

Detection of near-surface fissures by generalized S-transform of Rayleigh waves

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Abstract—Because of the strong energy of Rayleigh wave, high signal to noise ratio and high efficiency, as a new type of engineering geophysical exploration methods, Rayleigh wave exploration get more and more attention in recent years. And because of the in-homogeneity of the earth's surface medium, the Rayleigh Wave velocity that spread in it changes with frequency. This kind of phenomenon is called the dispersion phenomenon of the Rayleigh Wave. So, making use of the dispersion characteristic of the Rayleigh Wave, the variety of the property and structure that underground medium could be opened out. A rotated the staggered-grid finite-difference method was adopted in wave field modeling to obtain the synthetic seismic record in this paper. Base on the study of Xia, we performed a little modification to the travel time equation for the Rayleigh-wave diffraction, and we use the generalized S-transform which is more suitable for non-stationary signal processing was adopted to extract the arrival times of the diffracted Rayleigh waves from the boundary of the fissure at a certain receiver. And then the arrival times were used to calculate the locations of the boundary of the fissure.

Keywords—rayleigh wave; generalized s-transform; fissure

I. INTRODUCTION

Ground fissure is a unique urban geological disasters. It occurs at the surface and has a small length, so it's difficult to precisely detect the position of ground fissure. Rayleigh waves propagate along the surface of the earth with much more energy than that of body waves. And a dispersion phenomenon (the phase velocity of surface wave varies with frequency) will happen when media underground is in-homogeneous. In 2007, Xia et al. [1] put forward a method to detect the location and depth of the void directly by using Rayleigh wave diffraction. The hyperbolic travel time equation for the Rayleigh-wave diffraction was deduced in their paper. Considering the non-stationary characteristics of seismic signals, it is difficult to determine the apex and any other point on the diffraction hyperbola accurately. So the generalized S-transform which is more suitable for non-stationary signal processing was adopted to extract the arrival times of the diffracted Rayleigh waves from the boundary of the fissure at a certain receiver. And then the arrival times were used to calculate the locations of the boundary of the fissure.

II. THEORY

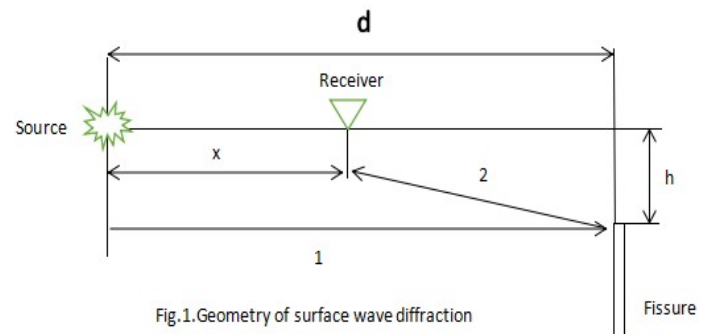


Fig.1. Geometry of surface wave diffraction

Fig.1 is the geometry of surface wave diffraction Schematics, where d is the distance from the source to the front boundary of the fissure respectively. x is the distance between the source and the receiver. h is the depth to the top of the fissure. v is the phase velocity of the diffracted Rayleigh waves. t_x is the arrival time of the diffracted Rayleigh waves at x . The corresponding diffracted Rayleigh wave equation is shown as equation (1).

$$t_x = \frac{1}{v} \left(d + \sqrt{(d-x)^2 + h^2} \right) \quad (1)$$

When $d-x \gg h$, (1) can be approximated as:

$$d = \frac{1}{2} (vt_x + x) \quad (2)$$

Fortunately, the phase velocity of the diffracted Rayleigh waves v can be determined by the ratio of the distance difference between any two traces (x_1 and x_2) and their corresponding arrival time difference. That is:

$$v = \frac{|x_2 - x_1|}{|t_{x2d} - t_{x1d}|} \quad (3)$$

Where, t_{x1d} and t_{x2d} are the arrival times of the direct Rayleigh waves at x_1 and x_2 respectively. Therefore, the key problem lies in how to effectively extract the arrival times of the diffracted Rayleigh waves at a certain trace. As the generalized S-transform can finely depict the time-frequency distribution of a weak signal in time-frequency domain, we take advantage of this characteristic of the generalized S-transform to identify the arrival times of the diffracted Rayleigh waves. Firstly, we extract the arrival time t of the energy peak on the time-frequency spectrum. And then, the

