

Field Test on Electro-Osmosis in a Heavy Metal Contaminated Soil: Electrokinetic Remediation and Reinforcement of the soil

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With the acceleration of urbanization, less land is available for the direct construction of infrastructure. The reuse of landfills can provide resources in this respect; however, this approach requires the simultaneous removal of heavy metal ions and the strengthening of foundation. In this study, Ningbo's landfill was selected as a field test site. The concentrations of five heavy metal elements (Cu, Zn, Pb, Cd, Cr) gradually decrease with depth. Fulvic acid can complex with heavy metal salts to form a stable soluble conjugate, which greatly improves the electric repair effect. The removal rate of heavy metals after electrokinetic remediation is approximately 25%-35%. The heavy metal removal effect of the F2 test group was the best. The anode settlement of each group of experiments is approximately 12% larger than the cathode settlement.

Keywords: Electrokinetic remediation; Pore water pressure; Landfill test; Reinforcement

1. INTRODUCTION

With the acceleration of urbanization, land that can be directly used to build infrastructure such as houses becomes scarcer, resulting in insufficient land resources. The development of and construction on polluted land has gradually become more common [1-2]. The treatment of contaminated soil foundations is different from that of ordinary foundation soil. To meet environmental protection standards and engineering construction requirements, it is necessary to both remove heavy metal ions and strengthen the foundation [3-4]. The electric repair method can achieve these two goals at the same time. Due to the limitations of indoor test sizes and proportions, laboratory tests often fail to reflect the actual effects of electroosmosis methods. Based on laboratory tests, we selected the landfill in Ningbo for field test research.

The Ningbo Tongpenpu landfill site is located in the southwestern suburb of the city of Ningbo. The landfill area of domestic garbage is approximately 250,000 m², and the average landfill depth is approximately 12 m. The Tongpenpu Landfill combines a large amount of toxic substances with domestic garbage and includes various components, such as domestic garbage, sewage sludge, and scrap metal. We took soil from the site to study its basic physical properties and heavy metal pollution in the laboratory.

After preliminary explorations, we chose to drill and explore the soil on the northwest side of the landfill. The XY-1 type drilling rig was used with diameters of 110 mm and 75 mm. The hole was drilled continuously every 2 m. From top to bottom, it was numbered as #T1 1-16 and #T2 1-16. The open and sampler is 300mm in length and 70mm in inner diameter.

2. EXPERIMENTAL

The heavy metals in the landfill leachate will migrate to the deep and surrounding soil layers under the action of the leachate head and concentration gradient. An analysis of the basic physical characteristics of heavy metal content in soil at different depths can provide a reference for landfill pollution assessment and control [5-6].

2.1 Basic physical properties

The basic physical-mechanical properties of the contaminated soil samples from the Tongpenpu Landfill are as follows.

Table 1. Basic physical-mechanical properties of the contaminated soil

Parameter	Plastic limit / (%)	Liquid limit / (%)	Plasticity index / (%)	Water content / (%)
Value	30.20	65.50	35.30	48.20

2.2 Heavy metal pollution test

The length of the open-end sampler is 30 cm. We took 10 g of soil from the top and bottom of the open-end sampler, according to the sampling situation on site. We dried it in a plastic tray, then ground it and passed it through a 100-mesh sieve. Two samples were taken using a cone-shaped quadruple method:

one was used for digestion and determining the content of heavy metals and the other was reserved for the control group [7-9].

We use the equipment in the Zhejiang University Institute of Environmental Resources to study the heavy metals in the soil.

2.3 Analysis and discussion of test results

The state of the heavy metal contaminants can generally be classified as two phases: those adsorbed onto solid particles and those dissolved in pore fluid. In general, the higher the charge and the smaller the hydrated radius, the more strongly the contaminants will adsorb to the particle. Fulvic acid can complex with heavy metal salts to form a stable soluble conjugate, which greatly improves the electric repair effect [10].

