Cathodic protection of extended sheet piling. A practical case.

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Abstract

The paper describes the study, execution and start-up of the cathodic protection system for a 5 km sheet piling. The sheet piling lays in the south of Italy (Sicily) and it is used to contain an area characterized by surface's pollution of the ground water. Because the sheet piling was intended to seal the ground water and not to hold the soil mechanically, cathodic protection was needed to prevent every kind of decay due to corrosion that could have nullify the functionality of this significant structure. The elements leading the planning of this cathodic system and its realization till the start-up, have been the size of the structure, the impossibility to execute big digging works, the need to avoid interferences with existent structures, even with a high protection current, and the little literature concerning cathodic protection of sheet piling in non-marine environment. The realization of the system entailed the installation of 36 current feeders for cathodic protection, in conjunction with the same number of anodic deep wells. During the calibration of the plants, the introduction of E-log I test has allowed reducing the current supply of the feeder, still granting the sheet piling protection.

Keywords: Cathodic protection, sheet piling, soil, corrosion, corrosion potential, Tafel curves, E-log I test .

1 Introduction

Cathodic protection with sacrificial anodes is usually applied in marine environment to protect sheet piling immersed in sea water from corrosion and in literature there are a lot of examples of its application. What is more unusual is to find steel sheet piling used to border a polluted area in order to pump away polluted ground water. In this case the resistive environment is not seawater but soil, so cathodic protection has to be designed using impressed current system, just like in pipelines corrosion protection.

Literature is very poor for issues concerning this kind of application and the choices taken to design the whole cathodic protection system were based above all on experience made on pipelines corrosion protection systems. Moreover, the area which the sheet piling rose in was about 5 km of bare steel surface, with the sea on one side and the system of water pumping wells on the other. Since there was not enough space for a wide system installation, deep well cathodic protection system was chosen. The plant was designed, built and started up, but, given the great size of it, to further verify the system efficiency, in addition to the standard start-up tests a series of measurements was performed using the "E-log I" test [1], [2], [3].

The "E-log I" test or criterion lies in the measurement of current transfer of the buried anodes and the corresponding variation of potential of the structure to protect, taken while current increase is applied to the DC feeder of the anodes. The sample curve of Fig. 1 shows the Tafel segments and their intersection identifies the minimum current required for protection. Above it, hydrogen evolution occurs, so the required current to protect the steel is between A point (intersection) and B point, corresponding

to the first point of the Tafel segment. Generally this criterion is used to determine the minimum current required for protection in the cathodic system sizing phase, but in the present work, it was performed for evaluating the existing CP system, verifying that the “minimum current required” matched the measured current of the start-up tests, assuring cathodic protection for all the sheet piling.

2 Methodology

The sheet piling was located in Sicily, Italy, and it was constituted by rolled carbon steel sheet piles joined together to form a containing wall for soil pollutant (Fig. 2). Each sheet pile changed in height in order to reach the impermeable underground layer and their width was 450 mm, with a “S” shape (“Larssen” section, total width: 600 mm) and folded ends for anchorage.

The corrosion protection system was sized starting from the soil resistivity. Resistivity design value was assumed to be 30 Ω.m and it was obtained from a series of resistivity measurements performed on the interested area, reckoning with the proximity of the sea. Electrical connection among the contiguous sheet piles and among the separate segments of the anti-pollutant barrier was realized to avoid functional issues due to insulation problems and to grant the effectiveness of the cathodic protection. The electrical connection was granted by means of steel rods welded on the top of the barrier and embedded, together with the top of the sheet piles, inside a concrete curb extending for the whole length of the anti-pollutant barrier.

The protection current density for the system was 10 mA/m^2, since the material used for the sheet piles was carbon steel in soil. The total steel surface to protect was about 150000 m^2 and the total required current for the whole system was 1770 A, supplied by n. 36 “50 V / 50 A” DC feeders connected to the same number of deep well anodes spaced all along the sheet piling (Fig. 3).

