Preparing the physical modeling facility to simulate injection/storage of fluids and gases in complex structures

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ABSTRACT

The physical modeling facility has been used for many years to simulate real world acquisition experiments with immense success. The system uses models to acquire data to test processing techniques and interpretation methods that have been developed to create an understanding of structure using seismic data more accurately.

To that end, steps were taken in recent years to simulate real world acquisition techniques more accurately. Being able to simulate activities currently being conducted in a smaller, very repeatable way, will be useful to create a database that can be used to determine or predict how varying factors can affect real world acquisition results.

Knowing that gas injection is an area of interest, we devised a scale model for physical modelling of seismic surveys monitoring gas injection into a geological water-saturated porous zone. The goal of this model will be to simulate 2D and 3D surface surveys as well as VSP acquisition in both land and marine environments. With the accurate repeatability of the modeling facility various time lapse experiments can be conducted to determine how injecting over time will change the results of a survey.

INTRODUCTION

With the goal in mind to simulate real world acquisition surveys further and better within the physical modeling laboratory it was decided to create a fluid replacement model. This model could be filled with different media and have different fluids injected into it. This would allow for experiments to be conducted in the lab that could be used to simulate such real-world activities as CO2 injection, which is a current topic of environmental interest.

THE INITIAL PLAN

This experiment began as thought of “can we do this in the lab?” Once the idea was brought up there was some excitement around the ability to perform timelapse surveys as injection was performed. Naturally, this led to a series of trials and errors.

The initial plan was to cut out material from a single layer of a two-layer model and then fill this void with the material to be injected into. The first issue that came to mind with this was that if the material was filled with the same water in the tank, it would not be compressible and that an escape route would be needed. The first model design was sketched onto a white board. This model mimicked real world injection sites with a vertical injection well. A second vertical well would be used to allow the fluid being replaced to escape, Figure 1.

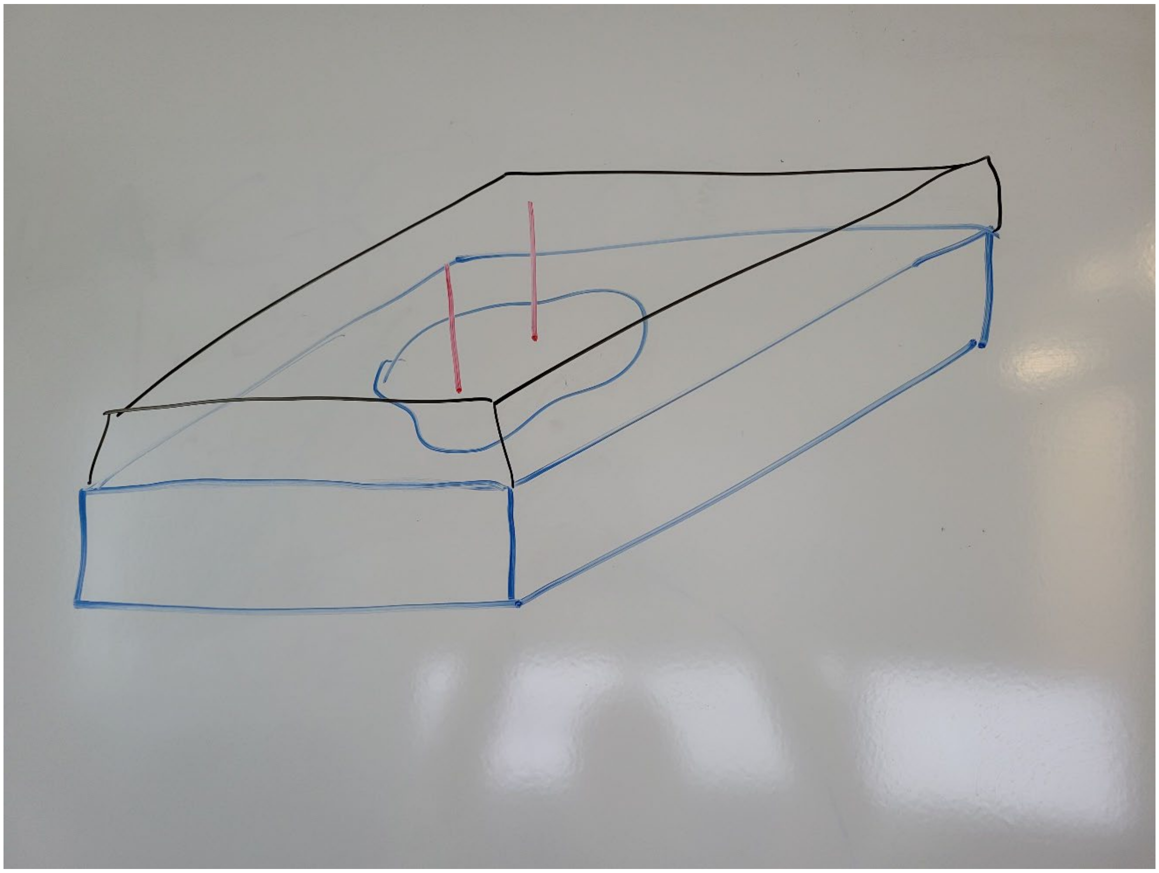

FIG. 1. The first design plan. The blue layer represents the layer with the void cut into it. The black layer represents the layer above the void with the two vertical wells, in red, installed in it.

With this model in mind, it was decided to use PVC plastic for the top layer, acrylic plastic for the layer with the cut out, and glass bead sandblasting material for the media to be injected into. These are all materials that were on hand and already available.

PVC plastic (V_p = 2350 m/s, V_s = 1100 m/s, ρ = 1300 kg/m^3),
water (V_p = 1485 m/s, V_s =0 m/s, ρ = 1000 kg/m3),
acrylic plastic (V_p = 2750 m/s, V_s = 1380 m/s, ρ = 1190 kg/m^3),
glass beads (V_p = 5580 m/s, V_s = 3860 m/s, ρ = 1000 kg/m3).

The acrylic layer of the model was then created using a plunge router. For this initial test no actual pattern was used. The design was simply a basin with the deepest part near the center of the basin. Figure 2 is a photograph of the partially constructed physical model. The milled-out zone in the acrylic layer will be filled with sub-millimeter-diameter glass beads to simulate a porous zone.

