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Three Dimensional Finite Element Modeling and Analysis of Different Subway Tunnels Stray Current Fields

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Abstract: In order to analyze the distribution rules and influence of stray current on subway rectangulartunneland subway Shield tunnel, threedimensional models were built separately. By changing the values of carry-current, ansys was used toanalyzeunder different geological conditions.Simulations show that the potential attenuation is nonlinear from the subway tunnel to the surrounding underground.The potential of the same location of surrounding media is different with different carry-current.The amount of leakage stray current of rectangular tunnel is less than Shield tunnel under same geological condition and same carry-current. Each points stray current in situation of surrounding soil media subway tunnel shield can be analyzed by the three-dimensional finite element model, and provide the basis for the protection range of stray current and the protection at a specific location.

Keywords: Ansys, Subway rectangulartunnel, shield tunnel, stray current field, three dimensional model.

1. INTRODUCTION

In subway traction power systems, the running rails are used as the return path of the train's current back to the supply source. Rails are not fully insulated from the ground as a part of current leaves rails to the ground. These leakage currents are called stray currents. Stray current causes a series of serious problems of electrical corrosion for buried metal structures [1] which affects the normal operation of urban rail transit. Therefore, all countries around the world attach great importance to the protection from stray current problem.

W.V. Baeckamnn, Mou Longhua and Liu Yan have established a model of stray current field under the ideal conditions [2-4]. An electric field which can solve underground electric field distribution was established by K.D. Pham and Pang Yuanbing [5, 6]. A two-dimensional finite element model of subway was built by M. Brenna, Alberto and Hu Yunjin [7, 8]. However, there is a difference between the results of these models and actual values. The major reason is that these models were established and simulated under ideal conditions which can analyze the effects of different factors on stray current macroscopically. The two-dimensional finite element model cannot know the condition of stray current along the length of subway. These models cannot be accurately simulated for complex structure of subway tunnel and geologicalconditions.

This paper has simulated the actual model of subway tunnel with FEM. The type of subway tunnel in the driving range is shield tunnel while at the station it is rectangular tunnel. Therefore, we have chosen the shield as well as the rectangular tunnel as our simulation models with ansys [9].

2. STRAY CURRENT FIELD MODEL IN SUBWAY

2.1. Geometrical Model

Three-dimensional model of stray current field computational domain in subway shield tunnel and rectangular tunnel were built according to the actual size. The sectional view of computational domain of subway stray current field, as shown in (Fig. **1**). Fig. (**1**) illustrates that the ground was modeled with a length of 100m, a height of 60m and a width of 1000m cuboid. The top of this tunnel is located at a depth of 10m measured from the road surface. Fig. (**2**) shows the structure of subway shield tunnel and rectangular tunnel.

2.2. Mathematical Model

The potential basic equations of the stray current of the three-dimensional subway Shield tunnel, as shown formula (1):

$$\frac{\partial}{\partial x}(\gamma_x\frac{\partial\varphi}{\partial x})+\frac{\partial}{\partial y}(\gamma_y\frac{\partial\varphi}{\partial y})+\frac{\partial}{\partial z}(\gamma_z\frac{\partial\varphi}{\partial z})=0 \tag{1}$$

Where γ_x, γ_y and γ_z represent conductivity in the direction of x, y and z; φ represents potential(V).

For a constant current field, only the boundary conditions are needed to list. Equation (2) gives the definite conditions of equation (1).

$$\begin{cases}\dfrac{\partial\varphi}{\partial n}=0\\ \varphi_{\text{下表面}}=0\end{cases} \tag{2}$$

