APPLICATION OF 3D AMBIENT NOISE TOMOGRAPHY TO ENVIRONMENTAL AND ENGINEERING STUDY IN THE SACRAMENTO-SAN JOAQUIN DELTA

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Abstract

To develop non-invasive methods for environmental and engineering study of delta regions, geophysical investigations were carried out at several sites in the Sacramento-San Joaquin Delta including Twitchell, Sherman, and Bethel Islands. The geophysical methods include active and passive surface wave methods and ground penetrating radar. This paper summarizes acquisition and analysis of 3D passive surface wave data at two of the sites Twitchell and Sherman Islands. Thirty-six cableless seismic data acquisition units with vertical component 2 Hz geophones were used to record ambient noise. Each unit includes a GPS clock so that all units can be synchronized over any distance without cables. Data acquisition used a 45 x 45 m of square array of 36 geophones with a spacing of 9 m between geophones. One half of the geophones was moved up forward every 15 to 20 min. and the total survey areas were 180 x 45 m and 90 x 45 m at Twitchell and Sherman Islands, respectively. Total data acquisition took about a half day for each site. Recorded ambient noise data were processed using CMP-SPAC method and good-quality dispersion curves were obtained from a minimum frequency of 1 to 3 Hz to a maximum frequency of 10 to 20 Hz, depending on site. Dispersion curves are generally consistent with those obtained from the active surface wave method using small linear arrays and the passive surface wave method using small linear and large triangular arrays. Non-linear inversion was performed and 3D S-wave velocity (V_S) models were obtained to a depth of 40 m at both sites, providing 3D V_S models of 180 x 45 x 40 m and 90 x 45 x 40 m at Twitchell and Sherman islands respectively. Resultant V_S profiles are generally consistent with existing geological maps and geotechnical borehole logs.

Site of Investigation

The Sacramento-San Joaquin Delta consists of a network of river channels that originate in the Sierra Nevada and drain through the Carquinez Strait to San Francisco Bay. Because its outlet is constricted, deposits of peat and mud up to 10 m thick accumulated in the central Delta during the Holocene (Atwater and Belknap, 1980). The Delta is important to the State of California as a conduit and collection point for major aqueduct systems, a site of extensive agriculture, and critical habitat for a number of fish and bird species. During the past century, most of the tidal wetlands comprising the Delta were converted to farmland by building levees around the perimeter of islands and draining them. The safety of levees comes to public attention with an increased interest in Californian water resources. The risk of levee failure and flooding would be greatly increased by strong shaking due to an earthquake on any one of several faults in the San Francisco Bay-Delta region. Levees built on sites with soft near-surface soils, especially peat, are liable to experience strong shaking in the event of a large earthquake.

The S-wave velocity (V_S) of soft near-surface soils, especially peat, is generally very low and it appears that seismic methods can clearly distinguish such soils from stiff layers. In order to delineate the thickness and spatial extent of soft soils, passive surface wave methods were performed at two islands in the Delta (Figure 1). This paper summarizes data acquisition and analysis of surface wave data, including both high-resolution 3D investigations and deep 1D investigations.

Figure 1: Site of investigation at Sherman and Twitchell Islands.

High-resolution 3D Investigations Using Ambient Noise Tomography

Measurements were carried out over a survey footprint of 45 x 180 m at Twitchell Island, and 45 x 90 m at Sherman Island. Thirty-six Geometrics Atom cableless seismic data acquisition units with vertical component 2 Hz geophones were used to record ambient noise data. Each unit includes a GPS clock so that all units can be synchronized over any distance without cables. Figure 2 shows the schematic diagram of data acquisition. The 36 geophones were deployed on 6 x 6 grids with geophone spacing of 9 m (Figure 2a). Ambient noise was recorded 15 ~ 20 minutes and 18 geophones were moved up forward (Figure 2b). Ambient noise recording and geophone moving were repeated until the geophones reached the end of survey area (Figure 2c and 2d). The ambient noise recording array was rolled forward 6 times at the Twitchell Island site and 3 times at Sherman Island site. Data acquisition at Twitchell Island of (45 x 180 m survey footprint) was performed by six people in a half day. The survey at Sherman Island (45 x 90 m)