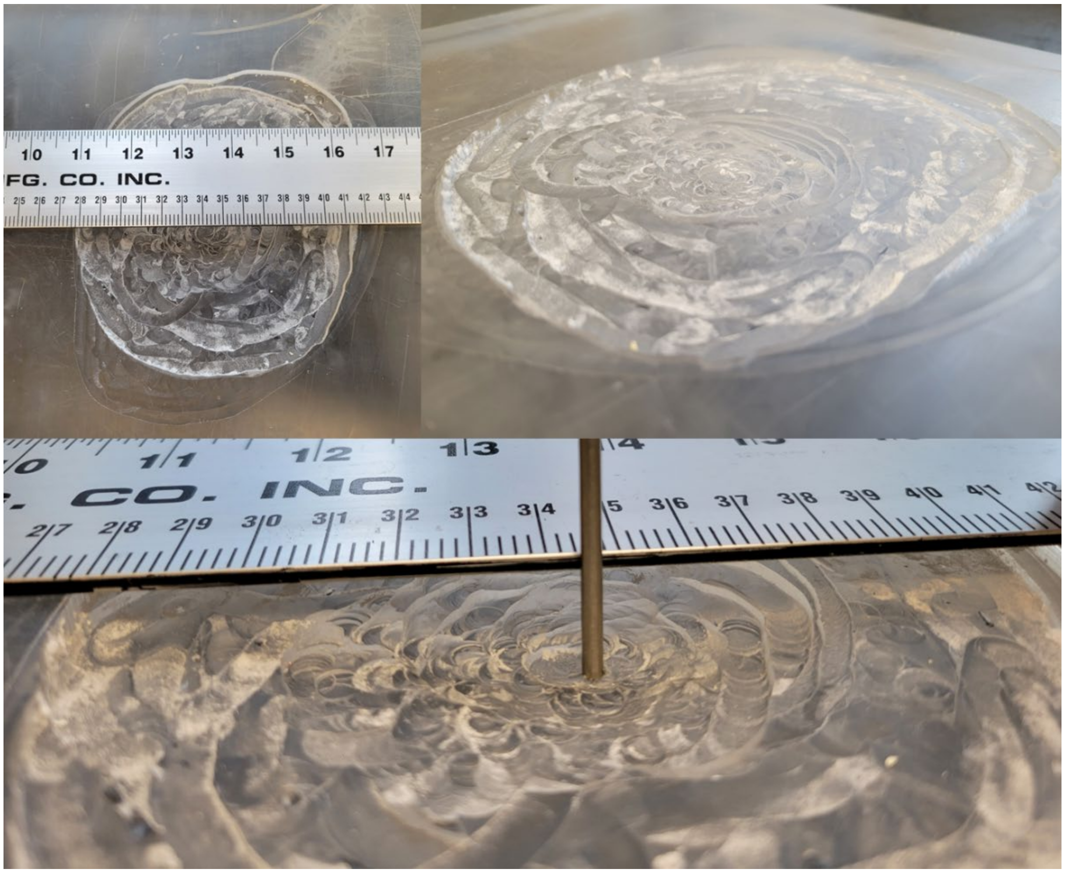

FIG. 2. The acrylic with material removed.

The porous zone can have porosity values ranging from 10% to 30% depending on the mixture of two diameters of small glass beads and how they are packed. For spherical beads of a single diameter, face-centered cubic (FCC) packing gives a porosity of 26%, body-centered cubic (BCC) packing of a single diameter gives a porosity of 32%, simple cubic (SC) gives a porosity of 48%. We cannot control the packing of spheres in the scale model, so we will need to determine an estimated porosity by measurement.

The volume of the basin was determined by measuring the amount of water it could hold. The basin in this model is approximately 124.2 cubic centimetres.

Drillholes through the PVC layer are shown on Figure 3 associated with injection points and there will be access points for VSP receivers. Because of the large-scale factor (10^4) used in physical modelling, the diameters of drillholes and ultrasonic transducers in the laboratory cannot truly represent real-world wells and seismic sources and receivers.

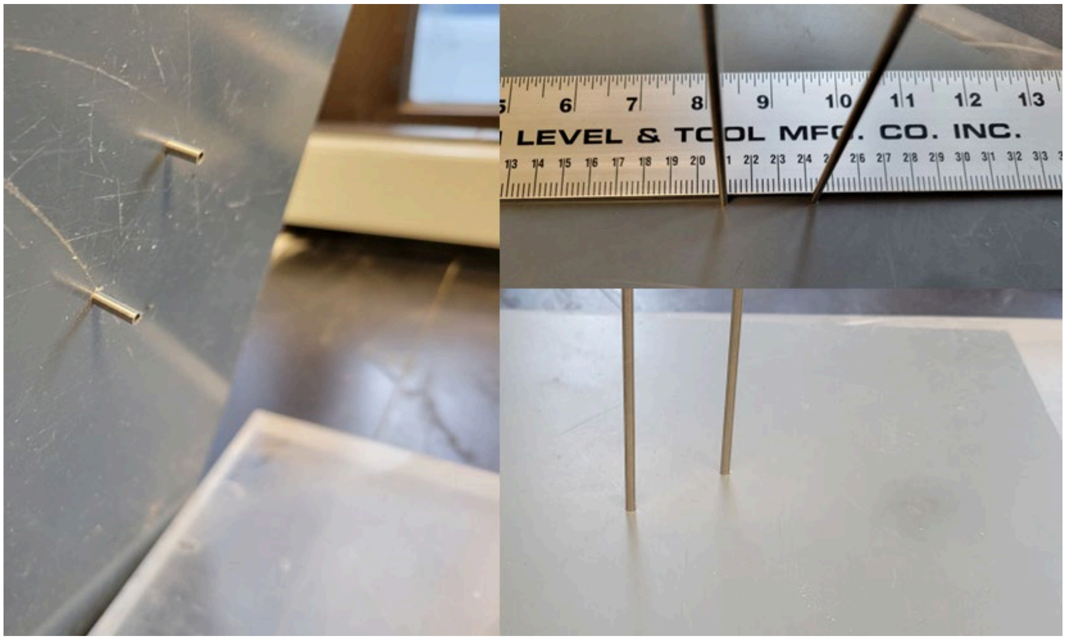

FIG. 3. Injection wells placed in the top layer of the model.

THE FIRST SURVEY

The initial survey conducted on this model was a simple 2D survey to provide a seismic profile across the deepest point in the basin. The acquired seismic profile can be seen in Figure 4. The interpretation from this data is shown in Figure 5.

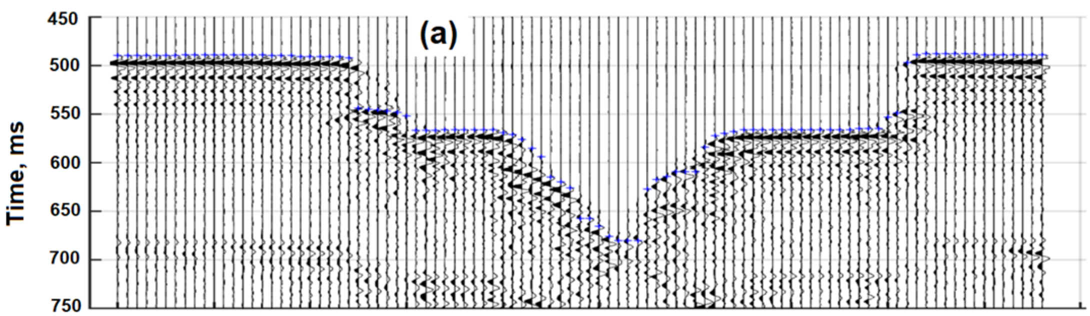

FIG. 4. The first seismic acquisition over the basin model.

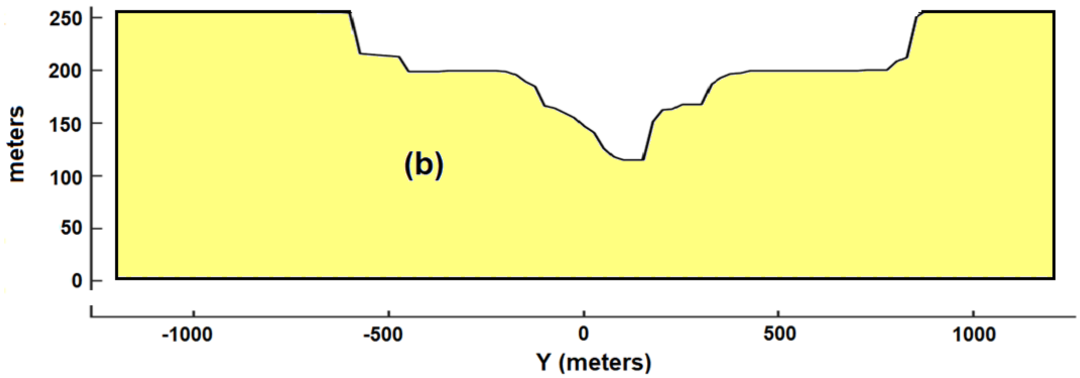

FIG. 5. The interpretation of the model using seismic data.

