Numerical Simulation of Transient Electromagnetic Response of Unfavorable Geological Body in Tunnel

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Abstract: To investigate the transient electromagnetic method of response characteristics in the tunnel geological prediction, the finite element numerical simulation of unfavorable geological body of different location, different resistivity sizes, different shapes, and different volume size were carried out by ANSYS finite element software. The results show that secondary electromagnetic field of different location of unfavorable geological body have same decay rate, when detection distance from 30m to 70m, transient electromagnetic responses are strongest, followed distance from 10m to 30m and from 70m to 90m. The shape, volume and resistivity of unfavorable geological body have strong influence on transient electromagnetic response, unfavorable geological body more sleek, the greater the volume and the smaller the resistivity of unfavorable geological body, the secondary electromagnetic field decay slower.

Introduction

Transient Electromagnetic Methods is an advanced detection method based on electromagnetic induction. The method was firstly used in the field of surface detection, and some experts[1~3] in this field have researched on the working ways as well interpretative methods and have indicated that the effect does work according to abundant practical application. In recent years, Transient Electromagnetic Methods are applied in advanced geological forecast in tunnel, of which the interpretation is generally analyzed by the advanced tunnel geological forecast experts combing with interpretation map and the geological condition of the tunnel workface. Though some experts[4] have improved the field working and the interpretation methods and have got some achievements, and some of them, such as H.Y.Yang[5], have explore the transient electromagnetic method in tunnel, and analyze its response characteristics, but the regularities and response characteristics of unfavorable geological condition are not summarized and unified.

From forecasting unfavorable geological body in tunnel, according to typical transient electromagnetic numerical simulation, this paper explore the transient electromagnetic response characteristics of different conditions of unfavorable geological body in tunnel.

The basic principle of Transient Electromagnetic Methods

The Transient Electromagnetic Methods (TEM) is a kind of time domain method, using Laplace domain waveform electromagnetic pulse, with no grounding back to the front line, vortex generates in the geologic body under the excitation of the primary field, and the size depend on the conductive ability of the geological body, and if the conductive ability is strong then vortex is strong. After the primary field disappears, vortex can not disappear immediately, because there is a transition process (attenuation process), and the transition process produces a quadratic field to the attenuation of underground. The changes of the quadratic field will reflect the electrical conditions of underground

medium by using receive coil to receive the quadratic field. According to different delay time in the case of measuring induction emf, we get the attenuation characteristics of quadratic field, thereby detecting various unfavorable geological targets.

The electromagnetic field is regarded as isotropic, linearity, then equation of Maxwell as follows[4]:

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} - \vec{J}_m$$

$$\nabla \times \vec{H} = \frac{\partial \vec{D}}{\partial t} + \vec{J}$$

$$(1)$$

Among the items concerned, $\vec{E}$, whose unit is V/m, is the electric field intensity; $\vec{D}$, whose unit is C/m^2, is the dielectric flux density; $\vec{H}$, whose unit is A/m, is the magnetic intensity; $\vec{B}$, whose unit is Wb/m^2, is the magnetic flux density; $\vec{J}$, whose unit is A/ m^2, is the electric current density; $\vec{J}_m$, whose unit is V/ m^2, is the magnetic current density. The constitutive equations as follows [4]:

$$D = \varepsilon E$$
$$B = \mu H$$
$$J = \sigma E$$
$$J_m = \sigma_m E$$

$$(2)$$

Among the items concerned, ε, whose unit is F/m, is the dielectric constant; μ, whose unit is H/m, is the permeance factor; σ, whose unit is S/m, is the electric conductivity; σ_m, whose unit is Ω/m, is the magnetic conductivity.

The model scheme of numerical simulation

The vertical length of mode was 200m and horizontal length of model was 60m × 60m, cross-section shape of tunnel was semi-circular, radius was 8m (Fig.1), The length of excavated tunnel was 30m. There were four types: air, exciting coil, wall rock and unfavorable geologic body, exciting coil was located in the center of wordface.

Numerical simulation scheme were shown in Table 1, the distance between unfavorable geological body and the working face was designed to 10m, 30m, 50m, 70m, 90m; shape of unfavorable geological body was designed for 4 types, respectively, the phere, cube, trapezoid bevel, cuboid; volume of unfavorable geological body was designed to 27m^3, 64m^3,125m^3, 216m^3, 343m^3; resistivity of unfavorable geological body was designed to 1Ω·m, 10Ω·m, 50Ω·m, 100Ω·m, 200Ω·m.

