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Vs30 SITE CHARACTERIZATION REPORT
Los Angeles, Orange,
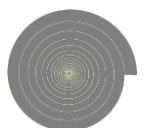**Ventura, San Bernardino and Riverside Counties**

California Strong Motion
Instrumentation Program
(CSMIP)

Petralogix Project Number: 2017-00006
DOC Agreement Number: 1016-990

Report Prepared for:
Department of Conservation CSMIP

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June 6, 2017

Vs30 SITE CHARACTERIZATION REPORT
Los Angeles, Orange,
Ventura, San Bernardino and Riverside Counties

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Los Angeles, Orange,
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PROJECT NO: 2017-00006

EXECUTIVE SUMMARY

Petralogix Engineering, Inc. (Petralogix) was contracted by the Department of Conservation's California Strong Motion Instrumentation Program (CSMIP) to determine the Vs30 value within one hundred and fifty (150) meters of thirteen (13) individual strong motion stations located within Los Angeles, Orange, Ventura, San Bernardino and Riverside counties. These locations are individually detailed in this report and subsequent appendices.

Per requirements of the Department of Conservation's contract, our firm was required to perform active Multichannel Analysis of Surface Waves (MASW) method (with interspersed sources) for each of the 13 sites. The MASW measurements were required to use forty (40) or more geophones spread approximately evenly over at least sixty-five (65) meters of survey line length. We were also required to perform a passive two-dimensional microtremor array method, which included two microtremor measuring lines perpendicular to each other, with at least twenty-two (22) geophones spread approximately evenly over at least one hundred (100) meters of survey line length. Lastly, our firm was required to perform the Horizontal/Vertical Spectral Ratio (HVSR) method, using a high resolution triaxial seismograph. As part of this survey method, our firm was required to collect (at a minimum) twenty (20) minutes of microtremor data for each of the 13 sites. In addition to this required work, we also provided Refraction Microtremor (ReMi) analysis of the 2D Passive data for a comparison.

All field surveying took place between May 11th and May 19th, 2017. Subsequent processing and reporting was performed thereafter, with a final report submission for each of the sites on June 1, 2017. In addition to the final report, digital seismic waveform data collected in the field was provided to the Department of Conservation. Our reports for each site included a detailed site map (which indicated the locations of the three (3) measurement methods), shear wave velocity profiles determined to at least forty (40) meters depth, Vs30 value determined in meters/second with estimated error, HVSR results as H/V vs frequency, dispersion curves derived from active and passive surface wave data, and representative/calculated surface wave dispersion diagrams (wavelength versus phase velocity).
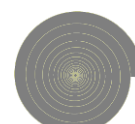
1.0   INTRODUCTION

1.1   Report Preparation

Petralogix Engineering, Inc. (Petralogix) was contracted by the Department of Conservation's California Strong Motion Instrumentation Program (CSMIP) to determine the Vs30 value within one hundred and fifty (150) meters of thirteen (13) individual strong motion stations located within Los Angeles, Orange, Ventura, San Bernardino and Riverside counties (Figure 1, General Location Map). The table below (Table 1. CSMIP Strong Motion Station Locations) lists the stations by name, and corresponds to the CSMIP station number.

Figure 1. CSMIP Strong Motion Stations that were surveyed as part of this study (taken and modified from DOC, 2017).
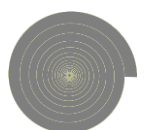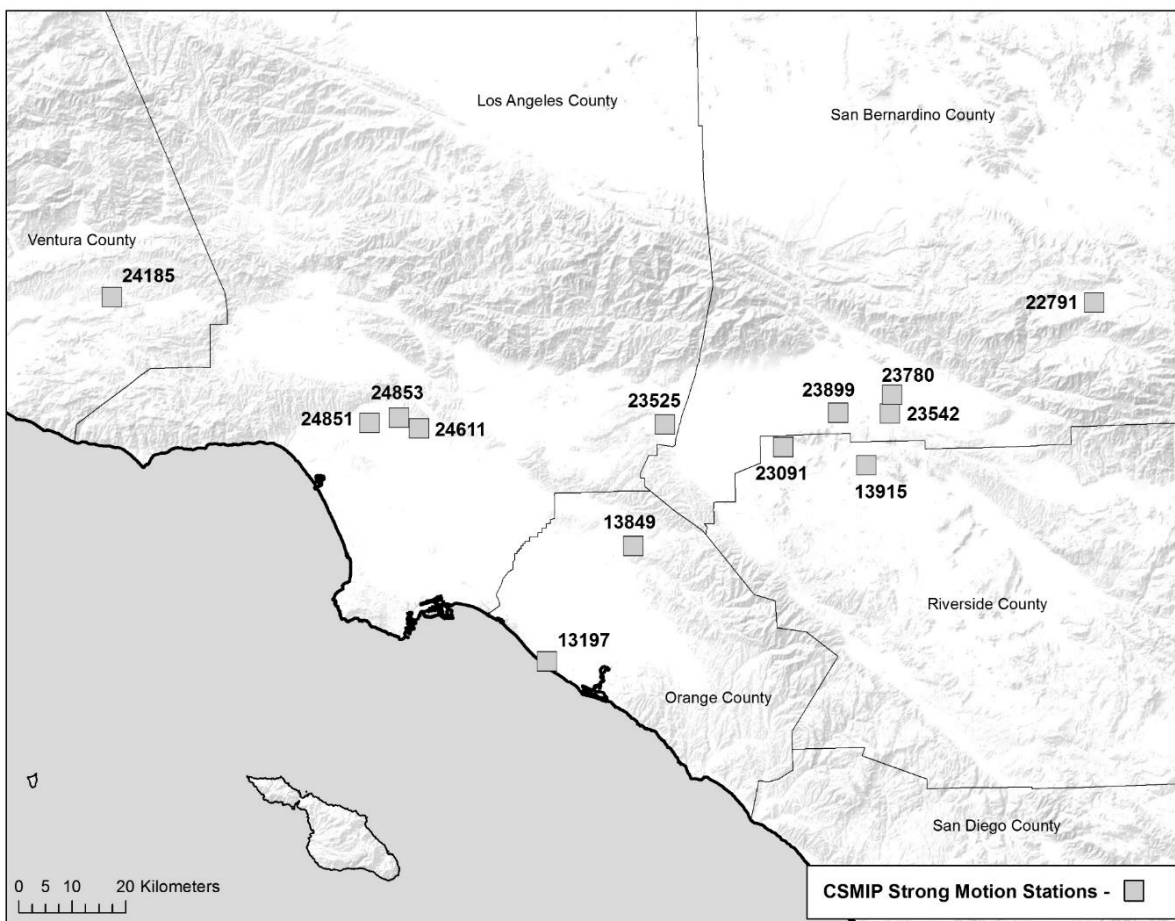
Table 1. CSMIP Strong Motion Station Locations (taken and modified from DOC, 2017).

Station #	Station Name	Latitude	Longitude
13197	Huntington Beach - Lake St Fire Station	33.6623	-117.9974
13849	Anaheim - Lakeview & Riverdale	33.8535	-117.8180
13915	Riverside - I215 & 3rd	33.9792	-117.3439
22791	Big Bear Lake - Fire Station	34.2411	-116.8724
23091	Mira Loma - Mission & San Sevaine	34.0136	-117.5106
23525	Pomona - 4th & Locust	34.0564	-117.7487
23542	San Bernardino - E & Hospitality	34.0656	-117.2928
23780	San Bernardino - Mtn View & Cluster	34.0964	-117.2872
23899	Rialto - I10 & Cedar	34.0692	-117.3981
24611	Los Angeles - Temple & Hope	34.0591	-118.2466
24851	Los Angeles - 3rd & La Brea LADOT	34.0695	-118.3464
24853	Los Angeles - Beverly Blvd & Virgil	34.0774	-118.2865
24185	Moorpark - Hwy118/Arroyo Simi Geo. Array	34.2876	-118.8646

1.2   Report Purpose

The purpose of this report and study is to provide Vs30 values for the individual CSMIP stations (as shown in Figure 1.). Per contract requirements, Petralogix herein provides the CSMIP with accurate, site-specific measurements of the shear wave velocity of the underlying soil/rock near the indicated/included strong motion instrument stations. Herein, we provide a detailed report for each site that includes the velocity profile determined (as spreadsheet and a plotted profile) for the top forty (40) meters, the Vs30 values, and detailed descriptions of the methods used.

2.0   OVERVIEW OF GEOPHYSICAL METHODS USED

2.1   MASW, 2D Passive, and ReMi

Multichannel Analysis of Surface Waves (MASW) is a seismic method-technique that is capable of mapping the upper 20 to 30 meters of the subsurface, while allowing for approximate estimation of the parameters of the soil/rock column. Surface wave analysis methods extract shear wave velocity information from the approximation of recordable/observable Surface waves. Surface waves (in particular Rayleigh waves) tend to have a 0.92 relative ratio to Shear waves, and by determining such wave velocities, Shear wave velocities can be effectively inferred. An important characteristic of
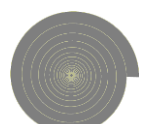
Rayleigh waves is that they are retrograde elliptical in motion, and are dispersive. This means that different frequencies have different velocities, and since different wavelengths occur (due to this phenomenon) different depths can be evaluated based on the relationship between frequency, wavelength, and phase velocities of the Surface waves. As a general rule of thumb the imaging depth of the process is half of the wavelength being observed. By observing and analyzing lower frequency waves greater depth can be attained, while higher frequencies assist in higher resolution profiling nearer to the surface. A natural tradeoff is resolution and depth between the various methods for Surface wave analysis.

In the case of MASW, the method utilizes (or requires) active source input (i.e. the Surface waves are actually generated as part of the survey and are observed/recorded). The recorded signals are incoming waves of elastic deformation within the earth's surface which impart motion on a geophone (magnet in a coil), which when oscillated produces an observable electrical signal (voltage). In general, a source input consists of a dropped weight, an accelerated weight, a vibratory machine, or a sledge hammer. From this input, energy in the form of Surface waves is observed and recorded on a seismograph at some distance. A fundamental-mode (M0), or primary energy associated with the source input, is observable. Other observable seismic inputs include background noise sources (i.e. cultural). Data from this is then interpreted using a time-series Fourier Transformation to distinguish group and phase velocities, and prepare a dispersion curve (DC). The dispersion curve is an image that allows the viewer to see the distinct energy amplitude relative to the varying Surface waves frequency verses phase velocity. In reviewing the DC image, the phase velocity versus frequency relationship can be determined, along the fundamental mode energy peaks. These selected data points along the DC generally form a curved line, and from this DC curve an inversion can be performed to compare the data to a theoretical model for shear wave value versus depth. This 1D model allows for multiple scenarios which could yield the observable DC curve, and for this reason multiple variations (iterations) of the model are generally run. In doing this, a best or "most likely" case model can be achieved which can then be compared against other known data for the site (i.e. geology, direct drill samples, other geophysical methods, etc.).

Another method which uses the same principle, but is not active, is the passive method of Surface wave analysis. In this method, the observed data is the relative background seismic record. This data would otherwise be considered noise, both cultural and natural, but for which this method is capable of analyzing. While MASW focuses on active input sources from those previously mentioned (which are higher in frequency and therefore less capable of deeper profiling), passive methods focus on long wavelength signals (generally speaking). Therefore, the depth of the survey is much greater than in active methods.

The 2D Passive method is a process which incorporates multiple geophones spaced in a 2D array across a larger area, and for which incoming signals are cross-referenced between the various geophones. There are many mathematical methods for determining the relationship of wave velocity to array shape, and there are many shapes which can be used in the field for 2D Passive analysis. Some of these include L-shape or T-shape lines, in which two individual survey lines are placed roughly perpendicular to one another. Other methods include circular, square, or triangular survey line layout. The same general principals and processing procedures for DC curve picking and inversion apply to this method as well. Another similar method is the Shear Wave Refraction Microtremor Technique of geophysical testing (or ReMi). It too can be applied to obtain vertical Surface wave profiles for seismic site characterization. Testing is performed using the same equipment as that used for the surveys previously mentioned above. The source for this technique is also ambient noise (microtremors) which are present within the earth at all times. For each of the sites we performed MASW, 2D Passive, and at our option, ReMi analysis.
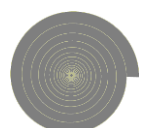
2.2   HVSR

The H/V spectral ratio method uses ambient noise seismic vibrations to estimate the fundamental frequency of soft-sedimentary and soil deposits and is used to supplement and corroborate other geophysical methods of soil site characterization. This is done using single station recordings of ambient vibrations from a three-component seismometer. The ratio of the Fourier amplitude spectra of the horizontal and vertical components is calculated and plotted against frequency. The frequency of the maximum HVSR response, or peak frequency, is considered an approximation of the fundamental frequency of the sediment at the site (Yong et al., 2013). The method is most effective for estimating the natural frequency of a soft soil site when there is a large impedance contrast with the underlying bedrock (SESAME European research project, 2004). The processing software used in this study (Geopsy) comes from the original J-SESAME software, which was designed specifically for the H/V technique. A detailed set of technical guidelines for both the field and data processing procedures of the HVSR technique and how to interpret the HVSR curves are available from the SESAME European Research Project's 2004 report.

3.0   FIELD PROCEDURES

3.1   MASW, 2D Passive, and ReMi

The MASW line was placed along the same linear path as one of the Passive 2D lines. Geophones were placed at 5 foot (1.524 meter) intervals, with a total line length of 235 feet (71.6 meters) using 48 channels/geophones (4.5 Hz). Off-end shots were performed at 100, 70, 40, and 10 feet (30.48, 21.34, 12.20, and 3.048 meter). Surveys were conducted in forward and reverse, with an additional shot taken at 1.5 feet (0.457 meters) on each end, and in the center of the array. The off-end shots were performed using a stack of 5 hits per record, with a 16-lb sledge-hammer. A single jack (4-lb hammer) was used at the 1.5 (0.457 meters) foot off-end shots to add a higher frequency noise content to the overall record. Recordings were triggered using a hammer switch and taken using a sampling rate of 1 millisecond (ms) for a total time of 2 seconds (s).

The 2D Passive and ReMi lines were arranged roughly perpendicular to each other. At each line geophones were placed at 15 foot (4.57 meter) intervals, with a total line length of 345 feet (100.6 meters) using 24 channels/geophones (4.5 Hz) for line 1, and at 15 foot (4.57 meter) intervals with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 2. Between the two lines, a total of 48 channels were utilized for the 2D Passive-ReMi surveys. Recordings were triggered automatically and taken using a sampling rate of 2 ms for a total time of 30 seconds (30 records were taken in total). Additional recording using a sampling rate of 1 ms for a total time of 15 seconds (30 records total) was performed as well. For both seismic line surveys two separate 24-Channel Geodes (by Geometrics) were combined and used for recording.

3.2   HVSR

HVSR readings were recorded after an equipment installation and warmup period of 20 minutes. Readings were taken using 500 Hz, 200 Hz, 100 Hz, and 1Hz sampling frequency settings. The total HVSR recording time for the site was roughly 2 hours in total length. Equipment used included a Kinemetrics Q330 Digitizer in combination with a 120 sec to 160 Hz Metrozet MBB-2 triaxial broadband sensor (an effective equivalent to the Trillium-120). The sensor was buried in a small hole and covered with a thermal insulator and bucket to decrease surface noise interference and temperature variations.
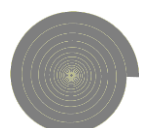
Experimental conditions are very important in the HVSR method because many types of disturbances can produce large signals that may influence the data and resulting HVSR analysis. First of all, it is important that the digitizers and sensors be allowed a warm up time of at least 10 to 15 minutes in order to assure that the instrument is stable. Seismology accelerometers not recommended for this method. The sensor should be level and the gain set to the maximum possible setting without inducing signal saturation. If possible, the sensor should be set directly on the ground, but preferably not on very soft ground or rain saturated soil. Generally, recording near structures like buildings and trees or above car parks, pipes, and sewers should be avoided; however, such ideal conditions are difficult in urban environments, and were often unavoidable. If wind is blowing, it can seriously affect the resulting H/V curves, so the sensor needs to be protected from the wind. Rain and low pressure meteorological events can also perturb the results. Measurements should not be taken near construction or large industrial machines, as these may produce false peaks in the H/V curves (SESAME European research project, 2004). In this study, measurements were obtained at sampling frequencies of 500, 200, and 100 Hz. For specific field procedures, see individual site reports.

4.0   DATA PROCESSING

4.1   MASW

Multichannel Analysis of Surface Waves (MASW) was performed using Surfseis Version 5.3 (KGS, 2017). The active method operation was chosen to evaluate the SEG-2 field files. A frequency overtone generator was used to develop a Phase Velocity-Frequency Image. From this process dispersion curves were generated for both forward and reverse geometries along the line using the 100, 70, 40, and 10 foot (30.48, 21.34, 12.20, and 3.048 meter) offsets. These individual dispersion curves were combined to create a single averaged curve for subsequent dispersion value (phase velocity vs. frequency) picking and extraction. Inversion was performed on the picked/extracted values in order to create a layer model for comparison and integration with other methods to obtain a best fit shear-wave approximation for the site. The model was allowed to run through the inversion process between 4 and 12 iterations (or until an optimum model was achieved), with a final model that reached a total depth of 30 meters. All data obtained from this processing was used to assist in developing an appropriate dispersion curve and a representative layer profile model, and for calculating the Vs30 for site class designation

4.2   2D Passive

For the 2D Passive analysis, data was collected on a field computer and then converted to the appropriate field setup geometry. Surfseis 5.3 uses UTM coordinate import files, so each of the geophones in the 2D line were surveyed in using WGS 84, and subsequent differential correction was applied to each geophone. The passive-remote mode operation was chosen to evaluate incoming surface wave velocity and frequency because it allows for the use of multiple evaluation points versus pairs or singular values, thus reducing ambiguities related to dispersion curves (DC) that are based on only one or two geophone recordings. Rather this method allows for all geophone signals to be incorporated into the DC and subsequent models. This method utilizes azimuth scanning in the frequency wavenumber power spectrum, thereby scanning all directions with 2D wavenumbers for all given frequencies. Individual geophone locations were converted to UTM coordinates and tabulated for use with the program. The geometry input file was then uploaded along with the 30 records for subsequent dispersion curve extraction. The files were preprocessed, and an automatic dispersion curve pick was achieved using similar settings as the active method described previously.
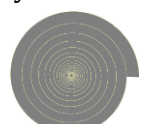
Each pick was reviewed and modified prior to the extraction of a final dispersion curve. The final DC was then created from the combined records and analyzed for the extraction of the fundamental-mode. An inversion process was then run on the DC curve to create a shear wave velocity profile.

4.3   ReMi

For the ReMi analysis, data was collected on a field computer and then converted into a general dispersion curve (showing spectral energy wave data for frequency versus phase velocity) using SeisOpt Remi 4.0 software (Optim Software). From this data image, a number of values are picked that represent the lower boundary of the spectral energy trend. These picked values are plotted in a second module of the aforementioned program. A dispersion inversion derives multiple layer and s-wave velocity approximations (conditions and scenarios) for the site. It must be understood that this type of interpretation (along with MASW and 2D Passive) may not result in a unique solution. From this a 1-dimensional (1D) image is created that shows the sum-averaged shear wave velocity for the length of analyzed survey line. This data was used to assess and compare with the MASW, 2D Passive, and HVSR data sets. Table 2. Vs30 Values Summary shows the representative shear-wave values for each site.

4.4   HVSR

Ambient noise data is processed using Geopsy software's H/V toolbox to create characteristic HVSR curves and determine the fundamental frequency of the site. Data is loaded into Geopsy with vertical and horizontal components and sampling frequencies (100 Hz, 200 Hz, and 500 Hz) specified. Data at these frequencies are processed separately. HVSR was typically calculated over the entire recording time and using a time window length of between 50 and 200 s, depending on the length of the individual recording, the number of transients (nearby foot and vehicular traffic or industrial sources), and the quality of the data. Time windows containing transients or segments yielding poor quality results are excluded from the analysis. The time windows were picked automatically using an anti-triggering algorithm applied to avoid transients. Detecting the transients is based on a comparison of the short-term average (STA, the average level of signal amplitude over a short period of time) and the long-term average (LTA, the average level of signal amplitude over a much longer period of time). In selecting windows without transients, the STA/LTA ratio should be below a small threshold value (SESAME, 2004). For each satisfactory time window, Fourier amplitude spectra are calculated and smoothed by the Konno and Ohmachi filter, which is recommended because it accounts for the different number of points at low frequencies, and using a smoothing constant between 30 and 40 (SESAME, 2004). The vertical amplitude spectra are divided by the root-mean-square of the horizontal amplitude spectra to calculate the HVSR for each window and then are averaged to produce a characteristic HVSR curve for the site. After calculating standard deviation of the HVSR amplitudes for each window, the average HVSR curve is divided and multiplied by the standard deviation to produce the minimum and maximum HVSR spectra, respectively (Yong et al., 2013; SESAME, 2004).

The peak of the H/V curve corresponds to the fundamental frequency (f0) of the site deposits; the reliability of this frequency is greater when the peak is sharper, but the amplitude of the H/V peak has no intrinsic meaning. In some cases, large H/V peak values may indicate a sharp impedance contrast at depth. In order for the H/V peak to be interpreted, the curve must be deemed reliable according to the following criteria (SESAME, 2004):

Reliability Conditions
1) $f0 > 10/l_w$, where l_w = window length
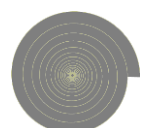
At the peak frequency, there need to be at least 10 significant cycles in each window. A stricter condition is f0 > 20/l_w.

2) $n_c = l_w * n_w * f0 > 200$,   where n_c = total # of significant cycles, n_w = # of windows
   $n_c > 400$ at low frequencies
   $n_c > 1000$ at high frequencies

3) $\sigma_A(f) < 2$,   f0 > 0.5 Hz, over a frequency range of at least [0.5f0, 2f0]
   $\sigma_A(f) < 3$,   f0 < 0.5 Hz, over a frequency range of at least [0.5f0, 2f0]
   There needs to be an acceptably low level of scattering in the amplitude of the HVSR curves of the different windows, since large standard deviation values mean that ambient vibrations are very non-stationary and are subject to perturbations that can affect the meaning of the H/V peak. While not an official criteria, H/V curves should not have amplitude values very different from 1 (less than 0.1 or larger than 10), since this is an indication that the measurements are bad due to sensor malfunction or artificial ambient vibrations (SESAME, 2004).

Ideally, the H/V curve should exhibit a clear peak at the fundamental frequency. A peak is a clear peak if the following criteria are met (SESAME, 2004):

Amplitude Conditions
i)   There exists one frequency f-, between f0/4 and f0, such that $A0/A_{H/V}(f-) > 2$
ii)   There exists one frequency f+, between f0 and f0*4, such that $A0/A_{H/V}(f+) > 2$
         These conditions mean that in the frequency bands adjacent to the peak frequency, the H/V amplitude does not exhibit another clear peak satisfying the same criteria.
iii)   A0 >2

Stability Conditions
iv)   The peak should appear at the same frequency (within a percentage of +/- 5%) on the H/V curve corresponding to mean + and – one standard deviation
v) σ_f must be lower than a frequency dependent threshold $\varepsilon(f)$
vi) $\sigma_A(f0)$ must be lower than a frequency dependent threshold $\theta(f)$

Frequency dependent thresholds for the above criteria and examples of clear peak cases are given in the SESAME European research project report (2004). If the H/V curve for a given site fulfills at least 5 out of these 6 criteria, then the f0 value can be considered as a very reliable estimate of the fundamental frequency. For a curve to have a "single" clear peak, none of the other local maxima of the H/V curve can fulfill the above clarity criteria.

One must be careful of sharp peaks that are actually of industrial origin and that do not truly represent the fundamental frequency of the site. Such peaks usually are a result of machinery, like a generator or pump, or even highway traffic. Such peaks usually show up on the raw Fourier spectra for each window on all three components at the same frequency. They also get sharper and sharper with less smoothing. Peaks of industrial origin must be completely discarded from any interpretation of the H/V curve. It is often the case, particularly in noisy urban settings, that an HVSR curve will not show a clear peak but will instead exhibit unclear low frequency peaks, broad peaks or multiple peaks, or in rare cases, two peaks that satisfy all of the criteria. Such peaks may result for many reasons; they are often a result of faulty data or recording conditions like wind or industrial sources or of inadequate processing parameters like short window lengths, but they can also be a true artefact
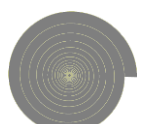
of the site conditions. For a detailed description on how to interpret these various HVSR peaks, see the SESAME European research project report (2004).

5.0   RESULTS

Values obtained from the above methods were combined and plotted for averaging of the site's Vs30 and layered models. Taking this data into account and comparing against the HVSR data, we were able to partially calculate a potential depth to bedrock interface. The equation for this is f0 = Vs4z, where Vs is assumed to be Vs-Total Depth, however we were only able to use the Vs30 value in meters, as we did not have the total depth Vs-Value of the soil layer down to bedrock. We generally performed a depth calculation with the idea that the value obtained would be a maximum, and it was used for comparison against other sources (i.e. geologic maps, drill logs, pre-established Vs30 values). In general, all of the depths seemed to be reasonable for what would be considered a bedrock material at the tested locations based on our geological review. In addition, all the associated Vs30 values seemed reasonable for each of the sites. See the table below for detailed values.

Table 2. Vs30 Values Summary

| CSMIP Station Number	Vs30 Value (m/sec)	Est. Error (+/-) in m/sec
24185	454	24
24611	392	21
24853	441	32
24851	424	60
13197	287	24
13849	303	24
23525	287	40
23091	881	100
13915	536	100
23899	390	64
23780	363	21
23542	301	22
22791	335	32
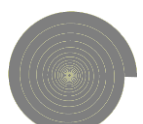
6.0   LIMITATIONS

The professional findings contained in this geophysical assessment are strictly based on a limited testing over a larger site, and are also based on the information provided regarding the proposed project, other consultant's reports and conclusions, surficial geologic conditions encountered across the site by others, and the geophysical sounding locations assessed. Furthermore, the analysis, conclusions and recommendations contained in this report are based on the site conditions as they existed at the time we performed our investigation.
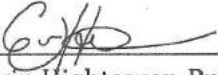
Herein, it is assumed that the geophysical test locations are representative of the subsurface conditions throughout the site, however, it should be noted that they are non-unique in many cases. Without direct evidence a level of uncertainty exists. It is standard practice to perform test drilling in areas of hazard concern, and without this information a full evaluation cannot be completed.

In reviewing data as presented in our Appendices, it should be noted that we evaluate multiple models, some of which are not presented herein. This initial test modeling is often necessary to calibrate and corroborate physical site data with geophysical "indirect data". In this process, many model iterations may be required prior to achieving a "best case" model that is of value to the end user. It is important to understand in concept that geophysical methods and processing are often non-unique, with much of the modeling input being based on professional judgment, experience, and interpretation of other known data sources.
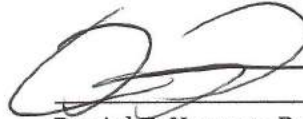
Our professional services were performed, our findings obtained, and our professional opinions are in accordance with generally accepted geologic principles and practices. This warranty is in lieu of all other warranties either expressed or implied. Our findings do not constitute a guarantee or warranty, expressed or implied.
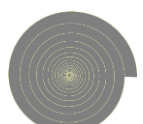
7.0   DATE AND SIGNATURE PAGE

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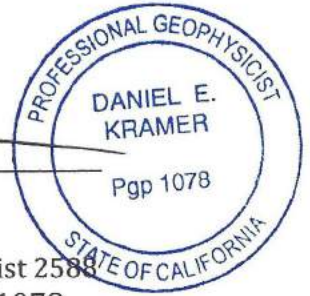
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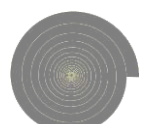
Appendix A

Report on Site Characteristics for
SMIP Station

<u>24185</u>

Station Name: Moorpark – Hwy 118/Arroyo Simi Geo. Array   **Station Number:** 24185

Location: Caltrans Area between Highways
Old Los Angeles Avenue and Highway 23
Moorpark CA, 93021

Latitude: 34.2876   **Longitude**: -118.8646
V$_{S30}$: 454 m/sec   **Estimated Error for V$_{S30}$: +/- 43 m/sec**

Site Geology:

The site area is underlain by Plio-Pleistocene sedimentary deposits of the Saugus Formation and by young Holocene alluvial fan deposits (Campbell et al., 2014). The sedimentary bedrock is relatively weak and semi-consolidated, and the alluvium is relatively loose, unconsolidated, and often saturated. These granular sediments generally consist of silty sand and sand, and groundwater is usually within 50 feet of the surface. As such, the site area and most of Moorpark are susceptible to liquefaction. The city lies between the Oak Ridge Fault to the north and the Simi-Santa Rosa Fault to the south (City of Moorpark Community Development Department, 2001). The project survey area is located on some of the younger alluvial material mentioned above (Upper 30 feet – 7.9 meters), but is flanked by the mountain geology of the Sespe and Camarillo Member of the Saugus Formations. Both of these units are older and denser, making for liquefaction at depth less of a concern and raising the potential Vs30 for the survey site.

Site Conditions:

The site is located on a slight grade, where the ground slopes down from the mountains to the creek-bed in the valley. It is also placed between two highway overpass bridges, which may generate a lot of ambient seismic noise; however, the location is generally rural, as it is away from the central part of Moorpark.

Description of Geophysical Methods and Locations of Arrays:

HVSR, MASW, and 2D Passive field procedures were performed for the site. The location of the respective test methods are shown in Figure 1, and were field surveyed using a Trimble GeoExplorer 6000 capable of sub-meter accuracy. Subsequent differential GPS corrections were made to the location files using Trimble Pathfinder to increase the accuracy of the start and end points of survey lines. Survey lines were laid out using a 300-foot tape, and bearings

were taken using a Brunton Compass. Any major elevation changes were determined in the field using a hand level and measuring rod. See Table 1 for detailed Latitudes and Longitudes.

HVSR readings were recorded after an equipment installation and warmup period of 20 minutes. Readings were taken using 500 Hz, 200 Hz, 100 Hz, and 1Hz sampling frequency settings. The total HVSR recording time for the site was roughly 2 hours in total length. Equipment used included a Kinemetrics Q330 Digitizer in combination with a 120 sec to 160 Hz Metrozet MBB-2 triaxial broadband sensor (an effective equivalent to the Trillium-120). The sensor was buried in a small hole and covered with a thermal insulator and bucket to decrease surface noise interference and temperature variations.

The MASW line was placed along the same lineal path as one of the Passive 2D lines. Geophones were placed at 5 foot (1.524 meter) intervals, with a total line length of 235 feet (71.6 meters) using 48 channels/geophones (4.5 Hz). Off-end shots were performed at 100, 70, 40, and 10 feet (30.48, 21.34, 12.20, and 3.048 meter). Surveys were conducted in forward and reverse, with an additional shot taken at 1.5 feet (0.457 meters) on each end, and in the center of the array. The off-end shots were performed using a stack of 5 hits per record, with a 16-lb sledge-hammer. A single jack (4-lb hammer) was used at the 1.5 (0.457 meters) foot off-end shots to add a higher frequency noise content to the overall record. Recordings were triggered using a hammer switch and taken using a sampling rate of 1 millisecond (ms) for a total time of 2 seconds (s).

The 2D Passive lines were arranged roughly perpendicular to each other. At each line geophones were placed at 15 foot (4.57 meter) intervals, with a total line length of 330 feet (100.6 meters) using 23 channels/geophones (4.5 Hz) for line 1, and at 15 foot (4.57 meter) intervals with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 2. Between the two lines, a total of 47 channels were utilized for the 2D Passive survey. Recordings were triggered automatically and taken using a sampling rate of 2 ms for a total time of 30 seconds (30 records were taken in total). We did additional recording using a sampling rate of 1 ms for a total time of 15 seconds (30 records total as well). For both seismic line surveys two separate 24-Channel Geodes (by Geometrics) were combined and used for recording.

HVSR Processing and Results:

Ambient noise data was recorded as MiniSEED files and processed using Geopsy software's H/V toolbox to create a characteristic HVSR curve and determine the fundamental frequency of the site. Data was loaded into Geopsy with vertical and horizontal components and sampling frequencies (100 Hz, 200 Hz, and 500 Hz) specified. Data at these frequencies were processed separately. HVSR was typically calculated over the entire recording time and using a time window length of 200 s. Time windows containing transients (nearby foot and vehicular traffic or industrial sources) or segments yielding poor quality results were excluded from the analysis. The time windows were picked automatically using an anti-triggering algorithm applied to avoid transients. For each time window, Fourier amplitude spectra were calculated and smoothed by the Konno and Ohmachi filter with a smoothing constant of 40. The HVSR was calculated for each time window and averaged to produce a

characteristic HVSR curve. After calculating standard deviation of the HVSR amplitudes for all windows, the average HVSR curve is divided and multiplied by the standard deviation to produce the minimum and maximum HVSR spectra (SESAME, 2004).

Averaging peak frequency values from data obtained at 100, 200, and 500 Hz gives a mean fundamental frequency of **0.76 Hz** (Figure 2). The peak at this frequency meets all of the criteria for a reliable HVSR curve. However, it does not meet at least five out of the six criteria for a clear peak because it fails to meet the amplitude criteria involving the peak's relative value with respect to the H/V value in other frequency bands. This is due to the fact that this is a multiple peak case. The location of the site on the sloping bank of a river may explain the multiplicity of low frequency peaks around the fundamental frequency. Despite the multiple peaks, f0 = 0.76 is the most logical option for the fundamental frequency.

There is another sharp peak at f = 4.09, which actually does meet both all the criteria for reliability and 5 out of the 6 criteria for a clear peak. Generally, this would make it a very reliable estimate of fundamental frequency. However, reprocessing with less and less smoothing reveals that this peak is likely of industrial origin, since it becomes noticeably narrower and sharper. Higher frequency peaks (greater than 1 Hz) are also predominantly related to human activity, in this case most likely resulting from highway and truck activity on the overpass that runs over the array site (Figure 1).

MASW Processing and Results:

Multichannel Analysis of Surface Waves (MASW) was performed using Surfseis Version 5.3 (KGS, 2017). The active method operation was chosen to evaluate the SEG-2 field files. A frequency overtone generator was used to develop a Phase Velocity-Frequency Image. Frequency ranges were allowed to span from 5 Hz to 50 Hz, with an allowed Phase Velocity window of 3 and 1,850 meters per second (m/sec). An automatic evaluation was performed which yielded a surface wave velocity range 226 m/sec to 5,500 m/sec, with a dominant frequency of surface waves of 9 Hz. The risk of contamination by higher modes was considered to be high, and the overall quality of input data was fair. From this process dispersion curves were generated for both forward and reverse geometries along the line using the 100, 70, 40, and 10 foot (30.48, 21.34, 12.20, and 3.048 meter) offsets. These individual dispersion curves were combined to create a single averaged curve for subsequent dispersion value (phase velocity vs. frequency) picking and extraction. Inversion was performed on the picked/extract values in order to create a layer model for comparison and integration with other methods to obtain a best fit shear-wave approximation for the site. The model was allowed to run through the inversion process for 12 iterations, with a final model that reached a total depth of 30 meters. All data obtained from this processing was used to assist in developing an appropriate dispersion curve and a representative layer profile model, and for calculating the Vs30 for site class designation (Figures 3, 4, and 5).

2D Passive Processing and Results:

2-Dimensional (2D) Passive data was analyzed using Surfseis Version 5.3 (KGS, 2017). The passive-remote mode operation was chosen to evaluate incoming surface wave velocity and

frequency because it allows for the use of multiple evaluation points versus pairs or singular values, thus reducing ambiguities related to dispersion curves (DC) that are based on only one or two geophone recordings. Rather this method allows for all geophone signals to be incorporated into the DC and subsequent models. Individual geophone locations were converted to UTM coordinates and tabulated for use with the program. The geometry input file was then uploaded along with the 30 records for subsequent dispersion curve extraction. The files were preprocessed, and an automatic dispersion curve pick was achieved using similar settings as the active method described previously. Each pick was reviewed and modified prior to the extraction of a final dispersion curve. The final DC was then created from the combined records and analyzed for the extraction of the fundamental-mode. An inversion process was then run on the DC curve to create a shear wave velocity profile. In addition to this method, Refraction Microtremor modeling was performed using ReMi (SeisOpt, 2017). ReMi analysis was performed in order to add a comparative model to our results of 2D Passive and Active methods already discussed above.

Summary of Shear Wave Data and HVSR Processing:

Values obtained from the above methods were combined and plotted for averaging of the site's Vs30 and layered models. Vs30 values ranged from between 343 m/sec to 458 m/sec depending on which model was used. The difference of these is relatively high, but it should be noted that the main variations in value were between the ReMi and 2D Passive/Active-MASW methods. The variation between the 2D Passive and MASW-Active methods themselves was only 1.7% (457 m/sec versus 451 m/sec, respectively), so they were in very good representative agreement. The observed large differences between the ReMi and other methods is likely due to the poor surface controls that the ReMi method had on near surface resolution of high frequency waveforms, as well as a poorly developed deep model which injected an infinite half-space at only 39 feet (12 meters) below the surface.

In addition, there was a significant observed velocity inversion for the ReMi analysis from 24 to 39 feet (7.31 to 11.89 meters) below ground surface. From our review, it is unlikely that this is a true scenario. In the other models from the 2D Passive/Active-MASW, the layering was deeper and more determinable up to about 40 meters below ground surface. ReMi tends to underestimate Vs30 for sites, due to its inability to distinguish fundamental modes from subsequent order energy modes. Through understanding these differences and analytical review of the data, we developed an average final estimated site Vs30 of 454 m/sec. The estimated error for this is between 9.5%, or 43 m/sec. This error is based on the likely variation in the sample mean from the population mean, which we have reviewed in some detail. This Vs30 gives the site a Site Class C designation of very dense soil to soft rock. In light of the geological review, it would appear that the designation is slightly higher than expected. However, upon closer inspection while the actual region around Moorpark is considered to be highly liquefiable and set upon soft unconsolidated alluvium, the site itself is very close to hillside formations of the Sespe Formation (a weathered poorly sorted conglomerate). This type of material at near depth could easily yield a much higher Vs30 value than that of soft alluvium.

