General Consideration about Current Distribution and Potential Attenuation Based on Storage Tank Bottom Modeling Study

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ABSTRACT

The efficiency of cathodic protection is driven by various environmental parameters, the main ones being: the geometry of the protected structure, the electrolyte resistivity, and of course the steel polarization curve. The aim of this study is to assess the influence of those parameters on the current distribution and on the potential attenuation. In particular, an investigation will be made into the apparently contradictory influences of the resistivity. For this investigation, two configurations of CP system applied to storage tanks bottom are studied by 3D modeling. The first is a tank bottom for which a membrane is installed a few tens of cm underneath, with an anodic grid system located in the confined space. The second is the usual design where no membrane is installed below the tank and where anodes are located around the periphery of the tank.

Key words: Cathodic protection, current distribution, potential attenuation, numerical modeling

INTRODUCTION

In cathodic protection, the efficiency of achieved protection is controlled by various environmental parameters, including the geometry of the protected structure, the electrolyte resistivity, and the steel polarization curve.

This study concerns the numerical modeling of storage tanks bottom cathodic protection for two configurations. The first is a tank bottom for which a membrane is installed...
a few tens of cm underneath, with an anodic grid system located in the confined space. This is a typical design for new tanks. The second configuration is the usual design where no membrane is installed below the tank and where anodes are located around the periphery of the tank. This is a typical design for an old tank.

The aim of this study is to assess notably the influence of environmental conditions on the current distribution and on the potential attenuation.

DETAILS OF THE CONFIGURATIONS

The first case is a tank with an impervious membrane. A rectangular section is selected for the study. The tank bottom is laid on 30 cm of sand cushion, isolated from external ground by the membrane. The dimension of the section is 5 m x 8 m. Four MMO ribbon anodes, 5 meters long, are installed parallel to the shorter side of the rectangle. Distance between ribbons is 2 meters, and they are installed symmetrically in the rectangle. A titanium conductor bar is installed on one longer side of the rectangle and feeds the ribbon anodes. There is only one current feed to the conductor (see Figure 2 and Figure 3). The current applied is 200 mA.

The ribbon anodes, located 2 cm above the membrane, have a rectangular cross-section 6.35 mm x 0.635 mm, and linear resistance of 0.15 ohm/m. The titanium conductor bar, which has resistance 0.05 ohm/m, is assumed to be insulated.

The second case is a 60 m diameter tank, laid on a 60 cm thick sand foundation. 8 vertical anodes are installed symmetrically around the tank, at 12 m from its circumference. Each anode is buried and extends from 3 m to 9 m depth. Anode diameter is 15 cm, and current output is 2 A each. Because of symmetry, modeling is performed only on a segment of the tank which represent 1/8 of the surface (see Figure 6)

Four sand resistivities have been studied: 10 Ohm-m, 100 Ohm-m, 1000 Ohm-m, and 5000 Ohm-m. Soil resistivity has been taken either at 70 ohm.m or equal to that of the sand cushion.

Two polarization curves for bare steel have been assumed (see Figure 1). Tank plates are painted and the coating breakdown factor of the painting has been assumed to be 10%. One polarization curve is supposed to represent a low oxygenated environment, and the other a highly oxygenated one (respectively called “low” and “high” in the rest of this document). We consider that the current density of the polarization curve is proportional to the coating breakdown factor.

These assumptions are of course not fully correct: the paint through-thickness resistance is not proportional to the percentage of bare surface, and thus the polarization curve should not be proportional. In addition for the same bare surface the defect resistance varies according the geometry. Last but not least, the resistance of the defect evolves with time depending on possible deposits. Nonetheless such simplifications do not change further analysis which remains mainly qualitative.

In this document only results at 10 ohm.m and 5,000 ohm.m are given. Those at other sand resistivities being between those two extreme cases and thus do not bring any additional information from an analysis point of view.
RESULTS

Modeling has been performed using a commercially available software package. Such software, the reliability of which is well recognized, is used by many major companies worldwide, and various comparisons exist which demonstrate that the physical model on which they are based (mainly electrostatic) is valid [1 2].

Case of tank with membrane

Figure 2 and Figure 3 show the simplified geometrical model and the installed cathodic protection system. Resulting variation of potential on the tank base along a line perpendicular to the anodes, is shown in Figure 4 for sand resistivity 10 Ohm-m and the "low" polarization curve.
Figure 2: Studied section of the tank

Figure 3: Cathodic protection system

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From the curve in Figure 4 we can see that potential rises by about 60 mV at mid-distance between two ribbon anodes. Also of note is the variation of potentials as we move away from the power feed point, which is evident as a gradually more positive potential at the anode position (the bottom peak which occurs at four locations in the figure). This variation of potential results from ohmic drop both in the titanium conductor bar and in the ribbon anodes. Such ohmic drop is in this case acceptable; as it corresponds to only about 20 mV in the present configuration (clearly in a complete tank base conductor bar spacing and power feed locations must be appropriately chosen).
With 5000 ohm.m resistivity (significantly higher than the previous case) potential rise is 850 mV between ribbon anodes. The value of -450 mV indicates that current which reaches mid distance between ribbons is almost nil.