Table 2. The concentration of five heavy metals at different depths

	Cd			Cr			Cu			Pb			Zn		
depth	standard value	T1#	T2#	standard value	T1#	T2#	standard value	T1#	T2#	standard value	T1#	T2#	standard value	T1#	T2#
1.3	0.9	1.2	1.0	200.0	195.8	196.8	100.0	102.1	96.1	80.0	90.2	85.2	250.0	401.5	376.5
3.3	0.9	0.7	0.6	200.0	185.6	190.6	100.0	98.4	92.4	80.0	82.7	77.7	250.0	269.5	244.5
5.3	0.9	0.6	0.3	200.0	175.3	176.3	100.0	83.0	83.0	80.0	61.5	56.5	250.0	204.1	179.1
7.3	0.9	0.5	0.4	200.0	154.6	155.6	100.0	76.4	76.4	80.0	54.0	49.0	250.0	180.6	155.6
9.3	0.9	0.5	0.3	200.0	156.4	158.4	100.0	83.0	77.0	80.0	55.0	50.0	250.0	188.3	163.3
11.3	0.9	0.5	0.3	200.0	146.8	148.8	100.0	87.7	81.7	80.0	50.0	45.0	250.0	114.5	89.5
13.3	0.9	0.5	0.4	200.0	126.5	124.5	100.0	80.9	74.9	80.0	40.2	35.2	250.0	175.4	150.4
15.3	0.9	0.4	0.3	200.0	115.9	117.9	100.0	69.0	63.0	80.0	43.0	38.0	250.0	175.0	150.0

Table 2 show the concentrations of five heavy metals at different depths. The concentrations of five heavy metal elements (Cu, Zn, Pb, Cd, Cr) in different soil layers was determined. The standard of the different heavy metals is shown in Table 2. According to the "Soil Environmental Quality Standards" (GB15618-1995) secondary standard evaluation, the evaluation method is compared with the standard limit analysis to determine the quality level of each factor. It can be seen from Table 2 that the five heavy metals (Cu, Zn, Pb, Cd, Cr) either exceeded the standard to a certain degree in the surface layer or were near the standard value, and the Zn content exceeded the standard value.

Observing the concentrations of the five heavy metals at different depths, the accumulation of Zn is obvious, followed by that of Cd; also, the contents of Cr, Cu and Pb met the standard values, according to the second-level standard value (dry land) stipulated in the Soil Environmental Quality Standard (GB 15618-2008). Five heavy metals exceeded the standard in the depth range of 0-4 m, while the standard

was met at below 4 m.

In addition to the heavy metal Ni, no other heavy metal content met the standard requirements in the full depth range. This result is mainly because the pH of the leachate of the fine particle component is weakly alkaline. It is therefore not conducive to the vertical migration of heavy metals in landfills [11].

2.4 Design of field experiment

After basic research in the indoor pre-experiment, we obtained the appropriate voltage and fulvic acid concentration range. The outdoor test length and depth were $1.5\text{ m} \times 1.5\text{ m} \times 2\text{ m}$. To compare the effects of different fulvic acid additions in the field test, we designed three sets of experiments for comparative study. The chelating agent was injected into the soil every half an hour, according to the designed test addition amount, for a total of 15 hours [12].

Tao found that the shear strength change under intermittent energization is more uniform than continuous power, indicating that intermittent energization is a relatively economic method [13]. Therefore, we use intermittent power supply to improve the efficiency of power utilization [14]. The voltage, current, and potential gradient of the test are shown in Table 3.

Table 3. Parameters of field test

Number	Voltage/V	Current/A	Power/W	Power mode	Potential gradient V/cm	Total amount of fulvic acid added /ml
F1	55	1.89	103.95	Intermittent energization	0.37	0
F2	55	1.89	103.95	Intermittent energization	0.37	900
F3	55	1.89	103.95	Intermittent energization	0.37	1800

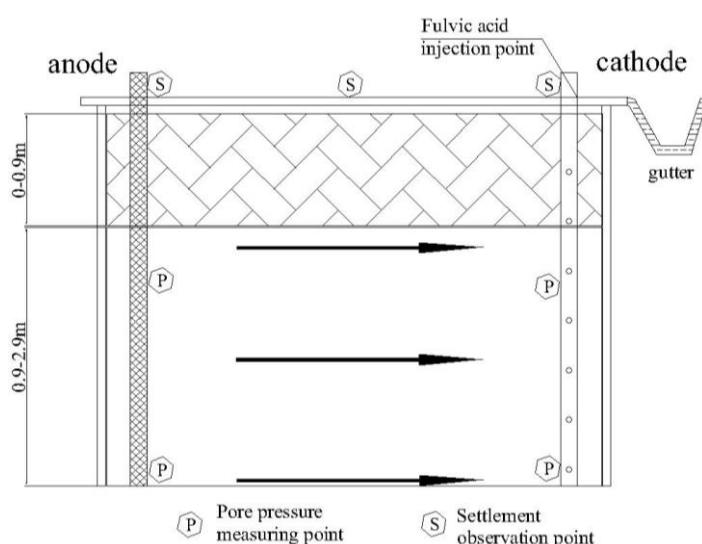


Figure 1. Sectional view of the site layout

The main experimental process was as follows:

(1) The XY-1 model drilling rig was used to drill through the miscellaneous filling layer, and then the electrode with a length of 2 m was pressed to the position of 0.9-2.9 m.