Taking this data into account and comparing against the HVSR data, we were able to calculate a depth to bedrock interface of 149 meters. The equation for this is $f_0 = \frac{V_s}{4z}$, where Vs is assumed to be Vs30 in meters, f0 is HVSR in Hz, and z is depth in meters. This depth seems to be reasonable for what would be considered a bedrock material at this location based on our geological review. According to the Department of Water Resources the alluvium within the Semi Valley area consists of gravels, sands, and clays with a maximum thickness of 730 feet, or 222 meters (DWR 1959). They note that the alluvium becomes shallow and constricted at the point where Arroyo Simi exits the western part of the valley (near our location).
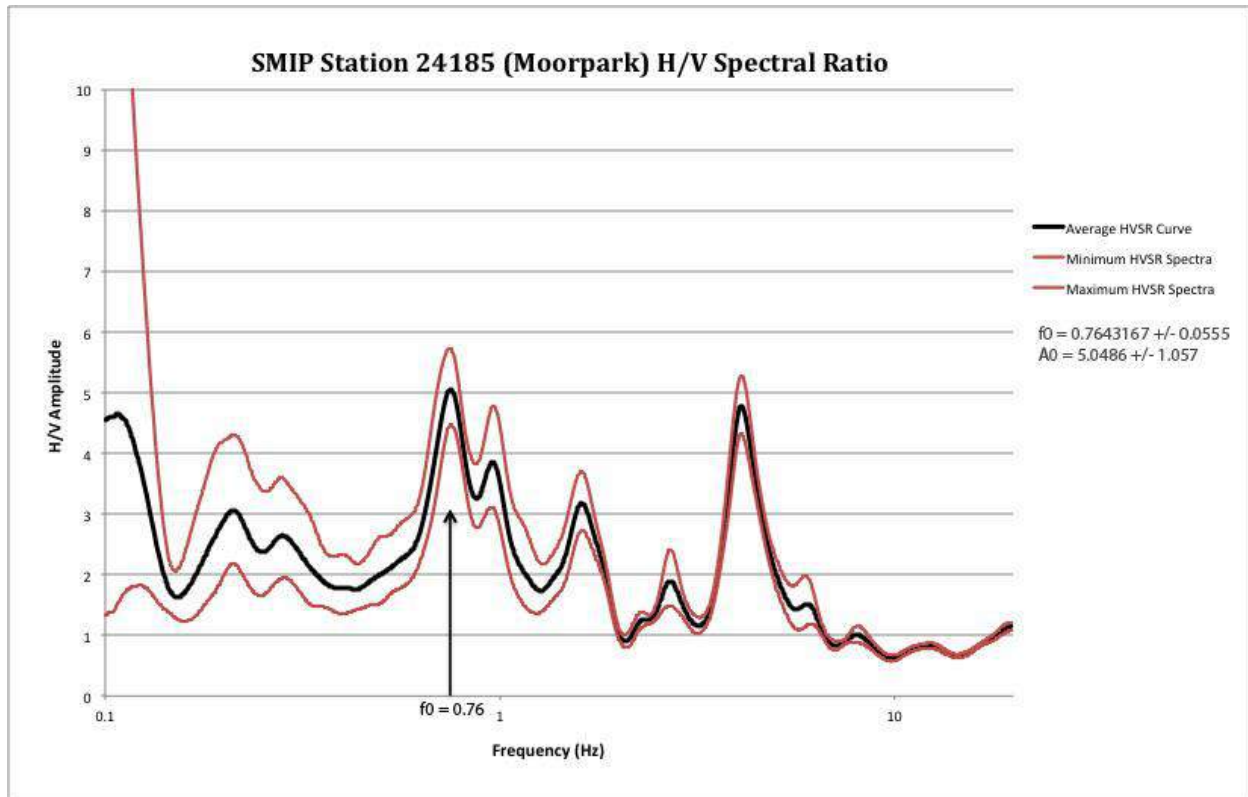
Figure 1: Site Map
SMIP Station 24185
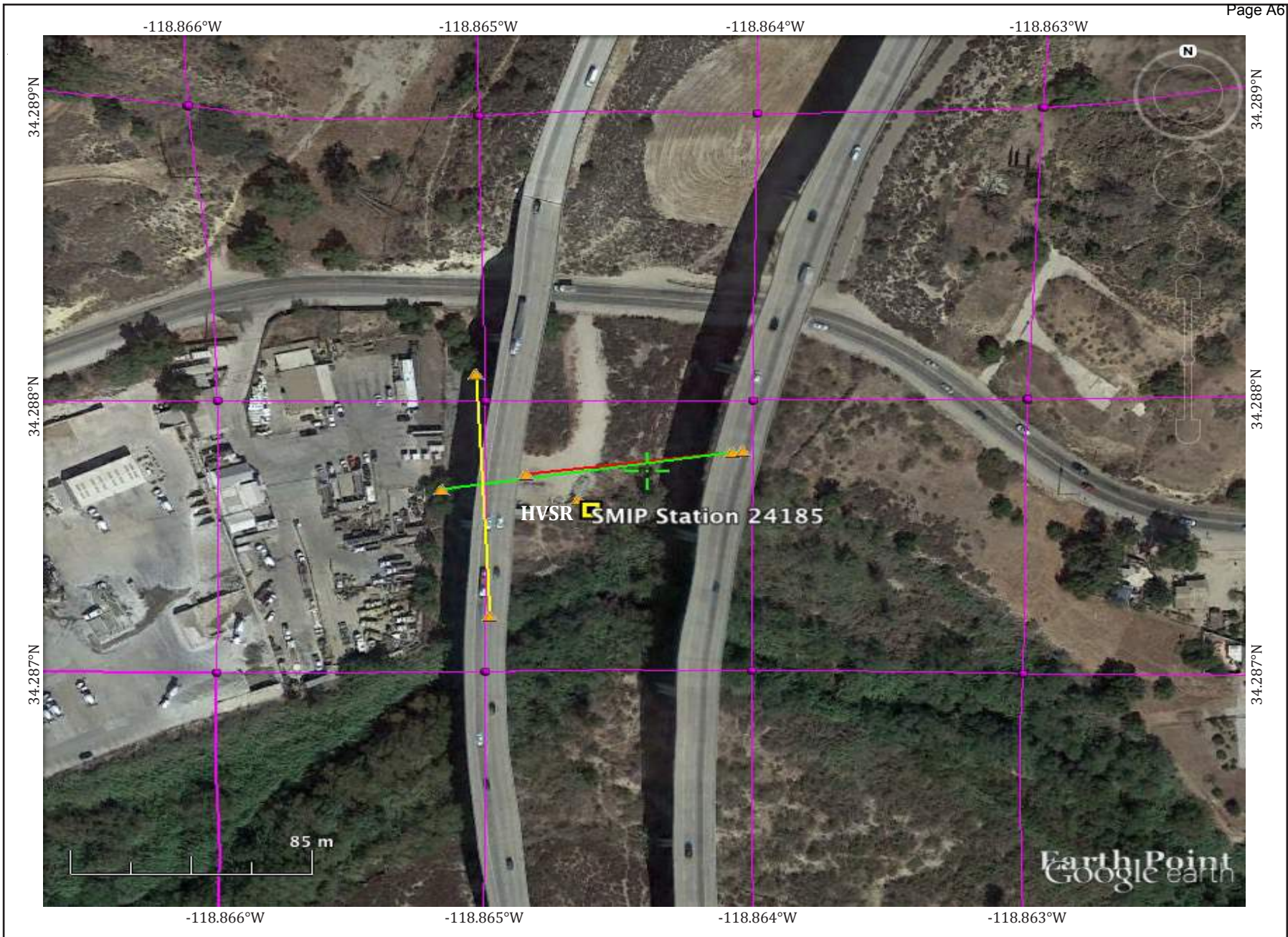
Legend

- ☐ SMIP Station 24185
- — Coordinate Grid
- — MASW Array
- — Passive Line 1
- — Passive Line 2

Figure 2 – HVSR Results: line graph showing HVSR results (H/V vs. frequency). Frequency of fundamental peak show with arrow (f0 = 0.76).
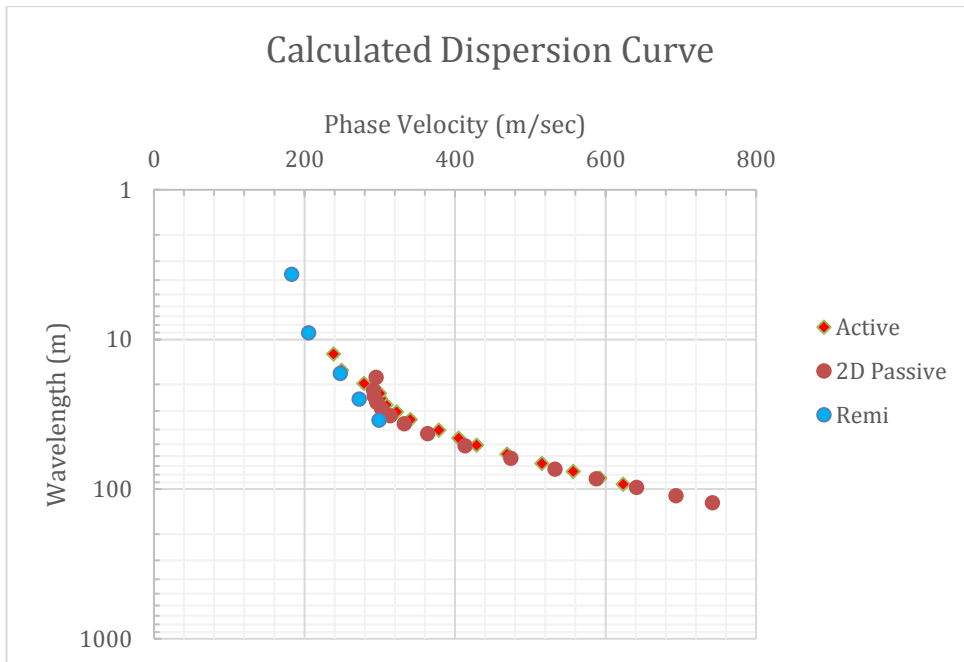
Figure 3 – Dispersion Curves: Final picked dispersion curve values for all methods.

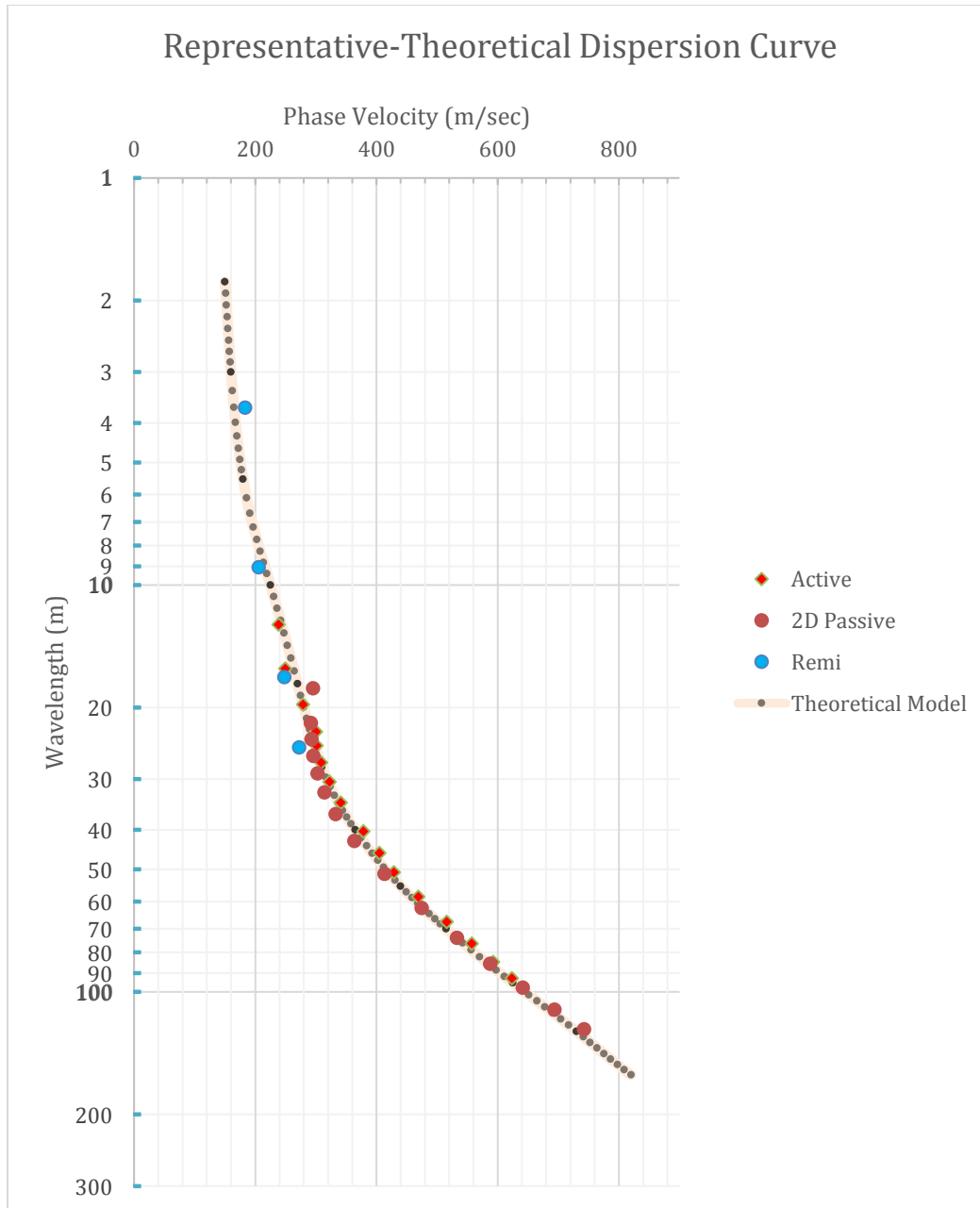Phase velocity (m/sec) vs. frequency (Hz)
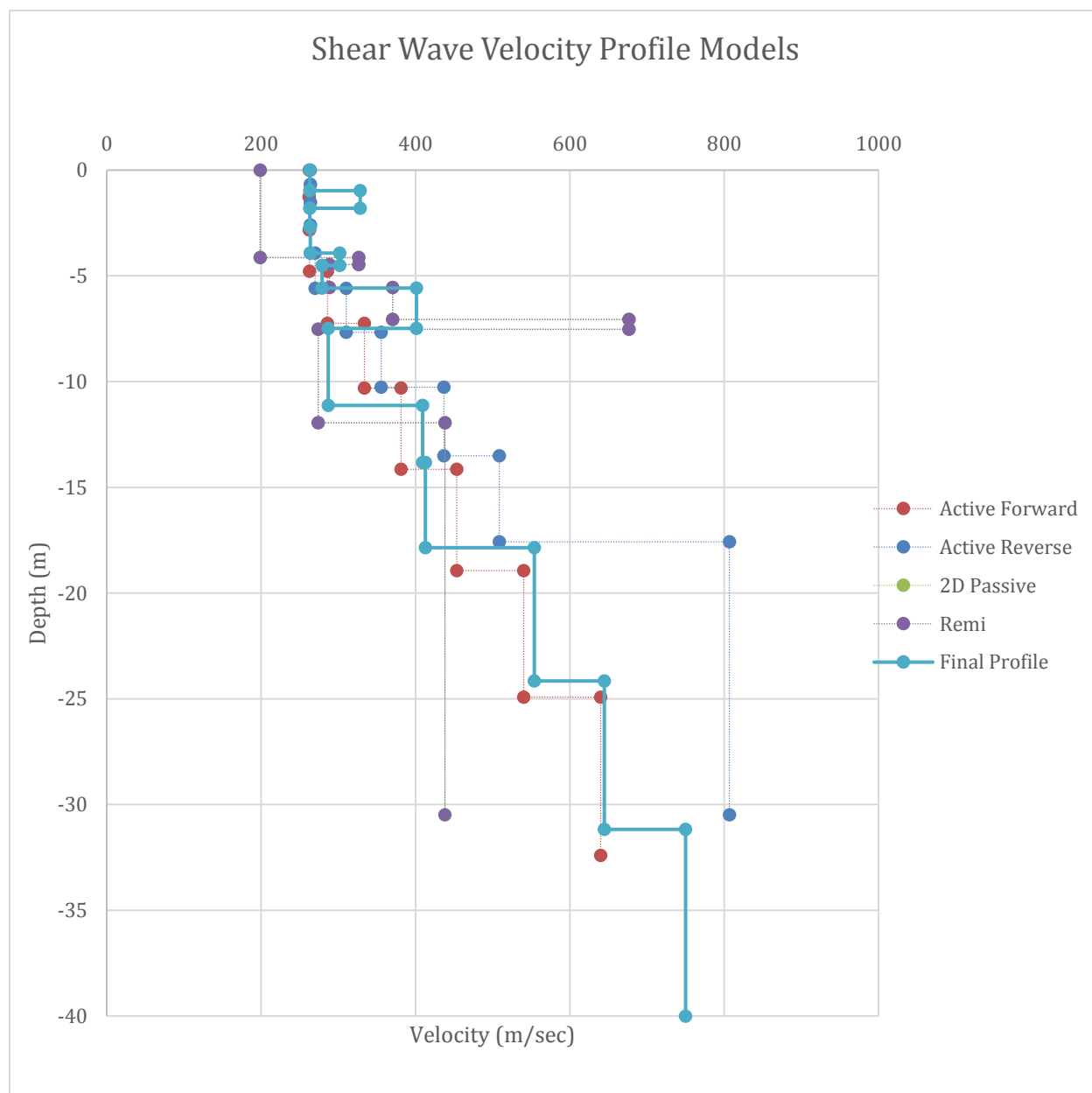

Wavelength (m) vs. phase velocity (m/sec)

Figure 4 – Representative and Calculated Dispersion Curves: Representative and calculated/theoretical dispersion curves. The field data used in the creation of the representative curve is also shown.

Figure 5 – Shear Wave Velocity Profile: Various profile models used to assess site and determine Vs30 and most likely layering scenario.

Tables:

Table 1: GPS Location Chart – Locations in latitude and longitude for MASW and 2D Passive lines – Shows location of start and end points.

Site 1 - 24185 MoorPark Hwy 118/Arroyo Simi Geo. Array

Method	Start (DD) Lat.	Start (DD) Long.	End (DD) Lat.	End (DD) Long.
MASW	34.28772919400	-118.86484794400	34.28781046000	-118.86407413400
Line 1 2D Passive	34.28767913850	-118.86511519600	34.28781509500	-118.86403440600
Line 2 2D Passive	34.28720552600	-118.86498288100	34.28809991700	-118.86503392300
	(DD) Lat.	**(DD) Long.**	-	-
HVSR	34.287635	-118.864651	-	-

Site Photos
Site 1 - 24185 Moorpark Hwy 118/Arroyo Simi Geo. Array

Figure 1 – View of onsite material and limits of survey line tape.

Figure 2 – View of GPS Unit looking down Line 1 - 2D Passive Survey.

References

Campbell, R.H., Wills, C.J., Irvine, P.J., and Swanson, B.J., 2014, Preliminary Geologic Map of the Los Angeles 30' x 60' Quadrangle, California, Version 2.1: California Department of Conservation, California Geological Survey, Scale 1:100,000, http://www.conservation.ca.gov/cgs/rghm/rgm/preliminary_geologic_maps.htm.

City of Moorpark Community Development Department, 2001, Moorpark 2000-2005 Safety Element: City of Moorpark General Plan, http://moorparkca.gov/DocumentCenter /View/173.

DWR 1959, California Department of Water Resources (DWR). 1959. Water Quality and Water Quality Problems, Ventura County. Bulletin 75. 195 p.

Geopsy Software, 2017, SESAME European Research Project: Release 0.0.0-snapshot-20170109, geopsy.org.

KGS, 2017, Kansas Geological Survey, Surfseis Version 5.3.

Optim Software, 2017, SeisOpt - ReMi Refraction Microtremor Analysis.

SESAME European Research Project, 2004, Guidelines for the Implementation of the H/V Spectral Ratio Technique on Ambient Vibrations: European Commission – Research General Directorate, Project No. EVG1-CT-2000-00026 SESAME.

Report on Site Characteristics for
SMIP Station

<u>24611</u>

Station Name: <u>Los Angeles – Temple and Hope</u>   **Station Number:** <u>24611</u>

Location: <u>Music Center Annex Parking Lot</u>
          <u>Temple Street and Grand Avenue</u>
          <u>Los Angeles, CA 90012</u>

Latitude: <u>34.0591</u>   **Longitude**: <u>-118.2466</u>
V$_{S30}$: 392 m/sec   **Estimated Error for V$_{S30}$: +/- 21 m/sec**

Site Geology:

The site sits close to a boundary between young rather unconsolidated Holocene age alluvium and more lithified Pliocene siltstone of the Puente Formation. Pleistocene age alluvial fan deposits are present within the general site area as well (Campbell et al., 2014). While the site itself is not located with an area designated as susceptible to liquefaction, a liquefiable area, with groundwater less than 30 feet deep, lies about 0.3 miles east of the site (Department of City Planning, 1996).

Site Conditions:

While the site itself is positioned on relatively flat topography, it and the surrounding area are built on top of a small cluster of shallow surface landslides (Department of City Planning, 1996). The site area is extremely urban, in downtown Los Angeles, which is likely to create a great deal of ambient seismic noise.

Description of Geophysical Methods and Locations of Arrays:

HVSR, MASW, and 2D Passive field procedures were performed for the site. The location of the respective test methods are shown in Figure 1, and were field surveyed using a Trimble GeoExplorer 6000 capable of sub-meter accuracy. Subsequent differential GPS corrections were made to the location files using Trimble Pathfinder to increase the accuracy of the start and end points of survey lines. Survey lines were laid out using a 300-foot tape, and bearings were taken using a Brunton Compass. Any major elevation changes were determined in the field using a hand level and measuring rod. See Table 1 for detailed Latitudes and Longitudes.

HVSR readings were recorded after an equipment installation and warmup period of 20 minutes. Readings were taken using 500 Hz, 200 Hz, 100 Hz, and 1Hz sampling frequency settings. The total HVSR recording time for the site was roughly 2 hours in total length. Equipment used included a Kinemetrics Q330 Digitizer in combination with a 120 sec to 160

Hz Metrozet MBB-2 triaxial broadband sensor (an effective equivalent to the Trillium-120). The sensor was buried in a small hole and covered with a thermal insulator and bucket to decrease surface noise interference and temperature variations.

The MASW line was placed along the same lineal path as one of the Passive 2D lines. Geophones were placed at 5 foot (1.524 meter) intervals, with a total line length of 235 feet (71.6 meters) using 48 channels/geophones (4.5 Hz). Off-end shots were performed at 100, 70, 40, and 10 feet (30.48, 21.34, 12.20, and 3.048 meter). Surveys were conducted in forward and reverse, with an additional shot taken at 1.5 feet (0.457 meters) on each end, and in the center of the array. The off-end shots were performed using a stack of 5 hits per record, with a 16-lb sledge-hammer. A single jack (4-lb hammer) was used at the 1.5 (0.457 meters) foot off-end shots to add a higher frequency noise content to the overall record. Recordings were triggered using a hammer switch and taken using a sampling rate of 1 milliseconds (ms) for a total time of 2 seconds (s).

The 2D Passive lines were arranged roughly perpendicular to each other. At each line geophones were placed at 15 foot (4.57 meter) intervals, with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 1, and at 15 foot (4.57 meter) intervals with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 2. Between the two lines, a total of 48 channels were utilized for the 2D Passive survey. Recordings were triggered automatically and taken using a sampling rate of 2 ms for a total time of 30 seconds (30 records were taken in total). We did additional recording using a sampling rate of 1 ms for a total time of 15 seconds (30 records total as well). For both seismic line surveys two separate 24-Channel Geodes (by Geometrics) were combined and used for recording.

HVSR Processing and Results:

Ambient noise data was recorded as MiniSEED files and processed using Geopsy software's H/V toolbox to create a characteristic HVSR curve and determine the fundamental frequency of the site. Data was loaded into Geopsy with vertical and horizontal components and sampling frequencies (100 Hz, 200 Hz, and 500 Hz) specified. Data at these frequencies were processed separately. The signals were first processed using a high-pass filter at 0.15 Hz in order to decrease scattered low frequency noise. The signals were then whitened in order to enhance the signal to noise ratio so as to more easily identify transients. HVSR was calculated over the entire recording time, using a time window length of 150 s. Time windows containing transients (nearby foot and vehicular traffic or industrial sources) or segments yielding poor quality results were excluded from the analysis. The time windows were picked automatically using an anti-triggering algorithm applied to avoid transients. Some windows were the manually removed because the signals appeared to contain notable transients within those windows that may have affected the results. For each time window, Fourier amplitude spectra were calculated and smoothed by the Konno and Ohmachi filter with a smoothing constant of 40. The HVSR was calculated for each time window and averaged to produce a characteristic HVSR curve. After calculating standard deviation of the HVSR amplitudes for all windows, the average HVSR curve is divided and multiplied by the standard deviation to produce the minimum and maximum HVSR spectra (SESAME, 2004).

Averaging peak frequency values from data obtained at 100, 200, and 500 Hz gives a mean fundamental frequency of **0.22 Hz**. The HVSR curve actually exhibits two peaks (f1 = 0.801 Hz), both of which meet all of the criteria for a reliable HVSR curve, as well as at least five out of the six criteria for a clear peak (Figure 2). Each of the peaks fails one of the amplitude criteria involving the peak's relative value with respect to the H/V value in other frequency bands. Because f0 and f1 are not sufficiently different such that they do not fail any of the clear peak criteria, it is unlikely that this is a legitimate two peaks case, where f0 and f1 represent two large impedance contrasts at two different scales. Nevertheless, the site is located close to a boundary between young rather unconsolidated Holocene age alluvium and more lithified Pliocene siltstone of the Puente Formation, which could be reflected in the two peaks. The second peak, however, is not stable in that it disappears completely with constant smoothing and almost disappears with proportional smoothing. The amplitude of this peak also decreases consistently with data obtained at lower sampling frequencies. This second peak could be an artifact of the filtering and whitening or could be of industrial origin. Thus, only f0 is considered valid, and the fundamental frequency is determined to be 0.22 Hz.

MASW Processing and Results:

Multichannel Analysis of Surface Waves (MASW) was performed using Surfseis Version 5.3 (KGS, 2017). The active method operation was chosen to evaluate the SEG-2 field files. A frequency overtone generator was used to develop a Phase Velocity-Frequency Image. Frequency ranges were allowed to span from 5 Hz to 50 Hz, with an allowed Phase Velocity window of 9 and 2,000 meters per second (m/sec). An automatic evaluation was performed which yielded a surface wave velocity range 30 m/sec to 1,890 m/sec, with a dominant frequency of surface waves of 7 Hz. The risk of contamination by higher modes was considered to be high, and the overall quality of input data was poor. This was a very noisy site, and for this reason the data was not of high quality (although there was some for extraction and use in comparison with the other methods).

From this process dispersion curves were generated for both forward and reverse geometries along the line using the 100, 70, 40, and 10 foot (30.48, 21.34, 12.20, and 3.048 meter) offsets. These individual dispersion curves were combined to create a single averaged curve for subsequent dispersion value (phase velocity vs. frequency) picking and extraction. Inversion was performed on the picked/extract values in order to create a layer model for comparison and integration with other methods to obtain a best fit shear-wave approximation for the site. The model was allowed to run through the inversion process for 10 iterations, with a final model that reached a total depth of 37.5 meters. All data obtained from this processing was used to assist in developing an appropriate dispersion curve and a representative layer profile model, and for calculating the Vs30 for site class designation (Figures 3, 4, and 5).

2D Passive Processing and Results:

2-Dimensional (2D) Passive data was analyzed using Surfseis Version 5.3 (KGS, 2017). The passive-remote mode operation was chosen to evaluate incoming surface wave velocity and frequency because it allows for the use of multiple evaluation points versus pairs or singular values, thus reducing ambiguities related to dispersion curves (DC) that are based on only one or two geophone recordings. Rather this method allows for all geophone signals to be incorporated into the DC and subsequent models. Individual geophone locations were converted to UTM coordinates and tabulated for use with the program. The geometry input file was then uploaded along with the 30 records for subsequent dispersion curve extraction. The files were preprocessed, and an automatic dispersion curve pick was achieved using similar settings as the active method described previously. Each pick was reviewed and modified prior to the extraction of a final dispersion curve. The final DC was then created from the combined records and analyzed for the extraction of the fundamental-mode. An inversion process was then run on the DC curve to create a shear wave velocity profile. In addition to this method, Refraction Microtremor modeling was performed using ReMi (SeisOpt, 2017). ReMi analysis was performed in order to add a comparative model to our results of 2D Passive and Active methods already discussed above.
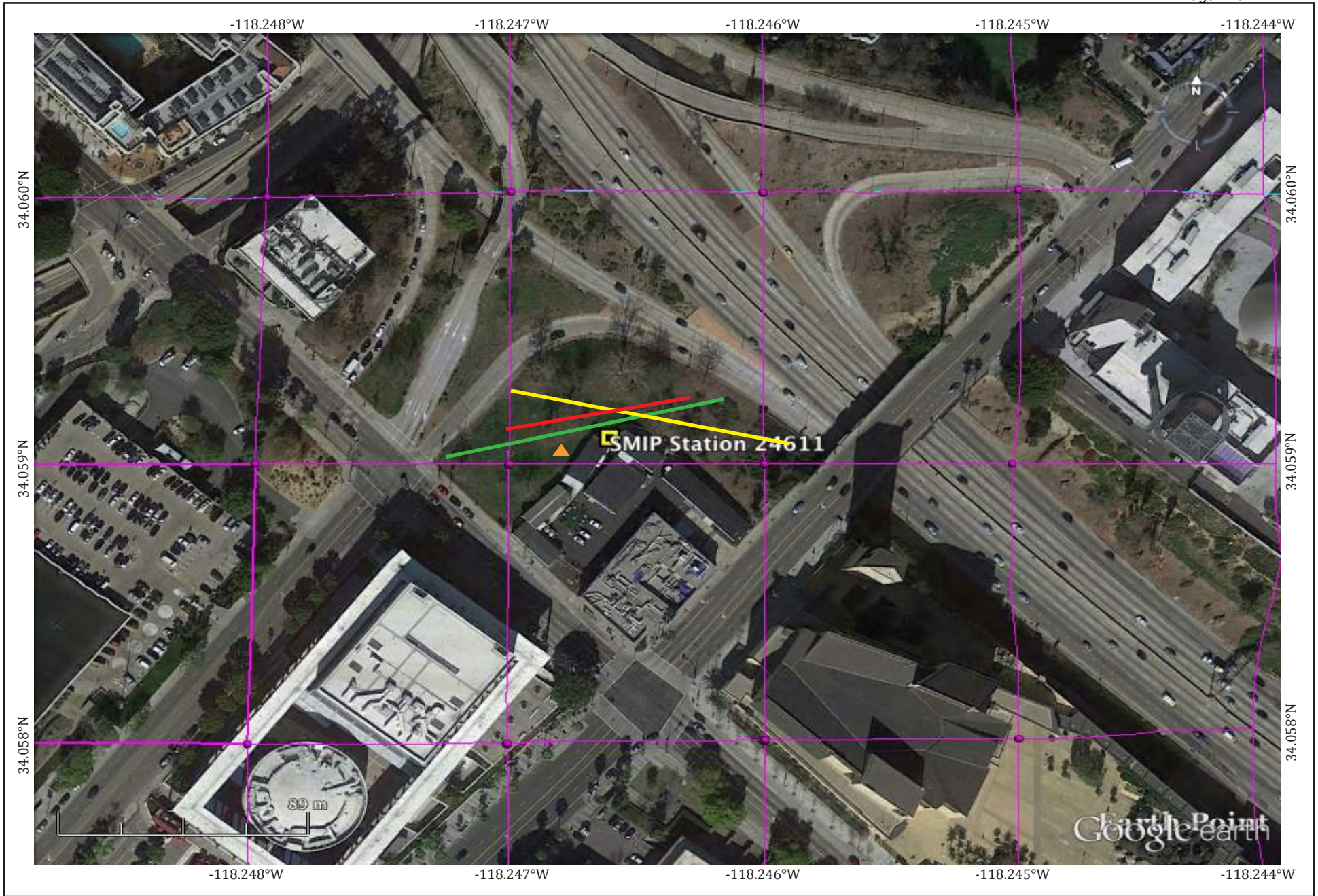
Summary of Shear Wave Data and HVSR Processing:

Values obtained from the above methods were combined and plotted for averaging of the site's Vs30 and layered models. Vs30 values ranged from between 344 m/sec to 456 m/sec depending on which model was used. The difference of these is relatively high, but it should be noted that the main variations in value were between the ReMi and 2D Passive/Active-MASW methods. The variation between the 2D Passive and MASW-Active methods themselves was still good at about 12% (450 m/sec versus 396 m/sec, respectively), so they were in moderate representative agreement. The observed differences between the ReMi and other methods is likely due to the poor surface controls that the ReMi method had on near surface resolution of high frequency waveforms.

In the 2D Passive/Active-MASW, the layering was deeper and determinable up to about 40+ meters below ground surface. ReMi tends to underestimate Vs30 for sites, due to its inability to distinguish fundamental modes from subsequent order energy modes. Through understanding these differences and analytical review of the data, we developed an average final estimated site Vs30 of 392 m/sec. The estimated error for this is 5.4%, or 21 m/sec. This error is based on the likely variation in the sample mean from the population mean, which we have reviewed in some detail. This Vs30 gives the site a Site Class C designation of very dense soil to soft rock.

In light of the geological review, it would appear that the designation makes sense and would be expected. The USGS has two Vs30 location tests roughly 1,000 meters downslope (roughly 30 meters lower in elevation) south of the site. These representative Vs30 values are 422 and 335 m/sec, respectively. Being upslope, and closer to the nearby hillside regions, the site could easily yield a Vs30 value of dense soil/soft rock. Taking this data into account and comparing against the HVSR data, we were able to calculate a depth to bedrock interface of

445 meters. The equation for this is $f0 = Vs4z$, where Vs is assumed to be Vs30 in meters, f0 is HVSR in Hz, and z is depth in meters. This depth seems to be reasonable for what would be considered a bedrock material at this location based on our geological review, and considering the nature of the valley infill and alluvium.

Image Source: Google Earth and Earth Point

Figure 1: Site Map
SMIP Station 24611

Legend

- 🟨 SMIP Station 24611
- — Coordinate Grid
- 🔺 HVSR Station
- — MASW Array
- — Passive Line 1
- — Passive Line 2

Figure 2 – HVSR Results: line graph showing HVSR results (H/V vs. frequency). Frequency of fundamental peak show with arrow (f0 = 0.22).

Figure 3 – Dispersion Curves: Final picked dispersion curve values for all methods.
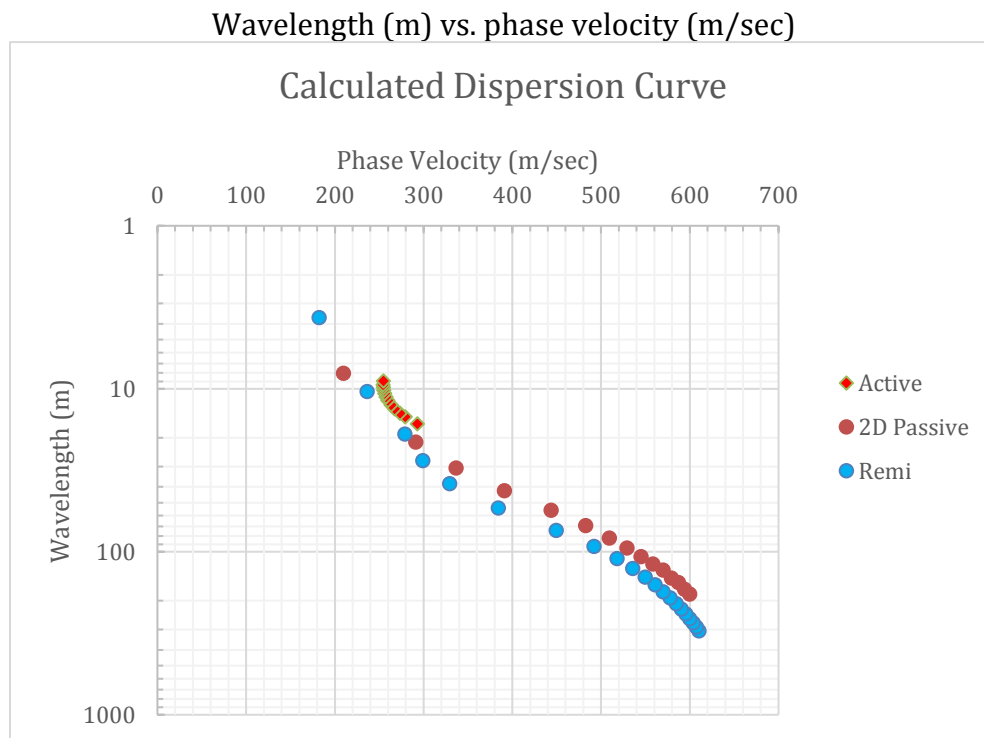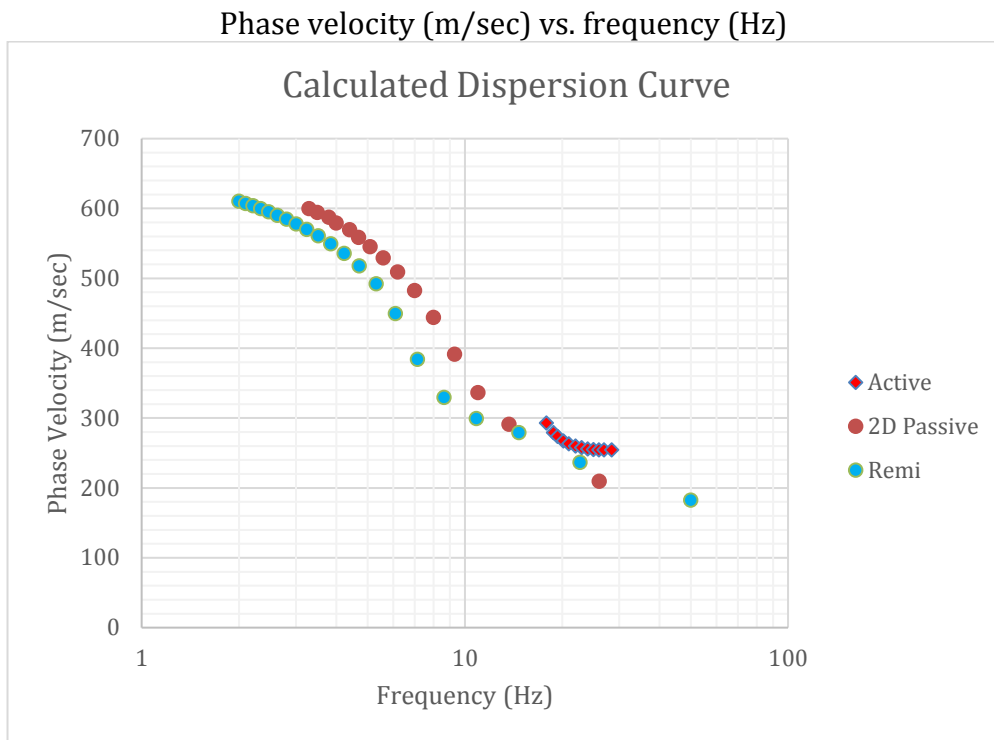
Phase velocity (m/sec) vs. frequency (Hz)

Wavelength (m) vs. phase velocity (m/sec)

Figure 4 – Representative and Calculated Dispersion Curves: Representative and calculated/theoretical dispersion curves. The field data used in the creation of the representative curve is also shown.
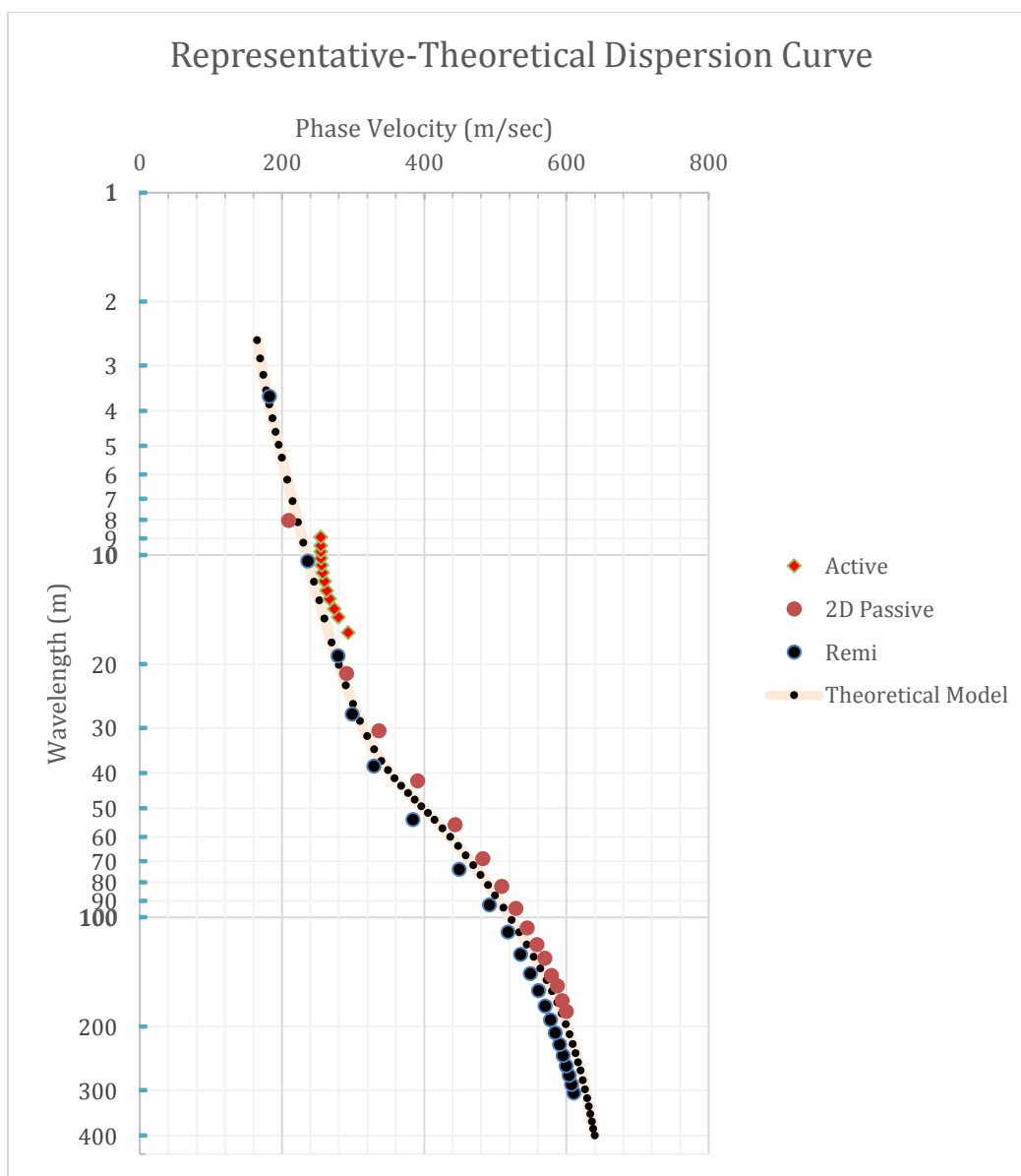
Figure 5 – Shear Wave Velocity Profile: Various profile models used to assess site and determine Vs30 and most likely layering scenario.

Tables:

Table 1: GPS Location Chart – Locations in latitude and longitude for MASW and 2D Passive lines – Shows location of start and end points.

Site Name 2 - 24611 Los Angeles Temple & Hope

Method	Start (DD) Lat.	Start (DD) Long.	End (DD) Lat.	End (DD) Long.
MASW	34.05922981600	-118.24625927000	34.05909510000	-118.24701454300
Line 1 2D Passive	34.05923867900	-118.24617540300	34.05902017900	-118.24724719400
Line 2 2D Passive	34.05906394200	-118.24588015300	34.05925863400	-118.24699626100
	(DD) Lat.	**(DD) Long.**	-	-
HVSR	34.05898700000	-118.24681700000	-	-

Site Photos
Site Name 2 - 24611 Los Angeles Temple & Hope

Figure 3 – View of seismic equipment and nearby traffic – Site Setup.

References

Campbell, R.H., Wills, C.J., Irvine, P.J., and Swanson, B.J., 2014, Preliminary Geologic Map of the Los Angeles 30' x 60' Quadrangle, California, Version 2.1: California Department of Conservation, California Geological Survey, Scale 1:100,000, http://www.conservation.ca.gov/cgs/rghm/rgm/preliminary_geologic_maps.htm.

Department of City Planning, 1996, Safety Element of the Los Angeles City General Plan: City Plan Case No. 95-0371, Council File No. 86-0662, https://planning.lacity.org/cwd/gnlpln/saftyelt.pdf.

Geopsy Software, 2017, SESAME European Research Project: Release 0.0.0-snapshot-20170109, geopsy.org.

KGS, 2017, Kansas Geological Survey, Surfseis Version 5.3.

Optim Software, 2017, SeisOpt - ReMi Refraction Microtremor Analysis.

SESAME European Research Project, 2004, Guidelines for the Implementation of the H/V Spectral Ratio Technique on Ambient Vibrations: European Commission – Research General Directorate, Project No. EVG1-CT-2000-00026 SESAME.

