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Case study

Electrolytic corrosion of water pipeline system in the remote distance from stray currents—Case study

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ABSTRACT

Case study of corrosion failure of urban water supply system caused by the harmful effects of stray currents was presented. The failure occurred at a site distant from the sources of these currents namely the tramway and railway traction systems. Diagnosis revealed the stray currents flow to pipeline over a remote distance of 800/1000 m from the point of failure. At the point of failure stray currents flowed from the pipeline to the ground through external insulation defects, causing the process of electrolytic corrosion of the metal. Long distance between the affected section of the pipeline and the sources of stray currents excludes the typical protection against stray currents in the form of electrical polarized drainage. Corrosion protection at this point can be achieved by using the earthing electrodes made of magnesium, which will also provide cathodic current protection as galvanic anode.

1. Introduction

Corrosion processes occurring on the outer surface of underground pipelines in the cities is not only a general corrosion process, where corrosion microcells equally covers the surface of corroding metal. On the surface of the pipeline may also arise corrosion macrocells [1–4] in which cathodic and anodic areas on the metal surface can be spaced apart by several tens or even hundreds of meters. Galvanic corrosion (bi-metal corrosion) [5] is an example of corrosion macrocells (created by electrical contact between two different metals, for instance: pipeline and fittings of another metal), differential oxygen corrosion [6] (produced by varying the diffusion of oxygen to the adjacent pipeline sections, for example: in the transition under way and beside the road), concentration cells (differential concentration corrosion) [7] (the transition pipeline by soil with varying levels of dissolved salts or by different types of soil).

The impact of stray currents on pipelines is extremely dangerous, the source of such are tram and rail tractions powered by direct current (DC) [8,9]. The stray currents are one of the most common causes of pipeline corrosion failure in the cities [10]. This result in leaks of media flow (DHW, heating water, gas, oil), outages of media to customers and high costs of repair [11,12]. Since the cathodic and anodic zones on the pipeline are arising as a result of mentioned above interactions, the damage can be spaced

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Fig. 1. View of pipeline corrosion failure.

Fig. 2. Zoom on the defect site.

apart up to several hundred meters or even several kilometers, so it is sometimes difficult to make the diagnosis of corrosion damage.

The paper presents a case of corrosion of DN 300 underground water pipeline made of steel belonging to the water supply system of the city of Krakow and describes the methodology of undertaken corrosion diagnosis. Corrosion damage was caused by the effects of stray currents. The failure occurred despite a considerable distance (nearly a kilometer) from the crossing the tram and train with pipeline.

Table 1
Criteria of soil aggressiveness.

Indicator	Soil aggressiveness:		
	low	average	high
Soil resistivity [Ω m]	More than 100	30/100	Less than 30
pH	7	6 or 8	Less than 6 or more than 9
Chloride content [mg/kg]	Less than 100	100/200	More than 200
Sulphate content [mg/kg]	Less than 200	200/ 1000	More than 1000
the content of hydrogen sulphide and sulphides by qualitative analysis (indicator of the presence of sulphate-reducing bacteria)	Lack of H_2S	Lack of H_2S	Presence of H_2S

Table 2
Results of soil resistivity measurements.

Distance between electrodes, a [m]	Result of measurement, R [Ω]	Resistivity, ρ [Ω m]
1	7.5	47.1
2	3.3	41.5
3	1.9	35.8
4	1.3	32.7

2. Description of corrosion failure

Described corrosion damage occurred on the steel water pipe DN 300 in bitumen isolation. The age of this fragment of pipeline is estimated to be about 18 years and actual thickness of the pipe wall in the place of damage is slightly more than half of its normal thickness and it is in the range of 9–11 mm. Pipeline in the place of damage is buried in the sandy type of soil. Uncovered damage after digging out the pipeline, removing the bitumen coating and cleaning the surface is presented in Figs. 1 and 2. The failure occurred at the beginning of branching of the pipeline. The figures show the circular pipe wall perforation having a diameter of about 4 cm, containing the soil with corrosion products. On the right side of the defect, just below it, significant loss of metal within the distance of tens of centimeters and a width of approximately 3–4 cm is visible. This broad defect is probably caused by mechanical damage occurred during the mounting of water pipe system in the ground. In this wide scratch the losses of metal in the shape of circular cavities of different diameters are clearly visible. The shape of these cavities on the surface of a metal pipe wall reminiscent of the effect that would be obtained by destroying surface using drilling tool. Such losses of metal are typical for electrolytic corrosion caused by stray currents flowing from the pipe into the ground through the metal/electrolyte phase boundaries in the protective coating defects [13].