Groundbeds, deep well type, were realized by means of tubular Ti/MMO rods, with a diameter of 16 mm and a length of 1000, chained together and equally spaced one another. Every chain was composed by 10 Ti/MMO anodes stacked inside a carbon backfill. Every anodic well was 100 m depth, with an active section of 40 m. (Fig. 3).

For potential measurements 36 fixed test points were provided. In every fixed test point a $Cu/CuSO_4$ reference electrode (CSE) was placed at a distance of 0,5 m ÷ 1 m from the sheet piling and buried 1 m deep, connected to the correspondent DC feeder. Other test points were added next to pipeline crossings and other structures, to perform potential measurements with a portable reference electrode.

After the building phase of the cathodic protection system, start-up measurements were performed. In order of time, they consisted in:

- free corrosion potential measurements (E_{corr}) for all the sheet piling test points, performed after complete depolarization of the structure;
- polarization potential measurements (E_{on}), taken during polarization time (60 days);
- “On-Off” potential measurements (E_{off}) taken after about 15 days of DC current supply;
- interference test recordings on the other test points (I.E. in correspondence with pipeline crossings, sheet piling interruption, etc.) performed during “On-Off” tests;
- E-log I tests performed for each of the 36 fixed test points.

Polarization potential (E_{on}) was checked daily for about 60 days, in order to test the effectiveness of the system, verifying that the maximum potential value of -850 mV vs CSE was reached in every test point and to make adjustments of current, optimizing the DC current intake.

E_{off} potential measurements, performed using the “On-Off” technique, are used to eliminate the IR drop from the measured potential. As it’s shown in Fig. 4, when the protection current is interrupted, IR drop disappear within 10^{-6} s. The value corresponding to point is the real potential value of the protected structure, E_{off}. As time goes on, the steel became depolarized, but it takes more time to reach the E_{corr} potential (> -0.85 mV) and to totally dissipate the overpotential.
According to the first cathodic protection system design, “E-log I” tests [1] were not included but, given the extend of the steel surface to be protected and the absence of previous experience for this particular work, the need to find another verification mean for the effectiveness of the cathodic protection system led to include the “E-log I” test to verify if all the protection current supplied by the DC feeders were sufficient to grant a good cathodic protection of the sheet piling. “E-log I” tests were performed in according to the following conditions: the cathodic protection system was switched off until complete depolarization of the sheet piling, then, starting from free corrosion potential value, an increase of current in logarithmic steps (0.2 A, 0.5 A, 1 A, 2 A, etc.) was applied to the DC feeder. After about 1 min – 5 min from the increase of current the new stable potential value was recorded and another increase of current was given to the DC feeder. The process was repeated until maximum CP feeder capacity, obtaining the E-log I curve.

3 Results and discussion

During the start-up phase of the cathodic protection system several issues arose, mainly due to not induce interferences to foreign structures and to the kinetic of the polarization process, secondarily to problems connected with soil and ground water pollution, excavation permissions and dangerousness of the site.

3.1 Excavation issues and design history

The first design approach was to protect the whole sheet piling by means of vertical anodic beds, as deep as the sheet piling itself, and to install them both on the earth-side and the sea-side. This solution was discarded as excavations were forbidden on the sea side of the area, with an exception of some confined zones. Test points were not allowed to be installed on the sea-side too, so the entire cathodic protection system was to be designed with extreme care. The choice was made to use anodic deep wells to grant cathodic protection of both the sheet piling sides, and only 5 anodic deep wells were installed on the sea-side, as it can be seen in Fig. 3. Since excavations on the earth-side of the piling were admitted only for groundbeds drillings, all the cables have been installed inside protected concrete conducts directly laid on the ground surface.