USGS, 2017, A Compilation of Vs30 Values in the United States, https://earthquake.usgs.gov/data/vs30/us/

Report on Site Characteristics for
SMIP Station

24853

Station Name: Los Angeles – Beverly Blvd. & Virgil   **Station Number:** 24853

Location: Beverly Blvd. LADOT
326 N. Virgil Avenue
Los Angeles, CA 90004

Latitude: 34.0774   **Longitude**: -118.2865

V$_{S30}$: 441 m/sec   **Estimated Error for V$_{S30}$: +/- 32 m/sec**

Site Geology:

The site overlies mostly Pleistocene age alluvial fan deposits, but also more consolidated Pliocene siltstone of the Puente Formation (Campbell et al., 2014). The site is located within a generally liquefiable area and close to a cluster of shallow surficial landslides to the northeast (Department of City Planning, 1996).

Site Conditions:

The general site area is located in a region of hilly topography, sloping down to the southwest; however, the specific site itself is on relatively flat ground. The site is also within an urban environment, next to a major freeway, which created a great deal of ambient seismic noise.

Description of Geophysical Methods and Locations of Arrays:

HVSR, MASW, and 2D Passive field procedures were performed for the site. The location of the respective test methods are shown in Figure 1, and were field surveyed using a Trimble GeoExplorer 6000 capable of sub-meter accuracy. Subsequent differential GPS corrections were made to the location files using Trimble Pathfinder to increase the accuracy of the start and end points of survey lines. Survey lines were laid out using a 300-foot tape, and bearings were taken using a Brunton Compass. Any major elevation changes were determined in the filed using a hand level and measuring rod. See Table 1 for detailed Latitudes and Longitudes.

HVSR readings were recorded after an equipment installation and warmup period of 20 minutes. Readings were taken using 500 Hz, 200 Hz, 100 Hz, and 1Hz sampling frequency settings. The total HVSR recording time for the site was roughly 2 hours in total length. Equipment used included a Kinemetrics Q330 Digitizer in combination with a 120 sec to 160 Hz Metrozet MBB-2 triaxial broadband sensor (an effective equivalent to the Trillium-120).

The sensor was buried in a small hole and covered with a thermal insulator and bucket to decrease surface noise interference and temperature variations.

The MASW line was placed along the same lineal path as one of the Passive 2D lines. Geophones were placed at 5 foot (1.524 meter) intervals, with a total line length of 235 feet (71.6 meters) using 48 channels/geophones (4.5 Hz). Off-end shots were performed at 100, 70, 40, and 10 feet (30.48, 21.34, 12.20, and 3.048 meter). Surveys were conducted in forward and reverse, with an additional shot taken at 1.5 feet (0.457 meters) on each end, and in the center of the array. The off-end shots were performed using a stack of 5 hits per record, with a 16-lb sledge-hammer. A single jack (4-lb hammer) was used at the 1.5 (0.457 meters) foot off-end shots to add a higher frequency noise content to the overall record. Recordings were triggered using a hammer switch and taken using a sampling rate of 1 milliseconds (ms) for a total time of 2 seconds (s).

The 2D Passive lines were arranged roughly perpendicular to each other. At each line geophones were placed at 15 foot (4.57 meter) intervals, with a total line length of 315 feet (96 meters) using 22 channels/geophones (4.5 Hz) for line 1, and at 15 foot (4.57 meter) intervals with a total line length of 330 feet (100.6 meters) using 23 channels/geophones (4.5 Hz) for line 2. Between the two lines, a total of 45 channels were utilized for the 2D Passive survey. Recordings were triggered automatically and taken using a sampling rate of 2 ms for a total time of 30 seconds (30 records were taken in total). We did additional recording using a sampling rate of 1 ms for a total time of 15 seconds (30 records total as well). For both seismic line surveys two separate 24-Channel Geodes (by Geometrics) were combined and used for recording.

HVSR Processing and Results:

Ambient noise data was recorded as MiniSEED files and processed using Geopsy software's H/V toolbox to create a characteristic HVSR curve and determine the fundamental frequency of the site. Data was loaded into Geopsy, with vertical and horizontal components and sampling frequencies (100 Hz, 200 Hz, and 500 Hz) specified. Data at these frequencies were processed separately. HVSR was calculated over the entire recording time, using a time window length of 200 s. Time windows containing transients (nearby foot and vehicular traffic or industrial sources) or segments yielding poor quality results were excluded from the analysis. The time windows were picked automatically using an anti-triggering algorithm applied to avoid transients. Some windows were the manually removed because the signals appeared to contain notable transients within those windows that may have affected the results. For each time window, Fourier amplitude spectra were calculated and smoothed by the Konno and Ohmachi filter with a smoothing constant of 40. The HVSR was calculated for each time window and averaged to produce a characteristic HVSR curve. After calculating standard deviation of the HVSR amplitudes for all windows, the average HVSR curve is divided and multiplied by the standard deviation to produce the minimum and maximum HVSR spectra (SESAME, 2004).

Averaging peak frequency values at data obtained at 100, 200, and 500 Hz gives a mean fundamental frequency of **0.14 Hz**. However, this peak is quite broad, exhibiting a

multiplicity of local maxima, and for this reason, the main peak fails to meet the amplitude criteria for a clear peak condition, though the peak is technically reliable (Figure 2). The slightly higher frequency but smaller peak, adjacent to the main peak is not stable in that it disappears with both constant and proportional smoothing parameters. The entire broad peak, including the peak frequency, also does not appear stable between different window types selected during processing (i.e. Tukey vs. Cosine), suggesting that this peak may not be a reliable indicator of the site's fundamental frequency. There is another very sharp peak at f = 0.05 Hz, but given it's low frequency and that it gets much sharper and narrow with less smoothing, it is clearly of industrial origin. There are no other peaks that would satisfy the reliability or clear peak criteria, so f0 is set at 0.14 Hz.

MASW Processing and Results:

Multichannel Analysis of Surface Waves (MASW) was performed using Surfseis Version 5.3 (KGS, 2017). The active method operation was chosen to evaluate the SEG-2 field files. A frequency overtone generator was used to develop a Phase Velocity-Frequency Image. Frequency ranges were allowed to span from 5 Hz to 50 Hz, with an allowed Phase Velocity window of 9 and 2,000 meters per second (m/sec). An automatic evaluation was performed which yielded a surface wave velocity range 270 m/sec to 1,890 m/sec, with a dominant frequency of surface waves of 13 Hz. The risk of contamination by higher modes was considered to be high, and the overall quality of input data was fair. This was a very noisy site, and for this reason the data was not of high quality (although there was some for extraction and use in comparison with the other methods).

From this process dispersion curves were generated for both forward and reverse geometries along the line using the 100, 70, 40, and 10 foot (30.48, 21.34, 12.20, and 3.048 meter) offsets. These individual dispersion curves were combined to create a single averaged curve for subsequent dispersion value (phase velocity vs. frequency) picking and extraction. Inversion was performed on the picked/extract values in order to create a layer model for comparison and integration with other methods to obtain a best fit shear-wave approximation for the site. The model was allowed to run through the inversion process for 6 iterations, with a final model that reached a total depth of 44.5 meters. All data obtained from this processing was used to assist in developing an appropriate dispersion curve and a representative layer profile model, and for calculating the Vs30 for site class designation (Figures 3, 4, and 5).

2D Passive Processing and Results:

2-Dimensional (2D) Passive data was analyzed using Surfseis Version 5.3 (KGS, 2017). The passive-remote mode operation was chosen to evaluate incoming surface wave velocity and frequency because it allows for the use of multiple evaluation points versus pairs or singular values, thus reducing ambiguities related to dispersion curves (DC) that are based on only one or two geophone recordings. Rather this method allows for all geophone signals to be incorporated into the DC and subsequent models. Individual geophone locations were converted to UTM coordinates and tabulated for use with the program. The geometry input file was then uploaded along with the 30 records for subsequent dispersion curve extraction.

The files were preprocessed, and an automatic dispersion curve pick was achieved using similar settings as the active method described previously. Each pick was reviewed and modified prior to the extraction of a final dispersion curve. The final DC was then created from the combined records and analyzed for the extraction of the fundamental-mode. An inversion process was then run on the DC curve to create a shear wave velocity profile. In addition to this method, Refraction Microtremor modeling was performed using ReMi (SeisOpt, 2017). ReMi analysis was performed in order to add a comparative model to our results of 2D Passive and Active methods already discussed above.

Summary of Shear Wave Data and HVSR Processing:

Values obtained from the above methods were combined and plotted for averaging of the site's Vs30 and layered models. Vs30 values ranged from between 435 m/sec to 500 m/sec depending on which model was used. The difference of these is only moderate. The variation between the closest models (ReMi and MASW-Active) was still good at about 3% (435 m/sec versus 445 m/sec, respectively), so they were in moderate representative agreement.

In the 2D Passive/Active-MASW, the layering was deeper and determinable up to about 45+ meters below ground surface. In general, ReMi tends to underestimate Vs30 for sites, due to its inability to distinguish fundamental modes from subsequent order energy modes. However, the 2D Passive method had the highest value of 500 m/sec (which was above the MASW-Active). Through understanding these differences and analytical review of the data, we developed an average final estimated site Vs30 of 441 m/sec. The estimated error for this is 7.3%, or 32 m/sec. This error is based on the likely variation in the sample mean from the population mean, which we have reviewed in some detail. This Vs30 gives the site a Site Class C designation of very dense soil to soft rock.

In light of the geological review, it would appear that the designation makes sense and would be expected. The site is upslope, and closer to the nearby hillsides than sites to the south where lower Vs30 values would be expected (due to thickening sediment-alluvium). Therefore, the site could easily yield a Vs30 value dense soil/soft rock.

Taking this data into account and comparing against the HVSR data, we were able to calculate a depth to bedrock interface of 788 meters. The equation for this is $f_0 = Vs4z$, where Vs is assumed to be Vs30 in meters, f_0 is HVSR in Hz, and z is depth in meters. This depth seems to be reasonable for what would be considered a bedrock material at this location based on our geological review, and the distance from the mountains to the north.
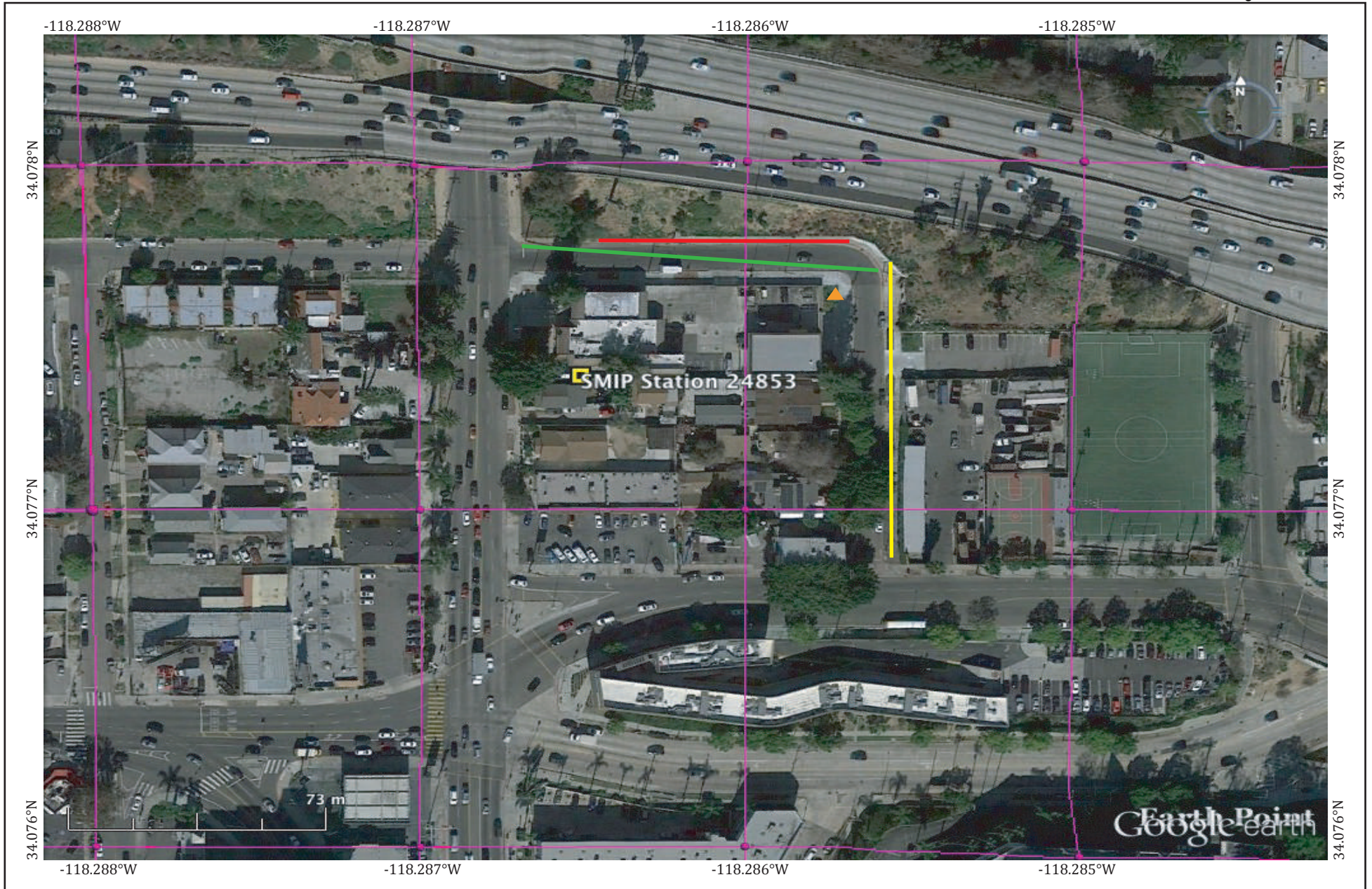
Figure 1: Site Map
SMIP Station 24853

Image Source: Google Earth and Earth Point

Legend

SMIP Station 24853
Coordinate Grid
HVSR Station

MASW Array
Passive Line 1
Passive Line 2

Figure 2 – HSRV Results: line graph showing HSRV results (H/V vs. frequency). Frequency of fundamental peak show with arrow (f0 = 0.14).
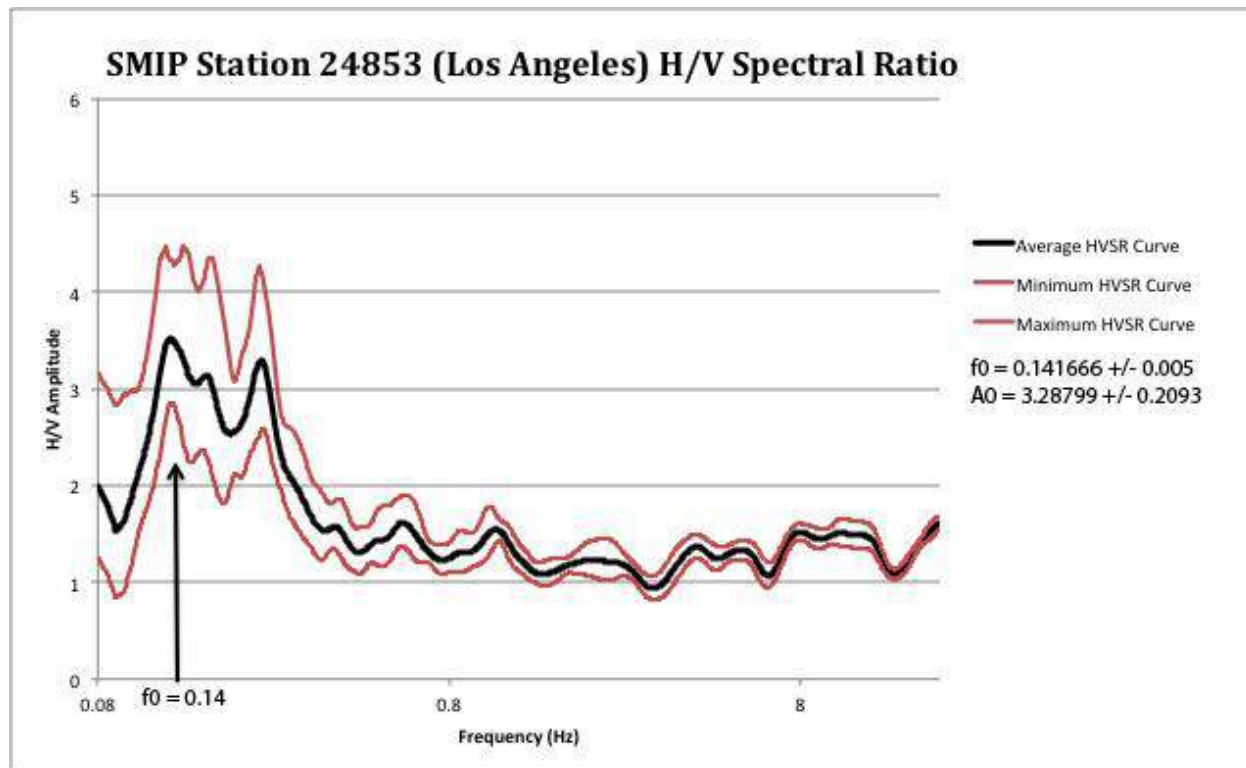
Figure 3 – Dispersion Curves: Final picked dispersion curve values for all methods.
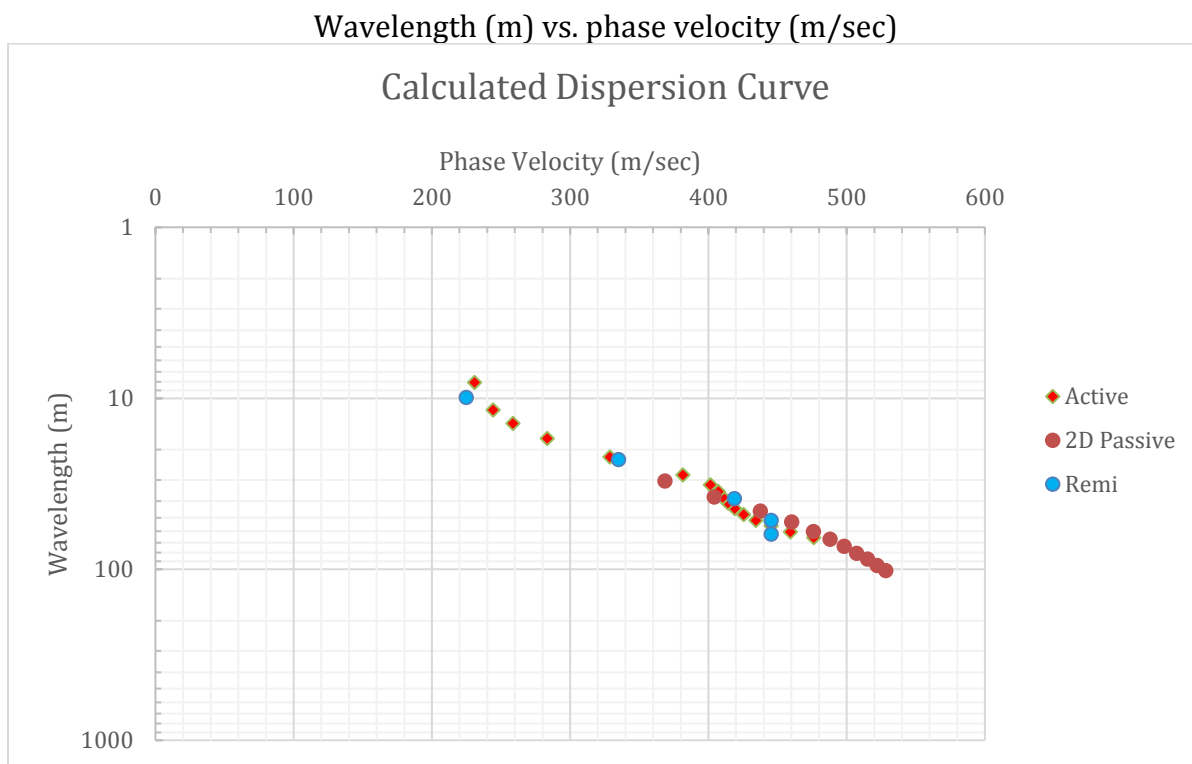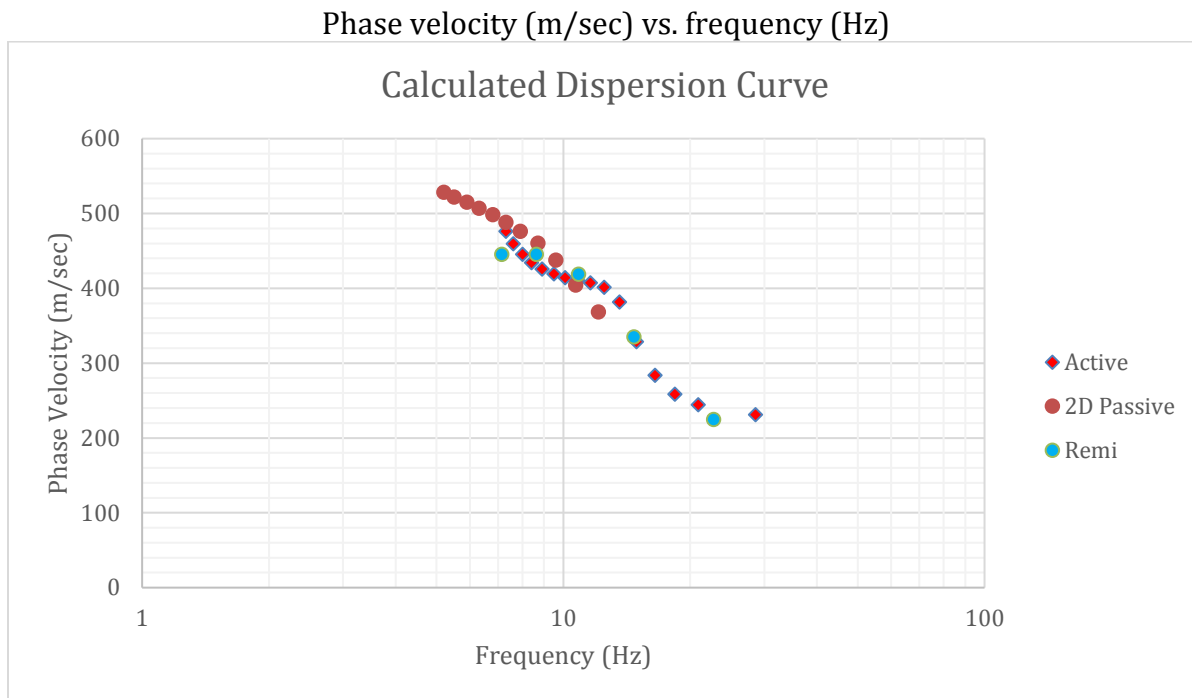
Phase velocity (m/sec) vs. frequency (Hz)

Wavelength (m) vs. phase velocity (m/sec)

Figure 4 – Representative and Calculated Dispersion Curves: Representative and calculated/theoretical dispersion curves. The field data used in the creation of the representative curve is also shown.
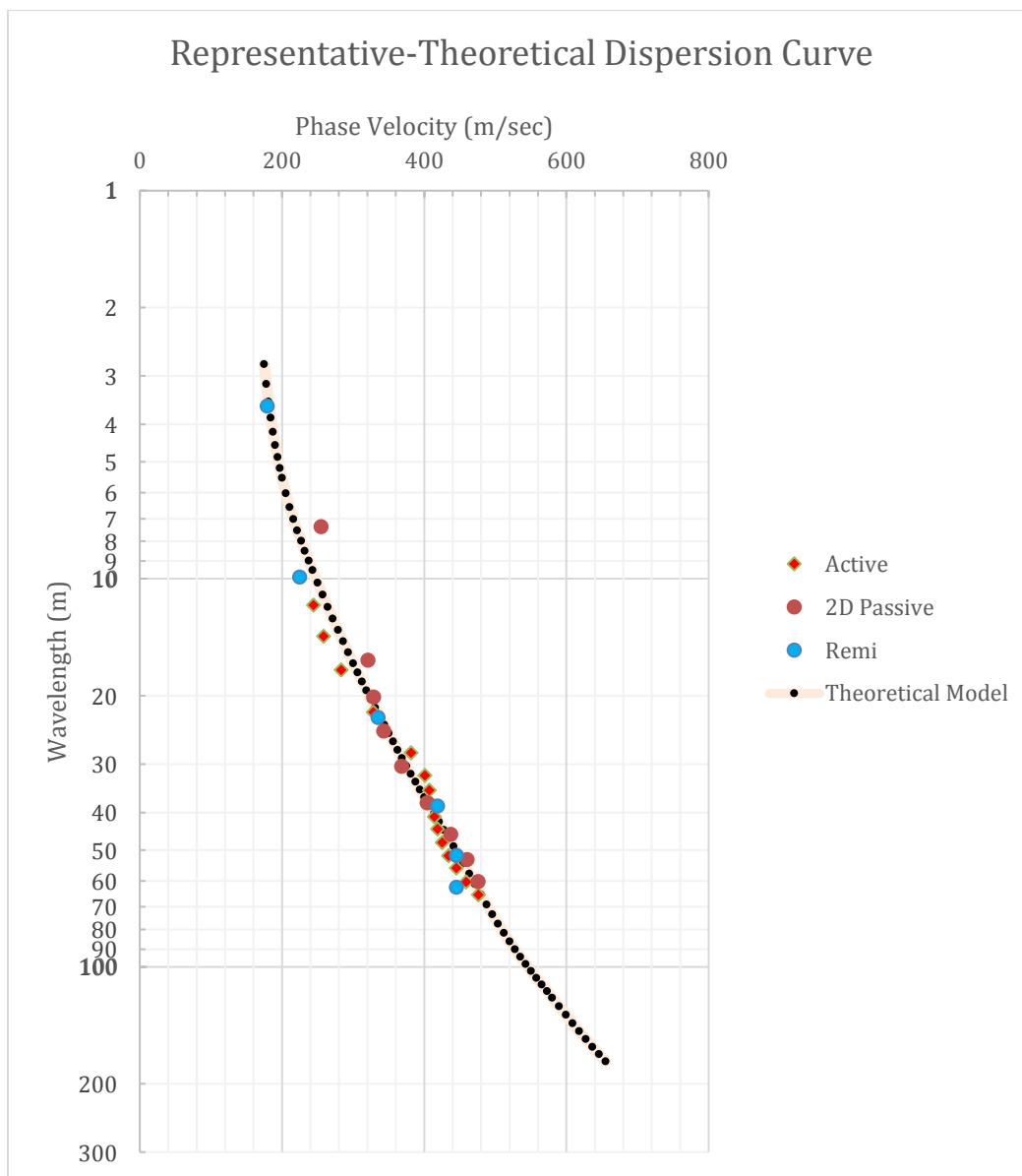
Figure 5 – Shear Wave Velocity Profile: Various profile models used to assess site and determine Vs30 and most likely layering scenario.

Tables:

Table 1: GPS Location Chart – Locations in latitude and longitude for MASW and 2D Passive lines – Shows location of start and end points.

Site 3 - 24853 Los Angeles Beverly Blvd. & Virgil

Method	Start (DD) Lat.	Start (DD) Long.	End (DD) Lat.	End (DD) Long.
MASW	34.07778546000	-118.28644841000	34.077785	-118.285674
Line 1 2D Passive	34.07771277600	-118.28557902200	34.07777224100	-118.28667635100
Line 2 2D Passive	34.07685404200	-118.28555451200	34.07772922400	-118.28554630700
	(DD) Lat.	**(DD) Long.**	-	-
HVSR	34.07762600000	-118.28572100000	-	-

Site Photos
Site 3 - 24853 Los Angeles Beverly Blvd. & Virgil

Figure 4 – View of equipment for MASW survey.

Figure 5 – View of geophones and alignment of 2D Passive line.

References

Campbell, R.H., Wills, C.J., Irvine, P.J., and Swanson, B.J., 2014, Preliminary Geologic Map of the Los Angeles 30' x 60' Quadrangle, California, Version 2.1: California Department of Conservation, California Geological Survey, Scale 1:100,000, http://www.conservation.ca.gov/cgs/rghm/rgm/preliminary_geologic_maps.htm.

Department of City Planning, 1996, Safety Element of the Los Angeles City General Plan: City Plan Case No. 95-0371, Council File No. 86-0662, https://planning.lacity.org /cwd/gnlpln/saftyelt.pdf.

Geopsy Software, 2017, SESAME European Research Project: Release 0.0.0-snapshot-20170109, geopsy.org.

KGS, 2017, Kansas Geological Survey, Surfseis Version 5.3.

Optim Software, 2017, SeisOpt - ReMi Refraction Microtremor Analysis.

SESAME European Research Project, 2004, Guidelines for the Implementation of the H/V Spectral Ratio Technique on Ambient Vibrations: European Commission – Research General Directorate, Project No. EVG1-CT-2000-00026 SESAME.

USGS, 2017, A Compilation of Vs30 Values in the United States, https://earthquake.usgs.gov/data/vs30/us/

Report on Site Characteristics for
SMIP Station

24851

Station Name: Los Angeles – 3rd and La Brea LADOT   **Station Number:** 24851

Location: LA Public Works/LADOT
        5821 W. 3rd Street
        Los Angeles, CA 90036

Latitude: 34.0695   **Longitude**: -118.3464
V$_{S30}$: 424 m/sec   **Estimated Error for V$_{S30}$: +/- 60 m/sec**

Site Geology:

The site overlies Pleistocene alluvial fan deposits as well as younger Holocene alluvium (Campbell et al., 2014). While the site itself is not located in a potentially liquefiable area, it is surrounded by liquefiable areas within about a 1 miles radius, and it is located almost within a 100-year flood plain area (Department of City Planning, 1996).

Site Conditions:

The site is located on flat topography in an urban/residential part of Los Angeles. Our survey areas consisted of on sidewalk and in alley way surveys behind the local fire station. A variety of ambient noise sources existed around site during surveying.

Description of Geophysical Methods and Locations of Arrays:

HVSR, MASW, and 2D Passive field procedures were performed for the site. The location of the respective test methods are shown in Figure 1, and were field surveyed using a Trimble GeoExplorer 6000 capable of sub-meter accuracy. Subsequent differential GPS corrections were made to the location files using Trimble Pathfinder to increase the accuracy of the start and end points of survey lines. Survey lines were laid out using a 300-foot tape, and bearings were taken using a Brunton Compass. Any major elevation changes were determined in the field using a hand level and measuring rod. See Table 1 for detailed Latitudes and Longitudes.

HVSR readings were recorded after an equipment installation and warmup period of 20 minutes. Readings were taken using 500 Hz, 200 Hz, 100 Hz, and 1Hz sampling frequency settings. The total HVSR recording time for the site was roughly 2 hours in total length. Equipment used included a Kinemetrics Q330 Digitizer in combination with a 120 sec to 160 Hz Metrozet MBB-2 triaxial broadband sensor (an effective equivalent to the Trillium-120). The sensor was buried in a small hole and covered with a thermal insulator and bucket to decrease surface noise interference and temperature variations.

The MASW line was placed along the same lineal path as one of the Passive 2D lines. Geophones were placed at 5 foot (1.524 meter) intervals, with a total line length of 235 feet (71.6 meters) using 48 channels/geophones (4.5 Hz). Off-end shots were performed at 100, 70, 40, and 10 feet (30.48, 21.34, 12.20, and 3.048 meter). Surveys were conducted in forward and reverse, with an additional shot taken at 1.5 feet (0.457 meters) on each end, and in the center of the array. The off-end shots were performed using a stack of 5 hits per record, with a 16-lb sledge-hammer. A single jack (4-lb hammer) was used at the 1.5 (0.457 meters) foot off-end shots to add a higher frequency noise content to the overall record. Recordings were triggered using a hammer switch and taken using a sampling rate of 1 milliseconds (ms) for a total time of 2 seconds (s).

The 2D Passive lines were arranged roughly perpendicular to each other. At each line geophones were placed at 15 foot (4.57 meter) intervals, with a total line length of 315 feet (96 meters) using 22 channels/geophones (4.5 Hz) for line 1, and at 15 foot (4.57 meter) intervals with a total line length of 330 feet (100.6 meters) using 23 channels/geophones (4.5 Hz) for line 2. Between the two lines, a total of 45 channels were utilized for the 2D Passive survey. Recordings were triggered automatically and taken using a sampling rate of 2 ms for a total time of 30 seconds (30 records were taken in total). We did additional recording using a sampling rate of 1 ms for a total time of 15 seconds (30 records total as well). For both seismic line surveys two separate 24-Channel Geodes (by Geometrics) were combined and used for recording.

HVSR Processing and Results:

Ambient noise data was recorded as MiniSEED files and processed using Geopsy software's H/V toolbox to create a characteristic HVSR curve and determine the fundamental frequency of the site. Data was loaded into Geopsy with vertical and horizontal components and sampling frequencies (100 Hz, 200 Hz, and 500 Hz) specified. Data at these frequencies were processed separately. HVSR was typically calculated over the entire recording time and using a time window length of 200 s. Time windows containing transients (nearby foot and vehicular traffic or industrial sources) or segments yielding poor quality results were excluded from the analysis. The time windows were picked automatically using an anti-triggering algorithm applied to avoid transients. For each time window, Fourier amplitude spectra were calculated and smoothed by the Konno and Ohmachi filter with a smoothing constant of 40. The HVSR was calculated for each time window and averaged to produce a characteristic HVSR curve. After calculating standard deviation of the HVSR amplitudes for all windows, the average HVSR curve is divided and multiplied by the standard deviation to produce the minimum and maximum HVSR spectra (SESAME, 2004).

Averaging peak frequency values at data obtained at 100, 200, and 500 Hz gives a mean fundamental frequency of **0.136 Hz**. This peak frequency meets all the criteria for reliability and at least 5 out the 6 criteria for the clear peak condition (Figure 2). Though the HVSR curve actually exhibits several clustered peaks, the higher frequency peaks are unstable in that they disappear (merging with the fundamental peak to form a broad curve) with proportional and constant smoothing parameters. The amplitude of the main peak is varies

notably among data obtained at different the sampling frequencies, but the peak itself remains sharp and appears relatively stable when using a variety of processing parameters . The broad/multiple nature of the peaks could be an artifact of the filtering and whitening or could be a result of the superposition of an industrial signal over a real site frequency peak. The busy streets of downtown Los Angeles no doubt complicate the HVSR data. However, the fundamental frequency of this site is very similar to that of SMIP Station 24853, located only 3.5 miles away and over similar terrain and geology; the principle of lateral continuity suggests these two sites would have similar subsurface geology and hence similar fundamental frequencies. Thus, f0 = 0.136 is the most likely value for the fundamental frequency of SMIP Station 24851.

MASW Processing and Results:

Multichannel Analysis of Surface Waves (MASW) was performed using Surfseis Version 5.3 (KGS, 2017). The active method operation was chosen to evaluate the SEG-2 field files. A frequency overtone generator was used to develop a Phase Velocity-Frequency Image. Frequency ranges were allowed to span from 5 Hz to 50 Hz, with an allowed Phase Velocity window of 9 and 2,000 meters per second (m/sec). An automatic evaluation was performed which yielded a surface wave velocity range 270 m/sec to 1,890 m/sec, with a dominant frequency of surface waves of 13 Hz. The risk of contamination by higher modes was considered to be high, and the overall quality of input data was fair. This was a very noisy site, and for this reason the data was not of high quality (although there was some good data for extraction and use in comparison with the other methods).

From this process dispersion curves were generated for both forward and reverse geometries along the line using the 100, 70, 40, and 10 foot (30.48, 21.34, 12.20, and 3.048 meter) offsets. These individual dispersion curves were combined to create a single averaged curve for subsequent dispersion value (phase velocity vs. frequency) picking and extraction. Inversion was performed on the picked/extract values in order to create a layer model for comparison and integration with other methods to obtain a best fit shear-wave approximation for the site. The model was allowed to run through the inversion process for 6 iterations, with a final model that reached a total depth of 44.5 meters. All data obtained from this processing was used to assist in developing an appropriate dispersion curve and a representative layer profile model, and for calculating the Vs30 for site class designation (Figures 3, 4, and 5).

2D Passive Processing and Results:

2-Dimensional (2D) Passive data was analyzed using Surfseis Version 5.3 (KGS, 2017). The passive-remote mode operation was chosen to evaluate incoming surface wave velocity and frequency because it allows for the use of multiple evaluation points versus pairs or singular values, thus reducing ambiguities related to dispersion curves (DC) that are based on only one or two geophone recordings. Rather this method allows for all geophone signals to be incorporated into the DC and subsequent models. Individual geophone locations were converted to UTM coordinates and tabulated for use with the program. The geometry input file was then uploaded along with the 30 records for subsequent dispersion curve extraction.

The files were preprocessed, and an automatic dispersion curve pick was achieved using similar settings as the active method described previously. Each pick was reviewed and modified prior to the extraction of a final dispersion curve. The final DC was then created from the combined records and analyzed for the extraction of the fundamental-mode. An inversion process was then run on the DC curve to create a shear wave velocity profile. In addition to this method, Refraction Microtremor modeling was performed using ReMi (SeisOpt, 2017). ReMi analysis was performed in order to add a comparative model to our results of 2D Passive and Active methods already discussed above.

Summary of Shear Wave Data and HVSR Processing:

Values obtained from the above methods were combined and plotted for averaging of the site's Vs30 and layered models. Vs30 values ranged from between 359 m/sec to 491 m/sec depending on which model was used. The difference of these is moderate. The variation between the closest models (ReMi and MASW-Active) was still good at about 13% (408 m/sec versus 359 m/sec, respectively), so they were in moderate representative agreement. The variation between the 2D Passive and ReMi was fair at about 17% (491 m/sec versus 408 m/sec, respectively), so once again these models were in moderate representative agreement. The main difference was between the MASW-Active and 2D Passive. These were subsequently reviewed and combined using a weighted averaging technique to address none conformance of the models and then compared against known geology for the area.

In the 2D Passive/Active-MASW, the layering was deeper and determinable up to about 40 meters below ground surface. In general, ReMi tends to underestimate Vs30 for sites, due to its inability to distinguish fundamental modes from subsequent order energy modes. However, the 2D Passive method had the highest value of 491 m/sec (which was above the MASW-Active). Through understanding these differences and analytical review of the data, we developed an average final estimated site Vs30 of 424 m/sec. The estimated error for this is 14%, or 60 m/sec. This error is based on the likely variation in the sample mean from the population mean, which we have reviewed in some detail. This Vs30 gives the site a Site Class C designation of very dense soil to soft rock.

In light of the geological review, it would appear that the designation makes sense and would be expected. Roughly 2 miles to the north an existing Vs30 value (USGS, 2017) has been estimated to be 317 m/s. The site is similar in topographic relief and general setting, so considering this, the value seems a little higher than expected. However, the models were thoroughly reviewed in detail, and rerun to review any specific modifications that could reduce Vs30 values. After a review, this value still stands as best case.

Taking this data into account and comparing against the HVSR data, we were able to calculate a depth to bedrock interface of 779 meters. The equation for this is f0 = Vs4z, where Vs is assumed to be Vs30 in meters, f0 is HVSR in Hz, and z is depth in meters. This depth seems to be reasonable for what would be considered a bedrock material at this location based on our geological review, and is similar agreement with neighboring SMIP Site 24853.

Figure 1: Site Map
SMIP Station 24851

Image Source: Google Earth and Earth Point
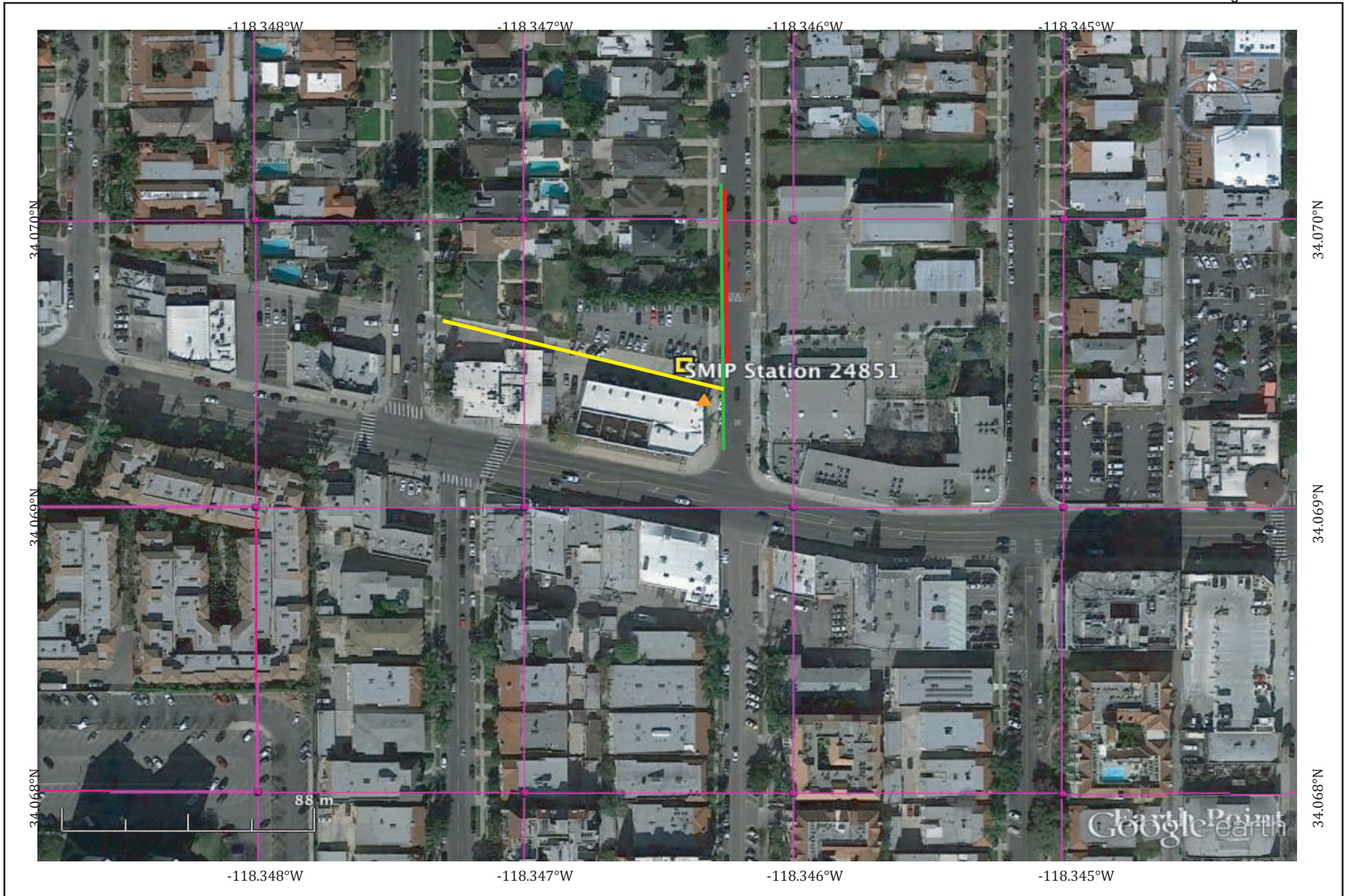
Legend

▢ SMIP Station 24851	▬ MASW Array
▬ Coordinate Grid	▬ Passive Line 1
▲ HVSR Station	▬ Passive Line 2

Figure 2 – HVSR Results: line graph showing HVSR results (H/V vs. frequency). Frequency of fundamental peak show with arrow (f0 = 0.136).

