Laboratory evaluation of laser vibrometer for non-contact rock damage assessment

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SUMMARY

The deterioration of ground such as rock delamination and fracturing can cause considerable safety concerns and result in significant interruption to production. There is a change in seismic resonant frequency when the strata are prone to collapse. A repeated seismic survey is an efficient way to diagnose the deterioration process and predict impending hazards. In this paper, a laser vibrometer method is proposed to sense rock condition in areas where normal seismic sensors cannot be deployed. A laboratory experiment using a laser vibrometer PDV-100 along with eleven geophones was carried out on a block of rock sample. The results have shown that the seismic waveforms obtained by non-contact laser vibrametry and the geophones are very consistent. Significant changes in seismic characteristics are evident when sensing across a rock surface with solid and hole sections behind it. It is also found that significant changes occur to the seismic signals when the holes of the rock sample are filled with different materials. The experiment has demonstrated great potential for laser vibrometer in sensing rock weakening process associated with vibration frequencies which is not resolvable using geophones.

Key words: Non-contact sensing, rock condition, seismic response, laser vibrometry.

INTRODUCTION

Poor rock conditions near the working face and in roadways in underground mining and civil engineering can cause considerable safety concerns to workers and result in significant interruption to production. Microseismic techniques have been used to map fracture patterns inside rock mass associated with stress changes due to mining (Cai et al., 2001). It was observed that the deterioration of ground such as rock delamination and fracturing can change significantly the strata resonant frequency (Shen et al. 2008). Repeated seismic sensing is an efficient way to diagnose the poor condition of the strata and predict impending hazards.

However, the deployment of sensors and cables in underground is tedious and laborious. In addition, in many hazard areas, their access is highly restricted for sensor installation. Therefore, a non-contact seismic sensing technology is in high demands for using in such an environment.

Laser vibrometry is a non-contact vibration sensing technology that has been used for non-invasive damage diagnosis of composite materials (Castellini and Revel 1998). In 1990's German Polytec developed a portable laser vibrometer, PDV-100 for industry use. The principle of the technology is based on the Doppler-effect; sensing the vibration through the frequency shift of back scattered light from a moving surface. This instrument features with non-contact velocity measurement in the frequency range from 0.5 Hz to 22 kHz and measurement distance from 0.1-30 m (www.polytec.com). Swanson (2002) evaluated this instrument for non-contact assessment of rock quality and obtained encourage results.

The laser vibrometer was further evaluated in the CSIRO microseismic laboratory in order to assess whether this technology is feasible for mining and civil engineering applications. This paper shows some preliminary results from the experiments.

LABOROTAY EXPERIMENT

The vibration sensors used in this experiment are one PDV-100 laser vibrameter, two GS-11D 4.5Hz and nine GS-20DX 14 Hz geophones. The geophones were sticked on the surface of a rock block at specified locations using epoxy. The laser vibrometer was located about 1-3 m from the sample block and sensed vibrations through laser lights scattered from pints next to the geophones. The usage of geophones together with the laser vibrometer is to identify any difference of the seismic signals acquired using the two different types of sensor technologies.

The rock sample used for the experiment is a granite rock block of a size of 120 cm long, 60 cm wide and 42 cm high (Figure 1). One third of the block is solid and the other portion was developed by 11 large holes of 25 cm in diameter. The structure of the sample block provides us with a good opportunity to sense the difference of seismic characteristics at different sample locations, in response to hammer tapping at specified points. During the experiment, these holes were sequentially filled with different materials (air, water, sand).

Hammer (steel and rubber) taps at different locations on the rock surface were used as seismic sources. Figure 2 shows the

locations of the tap and geophone/laser measurement points. The seismic signals obtained by the laser vibrometer and geophones were recorded by a 48 channel seismic recorder developed by China Huanzhou Company. This instrument has features of 24 bit ADC for each channel, trigger and continuous recording, up to 3.8 kHz sampling frequency for each channel and up to 32 times of gain. In this experiment we used sampling rate of 3.8 kHz and gain of 16. Data processing was conducted on waveform comparison and frequency analysis.