The initial diagnosis of the causes of the corrosion of water supply system based on the appearance and shape of corrosion cavities pointed to the effects of stray currents. Suspicion of such impact in this side of water supply network raised certain astonishment, due to the considerable distance from the sources of stray currents. The place of pipeline failure is 800 m away from passes under the tracks of the tram line and after next 200 m it passes under the railroad tracks.

As part of the diagnosis field measurements were performed to determine the source of corrosion danger and to indicate methods of prevention against corrosion in the future.

3. Methodology of diagnosis

Determination of soil corrosivity at the point of failure was made based on the following parameters [14]: soil resistivity, pH, chloride content [15], the sulphate content [16], the presence of sulphate-reducing bacteria (SRB). Ground resistivity measurements were performed by 4-electrode Wenner method in the place and depth of failure as well as presence of sulphate-reducing bacteria by adding few drops of diluted HCl on the soil. Presence of rotten-egg-smelling of hydrogen sulphide is inferred that iron sulfide is present and has been produced by SRB [17–19]. The content of chloride and sulphate were determined in the aqueous extract from the ground. These criteria considered in terms of each of these indicators are shown in Table 1. Corrosive aggressiveness of soil can be described as low if each tested parameter is in the range of low aggressiveness. On the other hand it is enough to any indicator was in the range of high aggressiveness to recognize that the soil has a high aggressiveness (analogous: average aggressiveness).

The threat of harmful effects of stray currents was determined on the basis of records of changes in potential of water supply system at the side of the accident and in the areas of pipeline underpasses both electric tractions. Measurements were also made based on the correlation of relation in changes of pipeline potential to sources of stray currents. On the basis of such research can be determined the direction of flow of stray currents between the rails and underground pipeline. The results clearly indicates whether the test side of the pipeline is an anodic zone (the out-flow of stray currents from the pipeline to the ground), or cathodic zone (the in-low of stray currents from the ground to the pipeline).

Table 3
Results of analysis of soil aggressiveness indicators.

Indicator	Result	Soil aggressiveness by indicator (according to Table 1)
pH of soil	7	low
pH of water extract	7.56	low
Chlorides content [mg/kg]	79.94	low
Sulphate content [mg/kg]	159.88	low
hydrogen sulphide and sulphides content	absence	low

