Application of Large Tonnage Vehicle-Mounted Vibrator Source in the Exploration of Underlying Xi'an Ground Fissure

- Take Xi'an Metro Line 6 as An Example

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***Abstract*—How to overcome the urban interference, especially to suppress day and night traffic vibratory noise in underlying Xi'an ground fissure exploration has been a difficult problem for shallow seismic prospecting in engineering purpose. Based on in Xi'an Metro Line 6 engineering, we try to use large tonnage vehicle-mounted vibrator source to suppress strong traffic noise, and wish to determine the location and extension of Xi'an ground fissure in information blank area with seismic reflection prospecting.Through the research works, we draw the following conclusion. Large tonnage vehicle-mounted vibrator source can effectively suppress the urban traffic noise and subsurface reflection horizons information can be obtained accurately. Seismic exploration has high credibility to determine Xi'an ground fissure. The locations determined by the seismic exploration coincide with those determined by the geological drilling very well. Using large tonnage vehicle-mounted vibrator source in prospecting underlying Xi'an ground fissure is feasible.**

Keywords—Xi'an ground fissure; vehicle-mounted vibrator; seismic source; seismic exploration

I. INTRODUCTION

Xi'an ground fissure is a special urban geological disaster, and its destructive power is unprecedented. After more than 3 decades research, Xi'an ground fissures formation mechanism and characteristics has been clarified. Xi'an ground fissures are a group of secondary faults of Lintong-Chang'An fault zone. Large-scale groundwater extraction cause difference subsidence on two sides of these secondary faults, and then ground fissures are formed. As result, they cause a series of disasters such as road, bridge, and civil construction facility damage[4][6].

In exploration of the underlying Xi'an ground fissure, the seismic reflection method has achieved successful experience [1][5], and has been accepted by its high accuracy. With the increasing of the vibration noise caused by urban traffic and city engineering, however, the most difficult problem is to suppress the noise in the seismic exploration. In order to overcome this problem, we introduce the large tonnage seismic vibrator source, successfully used in petroleum exploration, into Xi'an ground fissure exploration. For a known ground fissure, we made an experiment and achieved good results [5]. Basis on these achievements, we try to employ the vibrator source in the exploration of underlying Xi'an ground fissure for southwest section of Xi'an metro line 6. This area, at present, is almost a suburban countryside, and also an information blank area in the study of Xi'an ground fissure. Although there are above successful experience, it still has unknown challenges to accurately determine the positions of Xi'an ground fissure in a stretched gap area.

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II. FIELD DATA ACQUISITION

A. Site Location and Geology

The southwest section of Xi'an Metro Line 6 begins from southwest corner of 3rd ring road of Xi’an city, and goes along Yadi Road, then along Xitai Road straight ahead, and finally turns right to the South Railway Station. Along metro line 6, the known Xi'an ground fissure is f8, located at southwest corner of 3rd ring road. Southward from there, Xi'an Metro Line 6 is far from the known Xi'an ground fissures area (see Fig. 1). In order to ascertain Xi'an ground fissure situation in this unknown region, we designed seismic exploration scheme. The exploration line is about 9 kilometers, goes along Yadi Road and Xitai Road. The line’s location is shown in Fig. 1.

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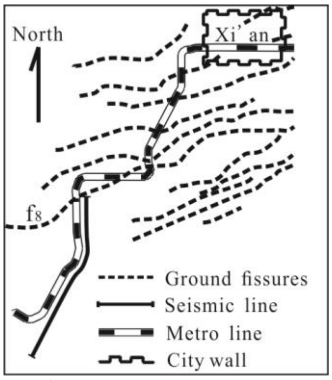


Fig.1 the location of Metro Line 6, seismic exploration line and the distribution of the Xi'an ground fissure

The southwest section of Xi'an Metro Line 6 lies within the Zaohe River and Fenghe River terraces area. The terrain of the area is flat by river erosion. Along the metro line, ground elevation is about 410~420 meters. The strata are Quaternary System with 800~1000 meters thickness. They are composed of river and lake alluvial and diluvia deposits, main components are sand and silty clay interbedded. The phreatic water table is about 10~15 meters deep. Seismic wave velocities of saturated sand and clay layer are about 1600~2200 meters per second.

Yadi and Xitai Road are important trunk roads of southwestern Xi'an city. Vehicle stream on the roads is heavy and there is no lack of large trucks. Therefore, the largest interference for seismic exploration is traffic vibration noise along the survey line.