time delay t_{delay} between the take off point and the peek point is subtracted from t . The result of $t - t_{\text{delay}}$ is regarded as the arrival time of the diffracted energy. The time delay can be obtained by subtracting the ratio value of the distance between the source and a certain trace over the phase velocity of the diffracted Rayleigh waves from the energy peak arrival time of the direct Rayleigh waves at the same trace. The computational equation is shown as (4):

$$t_{\text{delay}} = t - \frac{x}{v} \quad (4)$$

And then, (1) can be rewritten as:

$$d = \frac{1}{2} [v(t_x - t_{\text{delay}}) + x] \quad (5)$$

III. MODELING RESULTS

For all fissure models, the size of the computed region is 40 (m)×40(m).The modeling results for fissures were calculated with a cell size of 0.05(m) by 0.05(m).The trace interval is 0.5(m). The minimum offset is 1(m).The range of the receiver array is from 1(m) to 40(m). The source is at 0(m). The horizontal location of the front edge of the fissure is at 20(m).P- and S-wave velocities of the homogenous half space are 1000(m/s) and 200(m/s), respectively. These values define a Rayleigh-wave velocity about 190(m/s)(Knopoff, 1952). Densities of the half space and the fissure are 2000(kg/m³) and 10(kg/m³), respectively. P- and S-wave velocities of the fissure are 340(m/s) and 17(m/s), respectively.

A. Fissure Model 1

Fig.2a is the synthetic shot gather of the fissure model1(0.1(m)×10(m) with a depth to the top of the fissure of 2(m)). The distance from the source to the front boundary is 20(m) . The direct and diffracted Rayleigh waves all can be seen in the fig.. But the diffracted energy is relatively weak. Fig.2b is the F-K filtered diffracted Rayleigh wave record (only those events with negative apparent velocities are extracted in this paper).

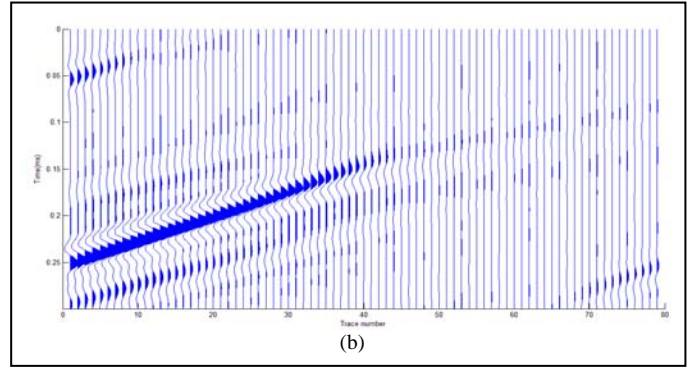
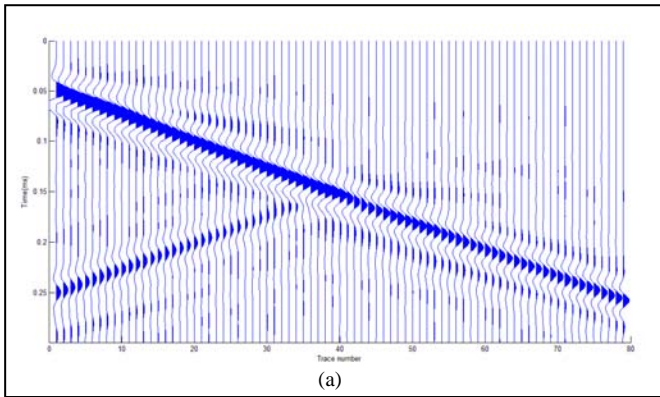


Fig .2.(a) A synthetic shot gather of the fissure model1. (b) Shot gather after F-K filtering.

Fig.3a is the generalized S-transform amplitude spectrum of the 9th trace before F-K filtering. It is obviously that the energy peak at 0.073(s) is ought to be the direct Rayleigh waves. But the diffracted energy occurs near 0.2(s) is not significant.Fig.3b is the generalized S-transform amplitude spectrum of the 9th trace after F-K filtering.The energy peak at 0.2285(s) which ought to be the diffracted Rayleigh wave from the boundary of the fissure.