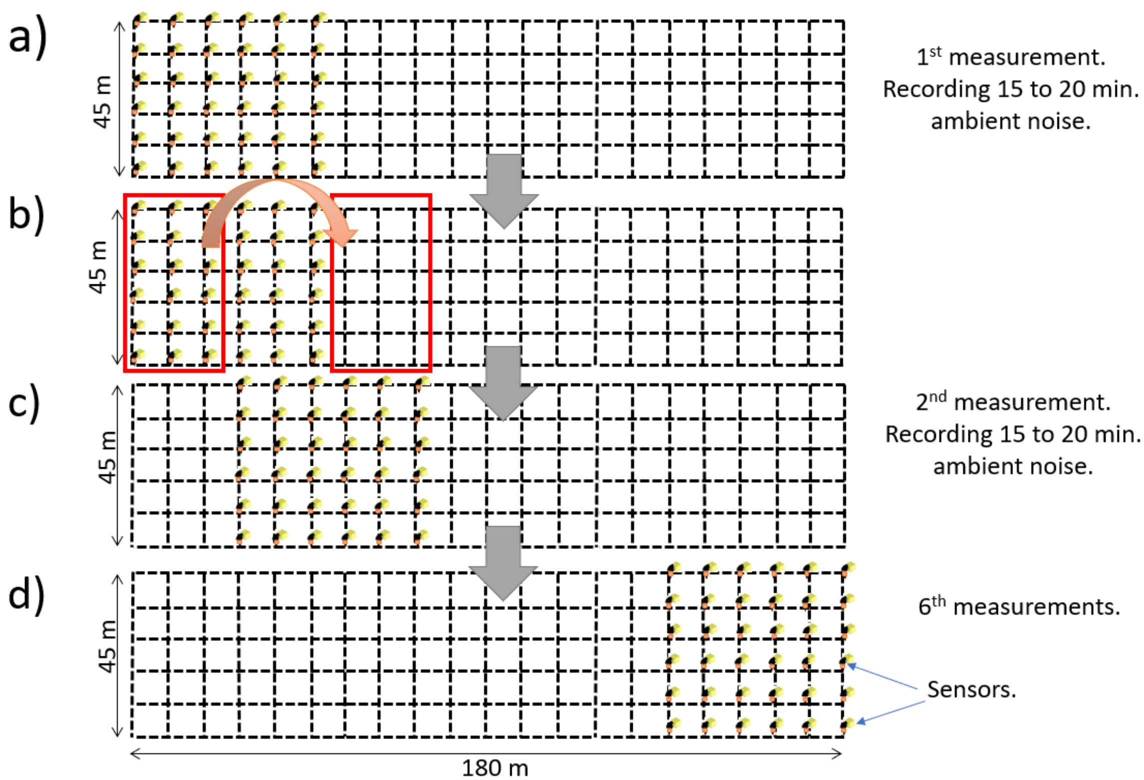

Figure 2: Schematic diagram of data acquisition (Twitchell Island). A square array of 36 sensors (yellow markers) was used. After each measurement, half of the array (red rectangle) was rolled forward.

