



# First South East European Regional CIGRÉ Conference

# SEERC

Portoroz, Slovenia, 7—8 June 2016

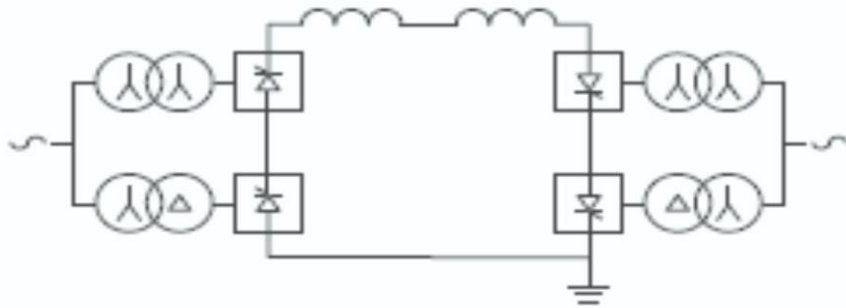
## An Innovative Concrete-Steel Anode for HVDC Submarine Links: Ideas for a Design of a Prototype

**Massimo Pompili – Bruno A. Cauzillo – Romeo Rendina**

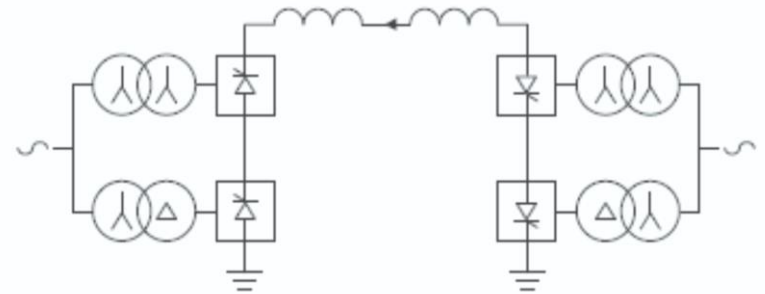
**SAPIENZA – University of Roma**



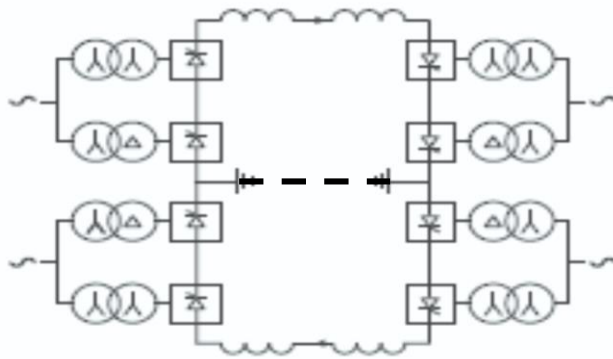
# HVDC possible system configuration



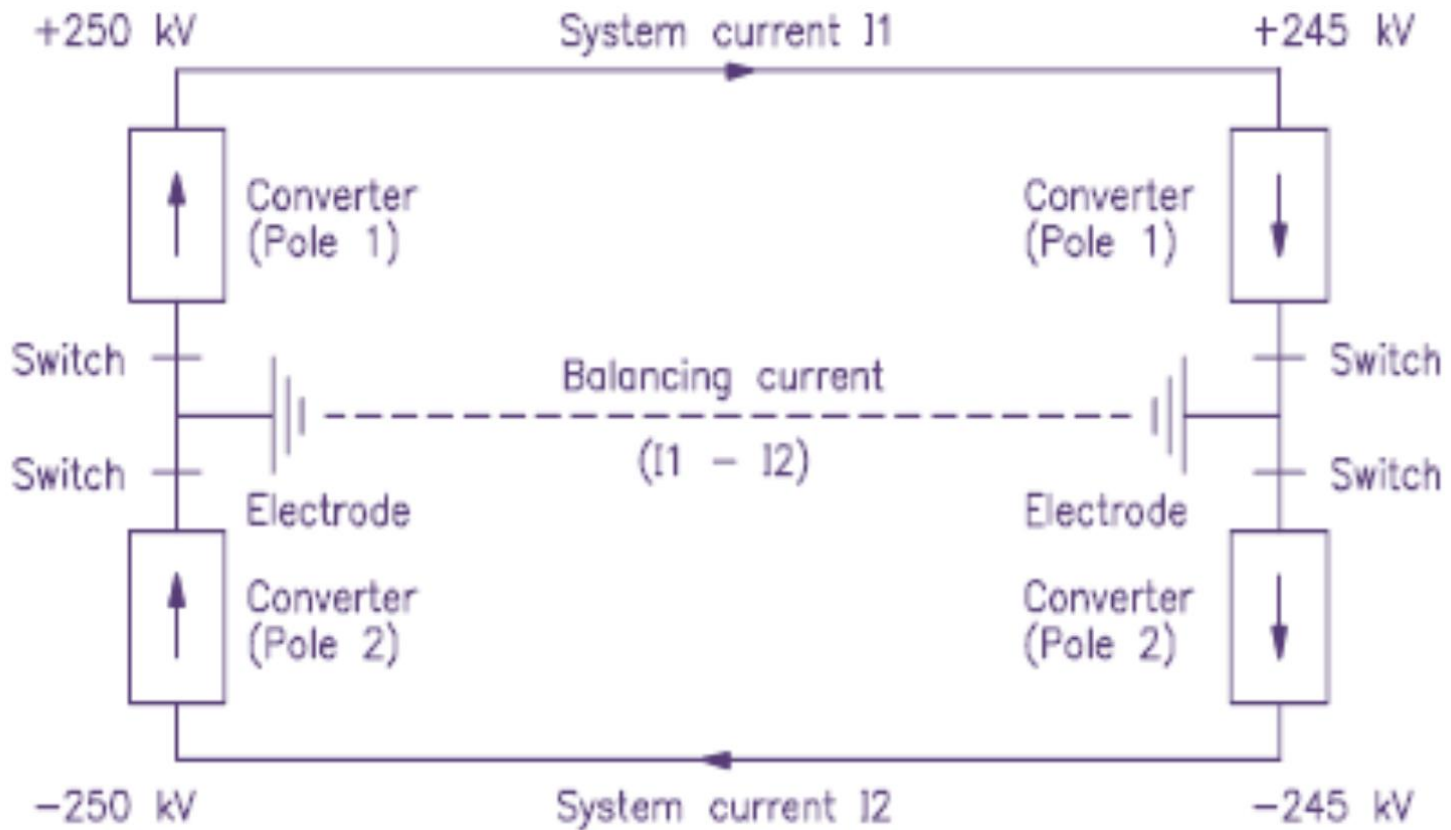
Monopolar Configuration with metallic return



Monopolar Configuration with ground return.