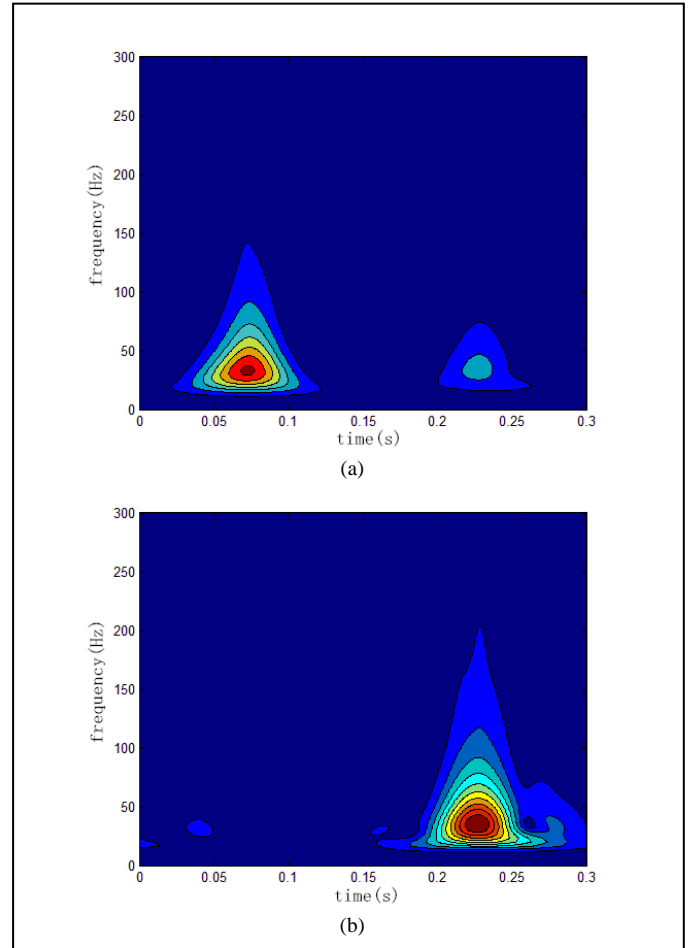


Fig.3.The amplitude spectrum of generalized S transform of the 9th trace; (a) before F-K filtering(b) after F-K filtering

Fig.4a is the generalized S-transform amplitude spectrum of the 19th trace before F-K filtering. The arrival time of direct Rayleigh waves is obviously at 0.0995(s). According to the distance between the 9th and 19th trace(5(m)) and their time difference, a phase velocity of the diffracted Rayleigh waves 188.68(m/s) can be obtained from (3), which is very close to its theoretical velocity(190(m/s)).Base on the arrival time of the direct Rayleigh wave energy peak (0.073(s)) at the 9th trace, an energy time delay 0.0465(s) can be calculated from (4). Fig.4b is the generalized S-transform amplitude spectrum of the 19th trace after F-K filtering. The energy peak at 0.2045(s) which ought to be the diffracted Rayleigh wave from the boundary of the fissure.For the 9th trace, the boundary of the fissure $d=19.67(m)$ can be obtained from (5). Similarly for the 19th trace, the calculated values of the boundary of the fissure is 19.9(m). The averaged values of the boundary of the fissure is 19.79(m), which is very close to the actual location (20(m)).