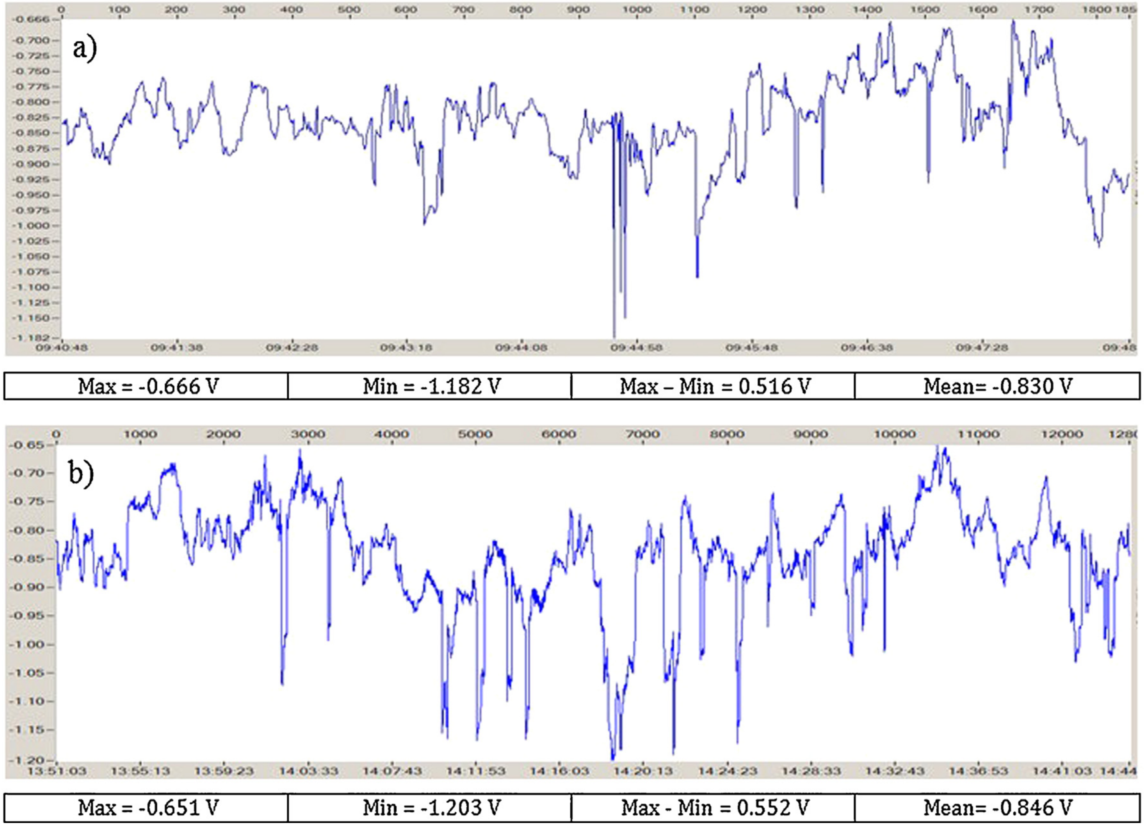

Fig. 3. Changes of pipeline potential caused by influence of railways.

Portable copper sulphate electrode (CSE) was used as a reference electrode to measure potential of pipeline. To minimize the IR component occurring in the values of the potential, when measured in the presence of stray currents flowing in the ground, a reference electrode was placed on the ground directly above the pipeline (to minimize the distance between the electrode and the pipeline). Voltage of the pipeline to tram and pipeline to railway was measured by connecting measuring wires to pipeline (positive input of recorder) and to rail (negative input). The measurements were performed using digital recorders mRA produced by L.Instruments Poland. Sampling frequency of signals was 4 readings per second.

4. Results

4.1. Measurements of soil aggressiveness

The results of measurements in field are presented in Table 2. Soil resistivity was calculated from following equation:

$$\rho = 2\pi \times a \times R$$

where: ρ—soil resistivity [Ω·m], a—distance between measuring electrodes [m], R—value of resistance measured for given distance between electrodes [Ω].

It is clearly visible that the soil resistivity decreases with depth of measurement. This is due to increasing soil moisture resulting from the groundwater level. Resistivity values are in the range of average soil corrosivity (it is from 30 to 100 Ωm) according to the criteria specified in EN 12501-2 [14]. In terms of this indicator corrosion aggressiveness of the soil is therefore average. The results of other indicators are given in Table 3.

The results of the measurements indicate that the corrosion aggressiveness of the soil in the area of failure is average according to soil resistivity, and low according to other examined indicators. Such large local metal loss and uneven dissolution of metal on the exposed surface were therefore caused by something else than the corrosive effect of soil.

4.2. Records of pipeline potential near the sources of stray currents

Records of potential of water supply system at various times a day at the point of passing under railways is shown in Fig. 3(a) and (b), and passing under the tramway tracks—Fig. 4(a) and (b).

