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INVESTIGATION OF A TECHNIQUE THAT USES BOTH ELASTIC AND ELECTROMAGNETIC WAVES TO DETECT BURIED LAND MINES

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INTRODUCTION

A system is being investigated that uses elastic waves as the primary detection mechanism to detect buried land mines [1]. The system is shown in Fig. 1. In the system, a stationary transducer, located on the surface of the soil adjacent to the search region, generates an elastic wave in the earth. The elastic wave propagates through the search region and interacts with the buried mine. This causes both the mine and the earth to be displaced. The displacement of the mine is different than that of the earth, because the mechanical properties of the mine are different than those of the earth. The radar is used to detect these displacements and, thus, the mine. The interaction of elastic waves with buried land mines is being investigated using both numerical and experimental models.

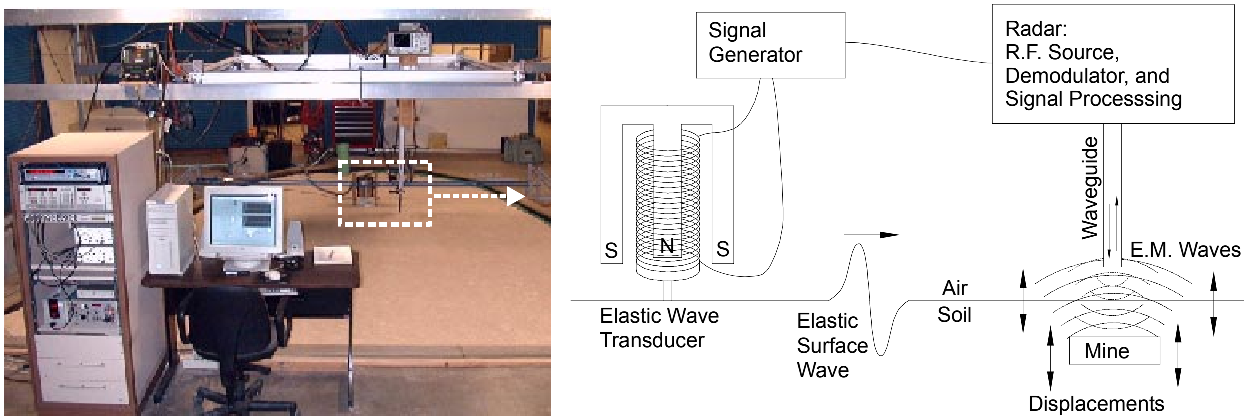

Figure 1. Photograph and schematic diagram of the experimental model**.**

EXPERIMENTAL AND NUMERICAL MODELS

Numerical and experimental models for the system have been constructed. The numerical model is a three-dimensional, finite-difference time-domain (FDTD) model for elastic waves traveling in the earth. The model is linear and is based on the first-order elastodynamic equations that are differenced in space and time. Pressure, shear, and Rayleigh (surface) waves are all modeled by the algorithm. A perfectly matched layer is used to absorb the waves at the edges of the model, and a free surface boundary condition is used to model the boundary between the earth and the air.

The experimental model uses an electrodynamic transducer to induce the elastic waves, a sand filled tank, a simulated mine, and a radar to measure the surface displacements. The transducer is a 20 LB moving coil shaker coupled to the sand through a narrow foot to preferentially excite surface waves. The tank is approximately 4.5 m wide, 1.5 m deep and 4.5 m long; and is filled with 50 tons of packed damp sand to simulate the earth. The radar is an 8 GHz

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continuous wave homodyne system specially designed for measuring the surface displacements. The radar is automatically scanned over the surface of the sand to measure the surface displacement field.

RESULTS

The models have been used to study the interaction of the elastic waves with a variety of different mines, simulated and inert. The results in this paper are for a simulated mine that consists of an air-filled plastic cylindrical container. The container is 9 cm in diameter and 2.2 cm in height and has thin flexible walls. This simulated mine was chosen because it is a simple structure that can be easily modeled using the current numerical code by neglecting the effects of the walls. The walls of the container are not expected to contribute significantly to the response of the mine because they are more compliant than the overlaying layer of sand. For the experiment, the simulated mine is buried in the sand and the sand is carefully re-compacted around the mine. The mine is placed 80 cm from the shaker in the center of the scan region.