3.2 Polluted ground water issues

The natural polluted ground water was found to be within the first 50 m below the ground level, above the first clay layer and it was isolated from the well by a concrete cage 50 m deep. During deep wells excavations, in some areas an artesian aquifer was found to be deep below the first clay layer. This fact caused water leakage outside some anodic deep wells. This issue was solved by re-designing the head of groundbed wells as shown in Fig. 3: a hermetic seal was realized at each well top, provided with an air valve, to be opened at stated periods of time in order to let out gas formed from the anodic reaction.

3.3 Interferences with other structures

The cathodic protection system was characterized by high current supply that could have created inconveniences and damages to the existing crossing pipelines and present structures. Every test point placed in correspondence of interfered structures was monitored during “On-Off” tests to evaluate all the interferences due to the cathodic protection system. It can be seen in Fig. 5 that cathodic protection current influenced other structures and crossing pipelines potential with a maximum decrease of about 40 mV: potential moves from -1470 mV vs CSE during the “Off” phase (a, e), to -1500 mV vs SCE during “On” phase (d). “On-spikes” can be seen on Fig. 5, caused by the switching on of the DC feeder and the anode supply (c) and railway interferences are visible too (b).

3.4 Slow polarization rate

Conventional polarization time for a steel cathodic protected structure, after the switching-on of the system, is usually around 48 h. Due to the presence of bare steel surfaces, polarization time was estimated to be 7 days, but for the present work, this period of time was insufficient to completely polarize the sheet piling, probably because of the great surface to protect and its wideness. Fig. 6 shows that a fair effective polarization took place only after 15 ÷ 20 days of anodic current supply, and a complete polarization of every test point of the sheet piling occurred only after 60 days.

3.5 “On-Off” potential values

Testing potential values for the 36 feeders are shown in Tab. 1. These values were measured after 60 days of power supply of the cathodic protection system and after current adjustments on the 36 DC feeders. E_{corr} values, measured at the beginning of polarization tests (with cathodic protection system switched off) and current supply for every DC feeder is reported too. Potential measurements were performed as interference tests in the other test points with the portable reference electrode and two of them are reported as a tracing curve in Fig. 5. These values show that cathodic protection is effective for all the 36 test points and for the other test points.

3.6 E-log I curves

Fig. 7 shows E-log I curves for test point n. 2, indicating that minimum cathodic protection current value is about 14 A. According to values of Tab. 1, the area of steel concerning DC feeder n.2 is protected, since current supply is 19.7 A, greater than the minimum current supply of 14 A. The two curves of Fig. 7 were obtained using both the fixed installed reference electrode and a portable similar reference electrode and the difference is very small. The first point of the two curves (~ -760 mV) represents E_{corr} and it’s very similar to the correspondent value in Tab. 1.

4 Conclusions

In this paper a cathodic protection system for a 5 km anti-pollutant steel sheet piling buried in soil is described. The CP system is realized by means of 36 deep well anodic groundbeds, each groundbed composed by Ti/MMO tubular rods. During the start-up phase free corrosion potential, polarization potential, “On-Off” potential and interference measurements were performed. “E-log I” tests were finally made to verify the good working of the cathodic protection system.

During the CP system building works several issues arose that led to some unusual design choices, such as the realization of hermetic head wells to prevent polluted water leakage or cables laid inside not-buried protected conducts.
Polarization potential measurements showed that, for wide steel buried surface conventional polarization time is insufficient to grant complete polarization: 15 days of polarization time are fair enough to understand if the system is working, but only after 60 days the entire structure is protected in every part.
Finally, “E-logI” tests were useful to understand the effectiveness of the cathodic protection system but other monitoring surveys are necessary to really be sure that the system is working correctly over time.

5 Tables and figures

Table 1: E_{corr}, E_{off} and current supplied values measured after 15 days of current supply to the CP system (grey background referred to Fig. 7 test point).