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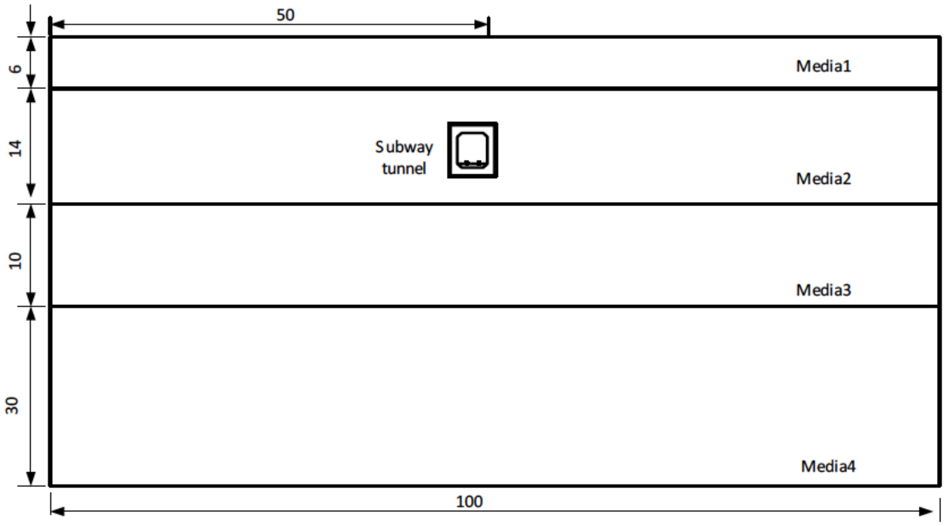
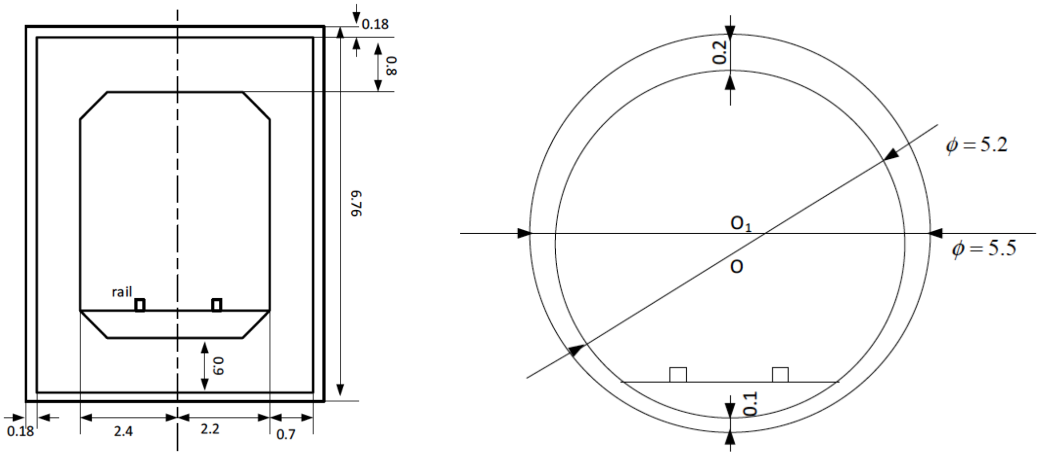


Fig. (1). Sectional view of computional domain of subway stray current field (m).



(**a**) Structure of rectangular tunnel (**b**) Structure of shield tunnel

Fig. (2). Structure of subway tunnel.

Table 1. Simulation parameters of homogeneous soil media.

Material Name		Ralative Permittivity	Resistivity (Ω·m)	Element
Tunnel	Shotcrete	7	552.9	SOLID231 PLANE230
	Reinforced Concrete	6.4	150	
Rail		1×107	2.1×10-7	
Soil		30	100	

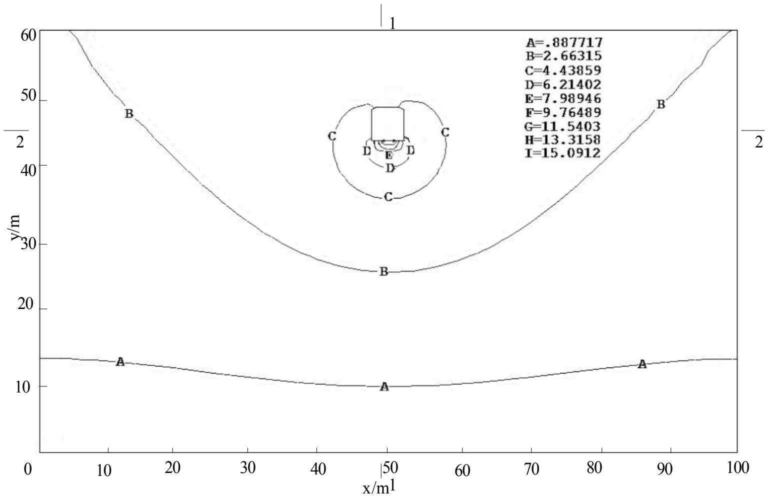
3. SIMULATION RESULTS AND DISCUSSION OF STRAY CURRENT FIELD

Since the actual boundary shape of the stray current field computational domain in subway is complex and changeable, and the geological condition is diverse. FEM is easy to simulate various structures of irregular shape, and can handle all types of boundary conditions [9]. Therefore, the distribution of stray current field was analyzed by ansys with the method of finite element.

