1-D Numerical Simulation for Comprehensive Geophysical Prospecting of Seismic Refraction and High Density Resistivity

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Abstract— Comprehensive geophysical prospecting has been widely used but the theoretical evidence has not been clear by most researchers. The paper shows out a one dimension seismic refraction simulation by ray-trace technology under a one dimension horizontal geo-model. And then using digital filter method and electrical sounding and interpretation to complete high density resistivity simulation with variable electrodes space. Both result are compared by each other, and the research result shows that both seismic and electronic method could couple with the geological model very well and the both can be mutually verified, so it improve the interpretation correctness. This work give the theories base for comprehensive geophysical prospecting technology with seismic and electrometric method and got some meaningful conclusion.

Keywords-Comprehensive geophysical prospecting; seismic refraction method; high density resistivity method; Numerical modeling of the pros and cons

I. INTRODUCTION

Seismic refraction is an engineering geophysical prospecting method, which determines the velocity in refraction interface and the embedded depth of foundation. However, High-density resistivity method is one of electric prospecting to predict the distribution rule of geological mass from electric property difference in the ground. Both the two and their comprehensive methodology are widely used in engineering investigation [1~4]. The comprehensive method is more often applied for engineering detection in China. It is commonly thought that comprehensive investigation method can reduce uncertainties, but few researchers focus on the theoretical basis of comprehensive geophysical method [5, 6]. The article has done a numerical simulation respectively on the two detection method regarding a geological model in a horizontal level. The result shows that high-density resistivity method can be synergistically applied with seismic refraction method. The thickness of weathered layer under the two methods dovetailed nicely, which further provides a theoretical basis for comprehensive geophysical method [7~9].

II. METHODOLOGY

When wave travels through the underground medium and meets an interface, reflection, refraction and transmission take place. If the wave velocity above the interface is smaller than that below the interface, the seismic signal refracts significantly [10]. Seismic refraction is to investigate the geological information through the initial value of shallow refractive wave. It covers the artificial excitation of seismic wave, and the relations between the arrival time of refractive wave on the ground to the local distance from the excitation point [2, 3]. High-density resistivity method is a prospecting technique by integrating electrical profiling and measurement. The resistivity method can get high-density sample, have imaging properties on two-dimensional geo-electric cross section, also intuitively reflect the medium change of different underground properties, and also shows the depth and characteristics of anomalous bodies [2, 11~12]. Therefore, it should be satisfied for comprehensive investigation method that there is difference in flexibility and electricity for refractive wave when the target and surrounding ground is investigated.

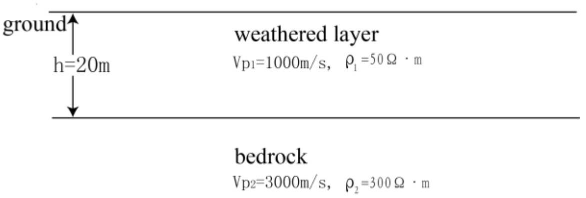


Figure 1. One horizontal layered geo-model

As indicated in Fig .1, there are two horizontal layers below the ground surface. The resistivities on each level are $\rho_1 = 50\Omega g m$ and 300 $\rho_2 = 300\Omega g m$ respectively. The wave speed is 1000 m/s and 3000 m/s. The thickness is 20 m and infinity. The electric current is I.

A. Direct calculation

1) one-dimension direct simulation

Directive wave is an earthquake wave that transmitted directly from the hypocenter to each acceptance point at a speed of v1 without any reflection or refraction. When the hypocenter lies near the ground surface and the observation is along the longitudinal measuring line, the time plot equation [3] is:

$$t = x / v_1 \tag{1}$$

Furthermore, if it is a single leveled refractive layer, the time plot equation of refractive wave is:

$$t = \frac{x}{v_2} + \frac{2h}{v_1}\cos(a\sin\frac{v_1}{v_2}) \tag{2}$$

If the reflective interface is parallel to the ground surface, the time plot equation for reflective wave is:

$$t = \frac{1}{v_1} g \sqrt{4h^2 + x^2} \tag{3}$$

Applying Eq. (1) ~ (3), numerical simulation is performed when h = 20 m, Vp1 = 1000 m/s, Vp2 = 3000 m/s. The simulation curve for directive wave, refractive wave and reflective wave and time plot curve can be obtained finally, which is indicated in Fig .2 and Fig .3.

