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Potential Calculation on the Oil-Gas Pipeline with Geosynthetic Clay Liners Based on BEM

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Abstract

Put geosynthetic clay liners around underground oil-gas pipelines can reduce the potential damage to environment but it will also affect the distribution of cathodic protection current. Geosynthetic clay liners can be regarded as anisotropic soil structure and the potential distribution on the pipeline between two adjacent cathodic protection stations was calculated based on boundary element method (BEM). The calculation results indicate that potential distribution on the pipeline with geosynthetic clay liner is lower than before. A 1500 m built pipeline with geosynthetic clay liners was selected to be calculated and to perform field test, which shows that the calculation results tally well with the field test results and the validity of the arithmetic in this paper was verified.

Keywords

Oil-Gas Pipeline; Geosynthetic Clay Liner; Cathodic Protection; Boundary Element Method (BEM)

1. Introduction

Impressed current cathodic protection is one of the most important measures to prevent corrosion and is widely used in underground oil-gas pipeline anticorrosion [1]-[5]. With the development of oil-gas pipeline construction in China, it has to go through diverse geographical conditions [6]. Put geosynthetic clay liners around underground oil-gas pipelines in environmentally sensitive areas can reduce the potential damage to environment when pipeline leakage occurred [7]-[10]. **Figure 1** shows the location of geosynthetic clay liners around the oil-gas pipeline.

Geosynthetic clay liners can be regarded as anisotropic soil structure around the pipeline because their resistivity are different from the soil. Potential distribution on the pipeline between two adjacent cathodic protection station were calculated based on BEM with and without geosynthetic clay liners. A 1500 m built pipeline with geosynthetic clay liners was selected to model and perform feeder test. Potential variation at the cathodic protection current inject point, 200 meters away from one head of the pipeline, was calculated and measured. The calculation results tally well with the test results and the validity of the arithmetic in this paper was verified.

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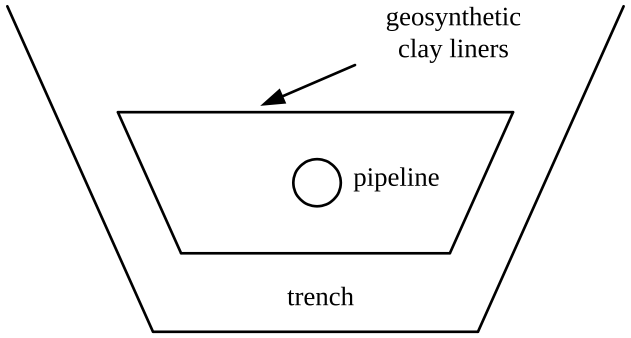


Figure 1. Sketch map of geosynthetic clay liners' construction.

2. Calculation Method of Potential Distribution on the Pipeline

First, Geosynthetic clay liners around underground oil-gas pipeline can be model as anisotropic soil structure and the potential anywhere in the soil can be calculated based on BEM. Here's the basic idea [11]-[16]:

Resistivity of geosynthetic clay liners are ρ_1 and the soil resistivity is ρ_2, Γ is the interface of geosynthetic clay liners and soil, which are marked as Ω_1 and Ω_2, just as shown in **Figure 2**.

Arithmetic in this paper based on assumptions as follows:

(1) Interface Γ is divided into m parts marked $\Delta S_1, \Delta S_2, \Delta S_3, \cdots, \Delta S_m$ and the surface charge density of every part is $\eta_1, \eta_2, \eta_3, \cdots, \eta_m$, η_i (I = 1, 2,… m), which can be regard as constant if ΔS_i (i = 1, 2,… m) is small enough, $\Delta S_1', \Delta S_2', \Delta S_3', \cdots, \Delta S_m'$ is the image of $\Delta S_1, \Delta S_2, \Delta S_3, \cdots, \Delta S_m$.

(2) Underground pipeline is divided into r parts marked $L_1, L_2, L_3, \cdots, L_r$ and the linear charge density of every part is $\xi_1, \xi_2, \xi_3, \cdots, \xi_r$,their images are $L_1', L_2', L_3', \cdots, L_r'$.

