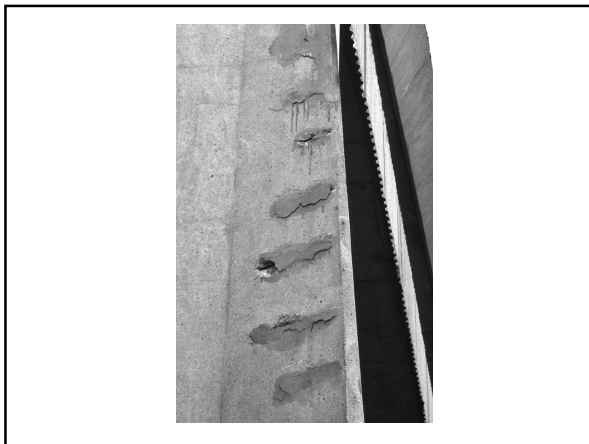
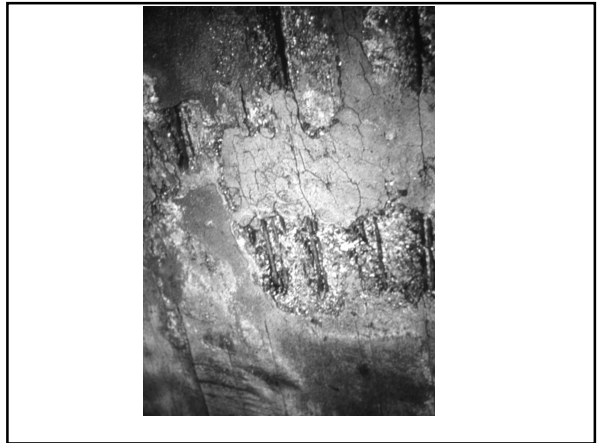
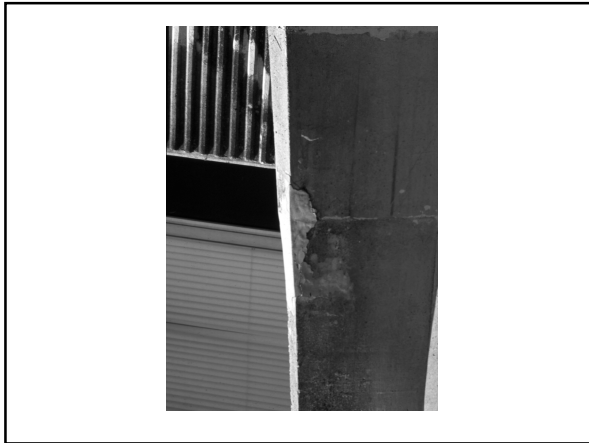


c)



d)