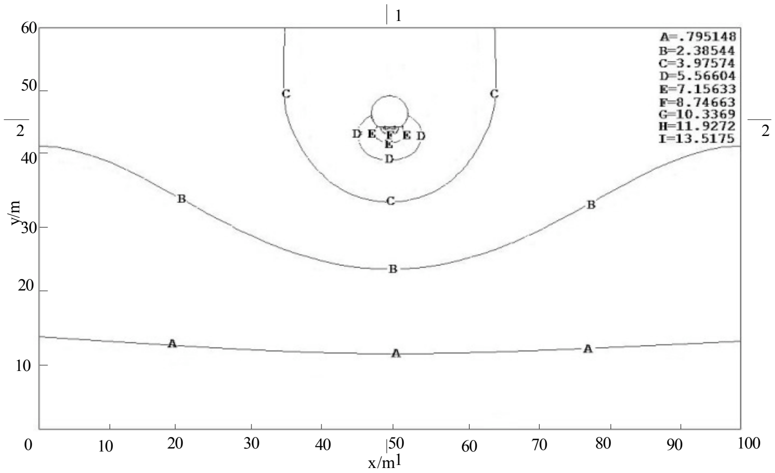
3.1. Analysis of Stray Current in Homogeneous Soil Media

Fig. (**1**) shows that media1-4 are the same media in homogeneous soil media. The parameters of calculation are shown as Table **1**.

In order to analyze the effects of different values of traction current and different types of tunnel on distribution of stray current field in homogeneous soil media, the values of rail current of 10A, 20A, 50A, 100A were loaded separately on one end of each rail. Because different loading currents



(a) Rectangular tunnel



(b) Shieldtunnel

Fig. (3). Electric potential contours in homogeneous soil media of 10A.

have the same contours, the only differences are potential value of contours. So this paper took the carry-current values of 10A as an example. Fig. (**3**) displays that the electric potential contours in homogeneous soil media when the value of current is 10A.

In order to analyze the distribution of stray current from the rail to the surrounding, the three-dimensional was divided into three sections: the longitudinal section was installed through the center of rail on the left, as shown in profile 1-1 of Fig. (**3**); the cross section was installed through the bottom of rail, as shown in profile 2-2 of Fig. (**3**) and the profile of rail. Fig. (**4**) shows that the potential curve of different depths in the longitudinal section; Fig. (**5**) shows that the potential curve of different locations in the cross section; Fig. (**6**) shows that the Potential curve of railway in homogeneous soil media. On the diagram, 0 is the position of current-carrying.

Figs. (**3-6**) show that the distribution of stray current from the rail to the surrounding with the different values of traction current. The following conclusions can be deduced:

(1) The potential of rail and from the rail to the surrounding underground are increasing with the loading current rise regardless of rectangular tunnel or Shield tunnel.

(2) In 1-1 profile, the maximum potential value of rectangular tunnel is greater than Shield tunnel, both of the minimum potential value are 0.

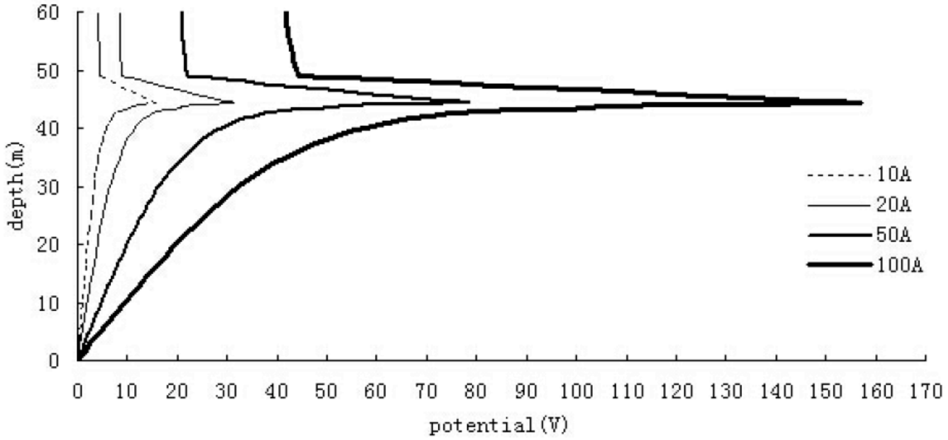
(3) In 2-2 profile, the maximum potential value of rectangular tunnel is greater than Shieldtunnel, but the minimum potential value is smaller than Shield tunnel.

(4) In railway, both of the maximum and minimum potential value of rectangular tunnel are greater than Shield tunnel.