Figure 3 – Dispersion Curves: Final picked dispersion curve values for all methods.
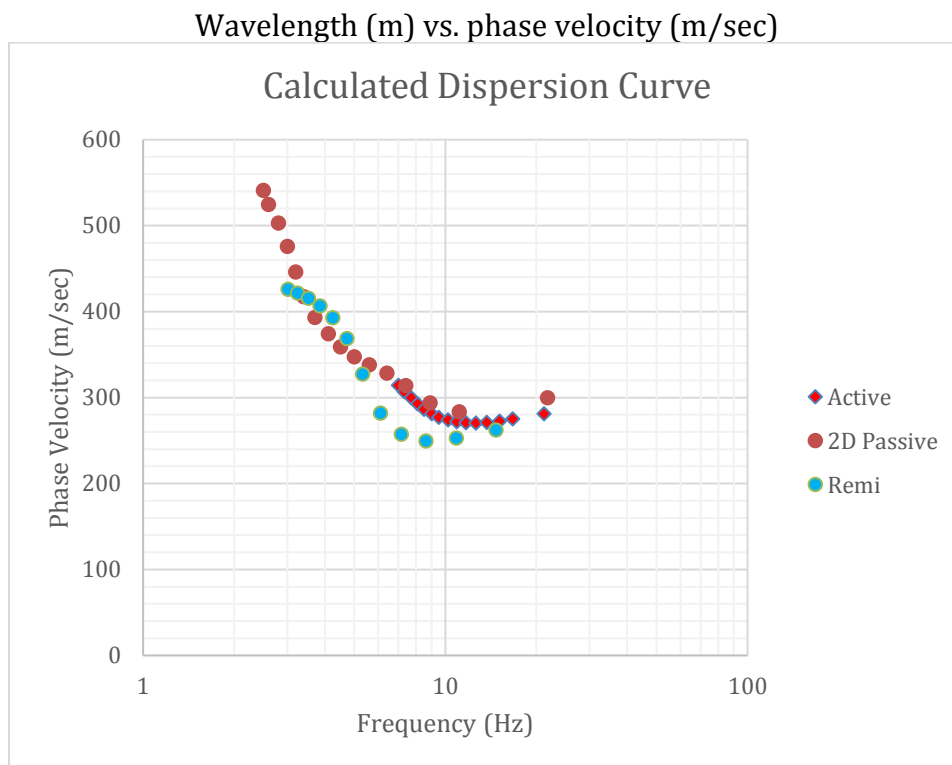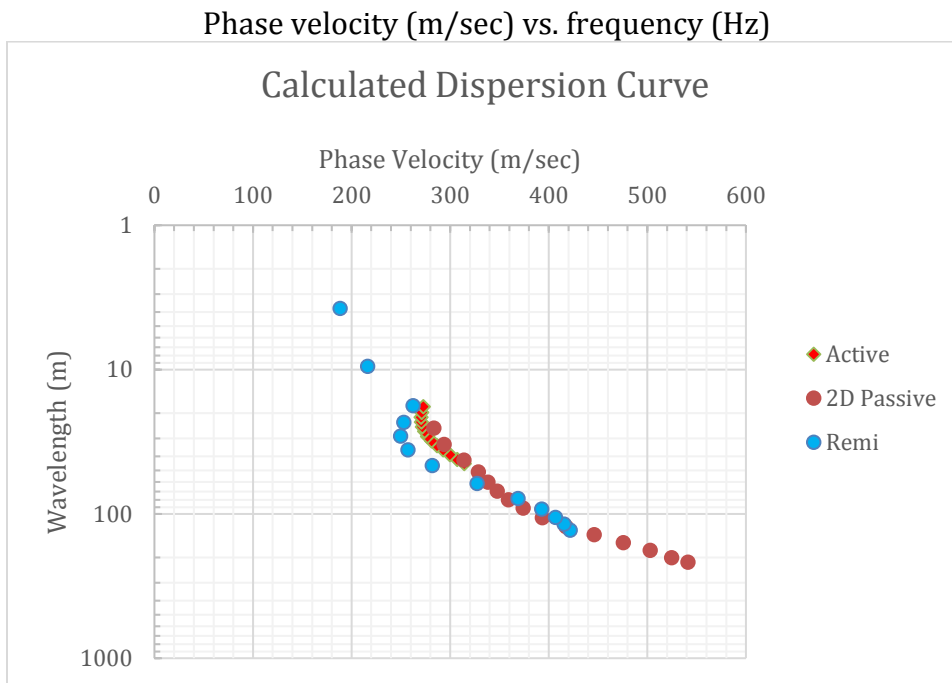
Phase velocity (m/sec) vs. frequency (Hz)

Wavelength (m) vs. phase velocity (m/sec)

Figure 4 – Representative and Calculated Dispersion Curves: Representative and calculated/theoretical dispersion curves. The field data used in the creation of the representative curve is also shown.
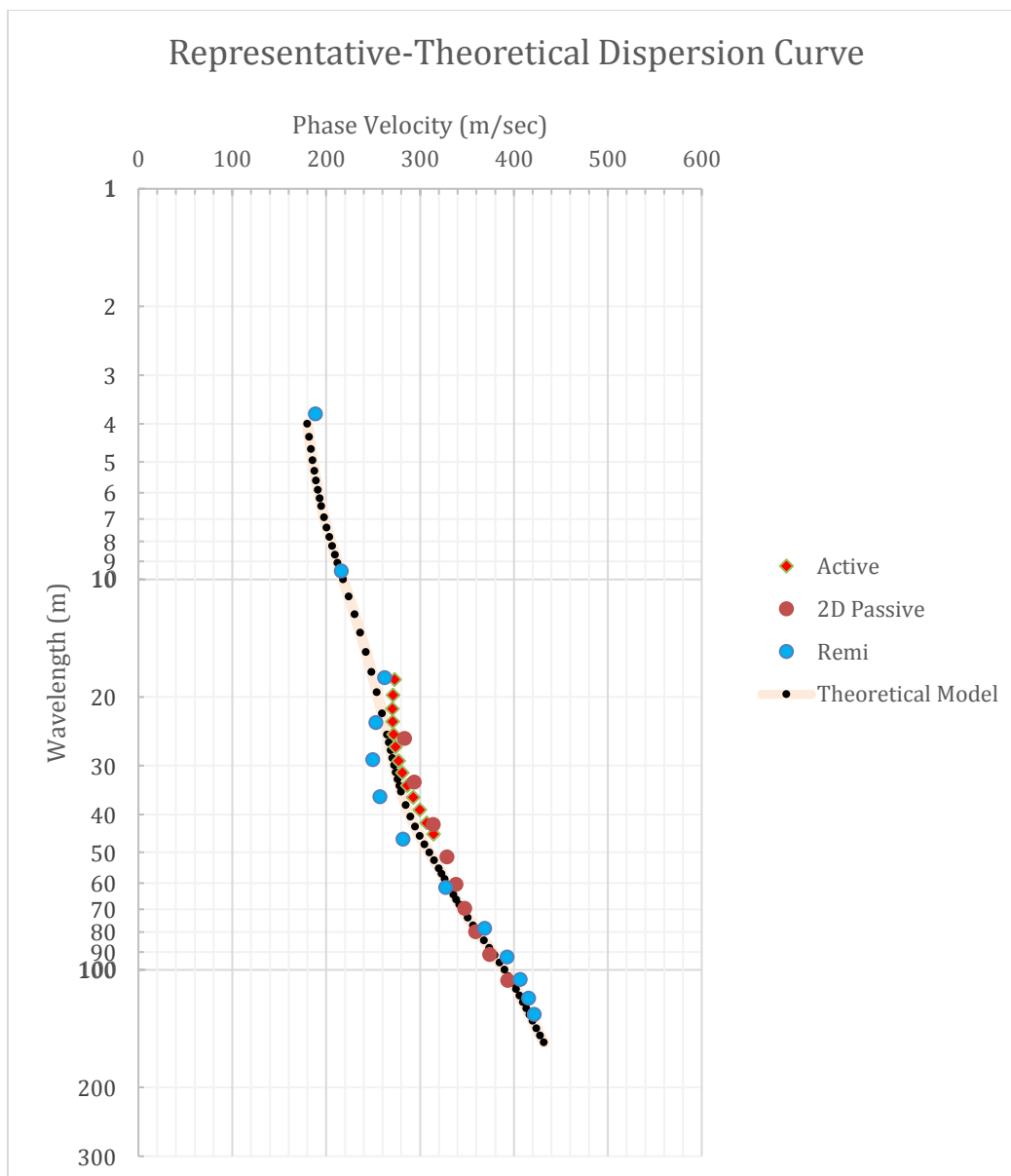
Figure 5 – Shear Wave Velocity Profile: Various profile models used to assess site and determine Vs30 and most likely layering scenario.

Tables:

Table 1: GPS Location Chart – Locations in latitude and longitude for MASW and 2D Passive lines – Shows location of start and end points.

Site 4 - 24851 Los Angeles 3rd & La Brea LADOT

Methods	Start (DD) Lat.	Start (DD) Long.	End (DD) Lat.	End (DD) Long.
MASW	34.06947801600	-118.34628359300	34.07012412200	-118.34628586700
Line 1 2D Passive	34.06920644000	-118.34628405700	34.07015359900	-118.34628677400
Line 2 2D Passive	34.06966703100	-118.34733646200	34.06942741000	-118.34628569300
	(DD) Lat.	**(DD) Long.**	-	-
HVSR	34.07012400000	-118.34628600000	-	-

Site Photos
Site 4 - 24851 Los Angeles 3rd & La Brea LADOT

Figure 6 – View of southwest corner of the site, facing east.

Figure 7 – View of 2D Passive line and general setup.

References

Campbell, R.H., Wills, C.J., Irvine, P.J., and Swanson, B.J., 2014, Preliminary Geologic Map of the Los Angeles 30' x 60' Quadrangle, California, Version 2.1: California Department of Conservation, California Geological Survey, Scale 1:100,000, http://www.conservation.ca.gov/cgs/rghm/rgm/preliminary_geologic_maps.htm.

Department of City Planning, 1996, Safety Element of the Los Angeles City General Plan: City Plan Case No. 95-0371, Council File No. 86-0662, https://planning.lacity.org /cwd/gnlpln/saftyelt.pdf.

Geopsy Software, 2017, SESAME European Research Project: Release 0.0.0-snapshot-20170109, geopsy.org.

KGS, 2017, Kansas Geological Survey, Surfseis Version 5.3.

Optim Software, 2017, SeisOpt - ReMi Refraction Microtremor Analysis.

SESAME European Research Project, 2004, Guidelines for the Implementation of the H/V Spectral Ratio Technique on Ambient Vibrations: European Commission – Research General Directorate, Project No. EVG1-CT-2000-00026 SESAME.

USGS, 2017, A Compilation of Vs30 Values in the United States, https://earthquake.usgs.gov/data/vs30/us/

Report on Site Characteristics for
SMIP Station

<u>13197</u>

Station Name: <u>Huntington Beach – Lake St. Fire Station</u> **Station Number:** <u>13197</u>

Location: <u>Lake Street Fire Station 5</u>
<u>530 Lake Street</u>
<u>Huntington Beach, CA 92648</u>

Latitude: <u>33.6623</u>   **Longitude**: <u>-117.9974</u>
V$_{S30}$: 287 m/sec   **Estimated Error for V$_{S30}$: +/- 24 m/sec**

Site Geology

The City of Huntington Beach lies over a coastal plain consisting of recently deposited sediment, overlying older bedrock formations several 1000s of feet below ground surface (bgs). Sediments are of marine and estuary origins and are exposed in coastal bluffs due to seismic uplift and wave erosion. Specifically, the surface geology around the site area consists of older Quaternary alluvial material. Given the site's proximity to the ocean, such material likely consists mostly of tidal flat and/or lagoonal fine-grained silts and clays with the potential for peat occurrence near the surface (City of Huntington Beach General Plan, 2009). Such deposits generally have poor geotechnical engineering properties. The site area has a low to moderate potential for the occurrence of expansive soils (6% - 27%), though there is a moderate to high occurrence of expansive soils (20% - 42%) about 0.25 to 0.5 miles east of the site. However, while the geology and soil conditions vary across the City, conditions at and around the site area are mostly uniform. Near surface groundwater lies more than 30 feet under ground at and around the site area but comes as shallow as 3 ft bgs in other parts of Huntington Beach.

The Newport-Inglewood Fault Zone is of most concern to the City; specifically, the South Branch Fault, a Category C fault line requiring special studies, such as subsurface investigation, for critical and important land uses, passes more or less directly underneath the site at Lake Street Fire Station #5 (City of Huntington Beach General Plan, 2009). However, this fault is not classified as active or potentially active, though it is not classified as extinct either. Moreover, the site area's potential for liquefaction is very low. In general, potential earthquake magnitudes upon which to base structural design for the City range from 6.5 to 7.0.

Site Conditions:

SMIP Station 13197 is located in an urban environment on one of the main avenues of Huntington Beach and approximately 0.5 miles from the beach. As such, this site is likely to

experience ambient noise resulting from city traffic and beach wave activity. The surrounding topography is relatively flat.

Description of Geophysical Methods and Locations of Arrays:

HVSR, MASW, and 2D Passive field procedures were performed for the site. The location of the respective test methods are shown in Figure 1, and were field surveyed using a Trimble GeoExplorer 6000 capable of sub-meter accuracy. Subsequent differential GPS corrections were made to the location files using Trimble Pathfinder to increase the accuracy of the start and end points of survey lines. Survey lines were laid out using a 300-foot tape, and bearings were taken using a Brunton Compass. Any major elevation changes were determined in the field using a hand level and measuring rod. See Table 1 for detailed Latitudes and Longitudes.

HVSR readings were recorded after an equipment installation and warmup period of 20 minutes. Readings were taken using 500 Hz, 200 Hz, 100 Hz, and 1Hz sampling frequency settings. The total HVSR recording time for the site was roughly 2 hours in total length. Equipment used included a Kinemetrics Q330 Digitizer in combination with a 120 sec to 160 Hz Metrozet MBB-2 triaxial broadband sensor (an effective equivalent to the Trillium-120). The sensor was buried in a small hole and covered with a thermal insulator and bucket to decrease surface noise interference and temperature variations.

The MASW line was placed along the same lineal path as one of the Passive 2D lines. Geophones were placed at 5 foot (1.524 meter) intervals, with a total line length of 235 feet (71.6 meters) using 48 channels/geophones (4.5 Hz). Off-end shots were performed at 100, 70, 40, and 10 feet (30.48, 21.34, 12.20, and 3.048 meter). Surveys were conducted in forward and reverse, with an additional shot taken at 1.5 feet (0.457 meters) on each end, and in the center of the array. The off-end shots were performed using a stack of 5 hits per record, with a 16-lb sledge-hammer. A single jack (4-lb hammer) was used at the 1.5 (0.457 meters) foot off-end shots to add a higher frequency noise content to the overall record. Recordings were triggered using a hammer switch and taken using a sampling rate of 1 milliseconds (ms) for a total time of 2 seconds (s).

The 2D Passive lines were arranged roughly perpendicular to each other. At each line geophones were placed at 15 foot (4.57 meter) intervals, with a total line length of 300 feet (78.9 meters) using 21 channels/geophones (4.5 Hz) for line 1, and at 15 foot (4.57 meter) intervals with a total line length of 300 feet (78.9 meters) using 21 channels/geophones (4.5 Hz) for line 2. This distance was less than the requested 100 meter length, however, we were able to achieve 40+ depth estimates from this profile. The shortened length was due to the small size of the city blocks and road interferences. Between the two lines, a total of 42 channels were utilized for the 2D Passive survey. Recordings were triggered automatically and taken using a sampling rate of 2 ms for a total time of 30 seconds (30 records were taken in total). We did additional recording using a sampling rate of 1 ms for a total time of 15 seconds (30 records total as well). For both seismic line surveys two separate 24-Channel Geodes (by Geometrics) were combined and used for recording.

HVSR Processing and Results:

Ambient noise data was recorded as MiniSEED files and processed using Geopsy software's H/V toolbox to create a characteristic HVSR curve and determine the fundamental frequency of the site. Data was loaded into Geopsy with vertical and horizontal components and sampling frequencies (100 Hz, 200 Hz, and 500 Hz) specified. Data at these frequencies were processed separately. HVSR was typically calculated over the entire recording time and using a time window length of 200 s. Time windows containing transients (nearby foot and vehicular traffic or industrial sources) or segments yielding poor quality results were excluded from the analysis. The time windows were picked automatically using an anti-triggering algorithm applied to avoid transients. For each time window, Fourier amplitude spectra were calculated and smoothed by the Konno and Ohmachi filter with a smoothing constant of 40. The HVSR was calculated for each time window and averaged to produce a characteristic HVSR curve. After calculating standard deviation of the HVSR amplitudes for all windows, the average HVSR curve is divided and multiplied by the standard deviation to produce the minimum and maximum HVSR spectra (SESAME, 2004).

Each of the HVSR curves exhibited two peaks (f0 = 0.206, f1 = 0.344) (Figure 2). Both peaks meet the necessary reliability criteria, but neither meet at least five out the six criteria necessary for a clear peak; both only meet four. Given that both peaks meet equal qualifications, the lower frequency peak, which is significantly more prominent, it designated the best estimate of fundamental frequency (f0 = **0.206 Hz**) given the limited clarity of the HVSR curves for this site. Moreover, this peak is stable among different smoothing parameters, whereas the peak at f1 disappears with less or proportional smoothing. Different filtering and processing parameters also reveal a sharp peak at around 0.1 Hz and unfiltered data exhibits a number of unclear low frequency peaks. While this very low frequency peak appears to be relatively stable with different smoothing parameters, it is not so with respect to its associated frequency. It also does not meet the reliability criteria and thus is most likely indicative of wind or traffic effects or a bad soil-sensor coupling. That being said the peak at the chosen fundamental frequency may in fact be associated with these unclear low frequency peaks and therefore may not be a very reliable estimate of fundamental frequency. However, ocean waves have their maximum energy at about 0.2 Hz, so given the proximity of the station to the beach, we should expect to see a sharp peak at low frequencies. Low fundamental frequencies are also indicative of very soft soil with a thickness of several tens of meters or normal sedimentary deposits several hundred meters thick. Given the geology of the site and the predominance of tidal and lagoonal silts and clays, a low fundamental frequency is expected.

MASW Processing and Results:

Multichannel Analysis of Surface Waves (MASW) was performed using Surfseis Version 5.3 (KGS, 2017). The active method operation was chosen to evaluate the SEG-2 field files. A frequency overtone generator was used to develop a Phase Velocity-Frequency Image. Frequency ranges were allowed to span from 1 Hz to 50 Hz, with an allowed Phase Velocity window of 10 and 3,000 meters per second (m/sec). An automatic evaluation was performed which yielded a surface wave velocity range of 2.74 and 3,109 m/sec, with a dominant

frequency of surface waves of 9 Hz. The risk of contamination by higher modes was considered moderate, and the overall quality of input data was good.

From this process dispersion curves were generated for both forward and reverse geometries along the line using the 100, 70, 40, and 10 foot (30.48, 21.34, 12.20, and 3.048 meter) offsets. These individual dispersion curves were combined to create a single averaged curve for subsequent dispersion value (phase velocity vs. frequency) picking and extraction. Inversion was performed on the picked/extract values in order to create a layer model for comparison and integration with other methods to obtain a best fit shear-wave approximation for the site. The model was allowed to run through the inversion process for 6 iterations, with a final model that reached a total depth of 49.6 meters. All data obtained from this processing was used to assist in developing an appropriate dispersion curve and a representative layer profile model, and for calculating the Vs30 for site class designation (Figures 3, 4, and 5).

2D Passive Processing and Results:

2-Dimensional (2D) Passive data was analyzed using Surfseis Version 5.3 (KGS, 2017). The passive-remote mode operation was chosen to evaluate incoming surface wave velocity and frequency because it allows for the use of multiple evaluation points versus pairs or singular values, thus reducing ambiguities related to dispersion curves (DC) that are based on only one or two geophone recordings. Rather this method allows for all geophone signals to be incorporated into the DC and subsequent models. Individual geophone locations were converted to UTM coordinates and tabulated for use with the program. The geometry input file was then uploaded along with the 30 records for subsequent dispersion curve extraction. The files were preprocessed, and an automatic dispersion curve pick was achieved using similar settings as the active method described previously. Each pick was reviewed and modified prior to the extraction of a final dispersion curve. The final DC was then created from the combined records and analyzed for the extraction of the fundamental-mode. An inversion process was then run on the DC curve to create a shear wave velocity profile. In addition to this method, Refraction Microtremor modeling was performed using ReMi (SeisOpt, 2017). ReMi analysis was performed in order to add a comparative model to our results of 2D Passive and Active methods already discussed above.

Summary of Shear Wave Data and HVSR Processing

Values obtained from the above methods were combined and plotted for averaging of the site's Vs30 and layered models. Initial Vs30 values ranged from between 361 m/sec to 367 m/sec depending on which model was used. The difference of these is low, however, site review illustrates these values to be much higher than expected. Neighboring sites have values in the of 250 m/sec range. Based on this a rerun model was performed using a reduction in high value layers that were suspect based on inverted Vs value or depth thickness (i.e. random high values in an otherwise low value Vs profile. Based on this a new Vs30 of 287 m/sec was achieved. This value was subsequently reviewed and combined using a weighted averaging techniques to address none conformance of the models, and was combined to make a final layer profile.

In the 2D Passive/Active-MASW, the layering was deeper and determinable up to about 40 meters below ground surface. In general, ReMi tends to underestimate Vs30 for sites, due to its inability to distinguish fundamental modes from subsequent order energy modes. However, the 2D Passive and Remi methods both had higher values than the achieved average Vs30 (365 and 361 m/sec, respectively). Through understanding these differences and analytical review of the data, we developed the final average value for Vs30 as discussed above (Vs30 = 287 m/sec). The estimated error for this is 8.3%, or 24 m/sec. This error is based on the likely variation in the sample mean from the population mean, which we have reviewed in some detail. This Vs30 gives the site a Site Class D designation of very dense soil to soft rock. Based on our review, the site appears to have the potential for liquefaction based on Vs, geology (soil types), and high groundwater.

In light of the overall review, it would appear that the designation makes sense and would be expected. Within a rough radius of approximately 2 miles of the site two existing Vs30 value (USGS, 2017) have been estimated to be at 220 and 203 m/sec, respectively. The site is similar in topographic relief and general setting, so considering this, the value seems slightly higher than expected. However, the models were thoroughly reviewed in detail, and rerun to review any specific modifications that could reduce Vs30 values. After a review, this value still stands as best case. Additional review of the site may be warranted to confirm other similar Vs30 values within a 0.25 to 0.5 mile radius of the site.

Taking this data into account and comparing against the HVSR data, we were able to calculate a depth to apparent bedrock interface of 348 meters. The equation for this is $f0 = Vs4z$, where Vs is assumed to be Vs30 in meters, f0 is HVSR in Hz, and z is depth in meters. This is reasonable when compared with local DOGGR (DOGGR, 2017) drill well data logs, which indicate a zone of fresh water transition (for protection of fresh water sources) at 425 meters. Although there is no bedrock, the material at this depth has a velocity characteristic of Vs = +1500 m/sec, which would equate to Site Class A (or bedrock characteristic in terms of shear wave value) at that depth. Therefore, we find this a reasonable assessment.
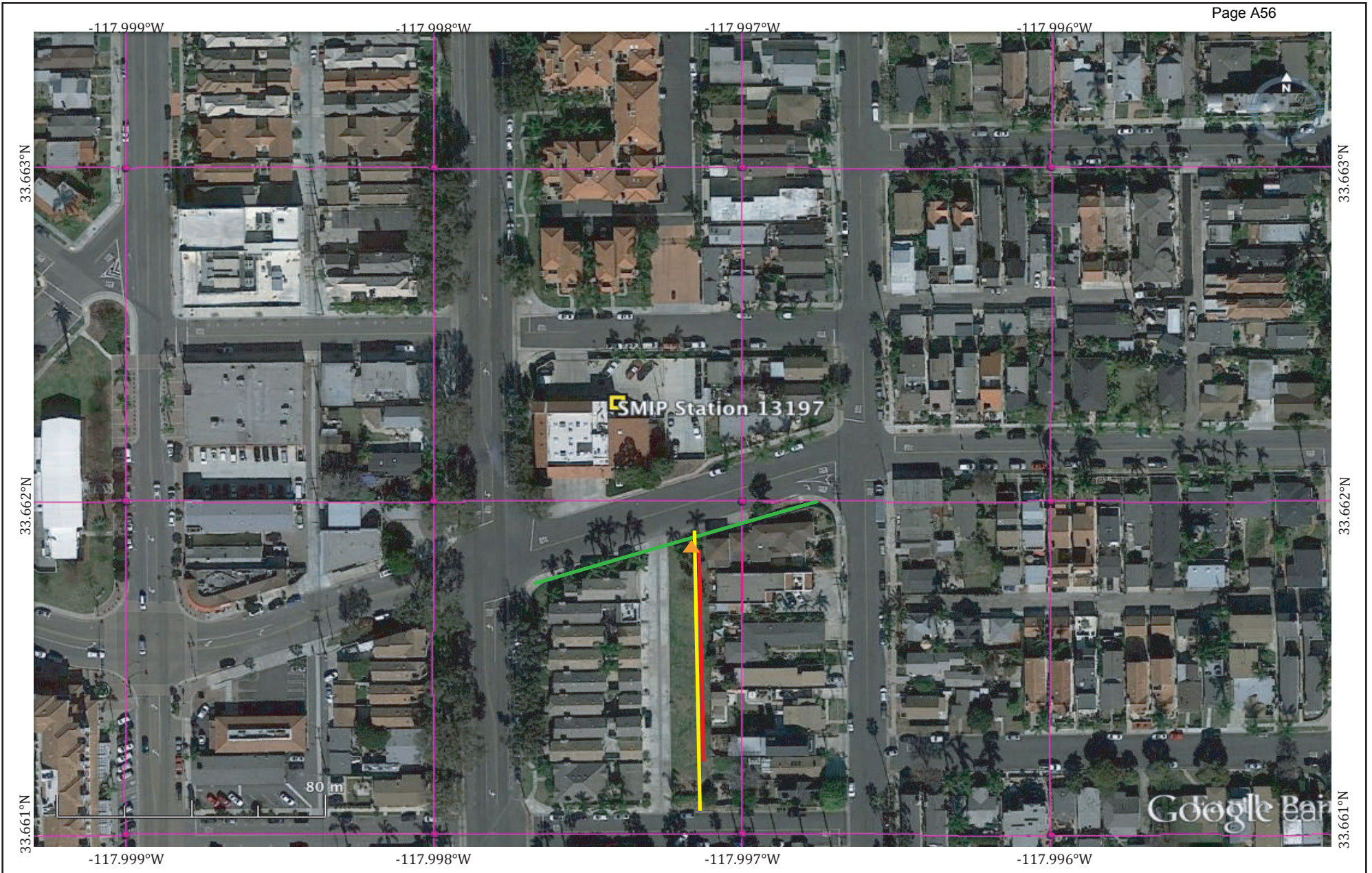
-117.999°W -117.998°W -117.997°W -117.996°W

33.663°N

33.662°N

33.661°N

SMIP Station 13197

Image Source: Google Earth and Earth Point

Legend

⬜	SMIP Station 13197	▬	MASW Array
—	Coordinate Grid	▬	Passive Line 1
▲	HVSR Station	▬	Passive Line 2

Figure 1: Site Map
SMIP Station 13197

Figure 2 – **HVSR Results:** line graph showing HVSR results (H/V vs. frequency). Frequency of fundamental peak show with arrow (f0 = 0.206).

SMIP Station 13197 (Huntington Beach) H/V Spectral Ratio

Figure 3 – Dispersion Curves: Final picked dispersion curve values for all methods.

Phase velocity (m/sec) vs. frequency (Hz)

Wavelength (m) vs. phase velocity (m/sec)

Figure 4 – Representative and Calculated Dispersion Curves: Representative and calculated/theoretical dispersion curves. The field data used in the creation of the representative curve is also shown.

Figure 5 – Shear Wave Velocity Profile: Various profile models used to assess site and determine Vs30 and most likely layering scenario.

Tables:

Table 1: GPS Location Chart – Locations in latitude and longitude for MASW and 2D Passive lines – Shows location of start and end points.

Site 5 - 13197 Huntington Beach- Lake St Fire Station

	Start (DD) Lat.	Start (DD) Long.	End (DD) Lat.	End (DD) Long.
MASW	33.66185927500	-117.99712293900	33.66121625900	-117.99711179400
Line 1 2D Passive	33.66200613900	-117.99672931400	33.66174957600	-117.99767139700
Line 2 2D Passive	33.66190977600	-117.99713155400	33.66108718400	-117.99712410900
	(DD) Lat.	**(DD) Long.**	**-**	**-**
HVSR	33.661216	-117.997112	**-**	**-**

Site Photos
Site 5 - 13197 Huntington Beach- Lake St Fire Station

Figure 8 – View of HVSR setup, in ground, thermal protection, and weighted bucket for wind protection.

Figure 9 – View of MASW – 5 foot (1.524 meters) spacing on geophones

References

City of Huntington Beach Planning Division, 2009, Environmental Hazards Element, *in* City of Huntington Beach General Plan, http://www.huntingtonbeachca.gov/files/users/planning/Environmental_Hazard_element2009.pdf.

DOGGR, 2017, Division of Oil, Gas, and Geothermal Resources, https://maps.conservation.ca.gov/doggr/wellfinder/#close

Geopsy Software, 2017, SESAME European Research Project: Release 0.0.0-snapshot-20170109, geopsy.org.

KGS, 2017, Kansas Geological Survey, Surfseis Version 5.3.

Optim Software, 2017, SeisOpt - ReMi Refraction Microtremor Analysis.

SESAME European Research Project, 2004, Guidelines for the Implementation of the H/V Spectral Ratio Technique on Ambient Vibrations: European Commission – Research General Directorate, Project No. EVG1-CT-2000-00026 SESAME.

USGS, 2017, A Compilation of Vs30 Values in the United States, https://earthquake.usgs.gov/data/vs30/us/

Report on Site Characteristics for SMIP Station

13849

Station Name: Anaheim – Lakeview & Riverdale   **Station Number:** 13849

Location: Kaiser Permanente Lakeview Medical Offices
       441 N. Lakeview Ave.
       Anaheim, CA 92807

Latitude: 33.8535   **Longitude**: -117.8180

V_{S30}: 303 m/sec   **Estimated Error for V_{S30}: +/- 24 m/sec**

Site Geology:

The City of Anaheim is divided into two different geologic areas. The western half of the city lies above a broad alluvial plain, which is covered by Holocene age alluvial deposits. These deposits consist primarily of unconsolidated gravel, sand, silt, and clay (Ninyo and Moore, 2001). Because the site is relatively close to the active Santa Ana River, the local alluvium deposits are likely less than 1000 years old and rather unconsolidated. Pleistocene terrace deposits are also present on elevated terraces near upper edges of alluvial plains and in hillside areas in other parts of the City. The nearby Peralta Hills and Santa Ana Mountains to the south and southeast consist of Tertiary to Cretaceous age marine and terrestrial deposits, where landslides are rather common on steep slopes (Ninyo and Moore, 2001).

The City of Anaheim is situated between the active Newport-Inglewood and Whittier-Elsinore Faults Zones, as well as the El Modeno, Peralta Hills, and Norwalk Faults. No faults pass directly through the site area. The aforementioned faults may be capable of producing an earthquake of magnitude 6.0 to 7.0, but the possibility of ground rupture within the city limits is considered low. However, the site is located within the liquefaction potential zone (Ninyo and Moore, 2001). The site is also located just outside the edge of the flood impact zone associated with failure of the Prado Dam (Ninyo and Moore, 2001)

Site Conditions:

The site is located in a vacant dirt lot about 450 ft. south of the Santa Ana River and next to the Kaiser Permanente Lakeview Medical Offices. The greater vicinity is mostly residential. Such conditions are likely to only cause a moderate amount of ambient seismic noise. In general, the terrain around the site is relatively flat, except for the slight gradient along the riverbank – an elevation change of only about 6 m in the general vicinity of the site.

Description of Geophysical Methods and Locations of Arrays:

HVSR, MASW, and 2D Passive field procedures were performed for the site. The location of the respective test methods are shown in Figure 1, and were field surveyed using a Trimble GeoExplorer 6000 capable of sub-meter accuracy. Subsequent differential GPS corrections were made to the location files using Trimble Pathfinder to increase the accuracy of the start and end points of survey lines. Survey lines were laid out using a 300-foot tape, and bearings were taken using a Brunton Compass. Any major elevation changes were determined in the field using a hand level and measuring rod. See Table 1 for detailed Latitudes and Longitudes.

HVSR readings were recorded after an equipment installation and warmup period of 20 minutes. Readings were taken using 500 Hz, 200 Hz, 100 Hz, and 1Hz sampling frequency settings. The total HVSR recording time for the site was roughly 2 hours in total length. Equipment used included a Kinemetrics Q330 Digitizer in combination with a 120 sec to 160 Hz Metrozet MBB-2 triaxial broadband sensor (an effective equivalent to the Trillium-120). The sensor was buried in a small hole and covered with a thermal insulator and bucket to decrease surface noise interference and temperature variations.

The MASW line was placed along the same lineal path as one of the Passive 2D lines. Geophones were placed at 5 foot (1.524 meter) intervals, with a total line length of 235 feet (71.6 meters) using 48 channels/geophones (4.5 Hz). Off-end shots were performed at 100, 70, 40, and 10 feet (30.48, 21.34, 12.20, and 3.048 meter). Surveys were conducted in forward and reverse, with an additional shot taken at 1.5 feet (0.457 meters) on each end, and in the center of the array. The off-end shots were performed using a stack of 5 hits per record, with a 16-lb sledge-hammer. A single jack (4-lb hammer) was used at the 1.5 (0.457 meters) foot off-end shots to add a higher frequency noise content to the overall record. Recordings were triggered using a hammer switch and taken using a sampling rate of 1 milliseconds (ms) for a total time of 2 seconds (s).

The 2D Passive lines were arranged roughly perpendicular to each other. At each line geophones were placed at 15 foot (4.57 meter) intervals, with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 1, and at 15 foot (4.57 meter) intervals with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 2. Using this length of survey line we were able to achieve 40+ meter depth estimate. Between the two lines, a total of 48 channels were utilized for the 2D Passive survey. Recordings were triggered automatically and taken using a sampling rate of 2 ms for a total time of 30 seconds (30 records were taken in total). We did additional recording using a sampling rate of 1 ms for a total time of 15 seconds (30 records total as well). For both seismic line surveys two separate 24-Channel Geodes (by Geometrics) were combined and used for recording.

HVSR Processing and Results:

Ambient noise data was recorded as MiniSEED files and processed using Geopsy software's H/V toolbox to create a characteristic HVSR curve and determine the fundamental frequency of the site. Data was loaded into Geopsy with vertical and horizontal components and sampling frequencies (100 Hz, 200 Hz, and 500 Hz) specified. Data at these frequencies were processed separately. HVSR was typically calculated over the entire recording time and using a time window length of 200 s. Time windows containing transients (nearby foot and vehicular traffic or industrial sources) or segments yielding poor quality results were excluded from the analysis. The time windows were picked automatically using an anti-triggering algorithm applied to avoid transients. For each time window, Fourier amplitude spectra were calculated and smoothed by the Konno and Ohmachi filter with a smoothing constant of 40. The HVSR was calculated for each time window and averaged to produce a characteristic HVSR curve. After calculating standard deviation of the HVSR amplitudes for all windows, the average HVSR curve is divided and multiplied by the standard deviation to produce the minimum and maximum HVSR spectra (SESAME, 2004).

Unfiltered and unwhitened data exhibit a great deal of unclear low frequency peaks, and the raw spectra on the north component have a very large amplitude and low frequency signal that may be a result of a sensor malfunction. However, there is a peak at around 0.2 Hz. The filtered data make it clear that this peak is most likely the peak frequency, giving an average f0 of **0.26 Hz**. This peak frequency meets all of the reliability criteria, but only four out of 6 criteria for a clear peak instead of the five necessary to be a true clear peak. The unclear low frequency noise, combined with the bad signal on the north component, suggest the likelihood of a bad soil-sensor coupling. There is another small peak at around 5.2 Hz on the unfiltered curves; however, this peak does not show up on the filtered curves and meets only 2 of the clear peak criteria as opposed to the four of the other peak. The fact that the peak at 0.26 Hz meets more of the criteria for a reliable and clear peak than any of the other peaks and does not appear to be of industrial origin suggest that it is the most reliable estimate of fundamental frequency.

MASW Processing and Results:

Multichannel Analysis of Surface Waves (MASW) was performed using Surfseis Version 5.3 (KGS, 2017). The active method operation was chosen to evaluate the SEG-2 field files. A frequency overtone generator was used to develop a Phase Velocity-Frequency Image. Frequency ranges were allowed to span from 1 Hz to 50 Hz, with an allowed Phase Velocity window of 20 and 2,000 meters per second (m/sec). An automatic evaluation was performed which yielded a surface wave velocity range of 30.5 and 214 m/sec, with a dominant frequency of surface waves of 10 Hz. The risk of contamination by higher modes was considered to be low, and the overall quality of input data was excellent.

From this process dispersion curves were generated for both forward and reverse geometries along the line using the 100, 70, 40, and 10 foot (30.48, 21.34, 12.20, and 3.048 meter) offsets. These individual dispersion curves were combined to create a single averaged curve for subsequent dispersion value (phase velocity vs. frequency) picking and extraction. Inversion was performed on the picked/extract values in order to create a layer

model for comparison and integration with other methods to obtain a best fit shear-wave approximation for the site. The model was allowed to run through the inversion process for 6 iterations, with a final model that reached a total depth of 131 meters. All data obtained from this processing was used to assist in developing an appropriate dispersion curve and a representative layer profile model, and for calculating the Vs30 for site class designation (Figures 3, 4, and 5).

2D Passive Processing and Results:

2-Dimensional (2D) Passive data was analyzed using Surfseis Version 5.3 (KGS, 2017). The passive-remote mode operation was chosen to evaluate incoming surface wave velocity and frequency because it allows for the use of multiple evaluation points versus pairs or singular values, thus reducing ambiguities related to dispersion curves (DC) that are based on only one or two geophone recordings. Rather this method allows for all geophone signals to be incorporated into the DC and subsequent models. Individual geophone locations were converted to UTM coordinates and tabulated for use with the program. The geometry input file was then uploaded along with the 30 records for subsequent dispersion curve extraction. The files were preprocessed, and an automatic dispersion curve pick was achieved using similar settings as the active method described previously. Each pick was reviewed and modified prior to the extraction of a final dispersion curve. The final DC was then created from the combined records and analyzed for the extraction of the fundamental-mode. An inversion process was then run on the DC curve to create a shear wave velocity profile. In addition to this method, Refraction Microtremor modeling was performed using ReMi (SeisOpt, 2017). ReMi analysis was performed in order to add a comparative model to our results of 2D Passive and Active methods already discussed above.

Summary of Shear Wave Data and HVSR Processing:

Values obtained from the above methods were combined and plotted for averaging of the site's Vs30 and layered models. Initial Vs30 values ranged from between 273 m/sec to 388 m/sec depending on which model was used. The difference of these is moderate. Neighboring sites have values in the of 320 m/sec range. Based on this a new Vs30 of 287 m/sec was achieved. This value was subsequently reviewed and combined using a weighted averaging techniques to address none conformance of the models, and was combined to make a final layer profile.