THE DESIGN CHANGE

Now that there was a two-layer model that the top layer could be used to simulate the ground surface with two wells installed was complete, the first problem arose. While this design did reflect a common real-world approach to such an experiment it would have one challenge for the modeling system. Simulated marine surveys would work fine with set up but should there ever be a desire to perform a surface "on model" survey the two wells would interfere with the modeling system's transducer movements.

The solution to this problem was simply to flip the model over and use it as a mound model instead of a basin model. Injection would then be carried out either through the bottom or side of the model. Once the model was flipped in the tank a 3D survey was carried out to determine the thickness of the mound. The results of this survey are shown in Figure 6.

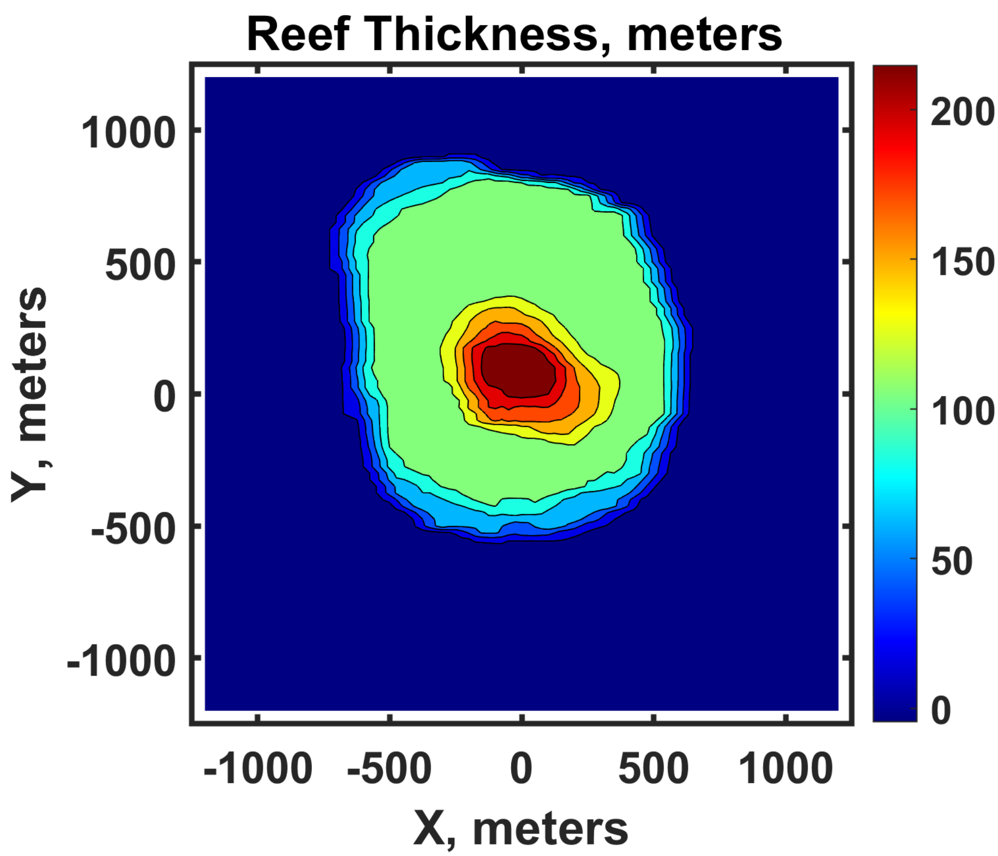

FIG. 6. The thickness of the mound, or “empty space” in the acrylic layer of the model.

Although the problem of running surveys with the transducers closer to, or even on the surface of the acrylic layer was solved there were two things to consider. The first being how to keep the media in the model. The second being how to inject into the model. To first was addressed by again using a secondary layer to contain the media. The second was solved by deciding to inject into the side of the mound.

The most challenging part of the new injection location was finding a drill bit of the correct size that was long enough to reach the mound. Figure 7 shows the drilling of the model and the new injection point.

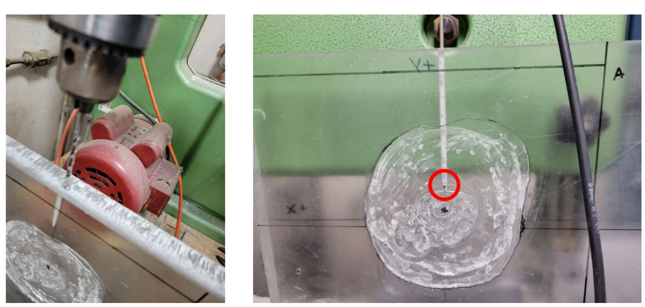

FIG. 7. Left: using a drill press and long bit to access the mound for an injection point. Right: the new injection point.

THE FIRST TEST

Now that the model could be injected into it was time to perform the first test. The initial test was to simply determine if it would be possible to measure changes in the model depending on whether the mound was filled with water or air. Confidence was very high that changes would definitely be evident in the recorded data. To begin with the model was filled with water and a 2D survey was carried out. The results are shown in Figure 8.

The capillary tube being used as the injection well was then connected to the lab compressed air supply and the mound was filled with air. The 2D survey was repeated and the results are shown in Figure 9.