# INSUCESSOS!

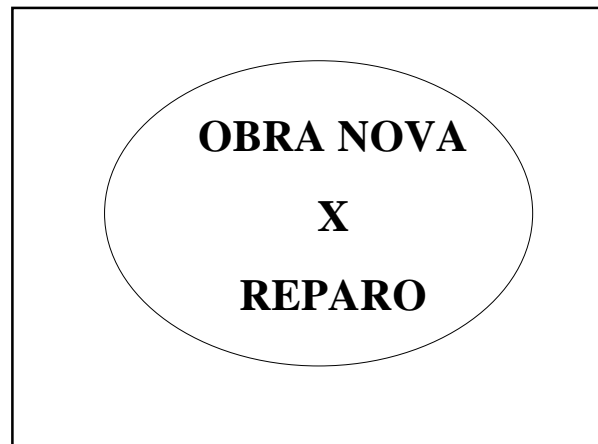
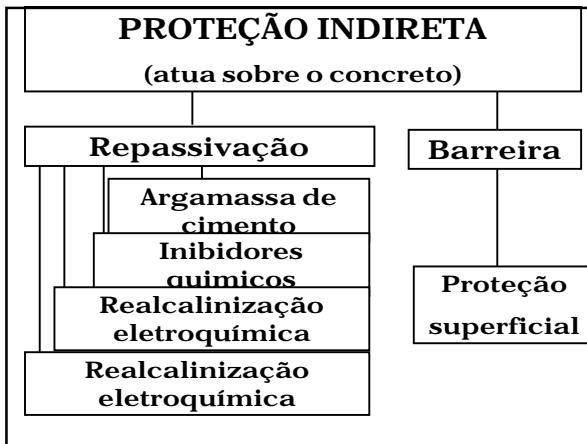
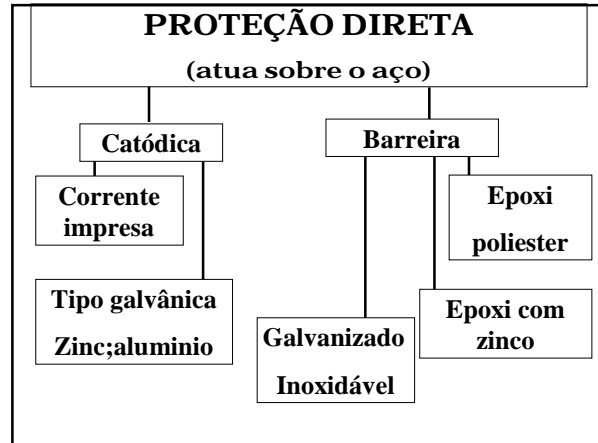
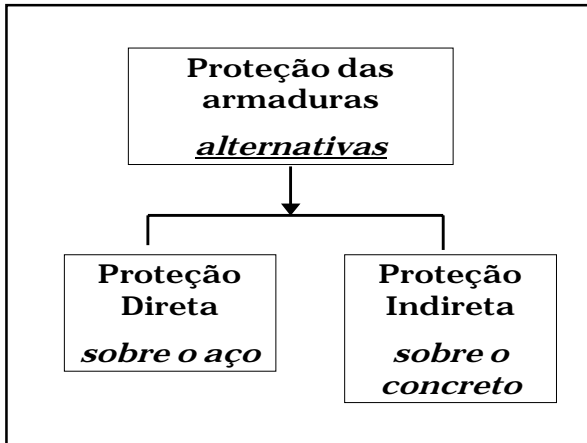


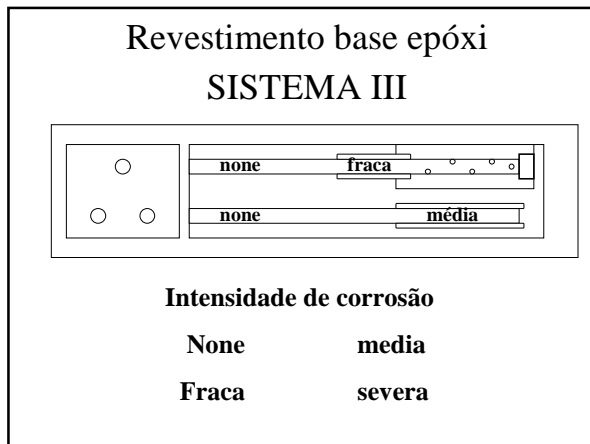
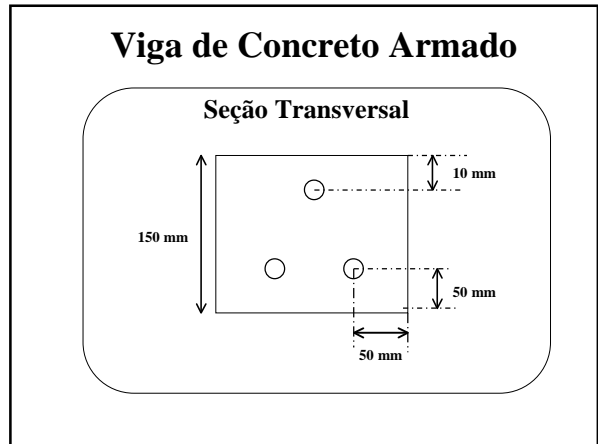
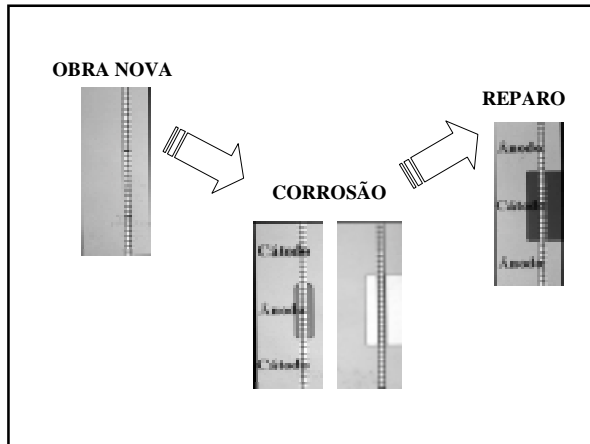


