Seismic physical modeling I: acquisition of 2D and 3D surveys involving HTI targets

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ABSTRACT

Scaled-down physical modeling of 2D land and 3D marine seismic surveys has been carried out over two models. Model #1 consists of a Plexiglas layer overlying a smaller rectangular prism of HTI phenolic material. Model # 2 is more complex, consisting of a PVC layer overlying an Plexiglas layer with HTI cylinders of various diameters and directions of HTI symmetry axes, both overlying a second Plexiglas layer with a cut channel. The land surveys were done using different combinations of P-type and S-type piezoelectric transducers. These surveys were done to produce research datasets that are available to CREWEs sponsors, staff, and in particular graduate students.

The marine surveys were conducted using piezopin transducers as sources and receivers. Several acquisition techniques employing single sources and single receivers, and arrays of multiple sources and multiple receivers, were tested to explore how different combinations used in different ways affected survey efficiency. Eight sources firing simultaneously into a single or an array of multiple receivers significantly increased acquisition speed. This procedure produced datasets consisting of super gathers that are the equivalent of the sum of eight separate common-source gathers. Standard migration techniques require that each super gather be deblended to yield eight separate common source gathers. Depending on the area covered, 3D surveys using super-gather acquisition were completed in 6 to 22 days. Each 3D deblended dataset contains on the order of half a million to two million individual seismograms.

INTRODUCTION

The University of Calgary Seismic Physical Modeling Facility (Wong et al., 2008a, b; 2009) consists of a precision 3D positioning subsystem, and a high-speed analogue-to-digital conversion subsystem. In operation, both subsystems are controlled and coordinated by software running under a Windows operating system. The software records seismograms and stores them into SEGY files for-post survey processing and analysis. In seismic physical modeling using ultrasonic transducers as sources and receivers, we typically will apply a scaling factor of 10^4. This means that 1mm in a model represents 10m in the real world, and a model time of 1 microsecond represents 10 real-world milliseconds. In this report, most dimensions and times will be expressed as real-world units.

During the summer and fall of 2013, the facility has been used to carry out several 2D land and 3D marine surveys over two different velocity/structural models that included HTI targets. The resulting SEGY files are available to all CREWEs sponsors and staff. CREWES graduate student in particular should find the experimental data to be valuable for their research projects.

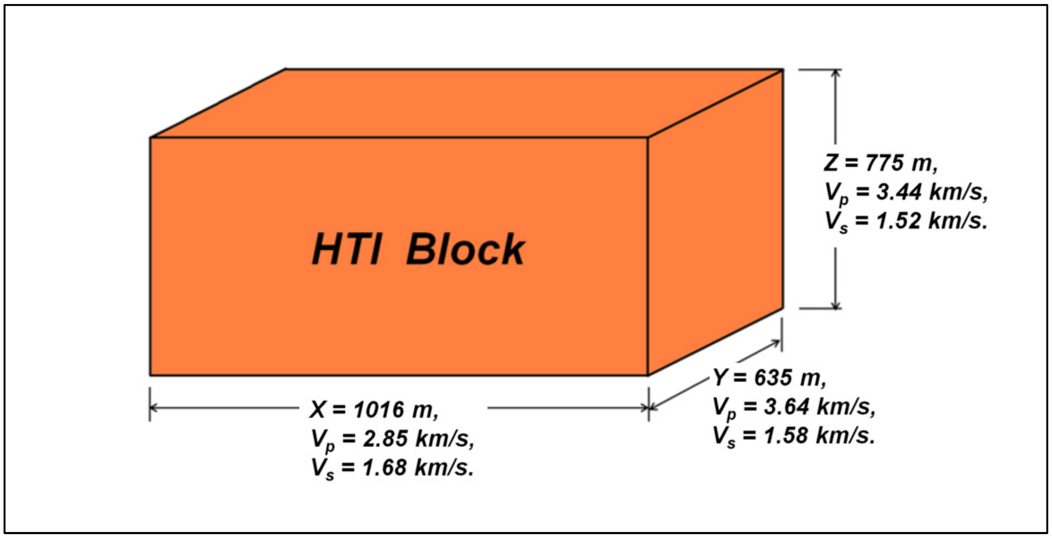

FIG. 1. The LE Phenolic block that serves as an HTI target in Model 1.

