Applications of the JARS Method to study levee sites in southern Texas and southern New Mexico

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Summary

We apply the joint analysis of refractions with surface waves (JARS) method to several sites and compare its results to traditional refraction-tomography methods in efforts of finding a more realistic solution to the inverse refraction-traveltime problem. The JARS method uses a reference model, derived from surface-wave shear-wave velocity estimates, as a constraint. In all of the cases JARS estimates appear more realistic than those from the conventional refraction-tomography methods. As a result, we consider, the JARS algorithm as the preferred method for finding solutions to the inverse refraction-tomography problems.

Introduction

The inverse refraction-traveltime problem (IRTP) has been found to have many possible solutions (Slichter, 1932; Healy, 1963; Ackerman *et al.*, 1986; Burger, 1992; Lay and Wallace, 1995). Different refraction and refraction-tomography algorithms can come up with different equally possible solutions (Sheehan and Doll, 2003). Ivanov *et al.* (2005) noticed that even using a simple three-layer model and assuming exact data the IRTP has a continuous range (valley) of possible solutions. This observation explained the wide range of solutions offered by present inversion algorithms for specific data sets. Each method would converge toward a solution in the valley of nonuniqueness based on its internal assumptions about the geological model and the type and degree of numerical regularization used. To overcome such preferential algorithm behavior, Ivanov *et al.* (2006) proposed the joint analysis of refractions with surface waves (JARS) method, which uses a reference compressional-wave velocity (V_p) model, derived from surface-wave shear-wave velocity (V_s) estimates by using an assumption about the V_p / V_s trend (e.g., that the general trend of V_p. follows that of V_s) The JARS method provided more realistic results than other IRTP algorithms when applied to seismic data acquired in the Sonora Desert, Arizona, USA (Ivanov *et al*,. 2006).

We tested the JARS algorithm at several levee sites located in the San Juan Quadrangle, Texas, USA (Figure 1a) and in the La Mesa Quadrangle, New Mexico, USA (Figure 1b) along the Rio Grande river. The acquired data were part of wide investigation efforts to evaluate the applicability of several seismic techniques to identify, delineate, and estimate the changes in physical characteristics or properties of materials within and below levees. Several surface seismic measurements were taken using state-of-the-art equipment and analyzed using well-established and new research methods. These methods included P- and S-wave refraction tomography, surface-wave propagation, surface-wave dwell, and multi-channel analysis of surface waves (MASW) of both Rayleigh and Love waves. The MASW techniques have proven capable of detecting anomalous shear-wave velocity zones within and below fill materials (Park et al., 1999; Xia et al., 1999) and provided the shear-wave velocity in and beneath the levee with the greatest reliability.

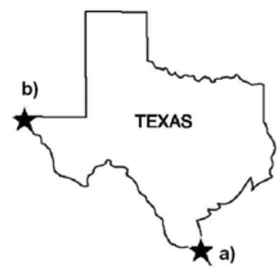

Figure 1: Location of a) the San Juan Quadrangle, Texas, USA and b) the La Mesa Quadrangle, New Mexico, USA.

We compared the JARS method solutions with those from conventional refraction-tomography (Zhang and Toksoz, 1998) approach to several seismic data sets acquired. In all instances the JARS estimates appeared more realistic than the ones from conventional refraction-tomography. Furthermore, the JARS solutions appeared more plausible for seismic data acquired at the levee toes than for the data from the levee crest.

Data Acquisition

Southern Texas Site

Two 2-D, 2-C survey lines were deployed along adjacent edges of the levee road. The levee crest was approximately 6 m wide, while the levee itself was 5 m high, with a 1-to-3 slope on each side. Receiver station spacing was 0.9 m with two receivers at each location (10 Hz compressional wave geophones and one 14 Hz shear wave geophone). The total spread length was 108 m with 120 channels recording compressional and 120 channels recording shear signals. Source spacing through the spread was 1.8 m with off-end shooting out to a distance equivalent to the maximum depth of investigation. Sources tested included various size sledgehammers and a mechanical weight drop, each impacting striker plates. Each data set (P & S) was processed using a variety of methods (Ivanov et al., 2005a).