(2) We turn on the power and load the voltage and current according to the experimental scheme. We injected fulvic acid through a syringe and a catheter near the cathode region. The fulvic acid was 0.5 mol/L in concentration and injected into the soil at intervals of half an hour.

(3) The potentiometer were placed at a depth of 1.4 m and 2.9 m to measure the pore pressure. The change in pore water pressure was measured every 30 minutes using a port pressure gauge [15].

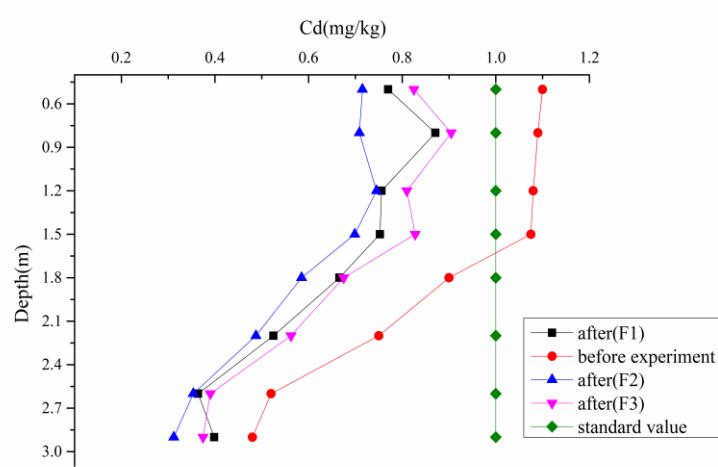
(4) After the test, we sampled and tested the heavy metal content and water content at different depths.

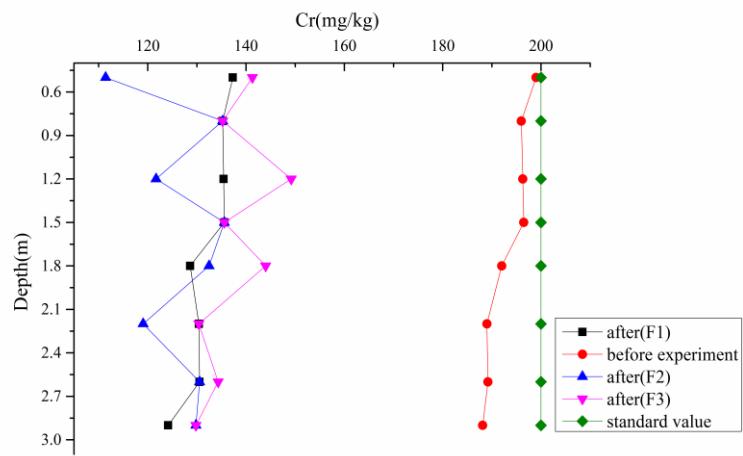
3. RESULTS AND DISCUSSION

The initial goal of the field test in this paper was to strengthen the foundation while removing heavy metals, thus meeting the requirements of environmental protection standards and settlement standards in engineering construction. Therefore, the four main monitoring indicators we selected were heavy metal content, water content, pore water pressure and surface sedimentation [16-17].

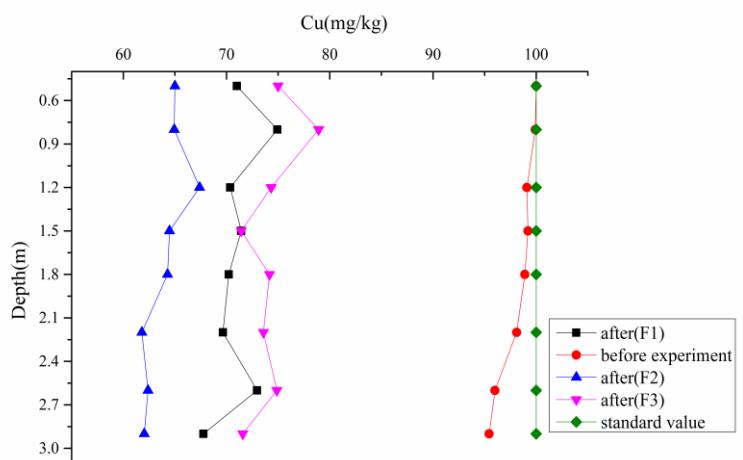
3.1 Change in heavy metal content

Figure 2 shows the concentration changes in the five heavy metals before and after the test at different depths. After the test, we used the rig to sample the change in soil metal content at different depths and locations to evaluate heavy metal pollution repair.