In the 2D Passive/Active-MASW, the layering was deeper and determinable up to about +40 meters below ground surface. In general, ReMi tends to underestimate Vs30 for sites, due to its inability to distinguish fundamental modes from subsequent order energy modes. Through understanding these differences and analytical review of the data, we developed the final average value for Vs30 = 303 m/sec. The estimated error for this is 7.9%, or 24 m/sec. This error is based on the likely variation in the sample mean from the population mean, which we have reviewed in some detail. This Vs30 gives the site a Site Class D designation of very dense soil to soft rock. Based on our review, the site appears to have the potential for liquefaction based on Vs, geology (soil types), and high groundwater potential (proximity to nearby river). In light of the overall review, it would appear that the

designation makes sense and would be expected, especially considering the location of a bordering river, and being on an alluvial flood plain.
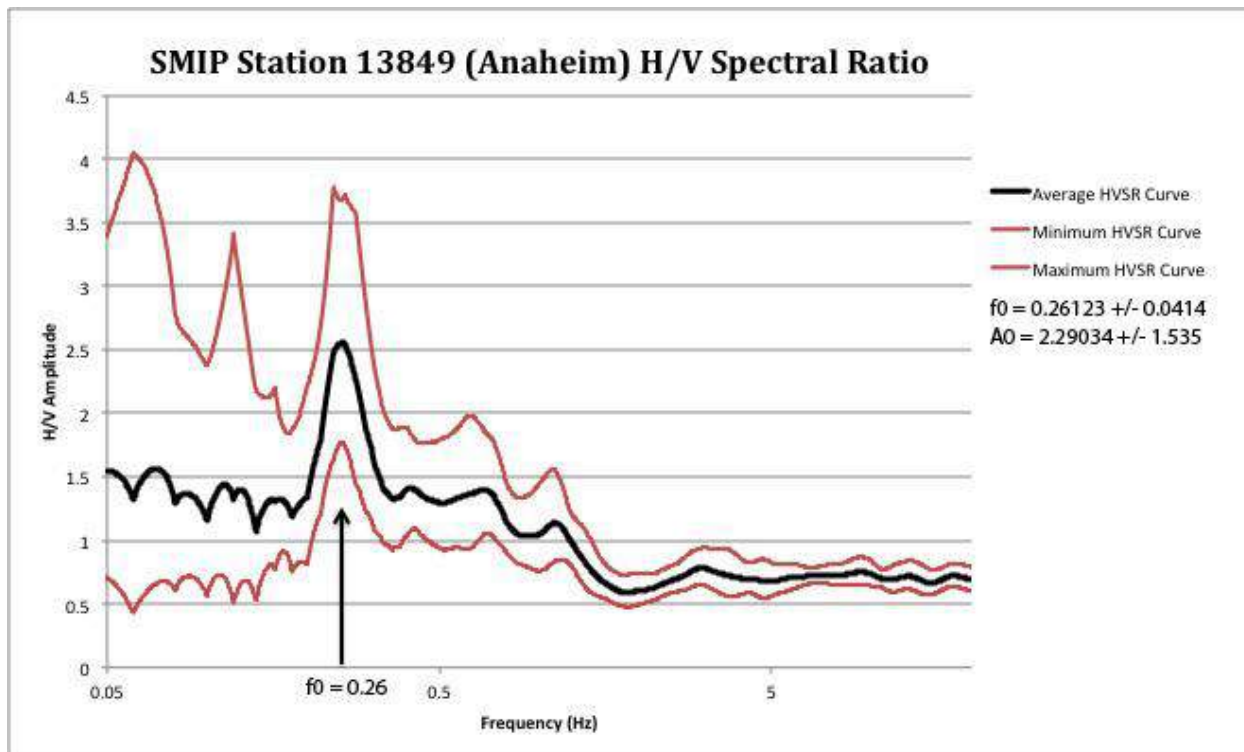
Taking this data into account and comparing against the HVSR data, we were able to calculate a depth to bedrock interface of 291 meters. The equation for this is f0 = Vs4z, where Vs is assumed to be Vs30 in meters, f0 is HVSR in Hz, and z is depth in meters. The site is roughly 2 miles away from the nearest mountain and is within an alluvial wash zone. In addition, it is next to a river/wash. With all of this considered, this depth seems to be reasonable for what would be considered a bedrock material at this location based on our geological review.
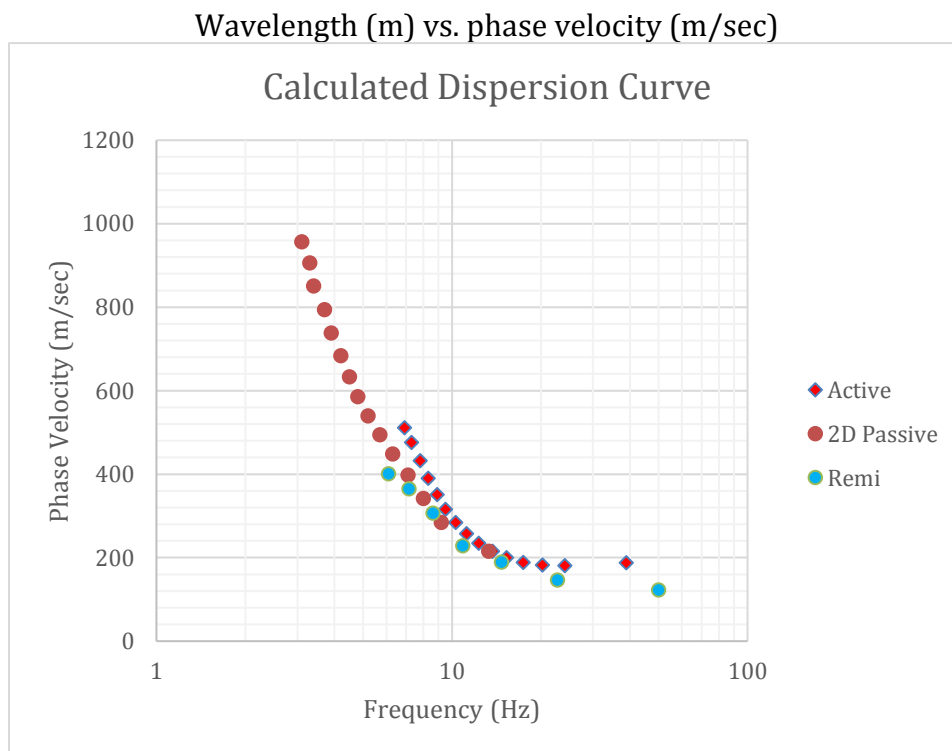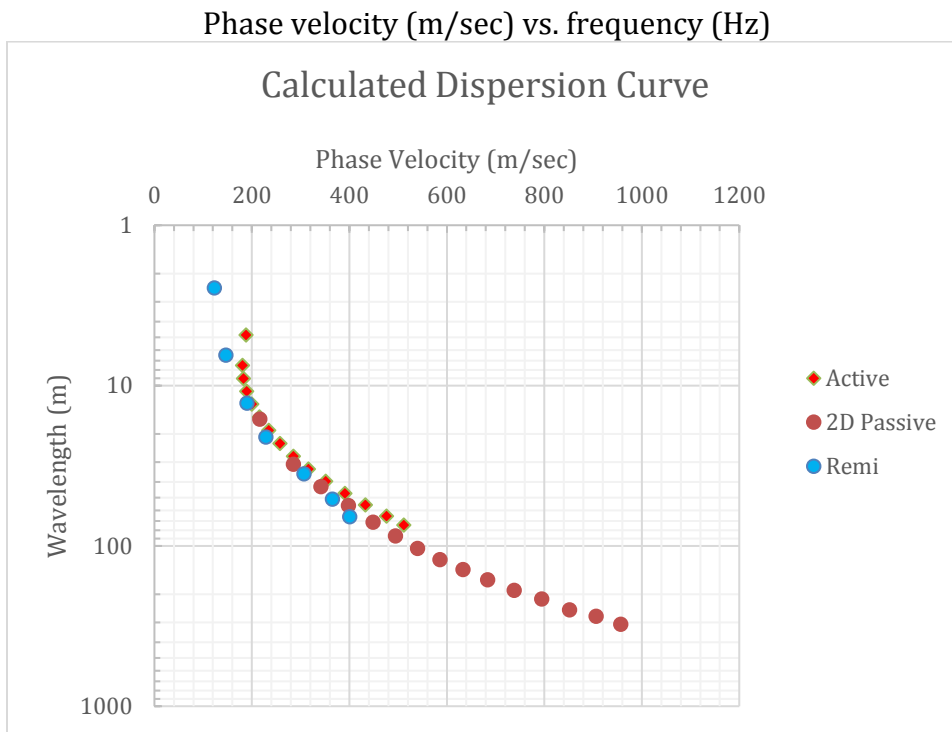
Figure 1: Site Map
SMIP Station 13849

Image Source: Google Earth and Earth Point
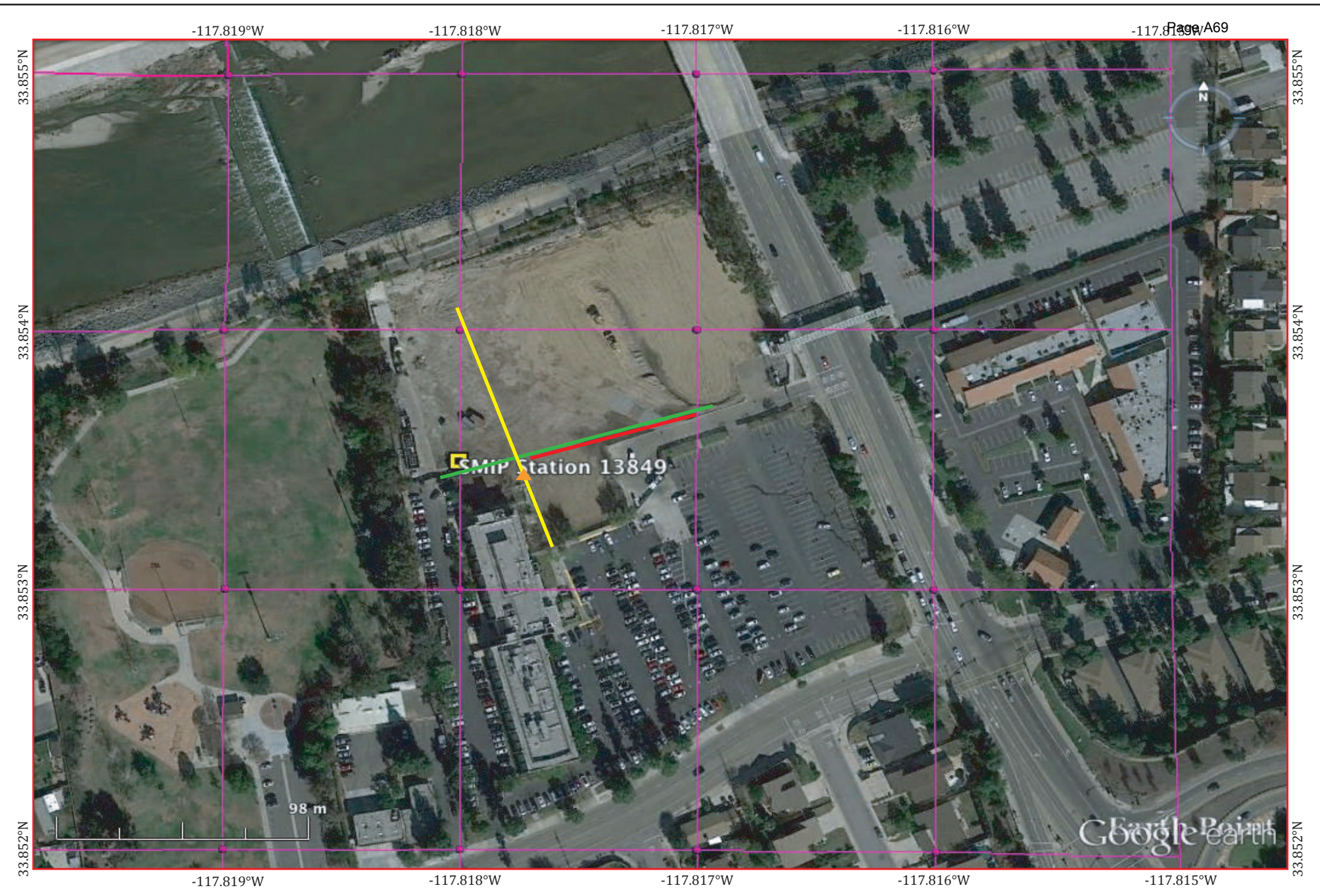
Legend

- SMIP Station 13849
- Coordinate Grid
- HVSR Station
- MASW Array
- Passive Line 1
- Passive Line 2

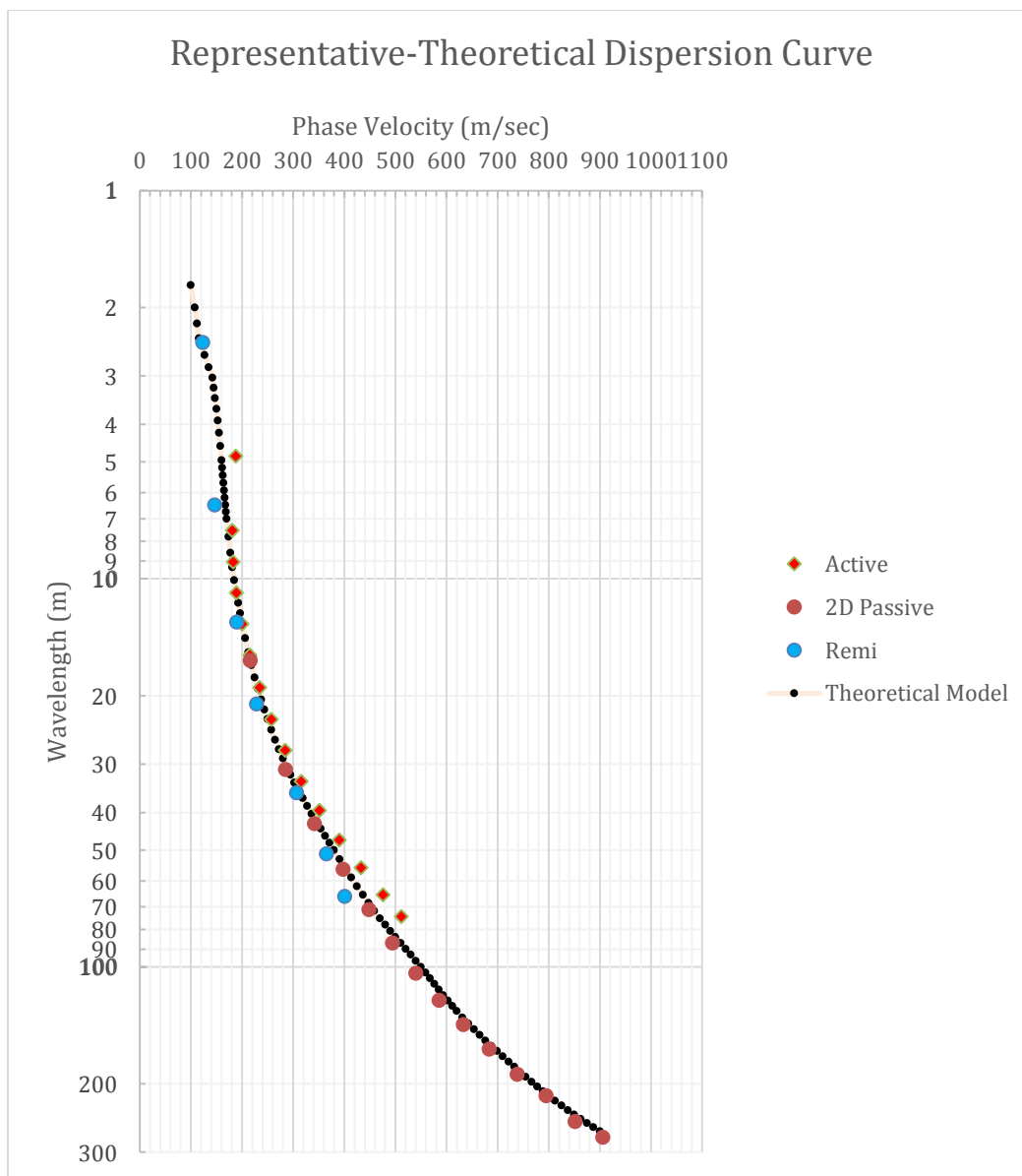**Figure 2 – HVSR Results**: line graph showing HVSR results (H/V vs. frequency). Frequency of fundamental peak show with arrow (f0 = 0.26).

SMIP Station 13849 (Anaheim) H/V Spectral Ratio

Figure 3 – Dispersion Curves: Final picked dispersion curve values for all methods.

Phase velocity (m/sec) vs. frequency (Hz)
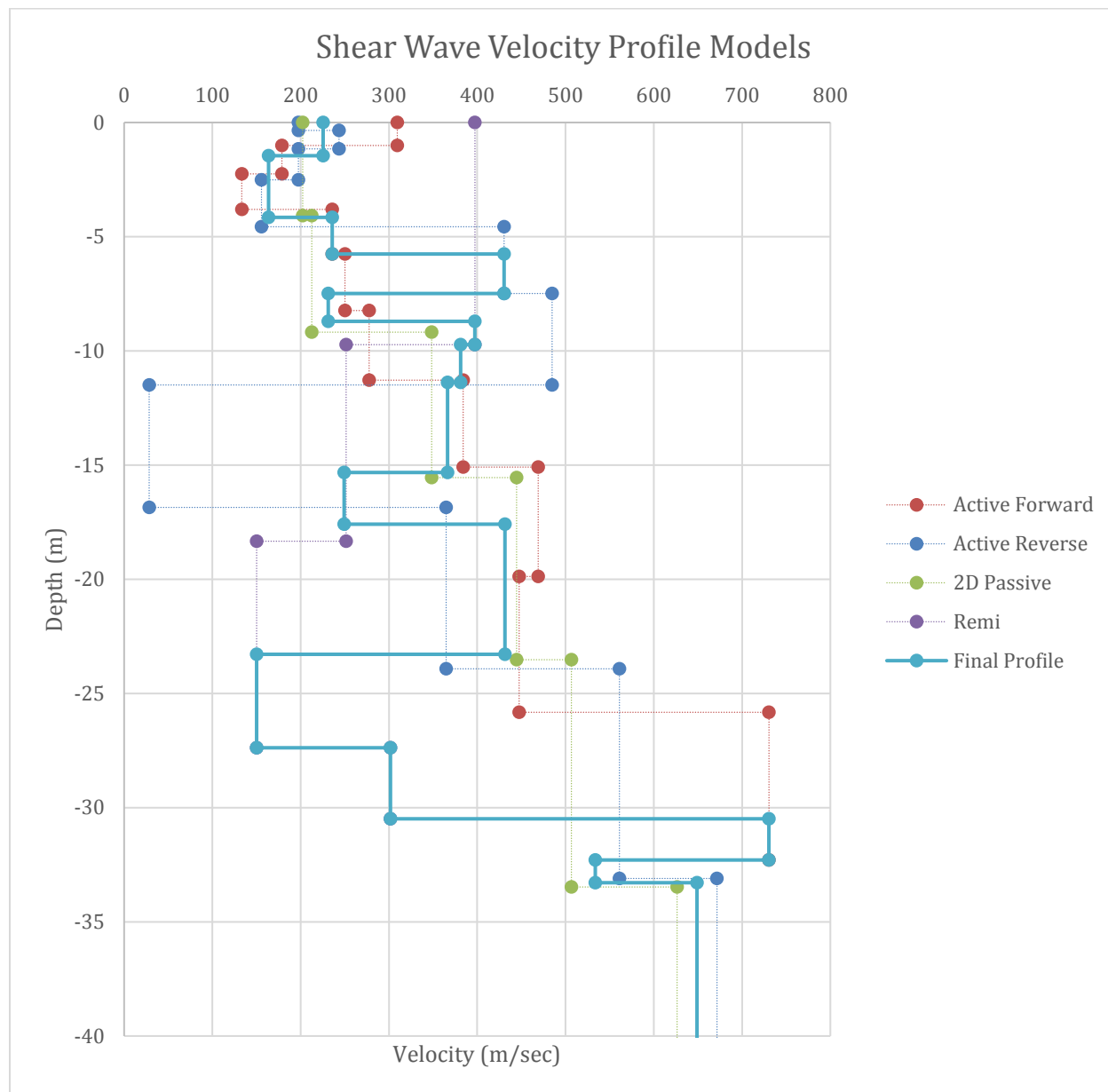

Wavelength (m) vs. phase velocity (m/sec)

Figure 4 – Representative and Calculated Dispersion Curves: Representative and calculated/theoretical dispersion curves. The field data used in the creation of the representative curve is also shown.

Figure 5 – Shear Wave Velocity Profile: Various profile models used to assess site and determine Vs30 and most likely layering scenario.

Tables:

Table 1: GPS Location Chart – Locations in latitude and longitude for MASW and 2D Passive lines – Shows location of start and end points.

Site 6 - 13849 Anaheim -Lakeview & Riverdale

Method	Start (DD) Lat.	Start (DD) Long.	End (DD) Lat.	End (DD) Long.
MASW	33.85350652200	-117.81775057200	33.85369249100	-117.81701267100
Line 1 2D Passive	33.85342350600	-117.81803047000	33.85371347800	-117.81694043900
Line 2 2D Passive	33.85317586900	-117.81760388200	33.85404634500	-117.81805194300
	(DD) Lat.	**(DD) Long.**	-	-
HVSR	33.853418	-117.81774	-	-

Site Photos
Site 6 - 13849 Anaheim -Lakeview & Riverdale

Figure 10 – View of MASW layout.

Figure 11 – View of MASW layout.

References

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Report on Site Characteristics for
SMIP Station

23525

Station Name: Pomona – 4th & Locust   **Station Number:** 23525

Location: 4th and Locust Parking Lot
          4th and Locust Streets
          Pomona, CA

Latitude: 34.0564   **Longitude**: -117.7487
V$_{S30}$: 287 m/sec   **Estimated Error for V$_{S30}$: +/- 40 m/sec**

Site Geology:

The site sits atop younger Quaternary alluvial fan deposits (Bortugno and Spittler, 1998). These deposits generally consist of unconsolidated course sands and gravel and are derived from the rocks of the San Gabriel Mountains to the north. Generally, such young alluvium is susceptible to liquefaction, but the site area is not located within an area designated at risk of liquefaction. Such soils are also at risk of ground lurching, moving in wave-like patterns during strong seismic movements (Rincon Consultants, Inc., 2013).

No known regional faults pass directly through the City of Pomona or the site area. However, potentially active local faults within the city include the Indian Hill, Chino, Central Avenue, and San Jose Faults. Of these, the alluvium buried Chino Fault passes closest to the site (Rincon Consultants, Inc., 2013).

Site Conditions:

The site is located in a topographically flat and urban area. Despite being located in an area designated as likely to experience less movement during an earthquake, the site appears to be surrounded by unreinforced masonry buildings and near a few representative locations of hazmat sites. A natural gas and a petroleum pipeline also pass underneath the general site area, about two blocks north of the station itself (Rincon Consultants, Inc., 2013).

Description of Geophysical Methods and Locations of Arrays:

HVSR, MASW, and 2D Passive field procedures were performed for the site. The location of the respective test methods are shown in Figure 1, and were field surveyed using a Trimble GeoExplorer 6000 capable of sub-meter accuracy. Subsequent differential GPS corrections were made to the location files using Trimble Pathfinder to increase the accuracy of the start and end points of survey lines. Survey lines were laid out using a 300-foot tape, and bearings

were taken using a Brunton Compass. Any major elevation changes were determined in the field using a hand level and measuring rod. See Table 1 for detailed Latitudes and Longitudes.

HVSR readings were recorded after an equipment installation and warmup period of 20 minutes. Readings were taken using 500 Hz, 200 Hz, 100 Hz, and 1Hz sampling frequency settings. The total HVSR recording time for the site was roughly 2 hours in total length. Equipment used included a Kinemetrics Q330 Digitizer in combination with a 120 sec to 160 Hz Metrozet MBB-2 triaxial broadband sensor (an effective equivalent to the Trillium-120). The sensor was buried in a small hole and covered with a thermal insulator and bucket to decrease surface noise interference and temperature variations.

The MASW line was placed along the same lineal path as one of the Passive 2D lines. Geophones were placed at 5 foot (1.524 meter) intervals, with a total line length of 235 feet (71.6 meters) using 48 channels/geophones (4.5 Hz). Off-end shots were performed at 100, 70, 40, and 10 feet (30.48, 21.34, 12.20, and 3.048 meter). Surveys were conducted in forward and reverse, with an additional shot taken at 1.5 feet (0.457 meters) on each end, and in the center of the array. The off-end shots were performed using a stack of 5 hits per record, with a 16-lb sledge-hammer. A single jack (4-lb hammer) was used at the 1.5 (0.457 meters) foot off-end shots to add a higher frequency noise content to the overall record. Recordings were triggered using a hammer switch and taken using a sampling rate of 1 milliseconds (ms) for a total time of 2 seconds (s).

The 2D Passive lines were arranged roughly perpendicular to each other. At each line geophones were placed at 15 foot (4.57 meter) intervals, with a total line length of 285 feet (86.9 meters) using 21 channels/geophones (4.5 Hz) for line 1, and at 15 foot (4.57 meter) intervals with a total line length of 285 feet (86.9 meters) using 21 channels/geophones (4.5 Hz) for line 2. Using this length of survey line we were able to achieve 40+ meter depth estimate. Between the two lines, a total of 42 channels were utilized for the 2D Passive survey. Recordings were triggered automatically and taken using a sampling rate of 2 ms for a total time of 30 seconds (30 records were taken in total). We did additional recording using a sampling rate of 1 ms for a total time of 15 seconds (30 records total as well). For both seismic line surveys two separate 24-Channel Geodes (by Geometrics) were combined and used for recording.

HVSR Processing and Results:

Ambient noise data was recorded as MiniSEED files and processed using Geopsy software's H/V toolbox to create a characteristic HVSR curve and determine the fundamental frequency of the site. Data was loaded into Geopsy with vertical and horizontal components and sampling frequencies (100 Hz, 200 Hz, and 500 Hz) specified. Data at these frequencies were processed separately. HVSR curves were calculated multiple times over the entire recording time and using time window lengths of 25, 50, 100, and 150 s. The 50 and 100 s window lengths were used on signals that were first processed using a high-pass filter at 0.2 Hz in order to decrease scattered low frequency noise. Time windows containing transients (nearby foot and vehicular traffic or industrial sources) or segments yielding poor quality results were excluded from the analysis. The time windows were picked automatically using

an anti-triggering algorithm applied to avoid transients. Some windows were then manually removed because the signals appeared to contain notable transients within those windows that may have affected the results. For each time window, Fourier amplitude spectra were calculated and smoothed by the Konno and Ohmachi filter with a smoothing constant of 30. The HVSR was calculated for each time window and averaged to produce a characteristic HVSR curve. After calculating standard deviation of the HVSR amplitudes for all windows, the average HVSR curve is divided and multiplied by the standard deviation to produce the minimum and maximum HVSR spectra (SESAME, 2004).

Averaging peak frequency values for the various HVSR curves produced from multiple processing parameters gives a mean fundamental frequency of **0.662 Hz**. While all of the HVSR curves were reliable, only one of the filtered curves actually met at least five out the six criteria for a clear peak (Figure 2). The rest failed to meet at least five criteria, so while this f0 = 0.662 is the best estimate of the fundamental frequency, the peak should be considered a broad peak. However, altering the smoothing parameters (proportional smoothing) does improve the clarity of this peak. There is a notable peak that occurs at the very low frequency of around 0.03 Hz. This peak does appear stable with different processing parameters, but is not reliable because its associated frequency is too low to meet the reliability criteria. Such unclear low frequency peaks may sometimes be an artifact of the site geology, given thick stiff sedimentary deposits. However, the fact that proportional smoothing does not improve the clarity or stability of this peak suggests that this peak is not due to a site characteristic. Thus, any unclear low frequency peaks are the result of wind or a bad-soil sensor coupling during data acquisition or an artefact of nearby machinery; there is a pump located on the building across the street from the HVSR station. Sharp peaks occurring in the frequency range of 0.05 to 0.15 Hz also appear strongly to be of industrial origin.

MASW Processing and Results:

Multichannel Analysis of Surface Waves (MASW) was performed using Surfseis Version 5.3 (KGS, 2017). The active method operation was chosen to evaluate the SEG-2 field files. A frequency overtone generator was used to develop a Phase Velocity-Frequency Image. Frequency ranges were allowed to span from 1 Hz to 50 Hz, with an allowed Phase Velocity window of 20 and 2,000 meters per second (m/sec). An automatic evaluation was performed which yielded a surface wave velocity range of 36.6 and 335 m/sec, with a dominant frequency of surface waves of 9 Hz. The risk of contamination by higher modes was considered to be moderate, and the overall quality of input data was good.

From this process dispersion curves were generated for both forward and reverse geometries along the line using the 100, 70, 40, and 10 foot (30.48, 21.34, 12.20, and 3.048 meter) offsets. These individual dispersion curves were combined to create a single averaged curve for subsequent dispersion value (phase velocity vs. frequency) picking and extraction. Inversion was performed on the picked/extract values in order to create a layer model for comparison and integration with other methods to obtain a best fit shear-wave approximation for the site. The model was allowed to run through the inversion process for 6 iterations, with a final model that reached a total depth of 40+ meters. All data obtained

from this processing was used to assist in developing an appropriate dispersion curve and a representative layer profile model, and for calculating the Vs30 for site class designation (Figures 3, 4, and 5).

2D Passive Processing and Results:

2-Dimensional (2D) Passive data was analyzed using Surfseis Version 5.3 (KGS, 2017). The passive-remote mode operation was chosen to evaluate incoming surface wave velocity and frequency because it allows for the use of multiple evaluation points versus pairs or singular values, thus reducing ambiguities related to dispersion curves (DC) that are based on only one or two geophone recordings. Rather this method allows for all geophone signals to be incorporated into the DC and subsequent models. Individual geophone locations were converted to UTM coordinates and tabulated for use with the program. The geometry input file was then uploaded along with the 30 records for subsequent dispersion curve extraction. The files were preprocessed, and an automatic dispersion curve pick was achieved using similar settings as the active method described previously. Each pick was reviewed and modified prior to the extraction of a final dispersion curve. The final DC was then created from the combined records and analyzed for the extraction of the fundamental-mode. An inversion process was then run on the DC curve to create a shear wave velocity profile. In addition to this method, Refraction Microtremor modeling was performed using ReMi (SeisOpt, 2017). ReMi analysis was performed in order to add a comparative model to our results of 2D Passive and Active methods already discussed above.

Summary of Shear Wave Data and HVSR Processing:

Values obtained from the above methods were combined and plotted for averaging of the site's Vs30 and layered models. Initial Vs30 values ranged from between 273 m/sec to 341 m/sec depending on which model was used. The difference of these is moderate. Neighboring sites have values in the range of 220 to 270 m/sec range (within 5 miles on flat similar terrain). From this review, we modified our assumptions and models to re-evaluate the Vs30 potential due to missing or mischaracterized high velocity layers. Based on this a new Vs30 of 287 m/sec was achieved. This value was subsequently reviewed and combined using a weighted averaging techniques to address none conformance of the models, and was combined to make a final layer profile.

In the 2D Passive/Active-MASW, the layering was deeper and determinable up to about 59 meters below ground surface. In general, ReMi tends to underestimate Vs30 for sites, due to its inability to distinguish fundamental modes from subsequent order energy modes. Through understanding these differences and analytical review of the data, we developed the final average value for Vs30 = 287 m/sec. The estimated error for this is 13.9%, or 40 m/sec. This error is based on the likely variation in the sample mean from the population mean, which we have reviewed in some detail. This Vs30 gives the site a Site Class D designation of very dense soil to soft rock. Based on our review, the site appears to have the potential for liquefaction based on Vs, geology (soil types). In light of the overall review, it would appear that the designation makes sense and would be expected, especially considering the location of a bordering river, and being on an alluvial flood plain.

Taking this data into account and comparing against the HVSR data, we were able to calculate a depth to bedrock interface of 108 meters. The equation for this is f0 = Vs4z, where Vs is assumed to be Vs30 in meters, f0 is HVSR in Hz, and z is depth in meters. This depth seems to be less than expected for a site that is as far into an alluvial plain, however, there are mountain regions within 1 mile to the north or the site. In addition, there is a variety of faults interacting in the region, as well as more mountains to the southwest. With all of this considered, the depth to bedrock seems reasonable.
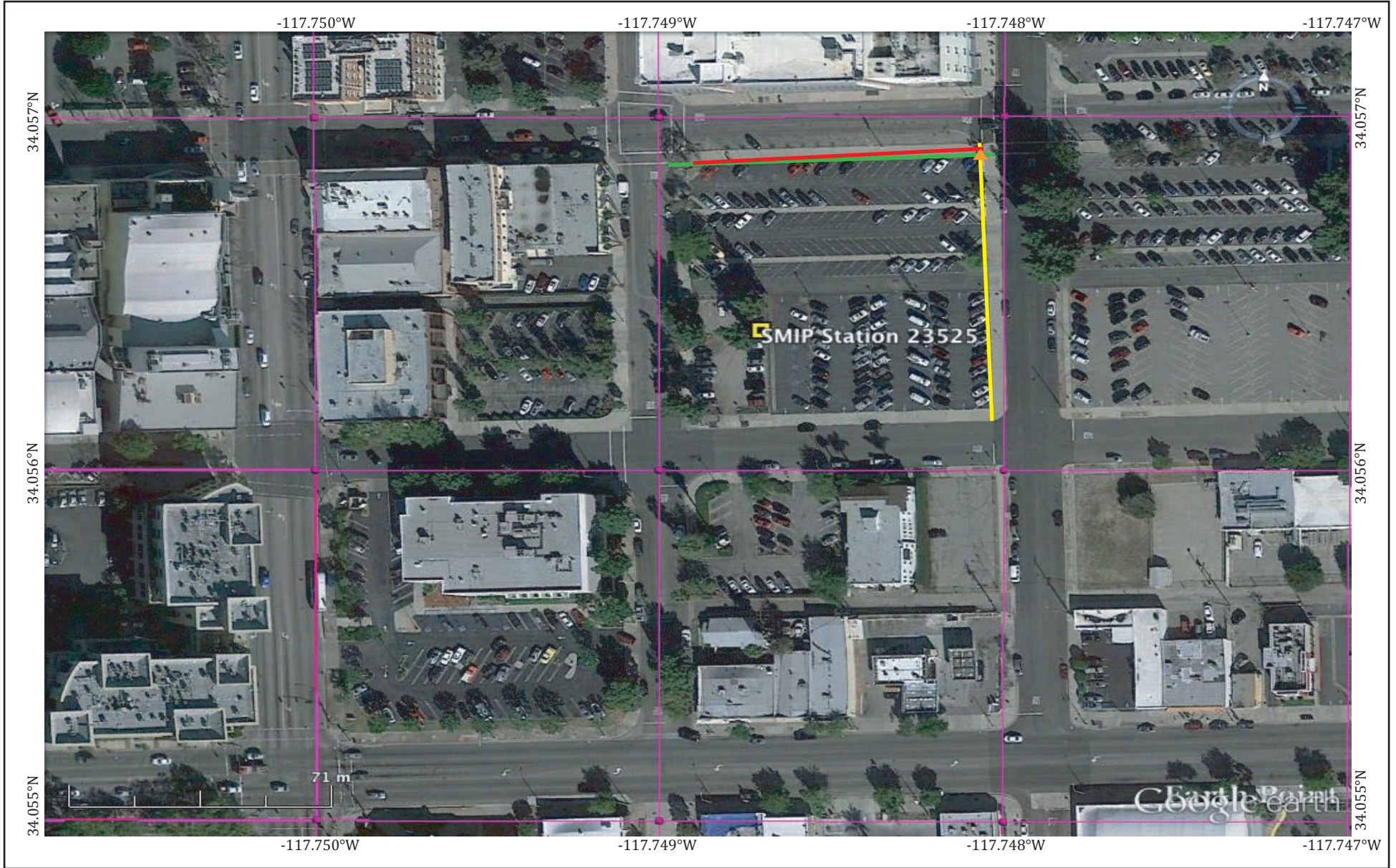
Image Source: Google Earth and Earth Point

Legend

▢ (yellow)	SMIP Station 23525
—	Coordinate Grid
▲	HVSR Station
— (red)	MASW Array
— (green)	Passive Line 1
— (yellow)	Passive Line 2

Figure 1: Site Map
SMIP Station 23525

Figure 2 – HVSR Results: line graph showing HVSR results (H/V vs. frequency). Frequency of fundamental peak show with arrow (f0 = 0.66).
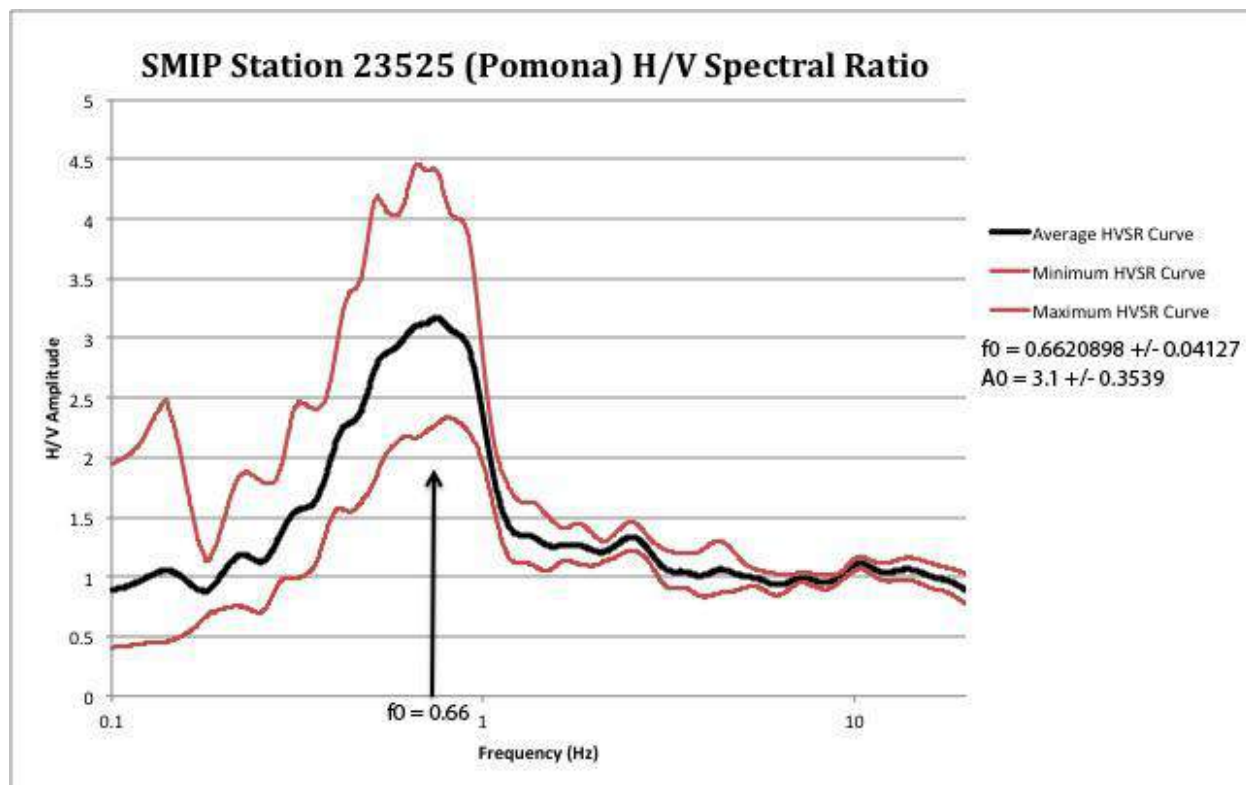
Figure 3 – Dispersion Curves: Final picked dispersion curve values for all methods.
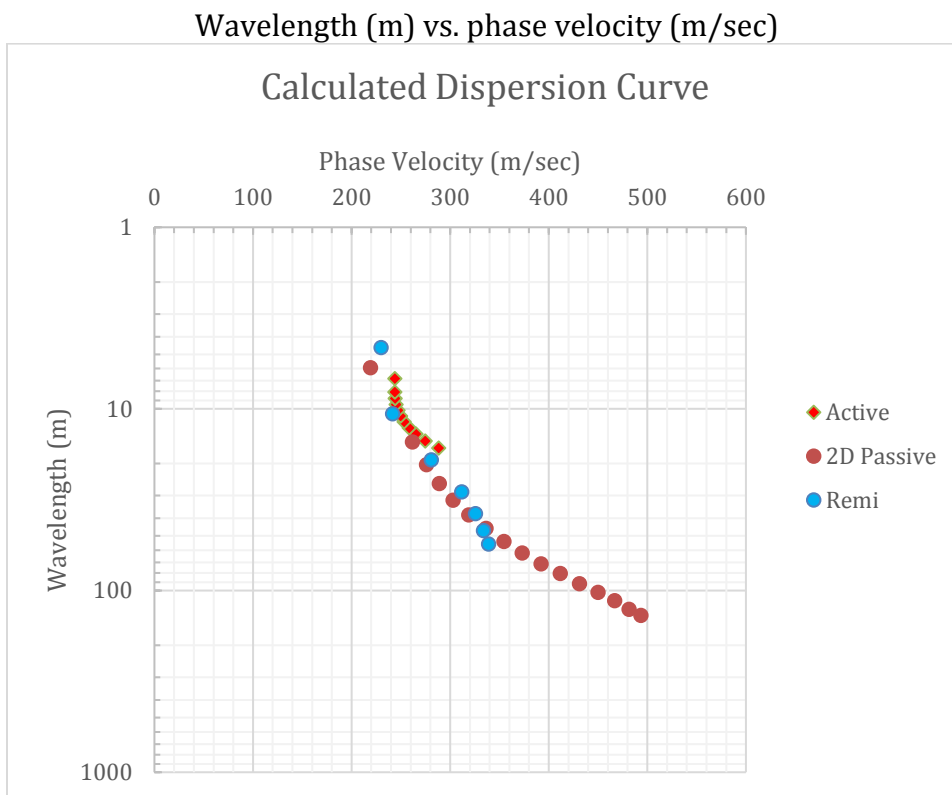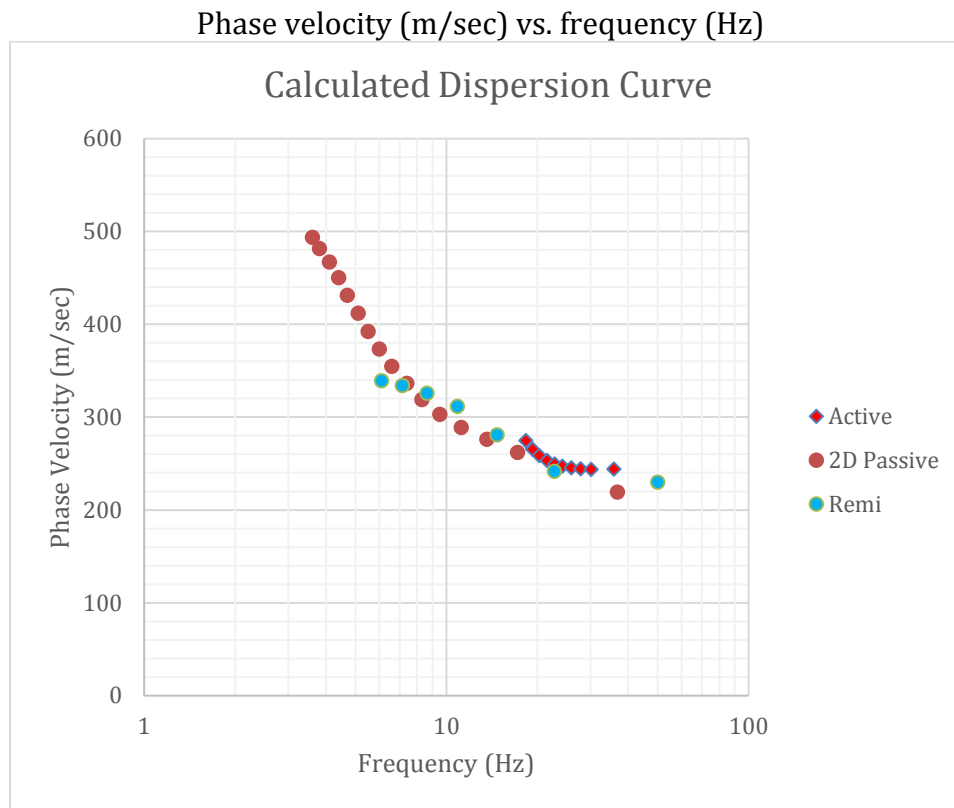
Phase velocity (m/sec) vs. frequency (Hz)

Wavelength (m) vs. phase velocity (m/sec)

Figure 4 – Representative and Calculated Dispersion Curves: Representative and calculated/theoretical dispersion curves. The field data used in the creation of the representative curve is also shown.
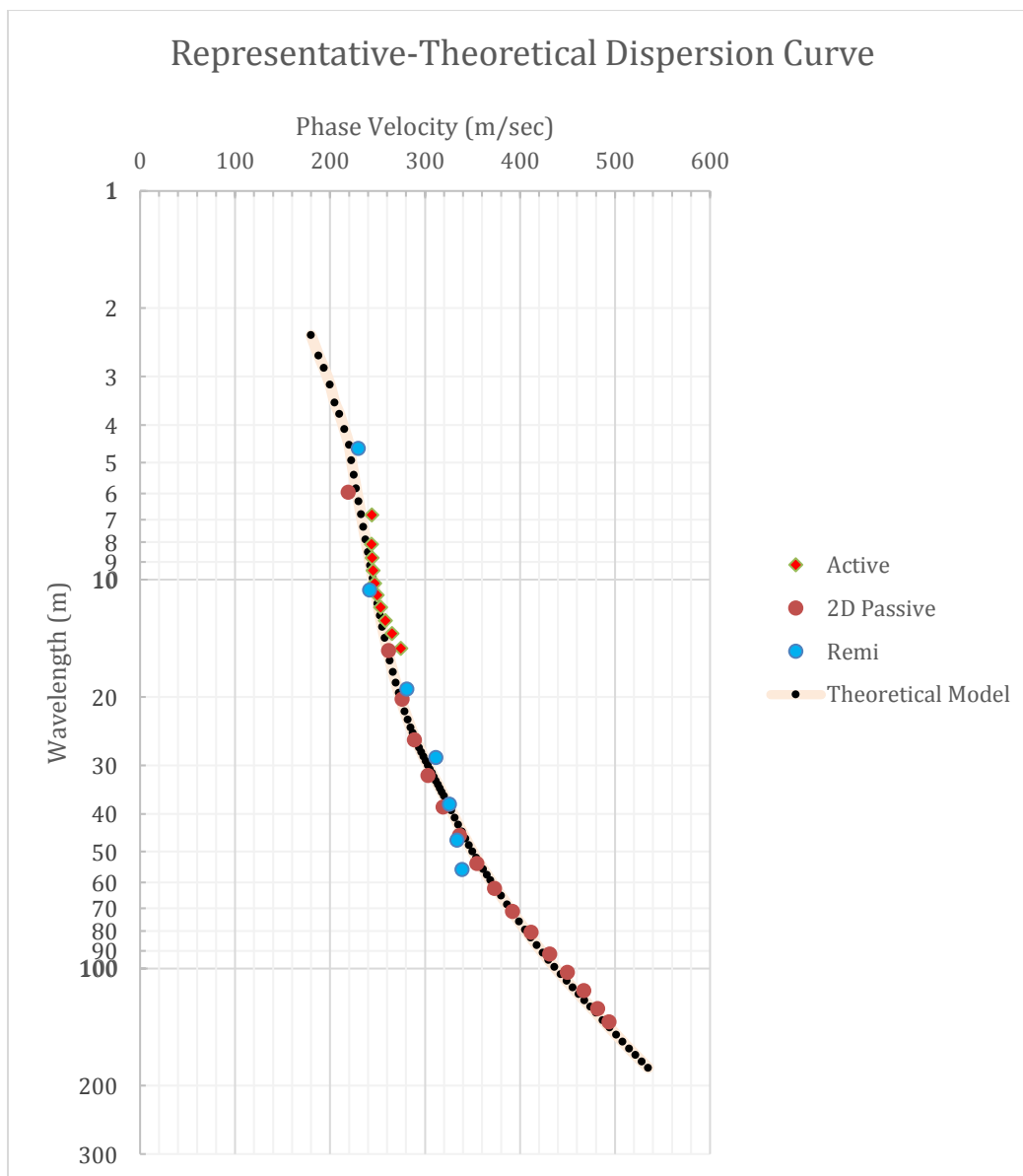
Figure 5 – Shear Wave Velocity Profile: Various profile models used to assess site and determine Vs30 and most likely layering scenario.