# Por quê?

falta:

- diagnóstico
- material
- procedimento
- visão sistêmica

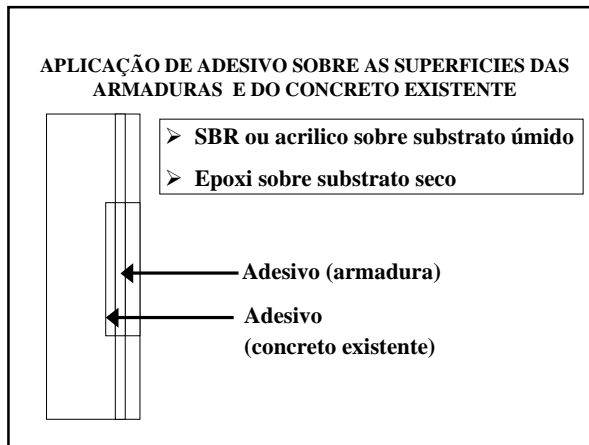
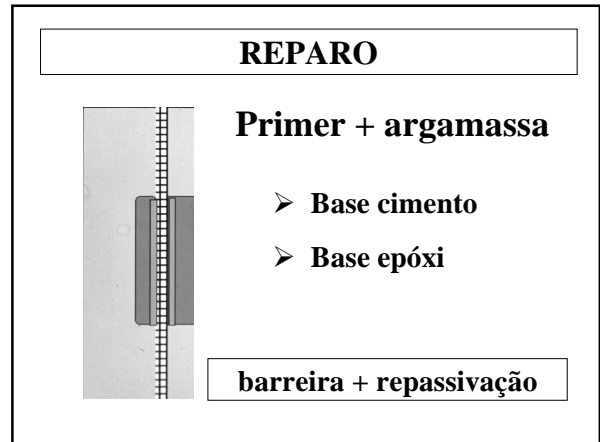
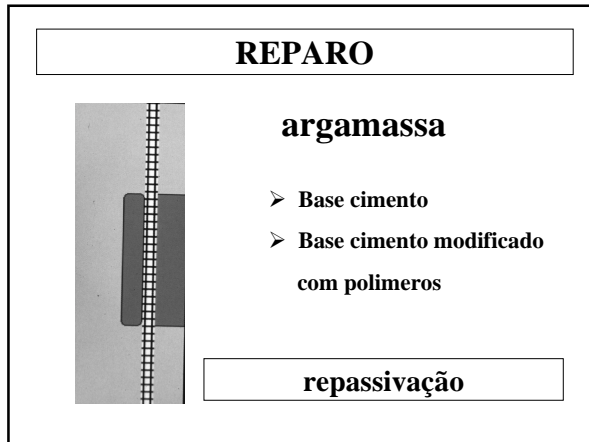




**Comprovação**

**FIGUEIREDO, Enio.** Avaliação do desempenho de revestimentos para proteção da armadura contra corrosão através de técnicas eletroquímicas: contribuição ao estudo de reparos em estruturas de concreto armado. Universidade de São Paulo PCC / USP, 15 abril 1994.

**MONTEIRO, Paulo & HELENE, Paulo.** Can local repairs be durable solution for steel corrosion in concrete? International Conference on Corrosion and Corrosion Protection of Steel in Concrete. Sheffield Academic Press, v.2, July 1994. P. 1525-38