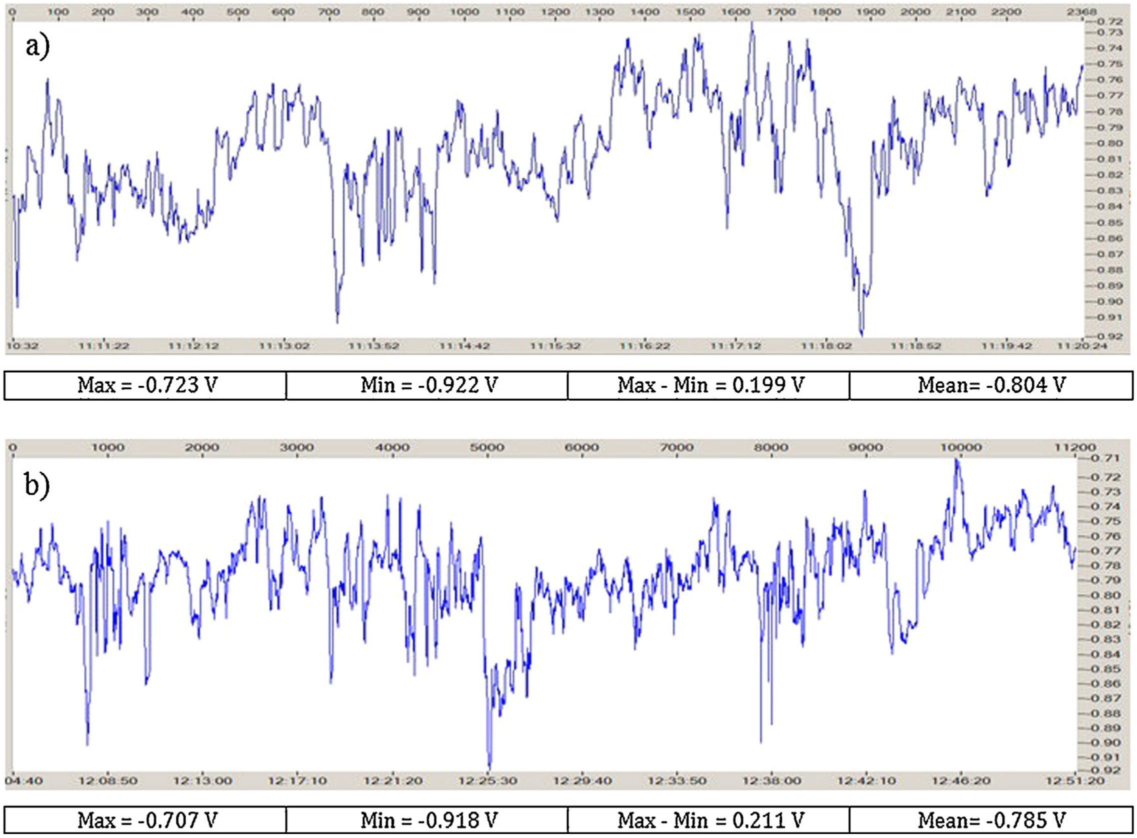

Fig. 4. Changes of pipeline potential caused by influence of tramway tracks.

The mean value of the potential of water supply system at the site of underpasses railroad at various times a day was −0.830 V and −0.846 V, and underpasses tram traction −0.804 V and −0.785 V vs. CSE. A typical value of the corrosive potential of the freely corroding pipeline, without the impact of stray currents, is much more positive and is mostly about −0.5 V [20]. As a result of such negative potential the section of the pipeline between the railway and tramway is cathodic zone affected by stray currents related to both the railway tractions. On the basis of records of potentials can therefore be concluded that in this region there is stray currents flow from the ground to the pipeline in the places of insulation defects. The consequence is a cathodic polarization of pipeline, reflecting the change of the potential of pipeline towards more negative values.

In order to confirm the above conclusions the correlations between potential of pipeline and pipeline to tram rails voltage (Fig. 5) and pipeline to train rails voltage (Fig. 6) were examined.

Voltage of pipeline relative to tram rails were predominantly negative in the most of time (periods of positive voltage was only 23%). The mean value of voltage between the pipeline and the rail was equal to −1.7 V, and the instantaneous minimum value reached almost −10 V. The negative value of this voltage means that the flow of stray current is directed from the rails through the ground to the pipeline. Currents flowing into the pipeline polarize it catholically. In the area of measuring point there is a pipeline cathodic zone. The correlation coefficient of 0.82 and diffuse shape of the graph of correlation suggests that changes of the potential of pipeline result from the interaction not only tram traction, but also other sources of stray currents—in this case railroad [21].

Very similar results of the measurements in the case of railroad were obtained. Pipeline to rail voltage during the measurements was exclusively negative and instantaneous values reached up to −50 V. In the place of measurement on the of pipeline there is also cathodic zone sourcing from the railroad influence. The result is a cathodic polarization effects on pipeline. The mean value of the potential of pipeline at the time of measurement was equal to −0.763 V. The coefficient of correlation of 0.87 and diffuse shape of the graph of correlation indicates that pipeline potential changes are caused not only by the railway traction, but also the tram.

