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# Corrosion Damage Assessment and Numerical Modeling Assisted Design of the Cathodic Protection for a Dry Dock Serving Large Vessels in the Gulf of Mexico

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## Abstract

We report the engineering work and numerical modeling for the complete diagnosis and refurbishing of the cathodic protection system for the largest dry dock in Mexico. The dry dock is located in the shore of the Gulf of Mexico at Tampico City and it is capable of serving ships as long as 250 meters. South bound this dry dock is the largest ship repair facility all the Atlantic coast until Panama. We report results of an overall diagnosis of corrosion damages of sheet piling, reinforced concrete, and pilings. Also we report an overall surface and underwater polarized potential measurement mappings. The cathodic protection of the dry dock components was fully redesigned. A complete new design was proposed to accomplish a sound distribution of impressed current anodes all along the steel sheet pilings, and the "dolphin" pilings. At the "dolphin" a new design for the anode support and its protection was developed. One of its main features of the anode supports is the allowance of 90° of bending freedom so the anodes supports could move and return to their intended position when impacted by the forest and waste debris usually present at the Pánuco River delta.

**Keywords**: Cathodic protection system, numerical modeling, dry dock, sheet pilling, reinforced concrete.

## Introduction

The dry dock of the Madero Maritime Terminal is the largest dry dock in Latin America. It is a strategic installation for the operation of the Maritime Terminal and for the Distribution Department of PEMEX Refinacion. It is constructed on the Panuco River on the state of Tamaulipas under environmental conditions that favor the corrosion of steel structures and the reinforcing steel of reinforced concrete structures. The Dry Dock is constructed mainly by a sheet piling and a steel Lock Gate.

There are four main different metallic structures under the effects of the environment, the sheet pilling which supports the Dry Dock, Bay Dock and Ship Repair Dock, the Lock Gate, which is considered as a floating ship, the Dolphin´s supporting piles and the Dry dock´s Gate Columns, made of reinforced concrete.

Different inspections were conducted in order to obtain an integral corrosion evaluation of the steel structures. Particular conditions found on each structure demanded complex solutions to improve the actual corrosion control systems. For the atmospheric exposed areas the solution is based on special coatings to be applied in irregular surfaces with many cavities which not allow regular paints.

For the submerged an buried structures the best solution is the application of cathodic protection, but the geometry makes it difficult to predict the current behavior, and the magnitude of the non-visible metallic structures makes necessary field tests and numerical simulation to estimate the amount of the total current requirements.

## Inspections and Results

### The Lock Gate

The Lock Gate is a steel structure divided internally in 5 chambers of different capacities (Figure 1). The chambers are filled and emptied with water according to need during the operation of the Gate, but when not operating, the chambers are always filled with water. The Lock Gate is in constant contact with river water from the Panuco River except for the wall facing the dry dock which is also exposed to the atmosphere when the water contained

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in the dock is emptied. The Lock Gate is protected from corrosion by means of anticorrosion coatings and by sacrificial anodes for both external and internal walls of the structure.