Model 1

Model 1 consists of a Plexiglas layer overlying a HTI block immersed in water. The block dimensions and physical properties are shown on Figure 1. The survey schemes for Model 1 are shown schematically on Figure 2. On Figure 2(a), the Plexiglas layer and the HTI block are fully immersed in water, with the active tips of the piezopin transducers raised 300mm above the water-Plexiglas interface. This configuration was used for 2D and 3D marine surveys. On Figure 2(b), the Plexiglas surface is above the water, and the active tips are in direct contact with the solid surface. We improved the coupling of the transducers to the solid material by spreading a thin layer of petroleum jelly on the Plexiglas surface.

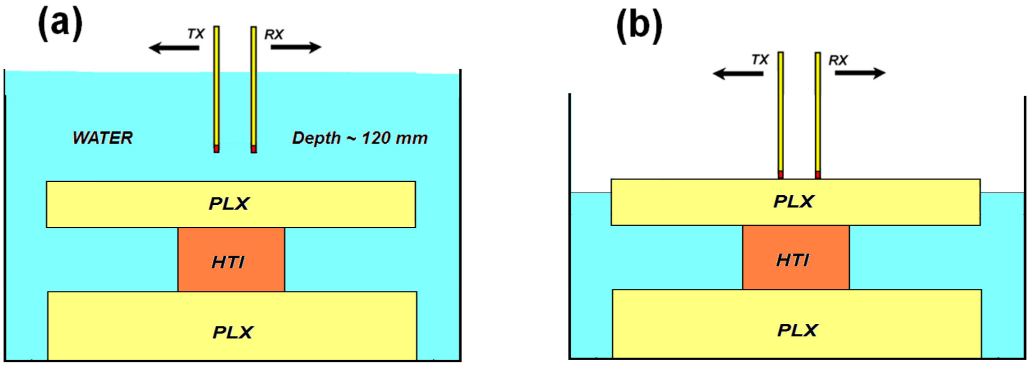

FIG. 2. Acquisition schemes for marine and land surveys involving Model 1.

Model 2

Model 2 consists of a PVC layer overlying a Plexiglas layer with embedded HTI cylinders of various sizes, overlying another Plexiglas layer with an open channel, all immersed in water. This model is shown schematically on Figure 2(c), and was used in a 3D marine survey.

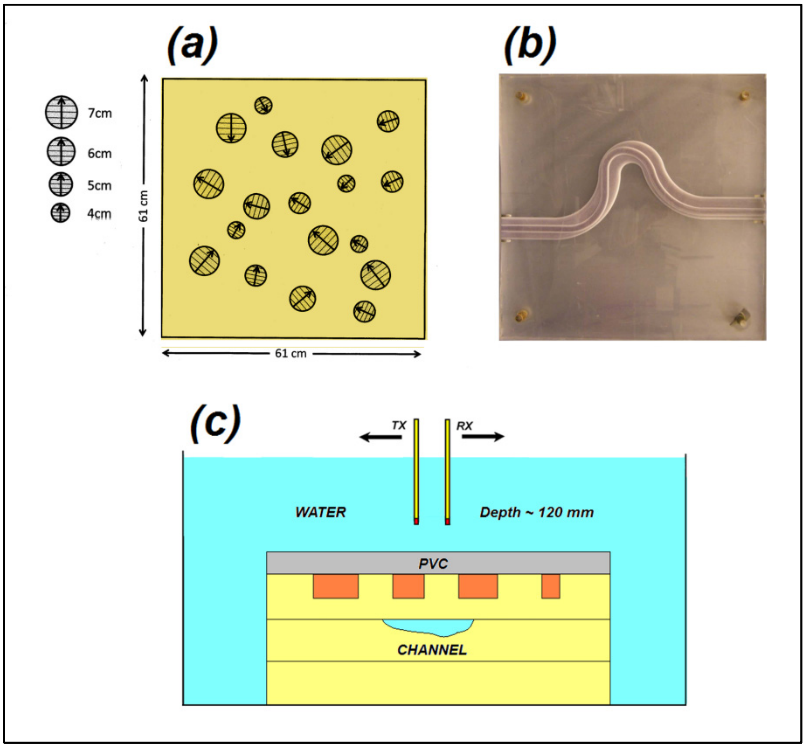

FIG. 3. (a) Top view of the Plexiglas layer with embedded HTI targets. (b) Top view of the Plexiglas layer with a cut channel. (c) Acquisition scheme for marine 3D surveys over Model 2. The P- and S-wave velocities of PVC are 2370m/s and 1120m/s, respectively; the density is 1300 kg/m^3.

ACQUISITION PROCEDURE

We desire that a high-resolution 3D seismic survey be completed in as short as time as possible. In doing such surveys, the act of moving source and receiver transducers from location to location, hundreds of thousands or millions of times, adds significantly to total acquisition time. Therefore, it makes sense to minimize the number of move commands issued by the motion control software. Digitizing and recording millions of seismograms into a SEGY disk files also requires significant time. Therefore, we should seek to reduce the number of traces in a 3D survey, but do this in such a way as not to reduce the total information content.

