3D mapping with MASW

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Abstract

A one-dimensional (1D) multichannel analysis of surface waves (MASW) seismic test is a quick and accurate sounding technique to collect V_S at depth. Combining a series of MASW-derived V_S soundings from specific depths is a convenient and cost-effective method of creating 3D maps. Three case studies provide useful examples of using MASW soundings to determine subsurface conditions. The depth to the top of rock is readily predicted from MASW soundings. In case study 1, the depth to the top of rock from multiple MASW soundings across a site provided an inexpensive, nonintrusive method of mapping the top of rock. Case study 2 presents the use of multiple MASW soundings to predict site-wide dynamic soil properties at depth. MASW soundings for case study 3 provided V_S data that was used to successfully image a thin lacustrine deposit within 10 m of glacial till.

Introduction

Multichannel analysis of surface waves (MASW) is a relatively new technique used to acquire high-resolution, near-surface, shear-wave-velocity (V_S) data (Xia et al., 1999; Miller et al., 1999; Park, et al., 1999). Nazarian and Stokoe (1984) introduced a nonintrusive surface-wave method using a single pair of receivers called spectral analysis of surface waves (SASW). This method produced results that were within 10–15% of measured V_S (Dennis and Woods, 1998).

MASW is a multiple-channel system and thus records higher-resolution, more consistent, more repeatable, and higher-amplitude energy than the SASW method (Park et al., 1999). MASW utilizes the low-frequency data from the Rayleigh wave traveling along the surface (Xia et al., 2002). Surface waves are dispersive, and this property is used to generate a shear-wave velocity-depth profile (Figure 1). Dispersion curves and the fundamental mode derived from the dispersion curve (phase velocity versus the frequency) produces a more accurate V_S -depth curve than SASW.

An advantage to testing with MASW is that V_S does not, in most cases, attenuate from velocity inversions with depth. Further, the MASW method of measuring V_S can be insensitive to the presence of subsurface utilities, to the occurrence of standing structures, to conductive soil, and to buried boulders, rocks, and concrete, when surface-wave wavelengths are much greater than the target (Hutchinson and Beird, 2011).

Multiple one-dimensional (1D) MASW tests can be used to produce three-dimensional (3D) maps (Miller et al., 2003; Hutchinson et al., 2008; Hutchinson et al., 2011). Advantages to using MASW 1D testing are many and include ease of interpretation, quick and simple setup, and low cost. MASW is not intrusive, so its impact or exposure to the site is minimal. Dynamic soil properties derived from MASW data have been successfully demonstrated to be equivalent to other methods of determining dynamic soil properties (Hutchinson and Beird, 2016).

Three-dimensional mapping with MASW is not complicated and consists of using many 1D soundings. Each test is recorded as a data point with regard to the velocity and depth. The velocity at a particular depth can be spatially oriented, and a map can be created through hand contouring or with a mapping program.

This paper presents three case studies from three different sites across North America that involved acquiring multiple 1D MASW soundings. Case study 1 used 1D MASW soundings to determine the top of rock (Figure 2). Case study 2 incorporated MASW soundings to delineate site-wide dynamic soil properties (Figure 3). One-dimensional MASW soundings were used to prepare an isopachous map of a subsurface stratigraphic unit in case study 3 (Figure 4).

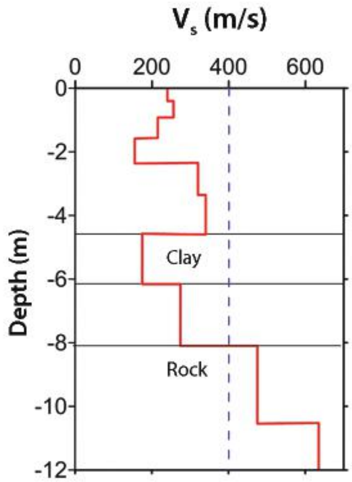

Figure 1. MASW derived shear-wave-velocity depth graph (red) from a site in upstate New York. Rock is arbitrarily placed at the shear-wave velocity of 400 m/s (dashed line).

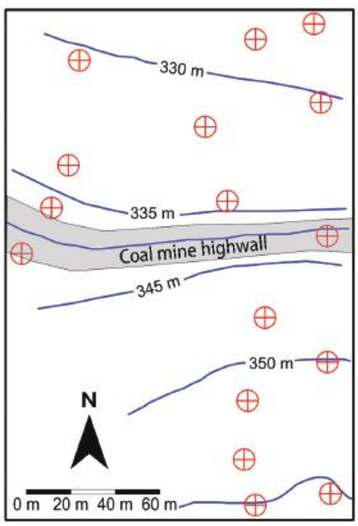

Figure 2. Plan map of a portion of the proposed hospital in western Pennsylvania showing the highwall and MASW test locations (red symbols). Several of the MASW test locations are located near borings (not shown) to help truth the shear-wave-velocity data. Blue contour lines represent top of rock in meters above sea level.