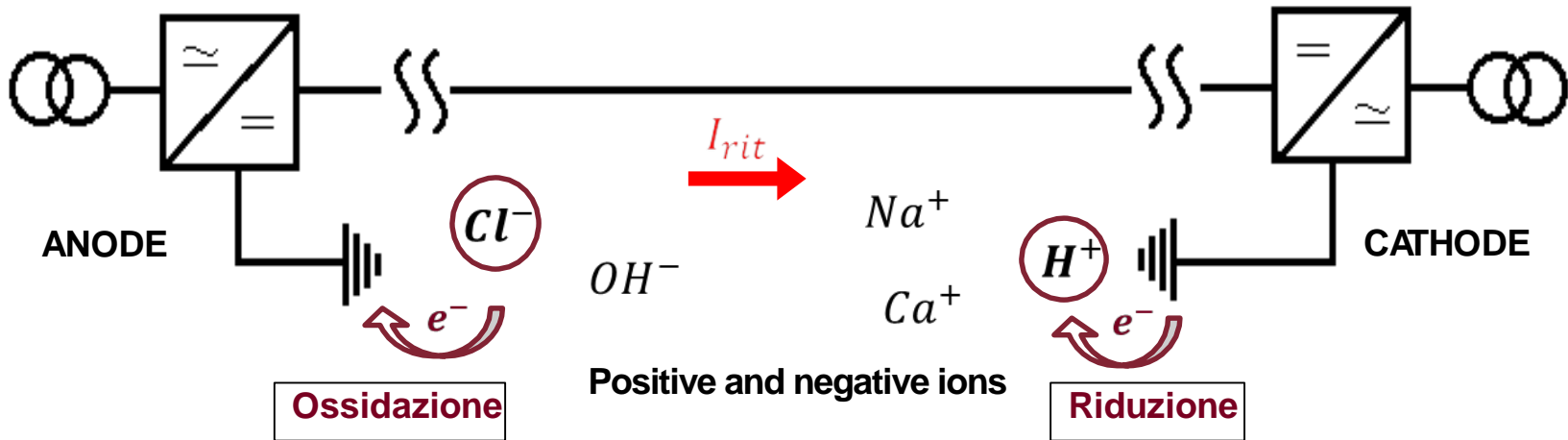


Bipolar Configuration with possible ground return.

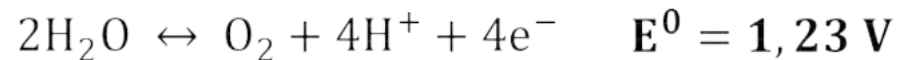
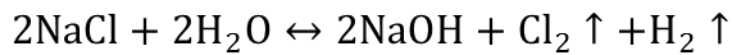


Balancing current in Bipolar HVDC link

# Reactions at the electrodes



## Reaction at the anode



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## Technologies for anodes

For HVDC submarine connection systems, the electrodes are normally designed in compliance with the following specifications:

- continuously current of 20% greater of the nominal capacity;
  - lifetime expectation of about 20 years or more;
  - reversible functionality (cathode/anode) for a limited period;
  - free chlorine emission in the proximity of the anode non greater of 0,2 mg/L;
  - electrode total voltage drop, at the nominal current of the system, greater than 12 V;
  - electrical field on the electrode surface not greater than 0,5 V/m, in the worst condition.
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## (Chemical) - Electrode project

The most common types of anode used in sea and shore anodes are:

- Titanium mesh or rods coated with platinum or other mixed metal oxides (MMO)
- Magnetite anodes ( $\text{Fe}_x\text{O}_4$ )
- Carbon/Graphite rods
- Silicon or Chromium High alloy steel (SiCrFe) rods.

Platinized titanium rods are the most used. The structure is composed of several rods suspended on a traversal insulating structure, generally wooden.

The rods are coated with a 5 – 20  $\mu\text{m}$  layer of a noble metal oxide, such as platinum, or a mixture of several of them.

**Titanium anodes, not protected, have a very high wear rate in the range of 6-8 kg/A·year**



# (Chemical) - Anode (Titanium)

**Tavola periodica degli elementi**

gruppo I II III IV V VI VII VIII gas nobili

1	I										VIII										2																																																																																																																																																															
1	H idrogeno 1,008																				2	He elio 4,003																																																																																																																																																														
2	Li litio 6,941										Be berillio 9,012										B boro 10,81										C carbonio 12,01										N azoto 14,01										O ossigeno 16,00										F fluoro 19,00										Ne neon 20,18																																																																																																													
3	Na sodio 22,99										Mg magnesio 24,31										Al alluminio 26,98										Si silicio 28,09										P fosforo 30,97										S zolfo 32,07										Cl cloro 35,45										Ar argo 39,95																																																																																																													
4	K potassio 39,10										Ca calcio 40,08										Sc scandio 44,96										Ti titanio 47,88										V vanadio 50,94										Cr cromo 52,00										Mn manganese 54,94										Fe ferro 55,85										Co cobalto 58,93										Ni nichel 58,69										Cu rame 63,55										Zn zinc 65,39										Ga gallio 69,72										Ge germanio 72,61										As arsenico 74,92										Se selenio 78,96										Br bromo 79,90										Kr cripto 83,80									
5	Rb rubidio 85,47										Sr stronzio 87,62										Y ittrio 88,91										Zr zirconio 91,22										Nb niobio 92,91										Mo molibdeno 95,94										Tc tecnecio (98)										Ru rutenio 101,1										Rh radio 102,9										Pd palladio 106,4										Ag argento 107,9										Cd cadmio 112,4										In indio 114,8										Sn stagno 118,7										Sb antimonio 121,8										Te tellurio 127,6										I iodio 126,9										Xe xeno 131,3									
6	Cs cesio 132,9										Ba bario 137,3										La lantano 138,9										* Hf afnio 178,5										Ta tantalio 180,9										W wolframio 183,9										Re renio 186,2										Os osmio 190,2										Ir iridio 192,2										Pt platino 195,1										Au oro 197,0										Hg mercurio 200,6										Tl tallio 204,4										Pb piombo 207,2										Bi bismuto 209,0										Po polonio (209)										At astato (210)										Rn rado (222)									
7	Fr francio (223)										Ra radio 226,0										Ac attinio 227,0										* Rf rutherfordio (261)										Db dubnio (262)										Sg seaborgio (263)										Bh bohrio (262)										Hs hassio (265)										Mt meitnerio (268)										Ds darmstadtio (269)										Rg roentgenio (272)										Uub ununbio (285)										Uut ununtrio (284)										Uuq ununquadio (289)										Uup ununpentio (288)										Uuh ununhexio (292)										Uus ununseptio (310)										Uuo ununottio (314)									

elementi di transizione

\* lantanidi

58	59	60	61	62	63	64	65	66	67	68	69	70	71
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
cerio	praseodimio	neodimio	promezio	samario	europio	gadolinio	terbio	disprosio	olmio	erbio	tulio	ytterbio	lutetio
140,1	140,9	144,2	(145)	150,4	152,0	157,3	158,9	162,5	164,9	167,3	168,9	173,0	175,0