We used three different acquisition procedures, employing sources and receivers singly or in arrays and in different combinations, in order to evaluate their relative acquisition efficiencies for 3D surveys.

The source array consisted of eight piezopin transducers (Dynasen CA-1136) aligned in the Y-direction and separated by 400m. The receiver array consisted of piezopin transducers (also Dynasen CA-1136) aligned in the Y-direction and separated by 200m.

The first procedure employed a single source piezopin transducer as the source, and a single piezopin transducer as a receiver. The datasets generated by this method consisted of separate common shot gathers, but required many motion commands in order to cover the survey area. The number of seismograms written into SEGY disk files is equal to the number of source positions times the number of receiver positions for each source position.

The second method used a source array of eight piezopin transducers and a receiver array of sixteen piezopin transducers. The sources and receivers were activated sequentially by electronic switching under computer control. Compared to the first procedure, this technique reduces the number of transducer movements by a factor of 144 for the same areal coverage, but the number of traces recorded into a SEGY file remains the same. One issue that arises in using arrays of transducers is that the transduction numbers (and therefore their responses to vibrations) of different transducers may not be identical, so “source and receiver consistent” processing might be required to balance the responses.

The third method used the same source and receiver arrays, but was conducted by firing all eight source transducers simultaneously (see Beasley, 2008, and Bouska, 2010). A gather of traces acquired in this way contains arrivals from all eight sources combined in every trace, and is called a super gather. The number of transducer movements and of recorded seismograms is decreased from that in the first procedure by a factor of eight, but in principle the information content remains the same. Prior to poststack migration by standard techniques, each super gather must be “deblended” or separated into eight common source gathers. In addition, “source consistent” processing might be needed to balance the amplitudes and shapes of events in the separated gathers.

A useful parameter to indicate acquisition efficiency is the average time required to record a single trace in a 3D dataset. This parameter is found by dividing the time in seconds taken to complete the survey by the number of traces in the final dataset.

LAND 2D SURVEYS OVER MODEL 1

Using P-type (Panametrics V133) and S-type transducers (Panametrics V156) placed on the solid surface of the Plexiglas layer, 2D reflection surveys were carried out over Model 1. Figure 2(b) is a schematic plot showing the placement of transducers on the solid top surface of the top-most Plexiglas layer. The 2D land surveys were conducted with TX and RX lines in the Y-direction running over the center of the HTI block.

Table A1 in the Appendix lists the types of SEGY files that were recorded. For example, in the filename “TP_RSX_2D_Sep_13_2013.sgy”, the first substring “TP” indicates the source (or transmitter) is a P-type transducer (responding to vertical motion), while “RSX” specifies that the receiver is S-type transducer with polarization oriented along the Y-direction.

MARINE SURVEYS OVER MODEL 1

Three 3D surveys were done over Model 1. Figure 2(a) is a cross-section view of the model. Figure 4 show schematically the locations of sources and receivers over the gridded survey area. The area covered by the surveys has dimensions of approximately X=2800m by Y=2800m.