(3) ΔS_q is any part on the interface Γ, $\hat{n}_q$ is unit normal vector and point from Ω_1 to Ω_2.

Surface charge density η_q (q = 1, 2,… m) of any part in the interface Γ is shown as follows:

$$\eta_q = -\frac{1}{2\pi}\frac{\sigma_k - \sigma_i}{\sigma_k + \sigma_i}\left(\sum_{\substack{l=1\\ l\neq q}}^{m}\eta_l \int_{\Delta S_l}\frac{(\vec{r}_q - \vec{r}_l)\cdot\hat{n}_q}{\left|\vec{r}_q - \vec{r}_l\right|^3}ds + \sum_{l=1}^{m}\eta_l \int_{\Delta S_l'}\frac{(\vec{r}_q - \vec{r}_l')\cdot\hat{n}_q}{\left|\vec{r}_q - \vec{r}_l'\right|^3}ds' \right.$$
$$\left. + \sum_{j=1}^{n}\xi_j \int_{L_j}\frac{(\vec{r}_q - \vec{r}_j)\cdot\hat{n}_q}{\left|\vec{r}_q - \vec{r}_j\right|^3}dL + \sum_{j=1}^{n}\xi_j \int_{L_j'}\frac{(\vec{r}_q - \vec{r}_j')\cdot\hat{n}_q}{\left|\vec{r}_q - \vec{r}_j'\right|^3}dL' \right) \tag{1}$$

where η is surface charge density (C/m^2), ξ is linear charge density (C/m), σ is electrical conductivity (S/m) and Equation (1) can be rewrite as follows:

$$\sum_{j=1}^{r} A_j^q \xi_j + \sum_{l=1}^{m} B_l^q \eta_l = 0 \tag{2}$$

Potential of arbitrary point on the pipeline u_p (p = 1, 2,… r) is shown as follows:

$$u_p = \frac{\xi_p}{2\pi\varepsilon_0}\ln\left[\frac{L_p}{2a_p} + \left(\frac{L_p^2}{4a_p^2} + 1\right)^{1/2}\right] + \frac{1}{4\pi\varepsilon_0}\left[\sum_{\substack{j=1\\ j\neq p}}^{r}\xi_j \int_{L_j}\frac{dL}{\left|\vec{r}_p - \vec{r}_j\right|}\right.$$
$$\left. + \sum_{j=1}^{r}\xi_j \int_{L_j'}\frac{dL'}{\left|\vec{r}_p - \vec{r}_j'\right|} + \sum_{l=1}^{m}\eta_l \int_{\Delta S_l}\frac{ds}{\left|\vec{r}_p - \vec{r}_l\right|} + \sum_{l=1}^{m}\eta_l \int_{\Delta S_l'}\frac{ds'}{\left|\vec{r}_p - \vec{r}_l'\right|}\right] \tag{3}$$

Equation (3) can be rewrite as follows:

$$\sum_{j=1}^{r} C_j^p \xi_j + \sum_{l=1}^{m} D_l^p \eta_l = u_p \tag{4}$$

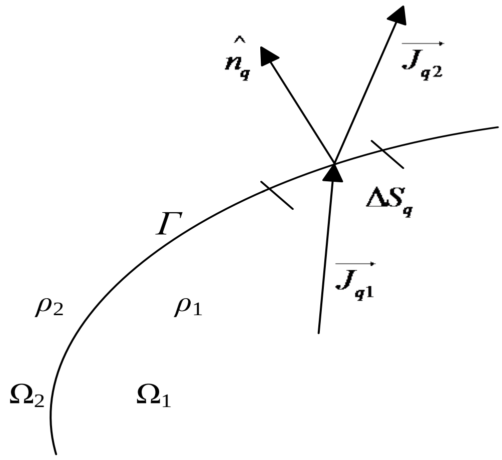


Figure 2. Sketch map of boundary element method.