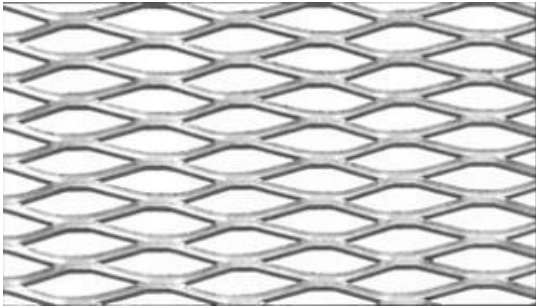
\* attinidi

90	91	92	93	94	95	96	97	98	99	100	101	102	103
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
torio	protattinio	uranio	nettunio	plutonio	americio	curio	berkelio	californio	einsteinio	fermio	mendelevio	nobelio	laurenzio
232,0	231,0	238,0	237,0	(244)	(243)	(247)	(247)	(251)	(252)	(257)	(258)	(259)	(260)



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## (Chemical) - Anode (Titanium)



Titanium is the ninth most abundant element in the Earth's crust.

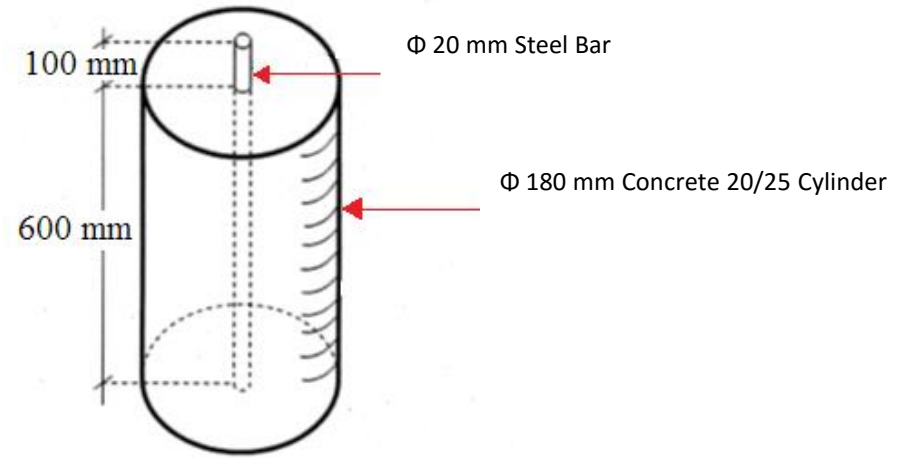
The two most useful properties are corrosion resistance and the highest strength-to-density ratio of any metallic element.

Related to its tendency to form a passivating layer, titanium exhibits excellent resistance to corrosion. However, it is attacked by concentrated acids. As indicated by its negative redox potential, titanium is thermodynamically a very reactive metal. One indication is that the metal burns before its melting point is reached. Melting is only possible in an inert atmosphere or in a vacuum.

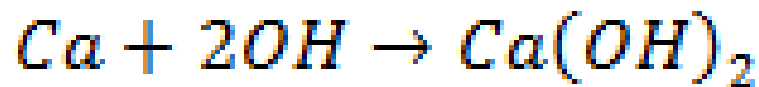


# Innovative Concrete Steel Anode

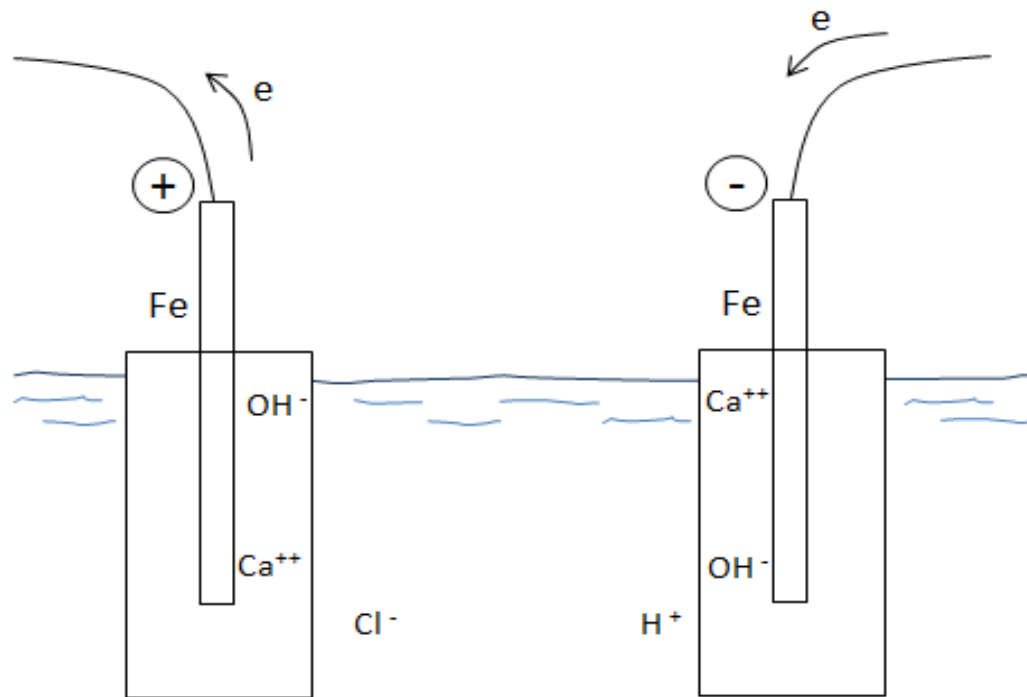
The prototype designed and built in University of Roma - Sapienza



## ***Cathode***



## ***Anode***



**Alkaline environment  
able to prevent corrosion**

# Experimental

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Preliminary Test

A)

- Comparative Test

- Protocol for A) and B)

- DC Circuit
- 56 h/test
- $J = 25-40 \text{ A/m}^2$
- Sea water

Evaluation  
of corrosion  
in Lab

B)