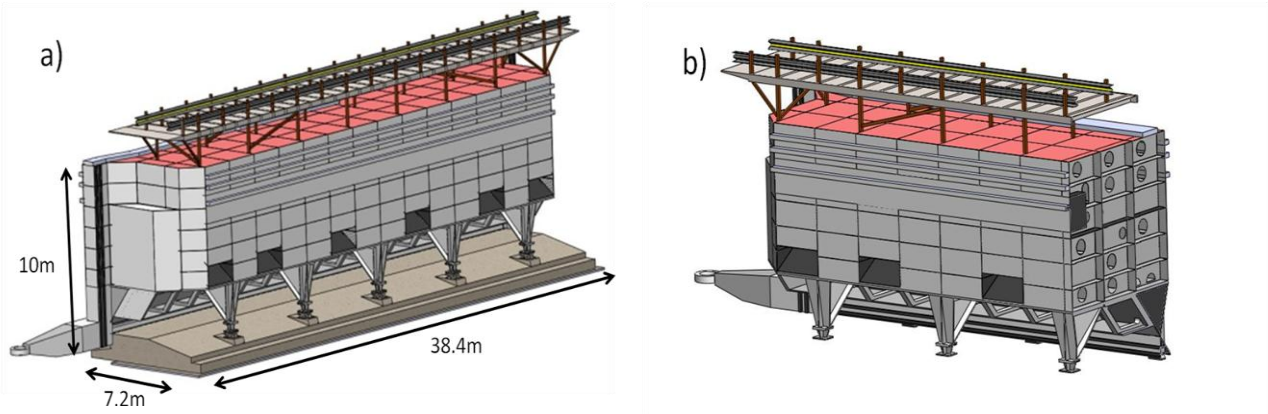


Figure 1. a) Tridimensional model of the Lock Gate. b) Transversal cut

The Lock Gate is an extremely important element of the dry dock. When the Gate is closed, it must maintain the dock dry by resisting a high pressure generated by the water from the river. A Lock Gate failure could cause a non-controlled flooding of the dry dock, just like in Dubai on March 27 of 2002 (figure 2), when the lock gate of the dry dock failed to contain the water causing vast material damages and loss of life of more than 20 people that were performing maintenance works on 5 docked ships[2].

Figure 2. Lock Gate failure on March 27 of 2002 in Dubai.

The principal risks that threat the Lock Gate integrity are ship collisions with the Gate and structural failures which can be caused by the deterioration of key structural components due to corrosion. Inspection of the internal and external walls of the Lock Gate showed that

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the coating was in a general good condition except for some areas with coating deterioration and a consequent localized corrosion. Corrosion was observed along sharp edges, like manhole borders and square beam edges. Deterioration of the coating due to maintenance works was also observed.

Three dimensional modeling of the Lock Gate electrochemical potential distribution was performed. The model considered the physical dimensions of the Gate, the local water properties, the zinc sacrificial anode electrochemical properties and spatial distribution. Results shown in figure 3 indicate that there is a sharp difference between the potentials near the zinc anodes (blue zones) and the potentials on the rest of the structure. Experimental validation of the model was performed by measuring the potential of the structure at various points. The comparison between simulated and measured potentials is presented in figure 4, where a good correlation between theoretical and experimental values can be observed.

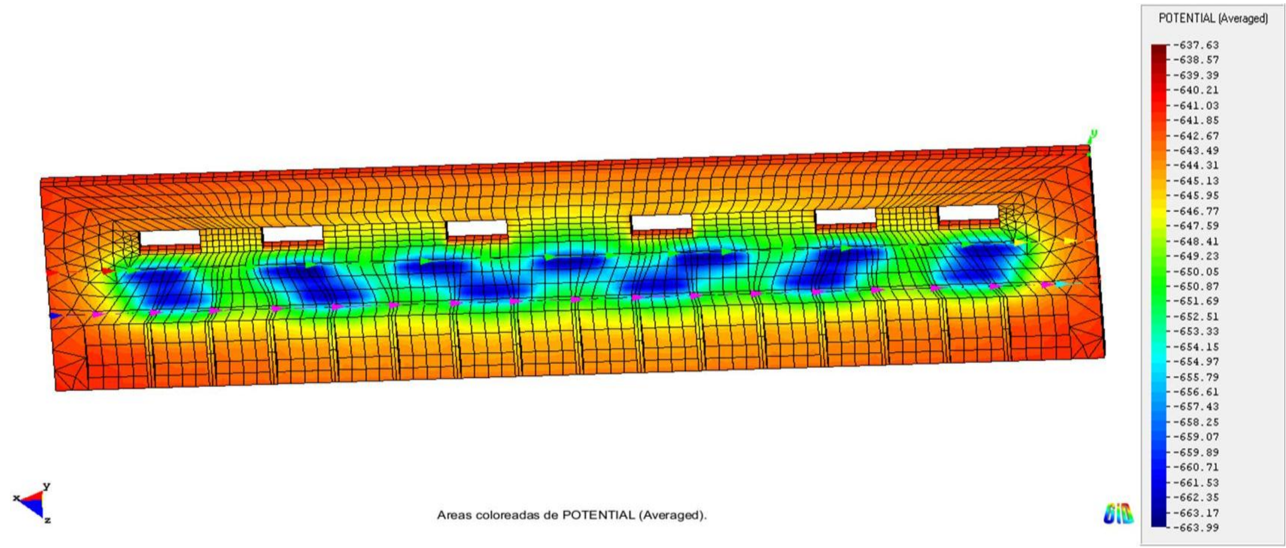


Figure 3. Electrochemical potential distribution according to the three dimensional model of the Lock Gate.