The results of measurements indicate that in the section of pipeline passing under the railway line and a bit further under the tram tracks the stray currents flow into the pipeline. These currents flow further trough pipeline, but it must return to its source in order to close its electrical circuit. Therefore, currents must flow from the pipeline to the ground, and this is done in these areas, which are favored by the configuration of the water supply system and electric traction and the electric field

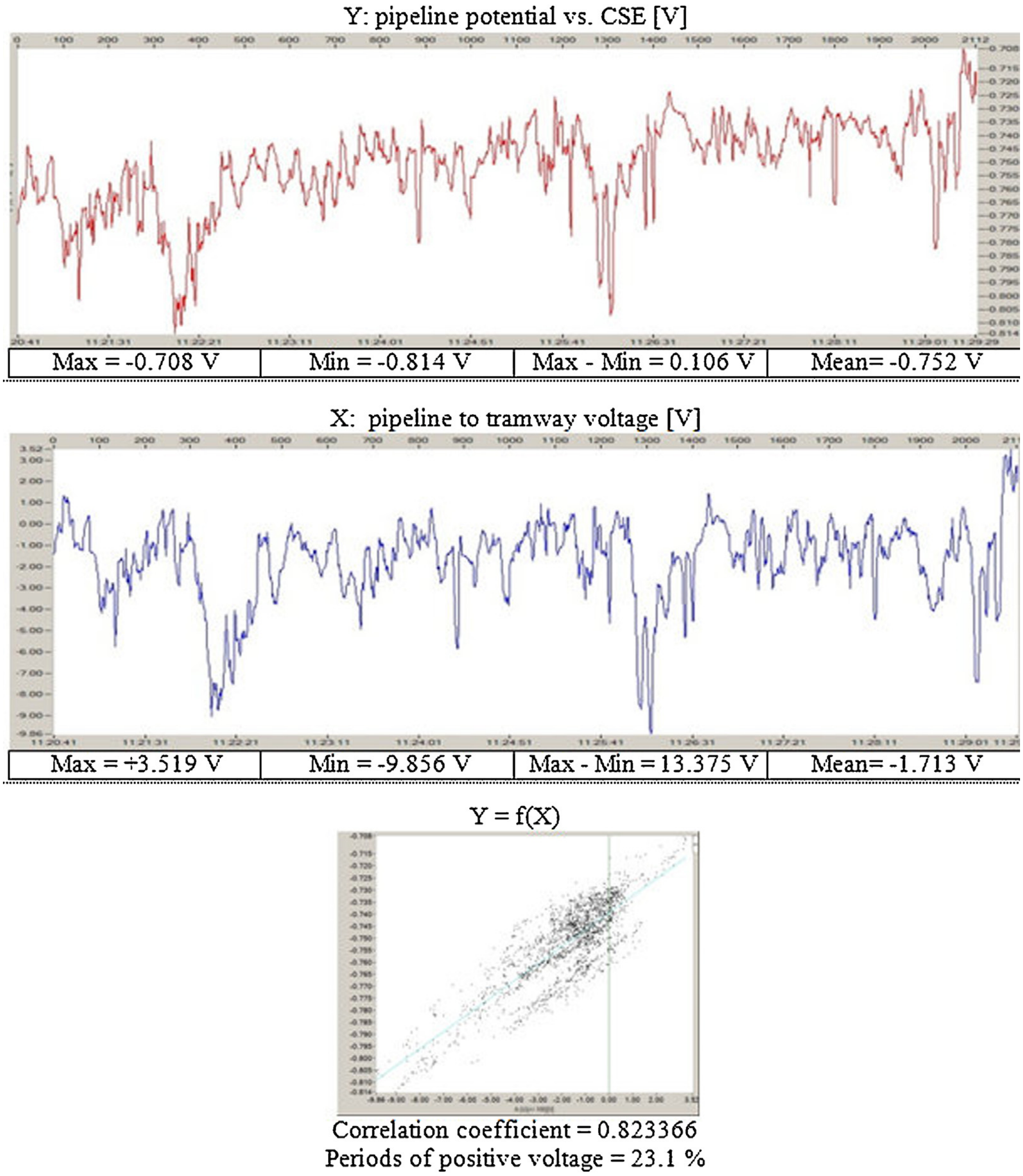

Fig. 5. Analysis of the tramway influence on pipeline.

between them. In places of the out-flow of current from the pipeline there is a process of electrolytic corrosion, which results in the dissolution of the metal.

4.3. Records of pipeline potential in the place of corrosion damage

Results of potential measurements of pipeline at the place of corrosion damage are presented in Fig. 7.

In the graph dynamic random changes in the value of registered potential are visible. The nature of potential changes is the same as in the vicinity of railway and tramway. So, the measurement results indicate the influence of stray currents from electric traction, despite considerable distance from the tram and rail. Of course, the fact of presence of potential changes is not a proof of stray current corrosion [22], but they indicate the likelihood of this type of corrosion.