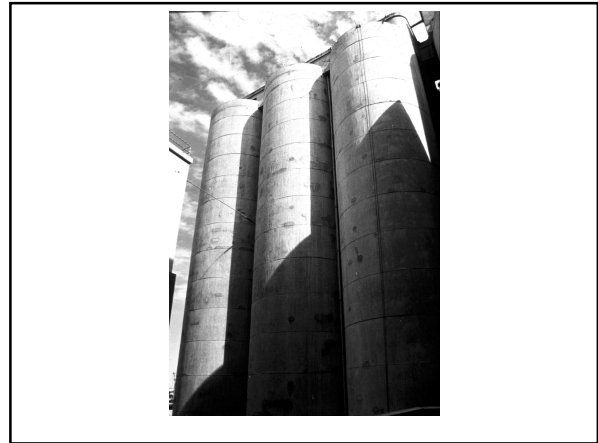
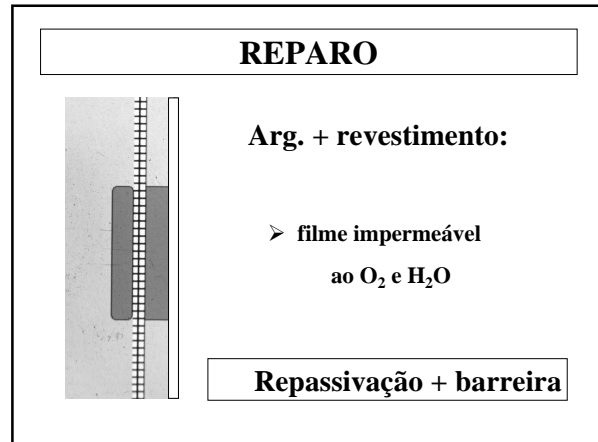


**RECONSTITUIÇÃO DO CILINDRO**





CONDIÇÃO	absoluto		relativo	
	MPa		%	
REFERÊNCIA	31,8		100	
UNIÃO ENDURECIDO COM FRESCO	NIHIL	26,3	13,1	82
	A	15,8	7,9	50
	B	27,1	13,5	85
	C	31,9	16,0	100
	D	25,0	12,5	79
UNIÃO ENDURECIDO COM ENDURECIDO	A	19,9	10,0	62
	B	30,3	15,2	95
	C	29,3	14,6	92
	D	28,7	14,4	90

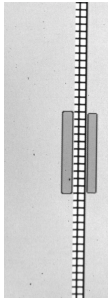


## Comprovação

**KAZMIERCZACK, Cláudio.** Contribuição para a análise da eficiência de películas aplicadas sobre estruturas de concreto armado com o objetivo de proteção contra a carbonatação.  
Universidade de São Paulo PCC / USP, 01 junho 1995.

**ISA, Mário.** Aderência concreto-armadura: influência da corrosão e da proteção catódica.  
Universidade de São Paulo PCC / USP, 06 junho 1997.

## REPARO



Secagem e  
impregnação com  
polímeros:

➤ metil metacrilato

barreira

## CATHODIC PROTECTION OF STEEL REINFORCEMENT IN CONCRETE



## FLORIDA DEPARTMENT OF TRANSPORTATION



### CORROSION RESEARCH LABORATORY



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## CORROSION ATTACK ON REINFORCING STEEL



- CORROSION ATTACKS THE REINFORCING STEEL IN CONCRETE STRUCTURES PRODUCING CRACKS, SPALLS, AND REDUCING THE CROSS-SECTIONAL AREA OF THE REBAR.
- IN MARINE STRUCTURES, CORROSION IS COMMONLY DEVELOPED AT TIDAL AND SPLASH ZONE ELEVATIONS.
- THE COSTS ASSOCIATED WITH CORROSION OF THE INFRASTRUCTURE IN THE U.S. ARE ESTIMATED AT AROUND 22.6 BILLIONS OF DOLLARS (FHWA-RD-01-156).

## COMPROMISES STRUCTURAL INTEGRITY



WHEN ADJACENT CONCRETE COMPONENTS ON A STRUCTURE ARE AFFECTED BY CORROSION, THE ABILITY OF THE STRUCTURE TO TRANSFER THE DESIGN LOADS AND RESIST LATERAL IMPACT FORCES IS REDUCED.