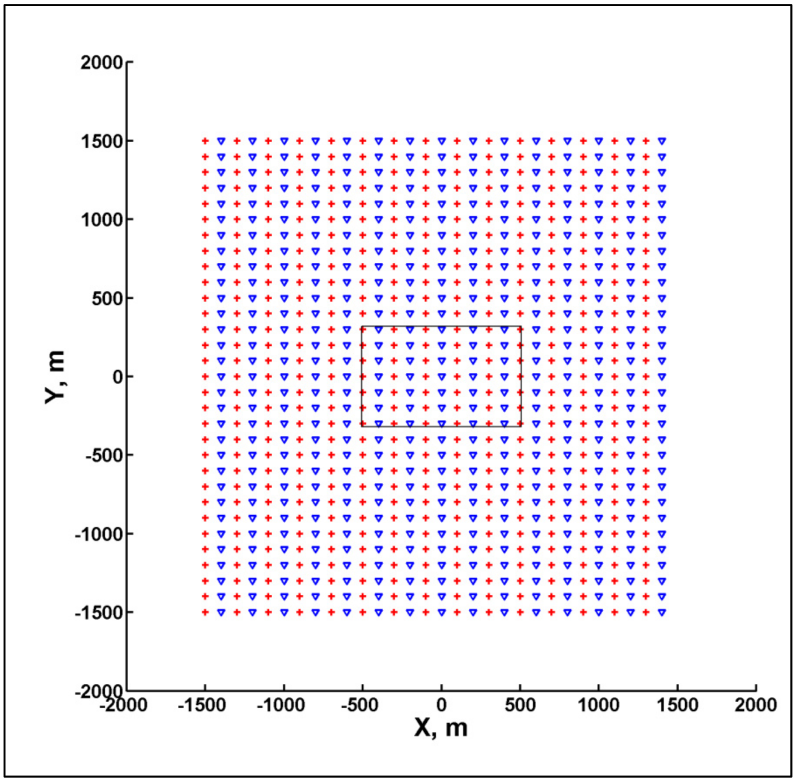

FIG. 4. Schematic representation of the areal coverage by sources (red stars) and receivers (blue triangles) for 3D marine surveys over Model 1. The black outline represents the HTI block beneath the Plexiglas layer.

The first survey list on Table A2 used the array of eight sources firing simultaneously into a single receiver. A single 2D line over the center of the HTI block was recorded. The first survey was a test survey recorded to gauge the effectiveness and speed of simultaneous source acquisition.

The second survey used a source array of eight piezopin transducers and a receiver array of sixteen piezopin transducers. The sources and receivers were switched electronically in sequence.

The third survey used the same source and receiver arrays, but was conducted by firing all eight source transducers simultaneously. The receivers operated were activated in sequence, with each receiver producing a "super trace" that is combines all events arriving from all eight simultaneous sources. A gather of common-receiver super traces is a super gather.

Table A2 in the Appendix lists the three SEGY files and relevant survey information for the three marine surveys over Model 1.

MARINE 3D SURVEYS OVER MODEL 2

The 3D survey conducted over Model 2 generated the three SEGY files shown on Table A3. Figure 3(c) is a cross-section view of the model; Figure 5 is a plan view of the area showing source and receiver locations in relation to the HTI targets beneath the PVC layer. The area covered by the surveys has dimensions of approximately X=5800m by Y=5800m.

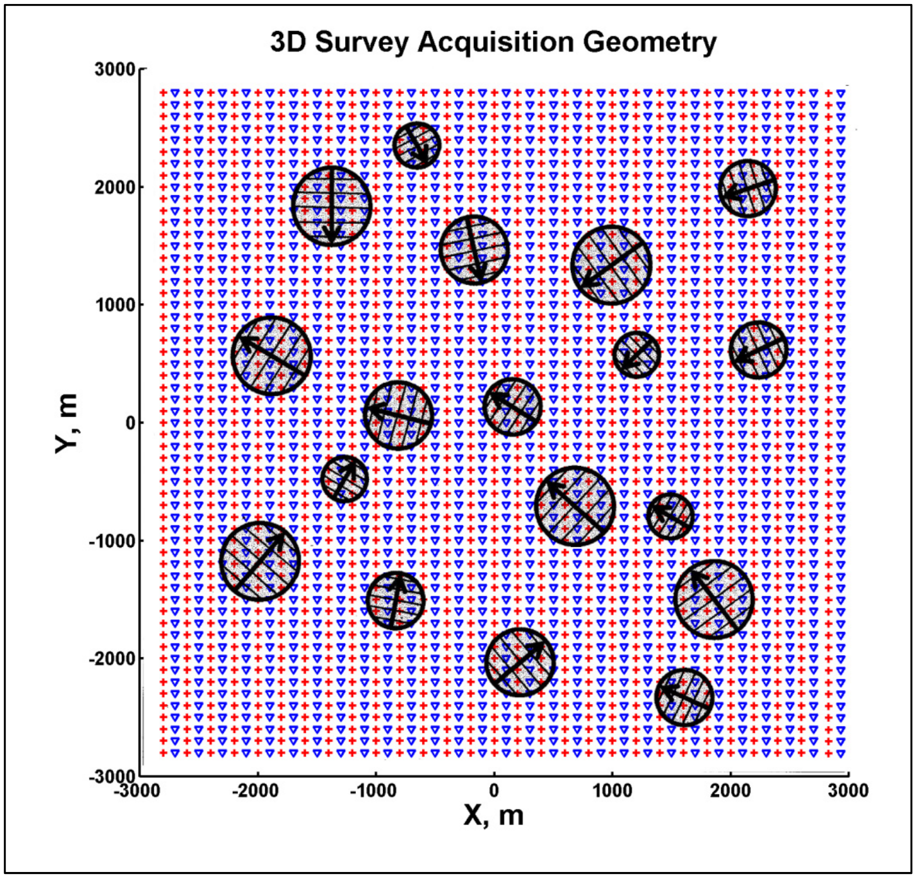

FIG. 5. Schematic representation of the areal coverage by sources (red stars) and receivers (blue triangles) for the 3D marine survey over Model 2. For reference, the HTI targets beneath the PVC layer are shown. The channel beneath the HTI targets is not shown.