Rewrite Equations (2) and (4) as matrix form:

$$A\xi + B\eta = 0 \tag{5}$$

$$C\xi + D\eta + U = 0 \tag{6}$$

where A, B, C, D are coefficient matrix, U is voltage vector of every section of the pipeline, when the section is small enough its potential can be regard as constant and the potential of section k can be regard as the average potential of the two attached nodes:

$$U = K \cdot V \tag{7}$$

where V is voltage vector of the pipeline nodes, K is coefficient matrix, if node i connect node j, $k_{ij} = 0.5$, otherwise $k_{ij} = 0$. Replace branch voltage in Equation (6) with node voltage in Equations (6) and (7) can be rewrite as follows:

$$C\xi + D\eta + KV = 0 \tag{8}$$

Branch current can be divided into two equal parts and allocated to attached nodes, then we can get Equation (9).

$$J_j = \sum_{k=1}^{r} c_{k,j} \frac{I_k}{2} \tag{9}$$

If node j connect branch k, $c_{k,j} = 1$, otherwise $c_{k,j} = 0$. Equivalent node current dissipate matrix J can be expressed in Equation (10).

$$J = K^T \cdot I \tag{10}$$

According to electrostatic analogy, electric density on the interface of pipeline and current dissipate can be expressed in Equation (11).

$$\xi_j = \frac{\rho_j \varepsilon_0}{L_j} I_j \tag{11}$$

Rewrite it as matrix as follows:

$$\xi = PI \tag{12}$$

If the node current vector is F, we can get Equation (13) based on node voltage method in circuit theory.

$$F - J = Y \cdot V \tag{13}$$

Equation (13) can be rewrite as follows combined Equations (10) and (12).

$$F - K^T \cdot P^{-1} \cdot \xi - Y \cdot V = 0 \tag{14}$$

Potential and current dissipate of each section of the pipeline can get from the simultaneous solution of Equations (5) (8) and (14).

3. Calculation and Analyse of Pipeline Potential Distribution

Model pipeline potential calculation is based on BEM according to part two. The length of the steel underground pipeline is 8500 meters, with a outside diameter 323.9 mm and a thickness 5.6 mm, relative resistance of the pipeline is 10 and the relative permeability is 636; soil resistivity is 593 Ω·m and the resistivity of geosynthetic clay liners is 200 Ω·m with a thickness 5 cm. Cathodic protection current at two ends of the pipeline are 50 mA, 100 mA, 150 mA and 200 mA. The varied potential distribution on the pipeline with and without geosynthetic clay liners are shown in **Figure 3**, represented by —×— and -·○-· separately, where l is the length of the pipeline (m), ΔU is the varied potential (V).

Calculation results indicate that the varied potential increased with cathodic protection current and the varied potential distribution on the pipeline seems to be inverted U, namely higher in the two ends and lower in the middle, and the voltage variation gradient in the two ends are much bigger than middle parts. Potential distribution on the pipeline with geosynthetic clay liners has overall declined compared to it used to be. The ratio of ΔU and its previous potential is defined as potential decrease percentage and the maximum value 10% occured at the two ends of the pipeline, namely the cathodic protection current inject points. So cathodic protection current should increased properly when geosynthetic clay liners are put around the underground pipeline.

4. Feeder Test and Analyse

In order to verify the accuracy of the arithmetic in this paper, field feeder test was performed in China and Myanmar oil-gas pipeline Jinning extension, the test pipeline is 1500 meters long and has been covered with geosynthetic clay liners. Feeder test method [17]-[19] is shown in **Figure 4**.