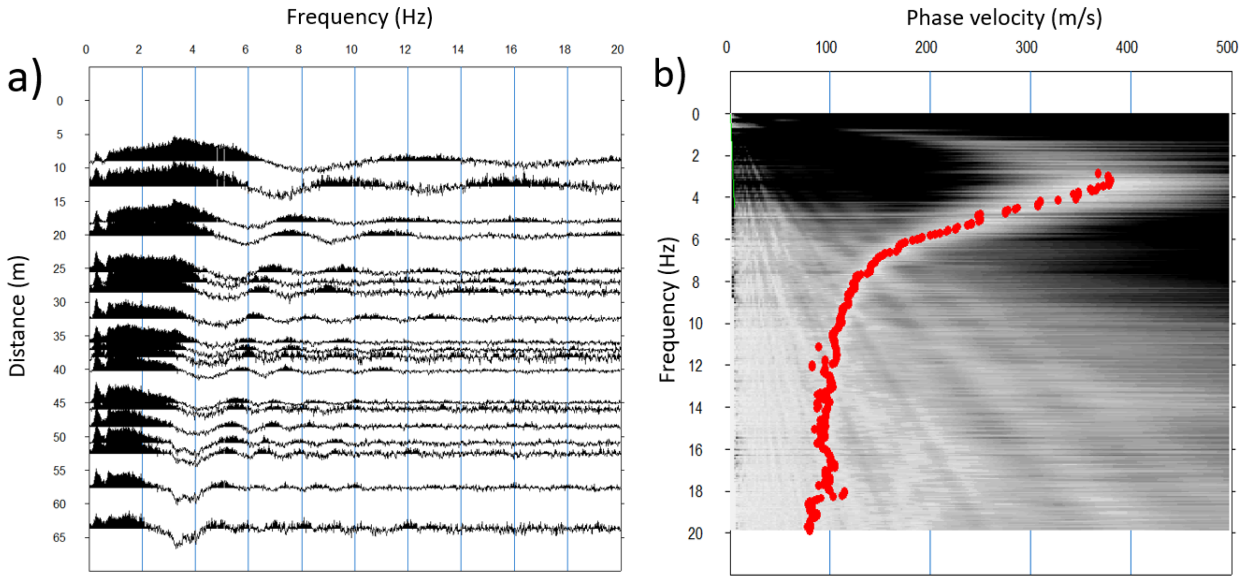

Figure 3: Examples of (a) coherence and (b) phase velocity images in frequency domain obtained at Twitchell Island. Red dots indicate dispersion curve.

areas was performed by four people, also in about half a day. Ambient noise data were processed using the CMP-SPAC method (Hayashi et al., 2015), also referred to as "ambient noise tomography". Figure 3 shows examples of (a) coherence and (b) phase velocity image in frequency domain obtained at the Twitchell Island. We can see that clear coherence is well behaved and a clear dispersion curve was obtained. As a rule of thumb, the penetration depth and resolution of the surface wave method is about one-half to one-third of the maximum and minimum Rayleigh wave wavelength respectively (e.g. Xia et al., 1999). The maximum wavelength obtained from the ambient noise tomography is approximately 120 m and it implies that V_S to a depth of 40 m can be estimated. The minimum wavelength obtained from the ambient noise tomography is approximately 5 m and it implies that shallow resolution is about 2 m.

Figure 4 shows V_S cross sections obtained from ambient noise tomography at the two sites. There is clearly a low velocity layer corresponding to surficial peat, with Vs lower than 100 m/s, at both sites. The thickness of the low velocity layer is approximately 5 to 10 m. Figure 5 shows the depth to a stiff layer with Vs higher than 200 m/s. It is

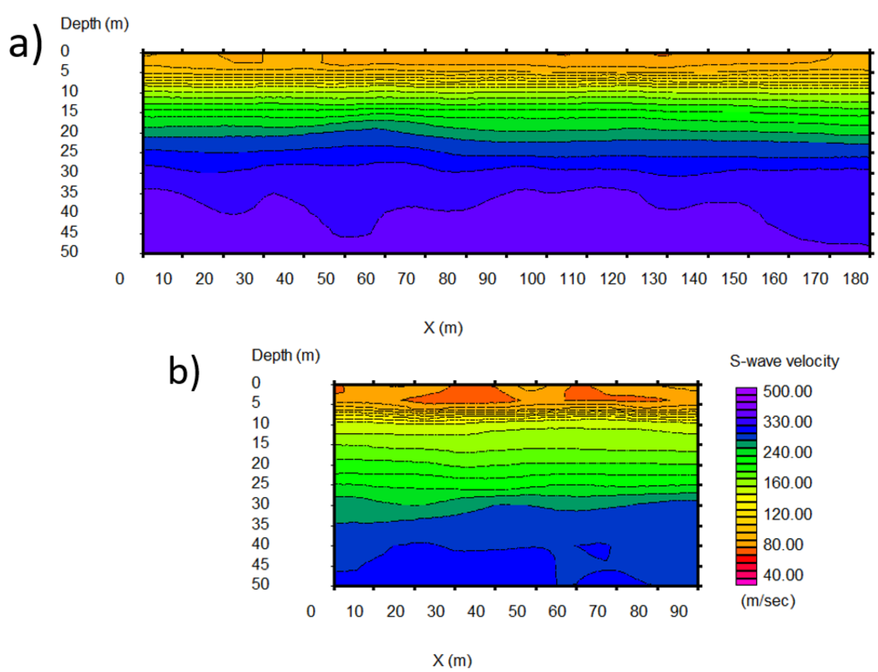

Figure 4: V_S cross section obtained from ambient noise tomography at (a) Twitchell and (b) Sherman Islands.