Test point	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
E_{corr} (mV CSE)	-754	-730	-759	-765	-781	-797	-771	-725	-692	-745	-762	-775
Current supply (A)	11.9	19.7	22.1	12.0	8.8	14.0	20.4	14.4	12.2	9.9	12.2	19.3
E_{off} (mV CSE, <-850)	-962	-876	-879	-900	-977	-912	-928	-894	-900	-940	-949	-923
Test point	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
E_{corr} (mV CSE)	-739	-735	-695	-752	-715	-705	-667	-742	-562	-535	-678	-734
Current supply (A)	13.3	20.0	32.0	2.8	10.9	11.8	13.1	12.5	12.0	12.8	24.7	12.3
E_{off} (mV CSE, <-850)	-957	-893	-884	-852	-959	-900	-870	-902	-914	-914	-877	-882
Test point	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
E_{corr} (mV CSE)	-685	-635	-665	-708	-714	-675	-681	-616	-652	-735	-692	-664
Current supply (A)	11.8	11.9	11.9	22.4	12.6	20.8	1.9	11.8	19.9	12.3	12.2	12.0
E_{off} (mV CSE, <-850)	-922	-879	-922	-869	-976	-880	-1426	-969	-870	-892	-948	-936

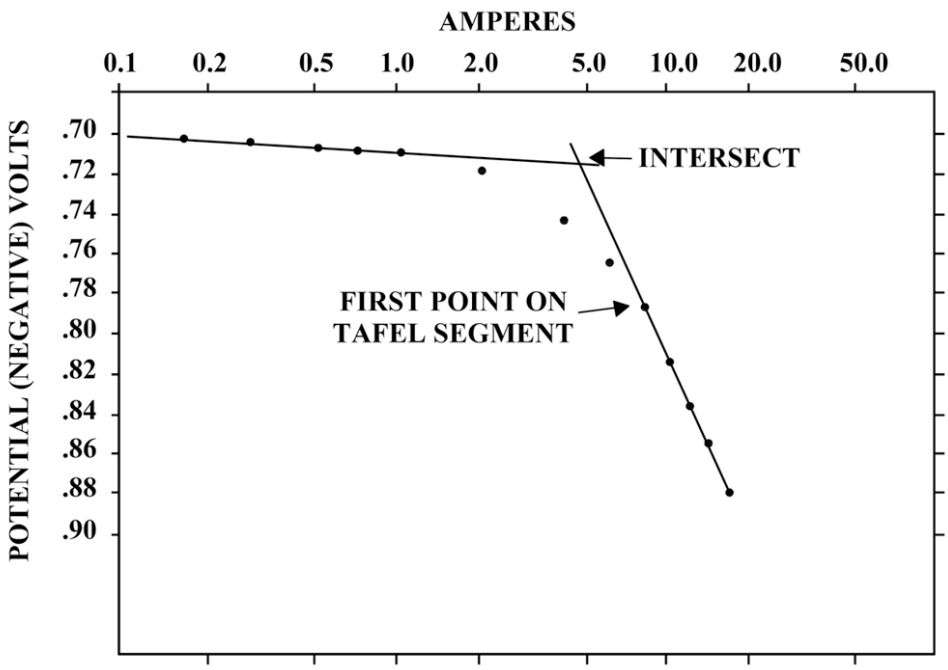

Figure 1: Sample E - log I plot [1].

