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CATHODIC PROTECTION FOR SOIL–STEEL BRIDGES[1]

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Cathodic Protection (CP) was first applied in 1824, before its theoretical foundation was known. Corrosion of metals is caused by potential difference and metal surface with lower potential becomes an anode in the circuit and gets consumed by corrosion. The principle of cathodic protection is to force the protected metal to become the cathode, by introducing a less noble metal (with higher potential) to be consumed or by introducing an external power source. In principle, cathodic protection is very simple but in practice there are many considerations that need to be addressed. Too low current may not protect the structure while too high current may lead to coating disbonding and hydrogen embrittlement. CP is widely used for pipelines, since corrosion is omnipresent in soil, coating repair is troublesome and expensive, and a gas/oil pipeline failure may be catastrophic. CP is also used to protect oil rigs and ships against corrosion in harsh marine environments.

Soil-steel bridges also are prone to corrosion from soil and water, and are difficult to repair, thus CP shows great promise in extending their lifetime. The article presents the principles of CP and the main issues that need to be taken into account in its design. One case study of CP used for a culvert is also discussed.

Key words: corrosion, cathodic protection, steel culvert

1. INTRODUCTION

Cathodic protection was first been to protect ship hulls from corrosion in the 19th century [1]. By mid-20th century cathodic protection became popular for protecting gas and oil pipelines, and in the 1980s it started to be used for underground structures such as underground storage tanks [2].

Corrosion is often a very complex phenomenon and the knowledge of corrosion assessment in corrosive environments is not yet sufficiently widespread. The World Corrosion Organization [3] warns that latest surveys show that the cost associated with corrosion is €1.3-1.4 billion annually. It is more than 3% of the global Gross Domestic Product and the figure includes only the costs of re-

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pair, maintenance and replacement. It does not take into account environmental damage and loss of materials.

Full understanding of the phenomenon of corrosion and its connection to electric potential of corroding metals made it possible to control these potentials externally and thus inhibit corrosion wherever it is unwelcome.

2. PRINCIPLES OF CATHODIC PROTECTION

Any metal submerged in electrolyte is prone to corrosion, which means it will release its ions into the electrolyte and corrode away. Some metals release ions faster than others. Those that release ions at lower rates are called noble, while those that release ions faster are less noble. When two different metal are in electrolyte the corrosion process on the more noble metal will be inhibited and that on the less noble metal will be accelerated. Also a single metal can corrode since it is not homogenous on the microscopic scale. For example, particles of mill scale on the surface of steel may become cathodes and less noble regions of steel will become anodes and thus corrode. The cathode also makes water alkaline and when OH^- ions bond with iron rust is created.

Corrosion resistance of metals is measured by its electric potential in a given electrolytic environment. Thus, the corrosion rate will depend on the acidity of the electrolyte (its pH) and oxygen level. Additionally, the corrosion rate for underground structures like pipelines and culverts may be increased by stray currents and currents induced by power lines or electric traction. Culverts are exposed to corrosion from two sides – the inside and the outside of the pipe. On the inside there the pipe is exposed to high water/moisture and oxygen conditions and on the soil side it is exposed to prolonged moisture and limited oxygen. Such conditions are likely to cause an electric potential difference and inhibit corrosion on the backfill side while accelerating corrosion on the inside of the culvert.

The goal of cathodic protection is to make the entire protected structure a cathode where no corrosion occurs. This is achieved by connecting the protected metal to an anode that has higher potential. The anode can be made of less noble metal in which case a galvanic cell is created. The current flows from the anode to the cathodic regions of the protected piece as shown in Figure 1. The direction of current flow is determined by the natural potential difference between the anode and the cathode. In this type of cell, the anode is sacrificial and corrodes away, thus it needs to be monitored and replaced whenever necessary. This type of protection is used for underwater and buried structures, especially those that have a fair coating and thus do not need high protection current, or when there is no powergrid to supply current for the impressed current circuit [4].