Southern New Mexico Site
A 2-D, compressional-wave geophone survey line was deployed along the edge of the levee road toward the pond. The levee crest was approximately 6 m wide, while the levee itself was 3 m high with a 1-to-3 slope on each side. The line was on the south side, next to the pond. 10 Hz compressional-wave geophones were spaced at 0.6 m Sources tested included various sized sledgehammers and a mechanical weight drop, each impacting striker plates. The total spread length was 72 m with 120 channels recording compressional signals. Source spacing through the spread was 2.4 m with off-end shooting out to a distance equivalent to the maximum depth of investigation

Results

Southern Texas Site
P-wave first-arrivals were picked from data acquired along the crest. Two distinctively different apparent first-arrival velocity trends can be observed from trace to trace (Figure 2). An IRTP solution was acquired using second-degree smoothing regularization (Depprat-Jannaud and Lailly, 1993), preferred over other types of regularization by Zhang and Toksoz (1998).

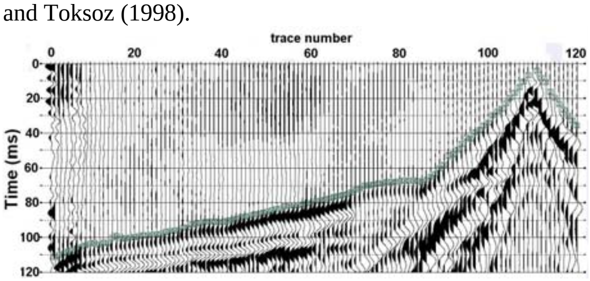

Figure 2. First-arrival picks from p-wave seismic shot record recorded at levee crest in southern Texas.

The Rayleigh-wave MASW method included three steps: fundamental-mode dispersion-curve estimation from compressional-wave shot record data, dispersion curve inversion into 1D vertical V_s profile, and calculation of a pseudo 2D V_s profile (Figure 3b) using an interpolation algorithm (Miller *et al.*, 1999). A V_p / V_s ratio map was calculated from each 2D V_p and V_s profiles (Figure 3c). Using the MASW 2D V_s profile as a reference, a 2D V_p section was created using the general assumption that the V_p trend follows that of V_s. Using the MASW derived 2D V_p model as a constraint a JARS IRTP 2D V_p solution was obtained (Figure 3d).

The JARS solution appears more realistic and consistent with the geologic expectation along the Rio Grande river valley. Channel-like features can be observed in the left half of the line below the base of the levee. Furthermore, a low velocity zone sandwiched between high-velocity layers can be noticed at the right half of the section below the levee base.

The processing sequence from above was applied at a levee toe starting with the acquisition of conventional refraction-tomography 2D V_p estimates (Figure 4a) and ending with a JARS 2D V_p solution (Figure 4b). MASW 2D V_s and V_p / V_s ratio images are not displayed for shortness. Again it can be noticed that the JARS image appears more plausible from geologic perspective.

Southern New Mexico Site
We applied the same processing steps on p-wave seismic data recorded on the levee crest. Comparing the conventional refraction-tomography 2D V_p estimates (Figure 5a) and the JARS 2D V_p solution (Figure 5b) it can be noticed that the JARS solution appears to be more likely. Similar to the southern Texas levee, a low-velocity layer sandwiched between high-velocity layers anomaly can be observed.

Further comparison of crest and toe data results from both sites showed similar pattern and are not presented for shortness.

Conclusions

In all case the JARS IRTP V_p solutions appeared more realistic than the ones from conventional refraction-tomography. In addition, the JARS method is capable of providing IRTP V_p solutions that include a low-velocity layer positioned between high-velocity layers. Such solutions are not offered by existing IRTP algorithms, which do not use such abundant *a priori* information as a reference.

Comparisons of the experimental results from the application of the joint analysis of refractions with surface waves method with conventional refraction-tomography methods demonstrate that the new method is an advancement of the inverse refraction-traveltime problem algorithms.