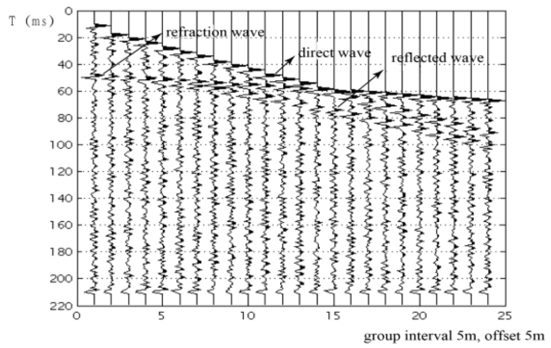


Figure 2. Numerical simulation for seismic direct wave, reflective wave and refractive wave in a si--ngle horizontal geo-model

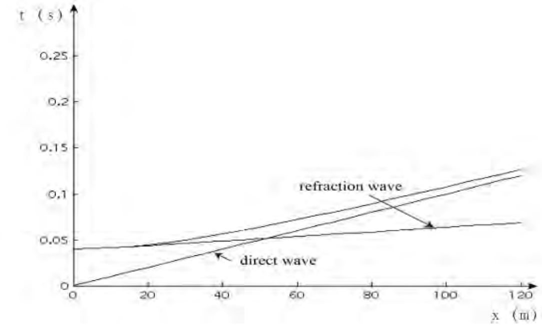


Figure 3. Time plot curve for direct wave, one-horizontal layered refractive wave and reflective wave

2) The direct simulation for 1-D model explored by high density resistivity method

From the equation in the journal [5] (1-105 ~ 1-109), the electric potential for point-source electric current on the ground surface (Z = 0) can be derived as:

$$U_1(r,0) = \frac{\rho_1 I}{2\pi}\int_0^\infty [1+2B(m)]J_0(mr)dm \tag{4}$$

The ρ_s expression for symmetrical quaternary depth finder ($MN \to 0$) is:

$$\rho_s(r) = r^2\int_0^\infty T_1(m)J_1(mr)mdm \tag{5}$$

where $T_1(m)$ is resistivity transfer function, $T_1(m) = \rho_1[1+2B(m)]$, and $B(m)$ is kernel function. In Eq. (5), the resistivity transfer function can be derived from digital filtering method, which is:

$$T(k\Delta x) = \sum_{i=-\infty}^{\infty} \rho_s'(i\Delta x)a[(k-i)\Delta x] \tag{6}$$

In Eq. (6), $a[(k-i)\Delta x] = \int_{-\infty}^{\infty}\frac{\sin\frac{\pi s}{\Delta x}}{\frac{\pi s}{\Delta x}}J_1'[(k-i)\Delta x - s]ds$ is called filter factor.

If $r = e^x, m = e^{-y}$ and $T(y) = T_1(e^{-y})$ and $\rho_s'(x) = \rho_s(e^x)$ the resistivity is changed to a faltung form: $\left.\begin{matrix}\rho_s'(x)=\int_{-\infty}^{\infty}T(y)b(x-y)dy \\ b(x-y)=J_1(e^{x-y})e^{2(x-y)}\end{matrix}\right\}$ and discrete sampling is done, Equation (5) can be derived into another form:

$$\rho_s'(i) = \sum_{i-k=l}^{L} T(k)b(i-k) \tag{7}$$

where the filter factor is $b(i-k) = \int_{-\infty}^{\infty}\frac{\sin\frac{\pi s}{\Delta y}}{\frac{\pi s}{\Delta y}}J_1[(i-k)\Delta y - s]e^{2[(i-k)\Delta y - s]}ds$.

when $\rho_1 = 50\Omega g m$, $\rho_2 = 300\Omega g m$, $h = 20m$, $h_2 \to \infty$, $\rho_s'(i)$ can be obtained using digital filtering method. Moreover, T(y) can be calculated. Finally the

ρ_s theoretical curve can be obtained using digital filtering. The apparent resistivity curve is shown in Fig .4. The imaging is performed using Res2dinv software and finally the direct simulation curve is found in Fig .5.

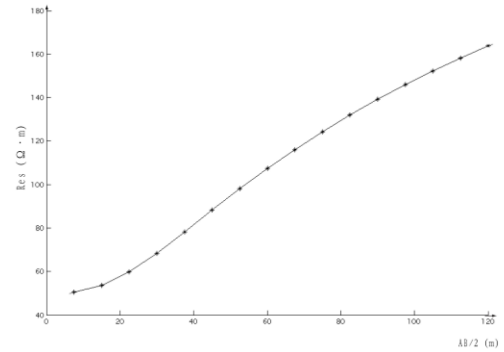


Figure 4. The apparent resistivities curve under the single-layered geo-model via high density resistivity method.