According to Table 1 in the standard EN 50162 [23] acceptable potential shift of a pipeline as a result of stray current influence is equal to only 20 mV. Whereas the potential change of investigated pipeline was 41 mV (Fig. 7). This indicates the harmful effects of stray currents on the pipeline.

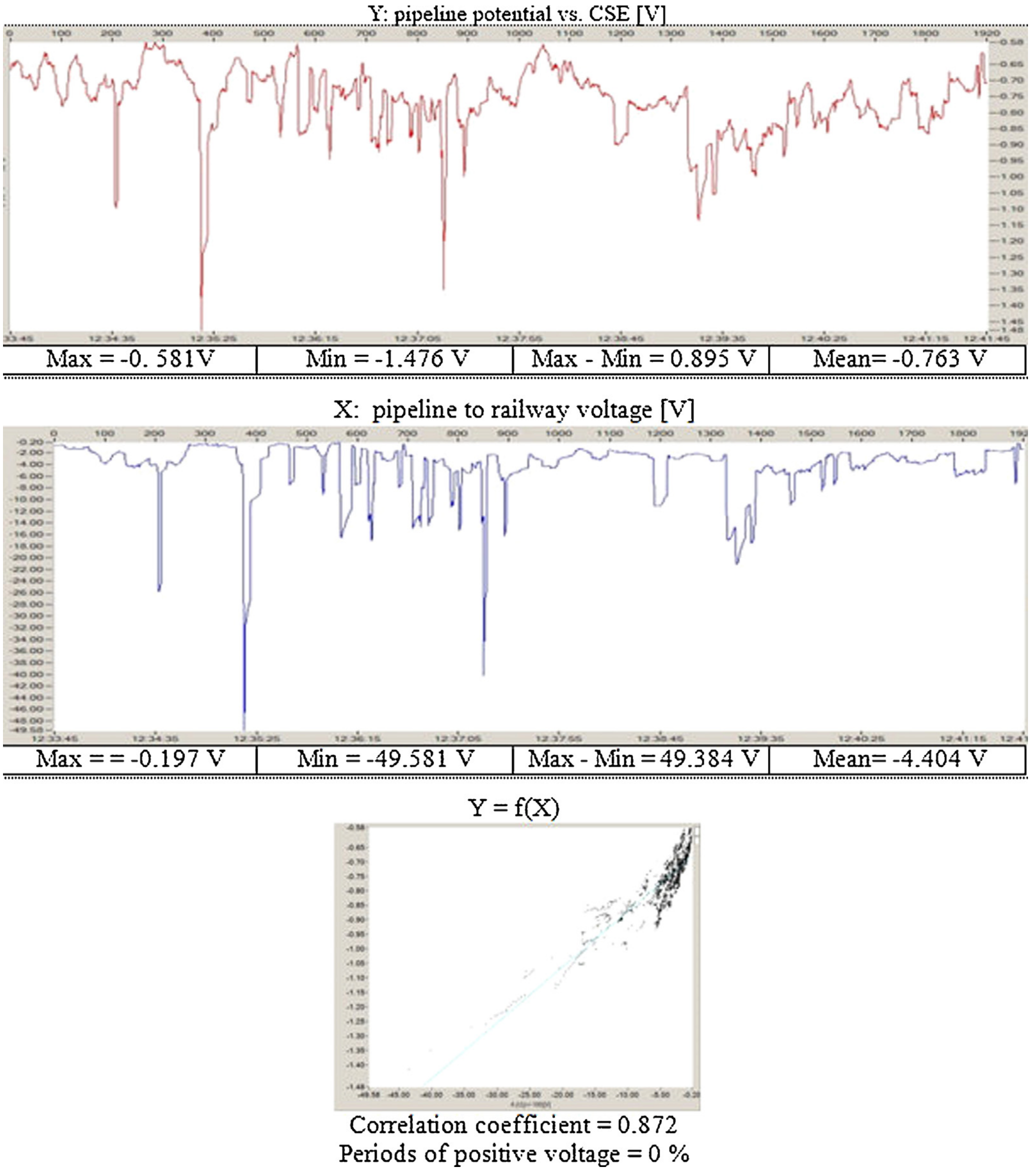

Fig. 6. Analysis of the railway influence on pipeline.

