The Application of Shallow Seismic in the Exploration of Aeolian Sand Strata

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Abstract: Shallow seismic exploration has significant application effects in terms of bedrock surface and underground structure exploration, detection of underground cavities and unfavorable geological bodies. It is a scientific and economical technical method to provide basic information of feasibility study and engineering planning for site selection of highways, airports and high-rise buildings. Taking the pre-selection of a tunnel project in Gansu as an example, this paper elaborates on the interpretation methods and techniques of the shallow seismic exploration data processing in the aeolian sand stratum based on the geophysical characteristics of the work area. Generally speaking, the interpretation results are highly consistent with the drilling results and can be applied to engineering surveys in similar strata.

1. INTRODUCTION
With the development of science and technology, people have more strict requirements for important engineering construction. It is usually necessary to understand the thickness of the Quaternary cover, the burial depth of the underlying rock surface and the undulating shape of the interface, the distribution characteristics of rock-soil layer and its geophysical properties. At the same time, the location, scale, and the feature of the unfavorable geological bodies such as concealed structures and landslides should also be identified. These data will provide reliable geological basis and geophysical parameters for designing¹, and then the comprehensive survey and evaluation should be followed up. Shallow seismic exploration have the following characteristics: high resolution, large depth range, and intuitive results. It can also provide continuous section or area engineering design parameters, geological information, and save a lot of funds on engineering drilling. Considering these obvious advantages, this method is applied in various infrastructure construction², especially in the aspect of bedrock surface, underground structure exploration, underground cavity and poor geological body detection. It is one of the most important and most commonly used methods in hydrogeology, engineering geology and geophysical prospecting³. At the same time, this method is also one of the important methods for the division of shallow underground structures. It can offer continuous detection and its resolution is high. The underground longitudinal wave velocity can be obtained and analyzed to obtain a continuous geological section⁴. This not only facilitates the use of multiple coverage techniques to suppress interference, improving the signal-to-noise ratio of seismic data, but also utilizes the rich reflection wave group features on the reflection profile to determine subsurface anomalies and their basic parameter characteristics⁵. This paper takes the pre-selection of a tunnel project as an example, which is located in the pre-desert area of the northern foot of the Dunhuang Mogao Grottoes in Gansu Province. By understanding the geophysical characteristics of the field, the
interpretation method of processing the shallow seismic exploration data in the aeolian sand stratum are described in detail.

2. GEOLOGICAL OVERVIEW AND GEOPHYSICAL CHARACTERISTICS OF THE WORK AREA

2.1 Geological Overview
The work area is located in the desert area of the northern foothills of the Mogao Grottoes in Dunhuang, Gansu Province and is piedmont molasse deposition. The upper lithology is sandy soil and sub-soil layer. The conglomerate is argillaceous-arenaceous/calcareous cemented or semi-cemented, and the lower lithology is gray conglomerate and glutenite. The gravel has a good psephicity and is tapered from the front of the mountain. Unconformity contact with the underlying formation angle and suffering wrinkling and breaking to a certain extent.

2.2 Geophysical Properties
Geophysical exploration studies geological structure and solves geological problems through physical principles. The difference in formation physical is a prerequisite for geophysical exploration. Therefore, it is the key point to collect and study physical parameters of the rock and analyze the difference of the physical parameter, and then to choose the best geophysical exploration method. By collecting and verifying the drilling logging parameter data in the work area and the physical data of the shallow elastic wave velocity of related stratum, the scientific basis are provided for the selection of effective geophysical exploration method and interpretation of geophysical geological inference and interpretation (Physical Property Parameter Statistics Table 1~3).

| Layer                  | Elastic Wave Velocity (m/s) | Density (g/cm³) | Resistivity (Ω·m) | Remarks                                      |
|------------------------|----------------------------|-----------------|-------------------|---------------------------------------------|
| gravel, pebbles        | ≥2000~3000                 | 2.2~2.5         | ≥800              | 80~400 good cementation (possible with boulder) parameter values increase |
| gravel                 | 1000~2000                  | 2.2~2.4         | 400~800           | 100~200                                      |
| gravel sand            | 800~1200                   | 2.0~2.2         | 200~600           | 80~200                                       |
| sand and sub-sand interbed | 400~800                | 1.6~2.0         | 80~200            | 60~150 gravel-bearing electrical property and density value increases |
| fine sand and sub-clay interbed | ≤500                 | 1.5~1.7         | 20~100            | 10~80 dry, loose, and resistivity ratio is increased |