B. *Data Acquisition*

According to the preceding successful experience (Li et al., 2015), SUMMIT digital seismometers, German DMT company products, were employed in field data acquisition. Seismic source was an 18-ton vibrator truck, model M18/612, Metrz company USA. The source scanning parameters are 30-200 Hertz frequency with 8 seconds duration. The geophone frequency is 60 Hertz, and 3 in a group for one trace. Before beginning of the data acquisition, the zero offset experiment was carried out. Total recording traces is 290 with 3 meters separation. The recording length is 2048 milliseconds, and the zero offset record is shown in Fig. 2.

From Fig. 2, direct waves are clear on whole 290-trace records. Within 600 milliseconds in the record, reflection waves are rich and distinguishable in range of 1-200 traces. According to the zero offset experiment results, the observation system of the reflection wave data acquisition is set as follows: 3 meters trace spacing, 240 traces, and 24 folds. The source point is set inside the spread with asymmetric excitation mode. There are 80 traces on the small station number side, and 160 traces on the opposite. The exploration targets of 1st~80th traces are the middle to shallow layer and 81st~240th traces are middle and deep layer. In order to enhance excitation energy, no less than 12 times vibrations are repeated at each shot point.

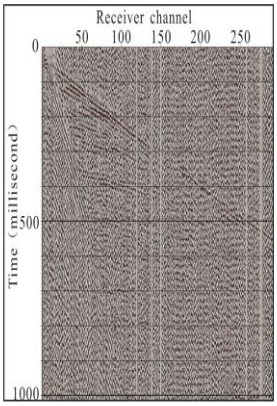


Fig. 2 site zero offset record

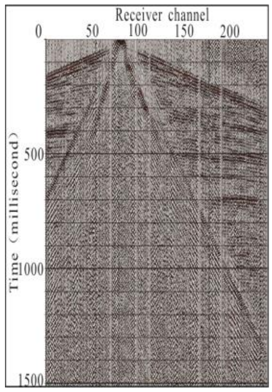


Fig. 3 single shot record

In fact, zero offset experiment lies at the northern end of the whole survey line, where is close to BYD Auto Company. There are heavy interferences caused by large transport vehicles. In subsequent data acquisition area, traffic interference is relatively weaker. The recording data quality is significantly higher than that of the experiment. Fig. 3 is a record lies in middle of survey line. This record shows not only the reflection horizons are richer and prominent than that of experiment shot record, but also the identifiable reflection time is as deep as 1100 milliseconds.

III. Data Processing, Interpretation and Verification

A. *Data Processing*

Because the collected row data has a high signal to noise ratio, the employed data processing are of mainly conventional reflection processing modules. After above data processing, we achieved the horizontal stacking time profile, as shown in Fig. 4.

B. *Interpretation and Analysis*

From Fig.4 we may see there are multiple sets of strong reflection events in the profile within 1000 milliseconds of two-way reflection time. These events represent the subsurface interfaces. The event features show that there are some differences between the middle of the section and the north and south of the section. From 2000 meters to 6800 meters in distance, the interfaces distribute horizontally and the reflection energy is strong. The reflection events can be traced continuously in wide range. Compared with the middle part, the north section smaller than 2000 meters and the south section over 6800 meters are more complex. Their interfaces are piecewise continuous, and the attitudes of interfaces are locally varied. Also there are many faults in the reflection events. According to the interfaces fault characteristics and attitude variation, also in combination with Xi'an ground fissure features, 8 anomalies are determined as potential Xi'an ground fissures. They are marked with F1~F8 from north to south. In addition, the large scale north dipping fault in the south end of the survey line is inferred to be FN, the north fault of the Lintong-Chang'an fault zone [2].

