Numerical analysis of wall deformation of impervious material based on polyvinyl alcohol modification

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Numerical analysis of wall deformation of impervious material based on polyvinyl alcohol modification

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Abstract. In order to study the deformation law of the impervious slurry modified by polyvinyl alcohol in practical application, we adopted the method of simulation experiment combined with finite element analysis. The geological conditions of the project site were used as a reference to complete the pouring of the indoor model and the filling of the model soil, and the anti-seepage wall was modeled and analyzed by software. The research shows that the horizontal displacement of the wall gradually decreases from the top of the wall, there is no reverse displacement. And from the bottom of the wall, the proportion of displacement changes gradually and then tends to a certain constant. The overall displacement curve is basically consistent with the measured curve. The ultimate deformation ability of the polyvinyl alcohol modified slurry can meet the deformation requirements of the anti-seepage wall. The cut-off wall does not produce plastic deformation, has good deformation coordination, and can meet the deformation requirements of the surrounding soil.

1. Introduction
Recently, with the continuous advancement of urban infrastructure, the living standards of the people have greatly improved, and the city's domestic garbage has also increased dramatically [1]. At present, the annual growth rate of garbage in the world is 8.42%, while the growth rate of China's garbage is more than 10%. The world produces 490 million tons of garbage every year, and China alone produces nearly 150 million tons of municipal waste every year. The cumulative storage of municipal solid waste in China has reached 7 billion tons, of which 66% can be disposed of harmlessly. Nearly one-third of the garbage can only be landfilled. Urban waste disposal and pollution prevention have become prominent problems in environmental protection. Landfill has become a widely used waste disposal method at home and abroad due to its simple technical process and low maintenance costs [2].

At present, the main construction methods of cutoff wall in the world are steel sheet pile cutoff wall and bentonite seepage prevention wall, the vertical cutoff wall constructed with bentonite as the main material has the characteristics of low cost and easy to repair, and is the most popular way to adopt the seepage control system of landfill. SS Yeo [3] investigated the Compatibility of three commercially available bentonite products with the free oil-products and the oil-contaminated ground water found at some locations in the landfill, and proposed A specific design mix methodology for evaluating the chemical compatibility of soil-bentonite slurry mixes with permeants. K Joshi [4] described and discussed an experimental investigation on contaminant-cement bentonite mixture interactions, and used it for a cut-off wall to isolate a hazardous waste landfill. He also found that the mixture had good long-term hydraulic properties under leachate erosion. S Inazumi [5] used seepage flow/dispersion analysis to evaluate the effect of disturbed zone on the overall environmental protection function of
the coastal landfill site, and found that the use of cement soil to improve the surrounding soil can effectively inhibit the release of toxic substances. E. Koda [6] studied the important role of bentonite vertical cutoff wall in the prevention of leachate migration and groundwater pollution, in this paper, a dual device is proposed, which adopts the monitoring and numerical simulation process to control the self-purification of the soil-water environment after the implementation of the containment system on the contaminated site. NS Thankam [7] found that when clay-bentonite blends were used as landfill liner materials, when the content of bentonite changed from 0 to 30%, the water conductivity dropped from $7.18 \times 10^{-7} \text{cm/s}$ to $1.894 \times 10^{-8} \text{cm/s}$ when the deionized water penetrated. X Li [8] used soil bentonite as a geotechnical barrier to control contaminants, and found that with the increase of bentonite content, Soil-bentonite's coefficient of consolidation and water conductivity decreased. However, when the content of bentonite increases more than a certain percentage, Soil-bentonite's water conductivity decreases very little.

In general, many researchers in the world have studied the vertical cutoff wall with bentonite as the main material. Based on the previous study, polyvinyl alcohol was used as modifier to prepare the cement-bentonite insulating wall by blending bentonite with modified bentonite, mixed cement, fly ash and other materials. According to the actual situation of the landfill, the solid model is made, the finite element analysis software is used to analyze the model. The deformation data of the solid model and the finite element analysis are compared to verify the practical applicability of the polyvinyl alcohol modified impermeable slurry in the actual landfill site.