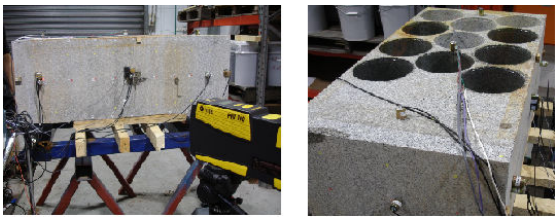

Figure 1. The installation of vibration sensing experiment, showing the granite rock sample, the locations of the PDV-100 laser vibrameter and geophones (left). The rock sample has 11 large holes (right) in which different materials were filled during the experiments.

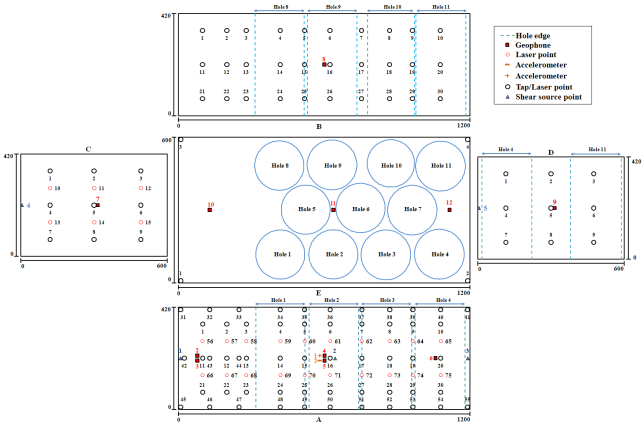

Figure 2. Locations of the tap and vibration sensing points on the five sides of the rock block. The majority of laser survey points are on the A side (at bottom).

RESULTS AND DISCUSSIONS

The results given in the following were obtained in accordance with such a survey configuration: the vibration sensing points are on the front panel (side A) of the block and the tapping points are on the back panel (side B). Two experiments were conducted: when the holes are empty (filled with air) and filled up with sand.

Figure 3 shows the seismic waveforms recorded by the laser vibrometer and two geophones (GS-11D and GS-20DX) in the centre of side A, at points 16 (laser sensing point), 4 (GS-11D is located) and 5 (GS-20DX is located), in response to tapping on point 12 (in the solid area) on side B. The waveforms between the laser vibrometer and geophones are very consistent.

The high consistency of the waveforms between the laser and geophones has also found in the tap tests at other points. Figures 4 and 5 show the waveforms associated with tap tests on points 14 (near the edge of the area with holes) and 17 (in the middle of the area with holes) on side B, respectively.

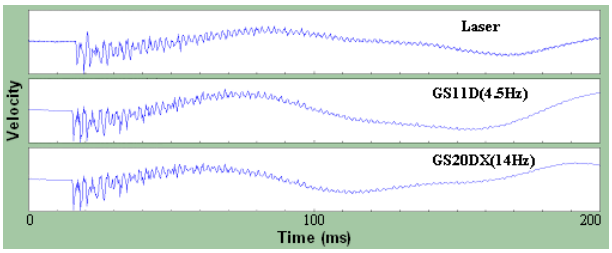

Figure 3. Seismic waveforms of the laser vibrometer and geophones on side A, generated by a tapping at point 12 on side B (at a solid section). The holes are empty.

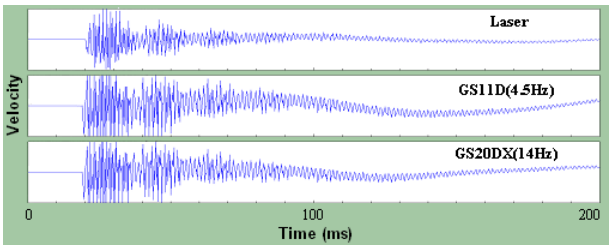

Figure 4. Seismic waveforms of the laser vibrometer and geophones on side A, generated by a tapping at point 14 on side B (near the edge of the hole area).

