Application of Self-Propelled Light Electro-Hydraulic Servo Vibrator Vehicle: A Case of Chaganhua Town, Jilin Province, China

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Abstract. In order to test the performance of the LVIB-15 self-propelled light electro-hydraulic servo vibrator developed by Jilin University, a comparative test was conducted on different excitation conditions of a hard pavement and sandy road in Chaganhua town, Jilin Province, China. The optimum scanning frequency was determined by comparing different scanning frequencies. And seismic exploration with a length of 1.2 km was completed. The results show that the reflections were very clear and had good consistency. The signal-to-noise ratio of seismic signal was very high, reaching a reflector of 1400 ms, proving that the seismic data of vibroseis had high accuracy and reliable results and it meets the demand of geophysical prospecting.

1. Introduction
Seismic exploration is an important means of oil and gas exploration [9] and the vibroseis is an important part of seismic exploration [8]. Vibroseis can be divided into two types according to their energy sources. Electromagnetic vibroseis is composed of current coil and magnet coil, with an operating frequency range up to thousands of Hertz. Portable electromagnetic vibroseis has been developed in the Netherlands, Japan, and the United States [5]. Jilin University designed the first portable electromagnetic vibroseis in China [7,10]. The second type is hydraulic-driven vibroseis [1,6]. This type of vibrator uses hydraulic oil to drive the vibrator, which generates an inertial force on the hammer and affects the ground through the plate to generate seismic waves. At present, mature hydraulic vibrators are large-scale vehicle-mounted, and the most representative ones are the Nomad series vibrators developed by the Sercel company of France [4], EnviroVibe vibrators by IVI in the USA [3], and the KZ series produced by the Bureau of Geophysical Prospecting in China. Because the deadweight of this type of source is more than several tons, its volume is also large, so it is unable to meet the requirements of complex terrain and street alley in city.

In order to solve this problem, a type of light self-propelled electro-hydraulic servo vibrator vehicle (LVIB-15) was produced by the authors of this paper. This vibroseis includes three parts: hydraulic system, vibration system, and measurement and control system. After optimized design, the total body weight is 1.8 t, and the length, width, and height are 2.2 m, 1.4 m, and 1.35 m, respectively. The peak output of the vibroseis is 15 kN and the scanning frequency is 5–250 Hz. In order to analyze the records of seismic waveforms under different excitation conditions, a comparative test was conducted, in which
the vibroseis vibrated on concrete road and sandy road in the Chaganhua area. The optimum scanning frequency was determined by comparing different scanning frequencies. Then a seismic exploration 1.2 km in length was completed on the pavement of sandy road in this area. The signal-to-noise ratio of the data collected by LVIB-15 vibroseis was high, and the information of reflected waves was clear. The LVIB-15 vibroseis takes full advantage of "small volume and large energy" and has broad application prospects.

2. Results and Discussion

2.1. Results of different excitation conditions

The experiment consisted of three parts. First, the test was carried out with different excitation conditions. The adaptability of the vibroseis to different types of ground was evaluated by single-shot recording.

The project was carried out along paths in villages in the forest belt. The LVIB-15 vibroseis vibrated on hard concrete pavement and soft sandy road. Figure 1 shows the operation of the vibroseis in the two conditions. The geophones were arranged in the soil layer on the shoulder of the road. Each acquisition trace had three geophones of 60 Hz in a linear combination. The data collection system was the SE863 of Jilin University [2]. The parameter settings of the two experiments are the same: sampling interval is 1ms, record points are 2048, group interval is 5m, offset is 220m, and coverage times is 24.

![Figure 1](image1.jpg)

**Figure 1.** Working conditions: (a) vibrating on concrete road; (b) vibrating on sandy road

![Figure 2](image2.jpg)

**Figure 2.** Record obtained from single shot under different conditions: (a) vibrating on concrete road; (b) vibrating on sandy road.

Figure 2 shows the records obtained from single shots of different work situations: vibrating on the concrete road in Figure 2a, and vibrating on the sandy road in Figure 2b. The shape and position of the reflected waves in the two records are almost identical, the first arrival time is very clear, and eight groups of reflected waves can be clearly seen. The difference is that the recording noise of the vibration...
on the concrete road is slightly higher. The reason is that the coupling degree of the vibroseis on cement is not as good as that on sand.

The record was analyzed further to obtain the spectra shown in Figure 3. It can be seen from the spectra that their distribution characteristics are similar and frequency components of the recording under the two conditions are abundant, and the energy of lower frequencies is higher. On the whole, the seismic records in the two conditions are not very different, but the seismic waves generated in the loose soil layer is more continuous and clear. So, the next experiment was conducted on sandy soil.

