CMP Gathers Over FRACTURE vs. SOLID Pexiglas

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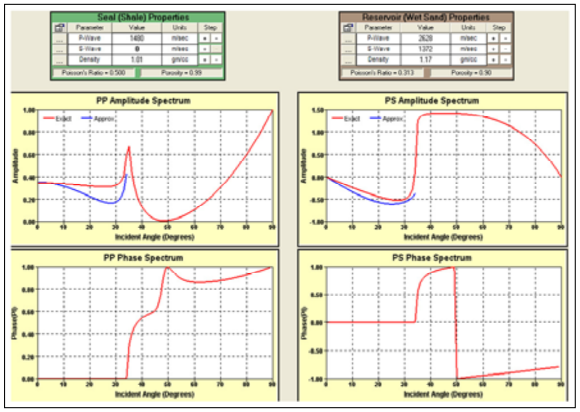
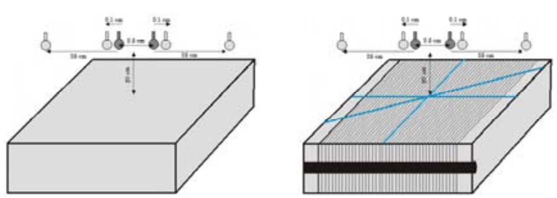
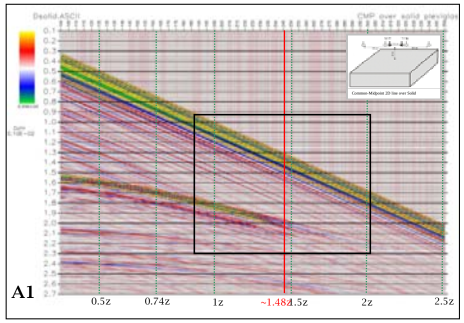
P-P AND P-S REFLECTION OFF A FLAT SOLID PLEXIGLAS – WATER BOUNDARY

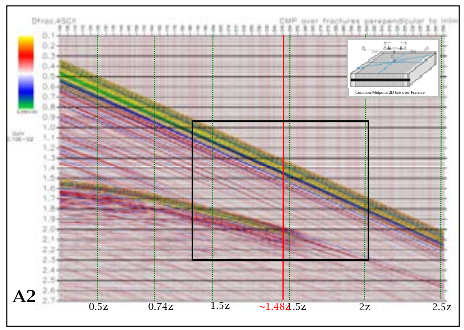


Exact and approximate solutions to Zoeppritz' equations describing seismic waves reflected off the surface of a solid plexiglas model immersed in water indicate that the amplitude of the reflected P waves stay constant or decrease slightly with increasing incident angle. Reflection amplitudes then increase at incident angles approaching the critical angle (~42°) for both P-P and converted P-S waves. The amplitude of P-P waves significantly diminishes when the incident angle is past the critical angle. Moreover, the reflected seismic waves also undergo a polarity reversal or a 180° – phase shift for the P-P case and a 90° – phase shift for the P-S converted waves. Although energy partitioning as a function of incident angle is well-understood for P-P or P-S reflections coming off the interphase of two isotropic media (*i.e.* Zoeppritz' equations), the same can not be said of seismic reflections coming from the surface of an anisotropic medium. The following experiment was designed to illuminate some aspects of seismic wave propagation in a horizontally transverse istropic (HTI) medium such as a Plexiglas fracture model. Our principal objective was to investigate the behavior of reflected waves coming off the fracture model especially at angles close to the critical incident angle.

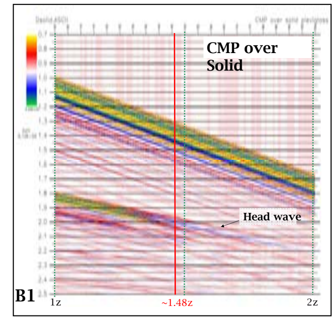


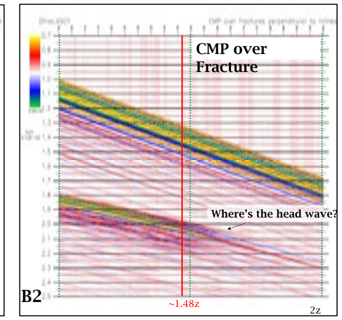
The main idea behind our experiment is to compare how the P-P reflections coming off a an isotropic medium differs from those coming off an anisotropic medium, which in this case is a fracture model where the axis of the vertical fractures is oriented perpendicular to the path of propagating seismic energy. To implement the comparison, we collected a common-midpoint gather over the center of a solid Plexiglas model and another one over the center of a correctly-oriented Plexiglas fracture model. The geometry of the two surveys is identical with the source and receiver transducers fixed 20 cm above the respective models and spaced about 2.5 cm apart from each other for the first trace. Both transducers were then moved 1 mm in opposite directions for the subsequent shots with each shot recorded as a seismic trace. In the end, what we have is a seismic section where (arrival) times in the y-axis is plotted versus the source-receiver offset in the x-axis, which is also a proxy for incident angle.