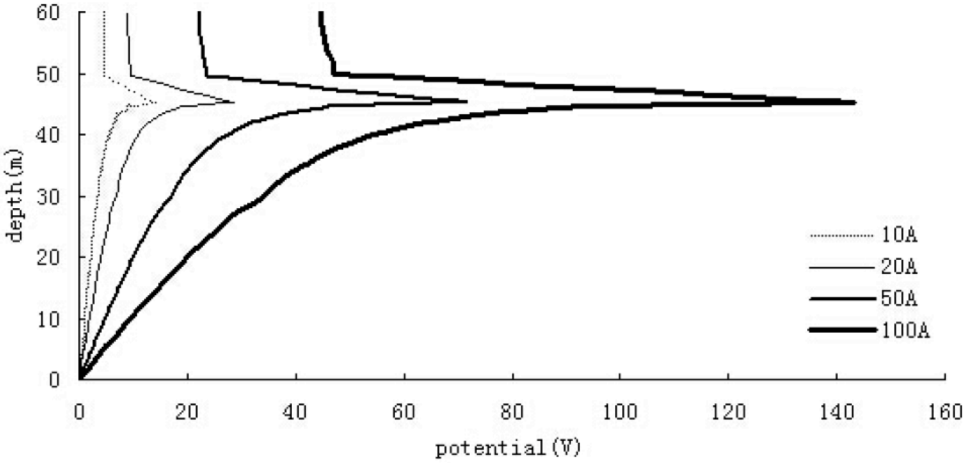
Therefore, the amount of stray current of rectangular tunnel is less than Shield.

3.2. Analysis of Stray Current in Stratified Soil Media

In stratified soil media, Fig. (**1**) shows that media1-4 is the different medias. The type of element and parameters of

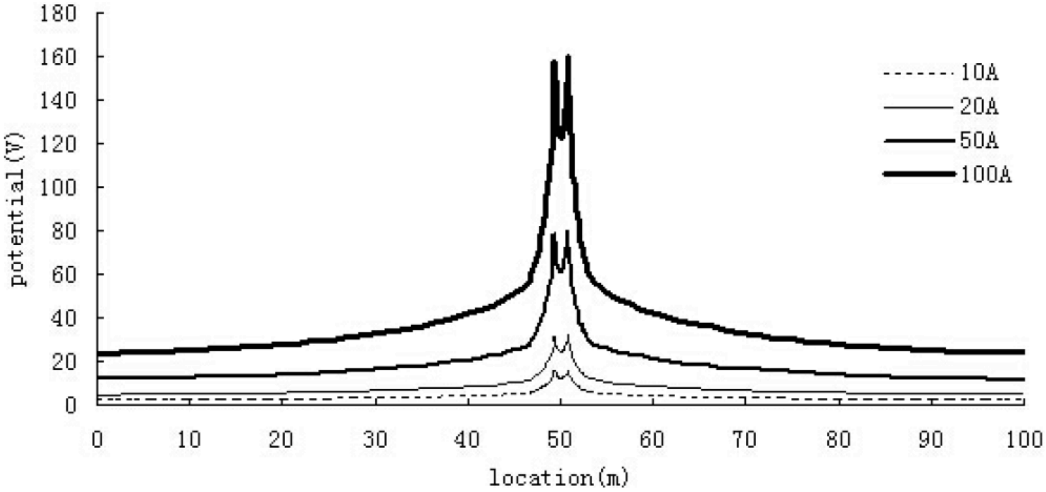


(a) Potential curve of rectangular tunnel



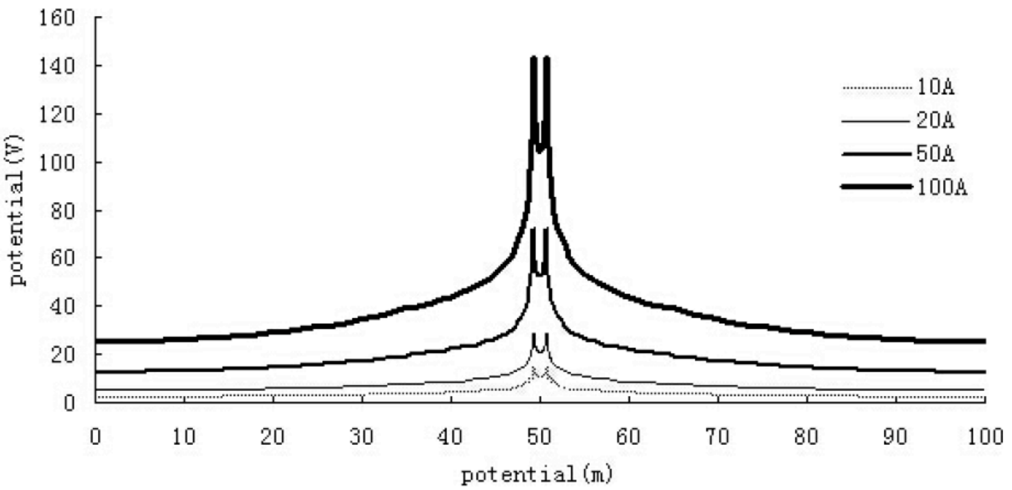
(b) Potential curve of Shieldtunnel

Fig. (4). Potential curve of 1-1 inhomogeneous soil.