Temporary anode bed in the field test was made up by 6 angle steels with a length of 1 meter, which are parallel connected with each other, the temporary anode bed was 100 meters away in vertical distance from the test pipeline. Anode of the DC power was linked to the temporary anode bed and the cathode of the DC power was linked to the pipeline by a test pile 200 meters away from one head of the pipeline. Spontaneous potential of the

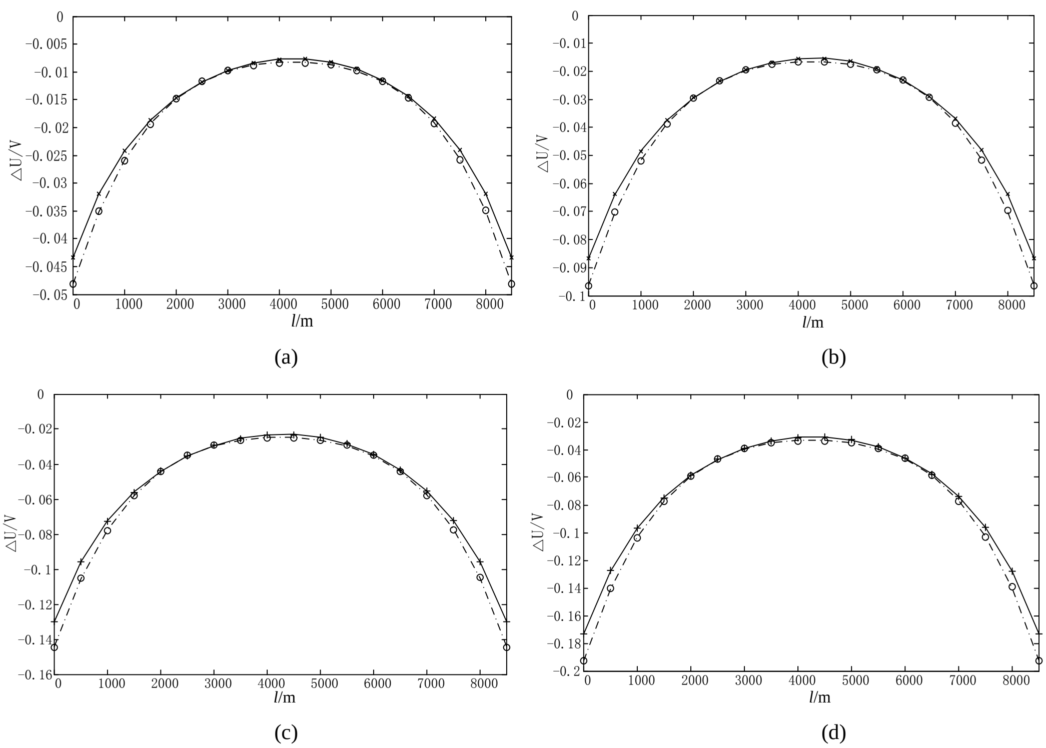
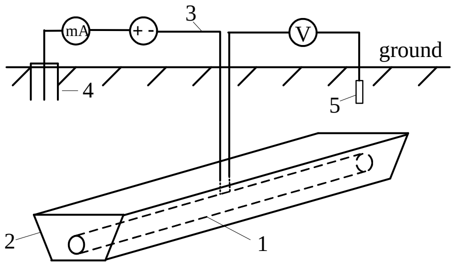


Figure 3. Potential distribution on the pipeline with different cathodic protection current.



1—underground pipeline; 2—geosynthetic clay liners
3—connected cable; 4—temporary anode
5—copper sulfate reference electrode

Figure 4. Sketch map of pipeline feeder test.

pipeline was −1 V and the pipeline potential became −1.2 V when adjust cathodic protection current to 120 mA, potential variation $\Delta U = -0.2$ V. Based on the arithmetic in this paper, the calculation result of cathodic protection current is 113 mA when potential variation ΔU at the current inject point is −0.2 V, relative error is 5.83%, which indicate that the calculation result agree well with the test result.

5. Conclusion

Potential distribution on the pipeline with geosynthetic clay liners was calculated based on BEM in this paper and it indicated that the pipeline potential get a slight decline when geosynthetic clay liners were put around the pipeline. Both the maximum potential variation and the maximum potential decrease percentage were occurred at the cathodic protection current inject point. Validity of the arithmetic in this paper to calculate potential distribution on the pipeline with geosynthetic clay liners was verified by the comparison with field test.

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