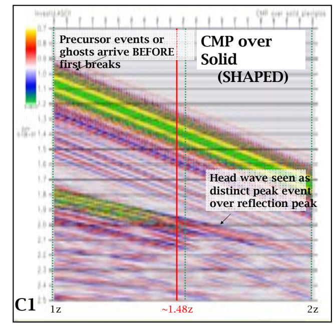


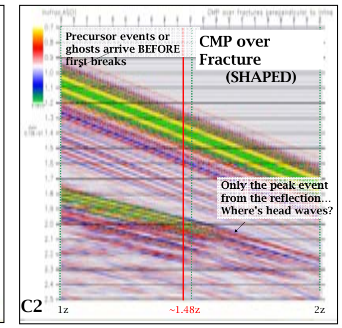


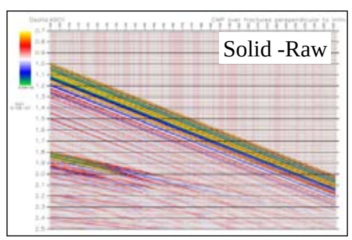
Figures A1 and A2 (left). The seismic sections shown are CMP gathers from the solid (A1) and the fracture (A2) Plexiglas models. Dashed green lines locate the traces recorded when the source-receiver (S-R) offsets are 0.5, 0.74, 1, 1.5, 2, 2.5 and 3 times the depth (z) from the transducers to the reflecting boundary. The critical angle for the incident waves occur at about 42° or when the S-R offset is about 1.48z. Zooming in on the 100 traces from offset = depth to offset = 2z highlights the disparity between the two CMP gathers. **Figures B1 and B2 (top right).** Figure B1 and B2 are the respective close-up views of the boxed areas in figures A1 and A2. Just as the Zoepprittz' equations predicted, P-P waves reflected off the isotropic media (*i.e.* solid Plexiglas) decreases in amplitude and reverses in polarity after the critical angle. However, the reflections coming off the fracture model at the same incident angles show no indications of decreased amplitude nor phase reversal. Moreover, whereas a head wave is clearly seen arriving just past the critical angle for the solid model, such event is either delayed or does not come in yet at the same S-R offsets for the CMP over the fracture model. The shaped seismic data over the solid and fracture models (C1 and C2 respectively) show the disparity in the reflection events close to the critical angle of incident especially the lack of head waves from the CMP data gathered over the fracture model. Our observations with the CMP gathers over the solid isotropic medium vs. the horizontally transverse isotropic (HTI) medium led us to postulate that the characteristics of the reflected P-P waves at incident angles close to the critical incident angle could be potential indicators of (vertical) fracture density and azimuth.

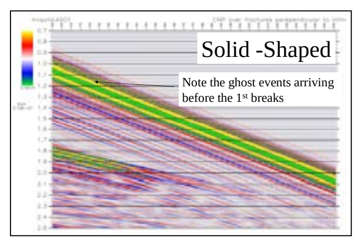












Since the signal from our transducers is rather ringy, we applied an inverse filter to deconvolve our data and make the source wavelet more compact. The figures above show how applying an inverse filter makes the image quality of the "shaped" seismic section sharp and crisp. Clearly shown are the head waves arriving in the traces shot just beyond the critical incident angle. However, the filtering process also introduced precursor energy that are best seen as ghost events arriving even before the first breaks. We are still devising ways to improve our signal quality without introducing artifacts that could lead to erroneous analysis of our experiment results.

SUMMARY

Seismic data was collected using common-midpoint surveys over a solid isotropic Plexiglas model and a horizontally transverse isotropic (HTI) Plexiglas model to examine how the characteristics of P-P waves reflected off isotropic medium differ from the reflections coming off azimuthally anisotropic medium. The CMP data we collected over an HTI (fracture) model suggests that the energy of P-P reflections from vertically fractured media do not partition in the manner described by the Zoepprtiz' equations. Specifically, the P-P waves coming off the fracture model do not decrease in amplitude and do not undergo the polarity reversal as Zoepprtiz' equations predict for seismic reflections coming from an isotropic medium at post-critical incident angles. Another interesting observation is that head waves, which are distinctly seen in the CMP seismic section of the solid model, are either absent of comes in at a much later time in the CMP data shot over the fracture model. The empirical results tell us that the characteristics of reflected P-P waves at incident angles close to critical angle can be indicators for fracture density and azimuth. However, further work is needed to dynamically describe what happens to seismic energy that is reflected from the fractured model. We are conducting follow-up experiments that will address related questions such as azimuth-dependence of our initial results. Existing theory on head wave propagation at angles equal to or just past the critical reflection angle will be examined to see if our empirical results bear upon theoretical predictions. Ultimately, our goal is to present diagnostic seismic indicators of vertical fractures that can be theoretically explained, numerically and physically modeled then verified with field data.