For this survey, we used a source array of eight piezopin transducers and a single piezopin receiver. The single receiver was used instead of an in order to avoid the “receiver-consistent” issue previously mentioned.

Table A2 lists the various SEGY files and relevant survey information for the marine surveys over Model 1. The total time to cover the survey area with moderate spatial sampling is about 22 days.

DEBLENDING OF SUPER GATHERS

Acquisition is much more efficient when multiple seismic sources are activated simultaneously. The technique results in "super" common-receiver gathers. On such super gathers, the seismograms associated for a given receiver contain arrivals from all the simultaneous sources. For example, if eight (spatially well-separated) simultaneous sources are used, each super gather will contain events from all eight sources so that displays of the gather have a tangled appearance.

Traditional migration techniques start from data acquired as common source gathers, so that each super gather must be untangled to yield eight separate common source gathers. The process of separating one super gather to obtain multiple common-source gathers is known as "deblending".

In this section we will show the initial steps for separating a super gather from the present 3Dmarine surveys into individual common-shot gathers.

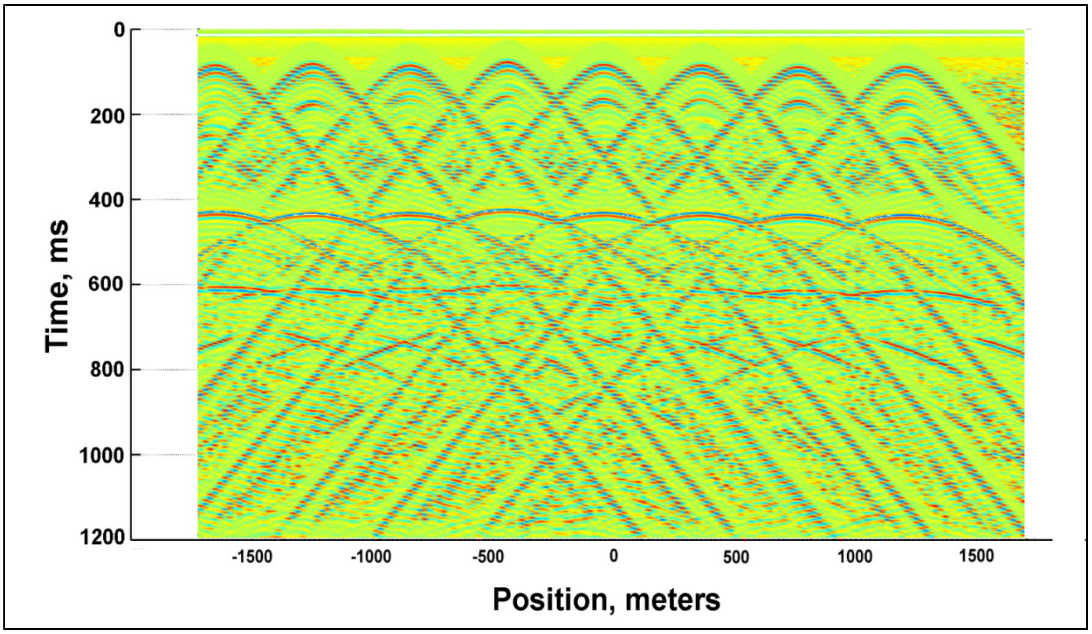

FIG. 6. A super gather of seismograms recorded with eight simultaneous sources. The top-most hyperbolas are direct arrivals though water.

Figure 6 shows an AGC plot of a super gather from the 2D marine survey over Model 1. On this plot, we see the strong hyperbolas assocaited with the water-wave arrivals and the water-Plexiglas reflections from the top of the first Plexiglas layer. The hyperbolas associated with reflections from the bottom of the first Plexiglas layer begin at times just past 600ms. The goal of the survey is to image the HTI target located in the middle of the line, where we can see a low-amplitude anomaly just below 600ms.

In such clear data, it is relatively easy to find time trajectories that match all the visible coherent events. Once this is done, we have effectively separated all the relevant events.