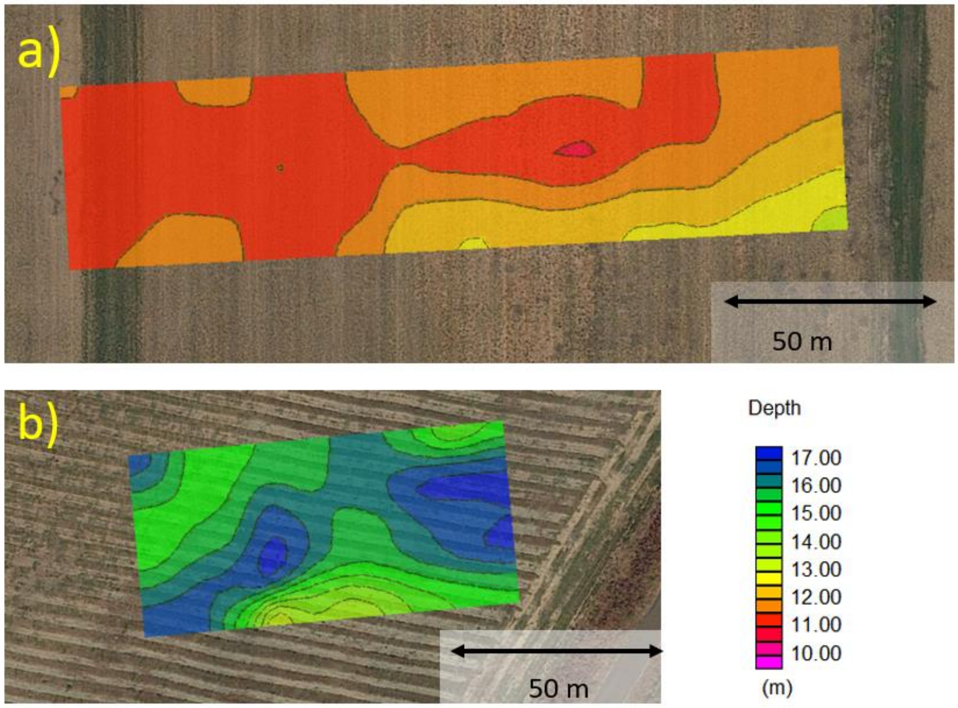

Figure 5: Depth to a stiff layer with Vs higher than 200 m/s at Twitchell (a) and Sherman (b) Islands.

approximately 11 to 13 m deep at Twitchell Island, and about 14 to 17 m deep at Sherman Island. At Twitchell Island (Figure 5a), the top of the stiff layer is deepest at the southeast corner of the site. At Sherman Island (Figure 5b), the arcuate feature oriented E-W may represent a former stream channel.

Deep 1D Investigation Using Large Triangular Arrays

Deep 1D microtremor array measurements using large triangular arrays were performed to investigate deeper structures. Three different sizes (58, 115 and 231 m radius) of triangular arrays were used with seven sensors in the measurements. An example of the array pattern is shown in Figure 6. The same type of seismograph and geophone was used for all measurements and sensor separation varied from 29 to 400 m. Figure 7 compares dispersion curves and analyzed V_S profiles at both sites. V_S was estimated to a depth of 200 m at Twitchell Island and 400 m at Sherman Island. It is clear that phase velocities are lower and depth to a stiff layer is deeper at Sherman Island than at Twitchell Island.