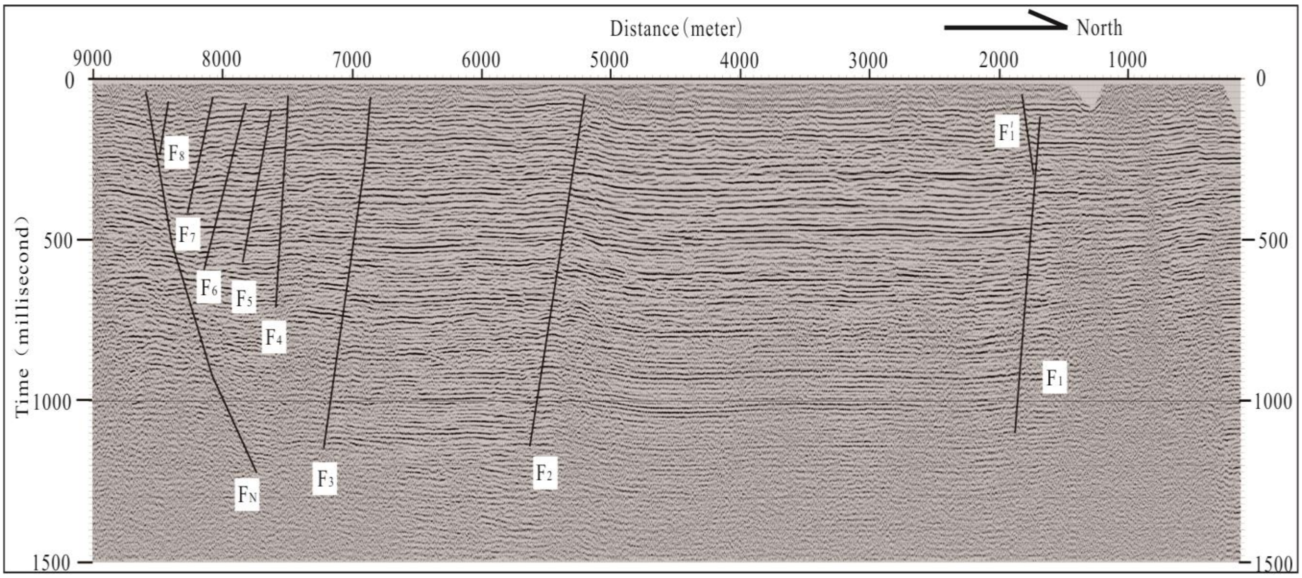


Fig. 4 horizontal stacking time profile

C. Drilling Verification

In consideration of importance of the metro project, the above interpretation anomalies were verified one by one with geological drilling investigation. The drilling investigation lines overlapped with seismic survey line for the convenience of comparison each other. The boreholes, 80 meters in depth, were arranged in range of 150 meters on both sides of seismic anomaly positions. Drilling investigation results for each anomaly are described as follows:

F1 and F1' anomalies: Drilling profile shows that Paleosol layer, more than ten meters deep, is of continuity at F1 anomaly. But Middle Pleistocene series, below about 50 meters deep, is faulted obviously. For F1' anomaly, however, the fault displacement of the bottom of Paleosol layer is 1.5 meters. Below the Paleosol layer is Upper and Middle Pleistocene series. They are composed of alluvial, diluvia and lake deposits and these deposits form sedimentary cycles with coarse-grained facies and fine-grained facies. The sedimentary cycles show discontinuity and thickness variation obviously at F1' anomaly, shown in Fig. 5.

F2 anomaly: Drilling profile illustrates that the Paleosol layer, about 10 meters deep, was faulted up to 4.6 meters within 8 meters width at F2 anomaly. Below the Paleosol layer, Upper Pleistocene and Middle Pleistocene series are of apparent discontinuity and thickness variation. Relative to the hanging wall (northern), the foot wall (southern) declines apparently. And strata of the hanging wall are thicker. They are shown in Fig. 6(a).

F3 anomaly: Drilling profile indicates that two sides of the anomaly have different layer facies. The hanging wall (northern) has only 3 layers of coarse-gained facies relative to 7 layers on the foot wall. The anomaly is obvious as shown in Fig. 6 (b).

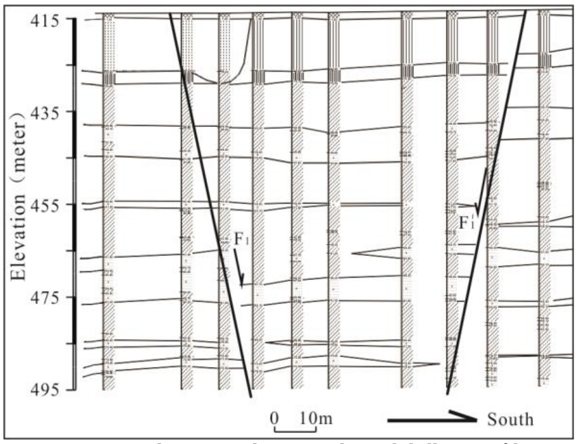
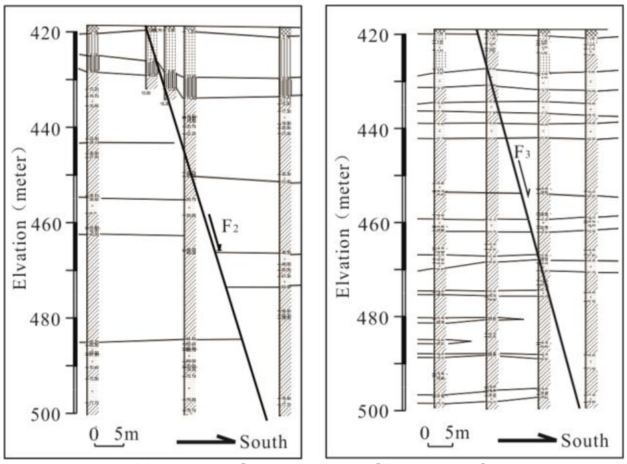