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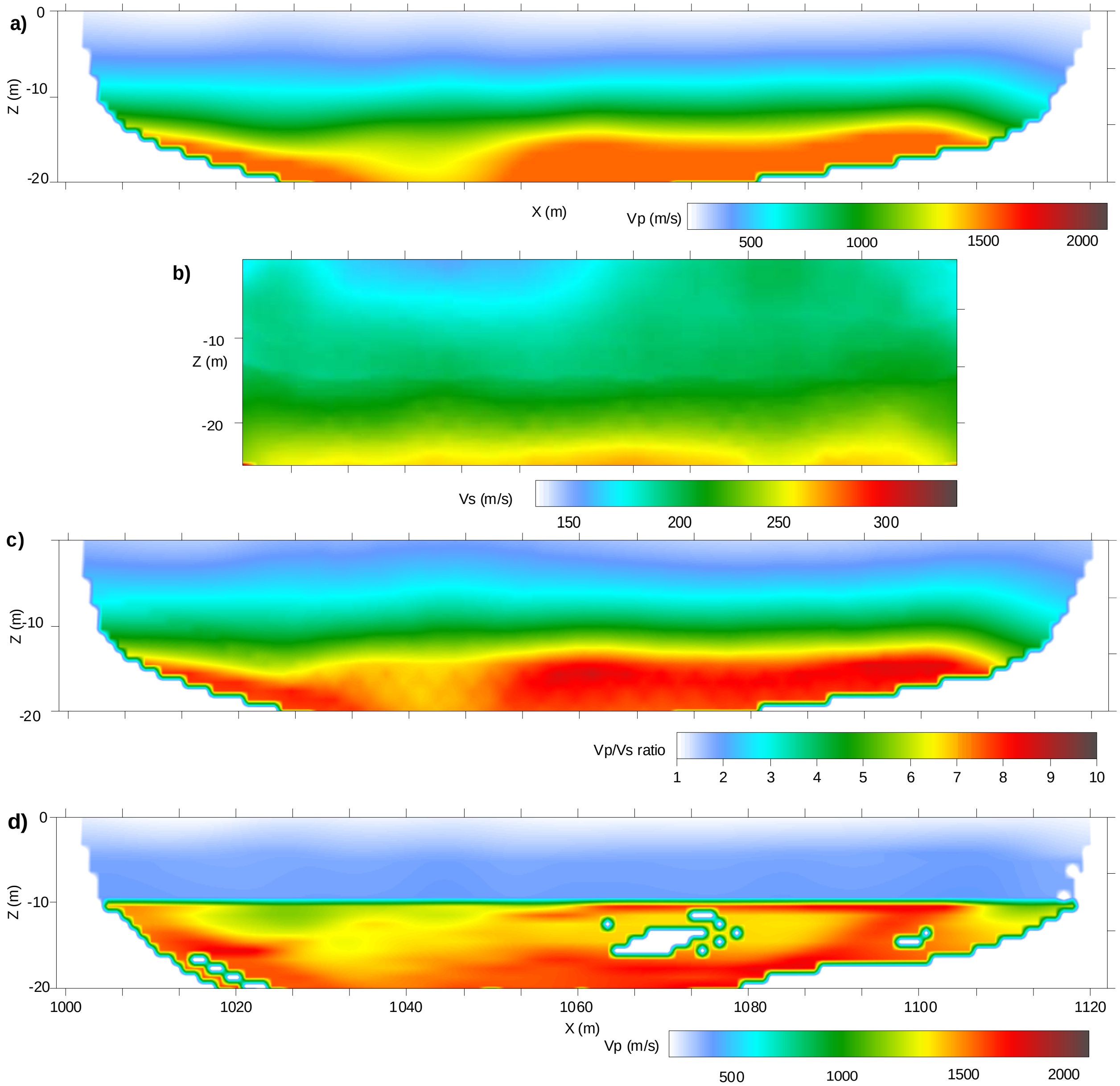

Figure 3. Southern Texas 2D images from p-wave seismic data acquired at the levee crest: a) conventional p-wave refraction-tomography solution, b) Rayleigh-wave MASW shear-wave estimates, c) Vp/Vs ration from a) and b), and d) JARS p-wave solution. Blank areas within the image indicate lack of ray coverage and are deliberately left in.