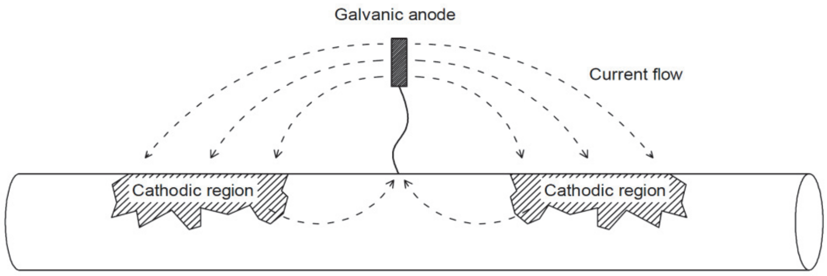

Figure 1. Galvanic anode cathodic protection circuit

The anodes of a galvanic protection are usually made of magnesium, zinc or aluminum. The anode is typically placed underground in a cotton bag filled with gypsum-bentonite mixture which keeps the anode moist, reduces electrical resistance and prevents the corrosion products from forming a poorly-conducting layer on the anode's surface.

This type of protection is easy and inexpensive to install and does not need external power to function but if the demand for protection current is high the anodes may need frequent replacement. Typical applications include underground pipelines and cables, buried tanks, ships and marine structures.

Another type of cathodic protection is Impressed Current protection, based on forced current flow. The system is connected to a direct current source and the flow is from the anode to the cathode, as shown in Figure 2. Since the system is not based on the natural potential difference between two metals, the anode can be made of corrosion resistant materials such as graphite, high-silica iron, or conducting polymers. In such case the buried anode does not need to be replaced since its corrosion is negligible.

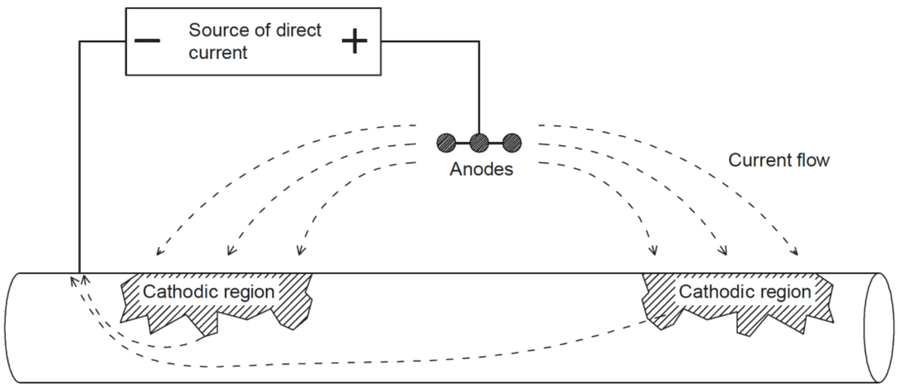

Figure 2. Impressed current protection circuit

This type of system should also be equipped with a control circuit to measure the potential difference between the anodes and the protected structure to enable adjustment of the protection current. The applied current may be kept constant by the source or adjusted so that the potential of the structure is kept at the required level.

Impressed current cathodic protection is typically used for buried pipelines and concrete reinforcements.

3. DESIGN CONSIDERATIONS

Design process for cathodic protection starts with measurements performed on an existing structure. The density of current necessary to protect the structure will depend on many factors: coating quality and the number of its defects, water and soil pollutants and salinity, bacteria present in the soil, oxygen level in the ground, stray currents and presence of other infrastructure. All these factors influence the potential of the structure. The potential is measured with a voltmeter. The voltmeter is connected with one cable to the structure and with another to a reference electrode – a copper electrode in saturated $CuSO_4$. The reference electrode is placed on the ground in the vicinity of the structure to determine where the structure has anodic regions that need protection.

For the cathodic protection to work properly, electric continuity of the structure is a must. The cables connecting the anodes to the structure should be pin-brazed to the structure. Each isolated part of the structure should have its own cathodic protection. Any connection between the structure's elements lowers the potential of the protection current, whether anodic or impressed.

Detailed information on measurement techniques as well as general information about CP and its application can be found in European codes: EN 12954 and EN 13509 [5,6] that govern these issues.