## CONVENTIONAL REPAIRS

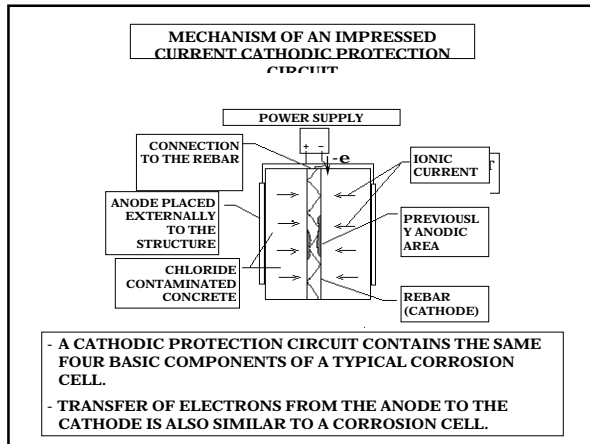
- STANDARD REPAIR METHODS DO NOT ELIMINATE CORROSION.

- TYPICALLY, NEW CORROSION CELLS ARE DEVELOPED.

- CORROSION RATES ARE ACCELERATED.

- IN GENERAL, THESE REPAIRS ARE NOT CONSIDERED LONG TERM SOLUTIONS FOR MARINE ENVIRONMENT STRUCTURES.