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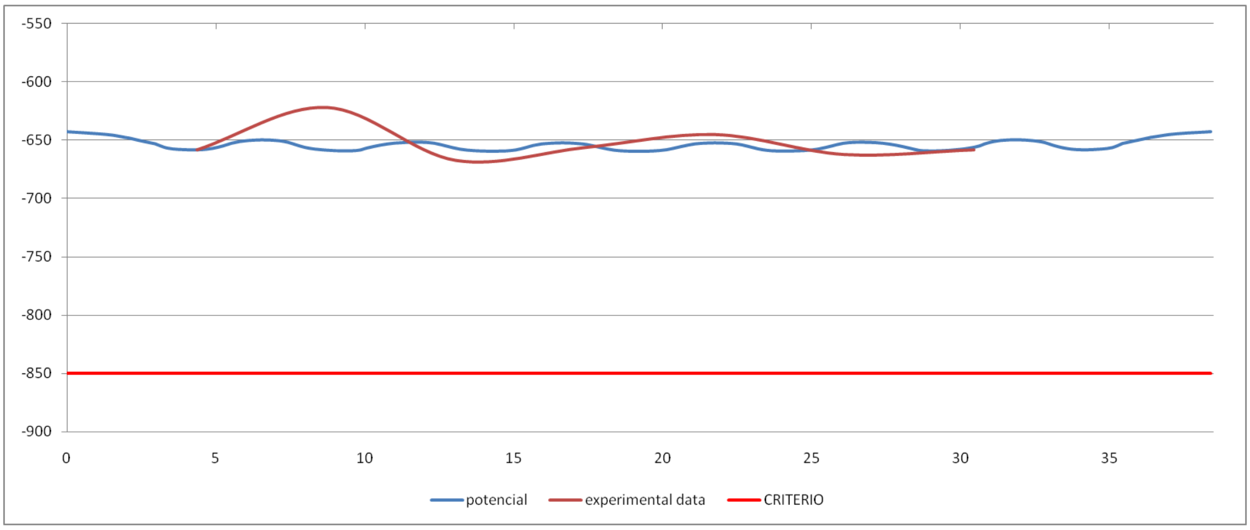


Figure 4. Comparison between simulated and measured potential values at different points of the Lock Gate.

## The Sheet piling

Dock sheet pilings are usually exposed to three different media; the bottom of the sheet piling is immersed in the underwater soil, the middle part is on one side exposed to water and on the other side to soil, the top part is exposed to the air. This exposure to different media can cause potential gradients that can promote corrosion processes on the structure. Figure 5 shows the different environments the sheet pilling is exposed to.

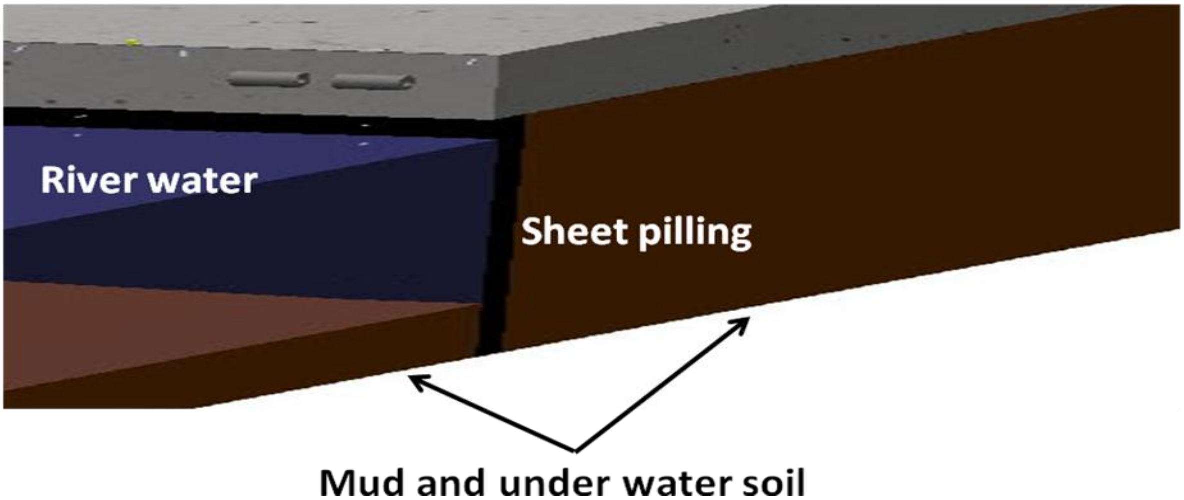


Figure 5. Schematic representation of the sheet piling showing the different media to which its surface is exposed.