Tab.2 Specific resistance of Quaternary Substratum

| Geological Age | Major Lithology | Density (g/cm³) | Resistivity(Ω·m) | Remarks                                      |
|----------------|-----------------|-----------------|------------------|---------------------------------------------|
| Tertiary (N)   | mudstone, fine  | 2.05~2.35       | 10~25            | glutenite Resistance Ratio 100~150         |
sandstone

| Lithology | Wave speed (m/s) | Resistivity (Ω·m) | Density (g/cm³) | Remarks |
|-----------|-----------------|-------------------|----------------|---------|
| Dry and loose sand | ≤1250 | 200~275 (Median 250) | 1.8~2.2 (with gravel) | Surface aeolian and alluvial sand with gravel |
| Yellow sand layer (fine, medium, thick) | ≤1250 | 25~85 (Median 50~60) | 1.9~2.25 | |
| Gravel yellow sand layer | 1333~2222 | 85~140 (Median 100) | >2.25~2.4 | |
| Sub-sand layer | 1200 | ≥5~30 (medium≤25) | 2.15~2.3 | boulder≥2.7 |
| Gravel layer | 2000~4000 | 100~250 (Median 150) | 2.5~2.75 | |
| Sand and sub-sand interbed | 1333 | ≤25~75 (Median 50) | 2.1~2.35 | |

The above physical parameter statistics of the work area reflect the following physical characteristics:

1. There are differences in elastic wave velocity, resistivity and density between the Quaternary geotechnical layer and the underlying old stratum. The division of the Quaternary and underlying old stratum could be applied to seismic, electrical and gravity method. Among them, the difference between wave velocity parameters and electrical parameters is obvious.

2. The geotechnical parameters in the Quaternary are changed due to lithological changes. The main factors causing the change of physical property parameters are the granularity, structure, compactness and dryness of the rock-soil layer. When the particles of the rock-soil layer change from fine to coarse, the wave velocity, resistivity and density value gradually increase. However, there is an exception: dry and loose sand-soil layers generally have an increased electrical resistivity.

3. The results of previous geological survey and drilling verification results reflect that there are great changes in Quaternary geotechnical layers lithology of this area. There is also an obvious stratification. From the analysis of the main characteristics of physical parameters, the results of...
seismic exploration are more intuitive and easy to be indentified. Electrical exploration also can be used as an aid.

Through the analysis of geophysical characteristics and the consideration of the exploration task, the shallow seismic high-resolution seismic exploration is selected. The reflected wave method is the main method, and the refracted wave and surface wave method are served as an aid. Such combination could afford maximize access to information and the information could be mutual verified to improve the effect of the geophysical exploration.

3. FIELD DATA COLLECTION

3.1 Field Work Arrangement
The shallow seismic exploration mainly adopts seismic reflection method, supplemented by refraction method. On the basis of mapping and obtaining the coordinates and elevation of the seismic exploration section point, the shallow seismic reflection profile is arranged (seismic big-refraction: long spread, long distance excitation; seismic small-refraction: short spread, short distance excitation). A total of six seismic reflection profiles were arranged to investigate lithologic stratification and underground geological structure. The large refraction section of the seismic not in the same area as the seismic reflection survey. The large refraction seismic line is arranged in the valley of the work area. The section is arranged along the ditch in the north-south direction. The main purpose is to detect the underground lithology stratification of the gully and understand the underground burial depth. Then compared with the reflection data to mutually confirmed the data. The small refraction seismic exploration points are arranged on the representative points of the seismic reflection profile. The purpose of arranging small refraction detection is to investigate the distribution of thickness and velocity variation of the low-speed belt in the work area.

3.2 Working method and technical parameter selection
(1) Instrument: R48 high-resolution digital seismograph produced by Geomitris, USA;
(2) Detector: SSJ ~ 60 (natural frequency 60Hz), a combination of sensitivity areas such as six detectors;
(3) Observing system: 0~10~470~10, the offset distance:10m, the group interval:10m, the arrangement length:470m, the maximum offset: 10m, the stacking fold numbers:24
(4) Excitation well depth: single well excitation, 5m;
(5) Quantity of explosive: 1kg;
(6) Instrument factors: sampling rate 0.5ms, preamplifier gain 36db, recording length 2s, broadband reception without filtering.