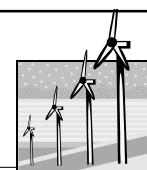


### NDT TECHNIQUES TO MEASURE PERFORMANCE OF CATHODIC PROTECTION ON REINFORCED CONCRETE

- E Log I
- POLARIZATION OF 100 MILLIVOLT
- POLARIZATION DECAY

*NACE Standard RP0290-2000*

## *Impressed Current Cathodic Protection Systems (CASE HISTORIES)*

### TITANIUM MESH ANODE SYSTEM

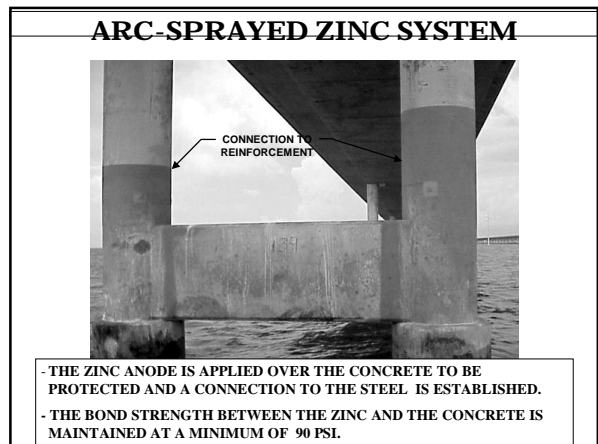
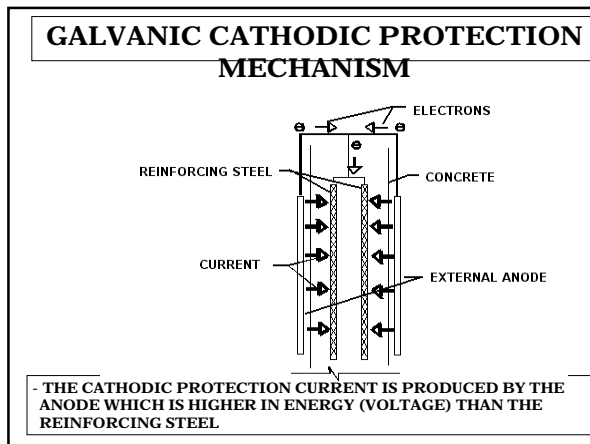
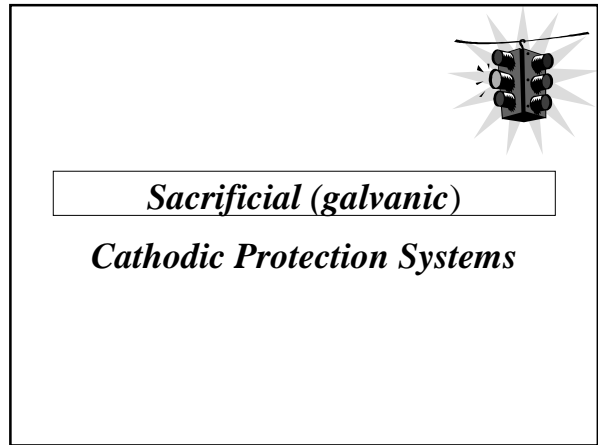
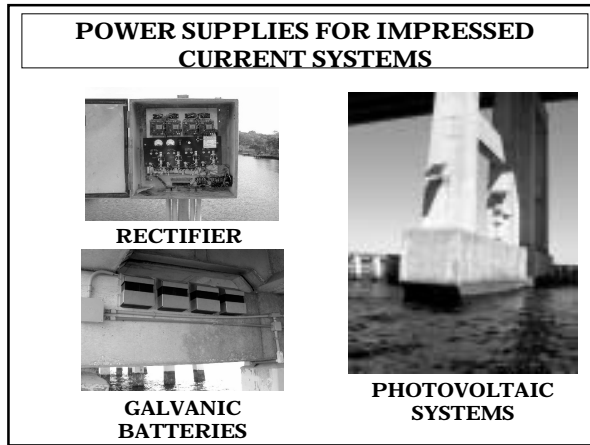
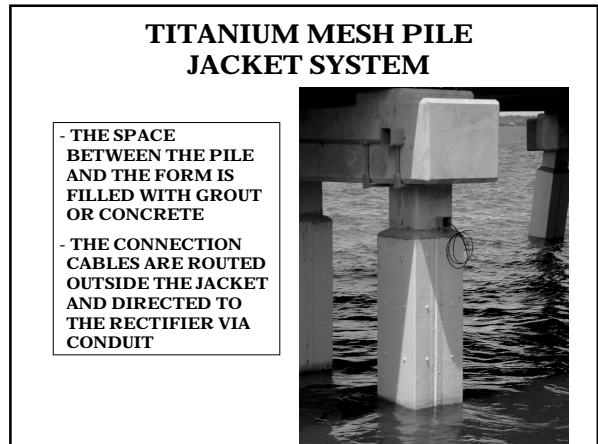
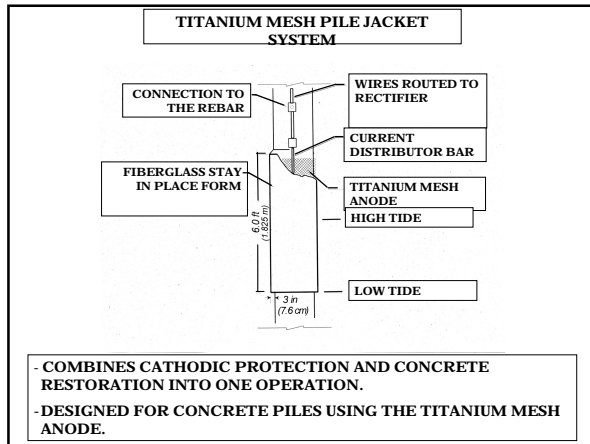
- THE MOST USED IMPRESSED CURRENT ANODE FOR REINFORCED CONCRETE STRUCTURES.
- THE ANODE IS INSTALLED DIRECTLY OVER THE CONCRETE SURFACE TO BE PROTECTED USING NON-METALLIC PINS.
- ANY STEEL COMPONENTS PRESENT ON THE SURFACE MUST BE ISOLATED FROM THE MESH.

### TITANIUM MESH ANODE ENCAPSULATED IN GUNITE

- GUNITE IS APPLIED OVER THE CONCRETE COMPONENT ENCAPSULATING THE ANODE. WIRES ARE ROUTED TO THE POWER SUPPLY.

### TITANIUM MESH ENCAPSULATED IN STRUCTURAL CONCRETE

- THE MESH ANODE PROVIDES CATHODIC PROTECTION TO THE NEW AND EXISTING CONCRETE.
- EXTREME CAUTION MUST BE OBSERVED TO ENSURE THAT NO CONTACT EXISTS BETWEEN THE ANODE AND THE REINFORCEMENT



## ARC-SPRAYED ZINC APPLICATION



- SPECIAL EQUIPMENT IS USED FOR THE APPLICATION OF THE ANODE.
- SURFACE PREPARATION INCLUDES THE REMOVAL OF UNSOUND CONCRETE AND SANDBLASTING.