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The Madero Maritime Terminal has a steel sheet pilling divided in three zones: the Bay Dock, the Dry Dock and the Ship Repair Dock. In total, the sheet piling has an area of 30,085 $m^2$, which means 60,170 $m^2$ of metallic structure that has to be protected against corrosion. Nevertheless, only 8 % (4606 $m^2$) of the sheet piling surface is protected by cathodic protection systems. Figure 6 shows the three areas where the sheet pilling is located.

Figure 6. Satelite image of the Ship Repair Dock, the Dry Dock and the Bay Dock. The yellow line shows the location of the sheet piling.

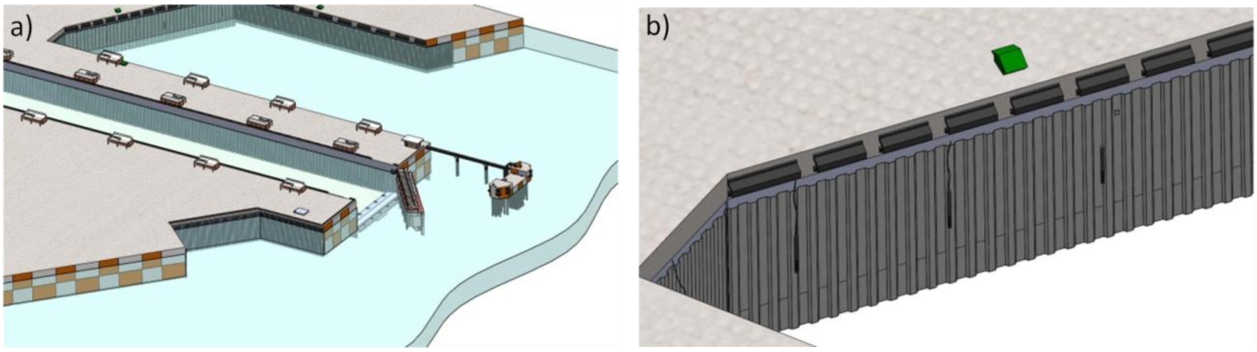


Figure 7. a) General distribution of the sheet piling. b) Bay Dock sheet piling detail.

Physicochemical analysis of the water showed a high concentration in chlorine (16000 ppm). This has caused a general thickness loss of more than 25 % due to corrosion on the

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unprotected face of the sheet piling which is in contact with soil. In addition, 300 corrosion pits were discovered where some of them have penetrated through the steel sheets (figure 8). In addition crevice corrosion was also present in almost every joint between the steel sheets forming the sheet piling [3].

Figure 8. Pitting corrosion example on the sheet piling showing water draining through the pit.

**Sheet piling protection.** In order to stop the generalized corrosion of the sheet pilling, an impressed current cathodic protection system using distributed semi-deep anodes was proposed. Current demand measurements were performed showing that approximately 0.48 amperes per linear meter of sheet piling was needed; meaning a total of 614 A. In addition a three dimensional model of the sheet piling and its surrounding media was performed using the boundary elements method. Simulations allowed to determine the optimal distribution of the anodes. Figure 9 shows in a color scale, the potential distribution calculated with the numerical modeling.

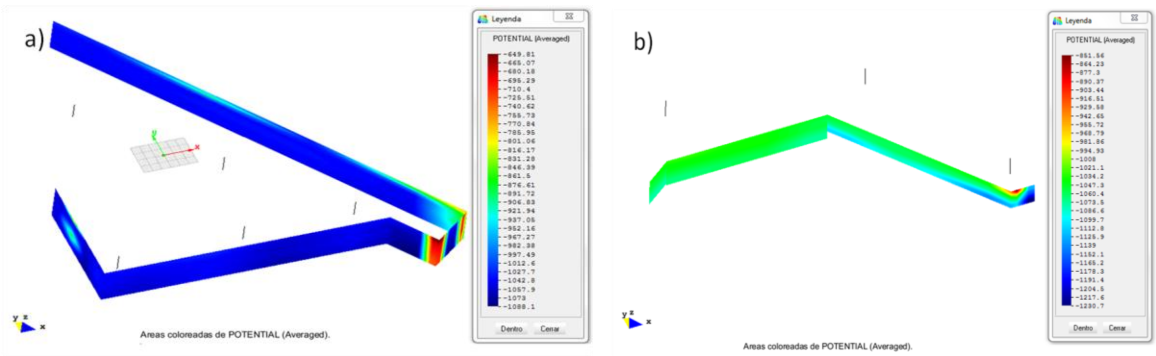


Figure 9. Results of the three dimensional modeling of the a) Ship Repair Dock and b) Bay Dock.