Fig. 5 F1 and F_1' anomalies in geological drilling profile



(a) F_2 anomaly (b) F_3 anomaly

Fig. 6 F_2、F_3 anomalies in geological drilling profiles are of discontinuity and thickness variation. These phenomena are apparent in Middle Pleistocene series, about 50 meters below ground, which are composed of alluvial, diluvia and lake sedimentary cycles with coarse-grained and fine-grained facies.

The seismic anomalies were verified by geological drilling investigation and to be proven existing stratigraphic faults near surface, except F7 anomaly. By measuring and positioning, surface positions both interpreted by seismic exploration and determined by drilling investigation are listed in Table 1 with ground surface distance parameter in unit meter. Actually, the location accuracy of the ground fissures in the ground is affected by 2 factors. One is the angle between the ground fissure's strike and exploration line (i.e. seismic survey line and the drilling investigation line). The other is spacing between two adjacent drilling boreholes. The small angle between ground fissure's strike and exploration line will lead larger ground positioning errors. According to Xi'an ground fissure's features, the angle might be ranging between 30 to 50 degrees. The borehole spacing is 10 meters for all anomalies except F2 anomaly being 4 meters. As shown in Tab. I, the maximum difference between seismic exploration abnormal position and geological drilling abnormal position is of 54 meters, and the minimum is of 9 meters. Taking account of above 2 positioning factors for actual situation, the positions determined by between seismic exploration and geological drilling are in good coincide.

TABLE I. COMPARISON TABLE OF ABNORMAL POSITIONS OF SEISMIC EXPLORATION AND GEOLOGICAL DRILLING

Anomaly	Seismic Exploration Position (in Meter)	Geological Drilling Position (in Meter)	Difference (in Meter)
F_1	1700	1748	48
F_1'	1810	1819	9
F_2	5190	5154	36
F_3	6840	6828	12
F_4	7490	7436	54
F_5	7630	7625	5
F_6	7800	7773	27
F_7	8080	-	-
F_8	8400	8440	40
F_N	8600	8584	16

IV. CONCLUSIONS

The following conclusions are drawn by the application of large tonnage of vehicle-mounted vibrator source in the exploration of underlying Xi'an ground fissure.

1) Using large tonnage seismic vibrator source can effectively suppress the interference of urban traffic, and obtain high signal to noise ratio seismic reflection records.

2) Both shallow and depth underground information may be obtained by employing large tonnage vibrator source with more than 200 traces digital acquisition device, using 24 folds reflection observation system, and setting max-shot-geophone distance to be 600-800 meters.

3) 7 of the 8 ground fissure anomalies determined by seismic exploration have been confirmed to be Xi'an ground fissures. The positions of the seismic exploration anomalies are in good coincidence with those of the geological drilling anomalies.

4) Employing large tonnage vibrator source for Xi'an ground fissures exploration in information blank area, the exploration results are reliable. This method and experiences can be extended to similar work.

REFERENCES

[1] Z-S. Li, "Seismic exploration in Xi'an ground fissures prospecting," Geotechnical Investigation & Surveying," no. 5, pp. 64-67, September 2004.

[2] Z-S. Li, Y-H. Song, H-Y. Gao, H-K. Yuan, Y. Cheng and L. Cong, "Study on the strike of western Lintong-Chang'an fault (F_N)," Earthquake Research in China, vol. 30, no. 2, pp.272 -279, June 2014.

[3] Z-S. Li, Z-L. Zuo, H-Y. Gao, H-K. Yuan, P. Ji, Y-H. Song and Y. Cheng, "Test study on application of vehicle-mounted vibrator in the seismic exploration of ground fissures in Xi'an," China Earthquake Engineering Journal, vol. 37, no. 4, pp. 915-918, December 2015.

[4] J-B. Peng, "Xi'an ground fissures disasters," Beijing:Science Press, 2012,

[5] D-R. Tang, W. Lei, and C. Peng, "Mini-Sosie shallow reflection technique with high resolution and its application for investigation the ground fissures in Xi'an City," Chinese Journal of Geophysics, vol. 31, no. 6, pp. 708-712, November 1988,

[6] J-M. Zhang, "Research on ground fissures in Xi'an city," Xi'an: Northwest University Press, 1990.