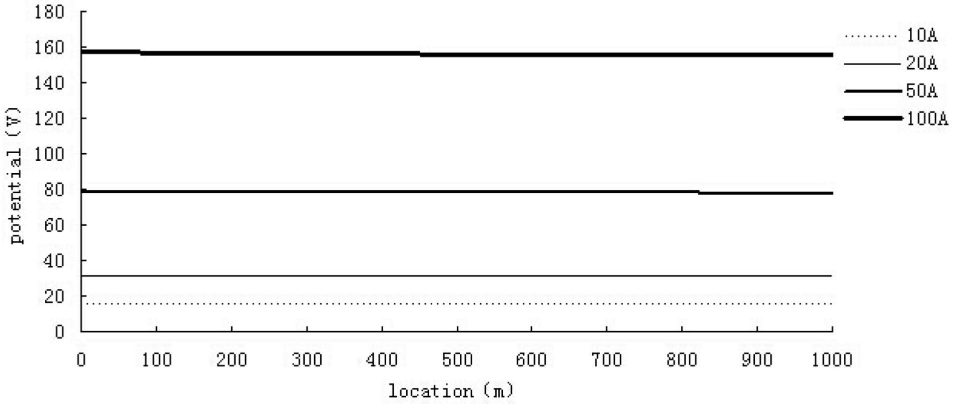
(a) Potential curve of rectangular tunnel

Fig. (**5**). Contd….

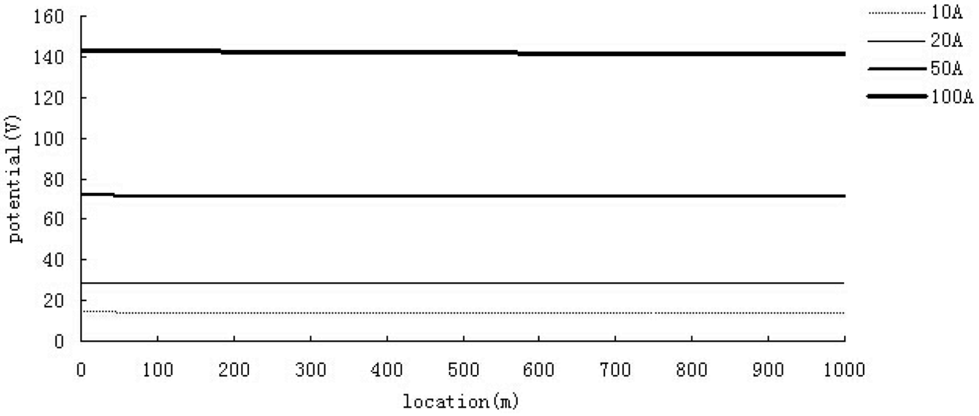


(b) Potential curve of Shield tunnel

Fig. (5). Potential curve of 2-2 inhomogeneous soil media.



(a) Potential curve of rectangular tunnel



(b) Potential curve of Shield tunnel

Fig. (6). Potential curve of railway in homogeneous soil media.

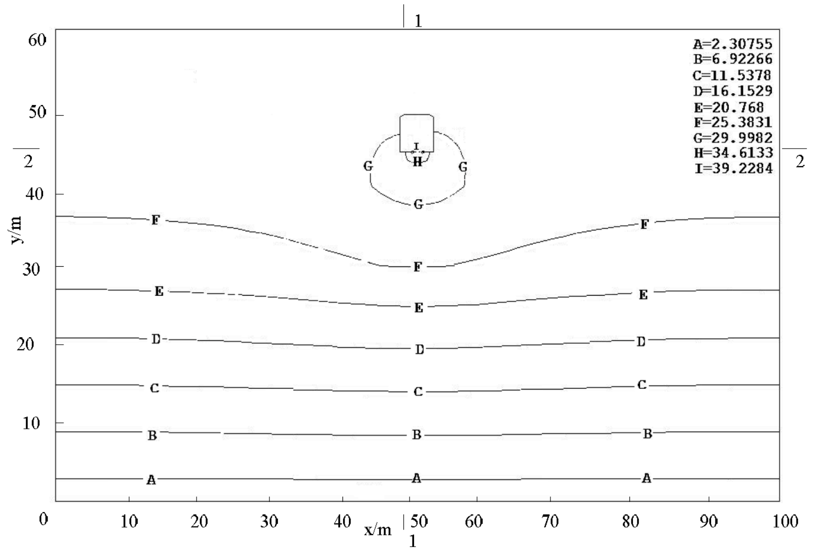
tunnel and rail chosen are not changing. The rsistivity parameters of each Soil [10], as shown in Table **2**.