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The sheet piling is supported with anchors and steel beams buried behind the sheet piling. The area known as "cofferdam" is a corridor with two parallel sheet piling sections attached to each other by steel beams (figure 10). By modeling such structure, it was proposed to install anodes between the sheet piling in order to protect both structures and the anchor beams.

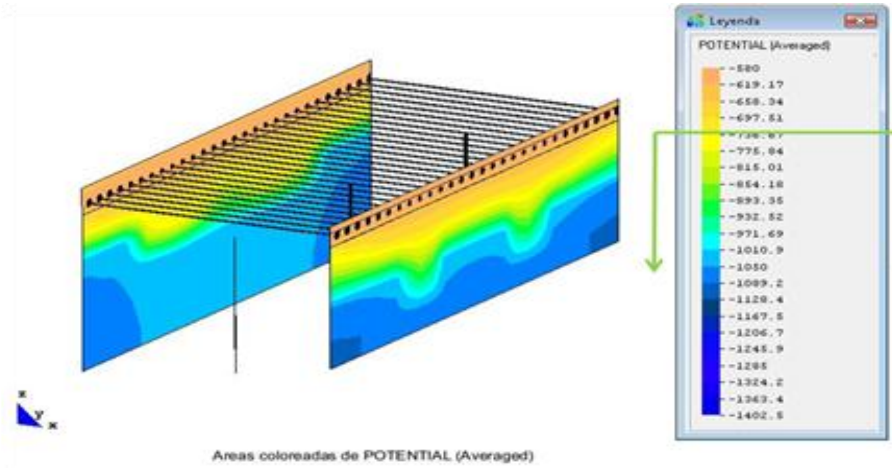


Figure 10. Results of the three dimensional modeling of a section of the two parallel sheet piling cofferdam in the cofferdam area.

## The Dolphin

The dolphin is a steel reinforced concrete structure supported by 50 steel piles. The piles measure 18 meters long of which 8 meters are immersed in water and the rest are buried under the river base soil. The two different views in Figure 11 show the distribution of the Dolphin´s piles.

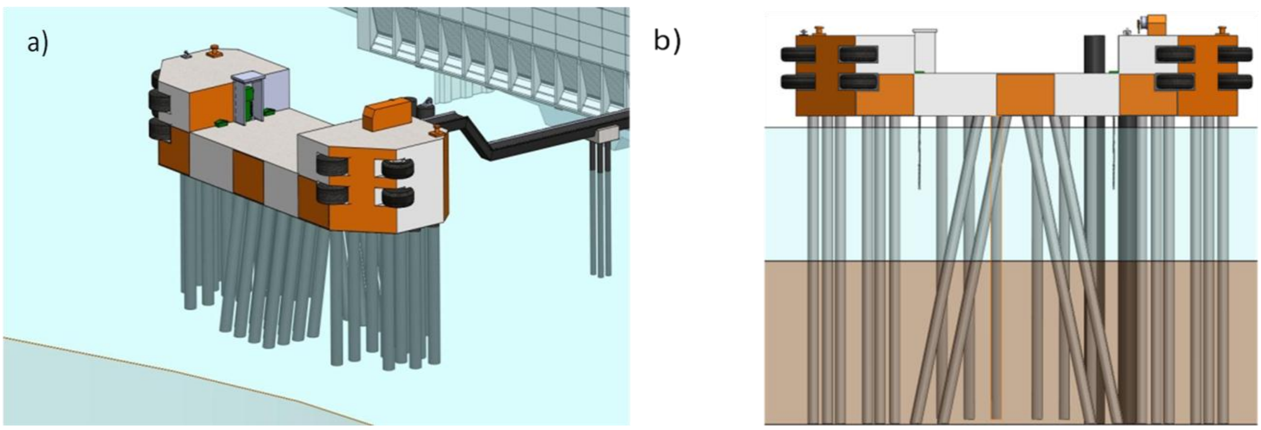


Figure 11. a) 3D model of the dolphin b) Detail of the steel piles

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The steel piles are exposed to corrosion risks. The total metallic surface of the piles is 1866.1 m$^2$ of which 829.4 m$^2$ are exposed to the water and 1036.7 m$^2$ are buried. The corrosion of the piles is controlled by an impressed current cathodic protection system of 12 volts and 80 amperes. Four platinized titanium anodes 1.5 m long are suspended under the dolphin. The anodes are evenly distributed between the piles. Computer simulations of the system showed that the anode distribution was appropriate (Figure 12). The principal problem with the system was the anode integrity. Floating debris periodically damaged one or more anodes. This has caused long periods with the system out of order.