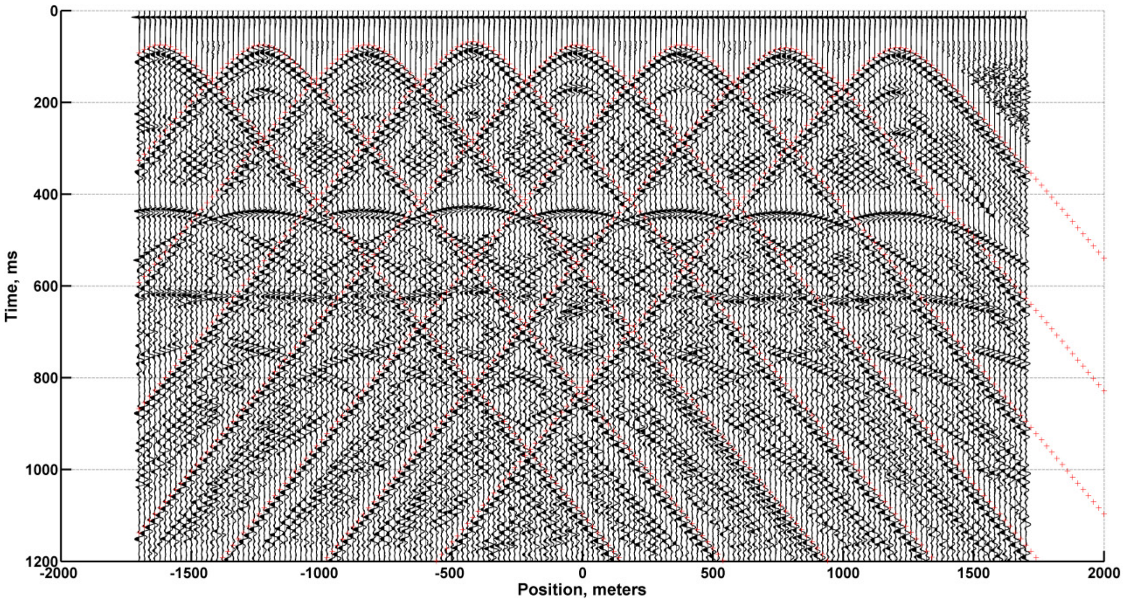

FIG. 7. Fitting hyperbolas to the direct water-wave arrivals is the first step to eliminating them.

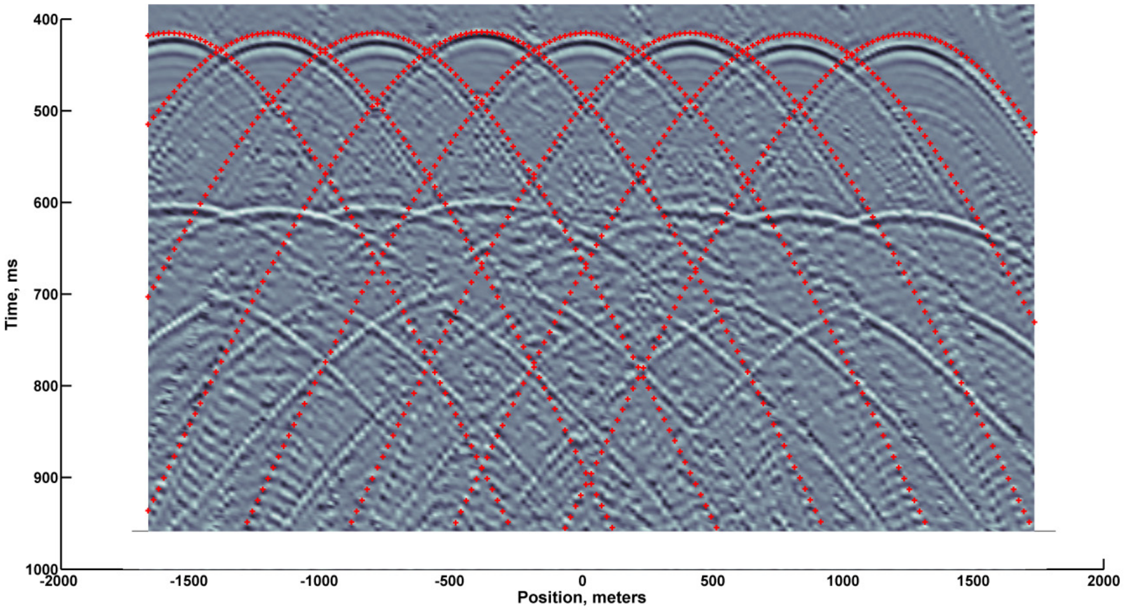

FIG. 8. Fitting hyperbolas to the reflections from the top-most water-Plexiglas interface, prior to stripping their energy from the super gather.

