Examining the Physical Modeling System:

Amplitude Calibration and Directivity Tests of Transducers; System Time Delay Study

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SUMMARY

Seismic experiments were conducted to calibrate the LABView-based acoustic physical modeling system. The experiments were designed to test the performance of the modeling facility in four key areas: (a) directivity of the source-receiver transducers; (b) effect of stacking traces on overall data quality; (c) time delay that the modeling system introduce to the data ; and (d) the effectiveness of match filter(s) derived from (seismic) data gathered using the physical modeling system. Our results indicate that the transducers we utilize transmit and receive pulse signals whose amplitude varies depending on the angle of shooting and the rotation of the transducers (on respective axes) relative to each other. However, the variation is negligible for the range of incident angles that are relevant to most of the reflection seismic data we aim to simulate. For situations where the relative incident angles is from zero (0) to about 63° or basically reflection experiments with source -receiver offsets up to three times the depth of target, the disparity in amplitude is no more than 5%. In addition, the relative rotation of the transducers to each other have minimal effect on the signal amplitude. Stacking improves signal:noise of seismic data but the iteration process can take considerable time in physical modeling experiments. For example, auto-stacking a trace 50 versus 1-10 times results to about 25% longer experiment run time. Auto-stacking more than 25 times have little perceptible improvement in image fidelity so for all succeeding experiments a tradeoff between data quality and the duration data collection was set by auto-stacking the data 25 times. System-related delay can manifest as incoherent events or corresponding peaks/troughs not being lined up. Although observed from the physical modeling data, the events are easily lined up by applying a static shift. Also, auto-stacking the data reduces the timing errors resulting from delayed system response. Lastly, the "best" pulse that modeling system can create is a very ringy signal that requires filtering. Significant improvement in data quality results from the application of an inverse filter.

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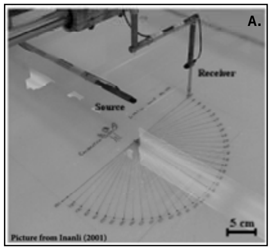

Picture from Inanli (2001)

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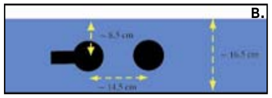

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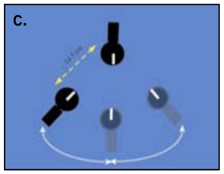

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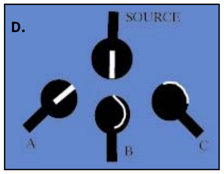

Experiment Setup

The setup for the amplitude calibration and directivity tests consists of one stationary arm and a rotating arm where the source and receiver transducers are mounted respectively (Fig. A). The transducers are set at the same level relative to the base of the tank so the source lies at the center of a semi-circular plane that is the path traced by the rotating arm. Shooting the source while moving the receiver around it simulates the incident angles by which the pulse is transmitted and received in an actual reflection seismic experiment. Figure B shows the relative positions of the transducers submerged in the water tank. A total of 37 traces were shot at regularly -spaced positions, starting from a relative incident angle of zero to 180° at 5- degree intervals (Fig. C). The receiver transducer was also rotated on its (stem) axis and finally the source and receiver transducers were interchanged (Fig. D). All in all, six different experiments were conducted for each transducer pair.

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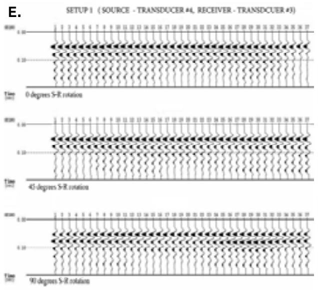

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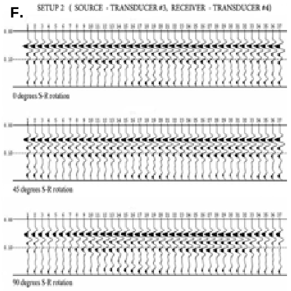

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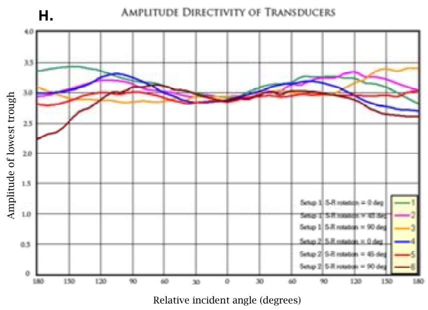

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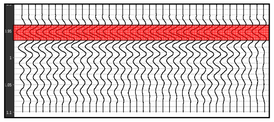
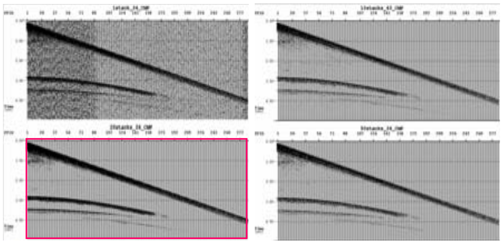