4. CP FOR STEEL CULVERTS – A CASE STUDY

Corrugated sheet culverts seem to be suitable for cathodic protection – they are steel structures buried underground and prone to corrosion due to constant contact with water and moisture. Corrosion poses a large threat to these structures since soil and water conditions in which the culvert is installed may change over the structure's lifetime. It is quite common for the local environment to be much more corrosive that originally assumed and the corrosion rate indicates that the culvert will not last as long as it was intended to. Such a situation actually occurred in Unostentie, the project described below, Cathodic protection was chosen there to extend the life expectancy of an existing culvert, after coating delamination.

The structure in question is a VN6 HelCor® produced by Viacon. The structure has a bottom length of 13 m. Its cross section is presented in Figure 3.

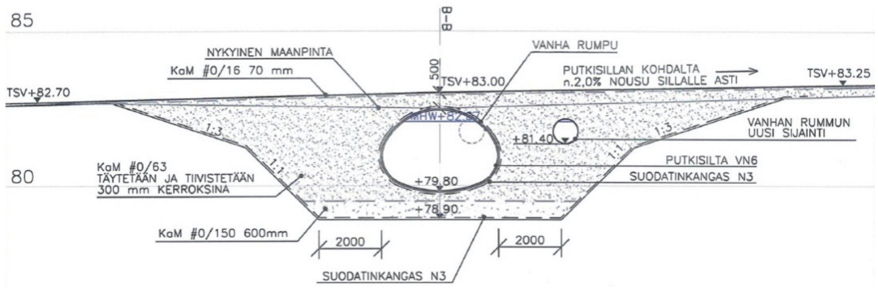

Figure 3. Cross section of the Unostentie structure (Finland)

The structure was designed to last 50 years, thus it was protected with a zinc layer of 85 µm and coated with an epoxy layer of 100 µm. Unfortunately, the coat delaminated at the water level and the exposed zinc offered only 44 years of resistance. Cathodic protection was designed by Tekimet company [7] to add 6 more years. A cathodic protection expert determined the consumption rate of zinc to be 19 µm annually, which is a typical amount for zinc consumption due to corrosion in fresh water in Finland. Since only the inner surface of the culvert was in need of protection, it was easy to see and measure the area of the structure where the coating was missing. The surface area that needed additional protection was 108 m^2. With that information the total amount of the zinc needed for 6 years was estimated at roughly 90 kg. The sacrificial zinc was attached to the structure in the form of bars (300mm long and 28mm in diameter). The bars hang from two cables attached to the structure at its ends, as illustrated by the schematics shown in Figure 4. The anodes after installation are shown in Figure 5.

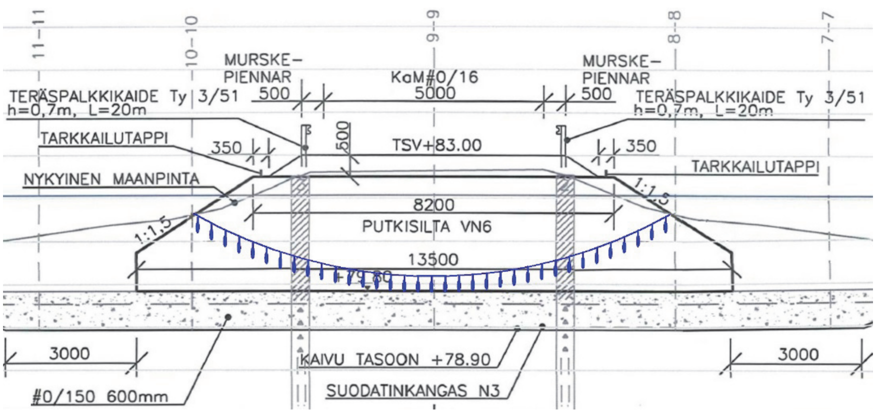

Figure 4. Schematics of anode locations

Figure 5. Cathodic protection anodes attached to a culvert

It should be noted that this type of protection is possible only for structures that are electrically continuous. The culvert in question was painted on site after assembly, which means that there is electrical connection between the plates (the galvanized plates touch each other). If each individual plate had been factory-painted (sealed), then each single plate would now need its own CP installation.