It should be noted that with this resistivity and this high attenuation, there is little variation of potential at positions of the four ribbon anodes: the attenuation inside the conductor bar and the anode is negligible compared to attenuation inside the electrolyte.

Uniformity of potential for the cathodic protection of the tank bottom installed with a membrane is poor. This can be explained by the confined space between the membrane and the tank bottom, which requires installation of a grid system with a short distance between anodes in order to correctly cover the whole surface of the tank.

We shall conclude this part of the investigation with the following assertion: the less resistive the sand cushion, the better is the uniformity of potential on the tank bottom.
Case of tank without membrane

Numerical modeling allows display of 3D contours of potential throughout the electrolyte as shown in Figure 6. Variation of potential on the tank surface can be shown in Figure 7.
If we consider the radial line intersecting the anode, we obtain variation of tank bottom potential with radius as shown in Figure 8.

We shall compare these curves and derive rules in terms of uniformity of potential, assessed as the difference between potential at the circumference and at the centre of the tank bottom. We will not focus on the values themselves, as of course with a “high” polarization curve the potentials are less negative since we have applied the same current in all cases.

From the curves shown in Figure 8 one can deduce:

- With a “high” polarization curve (highly oxygenated environment, high current demand), uniformity of potentials on the tank bottom is worse than with “low” polarization curve (low oxygenated environment, low current demand). This is particularly true if resistivity is high: in which case current demand significantly influences the attenuation.
- If resistivity is low, influence of current demand is reduced: attenuation is roughly comparable for low and high current demand.
- With high current demand and low resistivity, uniformity of potentials is rather better than at low current demand and high resistivity.
- At fixed current demand (either "high" or "low"); attenuation is higher if resistivity increases.
This last bullet corresponds to the case of the tank with membrane: \textit{the less resistive the soil, the better is the uniformity of potentials.}

Similarly, we can obtain current distribution curves as shown in Figure 9.

![Variation of current density with radius, for 4 combinations of polarization curve and resistivity (tank cushion resistivity same as external soil)](image)

**Figure 9**: Current density evolution with same resistivity between soil and tank cushion

We can look at current densities in a similar way, and we note one additional observation from the curves in Figure 9: at high resistivity, distribution of current is almost the same regardless of "current demand" (whether low or high current demand), and note this is not true for the potentials, as described previously.

Such curves confirm that \textit{the less resistive the soil, the better is the current distribution.}

Such conclusions could appear to contradict field findings which are well known: for instance, after raining, pipeline potentials might drop suddenly. This would tend to demonstrate that if soil becomes less resistive, attenuation is higher. Similarly, if we look at coating resistance...
(which is of course linked to polarization curve and defect geometry), we could say that if resistivity is higher, then coating resistance is higher, and thus potentials will be more uniform.

In order to solve this apparent contradiction, we are going to study the same curves, but with a fixed soil resistivity (70 ohm.m), and vary only the tank cushion resistivity. Results are as shown in Figure 10.

![Variation of potential versus radius for 4 combinations of polarization curve and tank cushion resistivity (soil resistivity: 70 ohm.m)](image)

**Figure 10**: Potentials evolution with different resistivity between soil and tank cushion.

For such a case, we can see that the conclusion is the opposite of the previous case: *the more resistive the sand cushion, the better is the uniformity of potentials.*

We can confirm this conclusion by considering the current density curves in Figure 11. Comparison with Figure 9 clearly shows the reversal of distribution: in this present case distribution is much better for high resistivity of the sand cushion, the opposite of the previous case.
ANALYSIS AND CONCLUSION

This evolution of current distribution and uniformity of potentials is significant. We have demonstrated that depending of the electrolyte configuration around the cathodic protection system; the distribution could be the reverse of that expected. We have studied a tank bottom case, but the reasoning would be the same for other buried structures. For instance, a pipeline is in an environment (shallow soil) with a resistivity which varies according to climatic conditions, whereas resistivity of the deepest soil layers is much more constant. Current distribution will be better if resistivity of the soil electrolyte surrounding the pipe is high.

In contrast to this, for seawater (where the electrolyte is almost uniform) the opposite is true: the less resistive the seawater, the better is the current distribution.

A schematic shown in Figure 12 makes an attempt to explain the phenomena in a simple way.
What is important for the evolution of current distribution is the resistivity of the soil surrounding the structure. The other parameters are important but are of second order, as they do not change the trends. We consequently conclude the following evolution rules:

When the (variable) resistivity of the environment between the anodes and the structure is the same everywhere the rule is: **the less resistive the environment, the better is the uniformity of potentials.**

When the (fixed) resistivity of the remote environment (containing the anodes) is different from the (variable) resistivity of the environment near the structure the rule is: **the more resistive the nearby environment, the better is the uniformity of potentials.**

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REFERENCES