Likewise, in stratified soil media the values of loading current of 10A, 20A, 50A, and 100A were loaded separately on one end of each rail. Fig. (**7**) displays that the electric potential contours in stratified soil media when the value of rail current is 10A.

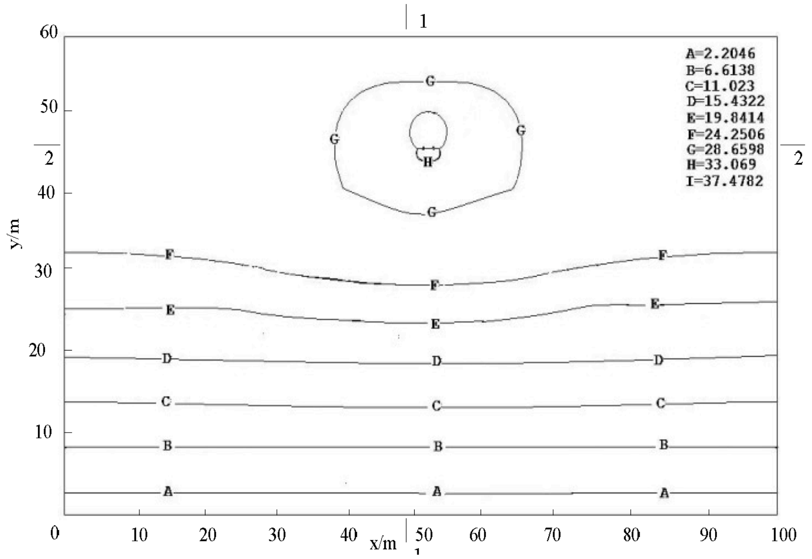
In order to analyze the distribution of stray current from the rail to the surrounding in stratified soil media is consistent with the homogeneous soil media. Fig. (**8**) shows that

Table 2. Rsistivity Parameters of each Soil.

Number	Name	Ralative Permittivity	Resistivity (Ω·m)
Media 1	Clay(wet)	8	10
Media 2	Soft soil	30	100
Media 3	Clay layer	40	500
Media 4	gravel	6	1000



(a) Rectangular tunnel

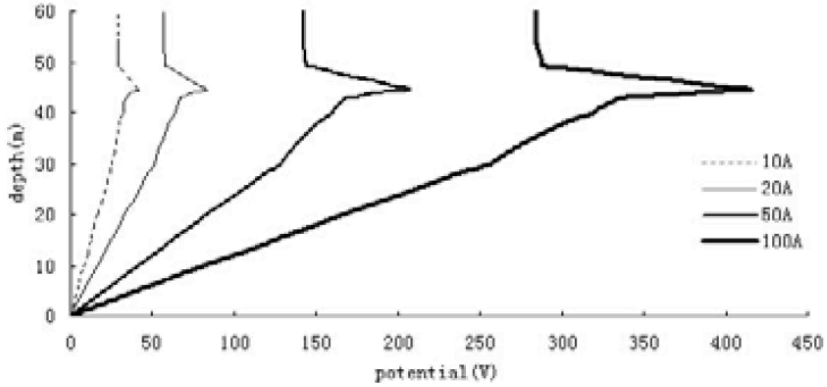


(b) Shield tunnel

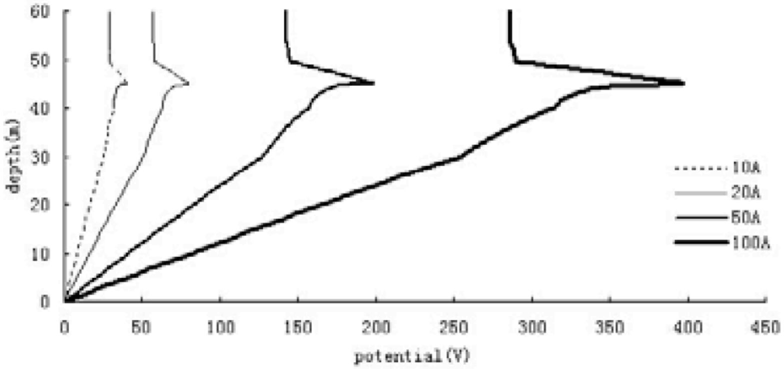
Fig. (7). Electric potential contours in stratified soil media of 10A.

the potential curve of different depths in the longitudinal section; Fig. (**9**) shows that the potential curve of different locations in the cross section; Fig. (**10**) shows that the Potential curve of railway in homogeneous soil media.

Figs. (**6-10**) show that different traction currents have the same effects whether homogeneous or stratified soil media in rectangular tunnel and Shield tunnel.