5. CATHODIC PROTECTION vs CULVERT RENOVATION

The best practice is to use cathodic protection as a second line of defense against corrosion. The first line would be to isolate the steel from the corrosive environment either by coating or galvanizing it and allowing the zinc to develop a passivated layer. This is the natural choice for newly built structures but it gets problematic when existing structures need repair.

It is difficult to assess the efficiency of cathodic protection on the Unostentie project since too little time has passed since CP was installed. Its efficiency will depend mostly on local water pH and average water level, and on how well the water current can flow through the structure. Access to oxygen also affects the system's behavior.

In general applications cathodic protection is the most effective in protecting small regions of bare steel, thus preventing localized corrosion. It works best when dealing with coating discontinuities in a well conducting environment like clay soils or seawater, and in electrically continuous structures.

For steel culverts, galvanic anode cathodic protection seems a good choice if the region that needs protection is not too large, when there is water in the culvert at all times and when the structure is electrically continuous – site-painted bolted structure or helically corrugated pipe.

Cathodic protection might not be the economical solution for culverts where the area to be protected is large. Whenever there is a possibility to divert the water flow and to repair the coating by painting or spraying polymers, or concreting the culvert bottom, a detailed economic analysis should be prepared to determine which solution is the best one in a given case.

6. SUMMARY

Cathodic protection is a good solution for inhibiting localized corrosion in painted structures that are buried or immersed in water. Cathodic protection can be implemented at existing structures (and only at existing structures) without excavating the whole structure from the ground. Taking into account the importance of keeping the roads and railroads safe and operational, CP seems to be a good solution for culverts that are corroding faster than expected and might not last their designed lifetime.

However, it should be noted that while the principles of cathodic protection are simple, its proper implementation is much more complex. Improper execution may lead to structure deterioration at a faster rate than without CP. Too low CP current will not inhibit corrosion while too high current might lead to coating disbondment and hydrogen embrittlement [1]. To address this problem, a preamble was added to all European norms [8] dealing with the subject, saying that all the personnel undertaking design, execution, inspection, monitoring and operation of CP installations should be certified according to EN 15257 "Cathodic protection. Competence levels and certification of cathodic protection personnel" [9]. Proper functioning of cathodic protection must be tested every three years. If the test is failed (cathodic current has insufficient voltage) sacrificial anodes must be replaced. If the system utilizes impressed current, it must be repaired by a corrosion expert [10].

While cathodic protection is well known and widely applied in many types of engineering structures, its application to soil-steel bridges can be questionable from technical (efficiency) and economical (cost) points of view, especially when the area to be protected is large. Limitations of CP use for the above bridges must be more clearly determined.

LITERATURE

1. Roberge, Pierre R., *Handbook of Corrosion Engineering*, ISBN 0-07-076516-2, 1999.
2. Agriculture and Natural Resources, *Underground Storage Tanks and NPS Pollution Managing Commercial and Municipal*, ANR-790-4.8.3, 1995.
3. Hays G.F., *Now is the Time*, World Corrosion Organization, 2016.

4. Żakowski K., Darowicki K., *Cathodic protection of subterranean and submerged metal structures*, Publishing House of Gdansk University of Technology, Gdansk, 2011 [in Polish].
5. European Committee for Standardization, *EN 12954: Cathodic protection of buried or immersed metallic structures. General principles and application for pipelines*, 2001.
6. European Committee for Standardization, *EN 13509: Cathodic protection measurement techniques*, 2003.
7. http://www.tekimet.fi/en.
8. Sokólski W., *Cathodic protection – simple rules, difficult practice*, Automatic Systems Engineering 2/2007, 2007 [in Polish].
9. European Committee for Standardization, *EN 15257: Cathodic protection. Competence levels and certification of cathodic protection personnel,* 2006.
10. Minnesota Pollution Control Agency, *Cathodic protection of underground storage tank systems, Inspection of Internally Lined Underground Storage Tanks*, t-y3-27, January 2010, 2010.