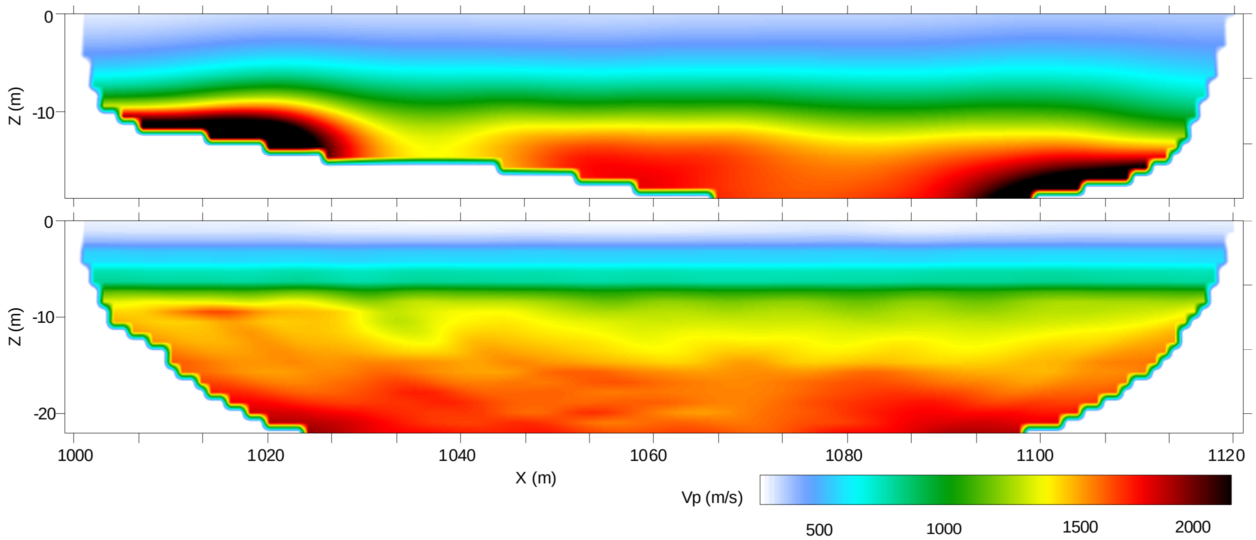

Figure 4. Southern Texas 2D images from p-wave seismic data acquired at the levee toe: a) conventional p-wave refraction-tomography solution, and b) JARS p-wave solution.

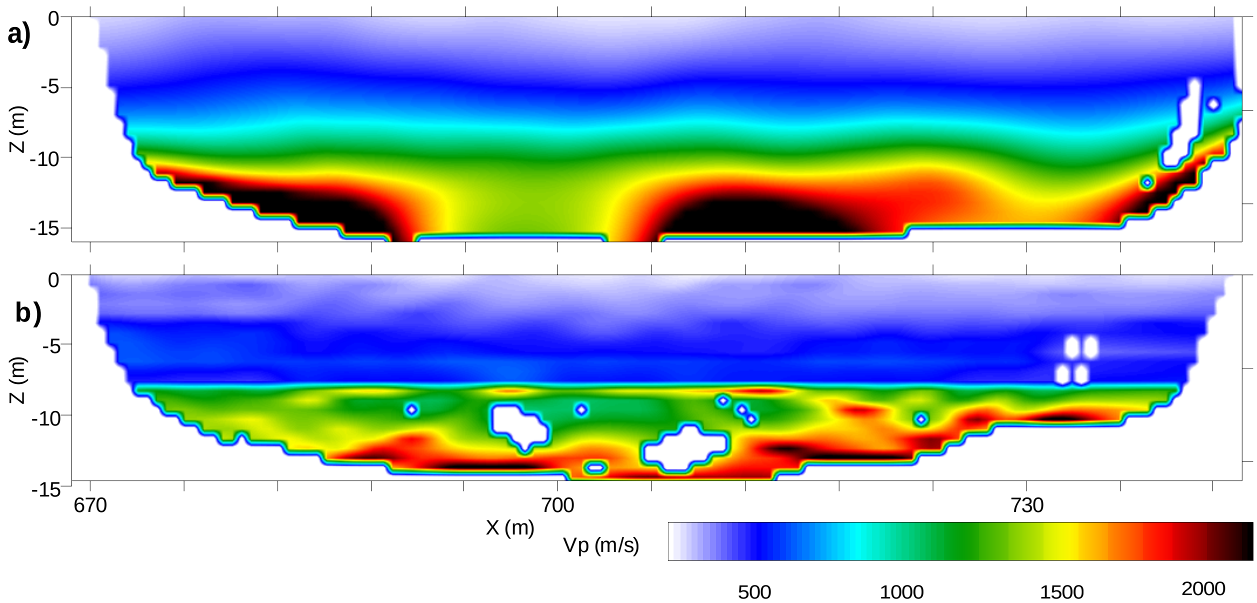

Figure 5. Southern New Mexico 2D images from p-wave seismic data acquired at the levee crest: a) conventional p-wave refraction-tomography solution, and b) JARS p-wave solution. Blank areas within the images indicate lack of ray coverage and are deliberately left in.

EDITED REFERENCES

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