4. DATA PROCESSING AND INTERPRETATION
Computer-processed seismic profile data requires comprehensive interpretation and inference of geology and geophysical. The results must be consistent with the actual situation[6]. Due to the characteristics such as thick low speed belt, low seismic wave velocity, large absorption coefficient, and fast wave attenuation and large loss of frequency component, the following treatments are mainly carried out according to the actual situation:
(1) Data decoupling and observing system definition. The original seismic data are recorded into the seismic processing system. According to the construction record and measurement results, the geometric relationship of the field single shot is accurately defined into the processing system.
(2) Static correction analysis and calculation. The static correction is performed based on the results of the low speed reduction zone measured by the small refraction (see Table 4, 1: 1:3480, 2:1480, 3:1230 are the intersection of the three lines). Static correction and velocity response have a great influence on the processing results. In order to increase the signal-to-noise ratio by CDP, the phase of the reflected wave is not allowed to have large deviations, especially static correction. Because the original phase-difference is large, the correction volume especially needs to be
determined to improve the analysis accuracy\cite{7}. For the single shot of the seismic, the reflection hyperbola is obvious (as shown in Figure 1(a)). For the CDP trace gathers, a clear reflection hyperbola can be also seen (as shown in Figure 1(b)).

| Line Number | Station Number | $V_0$ (m/s) | $H_0$ (m) | $V_1$ (m/s) | $H_1$ (m) | $V_2$ (m/s) |
|-------------|----------------|-------------|-----------|-------------|-----------|-------------|
| 1           | 2340           | 497         | 26        | 1068        | 33        | 1700        |
|             | 3480           | 622         | 27        | 986         | 33        | 1700        |
|             | 1480           | 622         | 27        | 986         | 33        | 1700        |
| 2           | 2990           | 762         | 31        | 1193        | 72        | 2880        |
|             | 4480           | 692         | 21        | 1124        | 69        | 2300        |
|             | 1230           | 622         | 27        | 986         | 33        | 1700        |
| 3           | 2215           | 500         | 17        | 678         | 24        | 1670        |

(3) Waste track editing and pre-stack noise attenuation. The waste track editing is eliminating seismic tracks that are heavily disturbed by noise or bad tracks. In addition, from the analysis of the noise on the seismic record, it can be found that the reflection area of the target layer is basically covered by the surface wave, refracted wave and the multiple refracted wave. It is difficult to see a clear reflection event. The difficulty in suppressing these noises lies in the following problems: the number of transverse tracks is small, and the apparent velocity of distance track is close to the reflected wave. To solve the problem, wavelet transform, linear correction, frequency-divided noise analysis and other techniques are used to separate and suppress noise. A good pre-stack denoising effect was finally achieved (Figure 2).
(4) Amplitude compensation. The spherical diffusion compensation and the surface uniform amplitude compensation are used to compensate the energy loss during the seismic wave propagation, and to eliminate the difference of the excitation energy between shots caused by the surface factors. In this way, the relative strong-weak relation of the reflection layer is well maintained in space, which brings convenience to geological interpretation.

(5) Speed analysis. According to the transformation of the topography and the reflection layer, the tract-change super-gather is flexibly used to form the cross-correlation velocity analysis spectrum, thereby obtaining a more accurate speed trend. At the same time, the speed fine adjustment is performed with reference to the linkage transformation of the superposition segments above 30 CDP points with the speed. Because the pre-stack denoising effect is good, the energy difference between the reflected wave and the multiple reflected wave can be well recognized. Therefore the influence of multiple reflected waves is well avoided in the speed picking process (Fig. 3).
(6) Anisotropic velocity analysis and high-order dynamic correction. Due to the shallow layers of the study, after the velocity analysis and picking, there must be a huge amount of stretching in the distant event. At the same time, the shallow deposition also determines the existence of anisotropy. Therefore, it is necessary to perform anisotropic analysis and high-order motion correction to reduce the amount of stretching and make more tracks in superposition.

(7) Dispose of the resection. Under the premise of accurate speed, the amount of resection volumes is an important factor affecting the superposition effect. The number of tracks participating in the superposition near the surface is very small, usually only 1 to 5, and if all are resected, the reflection information of this part could not be obtained. If the resection is less, it is easy to introduce the initial value of the far offset or the direct wave into the superposition result, and these samples are stretched. So that the obtained low-frequency event is not accurate. When the resection amount is appropriate, it is possible to obtain an event with a high frequency reflecting the characteristics of the near surface.

