Earth Science Systems
ESSENTIAL UNDERGROUND INFORMATION

ESS Cube Seismic System
V_S30 Case History

August 2022

Introduction

The ESS Cube Seismic simplifies seismic acquisition by using 8, 16, or 24 wireless receivers, a tablet PC, and any available seismic source. A possible use case is the measurement of V_S30, or the average shear wave velocity to a depth of 30 meters. V_S30 is often a requirement for building structures in earthquake prone regions (BSSC, 1994, *NEHRP Recommended provisions for the development of seismic regulations for new buildings*). In this example survey, a 20 lb. sledge hammer supplied the energy source while receivers recorded over a 30 meter spread (Figure 1). A MASW approach (Park et. al. *Geophysics,* 1999) inverted for the shear velocity model which was verified by refraction analysis.

Figure 1: The Cube Seismic system includes eight wireless seismometers (green boxes) mounted on eight-inch spikes and a tablet equipped with software for data processing and viewing. The 20 lb. sledgehammer used in this survey (shown) was provided by the user.

Data Acquisition

The survey was conducted in a field behind the Earth Science Systems headquarters in Wheat Ridge, Colorado (Figure 2). The receivers were laid out in a straight line approximately 30 meters long. Receiver spacings gradually increased from two to seven meters to prevent aliasing at higher frequencies while providing sufficient total offset to detect low frequency apparent velocity. The seismic excitation was made by sledge hammer strikes 4 meters to the west of the westernmost receiver at a location with soft soil (to increase low frequency energy, the blows went straight into the soil rather than into a plate). Ten hits were recorded and summed (Figure 3). A day after rainfall was chosen for damp soil and better seismic conductivity.

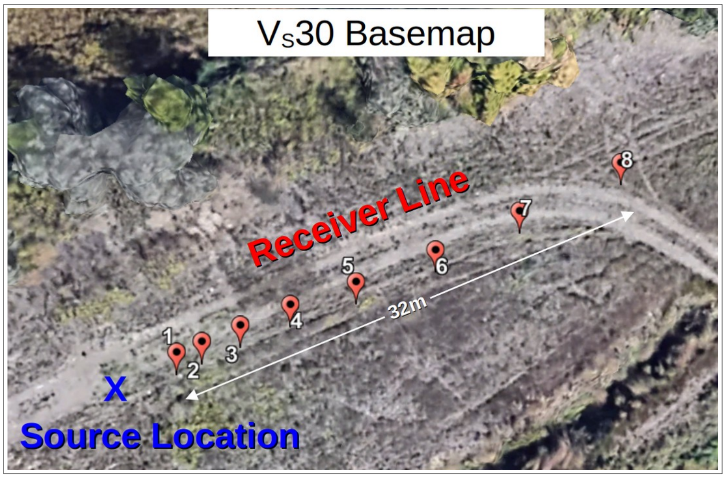

Figure 2: Basemap

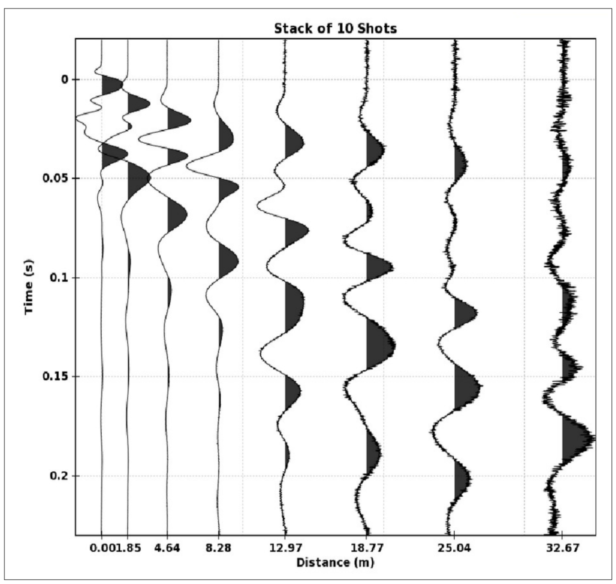

Figure 3: Shot record (stack of 10 hammer strikes or blows). Time is relative to energy onset at 1st station. Offsets shown are relative to 1st station (0 to 32.7 meters: East to West). Hammer strike location was 4 meters West of 1st station.

MASW Analysis

MASW (Multichannel Analysis of Surface Waves) builds a shear wave velocity model of the near surface by looking at the velocity dispersion of Rayleigh waves. The general principle is that low frequency waves sample deeper into the earth than higher frequency waves, so the lower frequency portion of the dispersion will control the deep part of the model, while the high frequency portion will control the shallow part. The actual process iteratively generates successively improved velocity models until the predicted dispersion matches the measured dispersion to within a certain tolerance.The first step is to calculate the shear wave velocity dispersion field (Figure 4).