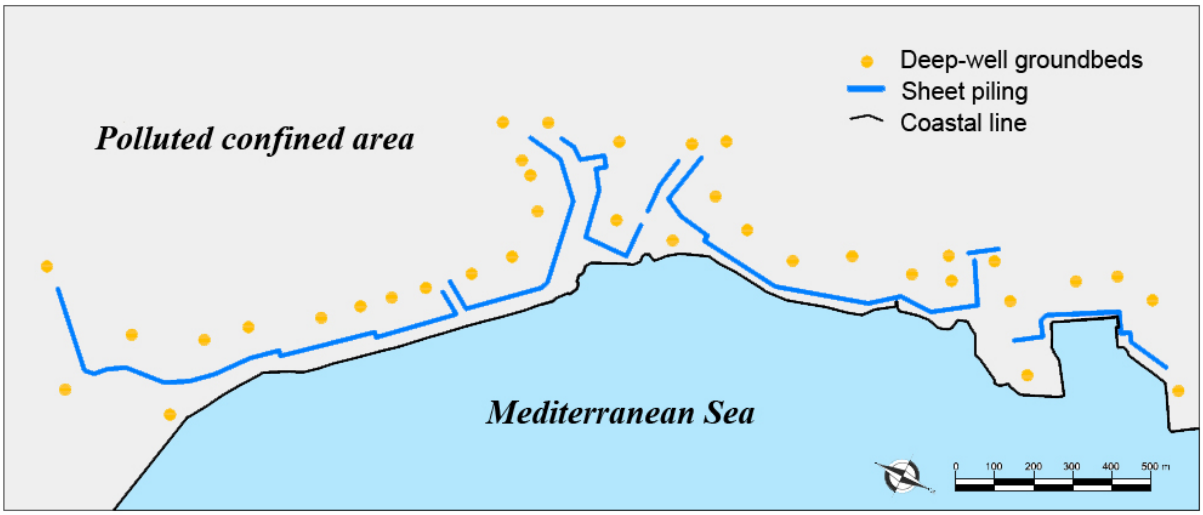

Figure 2: Polluted area, sheet piling position and deep wells location.