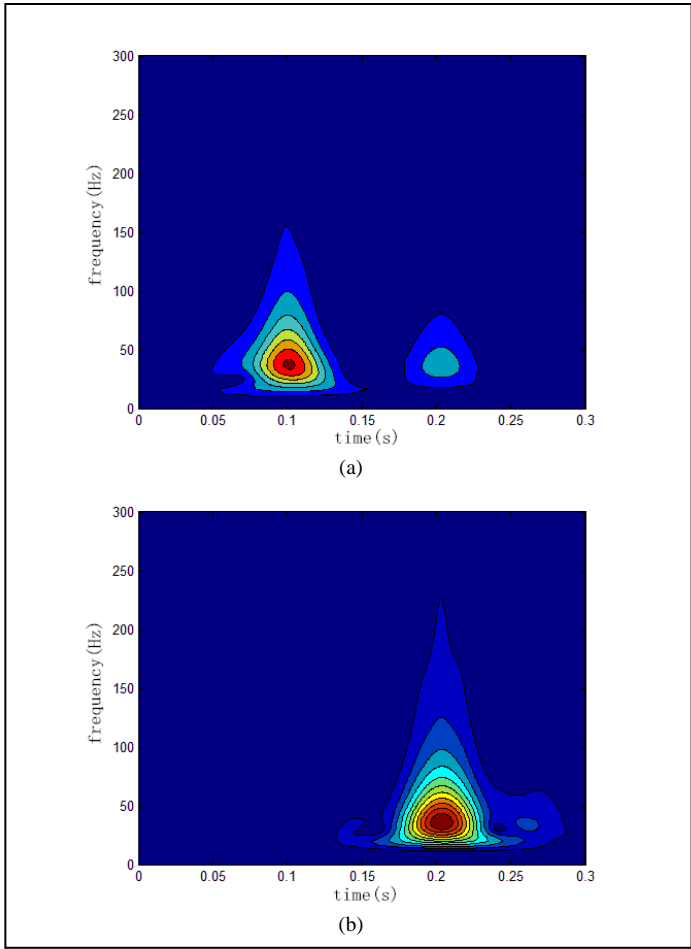


Fig.4.The amplitude spectrum of generalized S transform of the 19th trace; (a) before F-K filtering(b) after F-K filtering

B. A Real-world Example

In order to verify the real-world effect of the generalized S transform, we choose a ground fissure as a test point in Wucao brickyard at Shanxi Yuncheng.This section is located at the south of the village of Wucao.The length of section is about 96 (m).The width of the fissure is about 8(m).There is a trench

next to the fissure, we can still clearly see the ground fissure at depth of about 10(m).12 shots are collected.The shot interval is 6(m).The trace interval is 1(m). The minimum offset is 6(m).The length of the signal is 500(ms) with 1024 sample points. The sample rate is 0.5(ms).We choose the 9th shot. The distance from the source to the boundary of the fissure is 24(m) .Fig.5a is The 9th shot gather of the real data.Fig.5b is the F-K filtered diffracted Rayleigh wave record.

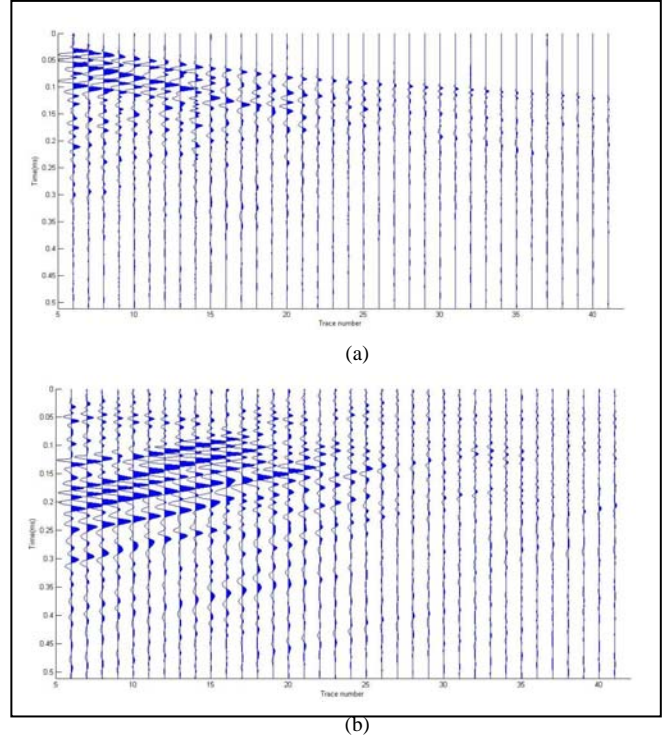
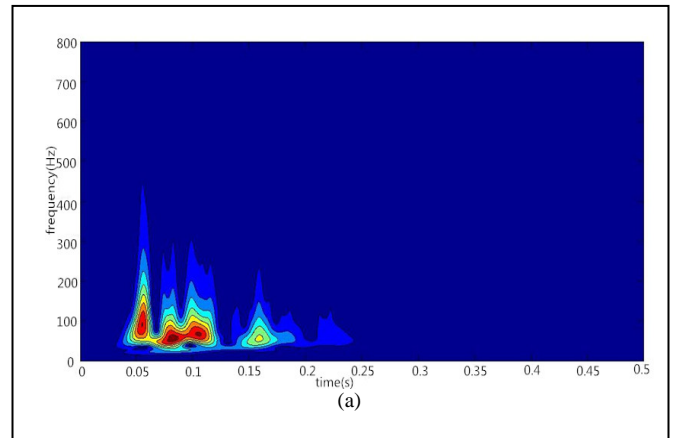


Fig.5.(a) A synthetic shot gather of the real data. (b) Shot gather after F-K filtering.