2. Parameters of experimental materials
The main material of the test slurry is modified bentonite, ordinary Portland cement, two grade fly ash. The bentonite was treated with polyvinyl alcohol and the sodium carbonate and polycarboxylate superplasticizer were added. Its specific content is: 20% cement, 22% bentonite, 0.2% polyvinyl alcohol, 0.03% polycarboxylate superplasticizer, 18% fly ash and 0.5% sodium carbonate. Sodium carbonate is the analysis of pure grade, polyvinyl alcohol is 1788 type, polyvinyl alcohol is mixed into bentonite slurry in the form of solution. The relevant mechanical parameters of the cutoff wall are determined by test in table 1.

| Elastic modulus E/Mpa | Poisson's ratio $\mu$ | Saturation severity $\gamma/ (\text{kN}\cdot\text{m}^{-3})$ | Cohesion C/Kpa | Internal friction angle $\phi/(^\circ)$ |
|------------------------|----------------------|--------------------------|----------------|---------------------|
| 200                    | 0.25                 | 20                       | 800            | 26                  |

3. Establishment of a solid model
The side plate of the solid model is made of 3mm steel plate. Due to neglecting the influence of the foundation, 1cm steel plate is used to simulate the rigid foundation of landfill site. The model has a net space size of 3.6 m long, 3.2 m wide and 2 m high. As shown in figure 1, the angle steel is mainly used to limit the deformation caused by the fill around the model box, and the detachable baffle is used for model pouring. The impervious wall is 25cm wide and the surrounding soil is 1.5m thick. Through the batching of the model pouring and curing, and using sand to simulate the soil around the impermeable wall of the landfill, the final casting model is shown in figure 2.
4. Model of finite element calculation

Based on the solid model, the changes in soil stress and traits caused by soil filling are not considered. It is assumed that the cut-off wall is in harmony with the deformation of the soil, that is, there is no slippage at the interface. In order to consider the characteristics of the wall-soil contact surface unit, the interface unit is provided at the interface. The SOLID45 solid element is selected, and the models of the wall and the soil are modeled using a hexahedral 8-node SOLID45 solid element. The elements in the entire calculation model are connected to each other by nodes, and the unit deformation satisfies the geometric continuity.

When the soil is filled, the actual stress of the seepage prevention wall in the landfill is simulated, and the soil is filled with sand. Therefore, the Drucker-Prager model is used to simulate the soil [9], and the D-P yield criterion is used to describe the material properties of the soil. The idea is to use the Hooke's law to solve the elastic deformation and the plasticity theory to solve the plastic deformation, the combination of the two is the total deformation. The D-P yield criterion is:

\[ f = \alpha I_1 + \sqrt{J_2} - k \]  

(1)

Where, \( I_1 \) is the first invariant of the stress tensor; \( J_2 \) is the second invariant of the stress tensor. \( \alpha \) and \( k \) are material constants and can be expressed as:

\[ \alpha = 2\sin\varphi/\sqrt{3(1 - \sin\varphi)}, \quad k = 6c\cos\theta/\sqrt{3(1 - \sin\varphi)} \]  

(2)

Where, \( \varphi \) is the internal friction angle of the soil; \( c \) is the cohesion of the soil.

The anti-seepage wall is subject to load deformation much less than the soil, and is basically in an elastic working state under load, so the material is defined as an elastic material [10]. In the simulation of the contact between the underground continuous wall and the soil, the surface-surface contact unit is used to simulate the nonlinearity on the wall-soil contact surface, and the rigid body-soft body contact unit is selected to simulate the nonlinearity of the wall-soil interface. The model is built as shown in figure 3.
5. Analysis of calculation results

The monitoring data to be compared mainly is the horizontal displacement of cutoff wall, and the horizontal displacement is measured by cx-3c type inclinometer. The oblique tube is reserved on the wall near the soil side, and 3 tubes are set up. The measured data of the two tubes are selected for analysis (tube 1 and tube 3), and the horizontal displacements of all the nodes are obtained at the corresponding positions of the finite element model, and then the two sets of data are compared and analyzed. The analysis results are shown in figure 4 (a), (b).

Comparing with the numerical simulation of horizontal displacement and actual horizontal displacement in figure 4 (a) and (b), both show similar trends in horizontal displacement. The actual monitoring horizontal displacement is slightly larger than the numerical simulation displacement value. This is mainly because the consolidation settlement of the soil itself is not considered in the numerical simulation calculation process, and the soil settlement produces negative friction force on the wall. The actual value is not much different from the calculated value, and the change trend is gentle.
6. Conclusion
The horizontal displacement of the wall increases with the height of the cut-off wall. The actual horizontal displacement and simulation value of cutoff wall show similar trend, and the difference is small. It is indicated that the actual characteristics of polyvinyl alcohol modified slurry cutoff wall conform to the assumption of numerical simulation. That is, the cutoff wall can be coordinated with the surrounding soil deformation, which can meet the requirements of the actual use of the seepage prevention wall of the landfill site.

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