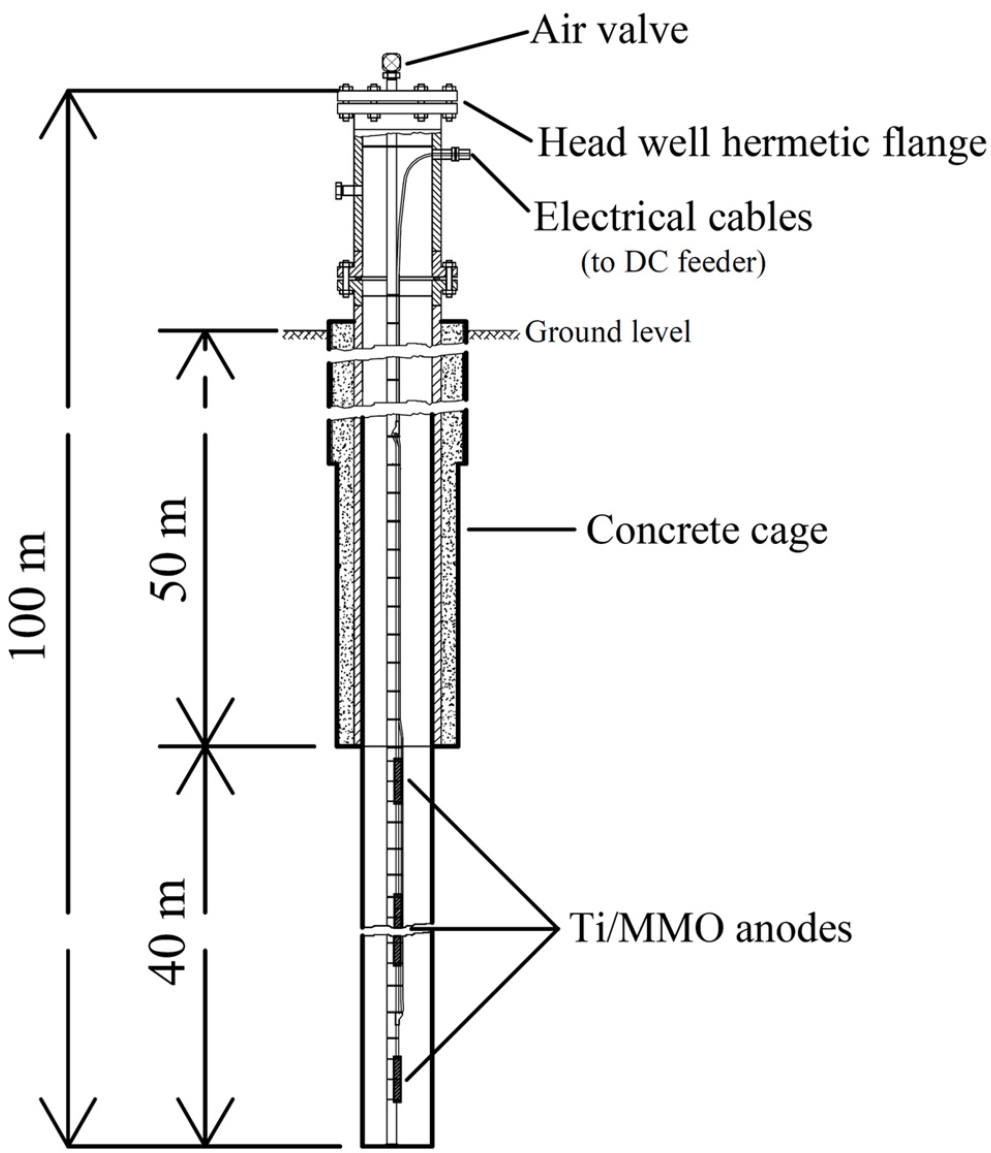

Figure 3: Anodic deep well scheme.

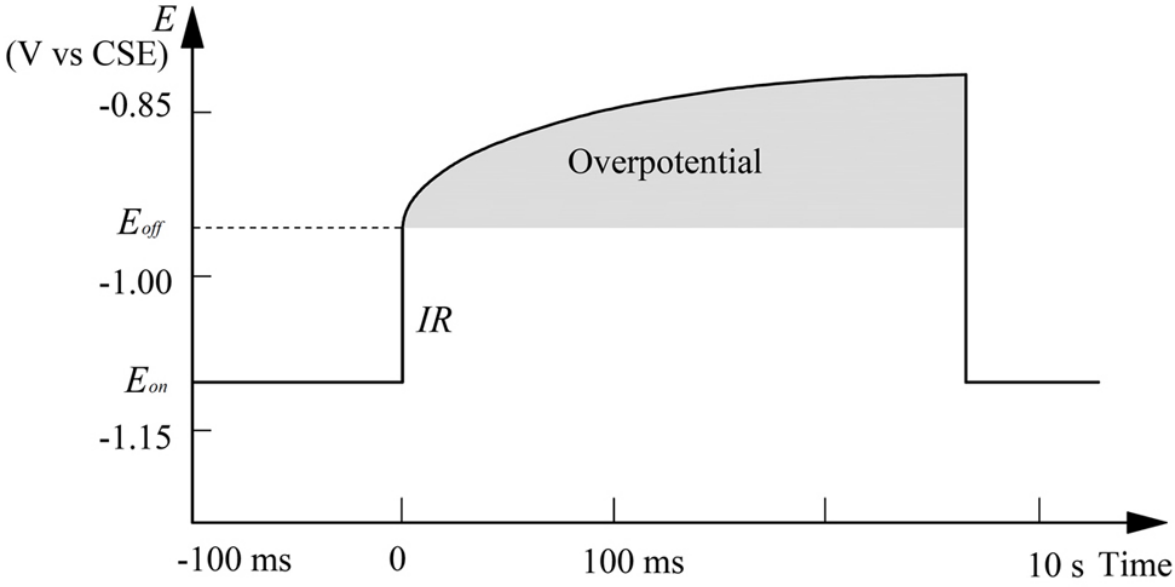

Figure 4: Example of potential recording in "On-Off" technique [4].