**A) Preliminary Test: Steel VS Concrete**

**B) Test in Lab: Anode in  
Steel/Titanium/MMO Titanium  
VS  
Concrete steel**

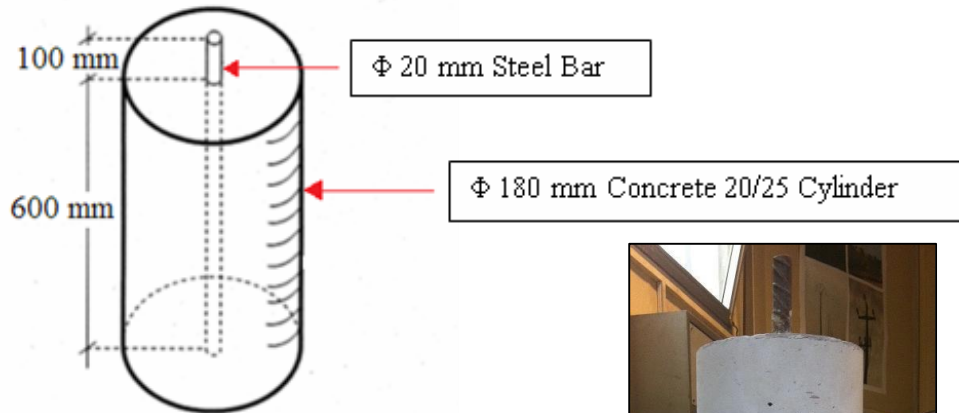
**C) Test in sea: Anode in Concrete in sea  
environment**

Test of concrete  
anode in sea  
environment

C)