Tables:

Table 1: GPS Location Chart – Locations in latitude and longitude for MASW and 2D Passive lines – Shows location of start and end points.

Site 7 -23525 Pomona -4th & Locust

Method	Start (DD) Lat.	Start (DD) Long.	End (DD) Lat.	End (DD) Long.
MASW	34.05688922200	-117.74806264200	34.05687261800	-117.74883398700
Line 1 2D Passive	34.05688580400	-117.74801563200	34.05686950800	-117.74895895100
Line 2 2D Passive	34.05692592700	-117.74806479700	34.05613819600	-117.74802694300
	(DD) Lat.	(DD) Long.	-	-
HVSR	34.05687100000	-117.74806700000	-	-

Site Photos
Site 7 -23525 Pomona -4th & Locust

Figure 12 – View of MASW layout.

Figure 13 – View of 2D Passive layout.

References

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SESAME European Research Project, 2004, Guidelines for the Implementation of the H/V Spectral Ratio Technique on Ambient Vibrations: European Commission – Research General Directorate, Project No. EVG1-CT-2000-00026 SESAME.

USGS, 2017, A Compilation of Vs30 Values in the United States, https://earthquake.usgs.gov/data/vs30/us/

Report on Site Characteristics for
SMIP Station

<u>23091</u>

Station Name: <u>Mira Loma – Mission & San Sevaine</u>   **Station Number:** <u>23091</u>

Location: <u>Riverside County Fire Station 17</u>
          <u>10400 San Sevaine Way</u>
          <u>Mira Loma, CA 91752</u>

Latitude: <u>34.0136</u>   **Longitude**: <u>-117.5106</u>
V$_{S30}$: 881 m/sec   **Estimated Error for V$_{S30}$: +/- 100 m/sec**

Site Geology:

The site is located close to a boundary between older and younger alluvial fan deposits, consisting of sand and cobble- and gravel-sand deposits; however, the composition of these units likely does not vary much across this boundary. The alluvium is derived from the San Gabriel Mountains and specifically from rock types including sheared and deformed "Black Belt" mylonite, metasedimentary limestones and marbles, Cretaceous quartz diorite, and Cretaceous granitic rock (Bortugno and Spittler, 1998). Young eolian deposits may also exist in proximity to the site, consisting of unconsolidated, well-sorted, fine- to medium-grained sand (Morton et al., 2002). Some metasedimentary rocks including quartzite, phyllite, and schist crop out about 0.5 miles northeast of the site along a prominent ridgeline (Bortugno and Spittler, 1998).

Site Conditions:

The site is located on flat topography, though there is a prominent ridgeline about 0.5 miles to the northeast. The station is also located in an industrial-urban area, across from a large railway track and yard, as well as less than half a mile from a major highway, both of which will cause a substantial amount of ambient seismic noise.

Description of Geophysical Methods and Locations of Arrays:

HVSR, MASW, and 2D Passive field procedures were performed for the site. The location of the respective test methods are shown in Figure 1, and were field surveyed using a Trimble GeoExplorer 6000 capable of sub-meter accuracy. Subsequent differential GPS corrections were made to the location files using Trimble Pathfinder to increase the accuracy of the start and end points of survey lines. Survey lines were laid out using a 300-foot tape, and bearings were taken using a Brunton Compass. Any major elevation changes were determined in the field using a hand level and measuring rod. See Table 1 for detailed Latitudes and Longitudes.

HVSR readings were recorded after an equipment installation and warmup period of 20 minutes. Readings were taken using 500 Hz, 200 Hz, 100 Hz, and 1Hz sampling frequency settings. The total HVSR recording time for the site was roughly 2 hours in total length. Equipment used included a Kinemetrics Q330 Digitizer in combination with a 120 sec to 160 Hz Metrozet MBB-2 triaxial broadband sensor (an effective equivalent to the Trillium-120). The sensor was buried in a small hole and covered with a thermal insulator and bucket to decrease surface noise interference and temperature variations.

The MASW line was placed along the same lineal path as one of the Passive 2D lines. Geophones were placed at 5 foot (1.524 meter) intervals, with a total line length of 235 feet (71.6 meters) using 48 channels/geophones (4.5 Hz). Off-end shots were performed at 100, 70, 40, and 10 feet (30.48, 21.34, 12.20, and 3.048 meter). Surveys were conducted in forward and reverse, with an additional shot taken at 1.5 feet (0.457 meters) on each end, and in the center of the array. The off-end shots were performed using a stack of 5 hits per record, with a 16-lb sledge-hammer. A single jack (4-lb hammer) was used at the 1.5 (0.457 meters) foot off-end shots to add a higher frequency noise content to the overall record. Recordings were triggered using a hammer switch and taken using a sampling rate of 1 milliseconds (ms) for a total time of 2 seconds (s).

The 2D Passive lines were arranged roughly perpendicular to each other. At each line geophones were placed at 15 foot (4.57 meter) intervals, with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 1, and at 15 foot (4.57 meter) intervals with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 2. Using this length of survey line we were able to achieve 40+ meter depth estimate. Between the two lines, a total of 48 channels were utilized for the 2D Passive survey. Recordings were triggered automatically and taken using a sampling rate of 2 ms for a total time of 30 seconds (30 records were taken in total). We did additional recording using a sampling rate of 1 ms for a total time of 15 seconds (30 records total as well). For both seismic line surveys two separate 24-Channel Geodes (by Geometrics) were combined and used for recording.

HVSR Processing and Results:

Ambient noise data was recorded as MiniSEED files and processed using Geopsy software's H/V toolbox to create a characteristic HVSR curve and determine the fundamental frequency of the site. Data was loaded into Geopsy with vertical and horizontal components and sampling frequencies (100 Hz, 200 Hz, and 500 Hz) specified. Data at these frequencies were processed separately. HVSR curves were calculated multiple times over the entire recording time and using time window lengths of 25, 75, 100, and 200 s. The 75 and 100 s window lengths were used on signals that were first processed using a high-pass filter at 0.1 Hz and 0.3 Hz, respectively, in order to decrease scattered low frequency noise. Time windows containing transients (nearby foot and vehicular traffic or industrial sources) or segments yielding poor quality results were excluded from the analysis. The time windows were picked automatically using an anti-triggering algorithm applied to avoid transients. Some windows were then manually removed because the signals appeared to contain notable transients within those windows that may have affected the results. For each time window,

Fourier amplitude spectra were calculated and smoothed by the Konno and Ohmachi filter with a smoothing constant of 40. The HVSR was calculated for each time window and averaged to produce a characteristic HVSR curve. After calculating standard deviation of the HVSR amplitudes for all windows, the average HVSR curve is divided and multiplied by the standard deviation to produce the minimum and maximum HVSR spectra (SESAME, 2004).

Averaging peak frequency values for the various HVSR curves from data obtained at 100, 200, and 500 Hz gives a mean fundamental frequency of **1.99 Hz**. All of the HVSR curves, which were all deemed reliable, exhibiting two peaks, both of which failed to meet at least five out the six criteria for a clear peak (Figure 2). However, the higher frequency peak at 1.99 Hz met more of these criteria than did the lower frequency peak. The lower frequency peak also almost completely disappears with constant smoothing, and while the assigned f0 does shift to the lower frequency peak with higher smoothing (smoothing constant of 20), smoothing parameters that are too large are not recommended since the need for such cases is rare and is often linked to unsatisfactory recordings. The peak frequency was also designated at around 1.99 in most cases, using both different window lengths and numbers and, filtering, and different smoothing parameters, whereas filtered greatly decreased the clarity of the lower frequency peak (Table 1). The lower frequency peak also became broader with more smoothing and sharper with less, suggesting a possible industrial origin. The fact that neither peak meets the clear peak clarity criteria and that they do not occur at notably different values suggests that a two-peak case is not valid, thought the variety of sedimentary rock types around the site area could be associated with a secondary peak. Given the results, 1.99 Hz is the most likely fundamental frequency of the site.

MASW Processing and Results:

Multichannel Analysis of Surface Waves (MASW) was performed using Surfseis Version 5.3 (KGS, 2017). The active method operation was chosen to evaluate the SEG-2 field files. A frequency overtone generator was used to develop a Phase Velocity-Frequency Image. Frequency ranges were allowed to span from 1 Hz to 50 Hz, with an allowed Phase Velocity window of 20 and 2,000 meters per second (m/sec). An automatic evaluation was performed which yielded a surface wave velocity range of 30 and 1,800 m/sec, with a dominant frequency of surface waves of 8 Hz. The risk of contamination by higher modes was considered to be low, and the overall quality of input data was excellent.

From this process dispersion curves were generated for both forward and reverse geometries along the line using the 100, 70, 40, and 10 foot (30.48, 21.34, 12.20, and 3.048 meter) offsets. These individual dispersion curves were combined to create a single averaged curve for subsequent dispersion value (phase velocity vs. frequency) picking and extraction. Inversion was performed on the picked/extract values in order to create a layer model for comparison and integration with other methods to obtain a best fit shear-wave approximation for the site. The model was allowed to run through the inversion process for 6 iterations, with a final model that reached a total depth of 40+ meters. All data obtained from this processing was used to assist in developing an appropriate dispersion curve and a representative layer profile model, and for calculating the Vs30 for site class designation (Figures 3, 4, and 5).

2D Passive Processing and Results:

2-Dimensional (2D) Passive data was analyzed using Surfseis Version 5.3 (KGS, 2017). The passive-remote mode operation was chosen to evaluate incoming surface wave velocity and frequency because it allows for the use of multiple evaluation points versus pairs or singular values, thus reducing ambiguities related to dispersion curves (DC) that are based on only one or two geophone recordings. Rather this method allows for all geophone signals to be incorporated into the DC and subsequent models. Individual geophone locations were converted to UTM coordinates and tabulated for use with the program. The geometry input file was then uploaded along with the 30 records for subsequent dispersion curve extraction. The files were preprocessed, and an automatic dispersion curve pick was achieved using similar settings as the active method described previously. Each pick was reviewed and modified prior to the extraction of a final dispersion curve. The final DC was then created from the combined records and analyzed for the extraction of the fundamental-mode. An inversion process was then run on the DC curve to create a shear wave velocity profile. In addition to this method, Refraction Microtremor modeling was performed using ReMi (SeisOpt, 2017). ReMi analysis was performed in order to add a comparative model to our results of 2D Passive and Active methods already discussed above.

Summary of Shear Wave Data and HVSR Processing:

Values obtained from the above methods were combined and plotted for averaging of the site's Vs30 and layered models. Initial Vs30 values ranged from between 415 m/sec to 965 m/sec depending on which model was used. The difference of these is large. Neighboring sites have values in the range of 400 to 640 m/sec range (within 2 miles on similar terrain). In the field we observed many surface exposures of granitic knockers, large cobbles, and boulders. The nearby mountains and hills are of the same material, and so it is logical that a very high Vs30 could come from the site. From this review, we modified our assumptions and models to re-evaluate the Vs30 potential due to high velocity layers that were related to granitic bedrock and alluvium. The values were subsequently reviewed and combined using a weighted averaging techniques to address none conformance of the models, and was combined to make a final layer profile.

In the 2D Passive/Active-MASW, the layering was deeper and determinable up to about 111 meters below ground surface. In general, ReMi tends to highly underestimate Vs30 for rock sites, due to its inability to distinguish fundamental modes from subsequent order energy modes, as well as the design of the program which uses picked dispersion values at the low end of the spectrum. Through understanding this information and analytical review of the data, we developed the final average value for Vs30 = 881 m/sec. The estimated error for this is 11.3%, or 100 m/sec. This error is based on the likely variation in the sample mean from the population mean, which we have reviewed in some detail. This Vs30 gives the site a Site Class B designation of very dense soil to soft rock. In light of the overall review, it would appear that the designation makes sense, but that considering the error and the fact that soil is on site at the surface, a Site Class C may be more appropriate based on additional geotechnical properties and exploratory findings.

Taking this data into account and comparing against the HVSR data, we were able to calculate a depth to bedrock interface of 111 meters. The equation for this is f0 = Vs4z, where Vs is assumed to be Vs30 in meters, f0 is HVSR in Hz, and z is depth in meters. The nearby "granitic" hill is less than 2000 feet to the east of the site. Based on this, and the high Vs30 encountered here, the depth seems to be reasonable for what would be considered a bedrock material at this location based on our geological review.

Figure 1: Site Map
SMIP Station 23091

Image Source: Google Earth and Earth Point

Legend

SMIP Station 23091

Coordinate Grid

HVSR Station

MASW Array

Passive Line 1

Passive Line 2

Figure 2 – HSRV Results: line graph showing HSRV results (H/V vs. frequency). Frequency of fundamental peak show with arrow (f0 = 1.99).
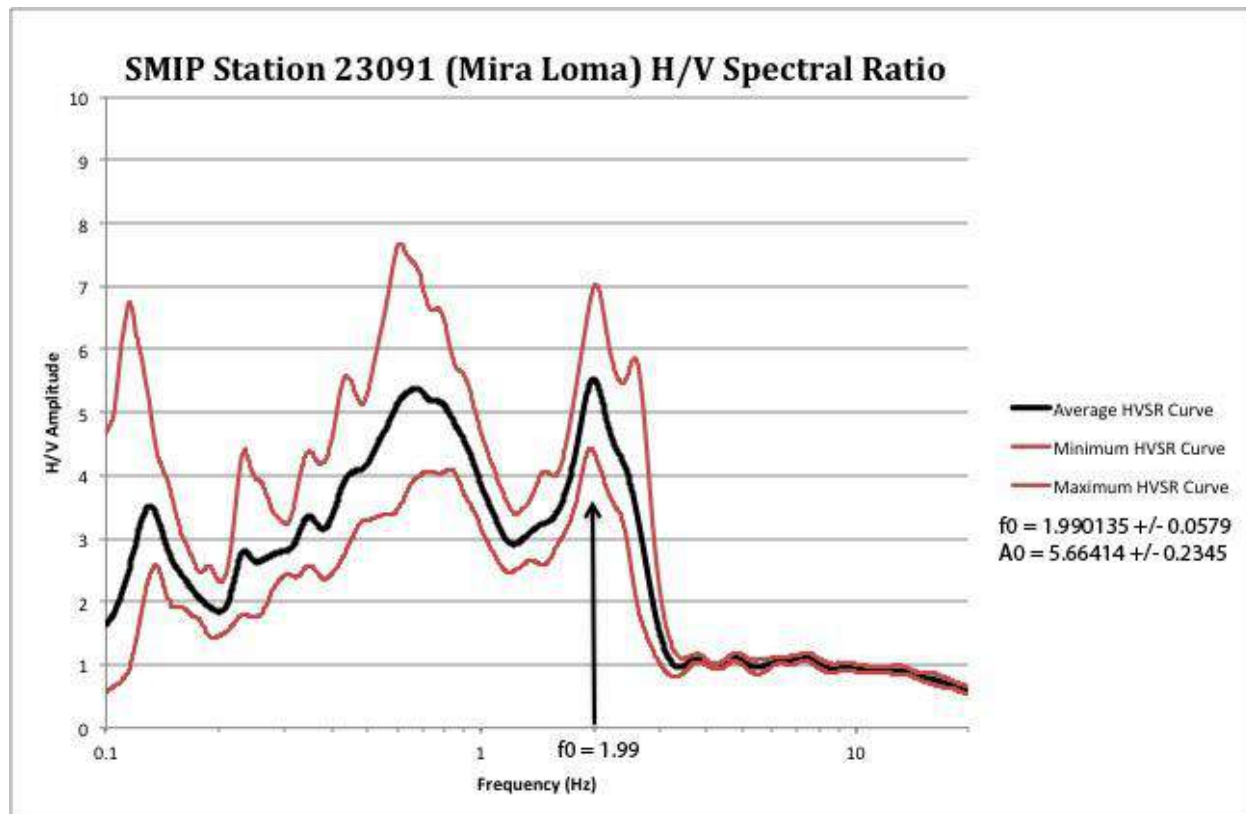
Figure 3 – Dispersion Curves: Final picked dispersion curve values for all methods.
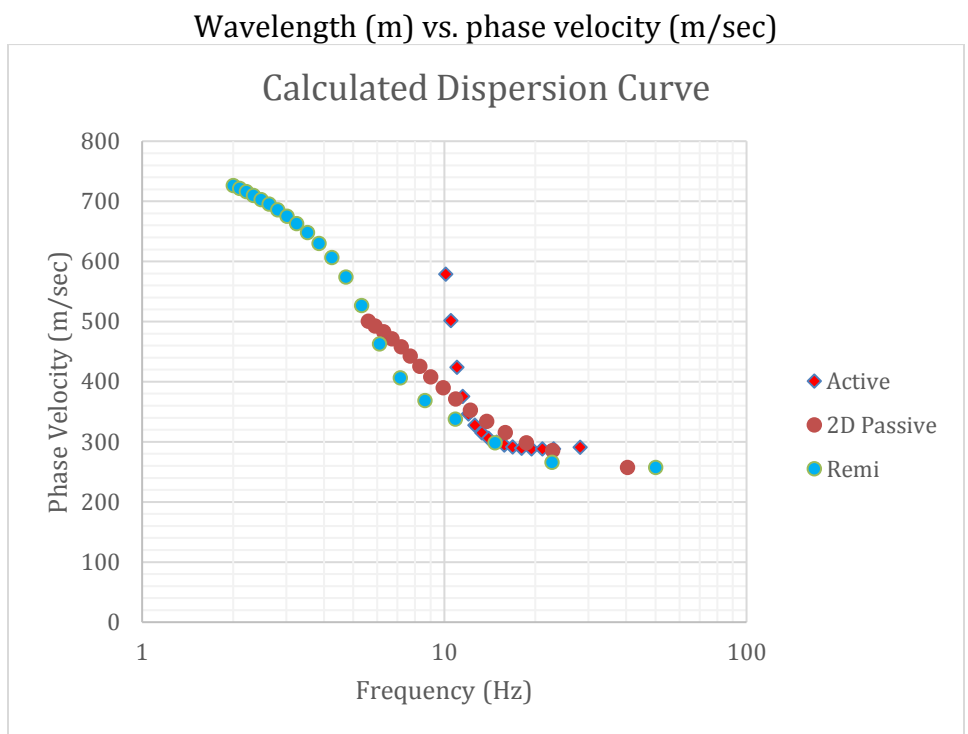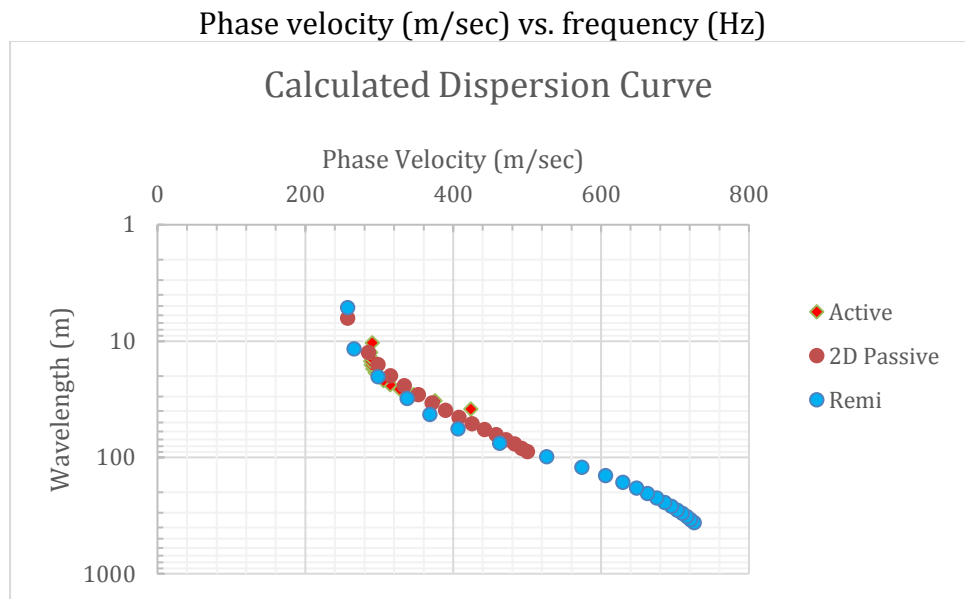
Phase velocity (m/sec) vs. frequency (Hz)

Wavelength (m) vs. phase velocity (m/sec)

Figure 4 – Representative and Calculated Dispersion Curves: Representative and calculated/theoretical dispersion curves. The field data used in the creation of the representative curve is also shown.
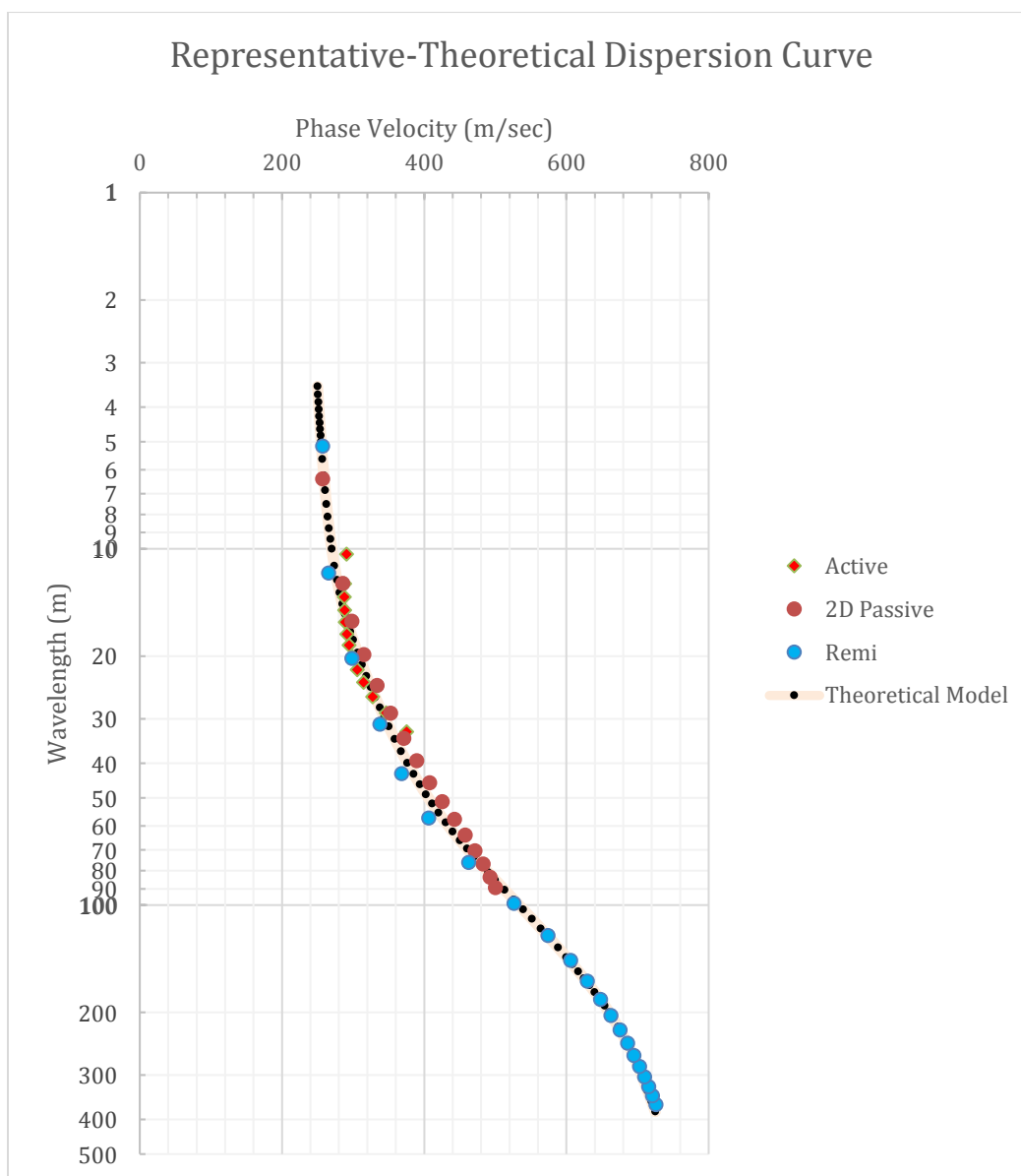
Figure 5 – Shear Wave Velocity Profile: Various profile models used to assess site and determine Vs30 and most likely layering scenario.

Tables:

Table 1: GPS Location Chart – Locations in latitude and longitude for MASW and 2D Passive lines – Shows location of start and end points.

Site 8 - 23091 Mira Loma - Mission & San Sevaine

Method	Start (DD) Lat.	Start (DD) Long.	End (DD) Lat.	End (DD) Long.
MASW	34.01389131400	-117.51132682200	34.01352917000	-117.51068445000
Line 1 2D Passive	34.01315301500	-117.51136304800	34.01410327300	-117.51135162500
Line 2 2D Passive	34.01406959800	-117.51155776100	34.01350889100	-117.51063838900
	(DD) Lat.	(DD) Long.	-	-
HVSR	34.01393500000	-117.51123200000	-	-

Site Photos
Site 8 - 23091 Mira Loma - Mission & San Sevaine

Figure 14 – View of field conditions, and 2D Passive layout.

Figure 15 – View of MASW layout.

References

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Report on Site Characteristics for
SMIP Station

<u>13915</u>

Station Name: Riverside – I215 & 3rd   **Station Number:** 13915

Location: Riverside Fire Station 4
     3510 Cranford Street
     Riverside, CA 92507

Latitude: 33.9792   **Longitude**: -117.3439

V$_{S30}$: 536 m/sec   **Estimated Error for V$_{S30}$: +/- 100 m/sec**

Site Geology:

Historically, Riverside was known for quarrying granitic rock. While these operations have ceased, the site is still located within a state-classified mineral resource zone (MRZ-3), specifically associated with economic deposits of feldspar and silica as well as other undefined rock products, suggesting the presence of granitic bedrock and derivative soils in and around the station area (City of Riverside, 2007). In general, the City and surrounding hills are made up of Mesozoic granitic rocks, granodiorite, Mesozoic mafic intrusive rocks, and alluvium, the latter of which is mostly predominant along the Santa Ana River.

No faults pass through the site area, but the City is at risk of earthquakes from the San Andreas, the San Jacinto, and the Elsinore faults. The site lies on the border between a zone of low liquefaction potential and a zone of moderate liquefaction potential, and is located within a small sliver of land with a 1% annual chance of flood (City of Riverside, 2007).

Site Conditions:

The site is located about 1000 ft from a major highway (I-215) and is located at an active fire station. Such conditions may create a considerable amount of ambient seismic noise. The topography around the site is relatively flat, with some small variations due to the long-wavelength rolling hills throughout the city.

Description of Geophysical Methods and Locations of Arrays:

HVSR, MASW, and 2D Passive field procedures were performed for the site. The location of the respective test methods are shown in Figure 1, and were field surveyed using a Trimble GeoExplorer 6000 capable of sub-meter accuracy. Subsequent differential GPS corrections were made to the location files using Trimble Pathfinder to increase the accuracy of the start and end points of survey lines. Survey lines were laid out using a 300-foot tape, and bearings

were taken using a Brunton Compass. Any major elevation changes were determined in the field using a hand level and measuring rod. See Table 1 for detailed Latitudes and Longitudes.

HVSR readings were recorded after an equipment installation and warmup period of 20 minutes. Readings were taken using 500 Hz, 200 Hz, 100 Hz, and 1Hz sampling frequency settings. The total HVSR recording time for the site was roughly 2 hours in total length. Equipment used included a Kinemetrics Q330 Digitizer in combination with a 120 sec to 160 Hz Metrozet MBB-2 triaxial broadband sensor (an effective equivalent to the Trillium-120). The sensor was buried in a small hole and covered with a thermal insulator and bucket to decrease surface noise interference and temperature variations.

The MASW line was placed along the same lineal path as one of the Passive 2D lines. Geophones were placed at 5 foot (1.524 meter) intervals, with a total line length of 235 feet (71.6 meters) using 48 channels/geophones (4.5 Hz). Off-end shots were performed at 100, 70, 40, and 10 feet (30.48, 21.34, 12.20, and 3.048 meter). Surveys were conducted in forward and reverse, with an additional shot taken at 1.5 feet (0.457 meters) on each end, and in the center of the array. The off-end shots were performed using a stack of 5 hits per record, with a 16-lb sledge-hammer. A single jack (4-lb hammer) was used at the 1.5 (0.457 meters) foot off-end shots to add a higher frequency noise content to the overall record. Recordings were triggered using a hammer switch and taken using a sampling rate of 1 milliseconds (ms) for a total time of 2 seconds (s).

The 2D Passive lines were arranged roughly perpendicular to each other. At each line geophones were placed at 15 foot (4.57 meter) intervals, with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 1, and at 15 foot (4.57 meter) intervals with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 2. Using this length of survey line we were able to achieve 40+ meter depth estimate. Between the two lines, a total of 48 channels were utilized for the 2D Passive survey. Recordings were triggered automatically and taken using a sampling rate of 2 ms for a total time of 30 seconds (30 records were taken in total). We did additional recording using a sampling rate of 1 ms for a total time of 15 seconds (30 records total as well). For both seismic line surveys two separate 24-Channel Geodes (by Geometrics) were combined and used for recording.

HVSR Processing and Results:

Ambient noise data was recorded as MiniSEED files and processed using Geopsy software's H/V toolbox to create a characteristic HVSR curve and determine the fundamental frequency of the site. Data was loaded into Geopsy with vertical and horizontal components and sampling frequencies (200 Hz and 500 Hz) specified. Data at these frequencies were processed separately. The signals were processed without a filter, with a band pass filter from 0.2 Hz to 20.0 Hz, and with a high pass filter at 0.3 Hz in order to compare results. HVSR was calculated over the entire recording time, using time window lengths of 25, 50, and 100 s. Time windows containing transients (nearby foot and vehicular traffic or industrial sources) or segments yielding poor quality results were excluded from the analysis. The time windows were picked automatically using an anti-triggering algorithm applied to avoid

transients. Some windows were then manually removed because the signals appeared to contain notable transients within those windows that may have affected the results. For each time window, Fourier amplitude spectra were calculated and smoothed by the Konno and Ohmachi filter with a smoothing constant of 40. The HVSR was calculated for each time window and averaged to produce a characteristic HVSR curve. After calculating standard deviation of the HVSR amplitudes for all windows, the average HVSR curve is divided and multiplied by the standard deviation to produce the minimum and maximum HVSR spectra (SESAME, 2004).

Averaging peak frequency values obtained from both filtered and unfiltered signals gives a mean fundamental frequency of **1.33 Hz**. The unfiltered data and the band-pass filtered data when using shorter window lengths (25 s) exhibit two peaks. On the unfiltered data, this peak is unreliable since it fails the amplitude criteria, and on the filtered signal, this lower frequency peak is not stable with greater smoothing and becomes broad and highly variable with longer, more stringent window lengths. The peak at f0 actually fails to meet at least five out of the six criteria for a clear peak case because it fails one of the amplitude criteria involving the peak's relative value with respect to the H/V value in the lower adjacent frequency bands [f0/4, f0] and the standard deviation of f0 fails is not within the threshold value. However, with the given data and resulting HVSR curves, f0 = 1.33 appears to be the most likely peak frequency, as it is relatively stable when the signal is processed with different window and smoothing parameters.

MASW Processing and Results:

Multichannel Analysis of Surface Waves (MASW) was performed using Surfseis Version 5.3 (KGS, 2017). The active method operation was chosen to evaluate the SEG-2 field files. A frequency overtone generator was used to develop a Phase Velocity-Frequency Image. Frequency ranges were allowed to span from 1 Hz to 50 Hz, with an allowed Phase Velocity window of 20 and 2,000 meters per second (m/sec). An automatic evaluation was performed which yielded a surface wave velocity range of 231 and 335 m/sec, with a dominant frequency of surface waves of 5 Hz. The risk of contamination by higher modes was considered to be moderate, and the overall quality of input data was good.

From this process dispersion curves were generated for both forward and reverse geometries along the line using the 100, 70, 40, and 10 foot (30.48, 21.34, 12.20, and 3.048 meter) offsets. These individual dispersion curves were combined to create a single averaged curve for subsequent dispersion value (phase velocity vs. frequency) picking and extraction. Inversion was performed on the picked/extract values in order to create a layer model for comparison and integration with other methods to obtain a best fit shear-wave approximation for the site. The model was allowed to run through the inversion process for 6 iterations, with a final model that reached a total depth of 40+ meters. All data obtained from this processing was used to assist in developing an appropriate dispersion curve and a representative layer profile model, and for calculating the Vs30 for site class designation (Figures 3, 4, and 5).

2D Passive Processing and Results:

2-Dimensional (2D) Passive data was analyzed using Surfseis Version 5.3 (KGS, 2017). The passive-remote mode operation was chosen to evaluate incoming surface wave velocity and frequency because it allows for the use of multiple evaluation points versus pairs or singular values, thus reducing ambiguities related to dispersion curves (DC) that are based on only one or two geophone recordings. Rather this method allows for all geophone signals to be incorporated into the DC and subsequent models. Individual geophone locations were converted to UTM coordinates and tabulated for use with the program. The geometry input file was then uploaded along with the 30 records for subsequent dispersion curve extraction. The files were preprocessed, and an automatic dispersion curve pick was achieved using similar settings as the active method described previously. Each pick was reviewed and modified prior to the extraction of a final dispersion curve. The final DC was then created from the combined records and analyzed for the extraction of the fundamental-mode. An inversion process was then run on the DC curve to create a shear wave velocity profile. In addition to this method, Refraction Microtremor modeling was performed using ReMi (SeisOpt, 2017). ReMi analysis was performed in order to add a comparative model to our results of 2D Passive and Active methods already discussed above.

Summary of Shear Wave Data and HVSR Processing:

Values obtained from the above methods were combined and plotted for averaging of the site's Vs30 and layered models. Initial Vs30 values ranged from between 434 m/sec to 696 m/sec depending on which model was used. The difference of these is moderate. Neighboring sites have values in the range of 360 to 390 m/sec range (within 2 miles on flat similar terrain). From this review, we modified our assumptions and models to re-evaluate the Vs30 potential due to missing or mischaracterized high velocity layers. However, our models still all proved a higher Vs30 than observed for neighboring sites. Based on this a new Vs30 = 536 m/sec was achieved. This value was subsequently reviewed and combined using a weighted averaging techniques to address none conformance of the models, and was combined to make a final layer profile.

In the 2D Passive/Active-MASW, the layering was deeper and determinable up to about 76 meters below ground surface. In general, ReMi tends to underestimate Vs30 for sites, due to its inability to distinguish fundamental modes from subsequent order energy modes. However, for this site it was higher than the other methods. For this reason we minimized it as a used input for the site. Through understanding these differences and analytical review of the data, we developed the final average value for Vs30 = 536 m/sec. The estimated error for this is 18.5%, or 100 m/sec. This error is relatively high and is based on the likely variation in the sample mean from the population mean, which we have reviewed in some detail. This Vs30 gives the site a Site Class C designation of very dense soil to soft rock. Based on our review, the site appears to more likely have a Site Class designation of border line C/D. For this reason, it would be our recommendation to perform additional Vs30 for the site, or investigate using geotechnical methods to confirm this possible high Vs30 as either true, or an anomaly.