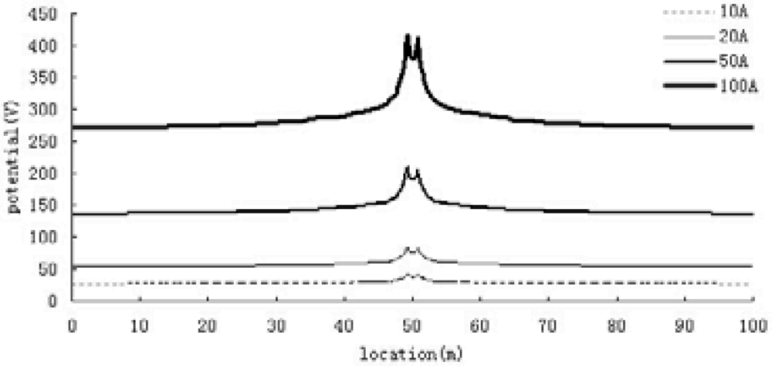


(a) Potential curve of rectangular tunnel

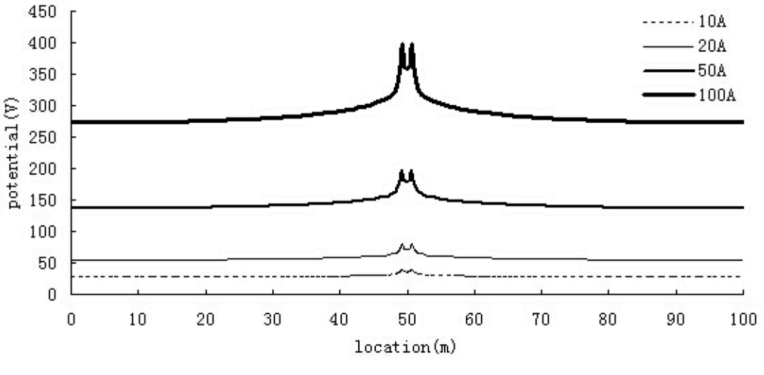


(b) Potential curve of Shield tunnel

Fig. (8). Potential curve of 1-1 in stratified soil media.

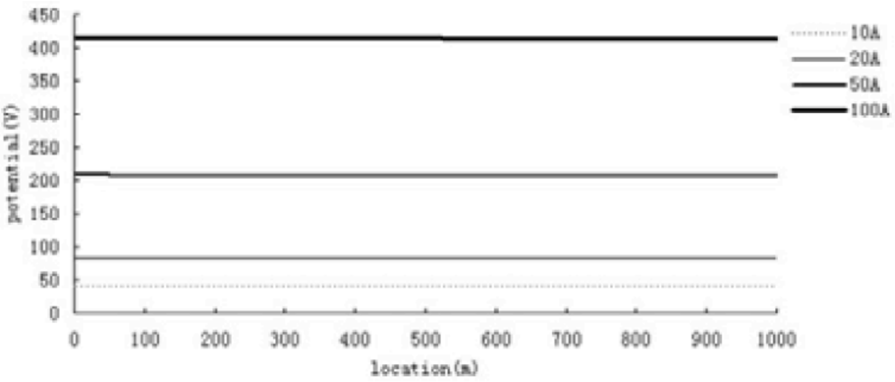


(a) Potential curve of rectangular tunnel

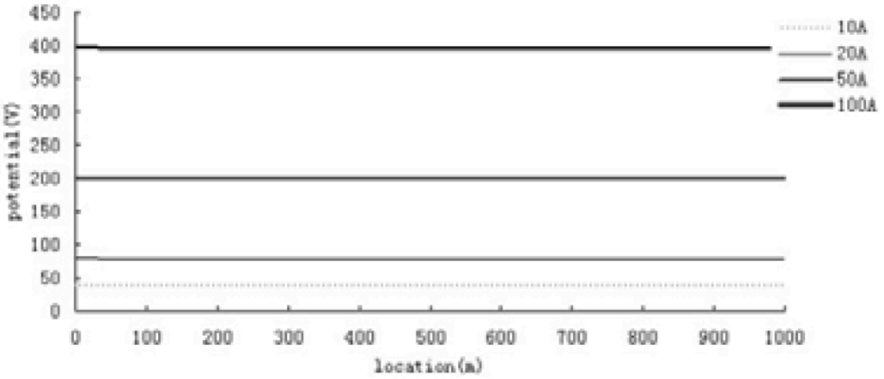


(b) Potential curve of Shield tunnel

Fig. (9). Potential curve of 2-2 in stratified soil media.



(a) Potential curve of rectangulartunnel



(b) Potential curve ofShieldtunnel

Fig. (10). Potential curve of railway in stratified soil media.

Table 3. Comparison of homogeneous soil media and stratified soil media on 1-1.