# Experimental

## Anode in Concrete



## Anode in Steel



## Anode in Titanium

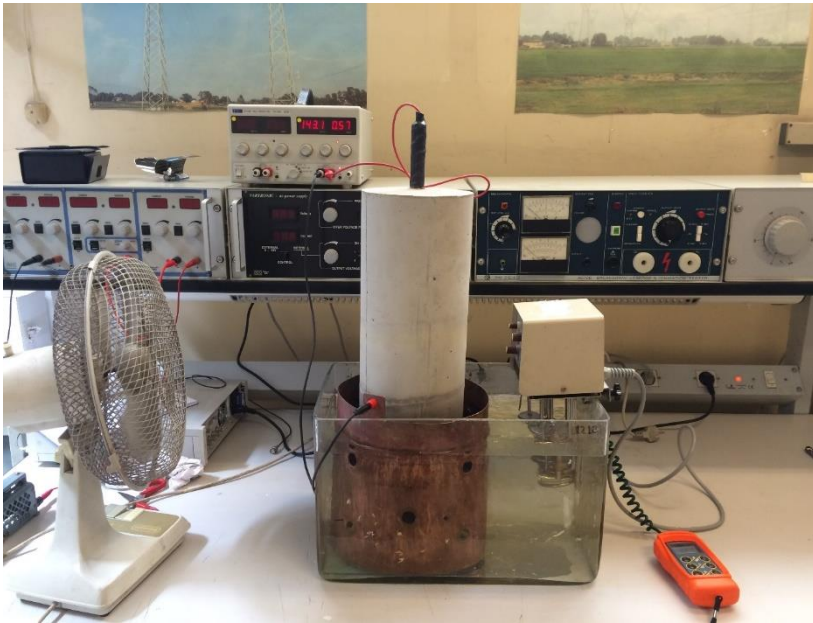


## Anode in Mesh MMO Titanium

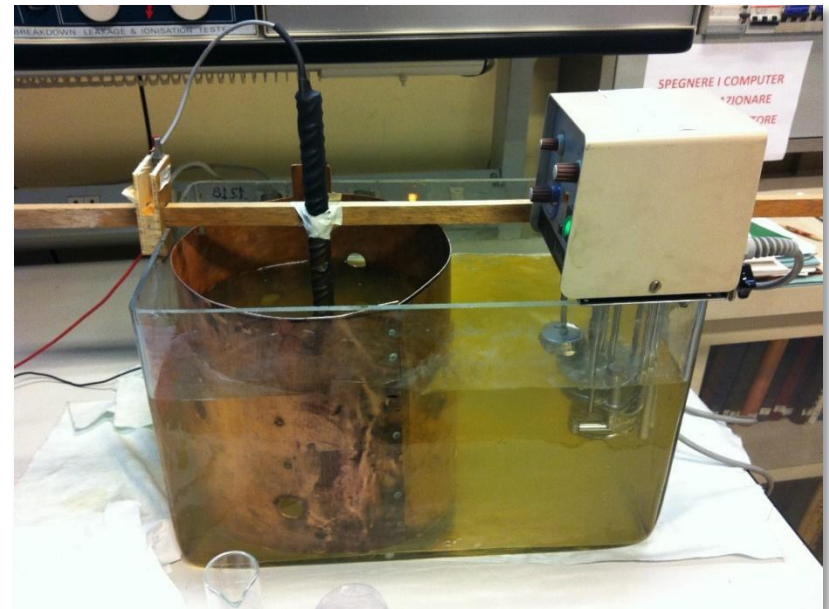


# Setup

Anode in Concrete



Anode in Steel



# Innovative Concrete Steel Anode

The preliminary experimental work performed at University of Roma - Sapienza



a) Concrete steel anode

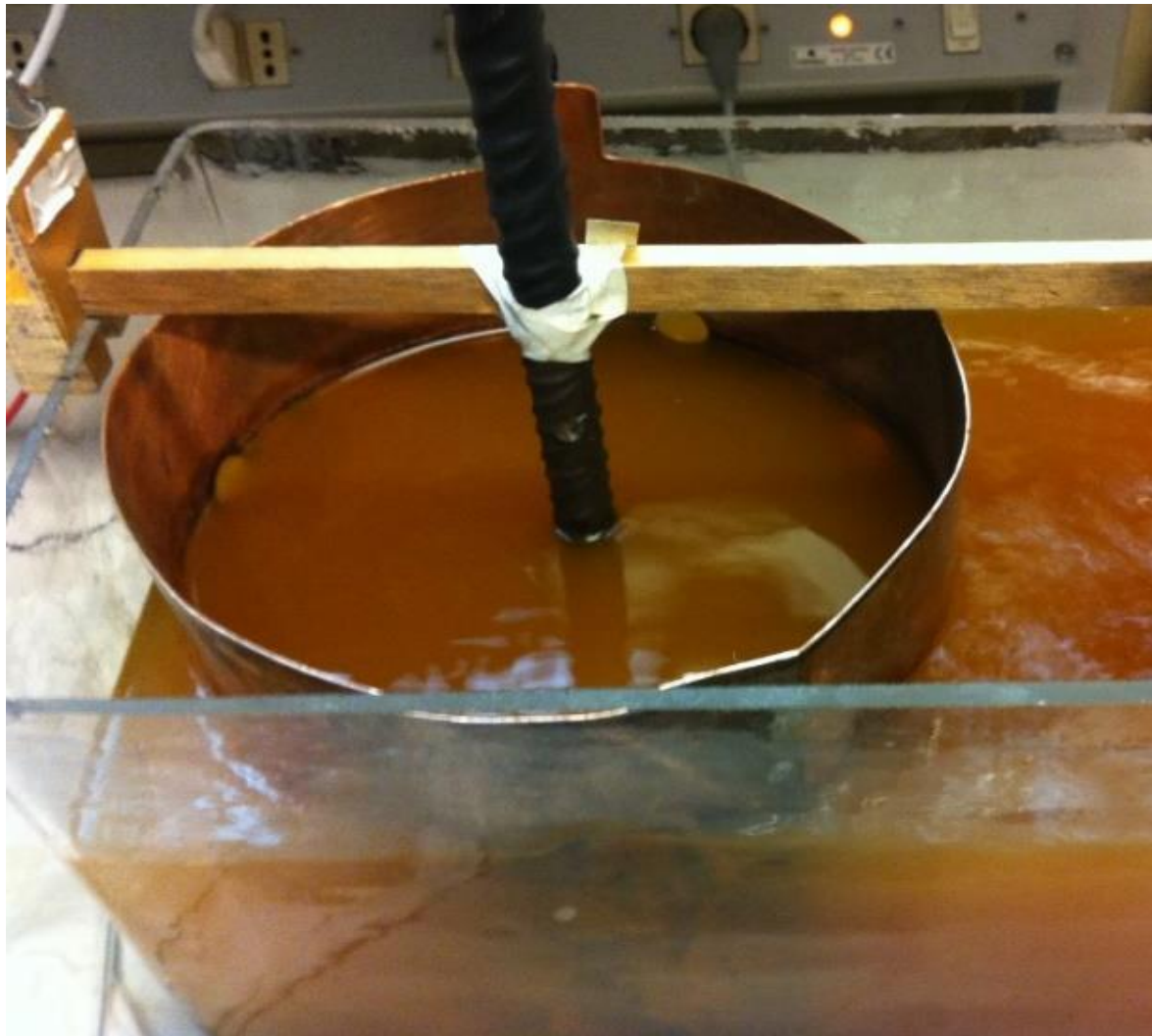


b) Steel anode

Comparison of solution coloration between steel-concrete anode and steel anode after the experimental work (56 hours) with current density  $25 \text{ A/m}^2$  (the normal density is  $1 \text{ A/m}^2$ )

(a): Colorless seawater after the Test (steel anode covered with concrete)

(b): Fire-brick or dark red seawater after the Test (steel anode without concrete)



# Experimental: Surface inspection

- No water infiltration in concrete anode
- Visible **deterioration** of the anode Steel
- **Fe deposits** in proximity of the **discontinuity of the concrete anode**





$$x = 4 \cdot \sqrt{\frac{t}{1200}}$$

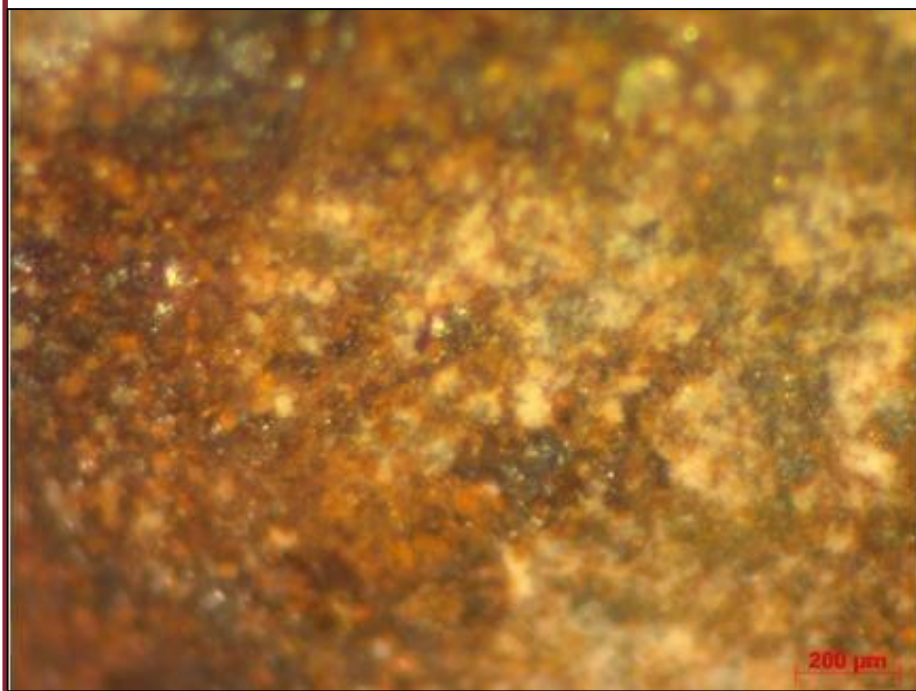


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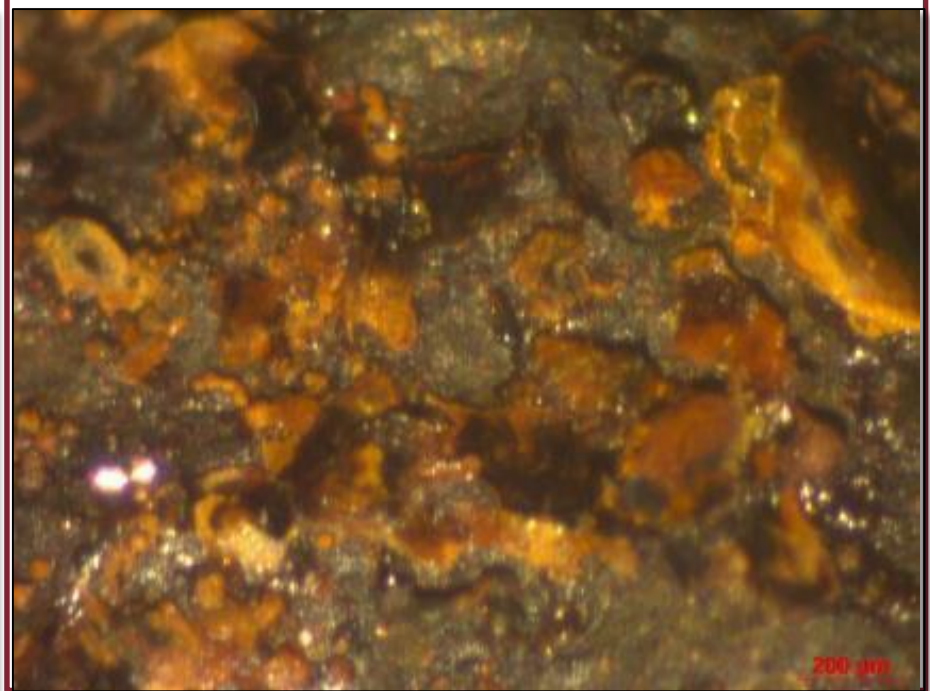
# Microscope inspection – Steel anode