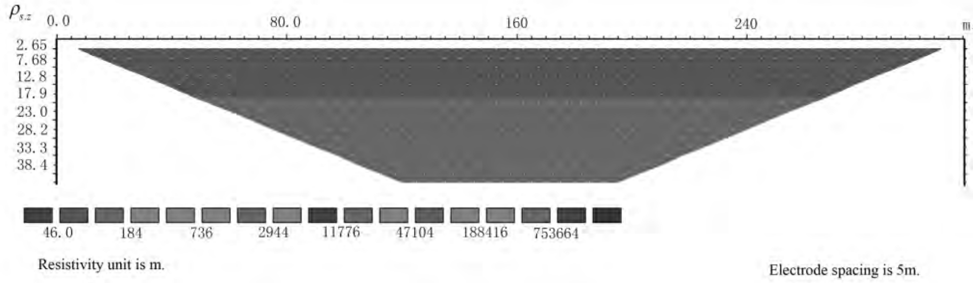


Figure 5. The direct simulations curve under the single-layered geo-model via high density resistivity method.

B. The data interpretation and inversion modeling

There are many data interpretation methods for seismic refraction, such as geo-metrograph by Hagedoom, Hales diagram, delay time method, interception-time method, Palmer generalized exchange method. The article adopts the t0 method in the meeting observation system and makes the data interpretation to the refractive wave in Fig .2, and thus h1 = 19.8 m. In addition, as observed in Fig .5, h2 = 19.3 m. The thickness for weathered layered are consistent to h = 20 in this model.

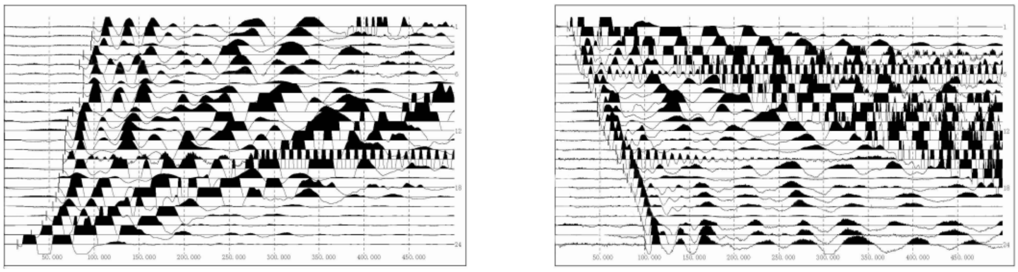
III. Result and Analysis

The investigation zone lies in the Ji'an section, Xia Lin Line that is frontier defense road. The project is to make a geological prospection on in-line tunnel construction.

The ground in this area is mainly composed of ignimbrite and overlying quaternary system. The higher the weathering level is for ignimbrite, the larger the thickness of covering layer changes in a lateral direction. The buried depth of bedrock usually ranges from 18 to 35 meters, and the velocity of longitudinal wave is around 2500~3900 m/s; the velocity of longitudinal wave in the superstratum changes from 500 to 1800 m/s. As a result, a velocity interface is well-defined between the bedrock to superstratum, which serves as prerequisite for detecting buried depth in the bedrock as well as structural configuration in seismic refraction. The resistivity of bedrock layer is relatively low, for which apparent value is usually 40~500Ω·m. The quaternary system is mainly distributed in some cleuch and foot slope, which is characterized as a loosely composed structure of graveled loam and loam sandy clay. The resistivity changes very significantly.

The detection has adopted NZ24 shallow layer seismograph. An explosive is selected as seismic in the exciting point of the hypocenter. Besides, a 38 Hz discriminator is applied a system to trace and detect wave signals. By making comparison in field investigation, the working parameters are: Maximum track pitch 10m, offset 5m, record length 1024 ms, sample rate 0.5ms. Fig .6 illustrates the original seismic wave form collected under the working parameters.

Moreover, seismic refraction processing software is adopted to process the original recorded data and obtain a group of initial value; the time graph for refractive wave is obtained by Grapher. The graph can be further interpreted using t0 method. Finally, the velocity and depth profile for refractive layer can be drawn by Auto Cad, as seen in Fig .7.