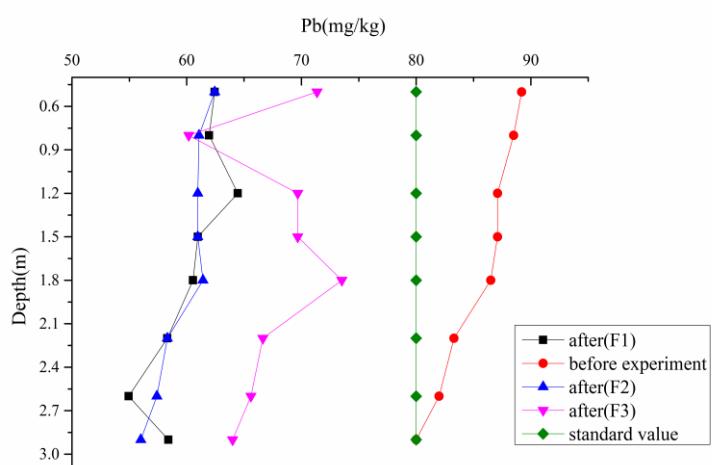




(b) Cr



(c) Cu



(d) Pb

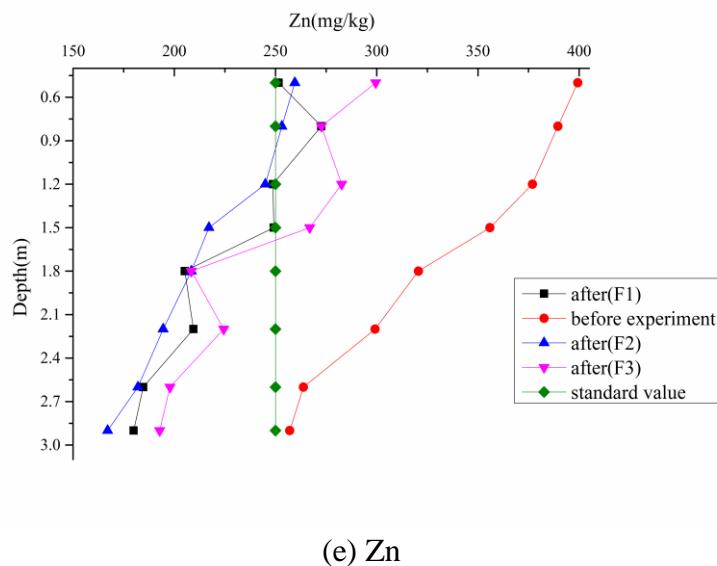


Figure 2. Changes in the content of five heavy metals before and after the test

From the analysis of heavy metal content before and after treatment, it can be seen that the removal rate of heavy metals was approximately 25%-35% after one abnormal point is removed, which is lower than the removal effect of the indoor test. The ions from the acid-induced dissolution of soil minerals flattened the electrical potential profile, which diminished electromigration in the acid region. This outcome appears to be one of the reasons for the relatively low removal rate of cationic and anionic contaminants in electrokinetic treatments [18-19]. The primary reason is that the pollution content of indoor soil is relatively simple, and the pollution situation at the site is more complicated. The electroosmosis method is more efficient in repairing single ions than multiple heavy metal ions [20-21].