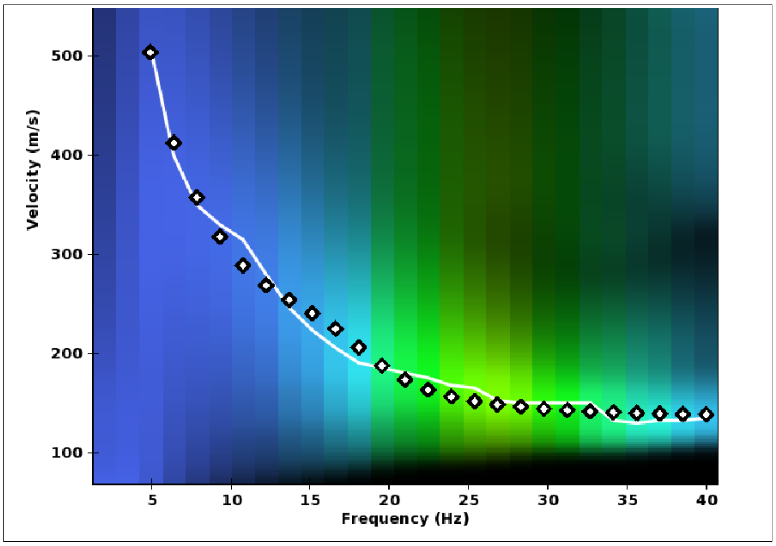

Figure 4: Shear wave velocity dispersion. Color indicates amount of energy at each frequency (blue is low, green is high). Shading indicates coherence at each frequency/velocity pair. White line shows the picked maximum coherence at each frequency. Black dots show the predicted dispersion from the inverted velocity model (Figure 5).

Once the change in shear wave velocity with frequency has been determined, a velocity model can be built. A benefit of the Cube Seismic system is that these results are displayed in the field so that adjustments can be made real-time to ensure a result with sufficient quality. Figure 5 shows the final model.

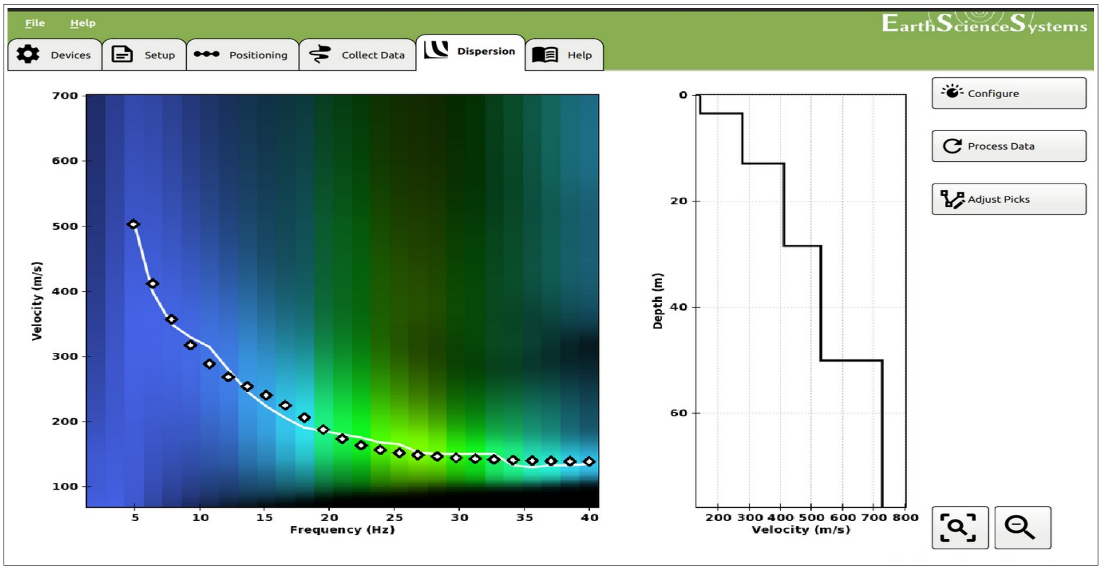

Figure 5: Shear wave velocity model.

Refraction Analysis

A refraction profile was also conducted to corroborate the MASW findings. Three shot locations were recorded: two four meters off each end of the line and one centered on the line. Ten sledge hammer blows were recorded and summed at each location. Receiver stations were placed at constant five meter intervals (Figure 6) Cube Seismic exported SEG-2 files for import into Refrapy (freely available software) for analysis.