Figure 7 show time picks plotted in red that fit the trajectories of the water-wave hyperbola. The energy in these hyperbolas can be eliminated using step-by-step event alignment and wavenumber filtering (this can also be accomplished using radial trace filtering). Figure 8 shows the super gather after eliminating the direct water-wave arrivals, and with a new set of time picks that fit the trajectories of reflections from the water-Plexiglas interface.

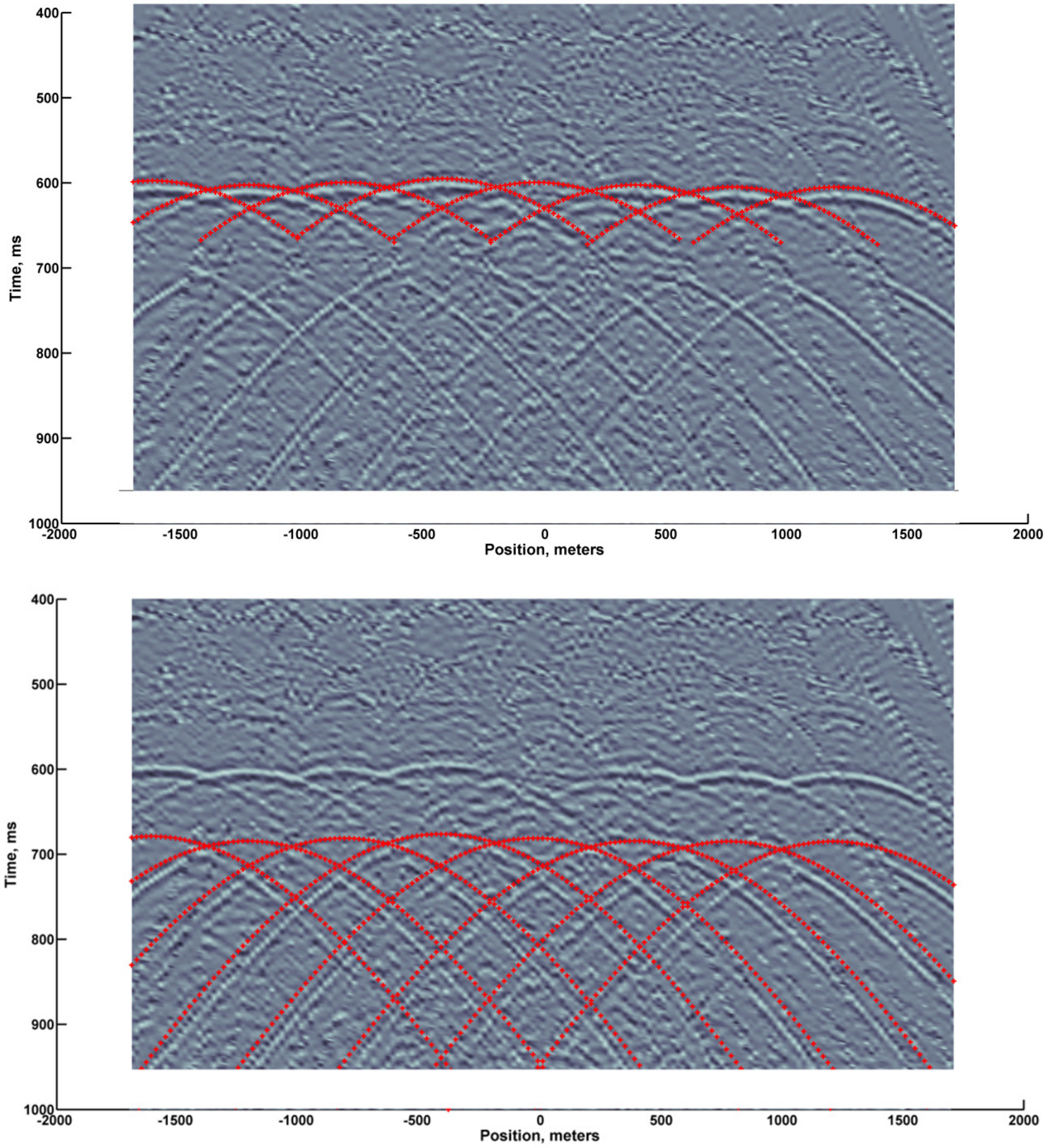

FIG. 9. Fitting hyperbolas to the P-P reflections and to possible P-S reflections from the boundary at the bottom of the first Plexiglas layer.

Figure 9 shows the deeper subsurface reflections on the super gather freed from interference by the direct water wave and the water bottom reflection. At this point, imaging the top of HTI block is almost trivial.