The model of transient electromagnetic field was created by ANSYS finite element software. It taked 3D- transient analysis method, SOLID117 unit was used to simulate element types. The geoelectric parameters of electromagnetic finite element model mainly contained permeability and resistivity, which were shown in Table 1. The magnetic line parallel boundary is a suitable boundary condition in ANSYS, so it was taked as boundary condition in the model.

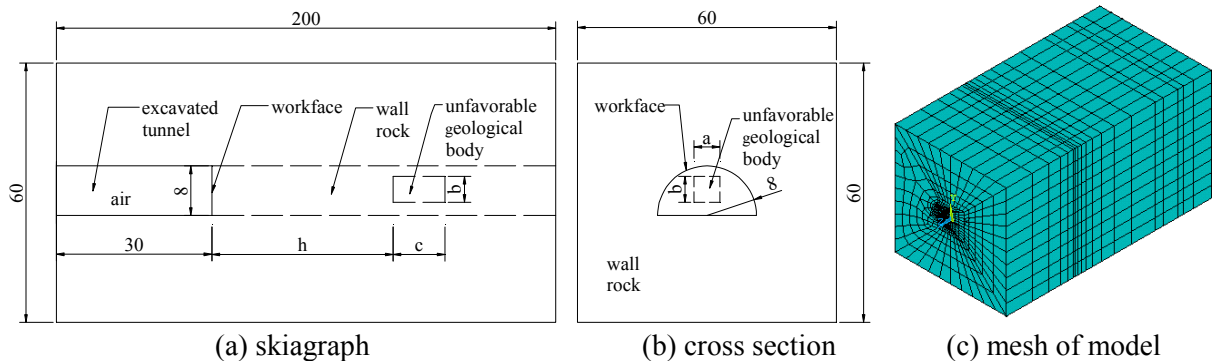   (a) skiagraph   (b) cross section   (c) mesh of model
Fig.1 Numerical simulation model (unit:m)

The process of simulation: First, constant current was loaded at exciting coil elements; first electromagnetic field was created after enough time, and then cut down the current flow, current flow was changed between 0 to 1, the calculation was stopped until satisfy certain time, a secondary induction field was formated. After simulation, the magnetic-field component of receiving coil was gotten, and then induced EMF curve can be calculated by integral.

Table1 The value of geoelectric parameters

distance/ h (m)	shape of unfavorable geological body	volume of unfavorable geological body (m³)	resistivity of unfavorable geological body /ρ(Ω·m)	resistivity of wall rock /ρ(Ω·m)	resistivity of coil /ρ(Ω·m)	permeability /μr
10	sphere	27	1	2000	1e^{-9}	1
30	cube	64	10	2000	1e^{-9}	1
50	trapezoid bevel	125	50	2000	1e^{-9}	1
70	cuboid	216	100	2000	1e^{-9}	1
90		343	200	2000	1e^{-9}	1

Analysis of simulation results

(1)Influence of distance

When length of unfavorable geological body away from the working face is not the same, and other conditions are the same, the induced EMF changes with time at center of tunnel working face as shown in Fig.2, and where the vertical axis is logarithmic function of the induced EMF, horizontal axis is time. Fig.2 show that the induced EMF decays exponentially, after conversion of the logarithmic function, induced EMF - time curve parallel to each other on above different Detection range, and, at the same time, the order of induced EMF is 50m> 30m> 70m> 10m> 90m, this shows that the transient electromagnetic response characteristics significantly, when detection distance change from 30m to 70m. This distance is suitable probing depth of the transient electromagnetic method in tunnel environment.