![Figure 3. Spectra of single shot recording: (a) vibrating on concrete road; (b) vibrating on sandy road.](image)

2.2. Result of different scanning frequencies

In order to explore the influence of different scanning frequencies on the excitation effect of vibroseis, four groups of experiments were conducted. Specific parameter settings are shown in Table 1. The result of single shot recording is shown in Figure 4.

| Project                  | a        | b        | c        | d        |
|--------------------------|----------|----------|----------|----------|
| Sampling interval        | 1 ms     | 1 ms     | 1 ms     | 1 ms     |
| Record points            | 2048     | 2048     | 2048     | 2048     |
| Group interval           | 5 m      | 5 m      | 5 m      | 5 m      |
| Offset                   | 220 m    | 220 m    | 220 m    | 220 m    |
| Acquisition traces       | 60       | 60       | 60       | 60       |
| Coverage times           | 24       | 24       | 24       | 24       |
| Sweeping length          | 20 s     | 20 s     | 20 s     | 20 s     |
| Listening time           | 1 s      | 1 s      | 1 s      | 1 s      |
| Starting frequency       | 5 Hz     | 5 Hz     | 5 Hz     | 5 Hz     |
| Ending frequency         | 60 Hz    | 80 Hz    | 100 Hz   | 120 Hz   |
| Output                   | 60%      | 60%      | 60%      | 60%      |
Figure 4. Comparison results at different scanning frequencies: (a) 5–60 Hz; (b) 5–80 Hz; (c) 5–100 Hz; (d) 5–120 Hz.

Through the comparison of the four experiments, it was found that the lower the scanning frequency, the more obvious the reflection axis looks. However, it is not good for seismic interpretation that only the in-phase axis with strong reflection energy can be distinguished. This result has a lower resolution in Figure 4a.

With increased scanning frequency, the resolution of the shallow layer will be greatly improved, and the tiny reflection axes will be more clearly displayed, as shown in the red box in Figure 4b-c.

However, high scanning frequency also brings disadvantages. If the scanning frequency is too high and the energy of the vibrator is too low, the underlying information will disappear. When the scanning frequency is 5–100 Hz, the reflection axis at 800 ms is still clearly visible, as shown by the arrow in Figure 4c. However, when the scanning frequency reaches 5–120 Hz, the reflection axis at 800 ms disappears, as shown in the red circle in Figure 4d. Through the above comparative analysis, the optimal scanning frequency of this experiment was determined to be 5–100 Hz.
2.3. Result of seismic section

Figure 5. Record obtained from single shot of LVIB-15

After the above experiment, we determined the optimal scanning frequency and vibration condition. Later, a seismic exploration with a length of 1.2 km was completed on the pavement of a sandy road. The observation system layout and collection parameters are shown in column d in Table 1, but the number of channels changed from 64 to 48. Figure 5 shows the record obtained from single shot of LVIB-15. The reflected wave group is clear and has good continuity. Figure 6a shows the seismic time profile of the exploration of the LVIB-15 vibroseis. In addition to the influence of stratigraphic characteristics, the seismic profile shows obvious distinct high-resolution layers of different wave groups. It is worth mentioning that the deepest reflection axis is 1400 ms in single shot record and seismic time section. This is the first time such a small vibroseis reached this exploration depth in China. It can be seen that the LVIB-15 electro-hydraulic servo vibroseis has the advantage of “small volume and large energy” and has broad application prospects.

This experiment achieved very good results and the expected purpose. In terms of excitation conditions, relatively good seismic records were obtained under different excitation conditions, and the reflector had a good consistency. From the seismic time section, a single vibroseis with a small volume reached a depth of 1400 m, showing its advantage and broad application prospects.
In order to verify the reliability of the exploration results, they were compared with the results of Nomad 65 in the same area in 2017. The parameters of the Nomad 65 observation were set as follows: frequency range 3–250 Hz, sweeping length 20 s, output 80%, group interval 20 m, and sampling interval is 1 ms. The data collection system was 428XL from France. Figure 6b shows the seismic time profile of two Nomad 65 vibrating at same time. By comparing Figures 6a and 6b, it can be seen that the reflection axes with strong energy in the two profiles are basically the same, appearing around 250 ms, 400 ms, 500 ms, 600 ms, 750 ms, 1050 ms, 1200 ms, and 1400 ms. It can be concluded that the LVIB-15 vibroseis is in line with the international technological level of mature vibroseis, and the exploration results have good credibility. Nomad 65's output (270 kN) is 18.7 times larger than LVIB-15's and its weight is 31.1 t, 17.3 times that of the LVIB-15, so its deep energy level is high. However, the LVIB-15 vibroseis achieved the better reflected record of 1400ms and it is clear that its shallow information is more distinct than Nomad’s. It can be seen that the advantage of the LVIB-15 vibroseis is greater.

3. Conclusions
The field exploration tests proved that the LVIB-15 electro-hydraulic servo vibroseis can meet the needs of high-precision deep mineral resource exploration and the data collected by the LVIB-15 vibroseis has a high signal-to-noise ratio. At present, the members of the research group will conduct further study on this basis, with a focus on realizing energy and bringing "small volume and large energy" into full play, which will certainly be important in deep metal exploration.

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