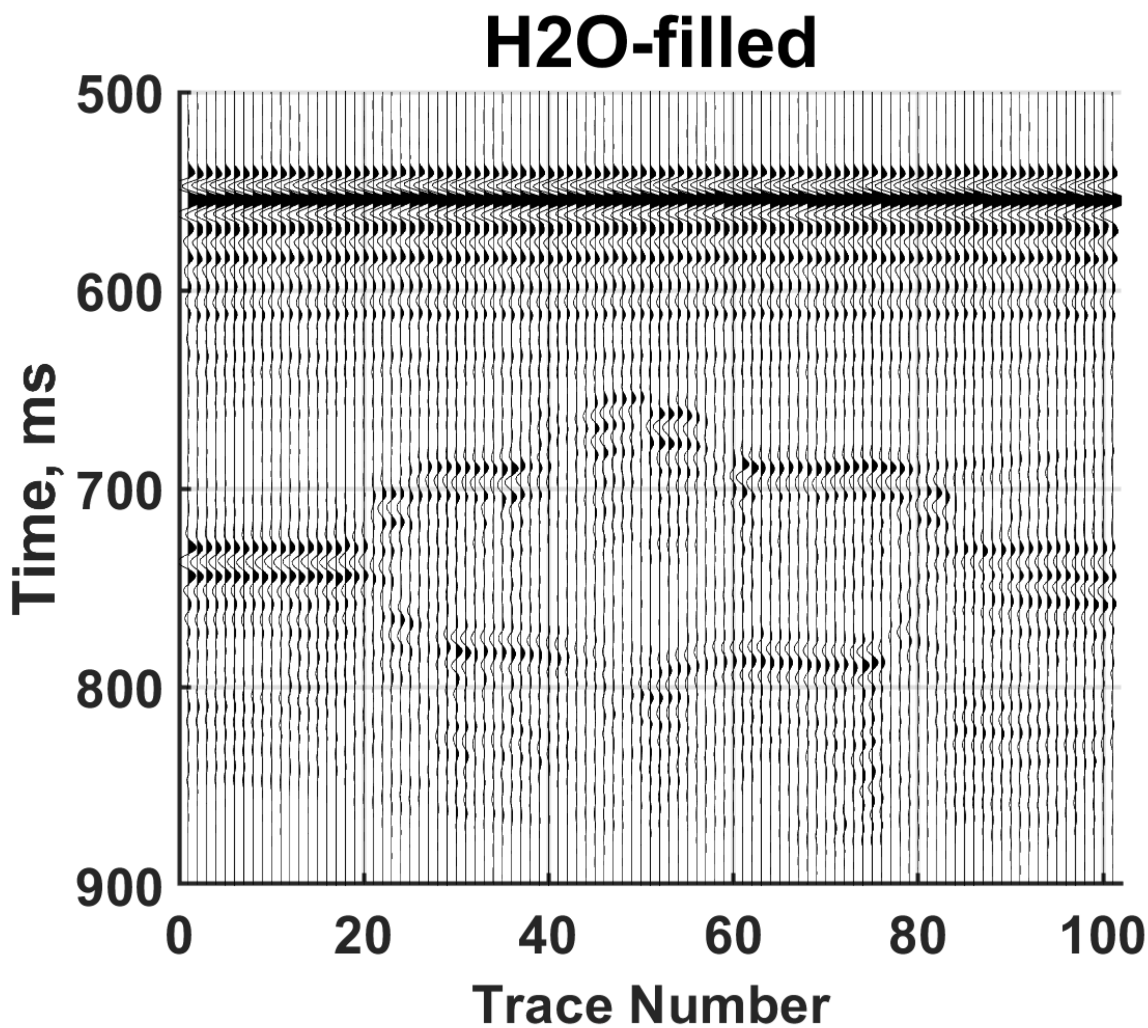

FIG. 8. The results of a 2D seismic survey of the mound filled with water.

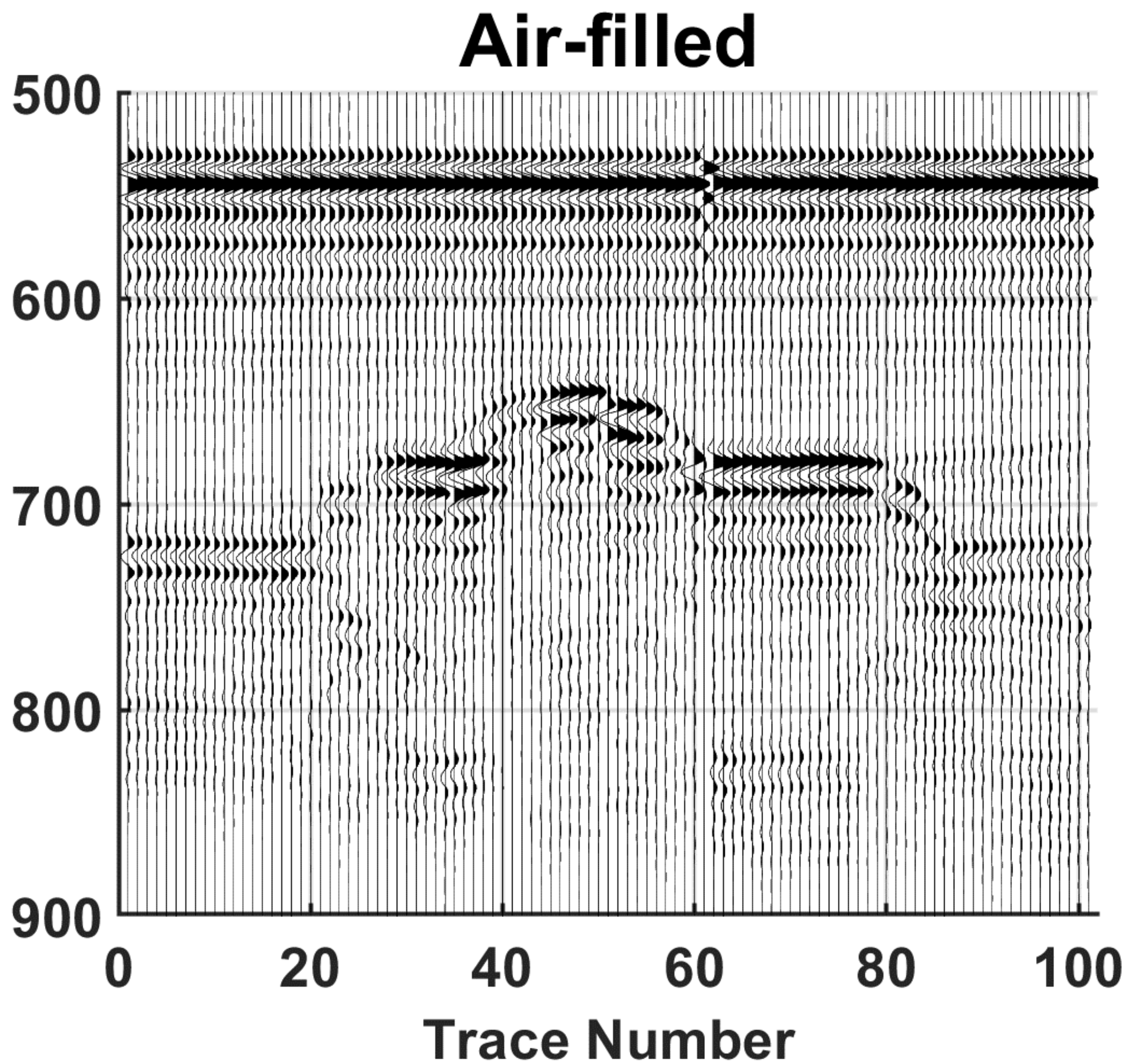

FIG. 9. The results of a 2D seismic survey with the mound filled with air.

Because the physical modeling system is designed to be very accurately repeatable the differences between water filled and air filled are quite obvious. The air filled offers a stronger reflection off the top of the mound.

ADDING A POROUS MATERIAL TO THE MOUND

Now that results proved that differences will be measured it was time to fill the mound with porous material. The material chosen was glass beads used for bead blasting as these were already available in the lab. The model was removed from the tank and dried off. The model was placed on the bench upside down and the void was filled with the beads. A straight edge was then used to level off the beads to match the surface of the model.

It was then decided that the porosity of this media should be determined. The weight of a small container of water was measured and then the media was saturated using this water, Figure 10. Once done the weight of the container of water was measured again. 46.5gm of water was used to fill the space between the beads, which is equivalent to 46.5cc. Previously knowing that the volume of the mound is 124.2cc the porosity is simply calculated as:

46.5cc / 124.2cc = 0.37

FIG. 10. Using water to determine the porosity of the glass bead blasting media.

Now that the porosity was known it was time to attempt to inject into the media. The first attempt was performed with the model still on the bench. It was only done to ensure that air could be injected into the glass media. This simply blew the bubble that is shown in Figure 11.