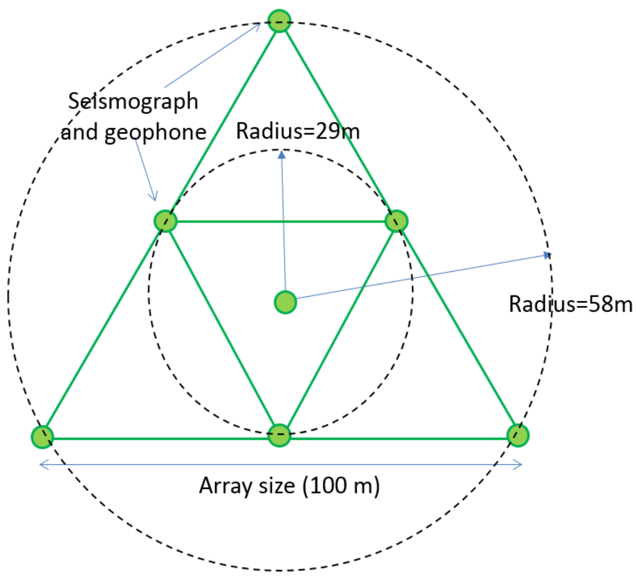

Figure 6: Initial array pattern used for deep 1D investigation. At the end of the recording period, sensors at intermediate radius are moved to larger radius.

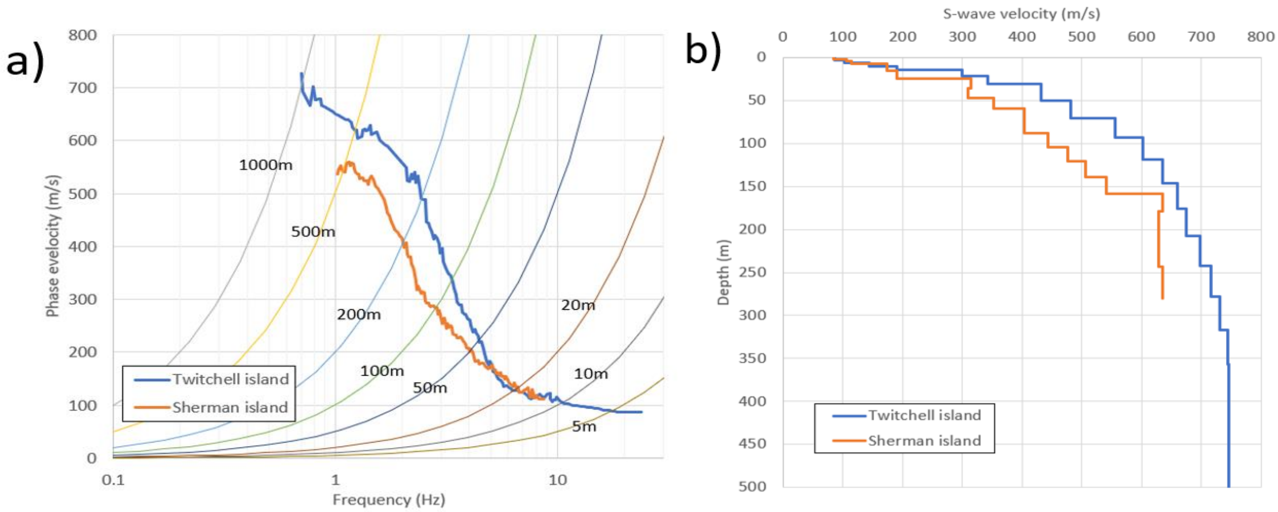

Figure 7: Comparison of dispersion curves (a) and V_S profiles (b) obtained by large triangular arrays.

Conclusions

V_S structures were estimated over a wide range of depths using ambient noise tomography. The results showed that cableless seismographs and ambient noise tomography could simply and quickly estimate 3D V_S structures to a depth of 40 m, and were able to detect a low-velocity layer in the upper 5 to 10 m. The same equipment was also used for deeper 1D soundings and provided V_S information to depths of 200 to 400 m.

References

Atwater, B. F. and Belknap, D. F., 1980, Tidal-wetland deposits of the Sacramento-San Joaquin Delta, California. Pacific Coast Paleogeography Symposium no. 4, 89-103.

Hayashi, K., Craig, M., Kita, T., and Inazaki, T., 2015, CMP spatial autocorrelation analysis of multichannel passive surface-wave data, SEG Technical Program Expanded Abstracts 2015, 2200-2204.

Xia, j., Miller, R. D. and Park, C. B., 1999, Estimation of near-surface shear-wave velocity by inversion of Rayleigh waves, Geophysics, 64, 691-700.