## ZINC MESH ANODE PILE JACKETS

- INSTALLATION CONSISTS OF PLACING THE FORM AROUND THE PILE AND FILLING ANNULAR SPACE WITH LOW ELECTRICAL RESISTANCE MORTAR OR CONCRETE
- CONNECTION TO THE REINFORCEMENT IS ESTABLISHED OUTSIDE THE JACKET LIMITS
- JACKETS ARE FABRICATED TO DIFFERENT WIDTHS AND LENGTHS



## SYSTEM SELECTION

### CONSIDERATIONS

#### SYSTEM SELECTION

- 1. IDENTIFICATION OF REHABILITATION OBJECTIVES**
  - A. TO ENABLE A SAFE USE OF THE STRUCTURE.
  - B. TO SATISFY OR EXTEND THE SERVICE LIFE OF THE STRUCTURE.
  - C. TO MEET OTHER CRITERIA ALREADY ESTABLISHED BY THE OWNER.
  - D. COMBINATION OF ABOVE.
- 2. IDENTIFICATION OF MINIMUM REPAIRS NECESSARY**
  - A. REPLACEMENT OR STRUCTURAL REPAIRS
  - B. INSTALL CATHODIC PROTECTION
  - C. INSTALL CATHODIC PROTECTION AND PERFORM STRUCTURAL REPAIRS
  - D. NO REPAIR NEEDED AT THIS TIME

#### SYSTEM SELECTION

- 3. SELECTION OF CATHODIC PROTECTION SYSTEM**
  - A. TYPE OF ANODE**
    - a. Can provide the driving voltage required
    - b. Can provide the service life required
    - c. Is applicable to structure geometry
  - B. POWER SUPPLY (if Impressed Current Anode Selected)**
    - a. Determine if AC service is available at the site.
    - b. Determine capacity requirements of the power supply.
    - c. Determine best type of power supply for the application.

#### SYSTEM SELECTION

- 3. SELECTION CATHODIC PROTECTION SYSTEM (Cont.)**
  - C. INSTALLATION PROCEDURE**
    - a. Level of difficulty of intended installation.
    - b. Surface preparation.
    - c. Correction of electrical continuity of the reinforcement.
  - D. PERIODIC MONITORING**
    - a. Availability of skilled personnel.
    - b. Possibility of remote monitoring.
    - c. Determine monitoring schedule and consult w/ owner.

## SYSTEM SELECTION

### 4. SELECTION CATHODIC PROTECTION SYSTEM (Cont.)

#### E. SYSTEM COST

- a. Initial installation costs.
- b. Yearly maintenance costs.
- c. Monitoring costs.

## AVERAGE COSTS

SYSTEM (Anode)	Number of Bridges	Years in Service	Initial Cost \$/ft <sup>2</sup>
Titanium Mesh in Gunite or Concrete	4	13	\$28.00*
Titanium Mesh Pile Jackets	10	12	\$94.00
Expanded Zinc Mesh Pile Jackets	26	6	\$103.00
Arc Sprayed Zinc	13	12	\$19.00*

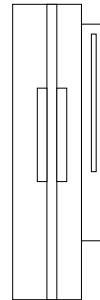
\* Does not include concrete repair or electrical system costs.  
- Years in service refers to the first installed system of this type.

## CUSTOS de REFERÊNCIA

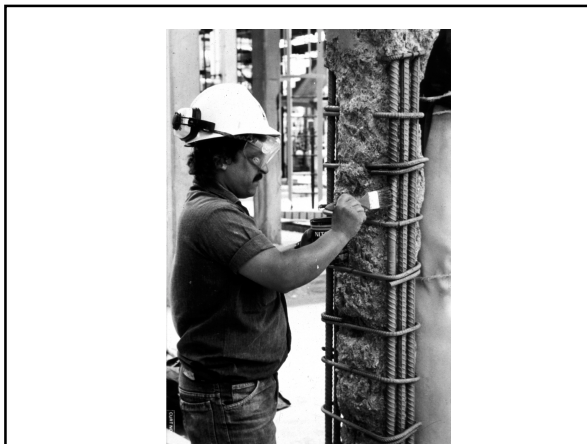
**Reparo Localizado Tradicional** US \$ 100/m<sup>2</sup>