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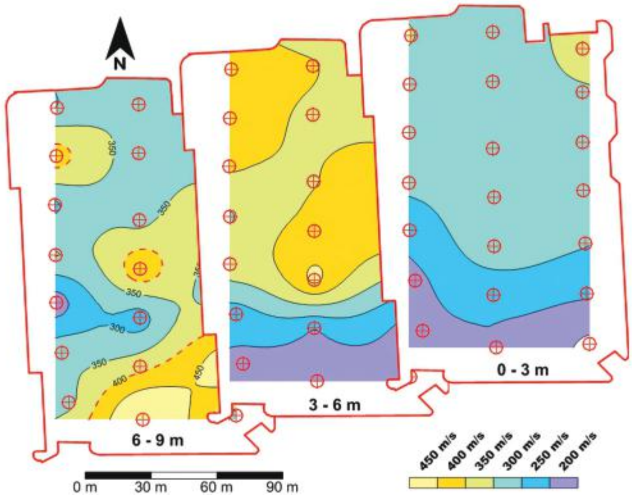

Figure 3. Three shear-wave interval velocity-at-depth maps of a proposed 16,000-square-meter industrial facility (red solid line is the building footprint) in Arizona showing 1D MASW test locations (red symbol). Interval depth ranges are posted at the bottom of each image. Red dashed line at 6–9 m below grade represents top of rock.

Case study 1: Top-of-rock mapping

The depth to top of rock can be extracted readily from velocity-depth graphs since overburden has a slower shear-wave velocity than bedrock (Figure 1). Case study 1 is from western Pennsylvania and involves the use of 1D MASW soundings to localize a surface coal mine highwall. During surface mining, coal extraction occurs after the rock overburden has been removed. Operators remove the overburden until the depth of coal burial is physically too much for their equipment, or too expensive to remove the overburden.

The surface mine is then abandoned, leaving a cliff referred to as a highwall. Subsequently, the highwall is buried to stabilize the area. Emerging communities have a strong need for land and often encroach upon former surface mines and their buried highwalls.

This case study involves the construction of a large hospital in an area with a known buried highwall (Figure 2). The depth to the top of rock (and to the floor of the surface mine) and the location of the highwall were necessary for the successful design of the hospital's foundation. After numerous attempts to locate the position of the highwall through drilling, site engineers requested that a number of 1D MASW tests be performed — many collected near existing borings to truth the data set.

A broad-brush north-south series of soundings along the west side of the study area were completed to determine the approximate location of the highwall. The collected MASW data were processed in the field to determine the approximate location of the highwall. Subsequent tests were performed to delineate the lateral orientation of the highwall. All of this work was completed in one day or, in terms of an intrusive test, at half the cost of a single boring.

Case study 2: Dynamic soil properties map

Dynamic soil compaction is used to densify an area. The method most often deployed consists of dropping a heavy weight systematically across the area of interest. Subsequently, it must be determined if the dynamic compaction process increased the soil density to a depth considered acceptable for the design basis of the project.

A construction and demolition (C&D) site in Arizona was targeted for the installation of a single-story factory. The C&D site was filled to an approximate thickness of 9 m with reinforced concrete pieces, wood debris, construction material, brick, and concrete blocks. The site was covered with one or more meters of fine-grained fill and underwent extensive dynamic compaction to densify the subsurface.

Site engineers were concerned that dynamic compaction of the 16,000-square-meter building's footprint did not reach the design basis to a depth of 6 m. A series of 1D MASW tests were conducted across the property, and interval velocity maps were created from the processed MASW data (Figure 3).

Unfortunately, no precompaction shear-wave-velocity data were collected. Postcompaction data show that from 0 to 3 m below grade, most of the site is above the design-build shear wave velocity of 200 m/s. The depth range of 3–6 m below grade shows even higher shear-wave interval velocities. Top-of-rock was intercepted at less than 9 m below grade in the southeast corner of the property. The lower shear-wave velocities in the remainder of the property suggest that dynamic compaction was only successful to approximately 6 m below grade.

Interestingly, the shallow portion (0–3 m below grade) of the site shows a much lower shear-wave interval velocity than the middle interval velocity map. The slower velocity values for the shallower portion of the site can be attributed to the application of more than 1 m of fine-grained fill on the former C&D cell. Presumably, the finer-grained material did not compact as densely as the C&D material.