A series of waterfall graphs of the displacement of the sand surface is presented in Fig. 2 for both the experimental and numerical results using two different burial depths for the simulated mine. In these graphs, the displacement is plotted as a function of time for 101 measurement points spaced in 1 cm increments away from the source in the direction of the mine. Each of the 101 time traces is shifted vertically from the previous one. The bottom trace represents the measurement point closest to the source. The region in which the mine is located is indicated in gray. Many of the discrepancies between the experimental and numerical results can be attributed to non-uniform motion of the shaker foot. The foot exhibits several sand-loaded resonances in the frequency range of interest. In addition, the depth dependence of the mechanical properties of the sand produced by the static pressure gradient is very coarsely approximated in the numerical model.

The incident pressure wave is seen to propagate toward and across the mine. The pressure wave is more apparent in the experimental data than in the model. The incident Rayleigh wave is also seen to travel toward and across the mine. Larger displacements are observed above the mine in all the data sets. These are due to a resonance of the buried mine. This resonance makes it much easier to detect the mine. In spite of the resonance, travelling waves reflected from the mine are seen to be relatively small. This indicates the difficulty that would be encountered in detecting this mine using a classical pulse-echo technique. The diameter of the mine is smaller than the wavelength of the Rayleigh wave at frequencies below 900 Hz. The resonance is spring mass like and occurs between 200 and 300 Hz. Thus, the resonance makes the mine detectable with a lower frequency seismic incident signal than would otherwise be expected. Since low frequencies attenuate more slowly in the earth, the resonance effect extends the possible search range outward from the source.

The effects of a mine resonance are not always repeatable in the experiments. This is probably due to variability in the coupling between the mine and the surrounding sand introduced when it is dug up and re-buried. Care is taken to uniformly compact the sand. However, there seems to be a long time scale cohesion of the sand that cannot be reproduced by simple wetting and compaction. Plots A and B are for burial depths of 2 and 4 cm. In both these cases, the sand in the entire scan region was tilled and repacked to make the sand more homogenous when the mine was buried. The surface displacement associated with the resonance is more pronounced for 2 cm burial depth. Plots B and C of Fig. 2 depict different results for the same mine at a 4 cm depth. The sand for case C was disturbed only above and immediately around the mine and then repacked. This approximates an actual mine burial. Case C was modeled numerically by defining a cylindrical region of earth around the mine with 20% lower wave speeds than the bulk of the medium. It can be seen from the plots that this model predicts most of the qualitative features of the data and reinforces the observation that recently disturbed volumes of soil can be more easily detected than mines. Several authors have noted this trenching effect. Interestingly, both the model and the experiment predict that the trenching effect enhances the resonant response of the mine.

Fig. 3 shows pseudo-color graphs of the displacement over the entire scan region in both the experimental and the numerical model for two different time instants. At time 1, the incident waves have not yet reached the mine. The wave fronts of the pressure and surface waves are seen to have separated in time. Small surface manifestations of head waves are discernable between these wave fronts. At time 2, both the pressure and surface incident waves have propagated beyond the mine. The circular wave fronts of scattered waves can be seen surrounding the mine location and a substantial amount of resonant motion can still be observed over the mine. Unlike the experimental data, the numerical model is able to reproduce displacements below the earth's surface. This can be seen in the cross-sectional graphs at the bottom of the figure. Here it is apparent that the surface manifestations of pressure waves have associated shear head waves propagating into the medium. It can also be seen that the dominant effect of the mine resonance is confined to the soil layer between the mine and the surface. Mode conversions can be seen to occur as both the incident pressure wave and surface wave are scattered from the mine. There is good agreement between the model and experiment at both times depicted.