**Proteção Superficial Verniz Acrílico** US \$ 15/m<sup>2</sup>

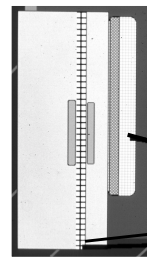
## REPARO



**Proteção catódica tipo galvânica com anodo interno**



## REPARO

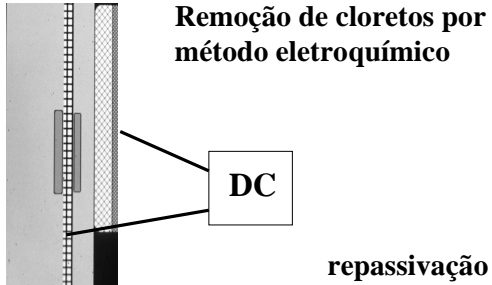


**Realcalinização por método eletroquímico**

DC

**repassivação**

## REPARO



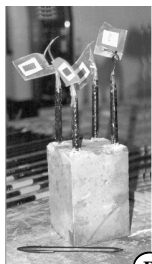
## REPARO

### ESPECIAIS

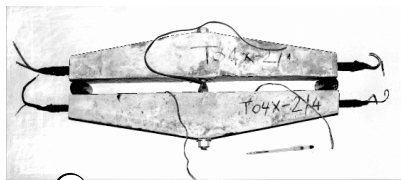
Acero Inoxidable

Galvanizado

## Tests



CONCRETE SPECIMENS



(T) Tensioned bars

(R) Relaxed bars

## Comprovação

TULA, Leonel. Contribuição ao estudo da corrosão de armaduras de aço inoxidável.  
Universidade de São Paulo PCC / USP, 31 março 2000.

✦ Exóticos

*"a caixinha"*





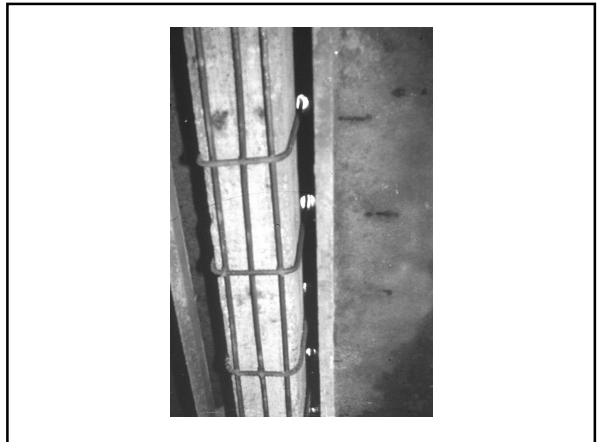
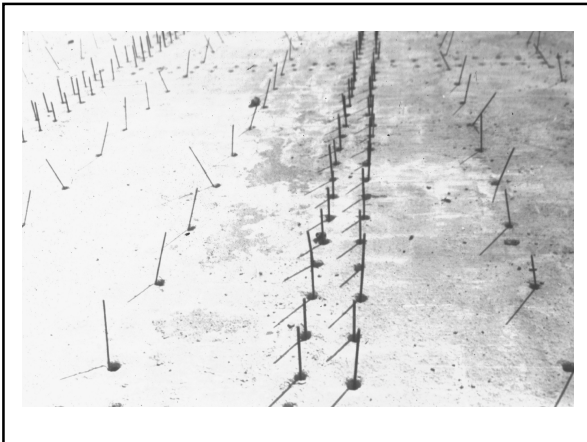


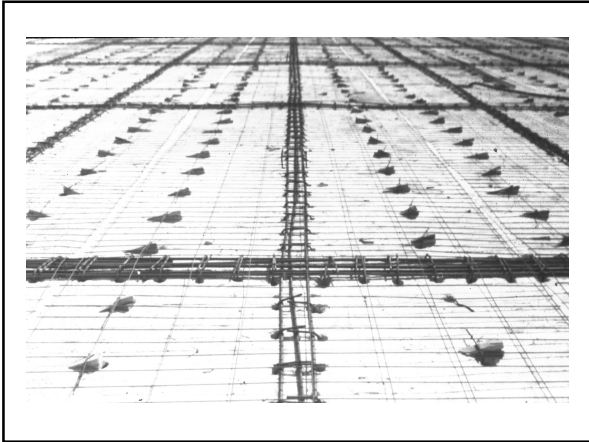




## ✚ Exóticos

*"o futurista"*





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