Subsurface space investigation jointly using seismic reflection and refraction tomography in urban area: a case study of Hangzhou, China

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Abstract. Seismic reflection method is one of the commonly used techniques in urban underground space exploration. However, in some areas, the effect of reflection seismic exploration is limited because of the difficulty of interpretation. In this paper, seismic reflection exploration and refraction travel time tomography are jointly used in Hangzhou to increase detection accuracy. The results show that different layers can be discerned for Quaternary sedimentary. The combined use of the two methods has obvious advantages and good practical value.

1. Introduction
The near surface seismic records usually contain much information, such as reflection and refraction wave, but they are seldom used together. The reflection wave method is based on the difference of wave impedance of different layers. It has strong stratification ability. The reflection information contains the underground formation shape and can effectively detect the concealed structure, but its detection precision is limited for the ambiguity of the interpretation [2,3]. The refraction wave exploration is simple and effective, and the thickness and P-wave velocity of each layer can be obtained through inversion and tomography technologies [1]. But when the formation velocity is reversed, low velocity layer cannot be imaged. Yang et al. [3] applied high-resolution refraction tomography in shallow reflection exploration failure area. But data acquisition is carried out separately, which increases the workload and exploration cost. In the study, we performed seismic reflection and refraction exploration by acquiring data using the same seismic array. After processing seismic data, joint interpretation was finished. The results show that it can make up for the defect of single method and improve the exploration accuracy.

2. Reflection method
200 sets of NSEIS-A1 node seismometers are used for field data acquisition, and 20dx-100 geophones with natural frequency of 100 Hz are connected externally. Figure 1 shows the distribution of shot point and geophone. The geophone is installed in the vertical direction, which is in close contact with the ground. In the two-dimensional measurement, linear equal channel spacing (channel spacing of 2.5 m) is adopted, with 500 observation points and 1.25 km measuring line. The mechanical ramming source is used as the reflection and refraction source. The distance between shot points is 5m. The coordinates and elevations of physical points are measured by real-time differential positioning (RTK),
and the positioning accuracy is centimeter level. In the process of reflection data processing, 60 shot records per shot are used, with zero offset.

In this paper, the methods of static correction, removal of interference wave, amplitude recovery and compensation, expansion of panel comparison, and surface consistent deconvolution are used to process the seismic reflection records acquired in the field, and to preliminarily interpret the reflection seismic section.

3. Refraction travel time tomography
Refraction travel time tomography uses the same seismic records as the reflection method. The refraction travel time tomography inversion first defines an inversion objective function, and then uses the optimization method to obtain the extreme point of the objective function, so as to obtain the best inversion model. Firstly, based on the geostatistical variogram theory, the inversion objective function term of the prior structure information constraint of well data is established and added to the seismic inversion objective function. Then, the joint inversion objective function with structural constraints is solved, which is based on L2 norm. Finally, the gradient type inversion method is used to optimize the iteration, and the velocity inversion model under structural constraints is obtained.

4. Joint interpretation of reflection and refraction results

Figure 2 is the interpretation map of reflection seismic section. The direct result of reflection processing is presented in the form of in-phase axis continuity. Its abscissa is the unit of line X (m), and its ordinate is two-way travel time t (MS). The results of well constrained first break travel time
tomography are presented by the velocity structure distribution from the surface to a certain depth under the ground with the maximum offset. The propagation speed of seismic wave in the underground is related to the nature and distribution of the underground medium. Therefore, combining with the geological data, we can infer the change information of the medium in a certain depth of the underground. The application of the two methods is closely related to the velocity of underground medium, which is an important physical parameter reflecting the transformation of underground lithology and structural distribution. Therefore, the two methods have sufficient theoretical basis for joint interpretation.

Figure 3. Speed structure diagram

Figure 4. Geological section

The topography in this survey area changes greatly in the transverse direction. The Quaternary overburden in the survey area is very thin, under which there is weathered gravel layer, and the underlying bedrock is mainly argillaceous siltstone. The elastic properties of the underground media in the survey area are quite different, which is the basis of shallow seismic exploration. In the survey area, the surface conditions of survey line layout vary greatly, including soil road, gravel road, cement hardened road and other types, and the receiving conditions of seismic waves vary greatly. The gravel layer in the survey area absorbs part of the source energy. Figure 3 shows the velocity structure of tomography inversion. Therefore, there are still some fine layers on the reflection seismic section that cannot be described, but these small layers can be described on the velocity structure map after the travel time tomography inversion. For example, the thickness of T6 wave group in the reflection seismic section is 40.05 m, but it still contains pebble layer, silty clay layer, completely weathered and strongly weathered argillaceous siltstone and other small layers. On the reflection seismic section, the direction and interface of these fine layers are not clearly depicted, but the structure diagram of junction velocity, we can clearly refine T6 wave group into pebble layer and silty clay sandwiched layer There are three small layers of silty sand, completely weathered and strongly weathered argillaceous siltstone, and the clear velocity interface stratification and the trend of horizontal upper layer can be obtained. In the description of the stratum in the shallow part of 50 m, the reflection seismic section depicts the distribution of the thin layer more carefully. For example, the thickness of the velocity structure map of the tomography inversion at the T2 layer is 9.3 m, but in fact, it still
contains the interface of plain fill, silty soil layer, silty sand and silty clay layer. Through the tracking
of the same phase axis, the reflection seismic section can more clearly describe the boundary within 50
m. The shallow strata are carefully depicted. Through the comprehensive analysis of the reflection
seismic section and the speed structure diagram after the first arrival travel time tomography inversion,
this work has a more comprehensive and detailed description of the near surface strata. The resulting
geological section is shown in Figure 4.

5. Conclusion
The resolution of the surface is not high because of the heterogeneity and low velocity of the surface
or shallow layer. The first break travel time tomography method can obtain reliable surface velocity
structure data by inversion in the shallow part with dense ray distribution, so as to infer the change of
underground medium structure and provide information for the strata and geological structures from
the surface to the shallower part. However, the reliability of inversion results is reduced because of the
sparsity of ray distribution in the deep. First break travel time tomography can also provide more
accurate and intuitive information for the buried depth of horizon boundary through the change of
velocity. In the joint interpretation, the advantages and disadvantages of the two methods can be
combined for comprehensive interpretation. The joint interpretation of the two methods has achieved
good results in the practice of Xiasha area in Hangzhou area, and made up for the existing problems in
the exploration of a single method, so the joint exploration method has practical significance and
needs.

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