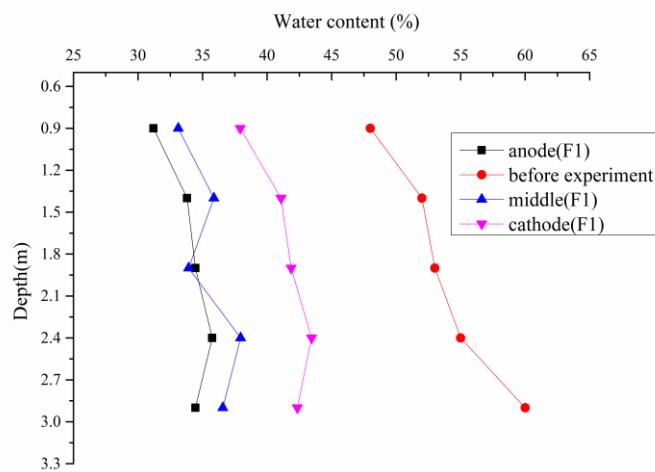
The removal effects of the three groups of F1, F2 and F3 were different. The three groups used 0.5 mol/L fulvic acid, and the total amount of fulvic acid added was 0, 900 and 1800 ml, respectively. The heavy metal removal effect of the F2 test group was the best, and the removal effect of the F3 test group with the most fulvic acid addition was not good. Excessive concentration of additives such as fulvic acid may affect the pH of the soil, thus affecting the effect of soil reinforcement by electroosmosis [22-23]. The primary reason for this observation is that the high content of fulvic acid will make the soil voids decrease; thus, the soil will become more compact, which leads to a change in soil electroosmotic properties, a decrease in electrical conductivity, a decrease in electroosmotic drainage, and a reduction in heavy metal removal efficiency. Therefore, it is necessary to consider the appropriate amount of fulvic acid when carrying out the reinforcement and treatment of the contaminated soil foundation.

3.2 Change in water content

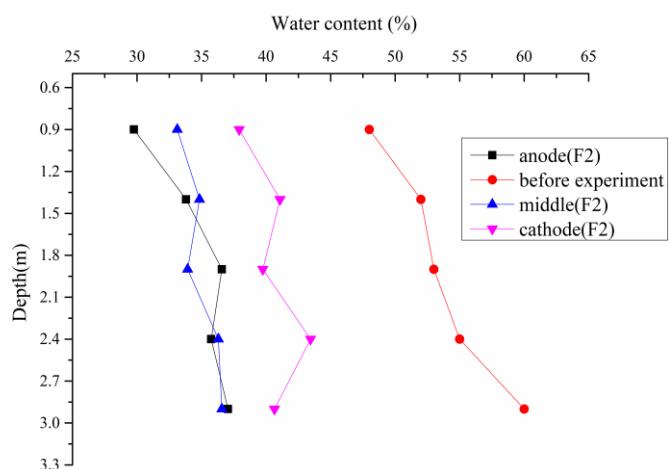
Before the field test, we measured the water content of each soil layer at different depths. After the test, the soil moisture content was measured by the open and sampler.

As shown in Figure 3, the change in the moisture content for each group increased from the anode to the cathode. The change in water content for F1 was similar to the F2 test group, which

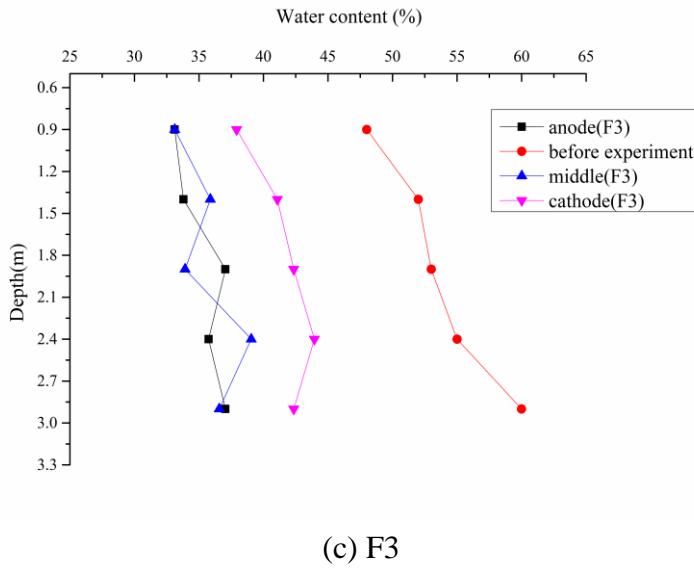
indicates that the addition of fulvic acid does not significantly improve the drainage effect. The water content of the F3 test group was relatively high, mainly because the F3 test group incorporated too much fulvic acid, which impacted the drainage effect [24-25].