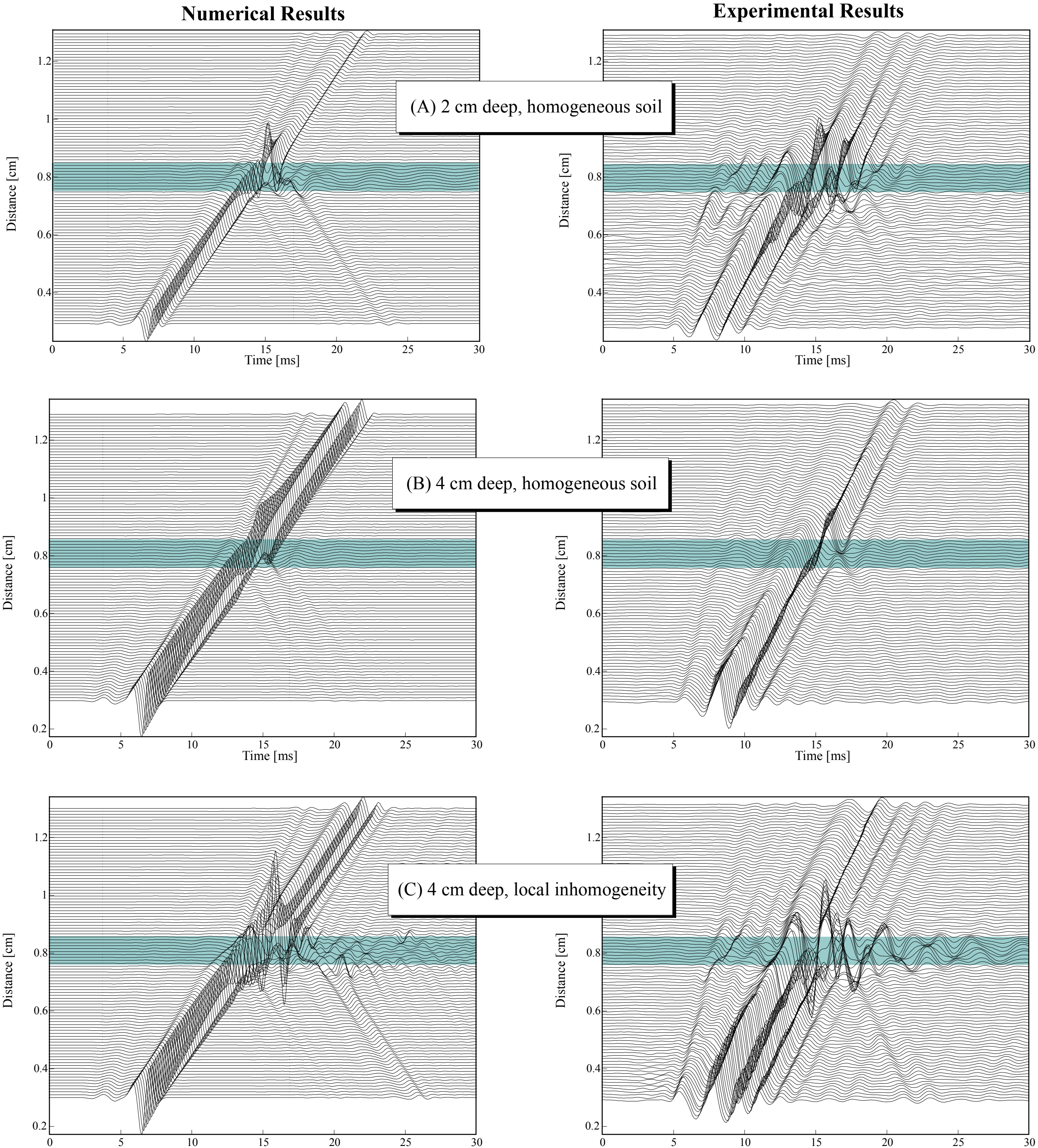

Figure 2. Waterfall graphs of the surface displacement.