(2)Influence of shape

When shape of unfavorable geological body is not the same, and other conditions are the same, the induced EMF changes with time at center of tunnel working face as shown in Fig.3, and where the vertical axis is logarithmic function of the induced EMF. Fig.3 show that the induced EMF decays exponentially, and at the same time, the order of induced EMF of different shape is sphere> cube> trapezoid bevel>cuboid, this shows that unfavorable geological body more sleek, more obvious transient electromagnetic response, the slower decay, whereas, the faster decay.
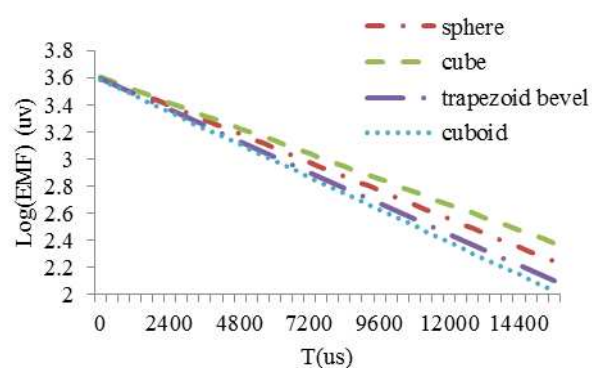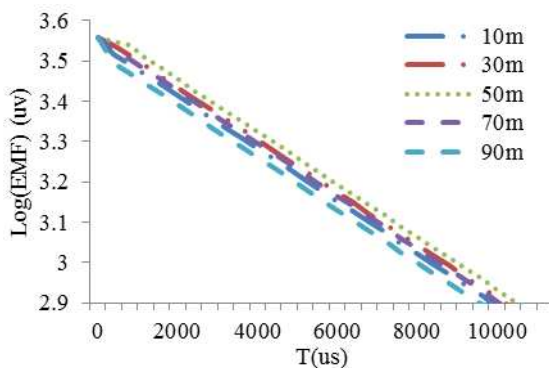

Fig.2 Induced EMF–time curve of different distance Fig.3 Induced EMF–time curve of different shape

(3)Influence of volume

When volume of unfavorable geological body is not the same, and other conditions are the same, the induced EMF changes with time at center of tunnel working face as shown in Fig.4, and where the vertical axis is logarithmic function of the induced EMF. Fig.4 show that the induced EMF decays

exponentially, and at the same time, the order of induced EMF is $343m^3 > 216m^3 > 125m^3 > 64m^3 > 27m^3$, this shows that the greater the volume of unfavorable geological body, the greater the induced voltage, the slower decay.

(4)Influence of resistivity

When resistivity of unfavorable geological body is not the same, and other conditions are the same, the induced EMF changes with time at center of tunnel working face as shown in Fig.5, and where the vertical axis is the induced EMF, horizontal axis is time. Fig.5 show that the induced EMF decays exponentially, and at the same time, the order of induced EMF is $1\Omega{\cdot}m > 10\Omega{\cdot}m > 50\Omega{\cdot}m > 100\Omega{\cdot}m > 200\Omega{\cdot}m$, this shows that the smaller the resistivity of unfavorable geological body, the greater the induced voltage, decay more slowly, transient electromagnetic method is sensitive for low resistance.
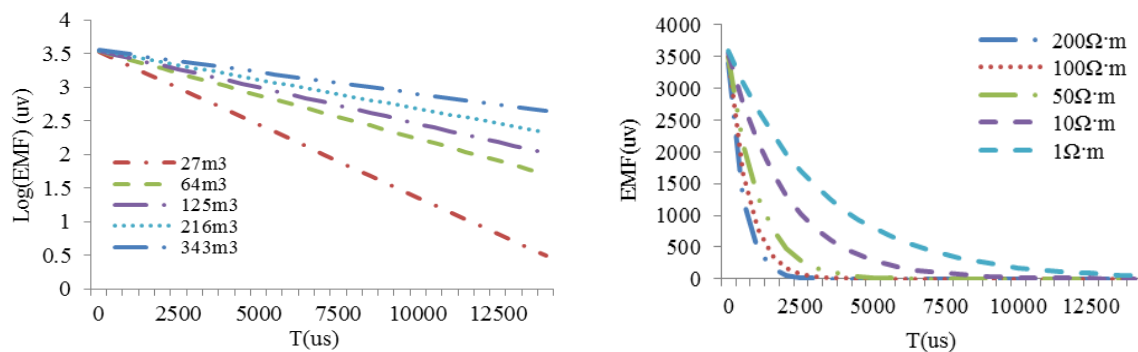

Fig.4 Induced EMF–time curve of different volume Fig.5 Induced EMF–time curve of different resistivity

Conclusions

By the analysis of numerical simulation of transient electromagnetism methods, understanding by the following:

(1) The location of unfavorable geological body has influence on transient electromagnetic response, secondary electromagnetic field of different location have same decay rate, when detection distance from 30m to 70m, transient electromagnetic responses are strongest, followed distance from 10m to 30m and from 70m to 90m, these be suitable probing depth of the transient electromagnetic method in tunnel environment.

(2) The shape of unfavorable geological body has influence on transient electromagnetic response, unfavorable geological body more sleek, secondary electromagnetic field decay slower.

(3) Volume and resistivity of unfavorable geological body are sensitive parameters, the greater the volume and the smaller the resistivity, the slower secondary electromagnetic field decay.

Acknowledgements

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