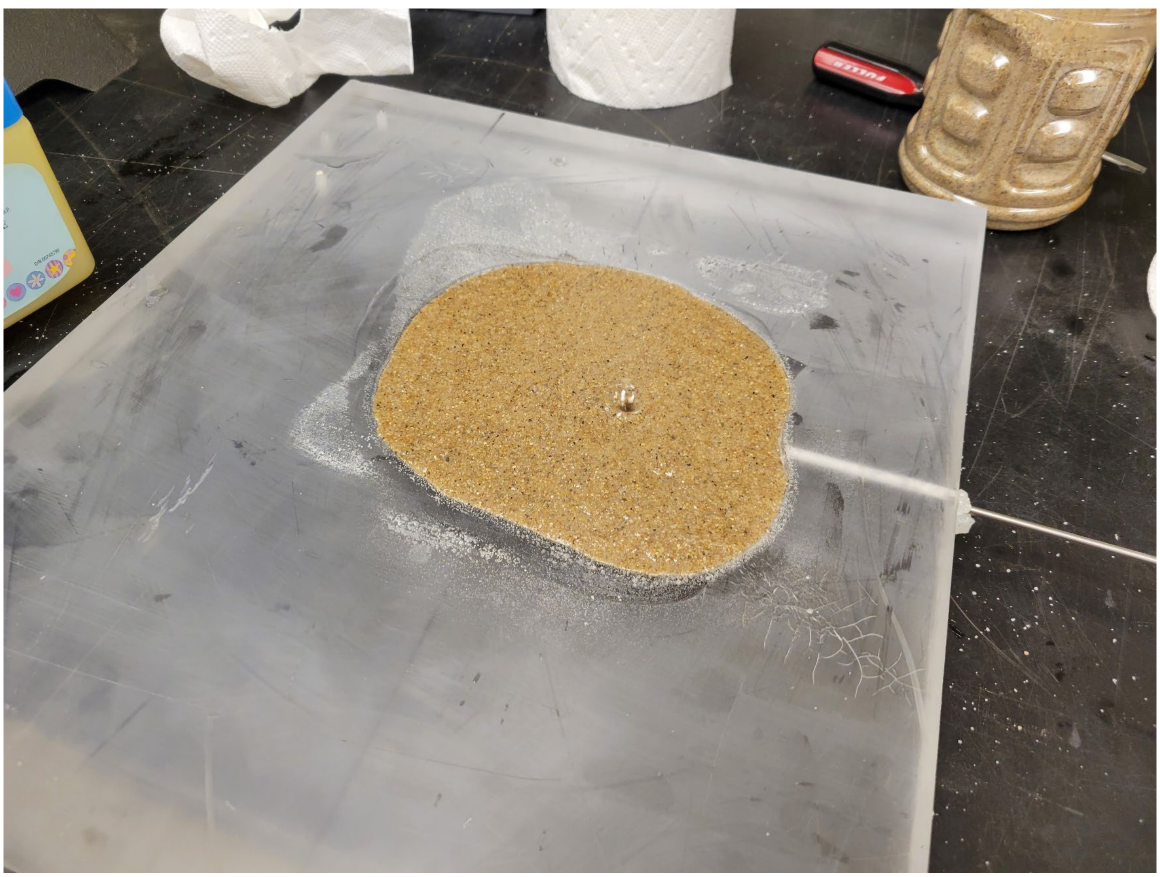

FIG. 11. The first proof of air injected into this media.

Now that the excitement level was high it was a rush to get the model into the tank to inject air into the sand. A thinner acrylic layer was placed over the water saturated beads and the model was flipped over in preparation for putting in the tank, Figure 12. A thin line of petroleum jelly was used as a breakable seal between the two layers.

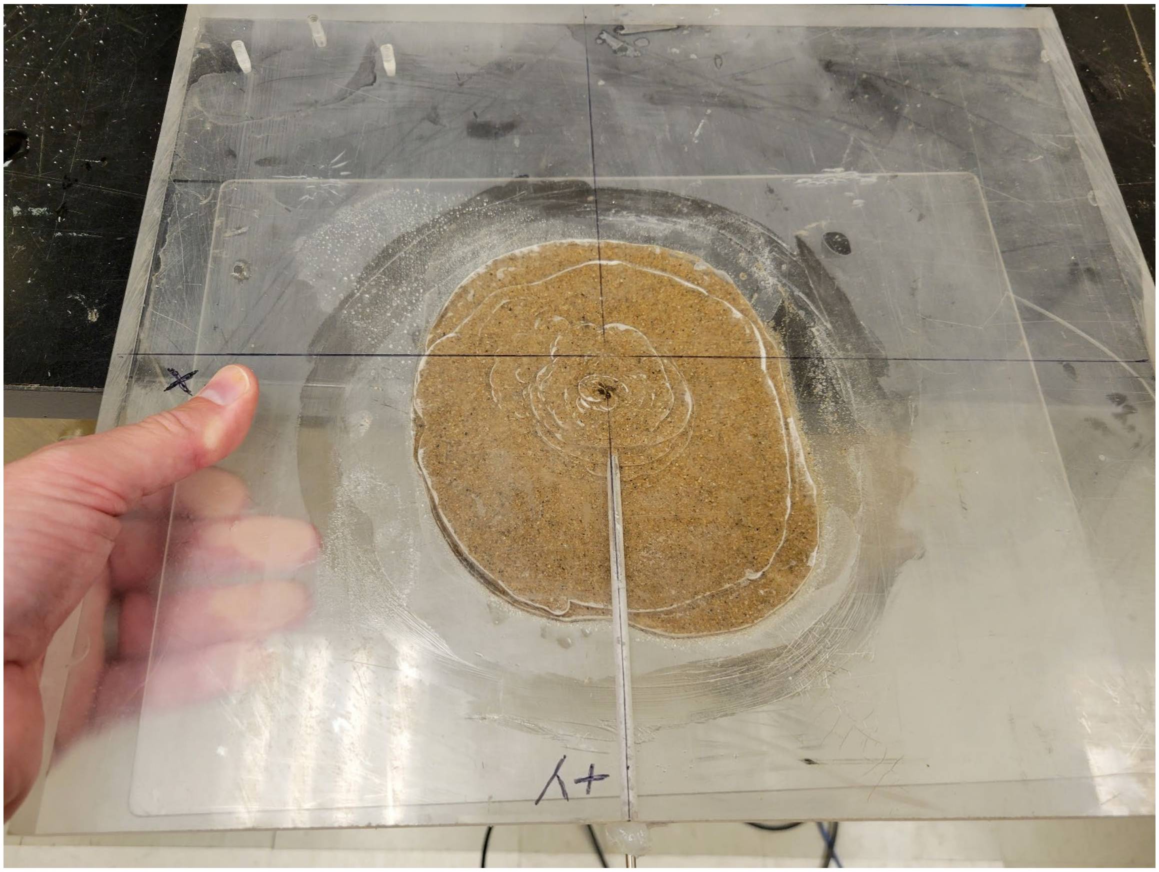

FIG. 12. The water saturated model is ready to be placed in the water tank. The ring of petroleum jelly can be seen surrounding the mound in the model.

The model was placed in the tank and once again the lab air supply was used to try and inject a small amount of air. Unfortunately, this did not end with success. The laboratory air supply was not designed for small adjustments. As such, even though only small adjustments to the valve were made, too great of a volume of air rushed into the model. This caused the model to lift off the layer under it and instead of simply displacing the water in the glass beads it displaced the glass beads. The aftermath of this is shown in Figure 13. A new, gentler method of injecting air would be needed.