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**Test 1 – 5x**



**Test 2 – 5x**



# Water chemical analysis

	Seawater	Cycle 4 (after 32 hours)		Cycle 8 (after 56 hours)	
		Anode in CA	Anode in Acc	Anode in CA	Anode in Acc
<b>Colour</b>	colorless	colorless	brownish	colorless	brownish
<b>pH</b>	8,0	9,1	5,4	9,2	6,8
<b>Conducib. (<math>\mu\text{s}/\text{cm}</math>)</b>	37.600	49.100	51.300	50.000	49.900
<b>Chlorides</b>	26.865	26.080	24.240	25.340	24.335
<b>Na (mg/L)</b>	9.025	9.120	7.750	8.250	7.250
<b>K (mg/L)</b>	715	735	695	685	650
<b>Mn (mg/L)</b>	< 50	< 50	950	< 50	979
<b>Fe (mg/L)</b>	< 0,5	< 0,5	131	0,5	119
<b>Ca (mg/L)</b>	400	362	373	320	380

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## Additional tests with titanium anodes

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Comparison among the titanium rods used during the tests for different times

Ph decreased also from 7.17 to 3.49.

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**Particularly titanium rod at the end of the accelerated testing**

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## Anode in Mesh of MMO Titanio

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PRODUCT NAME	COATING	COATING THICKNESS	SPECIFICATION
MMO Titanium Mesh	Ru-Ir	8 $\mu\text{m}$ (10g)	1x50x20 mm



**Before**

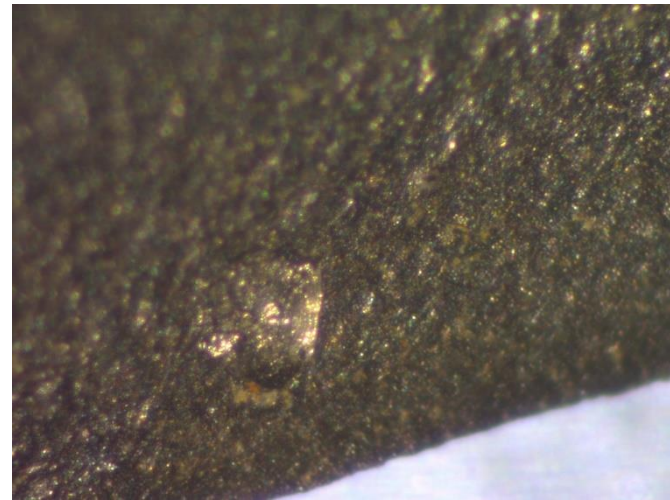
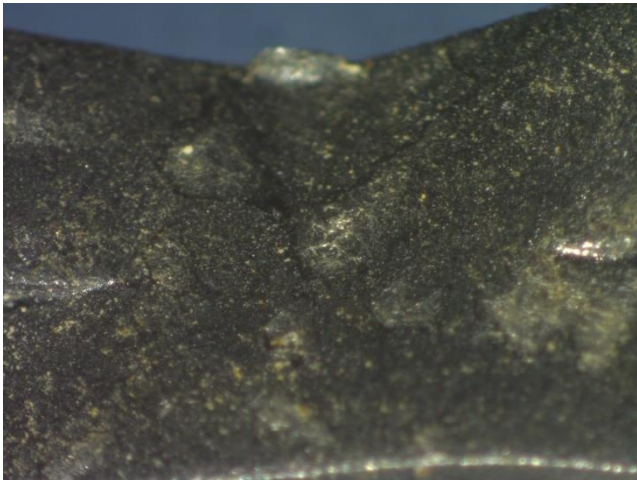


**After**

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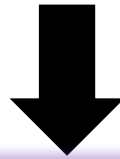
## Microscope inspection – Anode in Mesh of MMO Titanium

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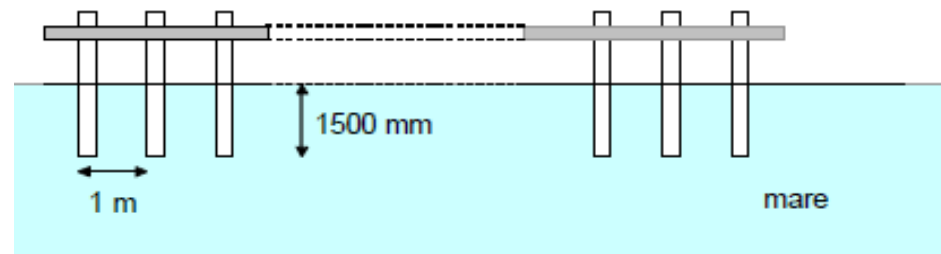
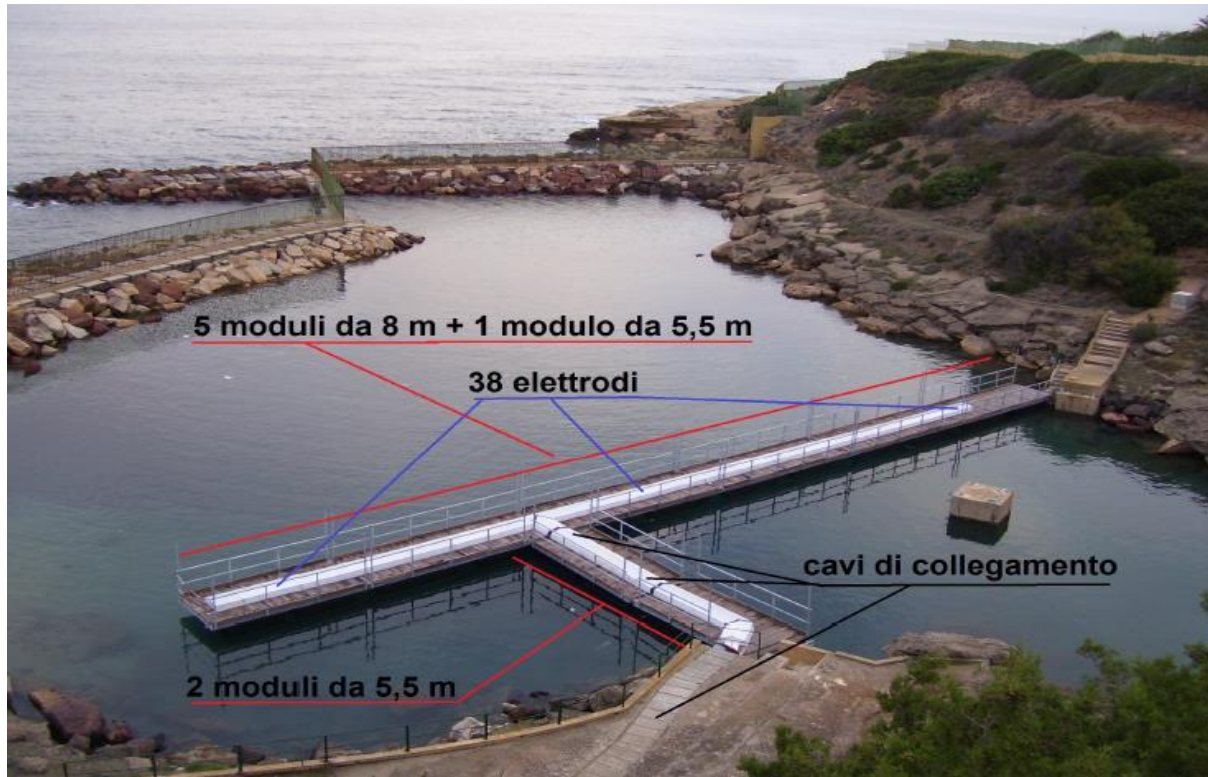
# Concrete anode test on-site