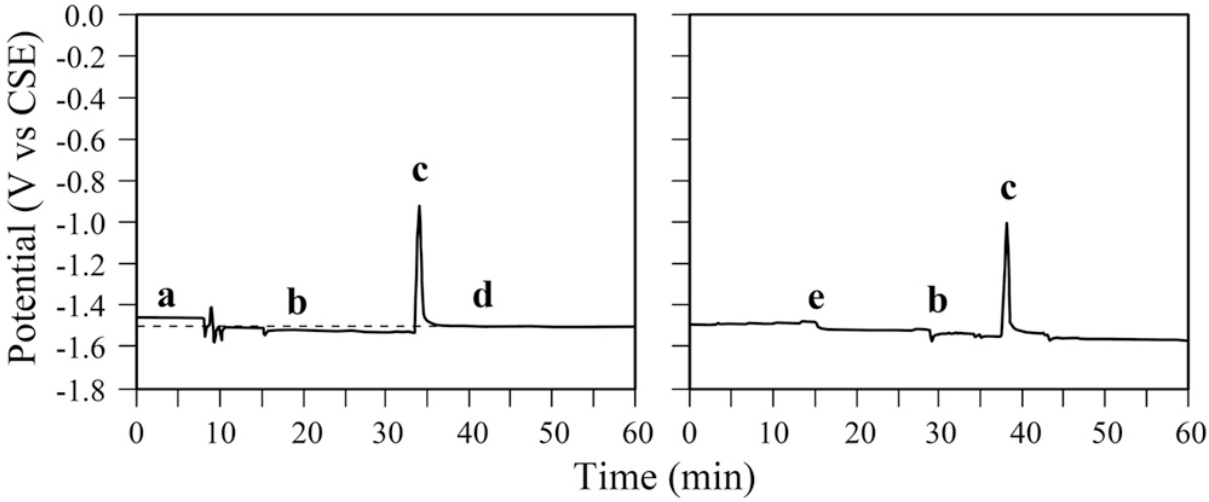

Figure 5: Potential monitored at “C15” test point (crossing pipeline), of maximum interference.