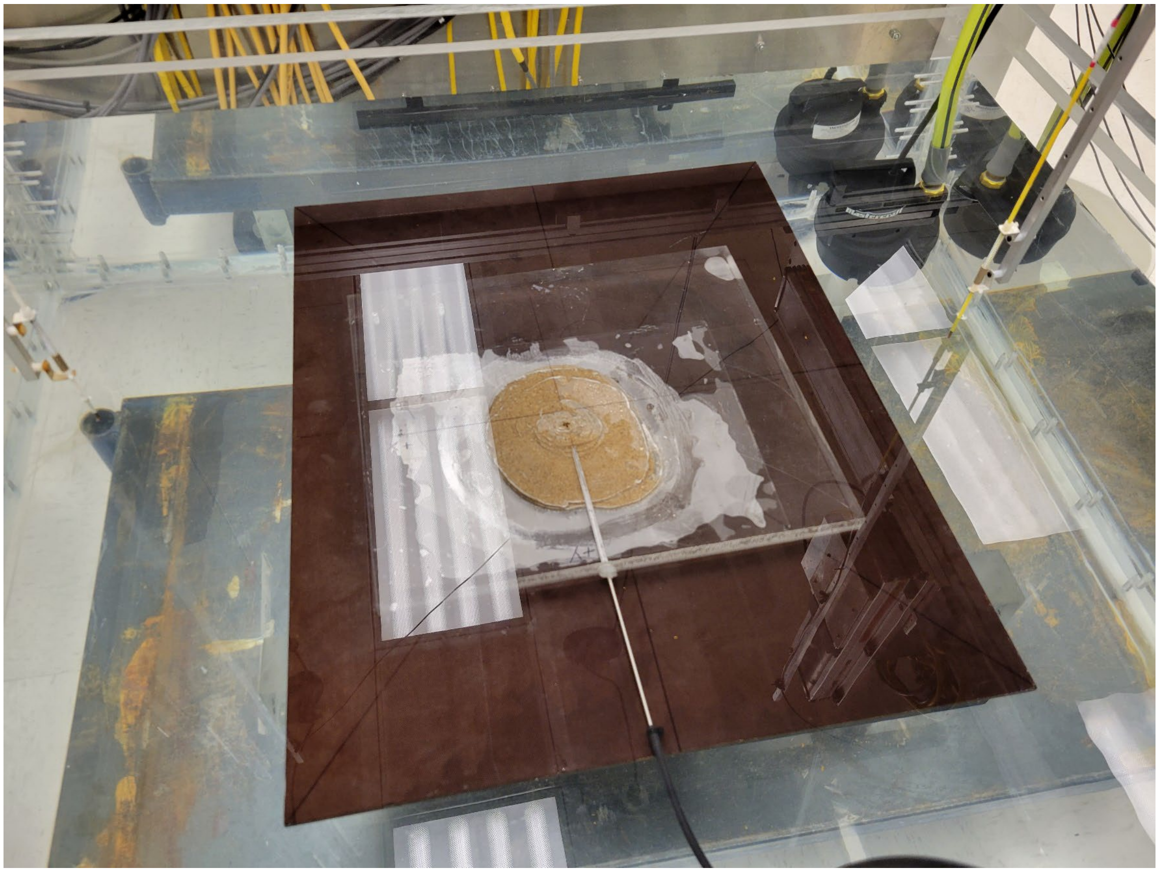

FIG. 13. The first attempt to inject air into the mound in the tank.

NEW INJECTION METHOD

After searching control valves for reducing the volume and pressure of the lab air supply it was determined to be more cost effective and simpler to instead use a manual bicycle pump. This allows for more control over how the air enters the model. It was also determined that for ease of use the layer that the new mound model would sit on should be able to attach to the layer under it. A piece of thin steel was used for this. Holes were drilled in both the acrylic layer and the steel and nuts and bolts were used to hold the two together.

Once the model had a base/top that could be bolted on it was filled with sand again and then flipped over so measurements could be taken. Unfortunately, this proved to be a little more difficult than anticipated. Although the two pieces were bolted together the sand was able to come out in the small gap between them. A successful method of filling the model with sand and flipping it over was found. Instead of filling the model with dry sand the sand was made wet using the demineralized water that the tank is filled with. Once the sand was leveled off a ring of petroleum jelly was applied outside void. Finally, four sheets of paper towel were placed over the sand and then wetted. This acts as a barrier that can be slightly compressed to hold the sand in and should allow air to pass through when it is pumped into the model.

INJECTING USING GLASS BEAD MEDIA

Now that the injection method and model had been improved to a working state it was finally time to perform the first injection experiment. A 2D line was acquired over the tallest part of the mound with sand and water both present in the mound, Figure 14.

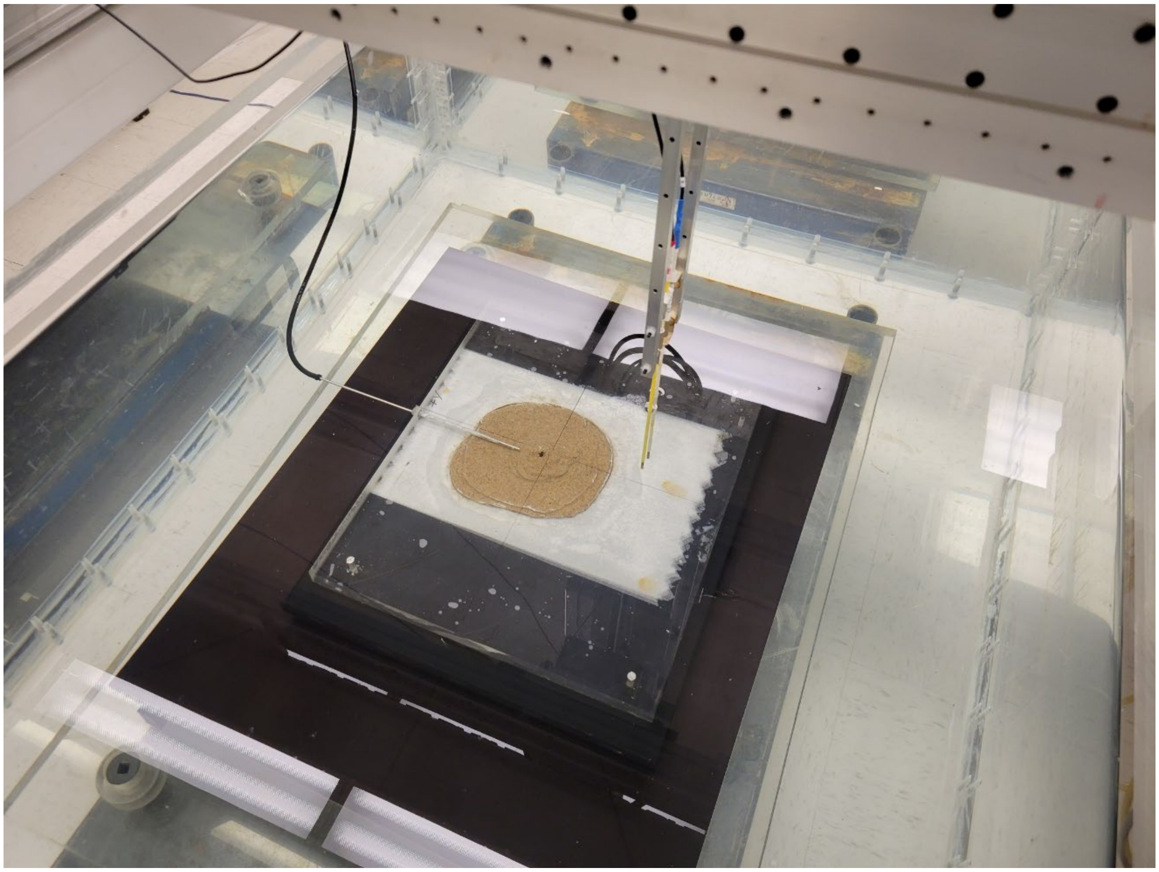

FIG. 14. The model in the tank ready for the first acquisition of both sand and water in the mound.