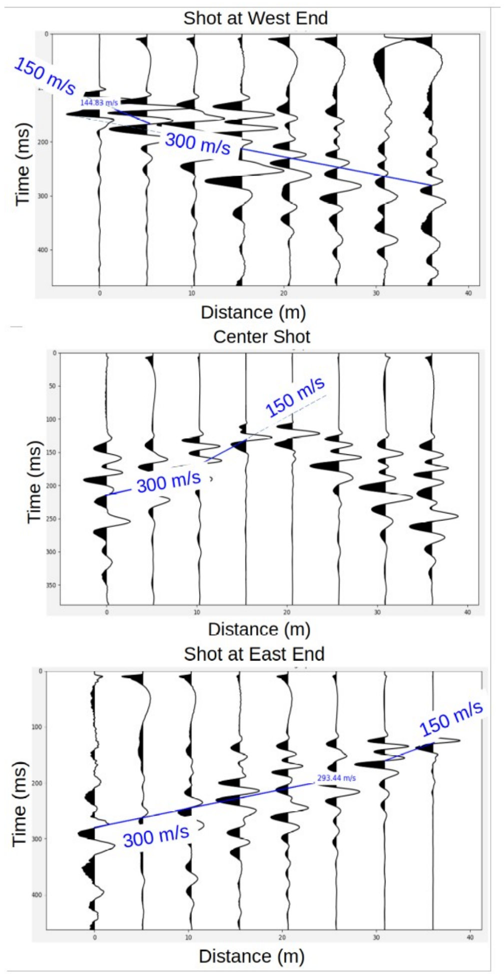

Figure 6: Refraction experiment shots with picked shear arrivals.

Multiple shot locations are necessary in refraction analysis to differentiate a dipping refractor apparent velocity from a true velocity. A dipping refractor will appear faster when the wave is traveling up-dip than down-dip. In such a case, the average of the two velocities would represent the true velocity. No significant velocity variation with refractor dip was noticed for this survey, indicating relatively flat refractors. Two apparent shear velocities are seen in the records. The first, at 150 m/s, is interpreted to be the shear velocity of the overburden. The second velocity, at 300 m/s, has similar character to the first wave but with faster velocity, and is therefore interpreted to be the refracted wave. Comparing the zero-offset intercept time of the two arrivals allows the estimation of the overburden thickness. The average zero-offset intercept time difference between the refractor picks from the 3 shot records is 45 ms. Since 45 ms is the two-way travel-time through the overburden, and the overburden velocity is 150 m/s, the thickness calculated is 3.4 meters.

Conclusions

The Cube Seismic system successfully recorded shear wave energy down to 5Hz allowing for MASW shear inversion down to 80 meters. This depth was more than enough for a reliable V_S30 measurement (see Figure 7). One advantage of MASW over seismic refraction is the ability to see deeper into the earth using a given receiver offset range. Using essentially the same receiver spread, the refraction technique was only able to detect velocities down to 3.4 meters, while MASW detected down to 80 meters. The region of overlap between the two models showed strong agreement, giving added weight to the 325 m/s V_S30 measurement. This V_S30 value is consistent with soil type D or “stiff soil” (Figure 8).

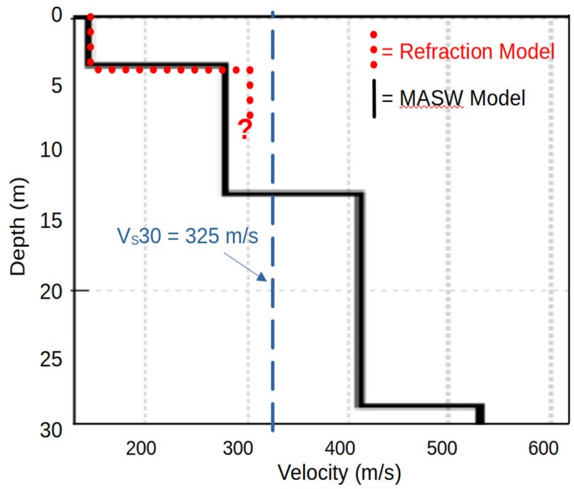

Figure 7: MASW vs. Refraction model comparison. The refraction model (red dashed) closely resembles the MASW (black solid) model down to a depth of ~5 meters. The refraction experiment did not detect any deeper refractors (farther offsets would be needed) and so cannot verify the deeper MASW velocities.

Table 1. Site classifications from the *NEHRP Provisions* [BSSC, 1994].

Soil Profile Type	Description	Geotechnical Properties
A	Hard rock	$V_S30 > 1500$ m/s
B	Rock	760 m/s $< V_S30 \leq 1500$ m/s
C	Very dense soil and soft rock	360 m/s $< V_S30 \leq 760$ m/s or $N > 50$ or $s_u \geq 100$ kPa
D	Stiff soil	180 m/s $< V_S30 \leq 360$ m/s or $15 \leq N \leq 50$, or 50 kPa $\leq s_u \leq 100$ kPa
E	Soil	$V_S30 < 180$ m/s or any profile with more than 3 m of soft clay with PI>20, $w \geq 40\%$, and $s_u < 25$ kPa

Figure 8: Soil types and geotechnical properties inferred from various VS30 values.

References

Park., C.B., Miller, R.D. and J. Xia, 1999, “Multichannel analysis of surface waves”, Geophysics, Vol. 64 No. 3, p. 800-808.

BSSC, NEHRP, 1994, “Recommended provisions for the development of seismic regulations for new buildings, part I: Provisions”, Building Seismic Safety Council, Federal Emergency Management Agency, Washington D.C.