The mean value of pipeline potential at this point in time of measurements was equal to −0.526 V. This value is approximately 300 mV more positive than at the cathodic zone in the vicinity of pipeline crossing under railways and tram (Figs. 3 and 4). The obtained results of the measurements indicate that the test site is the anodic zone of stray currents interference.

The obtained measurements results indicate that in the place of corrosion damage was:

- the influence of stray currents from electric traction,
- the interaction larger than the acceptable influence described in the relevant standard,
- in the vicinity of train and tram tractions by the cathodic zone of stray currents on pipeline,
- the existence in the place of corrosion damage the anodic zone on pipeline.

So, the above-mentioned facts show that stray currents out-flow from the pipeline to the ground in insulation leaks, causing anodic polarization of the pipeline (the change in potential on a more positive values) and dissolution of the metal. The result is presented corrosion failure.

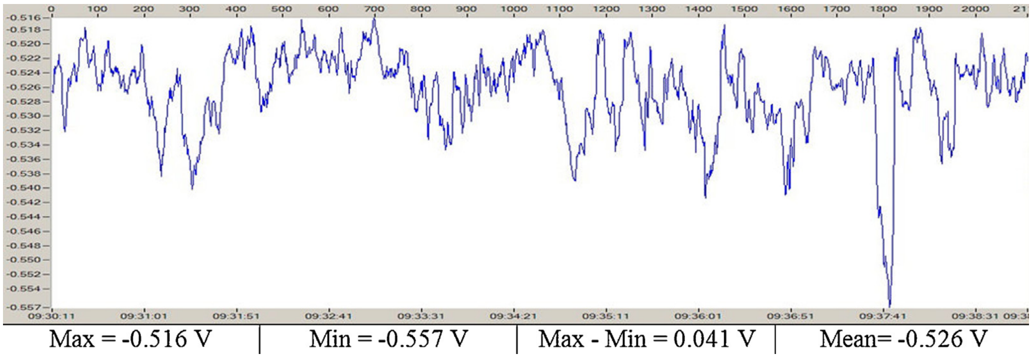

Fig. 7. Changes in potential at the place of corrosion damage.

4.4. Possible protection methods of pipeline from stray currents

Protection against stray currents corrosion is based on elimination of out-flow of these currents from the construction through the metal/electrolyte phase boundary. In the vicinity of tram and railway traction this is achieved by the use of polarized electrical drainage, which is a basic form of protection against stray current [13–25]. Then, stray currents flow from construction to rails is by cable, rather than through the interface metal/soil, so the phenomenon of dissolution of the metal is eliminated. The purpose of the diode inside drainage connection is to allow current flow only in the direction from construction to rail and preventing current flow in the opposite direction (during periods of opposite sign of the voltage between the construction and the rail).

Due to the very large distance from the place of damage to the rails, application of polarized electrical drainage would not make sense. In the region of the point of failure it is necessary to eliminate the phenomenon of leakage currents flow from the pipeline to the ground through the interface metal/electrolyte and this can be achieved by other methods. The simplest of these is the use of the earthing electrode [23], buried near the pipeline and connected to the pipeline by cable. Such a low resistance grounding has protective effect in the form of directing stray currents out-flow from pipeline to the soil trough this electrode instead of pipeline coating defects. Most preferably, the electrode made of magnesium is used, because it can function as a earthing electrode for stray currents and as a source of cathodic protection current (as an galvanic anode [26]). The values of the potential of pipeline as well as their changes shown in Fig. 7 indicates that the use of magnesium sacrificial anodes can provide effective protection against electrolytic corrosion.

5. Summary

Failure diagnosis made on the case of pipeline corrosion showed that in places of external insulation leaks occurred an electrolytic corrosion process. Metal oxidation was caused by the out-flow of stray currents from pipeline to soil. These currents in-flow to the pipeline in the area of the crossing under railways and tram, where both tractions run parallel to each other within a short distance. The flow of currents through pipeline takes place on the significant distance from traction. Out-flow of stray currents from the pipeline to the ground at the point of failure favored the configuration of the traction and the water supply system and the associated electric field distribution in the ground.

Elimination of the risk of water supply system electrolytic corrosion in the area of the point of failure can be achieved by using magnesium sacrificial anodes. They served also as the earthing electrodes through which stray currents can flow from the water supply system to the ground (instead of through the interface metal/electrolyte), and will be a source of cathodic protection current performed by means of sacrificial anodes.

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