Observation of Vp/Vs ratio in synthetic rocks with fractures

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SUMMARY

We measured the Vp/Vs ratio in two sets of synthetic rocks with controlled fracture geometry. The first set of rocks have a fracture density from 0% to 7.29%, with fracture length 3mm and fracture thickness 0.06mm, and the second set of rocks have the same fracture density (about 4.86%) but different fracture scales (lengths 2mm, 3mm, 4mm). P and S wave velocities in the 0°, 45°, 90° directions are measured to analyze Vp/Vs while the rocks are saturated by water. Our measurements show that Vp/Vs is sensitive to fracture density in the fracture-parallel direction, and Vp/Vsh decreases slightly while Vp/Vsv increases significantly as the fracture density increases. The results from the second set of rocks show that Vp/Vs varies with different fracture scale even though the fracture densities are all about 4.86% in the three fractured rocks. The measurements show the sensitivity of Vp/Vs ratio to fracture scale.
Introduction

Fractures are widely distributed in natural rocks in Earth’s crust and upper mantle. Fracture development in underground rocks has a significant effect on hydrocarbon accumulation and transportation, and knowledge of fracture development is essential to fracture reservoir prediction and hydrocarbon production. Equivalent medium theories were developed to describe the elastic modulus of fractured media; these theoretical models are based on various assumptions and give different results. Laboratory experiments are required for verifying theoretical predictions and observing the effect of fractures on seismic wave propagation. Synthetic samples have been used in previous studies on P and S wave velocities affected by fracture parameters in fractured media. In this study, we built sets of synthetic rocks containing a controlled fracture geometry to observe the effects of fracture parameters on Vp/Vs ratio. Penny-shaped fractures with controlled fracture density and fracture scale are imbedded in two sets of synthetic rocks. The first set of rocks contain fracture densities from 0% to 7.29%, the fracture length is 3mm and the fracture thickness is 0.06mm. The P and S wave velocities in directions 0°, 45°, 90° are measured with an ultrasonic testing system while the rocks are saturated by water, giving the Vp/Vs ratio in different direction in rocks with different fracture density. The second set contain the same fracture density but different fracture scales, the fracture density in three fractured rocks are 4.8%, 4.86%, 4.8% while fracture lengths are 2mm, 3mm and 4mm, respectively. The measured results show high Vp/Vs ratio in rocks with small fractures.

Construction of synthetic rocks with controlled fractures

To create fracture samples with different fracture densities, we used a 100×100mm mould. When laying the sand mixture in the mould each time, high molecular material discs were spread out on the surface of each layer. The surface of each layer was divided into four parts, and the number of high molecular material discs spread out on each part was 0, 20, 40 and 60. The thickness and diameter of these discs are 0.06mm and 3mm, respectively. The fracture number in each part is different, and the four parts have different fracture densities but the same background anisotropy. The sample was cut into four blocks and these were ground into octagonal prisms with about 50mm wide faces at increments of 45° to the fracture normal. To build the fracture samples with different fracture diameters, we choose discs with three different diameters and spread them in three different parts of each layer. The fracture thicknesses in the three fractured samples are all around 0.06mm and the fracture diameters are around 2mm, 3mm and 4mm. The fracture density in these samples is around 4.8%. Table 1 shows the fracture parameters in samples with different fracture density and the samples with different fracture scale. Figure 1 shows the fracture distribution in the two sets of samples during the construction process.

Figure 1 Fracture distribution in two sets of rocks containing different fracture density (left) and fracture scale (right).
Table 1. Fracture parameters in synthetic samples with controlled fracture density and with different fracture scale

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Samples with different fracture scale

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Measurement results

These rocks are saturated by water and measured using ultrasonic devices with 0.5 MHz transducers; Vp/Vs ratios are calculated by measuring velocity at different angles to the symmetry axis. The Vp/Vs ratio for the first set of rocks is shown in Figure 2, the values of Vp/Vs ratio are 1.7 to 1.9. In the unfractured rock, Vp/Vs is a little lower in the crack-parallel direction (90°), due to weak layer anisotropy which is inevitable in the construction process. Otherwise, the effect of fractures on Vp/Vs ratio is much stronger than the influence of layer anisotropy. Vp/Vs in the crack-perpendicular direction (0°) is basically not affected while the fracture density increases from 2.43% to 7.29%. In contrast, Vp/Vs in the 90° direction is strongly influenced by fracture density. Vp/Vsh is slightly lower in the 90° direction than the 0° direction, while Vp/Vsv is much higher in the 90° direction, increasing significantly as the fracture density increases. This different influence on Vp/Vs ratio is due to the different effect of fractures on SV and SH wave velocity. Vp/Vsv is much higher since the SV wave velocity is more sensitive to fractures: Vsv will substantially decrease as the fracture density increases. The results shows the sensitivity of Vp/Vsv to fracture density in crack-parallel directions.

Figure 2 Vp/Vs ratio in rocks with different fracture density
Figure 3 Vp/Vs ratio in rocks with different fracture length

The measurement results of Vp/Vs ratio in rocks with different fracture length are shown in Figure 3. Compared to rocks with no fractures, the fractured rocks also show a constant Vp/Vs ratio in the perpendicular direction and a higher Vp/Vs ratio for the SV wave in the parallel direction. Note that the Vp/Vs ratio is significantly influenced by fracture length even when the fracture density is constant (about 4.8%). The Vp/Vs ratio in the parallel direction is higher in rocks with small fractures than in rocks with large fractures. The measurement results show the sensitivity of Vp/Vs ratio to fracture scale due to the SV wave velocity being strongly influenced by fracture length.

Conclusions

We measured Vp/Vs ratio in two sets of synthetic rocks with controlled fractures. The first set of rocks contain fracture densities from 0% to 7.29%, and the results show the Vp/Vs ratio in parallel direction are substantially influenced by fractures. Vp/Vsv increase significantly as the fracture density increases, while the Vp/Vsh decrease slightly. The Vp/Vs ratio is high when elastic wave propagate in perpendicular directions, however the value of Vp/Vs ratio is not apparently influenced by the increasing fracture density. Only Vp/Vs for SV wave is significantly influenced by the fracture density. The second set of rocks with different scale fractures shows the Vp/Vs ratio is sensitive to fracture length, since the Vp/Vs ratio is obviously high in rocks with small scale fractures even though the fracture density of the three fractured rock are almost the same.

Acknowledgements

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References