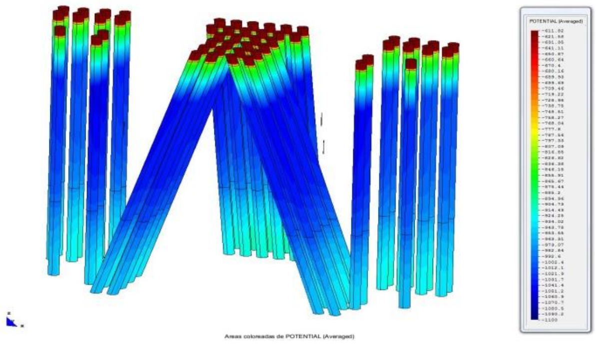

Figure 12. Potential distribution according to a 3D simulation of the system.

A solution to the problem was proposed by replacing the fiber glass anode supports with articulated reinforced nylon bars that can bend when floating debris is passing by. The weight of the anode support allows recovering the vertical position. (Figure 13)

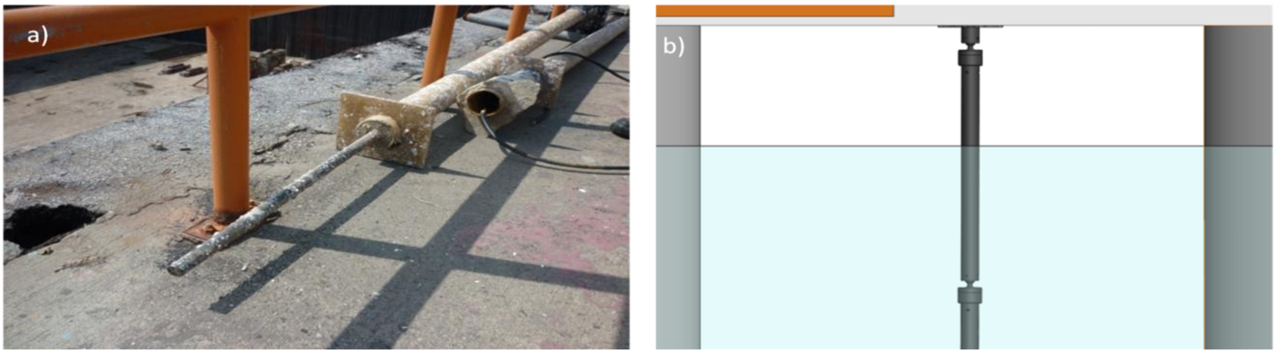


Figure 13. a) Damaged anode. b) Articulated design of the anode support.

## Conclusions

Highly complicated structures as a Dry dock require the use of advance numerical modeling that allow an adequate CP design. Traditional design leave vital structures without protection, such as structures lying beneath the ocean floor and internal faces of the sheet piling. Past accidents have showed the importance of critical elements such as the water tight door, its protection has required the input of several discipline corrosion specialists. Anodes support, monitoring and connections require specials designs that end into patents that fulfills the quite unique technology requirements of corrosion control systems in a Dry Dock.

For the buried and submerged steel surfaces, the cathodic protection is the best solution to mitigate corrosion deterioration, most of the steel structures are not accessible to be painted or replaced. The combination of distributed anodes in submerged surfaces and remote anodes for burred structures are intended to provide adequate protection, but many calculations and field test will be necessary to discard possible interferences in other structures such as pipelines due to the increased amount of current proposed in the CP design.

The coating system proposed for the internal walls of the Dry Dock involve a capability of filling the gaps between each steel sheet, and a great mechanical resistance to de sandblasting used in the ship maintenance. The coating application is meant to be after pitting repairs, consisting in welded steel sheets in areas where low thickness was detected.

## References

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[2] 'Diagnosis, Numerical Modeling and Development of the Cathodic Protection Refurbishing of the Metal Sheet Piling of the Docks of Quetzal Marine Terminal in Guatemala'. Martinez de la Escalera, L. M., Alvarez, O., Canto, J., Rivera, H., Godoy, A., Ventura, H.E., Ascencio, J.A., Martinez, L.