Fig.6a is the generalized S-transform amplitude spectrum of the 5th trace before F-K filtering. As Fig.6a shown, the energy peak of the direct Rayleigh waves is at 0.055(s). Fig.6b is the generalized S-transform amplitude spectrum of the 5th trace after F-K filtering.The energy peak of the diffracted Rayleigh waves is at 0.164(s).



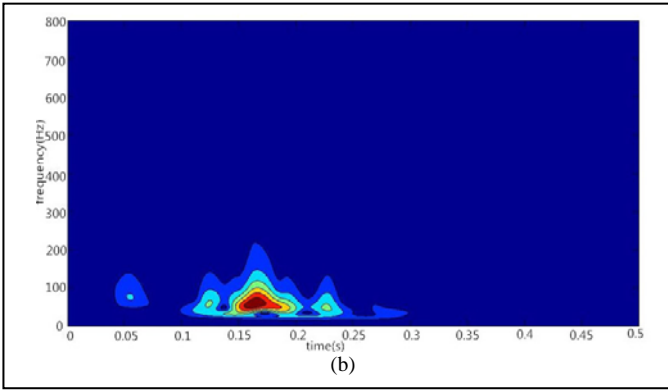


Fig.6.The amplitude spectrum of generalized S transform of the 5th trace; (a) before F-K filtering(b) after F-K filtering

Fig.7a is the generalized S-transform amplitude spectrum of the 7th trace before F-K filtering. The arrival time of direct Rayleigh waves is at 0.0625(s). According to the distance between the 5th and 7th trace(2(m)) and their time difference, a phase velocity of the diffracted Rayleigh waves 266.66(m/s) and the energy time delay 0.0175(s).Fig.7b is the generalized S-transform amplitude spectrum of the 7th trace after F-K filtering.The energy peak of the diffracted Rayleigh waves is at 0.154(s).For the 5th trace, the boundary of the fissure 24.53(m) can be obtained. Similarly for the 7th trace, the calculated values of the boundary of the fissure is 24.19(m). The averaged values of the boundary of the fissure is 24.36(m), which is very close to the actual location (24(m)).

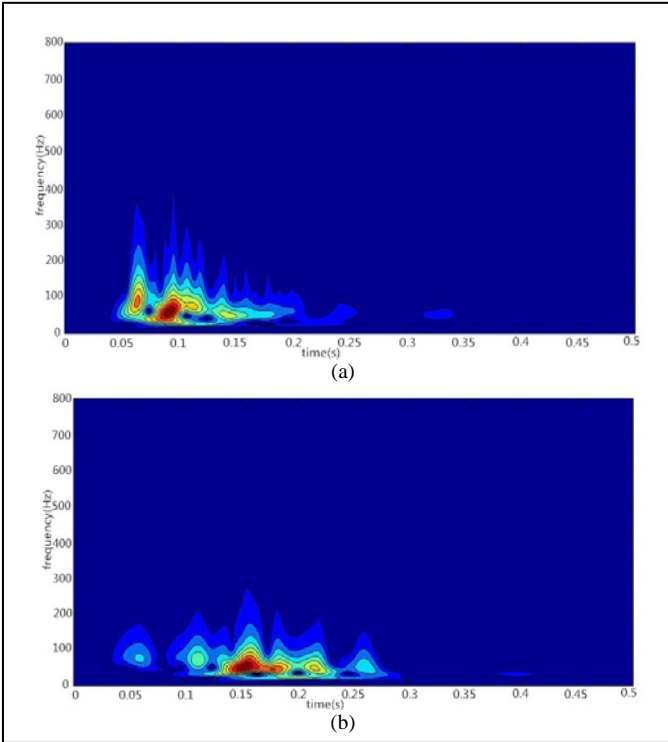


Fig.7. The amplitude spectrum of generalized S transform of the 7th trace; (a) before F-K filtering(b) after F-K filtering

IV. CONCLUSIONS

By modifying the travel-time equation for the Rayleigh-wave diffraction,we prove that it is feasible and effective to detect the near-surface fissure boundary by using the generalized S transform. And before performing the generalized S-transform, a suitable method should be used to extract the diffracted Rayleigh waves. F-K filtering method was adopted in this paper. The extracting precision of the diffracted Rayleigh waves can affect the estimate accuracy of the fissure's boundaries.

REFERENCES

- [1] Xia, J., Nyquist, J.E., Xu, Y., and Roth, M. Feasibility of detecting near-surface feature with Rayleigh-wave diffraction. Journal of Applied Geophysics. 2007 62(3), 244-253.