- Possibly avoid authorization (time consuming);
- Select a protected site close to the coast, having electrical supply
- Similar sea water condition for comparison purposes between concrete steel anode and existing titanium anode.



**It was supposed the «Tramontana bay» (Sardinia) where it is installed other HVDC traditional anodes**

# Sardinia HVDC traditional anodes [B1-101 CIGRE 2012]



# Possible anodes installation

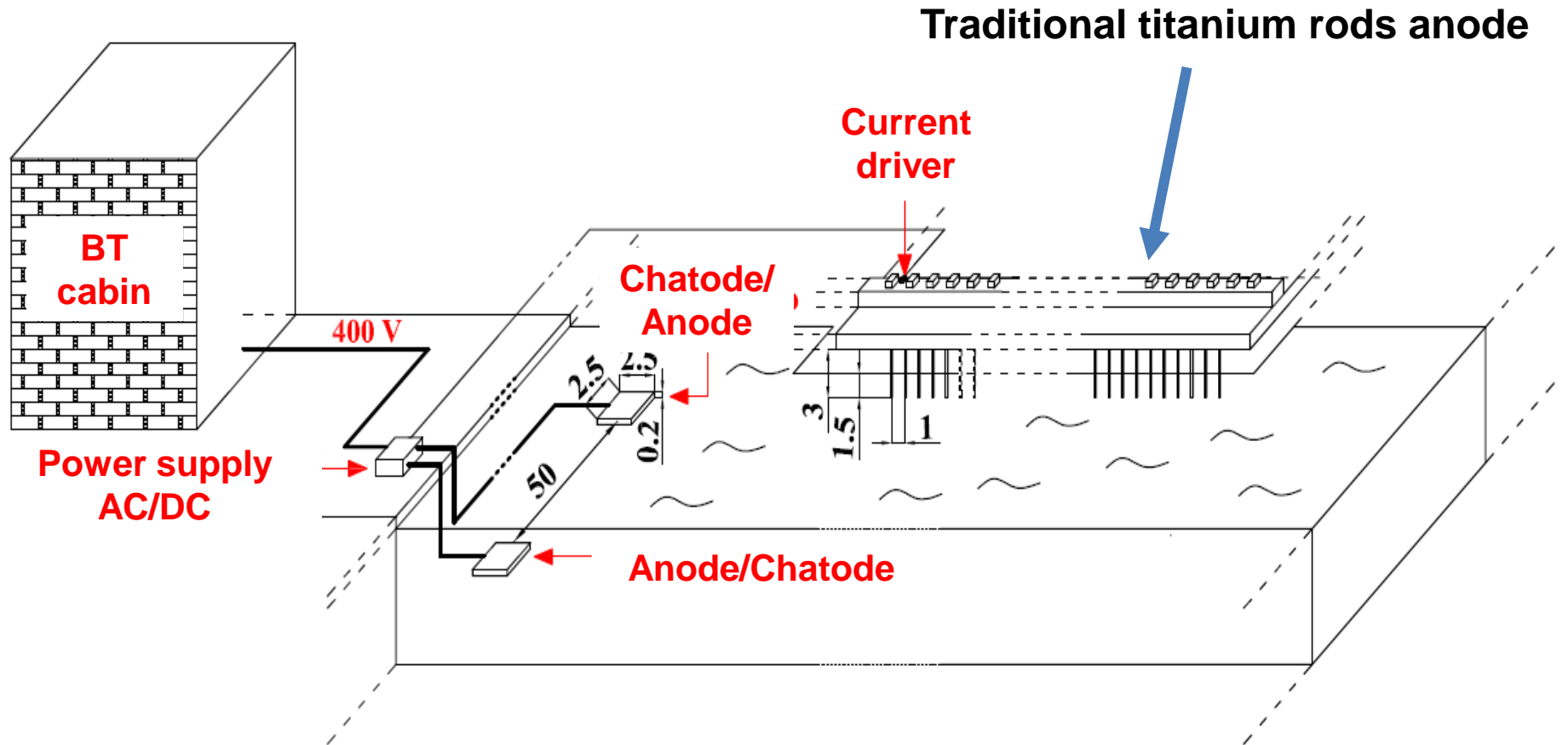


- Anode
- Cathode

# Pilot electrode (concrete) - Terms of reference

- DC density current greater than 20% of the nominal ( $1 \text{ A/m}^2$ )
- Lifetime 20 years or more;
- CL emissions near to the anodes less than  $0.2 \text{ mg/L}$ ;
- Total voltage drop at the electrode  $< 12 \text{ V}$ ;