(a) F1



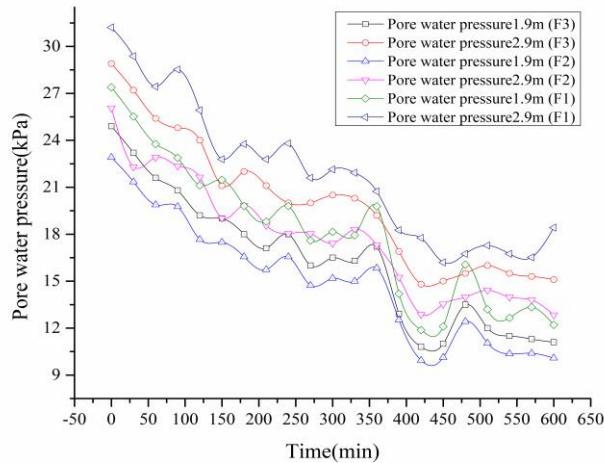
(b) F2



(c) F3

Figure 3. Changes of water content before and after the test

3.3 Pore water pressure

**Figure 4.** Variation of pore pressure with time

Han analyzed changes of pore water pressure related to the electroosmotic flow; when pH variations occurred in the soil, the zeta potential of the clay surface varied and electrical conductivity differences were produced, and thus the electroosmotic flow rate changed. In addition, these variations induced negative pore water pressure in the soil [26].

Figure 4 shows the variation of pore pressure with time in the middle (1.9 m) and bottom (2.9 m) of the anode during the electrokinetic remediation and reinforcement of the soil, which is consistent with the increase of pore pressure with increasing depth [27-28].

It can be seen from the data curve that the pore pressure dissipation rate was the fastest in the first 3 hours, the pore pressure dissipation rate slowed down in the third to seventh hours, and the dissipation

rate was the slowest in the 7th to the 10th hour [29-30]. From the data, the pore water pressure values of the F1, F2, and F3 test groups were basically the same. During the electroosmosis process, the moisture in the anode soil moved to the cathode under the action of the voltage, the anode soil becomes more compact, and the pore pressure dissipation speed gradually slowed .[31-32].

3.4 Soil settlement

The settlement of the soil can directly reflect the effect of foundation reinforcement. We placed two single-point sedimentation meters at the anode and cathode to calculate the average sedimentation value.

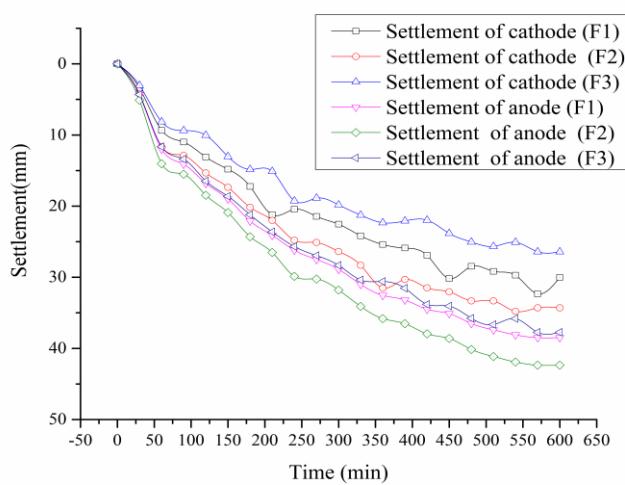


Figure 5. Change of soil settlement

As seen from Figure 5, the anode settlement of each group of experiments was approximately 12% larger than that of the cathode. The maximum anode settlement was 42.35 mm, and the minimum value was 37.7 mm [33]. The sedimentation rate in the first 3 hours was relatively fast, and the rate was gradually stable after that. The sedimentation rate and final sedimentation of the F1, F2 and F3 test groups were basically the same, and the total amount of fulvic acid added did not have a significant effect on soil settlement.

4. CONCLUSIONS

To meet redevelopment requirements for contaminated sites, it is necessary to remove heavy metal ions and strengthen the foundation simultaneously. In this study, Ningbo's landfill was selected as a field test site. The following conclusions can be drawn from this study:

- (1) The concentrations of the five heavy metal elements (Cu, Zn, Pb, Cd, Cr) gradually decrease with depth. Five heavy metals exceeded the standard in the depth range of 0-4 m, while they met the standard below 4 m.
- (2) Fulvic acid can complex with heavy metal salts to form a stable soluble conjugate, which

greatly improves the electric repair effect. When the concentration of fulvic acid is controlled at 0.5 mol/L, the migration effect of lead ions is best. The heavy metal removal effect of the F2 test group was better than the F3 test group, which had the most fulvic acid added.

(3) The removal rate of heavy metals after electrokinetic remediation was approximately 25%-35%. The anode settlement in each group of experiments was approximately 12% larger than that of the cathode settlement. For different contaminated soil sites, we need to choose the right voltage and fulvic acid concentration to achieve the best test results.

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