（a）shot locats at the trumpet from the east of the line （b）shot locats at the large size from the west of the line

Figure 6. The original record chart of seismic refractive wave

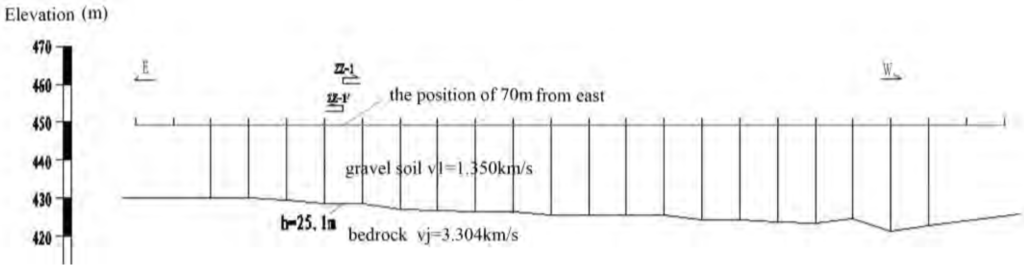


Figure 7. The resulting figure about the speed and depth of seismic refraction layer

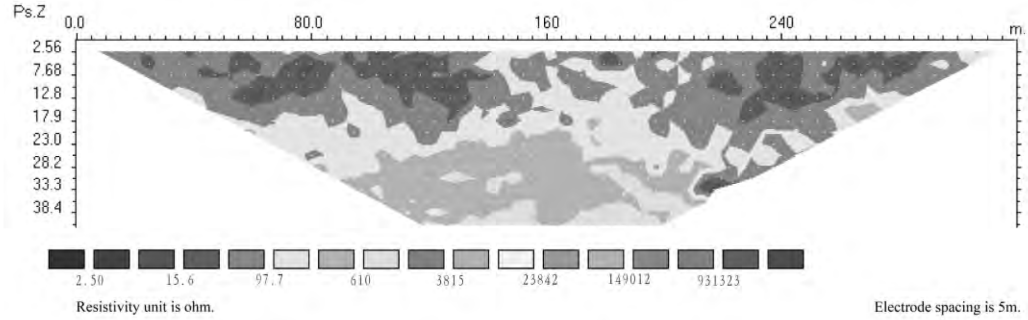


Figure 8. The forward chart of high-density resistivity method

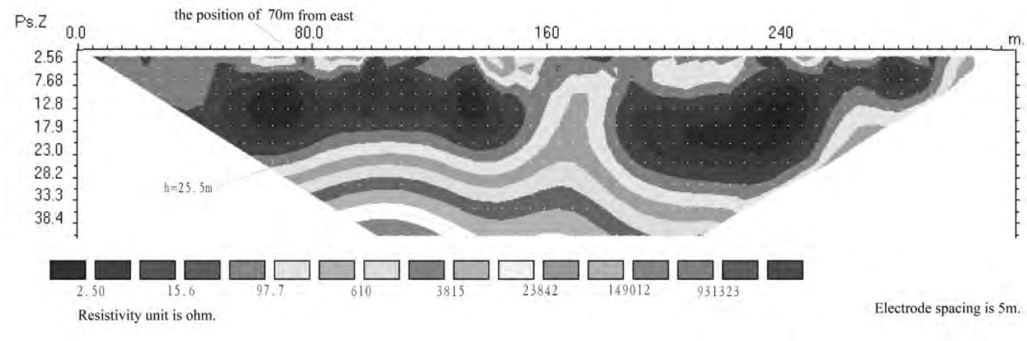


Figure 9. The inversion chart of high-density resistivity method

However, high-density resistivity method will apply Jiao Peng E60D electrical instrument. The winner operation is selected with 10-meter electrode spacing. After resistivity value under different electrode spacing is collected, data processing is performed by Res2dinv to get the inversion chart, as illustrated in Fig .8 and Fig .9.

It is found from seismic refractive chart (Fig .7) that, the buried depth of covering layer from east 70 meters is h_1 =25.1m. However this value is 25.5m for high-density resistivity chart in Fig .9 The two charts are approximately the same with minimal error. Moreover, both two charts show a gradual increasing buried depth from east to west.

IV. CONCLUSION

The theoretical basis for comprehensive investigation method is set by one-dimensional data simulation using seismic refraction and high-density resistivity technique. The shallow seismic refraction is based on the positive difference in wave velocity between bedrock and superstratum. High-density Resistivity method is based on the difference in electrical properties between target and wall rock. Hence both should be satisfied for comprehensive investigation technique. It is also found that refractive method can delineate the bedrock interface with high prospecting precision but only reflect the surrounding area of bedrock surface. As for high-density resistivity method, it can determine the change in electrical properties of the rock in different underground depth, but the precision is very low. Therefore, these two methods can synergistically work with complementary advantages.

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