Unsurprisingly the results of this acquisition looked similar to the purely water filled test that was run earlier. These results are presented in Figure 15.

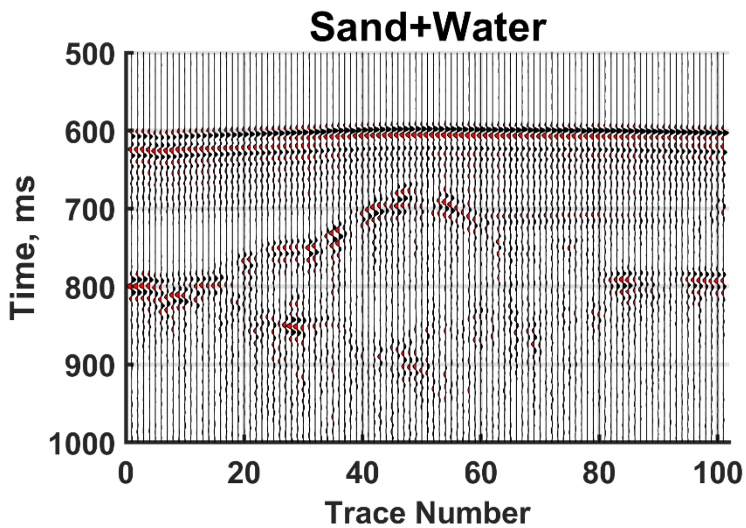

FIG. 15. Common offset gather of seismic data over the mound model with sand and water filling the void.

Now it was time for the first controlled injection of air. The plan was to use the pump in a gentle and slow manner to inject a small amount of air. Unfortunately, the seal created between the mound model and the layer beneath it benefitted with the pressure created by the water in the tank. This resulted in a pressure buildup in the hose between the pump and the model. Eventually the pressure built to the point where the seal could be overcome. This resulted in an initial flood of air into the model. Some of this air escaped through the seal and is clearly seen below the acrylic model in Figure 16. However, the glass beads remained in the model this time.

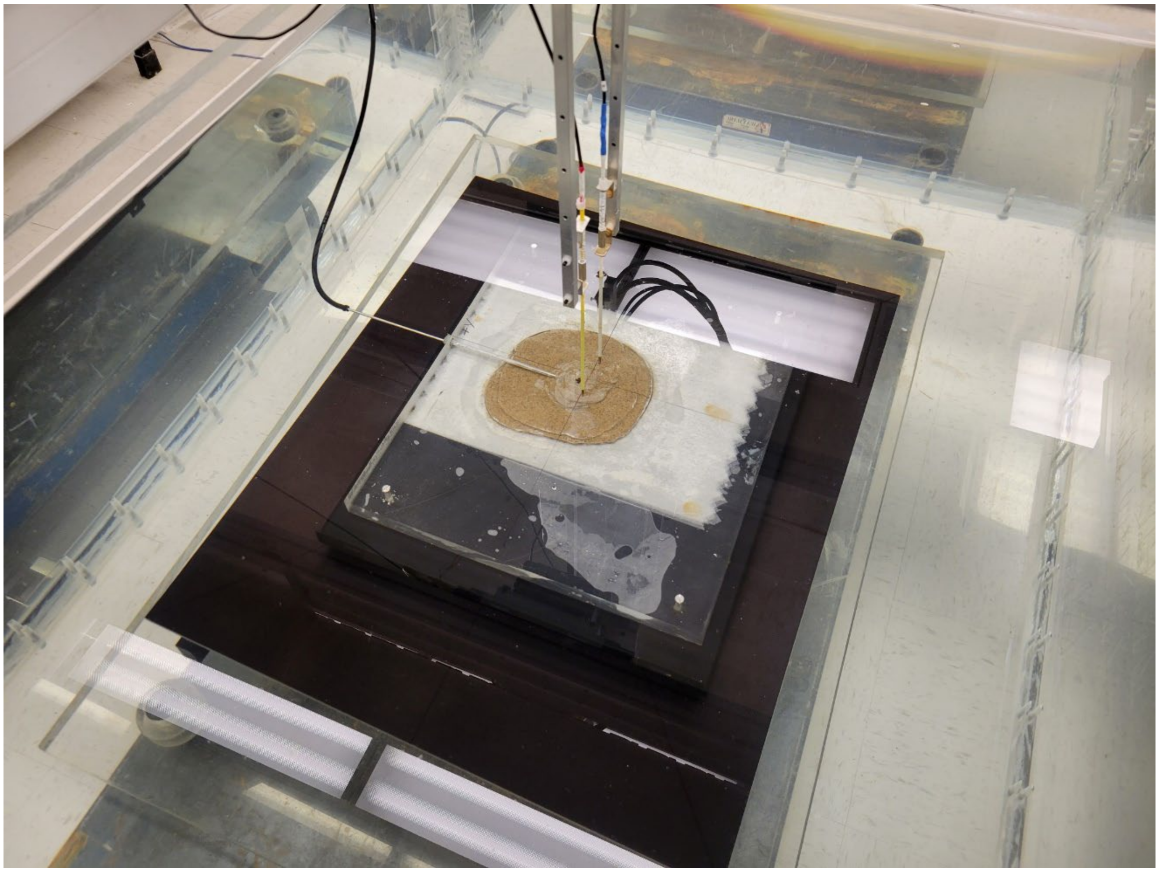

FIG. 16. A little too much air was injected into the model. This air followed the path of least resistance and ended up under the model.

Even though there was too much air injected into the model, this air did not settle inside the mound and ended up on the other side of the seal. As such the model was once again ready to be used for data acquisition. The same 2D line was acquired again. Happily, the data acquired did indeed appear different when compared to the sand and water acquisition. The results are shown in Figure 17. The difference between the two sets of data is presented in Figure 18.

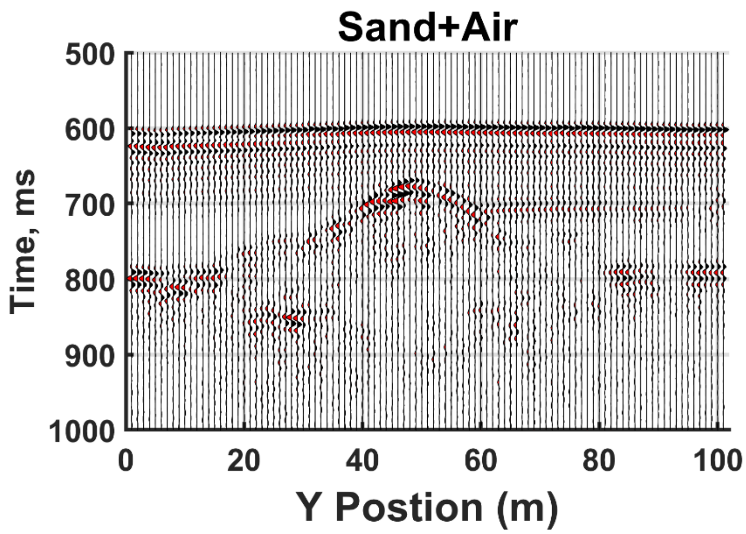

FIG. 17. The acquired data after the first successful injection of air into the glass bead media.