(8) Residual static correction. After superposition, selecting a stable reflection layer and referring the automatic residual static correction amount can further eliminate the static correction effect of the very shallow layer and improve the imaging of the profile.

(9) Multiple speed analysis. After the residual static correction, the relationship between the velocity and the reflection structure is repeatedly studied with reference to the superposition profile. The accurate velocity field distribution could be gradually obtained, thereby obtaining the final velocity scheme.

(10) Final stacking. The final velocity scheme is applied and the final stack section is obtained through the superimposing.

(11) Post-stack noise elimination. Most linear noises, such as multiple refractions, cannot be completely eliminated before stacking. Obvious noise interference can still be seen on the post-stack profile. Therefore, it is necessary to eliminate linear noise and random interference after stacking, and improve the signal-to-noise ratio of the profile.

(12) Time-depth conversion. After a certain smoothing of the final stacking velocity field, the root-mean-square velocity is obtained by the DIX formula. Through conversion, the average velocity can be obtained, and then the depth profile can be obtained through time-depth conversion.

(13) Trace-integration of time and depth inversion processing. The time and depth profiles are separately trace-integrated, and the time integral profiles of the time domain and the depth domain are obtained for preliminary lithologic inversion interpretation.

(14) Synthetic seismic record production and SEGY format output of logging data in adjacent work areas. The corresponding layer velocity curve can be obtained from the density curve of the logging data collected from the adjacent work area. Since the depth is known, the interval transit time curve can be obtained. Therefore the reflection coefficient curve is obtained. Given a minimum phase RICKER capital that is close to the dominant frequency of the reflection target layer, a synthetic
The seismic record corresponding to the well is obtained. Then the seismic data is outputted in standard SEGY format.

(15) Seismic section drawing. Draw the trace-intersection inversion color profile of time and depth. Draw the time-depth profile of survey line intersection, velocity, elevation, time of processing the reference plane.

5. RESULTS CORRECTION

The results of geophysical have multiplicity of explanations. That means there are many uncertain factors in the geological interpretation of geophysical prospecting results. The best way to eliminate the multi-explanation is to adopt a comprehensive method as much as possible to obtain a comprehensive comparative analysis of various geological information, finding out the internal rules through cross-reference to achieve a consistent interpretation of geophysical exploration results.

Two geological exploration holes were arranged in the north and south of the seismic exploration section of the work area to identify the stratification and lithology of the Quaternary. It is found that there is an intrinsic relationship between the seismic results, geological data and logging physical parameters, which provides a basis for geological interpretation of seismic exploration results. With the density, velocity, and converted wave impedance, the layer velocity is obtained through the Gardner empirical formula \( V_n = k \rho^{0.25} \). Thus the reflection coefficient \( K = (V_2 - V_1)/(V_2 + V_1) \) can be calculated. The wavelet is obtained according to the reflection coefficient and the seismic data collected by the field, and then the artificial synthetic seismic record of the corresponding well is prepared—this is, a one-dimensional earthquake model. The No. 2 geological exploration hole is located on the profile line, and the geological phase, seismic face and logging phase are in the same time domain, which is conducive to the geological interpretation of seismic exploration results. Through the comparative analysis of the shallow seismic line depth profile and the No. 2 borehole geological histogram (Fig.4), the macroscopic understanding of the seismic exploration results in this area is basically consistent with the drilling verification results. From the microscopic analysis, the inference and explanation of lithology stratification is highly conformed with the stratigraphic stratification of the borehole geological histogram.

\[ \text{Fig.4} \quad \text{Shallow seismic depth profile and drilling histogram chart} \]

6. CONCLUSION

Through the seismic exploration and data interpretation of the aeolian sand in this area, it can be concluded that:

(1) The interpretation of shallow seismic data is based on the multi-parameter, multi-faceted, and multi-functional, and the processing range is expanded. These new information provide a reliable scientific basis for inference and explanation of seismic exploration.

(2) This shallow seismic exploration has more accurately identified the thickness of the Quaternary overburden layer, the thickness of the aeolian sand stratum, and whether there are hidden faults, bad
engineering geology, etc. These works provide reliable information for engineering design and feasibility study.

(3) The appropriate shallow seismic exploration method can effectively and quickly solve the actual engineering problems. It can also shorten the construction period and save costs.

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