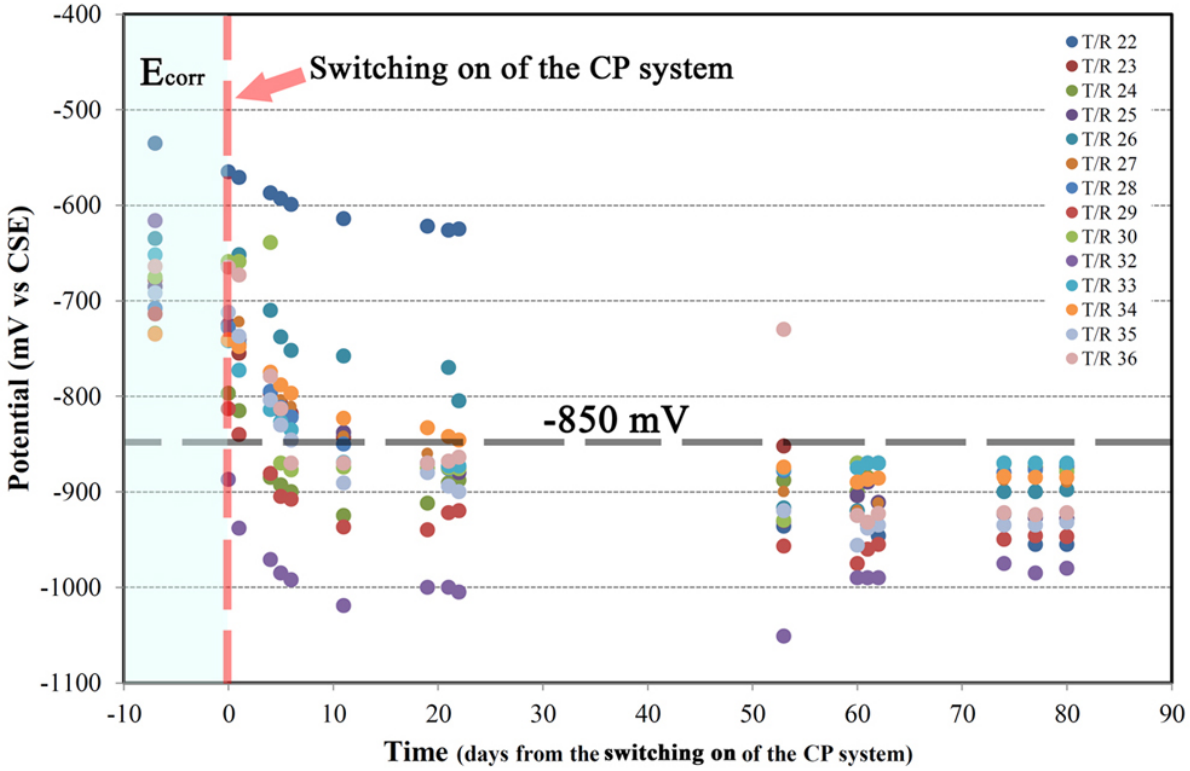

Figure 6: Potential monitored on 14 Transformer/Rectifier test points after the switching on of the Cathodic Protection system.

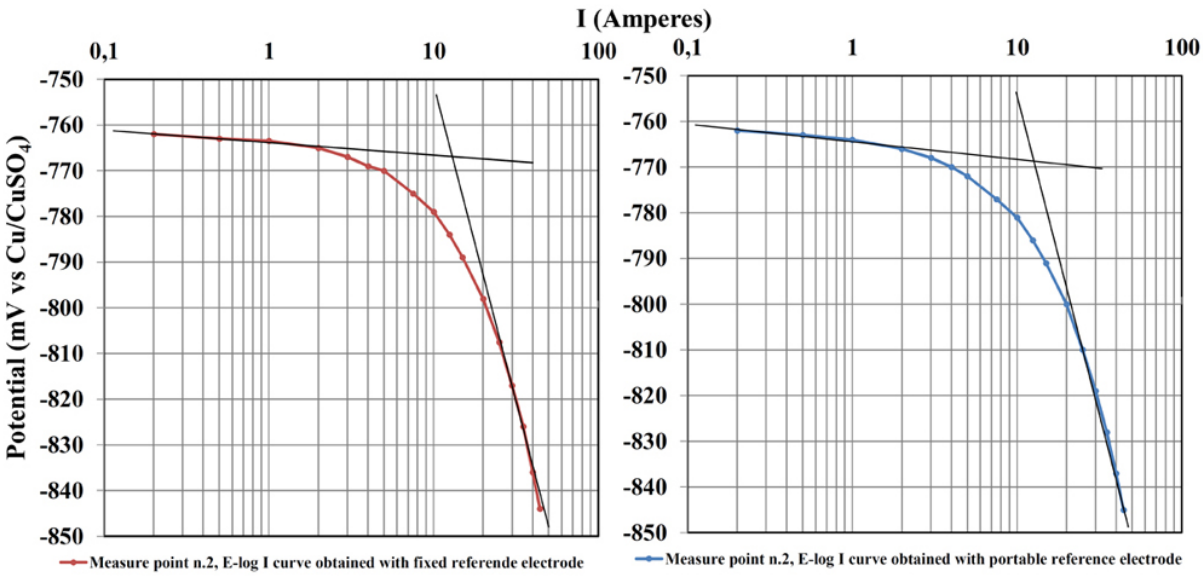

Figure 7: E-log I curves for test point n. 2.

6 References

[1] NACE SP0169-2007, Control of External Corrosion on Underground or Submerged Metallic Piping Systems, National Association of Corrosion Engineers, 2007.

[2] P. PEDEFERRI, Corrosione e protezione dei materiali metallici, Polipress, Milano, Italy, 2007.

[3] PEABODY, A.W., Control of pipeline corrosion, NACE Press, 2001.

[4] LAZZARI, L., PEDEFERRI, P., Cathodic Protection, Polipress, Milano, Italy, 2006.