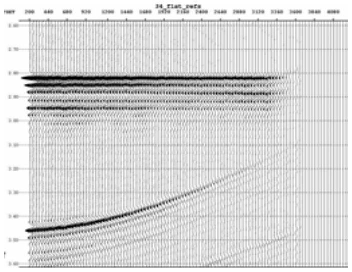
Directivity of Transducers

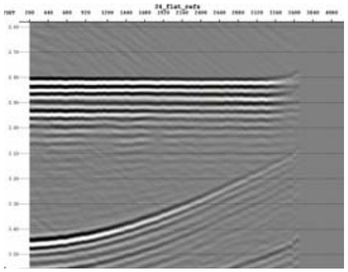
The transducers utilized in the physical modeling experiments emit ultrasonic signal whose characteristics depend on the properties and shape of the transducer. In addition, the pulse generator and signal pre-amplifier also influence the amplitude and phase of the recorded signal. The transducers generate compressional waves through piezoelectric effect. However, because the physical properties of water is considerably different from that of the component piezoelectric ceramics, the impedance mismatch leads to the generated pulse being ringy as clearly shown in figures E-F. Figure E shows three sections corresponding to the setup where transducer #4 was the source and transducer #3 was the receiver. The receiver was rotated on its axis and the experiment was conducted for the same setup at each rotation angle (*e.g.* 0,45 and 90 degrees). Then, the source and receiver were interchanged (Fig. f) so that we determine what particular transducer assignment and position achieves the best signal in terms of producing uniform amplitude and little directivity with angle of shooting. To study the amplitude variation with angle, we compared the maximum (absolute) amplitude of the direct arrivals as a function of the angle of shooting or essentially the relative incident angle of reflection in a simulated reflection seismic survey. Figure H shows that between 0-60°, the maximum amplitude of the signal fall within 5% of each other regardless of the source-receiver assignment or relative rotation. For the rest of the study, we utilized the setup with transducer #3 as the source and transducer #4 as the receiver, with the receiver rotated about 45° on its axis (red curve on Fig. H).

Shown here CMP gathers over a flat solid Plexiglas model using setup 2 (discussed in amplitude calibration section). Stacking the data results yields remarkable improvement of signal:ratio but the effect is more evident from 1-25 stacks than it is for 25-50 or higher. Auto-stacking by the physical modeling system can lengthen experiment run time. A single stacked trace takes about 0.2 s to collect whereas traces stacked 50 times or more need about 0.8 s to gather each. Such a minute increment, leads to big run-time differences when dense trace-sampling is needed especially for 3-D survey simulations. It was determined that stacking the data 25 times affords the best trade-off between run-time and data fidelity.

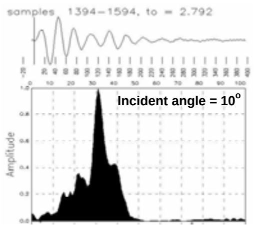


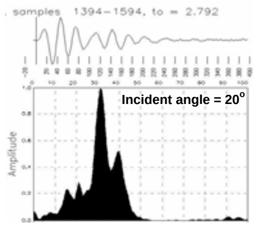
Time delays caused by the electronic components of the physical modeling system were easily corrected by simply picking the highest absolute amplitude reflection event and lining them up to arrive at a predicted time when the source-receiver offset is minimum (7 ° in this example). It is only close or past the critical angle that this technique fails as head waves start to interfere and arrive ahead of the reflection event as shown clearly in the figures below. Note that for the particular data shown here, critical angle is about 40° or roughly at offset equals 3200 (m).

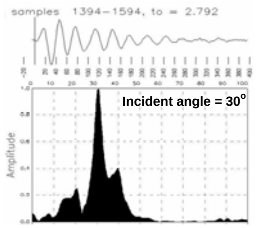


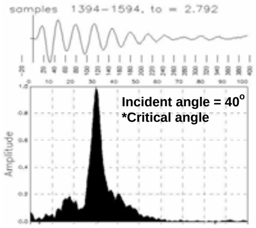


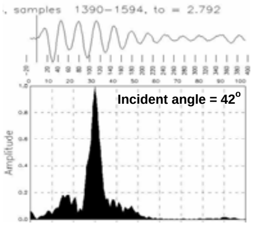
FILTERING THE REFLECTION DATA: WHAT WE GAIN AND LOSE?

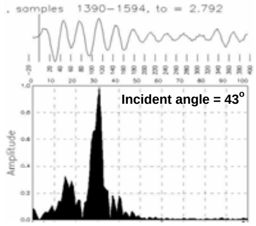


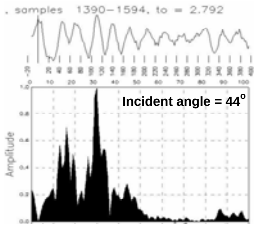


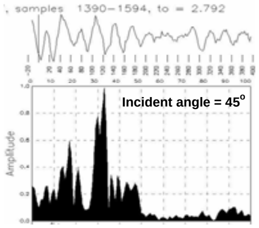












Shown above are the reflection events coming off the top of a CMP survey over a flat Plexiglas model. The data were specifically gathered to study how the source wavelet varies with reflection incident angle. As discussed previously, the seismic pulse coming from the ultrasonic transducer is ringy although it is also clear that the dominant frequency is centered around 33 Hz. The ringiness in source wavelet has a low-frequency character that can easily be eliminated with a properly-designed inverse filter. However, an interesting insight from this experiment is that past the critical angle when energy from the head waves start coming in, applying an inverse filter may in fact be destroying the information that the head waves carry. As shown clearly by the figures above, the amplitude of the low-frequency part of the reflected signal increases whereas its center frequency remains constant at reflection angles greater than the critical angle. Therefore, we determined that applying an inverse filter could significantly "sharpen" the image of the reflections by making the wavelet more compact but there is a need to compensate for the head wave signal lost during the filtering process. We are still in the process of understanding how the empirical data bear upon theory of head wave propagation.