Case study 3: Isopachous map

Shear-wave velocities derived from the MASW method can be very sensitive to lithologic changes in the near subsurface. In reality, dissimilar lithologies have different densities that translate into velocity contrasts. MASW method generates dispersion curves with fundamental modes that provide detailed density contrasts, especially shallower than 5 m below grade. This property, along with the nonintrusive nature of the data collection, provided an ideal opportunity to determine the thickness of a lacustrine clay bed in upstate New York.

A landfill in upstate New York, contiguous to a wetland, wanted to expand its footprint. Consistent with Federal Wetlands Protection Act 310 CMR 10.00 and the New York Article 24 Freshwater Wetlands, the landfill could remove the wetland and replace it by building another wetland in another portion of the property. Consequently, the landfill negotiated with the New York Department of Environmental Conservation (DEC) to remove the wetland and install a wetland in another portion of their site (Figure 4).

Unfortunately, and pursuant to the landfill permit, the landfill was only permitted to build the waste-containment portion over a glacially deposited lacustrine clay bed that is ubiquitous across the existing landfill and located approximately 4 m below grade.

The initial borings, B-2 and B-3, along the perimeter of the 90,000-square-meter tract, showed that the lacustrine clay was not present along the southern and eastern portions of the site. However, in B-1, on the northwestern side of the tract, the clay bed was more than a meter in thickness. This indicated that the clay bed, deposited in a Pleistocene periglacial lake, existed on the wetland tract. Unfortunately, the site had limited access to the wetland because the site was not permitted to build roads or disturb the wetland to install borings. Consequently, the site was unable, through intrusive methods, to determine the aerial footprint of the clay bed.

The landfill decided that a nonintrusive MASW investigation would help determine the margin of the lacustrine clay without disturbing the wetland. The DEP approved the work effort, and 34 MASW tests were collected at the site. Initially, several MASW tests were conducted adjacent to borings to determine if the intercalated clay could be distinguished from the adjacent sediments. Fortunately the sediments, mostly fine- to medium-grained sands overlying and underlying the clay bed, proved to have higher V_S (Figure 1).

The clay thickness, determined by the MASW method, indicated that the lacustrine clay bed ended halfway across the site and, by inference, so did the periglacial lake. This work was reported to the DEP, which then approved additional borings in the wetland. These borings proved to be consistent with the MASW model to within 10 cm except for one boring, PZ-1.

PZ-1 is located on the periglacial lake to the southeast. The layer, as determined from the MASW measurements of V_S, was predicted to be 0.7 m thick. However, Boring PZ-1 determined that the clay bed intercalated between very fine-grained silt beds is 0.85 m thick. The discrepancy may be because of the difference in locations, as the MASW was not collected directly on this boring, or because of variable stratigraphy at the edge of the periglacial lake. Either condition is possible for the noted discrepancy between boring and MASW record.

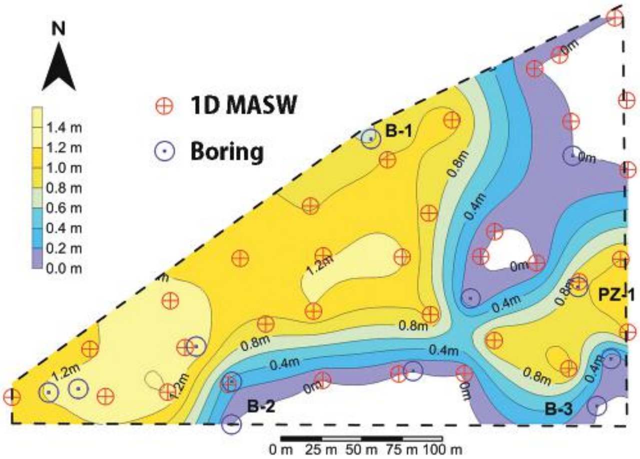

Figure 4. A 90,000-square-meter wetland located in upstate New York contiguous to a landfill (not shown) showing MASW test sites and subsequent boring locations. Piezometer PZ-1 was predicted by MASW method to have a 0.7 m thick, lacustrine clay bed, when in fact, this boring had a 0.85 m thick clay layer. Color scale represents thickness of clay in meters.

Discussion

MASW sounding and profiles are an inexpensive and effective method of imaging the subsurface. Further, velocity inversions, conductive soils, and other physical issues that plague other geophysical methods do not influence this method. There are, however, several limitations to this method; the most difficult of which to overcome is the presence of site acoustic noise from construction activities or truck traffic.

Often, sites are so busy with construction activities and truck traffic that collecting clean, active MASW data is a challenge. Space is also a limitation as the test often uses a 35-meter-long string of geophones. The last limitation is that this test works poorly on rock (Hutchinson et al., 2011). Despite these caveats, the 1D MASW test is a quick and effective method for imaging the subsurface. TLE

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