CONCLUSIONS

Good agreement has been shown between experimental and numerical models for the seismic mine detection system. This agreement could be improved by eliminating resonances of the source used in the experiments and by determining the actual depth dependence of the properties of the wet compacted sand. The measured source response and depth dependence can then be incorporated into the numerical model

REFERENCES

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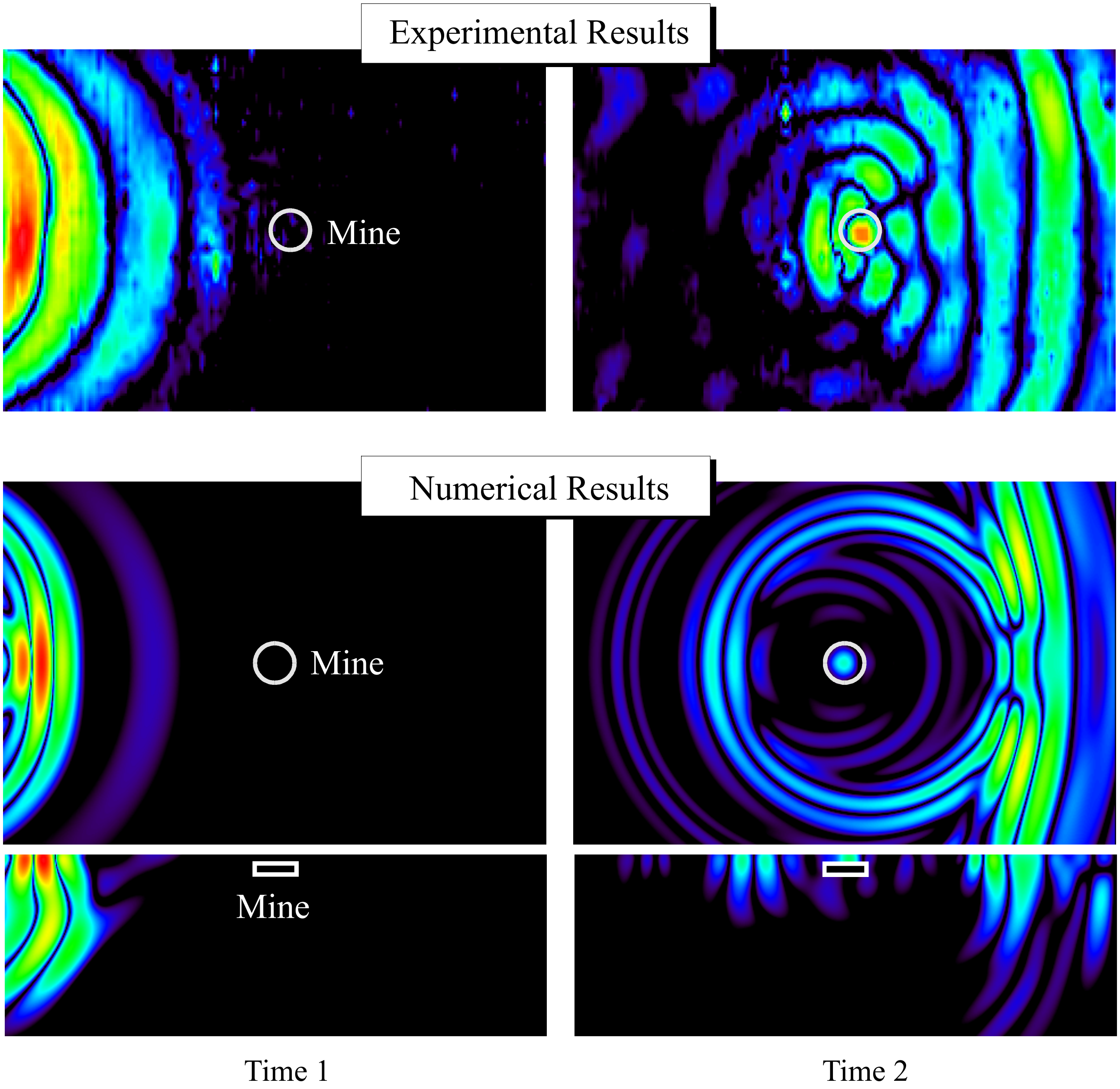

Figure 3. Pseudo-color graphs of the displacement over the entire scan region in both the experimental and the numerical model for two different time instants.