Taking this data into account and comparing against the HVSR data, we were able to calculate a depth to bedrock interface of 101 meters. The equation for this is f0 = Vs4z, where Vs is assumed to be Vs30 in meters, f0 is HVSR in Hz, and z is depth in meters. There is a nearby hill, and considering the higher Vs encountered at the site, this depth seems to be reasonable for what would be considered a bedrock material at this location based on our geological review.
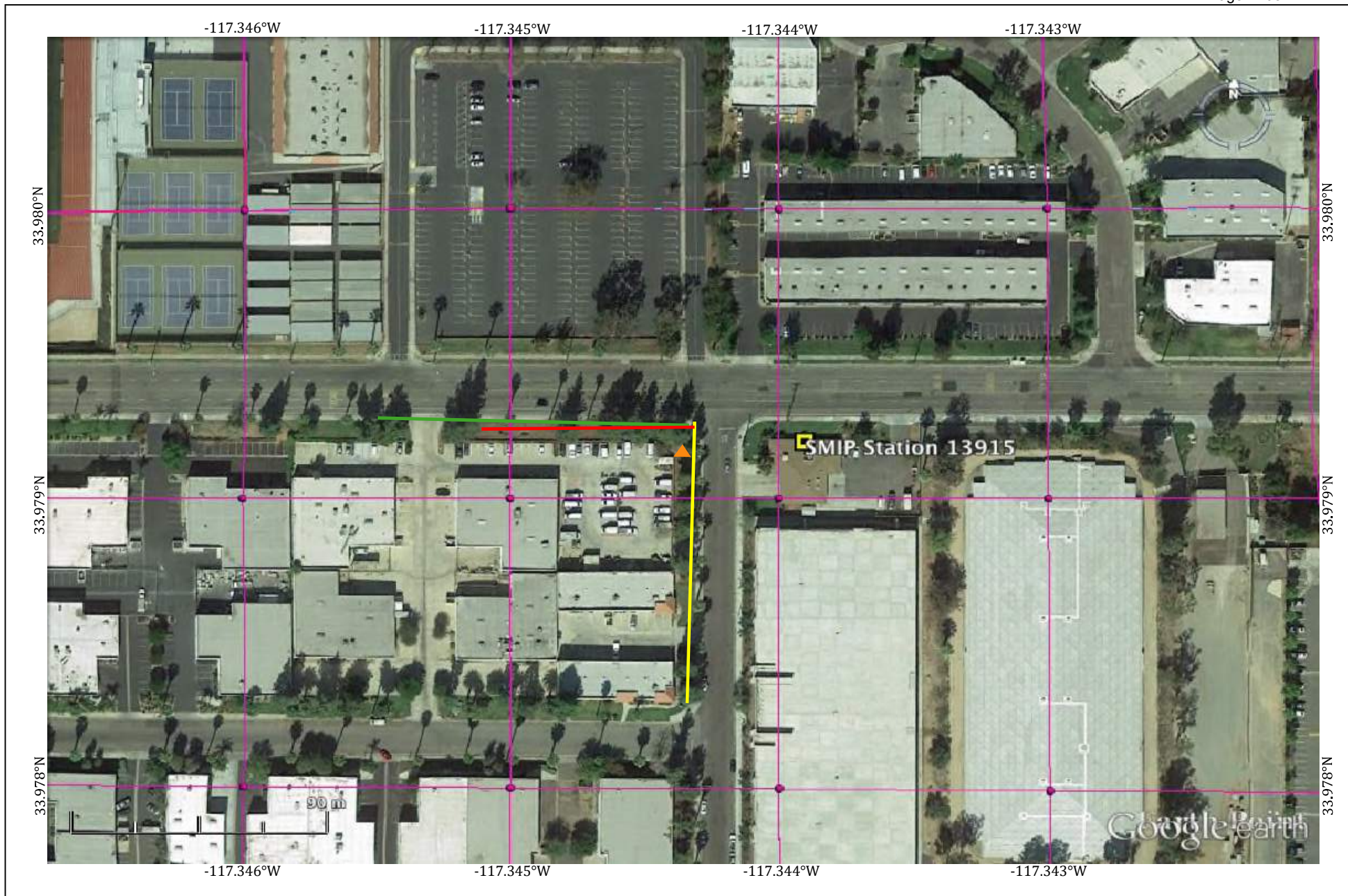
SMIP Station 13915

Image Source: Google Earth and Earth Point

Figure 1: Site Map
SMIP Station 13915

Legend

|	
▢ SMIP Station 13915	▬ MASW Array
▬ Coordinate Grid	▬ Passive Line 1
▲ HVSR Station	▬ Passive Line 2

Figure 2 – HVSR Results: Representative HVSR curve obtained from ambient noise data collected at 200 Hz, with a high-pass filter applied at 0.3 Hz prior to processing and a window length of 100 s.
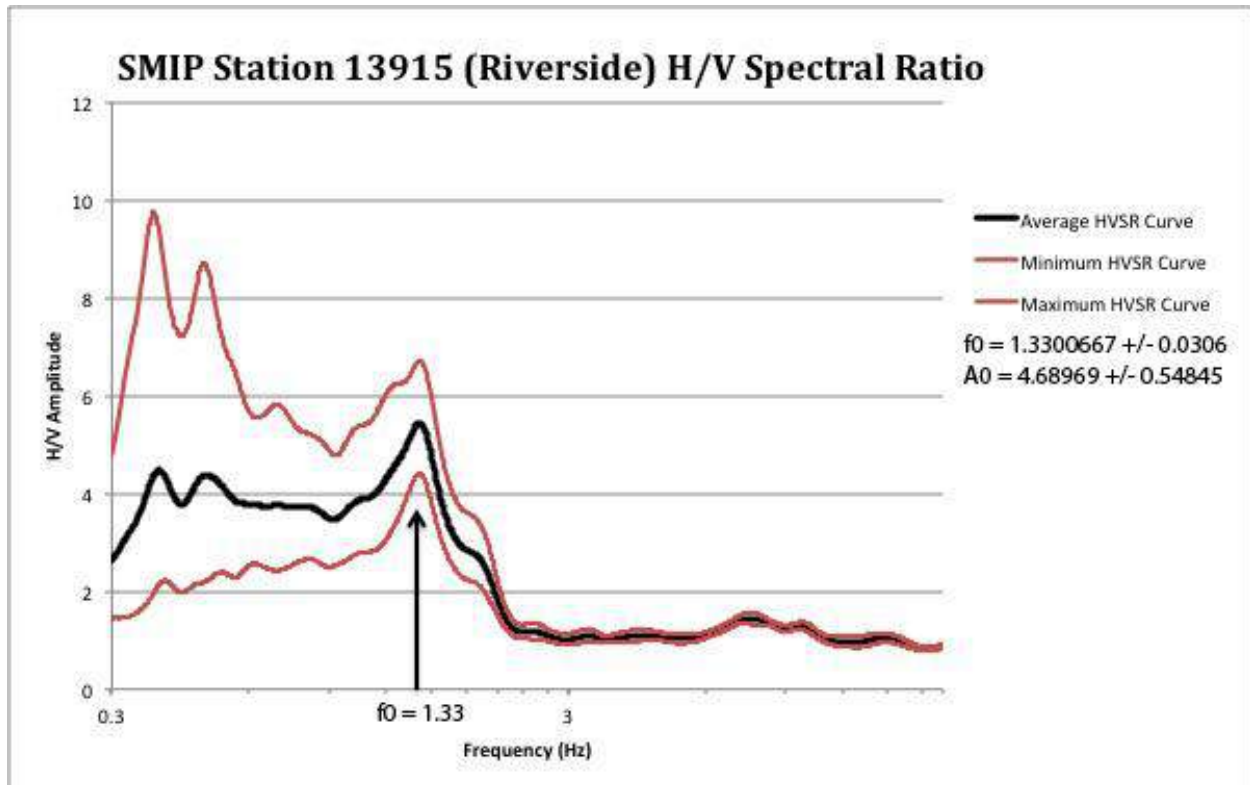
Figure 3 – Dispersion Curves: Final picked dispersion curve values for all methods.
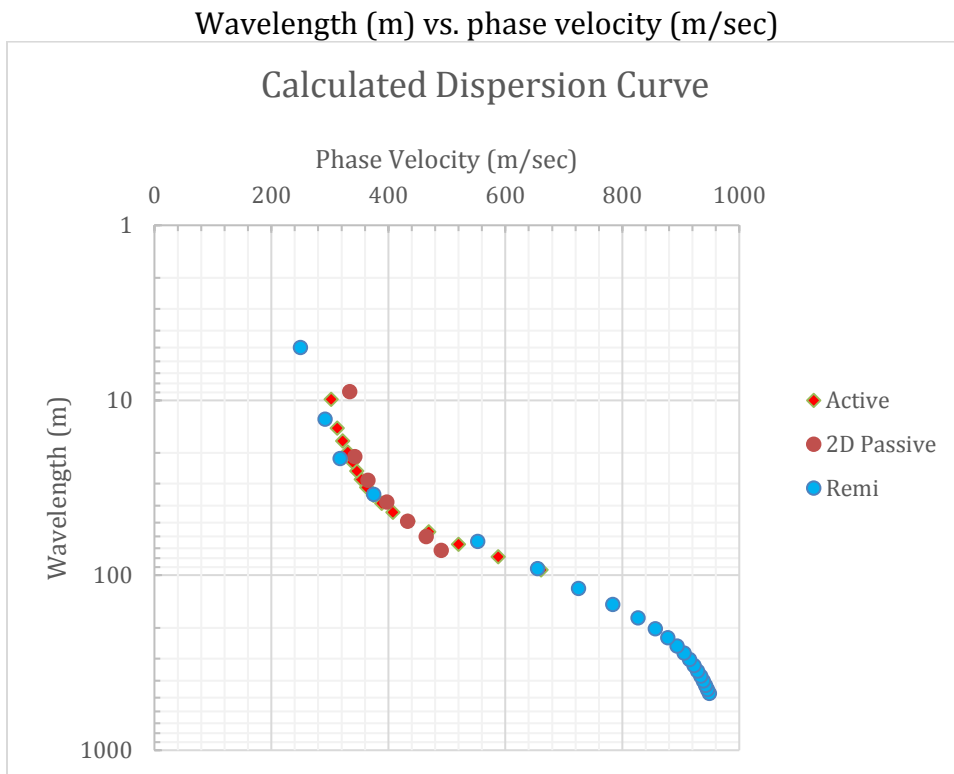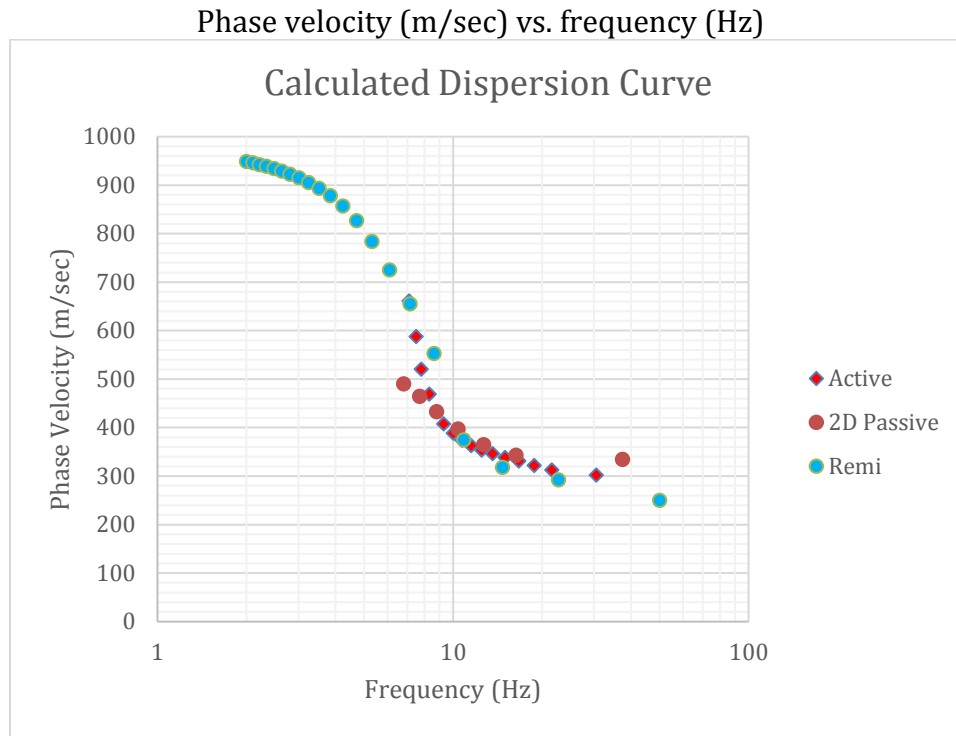
Phase velocity (m/sec) vs. frequency (Hz)

Wavelength (m) vs. phase velocity (m/sec)

Figure 4 – Representative and Calculated Dispersion Curves: Representative and calculated/theoretical dispersion curves. The field data used in the creation of the representative curve is also shown.
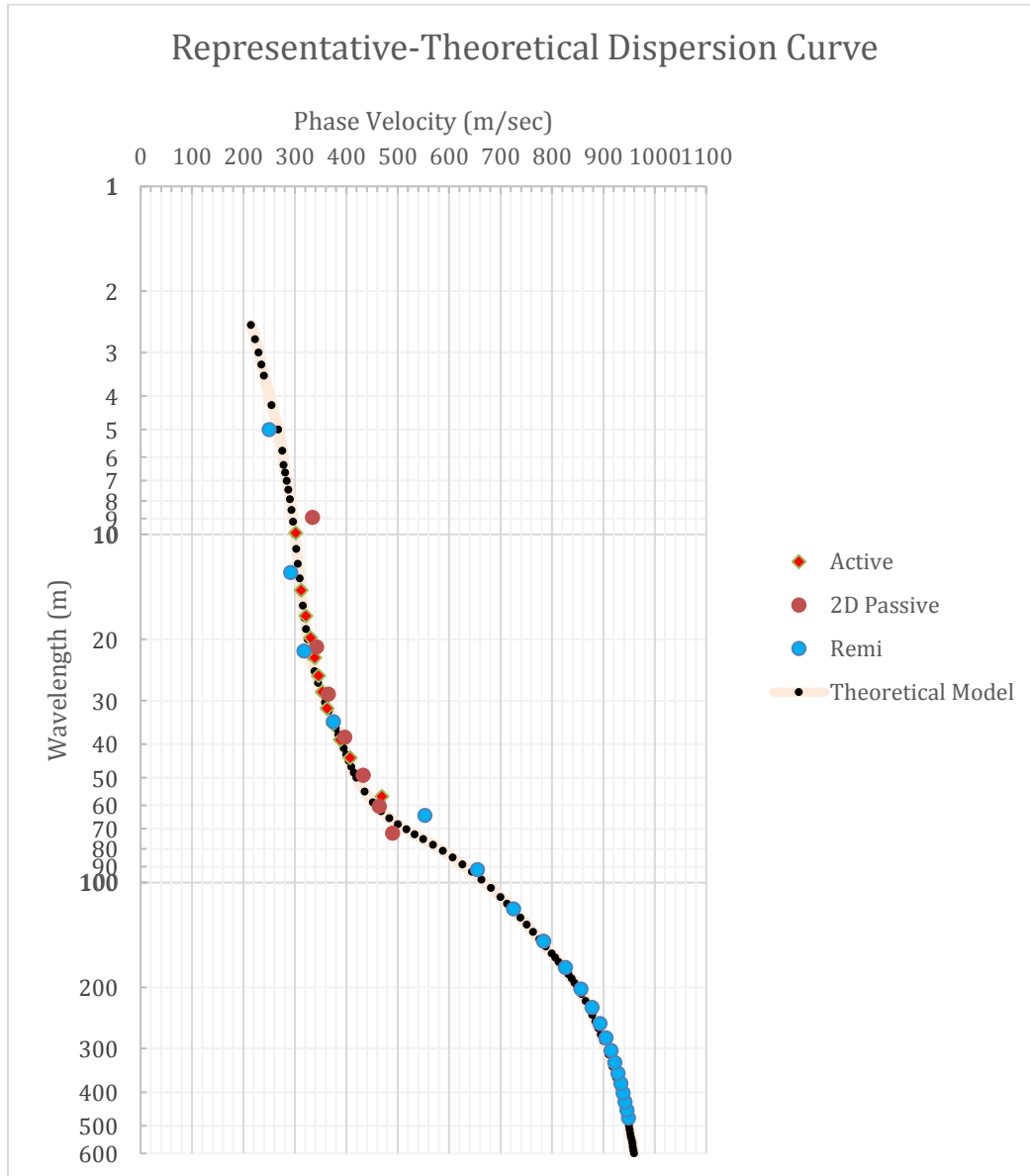
Figure 5 – Shear Wave Velocity Profile: Various profile models used to assess site and determine Vs30 and most likely layering scenario.

Tables:

Table 1: GPS Location Chart – Locations in latitude and longitude for MASW and 2D Passive lines – Shows location of start and end points.

Site 9 - 13915 Riverside I215 & 3rd

Method	Start (DD) Lat.	Start (DD) Long.	End (DD) Lat.	End (DD) Long.
MASW	33.97924691100	-117.34433367500	33.97924161000	-117.34510575300
Line 1 2D Passive	33.97925214400	-117.34546734800	33.97924577200	-117.34433359000
Line 2 2D Passive	33.97924576900	-117.34433351600	33.97829466700	-117.34431936800
	(DD) Lat.	**(DD) Long.**	-	-
HVSR	33.97916000000	-117.34439400000	-	-

Site Photos
Site 9 - 13915 Riverside I215 & 3rd

Figure 16 – View of seismic equipment and setup for 2D Passive.

Figure 17 – View of MASW layout.

References

City of Riverside, 2007, Open Space and Conservation Element *in* City of Riverside General Plan 2025, https://www.riversideca.gov/planning/gp2025program/GP/12_Open_Space_and_Conservation_Element.pdf.

City of Riverside, 2007, Public Safety Element *in* City of Riverside General Plan 2025, https://www.riversideca.gov/planning/gp2025program/GP/10_Public_Safety_Element.pdf.

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SESAME European Research Project, 2004, Guidelines for the Implementation of the H/V Spectral Ratio Technique on Ambient Vibrations: European Commission – Research General Directorate, Project No. EVG1-CT-2000-00026 SESAME.

USGS, 2017, A Compilation of Vs30 Values in the United States, https://earthquake.usgs.gov/data/vs30/us/

Report on Site Characteristics for
SMIP Station

23899

Station Name: Rialto – I10 & Cedar   **Station Number:** 23899

Location: San Bernardino County Fire Station 76
    10174 Magnolia Street
    Bloomington, CA 92316

Latitude: 34.0692   **Longitude**: -117.3981

V$_{S30}$: 390 m/sec   **Estimated Error for V$_{S30}$: +/- 64 m/sec**

Site Geology:

The site is underlain by a combination of younger and older alluvial deposits of the Lytle Creek Fan, as well as deposits of windblown sand (Bortugno and Spittler, 1998; Morton and Bovard, 2003). These deposits generally consist of unconsolidated, pebbly and cobbly alluvium with some boulder sized clasts (Morton and Bovard, 2003).

Site Conditions:

The site is located in an urban environment, adjacent to a major interstate, and just to the northwest of a large rail-yard, all of which are likely to produce a great deal of ambient seismic noise.

Description of Geophysical Methods and Locations of Arrays:

HVSR, MASW, and 2D Passive field procedures were performed for the site. The location of the respective test methods are shown in Figure 1, and were field surveyed using a Trimble GeoExplorer 6000 capable of sub-meter accuracy. Subsequent differential GPS corrections were made to the location files using Trimble Pathfinder to increase the accuracy of the start and end points of survey lines. Survey lines were laid out using a 300-foot tape, and bearings were taken using a Brunton Compass. Any major elevation changes were determined in the field using a hand level and measuring rod. See Table 1 for detailed Latitudes and Longitudes.

HVSR readings were recorded after an equipment installation and warmup period of 20 minutes. Readings were taken using 500 Hz, 200 Hz, 100 Hz, and 1Hz sampling frequency settings. The total HVSR recording time for the site was roughly 2 hours in total length. Equipment used included a Kinemetrics Q330 Digitizer in combination with a 120 sec to 160 Hz Metrozet MBB-2 triaxial broadband sensor (an effective equivalent to the Trillium-120). The sensor was buried in a small hole and covered with a thermal insulator and bucket to decrease surface noise interference and temperature variations.

The MASW line was placed along the same lineal path as one of the Passive 2D lines. Geophones were placed at 5 foot (1.524 meter) intervals, with a total line length of 235 feet (71.6 meters) using 48 channels/geophones (4.5 Hz). Off-end shots were performed at 100, 70, 40, and 10 feet (30.48, 21.34, 12.20, and 3.048 meter). Surveys were conducted in forward and reverse, with an additional shot taken at 1.5 feet (0.457 meters) on each end, and in the center of the array. The off-end shots were performed using a stack of 5 hits per record, with a 16-lb sledge-hammer. A single jack (4-lb hammer) was used at the 1.5 (0.457 meters) foot off-end shots to add a higher frequency noise content to the overall record. Recordings were triggered using a hammer switch and taken using a sampling rate of 1 milliseconds (ms) for a total time of 2 seconds (s).

The 2D Passive lines were arranged roughly perpendicular to each other. At each line geophones were placed at 15 foot (4.57 meter) intervals, with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 1, and at 15 foot (4.57 meter) intervals with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 2. Using this length of survey line we were able to achieve 40+ meter depth estimate. Between the two lines, a total of 48 channels were utilized for the 2D Passive survey. Recordings were triggered automatically and taken using a sampling rate of 2 ms for a total time of 30 seconds (30 records were taken in total). We did additional recording using a sampling rate of 1 ms for a total time of 15 seconds (30 records total as well). For both seismic line surveys two separate 24-Channel Geodes (by Geometrics) were combined and used for recording.

HVSR Data Processing and Results:

Ambient noise data was recorded as MiniSEED files and processed using Geopsy software's H/V toolbox to create a characteristic HVSR curve and determine the fundamental frequency of the site. Data was loaded into Geopsy with vertical and horizontal components and sampling frequencies (100 Hz, 200 Hz, and 500 Hz) specified. Data at these frequencies were processed separately. HVSR curves were calculated over the entire recording time, using time window lengths of 25 and 200 s. Time windows containing transients (nearby foot and vehicular traffic or industrial sources) or segments yielding poor quality results were excluded from the analysis. The time windows were picked automatically using an anti-triggering algorithm applied to avoid transients. Some windows were then manually removed because the signals appeared to contain notable transients within those windows that may have affected the results. For each time window, Fourier amplitude spectra were calculated and smoothed by the Konno and Ohmachi filter with a smoothing constant of 40. The HVSR was calculated for each time window and averaged to produce a characteristic HVSR curve. After calculating standard deviation of the HVSR amplitudes for all windows, the average HVSR curve is divided and multiplied by the standard deviation to produce the minimum and maximum HVSR spectra (SESAME, 2004).

Averaging peak frequency values for all the HVSR curves gives a mean fundamental frequency of **1.32 Hz**. All of the HVSR curves were deemed reliable and show only one clear peak (Figure 2). All of the curves also meet at least five out the six criteria for a clear peak;

those curves using a window length of 200 s met all six clear peak criteria. The peak in each curve is stable across different smoothing parameters and shows no signs of being of industrial origin. Thus, the fundamental frequency can be reliably estimated at 1.32 Hz.

MASW Processing and Results:

Multichannel Analysis of Surface Waves (MASW) was performed using Surfseis Version 5.3 (KGS, 2017). The active method operation was chosen to evaluate the SEG-2 field files. A frequency overtone generator was used to develop a Phase Velocity-Frequency Image. Frequency ranges were allowed to span from 1 Hz to 50 Hz, with an allowed Phase Velocity window of 20 and 1,000 meters per second (m/sec). An automatic evaluation was performed which yielded a surface wave velocity range of 10 and 200 m/sec, with a dominant frequency of surface waves of 15 Hz. The risk of contamination by higher modes was considered to be high, and the overall quality of input data was poor. There was a very large amount of noise due to the parallel freeway for this site, which caused difficulties in achieving good MASW data.

From this process dispersion curves were generated for both forward and reverse geometries along the line using the 100, 70, 40, and 10 foot (30.48, 21.34, 12.20, and 3.048 meter) offsets. These individual dispersion curves were combined to create a single averaged curve for subsequent dispersion value (phase velocity vs. frequency) picking and extraction. Inversion was performed on the picked/extract values in order to create a layer model for comparison and integration with other methods to obtain a best fit shear-wave approximation for the site. The model was allowed to run through the inversion process for 6 iterations, with a final model that reached a total depth of 40+ meters. All data obtained from this processing was used to assist in developing an appropriate dispersion curve and a representative layer profile model, and for calculating the Vs30 for site class designation (Figures 3, 4, and 5).

2D Passive Processing and Results:

2-Dimensional (2D) Passive data was analyzed using Surfseis Version 5.3 (KGS, 2017). The passive-remote mode operation was chosen to evaluate incoming surface wave velocity and frequency because it allows for the use of multiple evaluation points versus pairs or singular values, thus reducing ambiguities related to dispersion curves (DC) that are based on only one or two geophone recordings. Rather this method allows for all geophone signals to be incorporated into the DC and subsequent models. Individual geophone locations were converted to UTM coordinates and tabulated for use with the program. The geometry input file was then uploaded along with the 30 records for subsequent dispersion curve extraction. The files were preprocessed, and an automatic dispersion curve pick was achieved using similar settings as the active method described previously. Each pick was reviewed and modified prior to the extraction of a final dispersion curve. The final DC was then created from the combined records and analyzed for the extraction of the fundamental-mode. An inversion process was then run on the DC curve to create a shear wave velocity profile. In addition to this method, Refraction Microtremor modeling was performed using ReMi

(SeisOpt, 2017). ReMi analysis was performed in order to add a comparative model to our results of 2D Passive and Active methods already discussed above.

Summary of Shear Wave Data and HVSR Processing:

Values obtained from the above methods were combined and plotted for averaging of the site's Vs30 and layered models. Initial Vs30 values ranged from between 390 m/sec to 545 m/sec depending on which model was used. The difference of these is moderate. Neighboring sites have values in the range of 405 m/sec (within 2.5 miles on flat similar terrain - USGS, 2017). From this review, we modified our assumptions and models to re-evaluate the Vs30 potential due to missing or mischaracterized high velocity layers. Based on this a new Vs30 = 390 m/sec was achieved. This value was subsequently reviewed and combined using a weighted averaging techniques to address none conformance of the models, and was combined to make a final layer profile.

In the 2D Passive/Active-MASW, the layering was deeper and determinable up to about 117 meters below ground surface. In general, ReMi tends to underestimate Vs30 for sites, due to its inability to distinguish fundamental modes from subsequent order energy modes. Through understanding these differences and analytical review of the data, we developed the final average value for Vs30 = 390 m/sec. The estimated error for this is 16%, or 64 m/sec. This error is moderate to relatively high and is based on the likely variation in the sample mean from the population mean, which we have reviewed in some detail. This Vs30 gives the site a Site Class C designation of very dense soil to soft rock. Based on our review, the site appears to within a region that has such site class designations.

Taking this data into account and comparing against the HVSR data, we were able to calculate a depth to bedrock interface of 74 meters. The equation for this is $f0 = Vs4z$, where Vs is assumed to be Vs30 in meters, f0 is HVSR in Hz, and z is depth in meters. This depth seems to be a little low considering the distance from the nearest mountain/hill region (which is roughly 1.5 miles to the southwest). There was a lot of cultural disturbance due to the freeway interaction and industrial activities that were observed throughout the area. Due to these inconsistencies and obvious cultural impacts, additional investigation using direct sources is recommended to determine and confirm site Class Determination and Vs30.
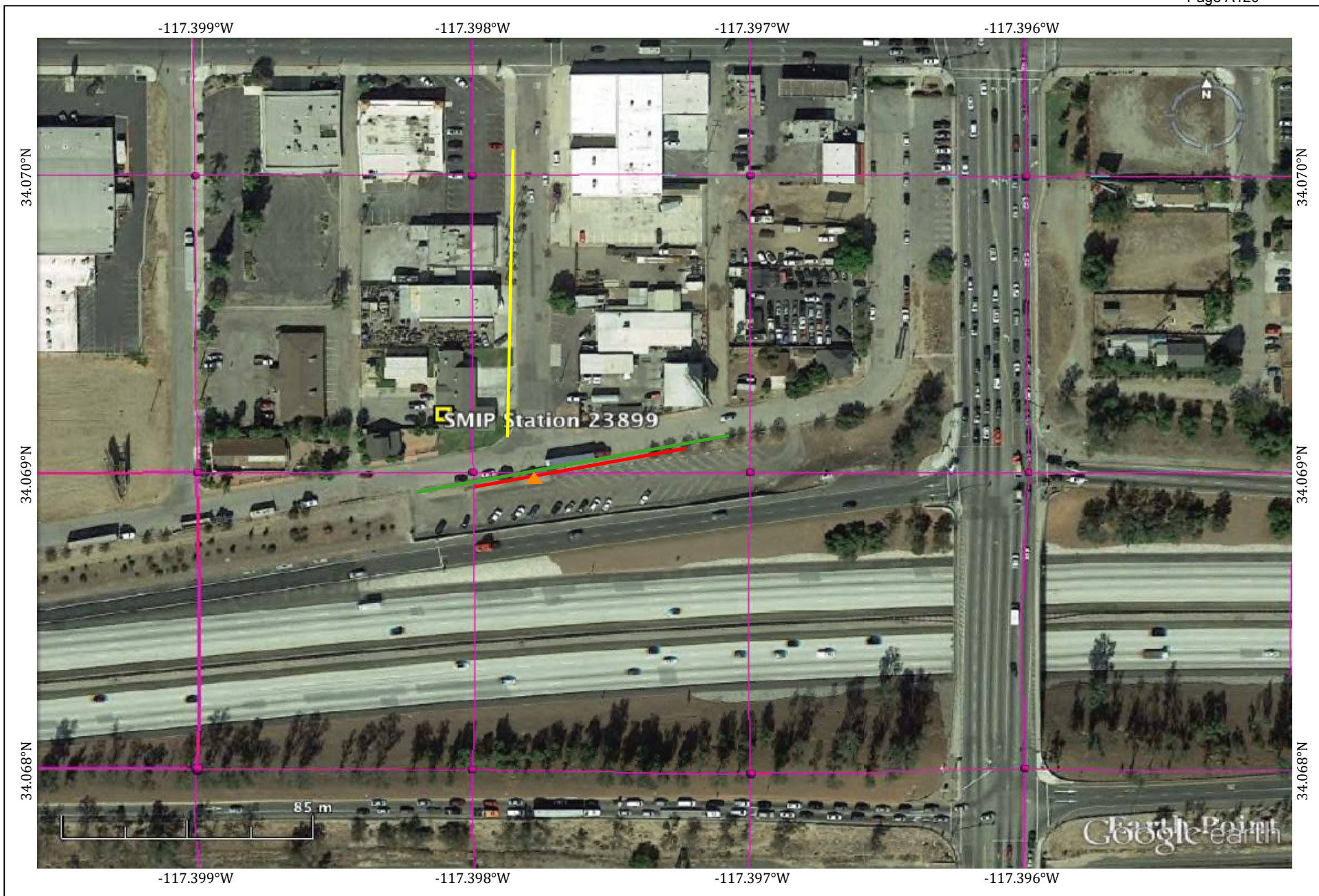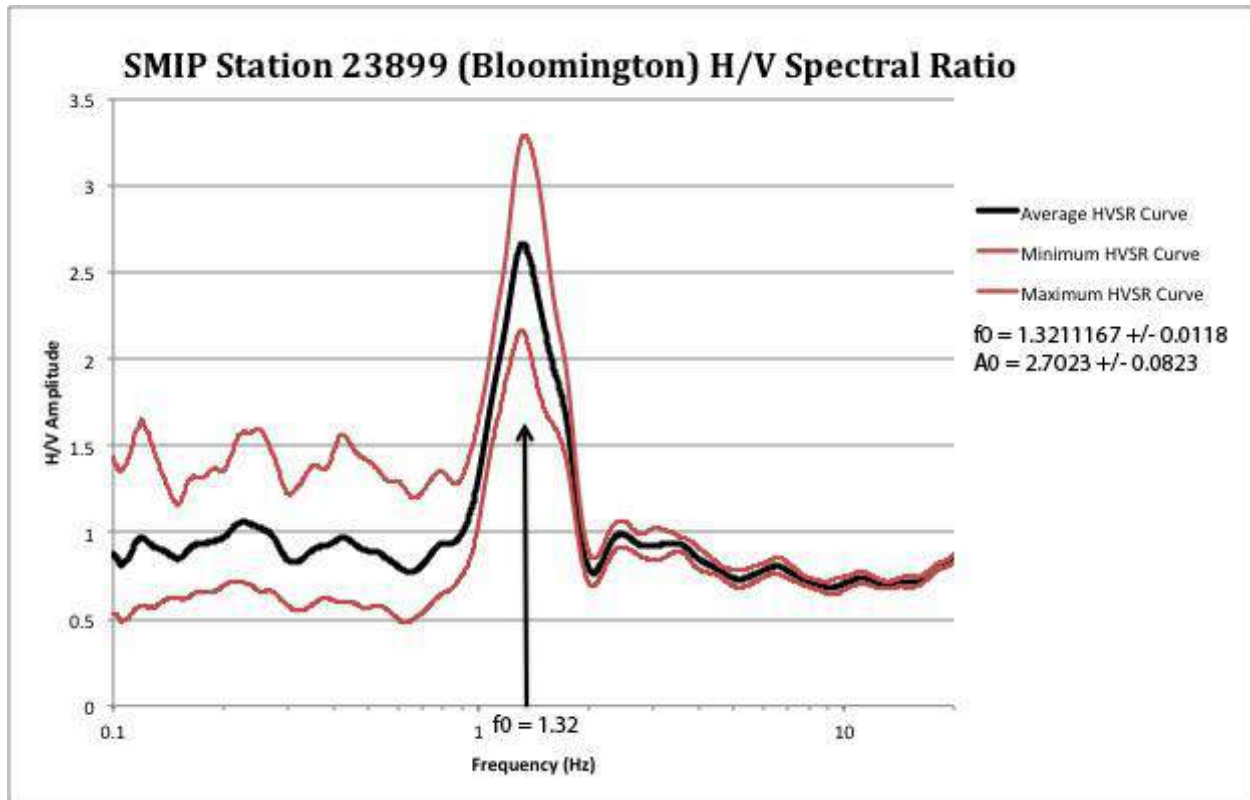
Legend

- SMIP Station 23899
- Coordinate Grid
- HVSR Station
- MASW Array
- Passive Line 1
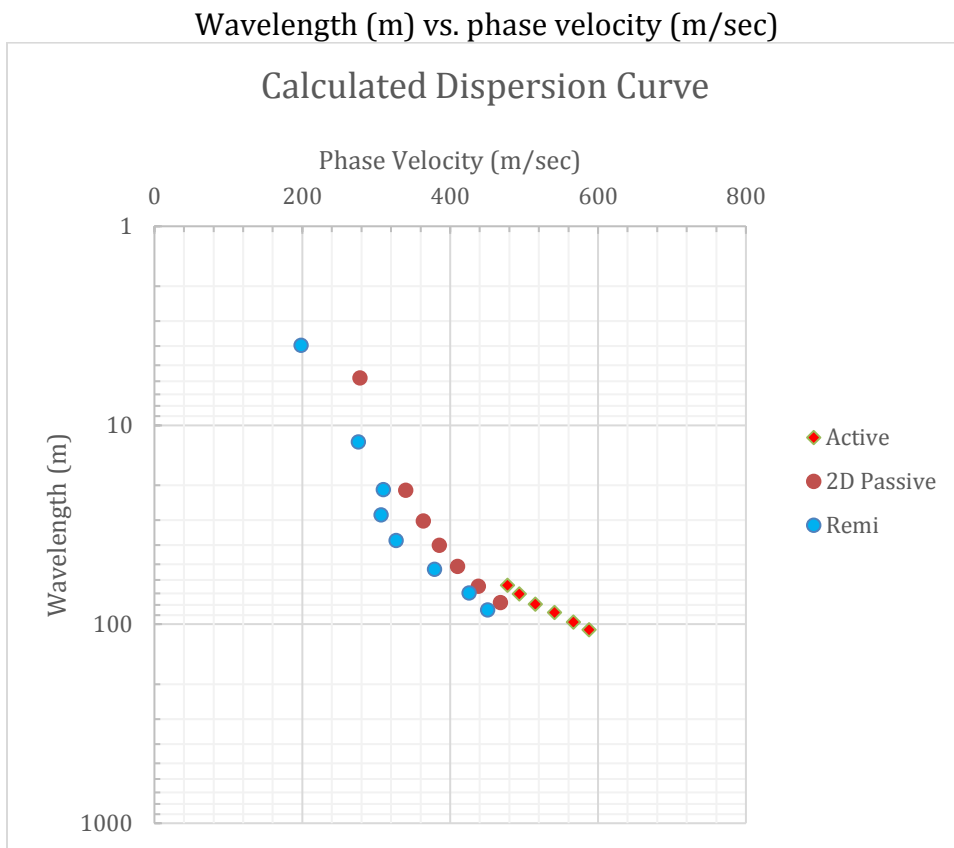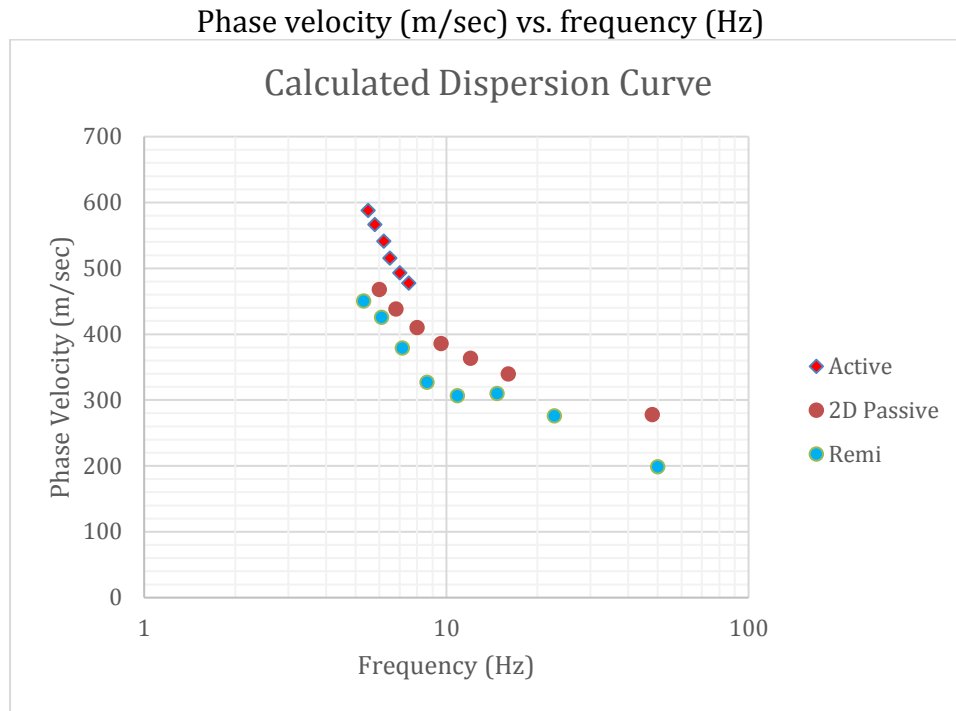- Passive Line 2

Figure 1: Site Map
SMIP Station 23899

Figure 2 – HVSR Results: Representative HVSR curve from data obtained at 200 Hz and processed using 200 s long windows.

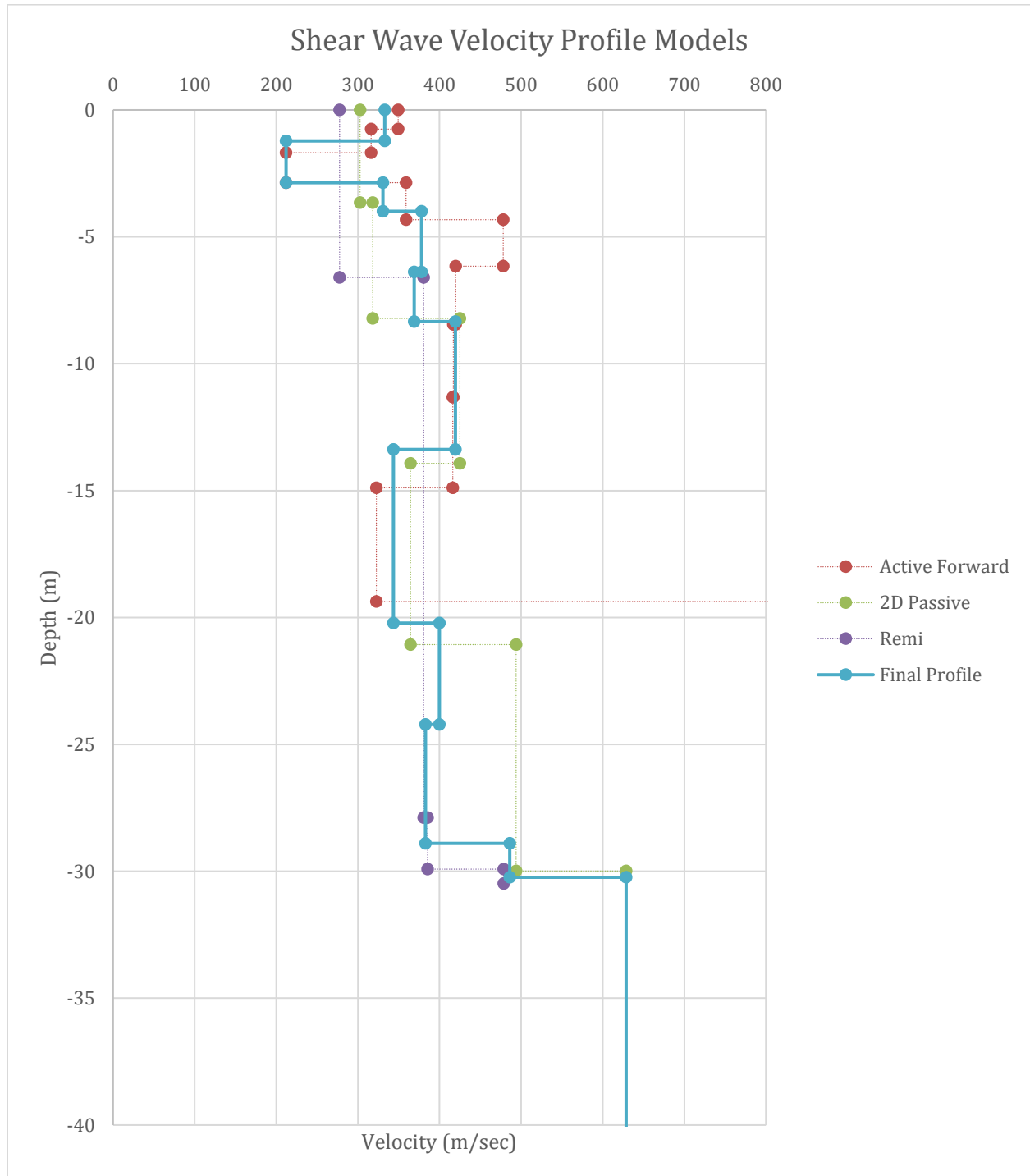**Figure 3 – Dispersion Curves**: Final picked dispersion curve values for all methods.