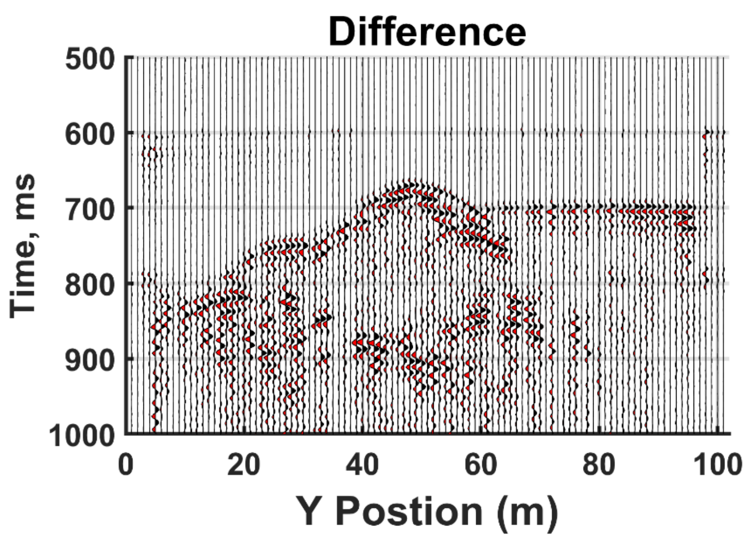

FIG. 18. The difference between the water filled sand and the sand with some air injected plotted.

The final test that was performed at the time of writing this report was a short time lapse to determine if the model would hold the injected air or if it would leak out. After ten minutes the same 2D line was acquired over the model again. The results are shown in Figure 20, and a difference plot between the initial post injection data and the later most recent data is shown in Figure 21.

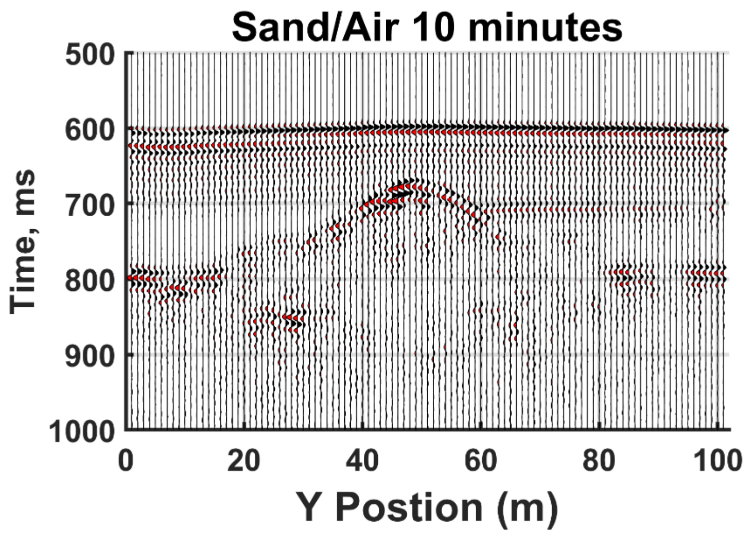

FIG. 20. The air injected data ten minutes post injection.

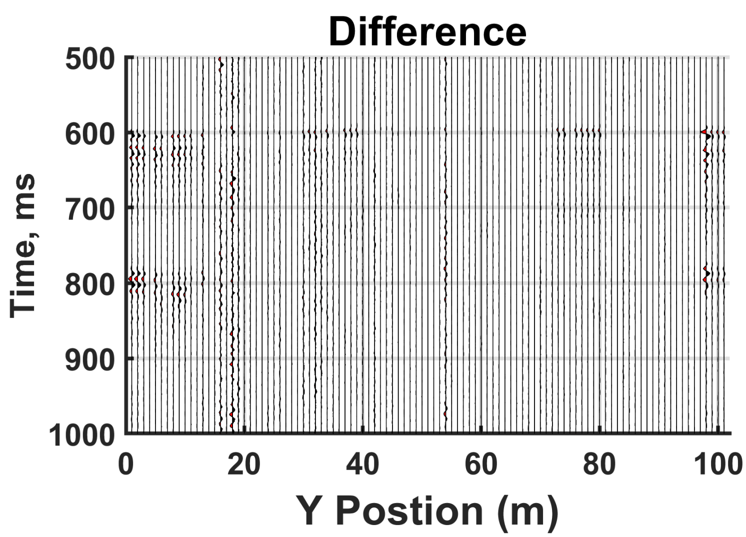

FIG. 21. The difference between the air injected data acquired from the model immediately post injection and ten minutes later.

CONCLUSION

This model has proven to be a success. Even though some things cannot be scaled, such as surface tension of water, this model can be used to demonstrate differences in seismic acquisition as the substance within a porous media is replaced. These tests can be used to help create a baseline for people and software to study the expected outcomes of injection and storage applications.

FUTURE WORK

Having proven that this model works to scale down an injection/storage application there are many further tests that can be performed. The first obvious change that should be explored is the inclusion of a VSP survey. This will require that a solid cased tube be placed in the model large enough that one of the modeling system transducers can be inserted and moved in the z-plane to record data at different depths. Unlike real world applications this "well" would have to be installed prior to the porous media being installed in the mound. An example of how this could potentially be inserted can be seen in Figure 22.

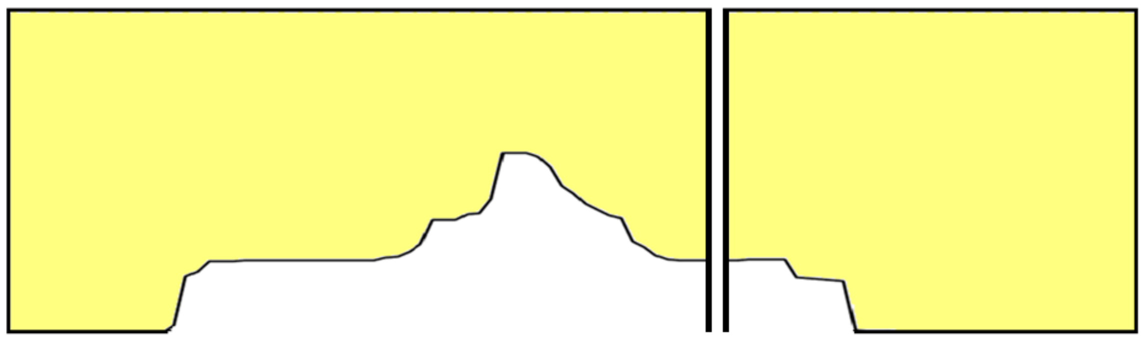

FIG. 22. The addition of a "well" for VSP surveys.

The media that was used in these initial surveys is an inexpensive bead blasting material that does not have strict control over the size of the individual grains. A new material, aluminum oxide, has since been purchased and will be used for another test. This material has more control over the grain size and will be more uniform. Once concern with this is that since the individual grains are the same size it will like pack tighter and will require more effort to inject air into it.

As mentioned earlier the model is built in a way that the transducers can be placed on directly on top of the model to change the acquisition survey from a modelled marine survey to a modelled surface survey.

All the intended acquisition surveys will also be extended to perform 3D acquisition. They will then be extended even further into time-lapse surveys with some injections performed after the previous record is acquired.

ACKNOWLEDGEMENTS

We thank the sponsors of CREWES for their continued support. This work was funded by CREWES industrial sponsors and NSERC through the grant CRDPJ 543578-19. This work was partially funded by Emissions Reduction Alberta (ERA), as part of the Accelerating Carbon Technologies (ACT) 4 project SPARSE (Sparse Passive-Active Reservoir monitoring using Seismic, Electromagnetics, gravity, and surface deformation).