We note that, in the long term, deblending may cease to be of much importance. Active research is being done to image the data in super gathers without first separating them into individual common shot gathers. In theory, imaging by reverse-time migration or by full-waveform inversion can be done effectively and more efficiently by using the total reflected wavefield in a super gather. It remains to be seen how this would work out in practice.

SUMMARY AND DISCUSSION

Three 3D surveys were done over Model #2. The survey area for Model #3 has dimensions of approximately X=5600m by Y=5600m.

We have seen how acquisition efficiency in physical modeling can be increased by using arrays of sources and receivers. An array of eight source transducers firing simultaneously has made it possible to complete high-resolution 3D surveys in a reasonable time. The examples included in this report has indicated that 3D super gathers with the information equivalent to over 2.5 million individual seismograms can be collected in about 22 days. Increasing the number of simultaneously source transducers to sixteen would decrease the survey time to 11 days. Of course, the decrease in acquisition time must be paid for by increased processing time if deblending of the super gathers is required. However, current research is ongoing on the topic of imaging using the information in the super gathers without deblending (reference required). There is no theoretical reason why reverse time migration or full-waveform inversion cannot be done using simultaneous signals from several sources, particularly if these sources are widely-separated in space.

In the present state of the U of C Modeling Facility, analogue-to digital conversion on the signals from multiple receivers must be done sequentially because we have only one A/D channel. Commercial products now exist that do very fast A/D conversions on four or eight channels simultaneously. If we upgrade the facility to include such a product, our acquisition efficiency would increase by a factor of four or eight, meaning that the survey time of 11 days would decrease to less than 4 days (four-channel A/D) or 2days (eight-channel A/D).

ACKNOWLEDGEMENT

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APPENDIX: TABLES OF 2D AND 3D SURVEYS

Model 1 Land Surveys

TABLE A1. Land 2D surveys over Model 1

SEGY File Name	Tx, Rx Spacings, m	Number of Traces	Time, hours
A. RP_TP_2D_Sep_11_2013.sgy	Δy: (100, 20)	4681	7.2
B. RS_TP_2D_Sep_10_2013.sgy	Δy: (100, 20)	4681	8.1
C. TP_RP_2D_Sep_13_2013.sgy	Δy: (100, 20)	2121	3.3
D. TP_RSX _2D_Sep_13_2013.sgy	Δy: (100, 20)	2121	3.3
E. TP_RS_2D_Sep_13_2013.sgy	Δy: (100, 20)	2121	3.3

The files listed on Table A1 are for 2D land surveys, conducted with a single source and a single receiver. The source and receiver transducers make direct contact with the solid surface of the Plexiglas. The 2D lines run in the Y-direction over the center of the HTI block for Model 1.

Model 1 Marine Surveys

TABLE A2. Marine 2D and 3D surveys for Model 1.

SEGY File Name	(Dx , Dy) Spacings, m	Number of Traces	Time, hours
A. Multi_TX_2D-01_Aug_07_2013.sgy	Tx: (0, 100) Rx: (0, 20)	684	0.95
B. Multi_TX_3D-01_Aug_o4_2013.sgy	Tx: (100, 100) Rx: (100, 50)	368,208	108
C. Multi_TX_3D-02_Aug_07_2013.sgy	Tx: (100, 100) Rx: (100, 20)	246,240	162

File A (for a 2D survey) was recorded with an array of eight sources and a single receiver, with all eight sources firing simultaneously, and receivers switched electronically, so that each trace is a super trace associated with a unique receiver.

File B (for a 3D survey) was recorded with an array of eight sources and an array of 16 receivers, with all eight sources firing simultaneously, and receivers switched electronically, so that each trace is a super trace associated with a unique receiver.

File C (for a 3D survey) was recorded with an array of eight sources and a single receiver, with the sources firing simultaneously, so that each trace is a super trace.

Model 2 Marine Surveys

TABLE A3. Marine 3D surveys for Model 2.

SEGY File Name	(Dx , Dy) Spacings, m	Number of Traces	Time, hours
H2O_PVC_PUCK_CHAN_Sep_16_2013.sgy	Tx: (100, 100) Rx: (100, 50)	23.780	15.5
H2O_PVC_PUCK_CHAN_Sep_17_2013.sgy	Tx: (100, 100) Rx: (100, 50)	391,000	254
H2O_PVC_PUCK_CHAN_Oct_01_2013.sgy	Tx: (100, 100) Rx: (100, 50)	418,600	270

The three files listed on Table A3 are all from the same 3D survey. Each file contains data from a different sub-region of the complete covered area.