# Setup of installation



# Electrical design

DC continuative nominal current related to the real electrode:

$$I_o = 1500/\text{number of rods (38)} \approx 40 \text{ A}$$

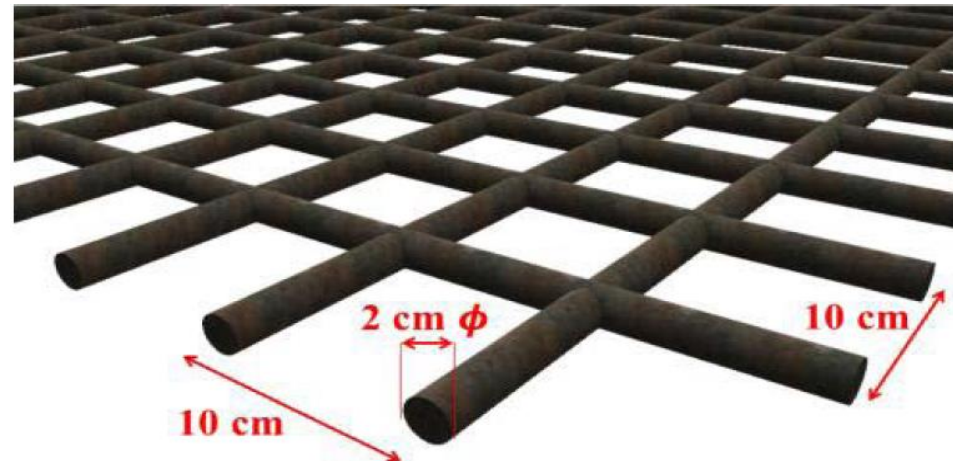
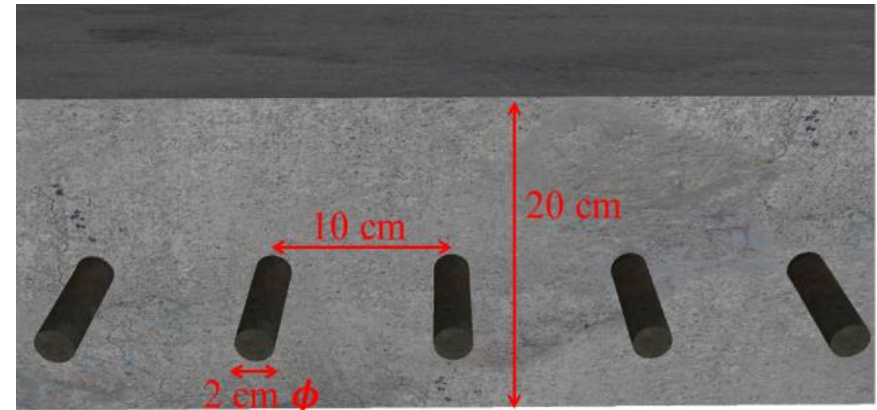
DC continuative max current related to the real electrode

$$I_{max} = 2500/38 \approx 66 \text{ A}$$

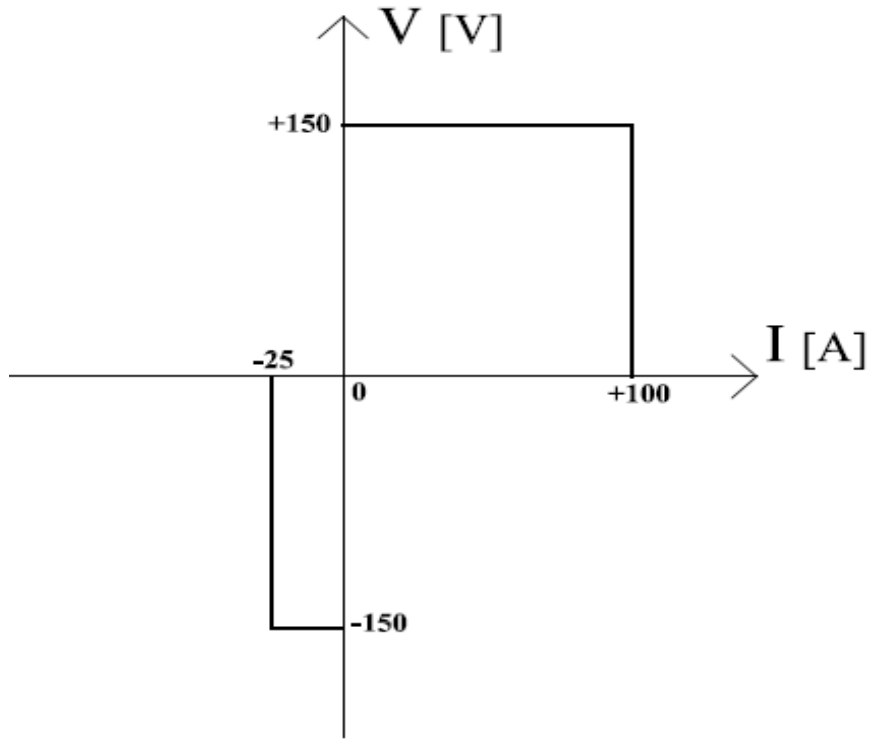
- Mesh side:  $L = 2.5 \text{ m}$
- Mesh area:  $S = 6.25 \text{ m}^2$
- Thickness:  $\delta = 0.20 \text{ m}$

Steel rods of the mesh (24+24)

- Length:  $b = 2.30 \text{ m}$
- Diameter:  $\varphi = 20 \text{ mm}$
- Step distance:  $10 \text{ cm}$



# DC Power supply



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## Conclusions

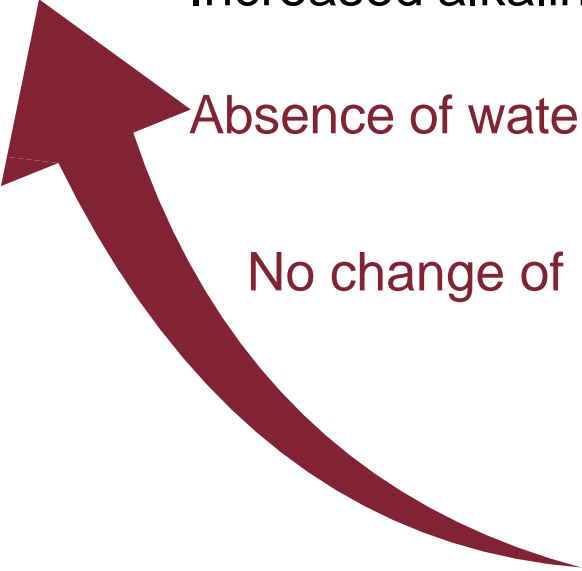
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Increased alkalinity of the solution with an anode in concrete

Absence of water infiltration in the body of cement

No change of Fe concentration in solution with an anode in concrete

Surface regularity and lack of corrosion



**With the use of concrete electrodes no dispersion of metals in the sea water**

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**Thanks for your kind  
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