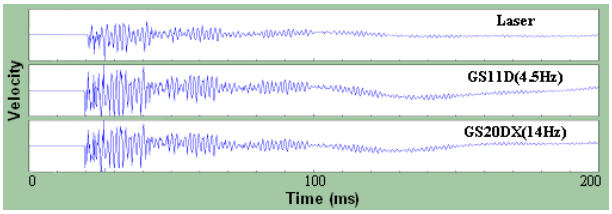

Figure 5. Seismic waveforms of the laser vibrometer and geophones on side A, generated by a tapping at point 17 on side B (in the centre of the hole area).

The spectrograms associated with the seismic signals showing in Figure 3 are shown in Figure 6. They are very similar and all dominated by a low frequency (<10 Hz) content.

The spectrograms associated with the seismic signals in Figure 4 and 5 are shown in Figure 7 and 8, respectively. Again, the high level of consistency is evident between the laser and geophone seismograms.

Significant changes in the patterns of seismic waveforms and frequency contents associated with tapping at different locations have been shown in these figures. When tapping at solid area, the low frequency (<10 Hz) content is dominant. However, when tapping near the edge of the hole-occupied area the dominant frequency occurs at about 420 Hz. The dominant frequency changes to about 180 Hz in response to tapping at the centre of the hole-occupied area.

Another experiment with same source-receiver configuration was carried out when the holes were filled with compacted sand. Figures 9, 10 and 11 show the seismic waveforms in response to tapping at points 12, 14 and 17, respectively. Compared with the waveforms obtained when the holes were filled with air, the seismic signals associated with the sand fills show a concentration of high frequency energy in their first arrivals.

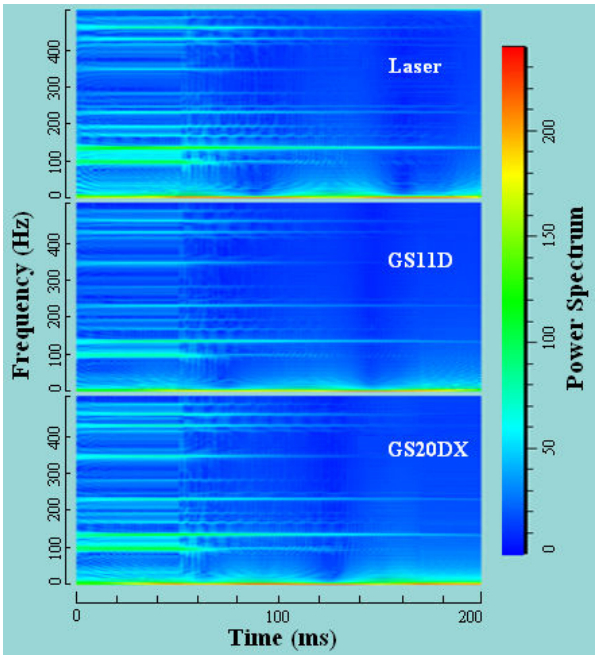

Figure 6. Spectrograms associated with the seismic signals in Figure 3.

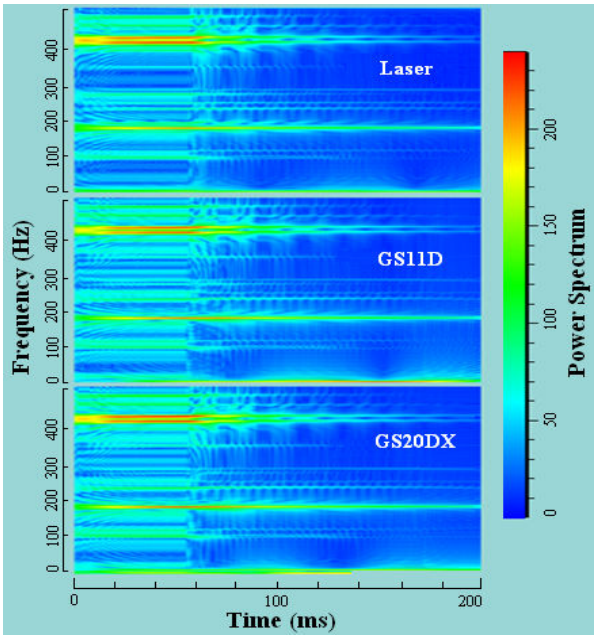

Figure 7. Spectrograms associated with the seismic signals in Figure 4.