Profile 1-1	y=30m		y=40m		Voltagedrop (V)	
	Potential (V)		Potential (V)			
	Rectangular	Shield	Rectangular	Shield	Rectangular	Shield
Homogeneous soil media	3.3	3.42	5.79	5.63	1.49	2.21
Stratified soil media	25.6	25.42	32.04	31.42	6.44	6

Table 4. Comparison of homogeneous soil media and stratified soil media on 2-2.

Profile 2-2	Minimum Value (V)		Maximum Value (V)		Voltagedrop (V)	
	Rectangular	Shield	Rectangular	Shield	Rectangular	Shield
Homogeneous soil media	2.37	2.53	15.98	14.31	13.61	11.78
Stratified soil media	27.14	27.30	41.54	39.68	14.4	12.38

Whether it is homogeneous or stratified soil media in rectangulartunnel and shieldtunnel, the potential attenuation is nonlinear from the rail to the surrounding under environment. In the same value of traction current which is 10A, the comparison of homogeneous soil media and stratified soil media on profile1-1, as shown in Table **3**; on profile 2-2 in Table **4**.

As can clearly be seen in Table **3**, in same tunnel structures, the voltage drop in homogeneous soil media is obviously smaller than the voltage drop in stratified soil media in 30-40m area of the profile 1-1. The main reason is that the voltage drop is mainly concentrated in the areas of high resistivity.

In different tunnel structures, the voltage drop in homogeneous soil media is obviously smaller than the voltage drop in stratified soil media in 30-40m area of the profile 1-1. This indicates that insulation of rectangular tunnel is better than shield tunnel.

As shown in Table **4**, in same tunnel structures, in homogeneous soil media goesnear to the voltage drop of stratified soil media in profile 2-2.

In different tunnel structures, the maximum potential value and voltagedrop of rectangular tunnel are greater than Shield tunnel, but the minimum potential value is smaller than Shield tunnel.

The greater the Resistivity is, the faster the speed it has, the less stray current leaks surrounding soil can get. But both of the rails, and tunnel near potential become greater.

CONCLUSION

In this paper, the distribution rule and influence range of stray current in different traction currents and different kinds of tunnels have been carried out by ansys. Analyzing the simulation results, it can be stated that:

(1) Three-dimensional model cannot solve but the two-dimensional model can solve the underground stray current field distribution.

(2)With the increasing value of current, the potential leakage of current into the surrounding media raise constantly. The greater the resistivity of the surrounding media, the less the stray current will leak.

(3) After comparing different kinds of tunnels, it was observed that the leakage of stray current in the rectangular tunnel is less than the shield tunnel.

The three-dimensional finite element model can analyze all points of stray current in the surrounding soil media subway shield tunnel and rectangular tunnel. On the basis of this study, the protection range of stray current and the protection of specific location can be inferred.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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REFERENCES

[1] L. Wei. *Stray Current Corrosion Detection And Prevention Technology in Subway*. HU JIANG SU: The Publishing House of China University of Mining And Technology, 2004: pp. 1-10.
[2] W.V. Baeckman, and HU Shixin. *Cathodic Protection Guide[M]*. BEI JING: The Publishing House of Chemical Industry, 2005, pp. 50-56.
[3] M. Longhua. "Metro Stray current distribution with current drainage". *Net. J. China Railway Soc.,* vol. 9, no. 3, 47-51, 2007.
[4] L. Yan, and W. Jingmei. "Mathematical model of distribution of metro stray". *Curr. Chinese. J. Eng. Math.,* vol. 4, 571-576, 2009.
[5] K.D. Pham, R.S. Thomas, W.E. Stinger. Analysis of stray current, track-to-earth potentials & substation negative grounding in DC. *IEEE/ASME. Join. Rail. Conference.,* 141-160, 2001.
[6] P. Yuanbing, and L.I. Qunzhan. "Discussions on Metro's Stray Current Model" *J. Chongqing. Inst. Technol.,* 2007, p. 11.
[7] A. Dolara, F Foiadelli, and S Leva. "Stray current effects mitigation in subwaytunnels" *In: IEEE. Trans. Power. Del.*, 2012. (In Press)
[8] HU Yunjin, H. Zhen, and F. Jingping. "Stray current field of finite element analysis in subway" *China. Railway. Sci.,* vol. 32, no. 6, p. 129, 2011.
[9] Z. Pan, L Liping, and F. Gang. "*Finite Element Analysis Guide: Modeling and Analysis of Structure*" China Machine Press, Beijing, 2010, pp. 29-55.
[10] W. Ziyang, and S. Wwiyun. "Cylindrical surface model of ground source heat pump considering soil stratification" *J. Zhejiang. Uni.,* vol. 47, no. 8: 1338-1443, 2013.

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