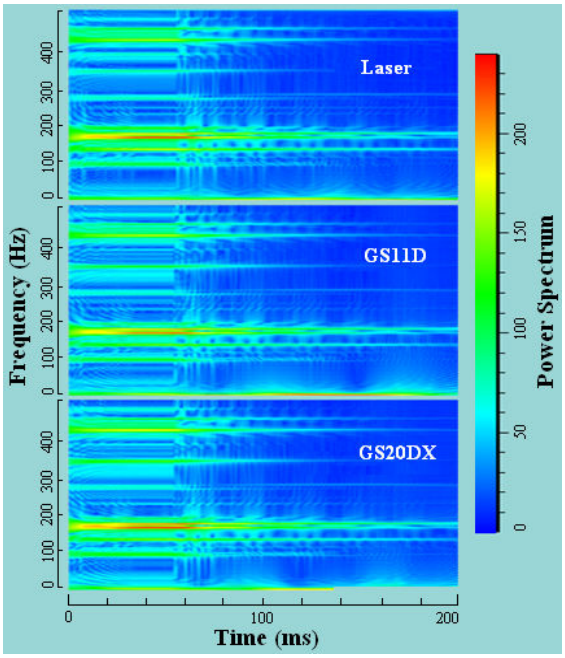

Figure 8. Spectrograms associated with the seismic signals in Figure 5.

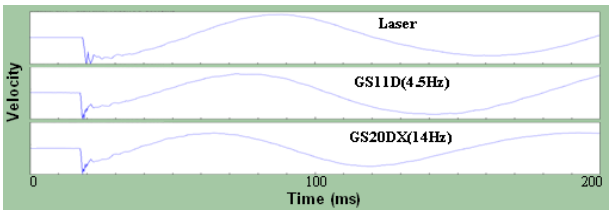

Figure 9. Seismic waveforms of the laser vibrometer and geophones on side A, generated by a tapping at point 12 on the B side (a solid section). The holes are filled with sand, here after.

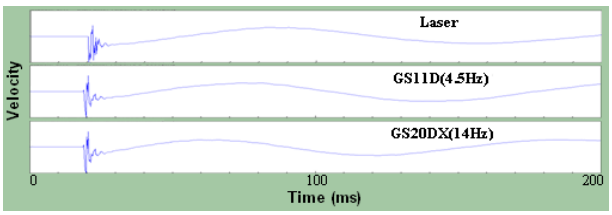

Figure 10. Seismic waveforms of the laser vibrometer and geophones on side A, generated by a tapping at point 14 on the B side (near the edge of the hole area).

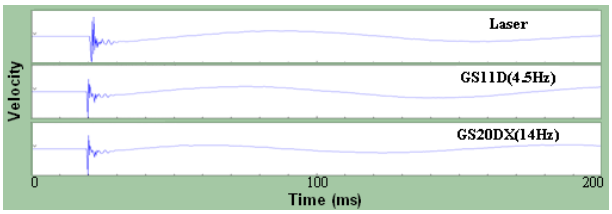

Figure 11. Seismic waveforms of the laser vibrometer and geophones on side A, generated by a tapping at point 17 on the B side (in the centre of the hole area).

CONCLUSIONS

These experiments have demonstrated that the non-contact laser vibrameter can obtain nearly identical seismic waveforms as the geophones. As it features with wide-band frequency measurement range (0.5 Hz to 22 kHz) and detectable distance from 0.1-30 m, the laser vibrometer has a great advantage over the geophones in many applications in underground mining and civil engineering where geophone deployments are impossible due to restricted access for installation.

The experiments have also shown significant changes of seismic characteristics in response to different rock conditions. This supports previous research results that the deterioration of rock mass condition, such as roof delamination, can be detected using seismic sensors.

We found that the change of seismic features can also occur to a seismic sensor that is placed at one location of the rock block while the vibration source was at different positions. We are carrying out a research on approaches to distinguish the change that is caused by ground deterioration or by vibration source locations.

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