Phase velocity (m/sec) vs. frequency (Hz)

Wavelength (m) vs. phase velocity (m/sec)

Figure 4 – Representative and Calculated Dispersion Curves: Representative and calculated/theoretical dispersion curves. The field data used in the creation of the representative curve is also shown.
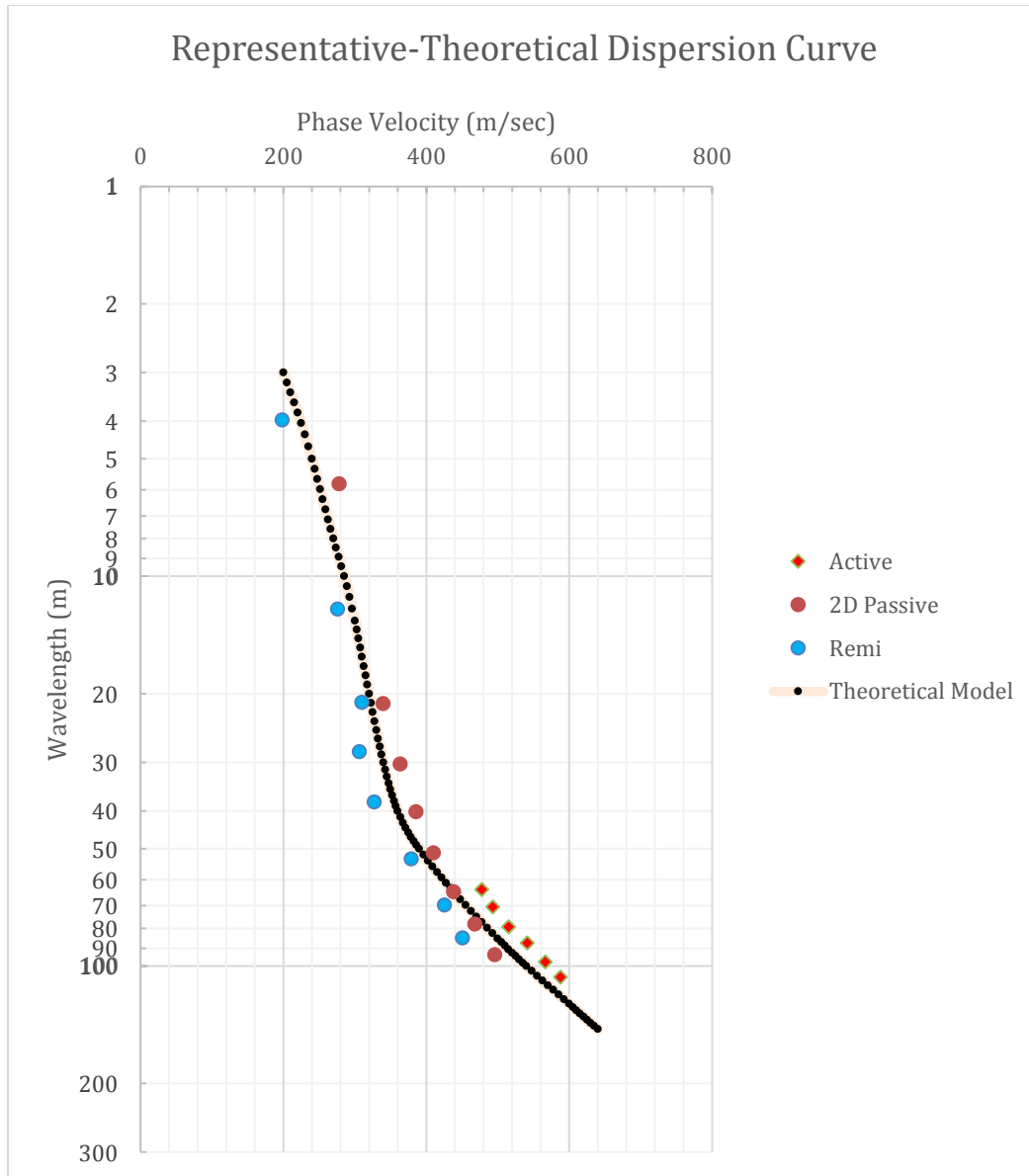
Figure 5 – Shear Wave Velocity Profile: Various profile models used to assess site and determine Vs30 and most likely layering scenario.

Tables:

Table 1: GPS Location Chart – Locations in latitude and longitude for MASW and 2D Passive lines – Shows location of start and end points.

Site 10 - 23899 Rialto I10 & Cedar

Method	Start (DD) Lat.	Start (DD) Long.	End (DD) Lat.	End (DD) Long.
MASW	34.06908809900	-117.39721290200	34.06896378700	-117.39797524200
Line 1 2D Passive	34.06893517000	-117.39817265600	34.06911801100	-117.39705657400
Line 2 2D Passive	34.06912321800	-117.39785208500	34.07007677200	-117.39784037600
	(DD) Lat.	(DD) Long.	-	-
HVSR	34.068985	-117.397819	-	-

Site Photos
Site 10 - 23899 Rialto I10 & Cedar

Figure 18 – View of laying out MASW.

Figure 19 – View of 2D Passive setup across street.

References

Bortugno, E.J. and Spittler, T.E., 1998, Geologic Map of the San Bernardino Quadrangle, California: State of California Division of Mines and Geology, Regional Map Series, San Bernardino Quadrangle, Map No. 3A, Scale 1:250,000.

Geopsy Software, 2017, SESAME European Research Project: Release 0.0.0-snapshot-20170109, geopsy.org.

KGS, 2017, Kansas Geological Survey, Surfseis Version 5.3.

Morton, D.M. and Bovard, K.R., 2003, Preliminary Geologic Map of the Fontana 7.5' Quadrangle, San Bernardino and Riverside Counties, California: U.S. Geological Survey in cooperation with California Geological Survey, Open-File Report 03-418, Scale 1:24,000.

Optim Software, 2017, SeisOpt - ReMi Refraction Microtremor Analysis.

SESAME European Research Project, 2004, Guidelines for the Implementation of the H/V Spectral Ratio Technique on Ambient Vibrations: European Commission – Research General Directorate, Project No. EVG1-CT-2000-00026 SESAME.

USGS, 2017, A Compilation of Vs30 Values in the United States, https://earthquake.usgs.gov/data/vs30/us/

Report on Site Characteristics for
SMIP Station

<u>23780</u>

Station Name: San Bernardino – Mountain View & Cluster **Station Number:** 23780

Location: Caltrans District 8 Building
    175 Cluster Street
    San Bernardino, CA 92408

Latitude: 34.0964   **Longitude**: -117.2872

V_{S30}: **363 m/sec**   **Estimated Error for V_{S30}: +/- 21 m/sec**

Site Geology:

The site is underlain by modern wash deposits, alluvium of abandoned washes, and older early Holocene alluvium (Bortugno and Spittler, 1998). The site is also located in an area of high liquefaction susceptibility and inside an area of potential subsidence due to the rather unconsolidated nature of the alluvium (City of San Bernardino, 2005).

Site Conditions:

The site is situated on flat topography in an urban industrial part of San Bernardino.

Description of Geophysical Methods and Locations of Arrays:

HVSR, MASW, and 2D Passive field procedures were performed for the site. The location of the respective test methods are shown in Figure 1, and were field surveyed using a Trimble GeoExplorer 6000 capable of sub-meter accuracy. Subsequent differential GPS corrections were made to the location files using Trimble Pathfinder to increase the accuracy of the start and end points of survey lines. Survey lines were laid out using a 300-foot tape, and bearings were taken using a Brunton Compass. Any major elevation changes were determined in the filed using a hand level and measuring rod. See Table 1 for detailed Latitudes and Longitudes.

HVSR readings were recorded after an equipment installation and warmup period of 20 minutes. Readings were taken using 500 Hz, 200 Hz, 100 Hz, and 1Hz sampling frequency settings. The total HVSR recording time for the site was roughly 2 hours in total length. Equipment used included a Kinemetrics Q330 Digitizer in combination with a 120 sec to 160 Hz Metrozet MBB-2 triaxial broadband sensor (an effective equivalent to the Trillium-120). The sensor was buried in a small hole and covered with a thermal insulator and bucket to decrease surface noise interference and temperature variations.

The MASW line was placed along the same lineal path as one of the Passive 2D lines. Geophones were placed at 5 foot (1.524 meter) intervals, with a total line length of 235 feet (71.6 meters) using 48 channels/geophones (4.5 Hz). Off-end shots were performed at 100, 70, 40, and 10 feet (30.48, 21.34, 12.20, and 3.048 meter). Surveys were conducted in forward and reverse, with an additional shot taken at 1.5 feet (0.457 meters) on each end, and in the center of the array. The off-end shots were performed using a stack of 5 hits per record, with a 16-lb sledge-hammer. A single jack (4-lb hammer) was used at the 1.5 (0.457 meters) foot off-end shots to add a higher frequency noise content to the overall record. Recordings were triggered using a hammer switch and taken using a sampling rate of 1 milliseconds (ms) for a total time of 2 seconds (s).

The 2D Passive lines were arranged roughly perpendicular to each other. At each line geophones were placed at 15 foot (4.57 meter) intervals, with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 1, and at 15 foot (4.57 meter) intervals with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 2. Using this length of survey line we were able to achieve 40+ meter depth estimate. Between the two lines, a total of 48 channels were utilized for the 2D Passive survey. Recordings were triggered automatically and taken using a sampling rate of 2 ms for a total time of 30 seconds (30 records were taken in total). We did additional recording using a sampling rate of 1 ms for a total time of 15 seconds (30 records total as well). For both seismic line surveys two separate 24-Channel Geodes (by Geometrics) were combined and used for recording.

HVSR Data Processing and Results:

Ambient noise data was recorded as MiniSEED files and processed using Geopsy software's H/V toolbox to create a characteristic HVSR curve and determine the fundamental frequency of the site. Data was loaded into Geopsy with vertical and horizontal components and sampling frequencies (100 Hz, 200 Hz, and 500 Hz) specified. However, due to a recording error, only the 100 Hz data was analyzed. HVSR curves were calculated over the entire recording time, using window lengths at 100 and 200 s. The signals were first processed using a high-pass filter at 0.1 Hz. Some of the signals were whitened before processing in order to decrease scattered low frequency noise and make identifying transients easier. Time windows containing transients (nearby foot and vehicular traffic or industrial sources) or segments yielding poor quality results were excluded from the analysis. The time windows were picked automatically using an anti-triggering algorithm applied to avoid transients. Some windows were then manually removed because the signals appeared to contain notable transients within those windows that may have affected the results. For each time window, Fourier amplitude spectra were calculated and smoothed by the Konno and Ohmachi filter with a smoothing constant of 40. The HVSR was calculated for each time window and averaged to produce a characteristic HVSR curve. After calculating standard deviation of the HVSR amplitudes for all windows, the average HVSR curve is divided and multiplied by the standard deviation to produce the minimum and maximum HVSR spectra (SESAME, 2004).

Both the filtered and unfiltered data exhibit a great deal of unclear low frequency peaks. Such an occurrence is likely due to the sites proximity to a major highway and thus traffic. The only peak that in most cases met both all of the reliability criteria and at least five out the six clear peak criteria occurred at a frequency of 0.14 Hz (Figure 2). Such low peak frequencies may sometimes be characteristic of thick stiff sedimentary deposits; however, the predominance of unconsolidated alluvium in the site area and that fact that alternate smoothing parameters do not necessarily improve the clarity of the data suggest that this low frequency peak may in fact not be a truly representative estimate of the site's fundamental frequency. However, from the given data and resulting HVSR curves **f0 = 0.14** is the best estimate of fundamental frequency for the site. Such a low frequency peak may also be an indication of a moderate impedance contrast at depth or a velocity gradient.

MASW Processing and Results:

Multichannel Analysis of Surface Waves (MASW) was performed using Surfseis Version 5.3 (KGS, 2017). The active method operation was chosen to evaluate the SEG-2 field files. A frequency overtone generator was used to develop a Phase Velocity-Frequency Image. Frequency ranges were allowed to span from 1 Hz to 50 Hz, with an allowed Phase Velocity window of 20 and 2,000 meters per second (m/sec). An automatic evaluation was performed which yielded a surface wave velocity range of 10 and 300 m/sec, with a dominant frequency of surface waves of 19 Hz. The risk of contamination by higher modes was considered to be low, and the overall quality of input data was excellent.

From this process dispersion curves were generated for both forward and reverse geometries along the line using the 100, 70, 40, and 10 foot (30.48, 21.34, 12.20, and 3.048 meter) offsets. These individual dispersion curves were combined to create a single averaged curve for subsequent dispersion value (phase velocity vs. frequency) picking and extraction. Inversion was performed on the picked/extract values in order to create a layer model for comparison and integration with other methods to obtain a best fit shear-wave approximation for the site. The model was allowed to run through the inversion process for 10 iterations, with a final model that reached a total depth of 40+ meters. All data obtained from this processing was used to assist in developing an appropriate dispersion curve and a representative layer profile model, and for calculating the Vs30 for site class designation (Figures 3, 4, and 5).

2D Passive Processing and Results:

2-Dimensional (2D) Passive data was analyzed using Surfseis Version 5.3 (KGS, 2017). The passive-remote mode operation was chosen to evaluate incoming surface wave velocity and frequency because it allows for the use of multiple evaluation points versus pairs or singular values, thus reducing ambiguities related to dispersion curves (DC) that are based on only one or two geophone recordings. Rather this method allows for all geophone signals to be incorporated into the DC and subsequent models. Individual geophone locations were converted to UTM coordinates and tabulated for use with the program. The geometry input file was then uploaded along with the 30 records for subsequent dispersion curve extraction. The files were preprocessed, and an automatic dispersion curve pick was achieved using
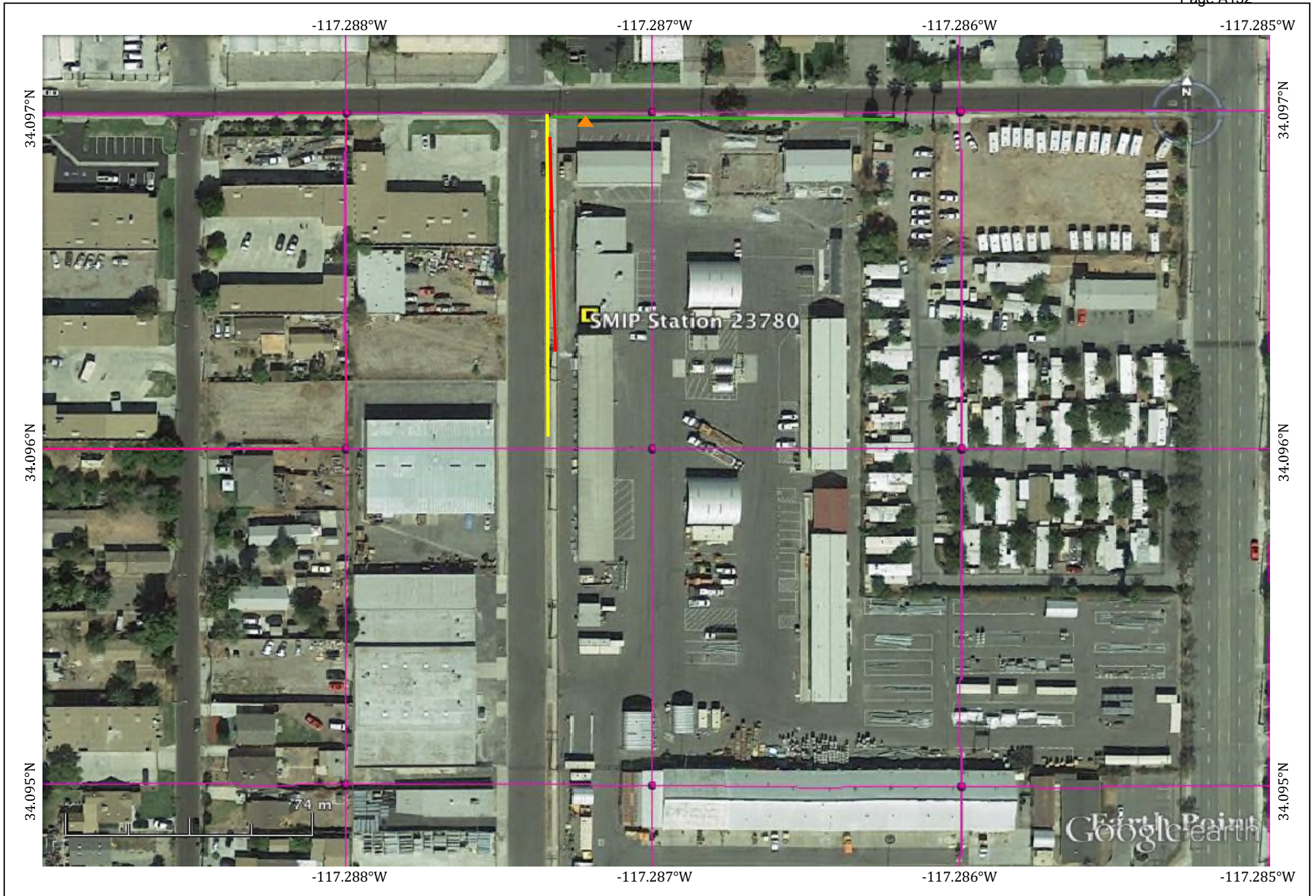
similar settings as the active method described previously. Each pick was reviewed and modified prior to the extraction of a final dispersion curve. The final DC was then created from the combined records and analyzed for the extraction of the fundamental-mode. An inversion process was then run on the DC curve to create a shear wave velocity profile. In addition to this method, Refraction Microtremor modeling was performed using ReMi (SeisOpt, 2017). ReMi analysis was performed in order to add a comparative model to our results of 2D Passive and Active methods already discussed above.

Summary of Shear Wave Data and HVSR Processing:

Values obtained from the above methods were combined and plotted for averaging of the site's Vs30 and layered models. Initial Vs30 values ranged from between 320 m/sec to 448 m/sec depending on which model was used. The difference of these is moderate. Neighboring sites have values in the range of 320 m/sec (within 1.5 miles on flat similar terrain - USGS, 2017). Based on this a new Vs30 = 363 m/sec was achieved. This value was subsequently reviewed and combined using a weighted averaging techniques to address none conformance of the models, and was combined to make a final layer profile.

In the 2D Passive/Active-MASW, the layering was deeper and determinable up to about 100 meters below ground surface. In general, ReMi tends to underestimate Vs30 for sites, due to its inability to distinguish fundamental modes from subsequent order energy modes. However, in this case Remi and 2D Passive methods better predicted the expected values based on geologic background review. Through understanding these differences and analytical review of the data, we developed the final average value for Vs30 = 363 m/sec. The estimated error for this is 5.7%, or 21 m/sec. This error is moderate to low and is based on the likely variation in the sample mean from the population mean, which we have reviewed in some detail. This Vs30 gives the site a borderline Site Class C/D designation. However, in a border line case, this site should be considered to be a Site Class D, based on neighboring site classifications and background geological review, as well as chance for liquefaction potential for the region being high.

Taking this data into account and comparing against the HVSR data, we were able to calculate a depth to bedrock interface of 645 meters. The equation for this is f0 = Vs4z, where Vs is assumed to be Vs30 in meters, f0 is HVSR in Hz, and z is depth in meters. This area is located within a very large and deep alluvial wash canyon, with a variety of steep cut faults within the region, therefore this depth seems to be reasonable for what would be considered a bedrock material at this location based on our geological review.

Image Source: Google Earth and Earth Point

Legend

|	
▢ (yellow)	SMIP Station 23780
— (purple)	Coordinate Grid
▲ (orange)	HVSR Station
— (red)	MASW Array
— (green)	Passive Line 1
— (yellow)	Passive Line 2

Figure 1: Site Map
SMIP Station 23780

Figure 2 – HSRV Results: Representative HVSR curve from data obtained at a sampling frequency of 100 Hz and processed with a high pass filter at 0.1 Hz. The only qualifying clear peak is at a very low frequency and my not be truly representative of the site's fundamental frequency.
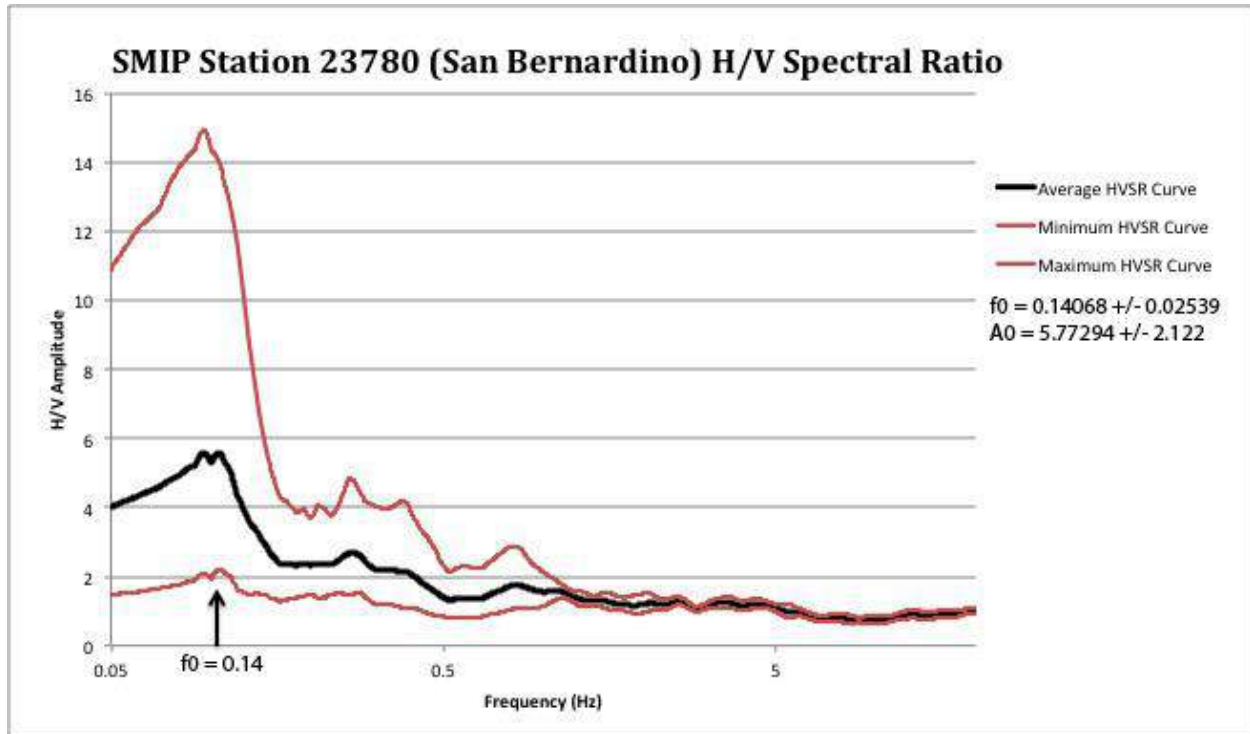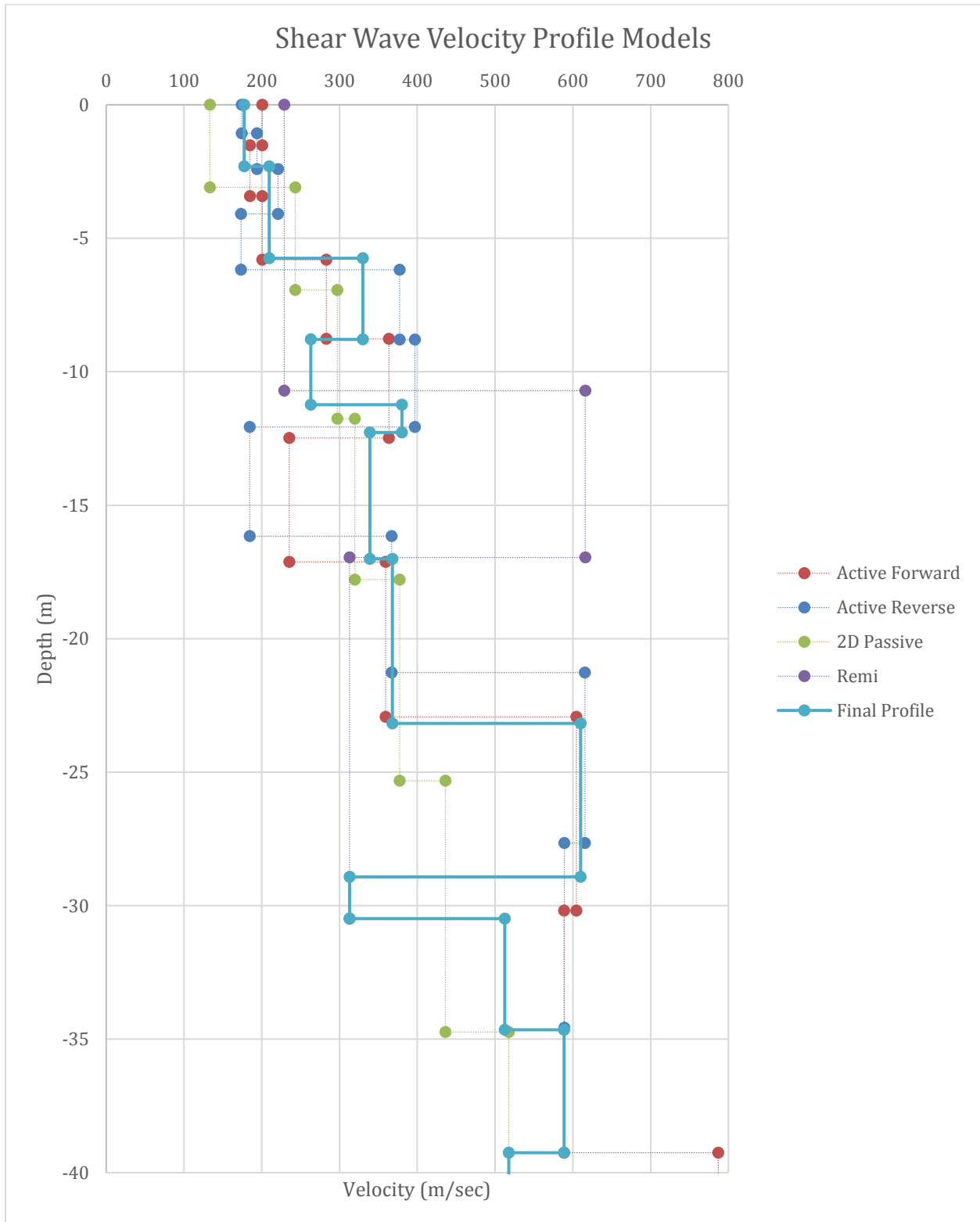

SMIP Station 23780 (San Bernardino) H/V Spectral Ratio

Figure 3 – Dispersion Curves: Final picked dispersion curve values for all methods.

Phase velocity (m/sec) vs. frequency (Hz)

Wavelength (m) vs. phase velocity (m/sec)

Figure 4 – Representative and Calculated Dispersion Curves: Representative and calculated/theoretical dispersion curves. The field data used in the creation of the representative curve is also shown.
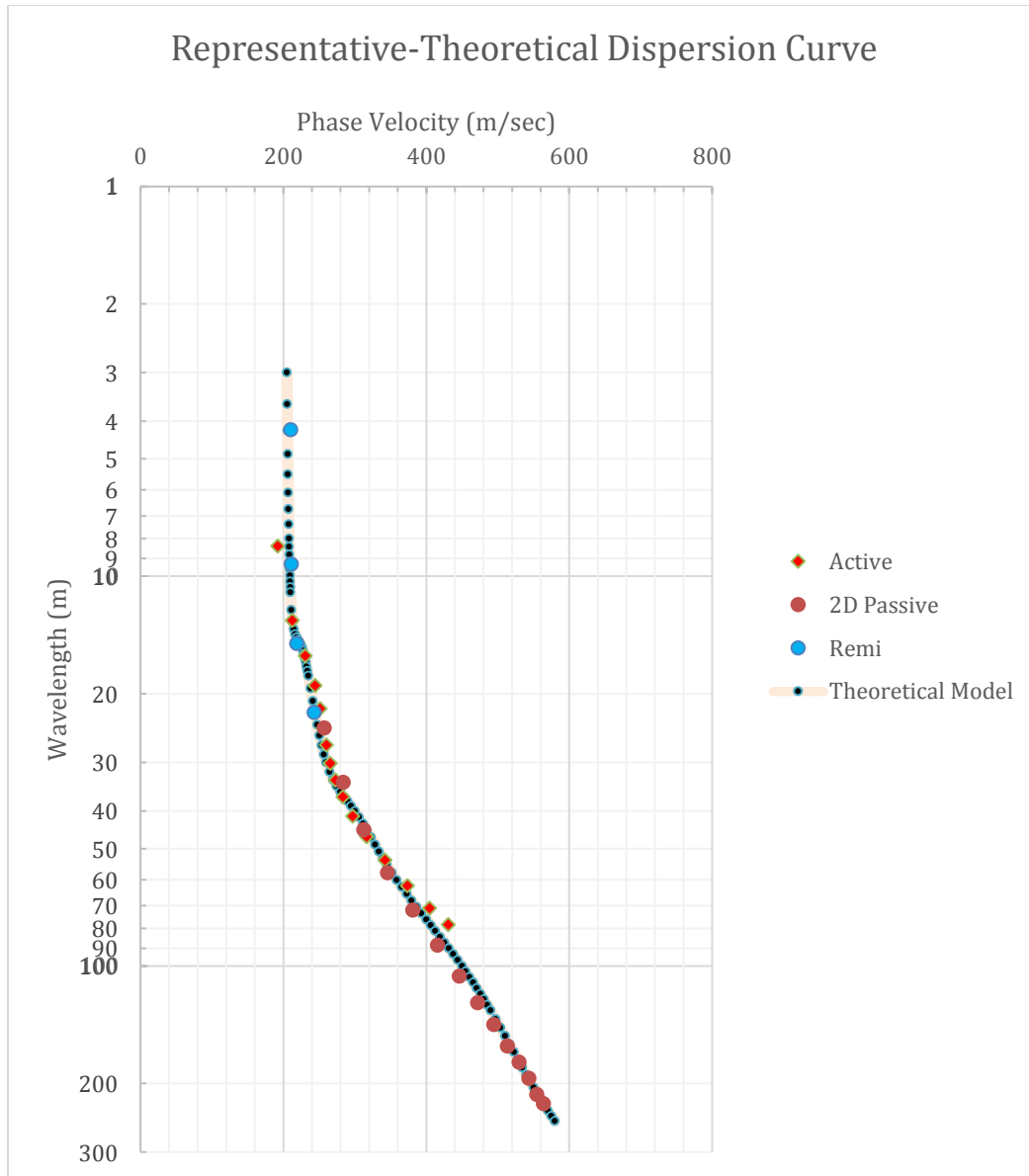
Figure 5 – Shear Wave Velocity Profile: Various profile models used to assess site and determine Vs30 and most likely layering scenario.

Tables:

Table 1: GPS Location Chart – Locations in latitude and longitude for MASW and 2D Passive lines – Shows location of start and end points.

Site 11 - 23780 San Bernardino -Mtn View & Cluster

Method	Start (DD) Lat.	Start (DD) Long.	End (DD) Lat.	End (DD) Long.
MASW	34.09696355500	-117.28732593300	34.09631904600	-117.28732427800
Line 1 2D Passive	34.09697343500	-117.28618501400	34.09698645800	-117.28732394500
Line 2 2D Passive	34.09698629200	-117.28732554600	34.09603977300	-117.28732976300
	(DD) Lat.	**(DD) Long.**	-	-
HVSR	34.09698100000	-117.28720100000	-	-

Site Photos
Site 11 - 23780 San Bernardino -Mtn View & Cluster

Figure 20 – View of MASW layout.

Figure 21 – Setup of 2D Passive on corner of site survey.

References

Bortugno, E.J. and Spittler, T.E., 1998, Geologic Map of the San Bernardino Quadrangle, California: State of California Division of Mines and Geology, Regional Map Series, San Bernardino Quadrangle, Map No. 3A, Scale 1:250,000.

City of San Bernardino, 2005, Safety Element: City of San Bernardino General Plan, http://www.sbcity.org/pdf/DevSvcs/General%20Plan%20Document.pdf.

Geopsy Software, 2017, SESAME European Research Project: Release 0.0.0-snapshot-20170109, geopsy.org.

KGS, 2017, Kansas Geological Survey, Surfseis Version 5.3.

Morton, D.M. and Bovard, K.R., 2003, Preliminary Geologic Map of the Fontana 7.5' Quadrangle, San Bernardino and Riverside Counties, California: U.S. Geological Survey in cooperation with California Geological Survey, Open-File Report 03-418, Scale 1:24,000.

Optim Software, 2017, SeisOpt - ReMi Refraction Microtremor Analysis.

SESAME European Research Project, 2004, Guidelines for the Implementation of the H/V Spectral Ratio Technique on Ambient Vibrations: European Commission – Research General Directorate, Project No. EVG1-CT-2000-00026 SESAME.

USGS, 2017, A Compilation of Vs30 Values in the United States, https://earthquake.usgs.gov/data/vs30/us/

Report on Site Characteristics for
SMIP Station

23542

Station Name: San Bernardino – E & Hospitality   **Station Number:** 23542

Location: State Comp. Inst. Fund Building Parking Lot
375 Hospitality Lane
San Bernardino, CA 92408

Latitude: 34.0656   **Longitude**: -117.2928

V$_{S30}$: 301 m/sec   **Estimated Error for V$_{S30}$: +/- 22 m/sec**

Site Geology:

The site lies on top of alluvial deposits from modern washes as well as slightly older Quaternary alluvium (Bortugno and Spittler, 1998). It is also located within a 500-year flood zone and adjacent to a 100-year flood zone, since the site is next to a modern wash. The site is also located on the boundary between an area of high liquefaction susceptibility and an area of moderate liquefaction susceptibility and just inside an area of potential subsidence due to the rather unconsolidated nature of the alluvium (City of San Bernardino, 2005). The San Jacinto Fault, an Alquist-Priolo Special Study Zone runs underneath the site area (City of San Bernardino, 2005).

Site Conditions:

The site is located in an urban environment at the intersection of two major interstates, I-10 and I-215, which will likely create a lot of ambient seismic noise. The site is on relatively flat topography.

Description of Geophysical Methods and Locations of Arrays:

HVSR, MASW, and 2D Passive field procedures were performed for the site. The location of the respective test methods are shown in Figure 1, and were field surveyed using a Trimble GeoExplorer 6000 capable of sub-meter accuracy. Subsequent differential GPS corrections were made to the location files using Trimble Pathfinder to increase the accuracy of the start and end points of survey lines. Survey lines were laid out using a 300-foot tape, and bearings were taken using a Brunton Compass. Any major elevation changes were determined in the field using a hand level and measuring rod. See Table 1 for detailed Latitudes and Longitudes.

HVSR readings were recorded after an equipment installation and warmup period of 20 minutes. Readings were taken using 500 Hz, 200 Hz, 100 Hz, and 1Hz sampling frequency settings. The total HVSR recording time for the site was roughly 2 hours in total length.

Equipment used included a Kinemetrics Q330 Digitizer in combination with a 120 sec to 160 Hz Metrozet MBB-2 triaxial broadband sensor (an effective equivalent to the Trillium-120). The sensor was buried in a small hole and covered with a thermal insulator and bucket to decrease surface noise interference and temperature variations.

The MASW line was placed along the same lineal path as one of the Passive 2D lines. Geophones were placed at 5 foot (1.524 meter) intervals, with a total line length of 235 feet (71.6 meters) using 48 channels/geophones (4.5 Hz). Off-end shots were performed at 100, 70, 40, and 10 feet (30.48, 21.34, 12.20, and 3.048 meter). Surveys were conducted in forward and reverse, with an additional shot taken at 1.5 feet (0.457 meters) on each end, and in the center of the array. The off-end shots were performed using a stack of 5 hits per record, with a 16-lb sledge-hammer. A single jack (4-lb hammer) was used at the 1.5 (0.457 meters) foot off-end shots to add a higher frequency noise content to the overall record. Recordings were triggered using a hammer switch and taken using a sampling rate of 1 milliseconds (ms) for a total time of 2 seconds (s).

The 2D Passive lines were arranged roughly perpendicular to each other. At each line geophones were placed at 15 foot (4.57 meter) intervals, with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 1, and at 15 foot (4.57 meter) intervals with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 2. Using this length of survey line we were able to achieve 40+ meter depth estimate. Between the two lines, a total of 48 channels were utilized for the 2D Passive survey. Recordings were triggered automatically and taken using a sampling rate of 2 ms for a total time of 30 seconds (30 records were taken in total). We did additional recording using a sampling rate of 1 ms for a total time of 15 seconds (30 records total as well). For both seismic line surveys two separate 24-Channel Geodes (by Geometrics) were combined and used for recording.

HVSR Data Processing and Results:

Ambient noise data was recorded as MiniSEED files and processed using Geopsy software's H/V toolbox to create a characteristic HVSR curve and determine the fundamental frequency of the site. Data was loaded into Geopsy with vertical and horizontal components and sampling frequencies (100 Hz, 200 Hz, and 500 Hz) specified. Data at these frequencies were analyzed separately. HVSR curves were calculated over the entire recording time, using window lengths at 150 and 200 s. The signals were first processed using a high-pass filter at 1 Hz. Time windows containing transients (nearby foot and vehicular traffic or industrial sources) or segments yielding poor quality results were excluded from the analysis. The time windows were picked automatically using an anti-triggering algorithm applied to avoid transients. Some windows were then manually removed because the signals appeared to contain notable transients within those windows that may have affected the results. For each time window, Fourier amplitude spectra were calculated and smoothed by the Konno and Ohmachi filter with a smoothing constant of 40. The HVSR was calculated for each time window and averaged to produce a characteristic HVSR curve. After calculating standard deviation of the HVSR amplitudes for all windows, the average HVSR curve is divided and

multiplied by the standard deviation to produce the minimum and maximum HVSR spectra (SESAME, 2004).

Both the filtered and unfiltered data exhibit a great deal of unclear low frequency peaks, mostly below 1 Hz. None of these peaks are sufficiently reliable or stable across different processing or smoothing parameters. The low frequency asymptote is also significantly greater than two, suggesting that they are indeed artefacts due to wind, traffic, or sensor malfunction. The close proximity of the site to two major interstate highways (within 300-400 meters) supports the fact that none of these low frequency peaks, even those that count as reliable, are not characteristic of the site conditions. Filtering the data at 1 Hz puts the most likely peak frequency at around **0.896** Hz (figure 2); however, while this frequency is reliable, it does not meet at least five out the six clear peak criteria. As such, this peak may in fact not be a truly representative estimate of the site's fundamental frequency. However, from the given data and resulting HVSR curves **f0 = 0.896** is the best estimate thus far of fundamental frequency for the site.

MASW Processing and Results:

Multichannel Analysis of Surface Waves (MASW) was performed using Surfseis Version 5.3 (KGS, 2017). The active method operation was chosen to evaluate the SEG-2 field files. A frequency overtone generator was used to develop a Phase Velocity-Frequency Image. Frequency ranges were allowed to span from 1 Hz to 50 Hz, with an allowed Phase Velocity window of 20 and 2,000 meters per second (m/sec). An automatic evaluation was performed which yielded a surface wave velocity range of 10 and 1000 m/sec, with a dominant frequency of surface waves of 11 Hz. The risk of contamination by higher modes was considered to be high, and the overall quality of input data was fair. The site had a significant amount of traffic that reduced overall quality of the data, as well as the nearby freeway.

From this process dispersion curves were generated for both forward and reverse geometries along the line using the 100, 70, 40, and 10 foot (30.48, 21.34, 12.20, and 3.048 meter) offsets. These individual dispersion curves were combined to create a single averaged curve for subsequent dispersion value (phase velocity vs. frequency) picking and extraction. Inversion was performed on the picked/extract values in order to create a layer model for comparison and integration with other methods to obtain a best fit shear-wave approximation for the site. The model was allowed to run through the inversion process for 10 iterations, with a final model that reached a total depth of 40+ meters. All data obtained from this processing was used to assist in developing an appropriate dispersion curve and a representative layer profile model, and for calculating the Vs30 for site class designation (Figures 3, 4, and 5).

2D Passive Processing and Results:

2-Dimensional (2D) Passive data was analyzed using Surfseis Version 5.3 (KGS, 2017). The passive-remote mode operation was chosen to evaluate incoming surface wave velocity and frequency because it allows for the use of multiple evaluation points versus pairs or singular values, thus reducing ambiguities related to dispersion curves (DC) that are based on only

one or two geophone recordings. Rather this method allows for all geophone signals to be incorporated into the DC and subsequent models. Individual geophone locations were converted to UTM coordinates and tabulated for use with the program. The geometry input file was then uploaded along with the 30 records for subsequent dispersion curve extraction. The files were preprocessed, and an automatic dispersion curve pick was achieved using similar settings as the active method described previously. Each pick was reviewed and modified prior to the extraction of a final dispersion curve. The final DC was then created from the combined records and analyzed for the extraction of the fundamental-mode. An inversion process was then run on the DC curve to create a shear wave velocity profile. In addition to this method, Refraction Microtremor modeling was performed using ReMi (SeisOpt, 2017). ReMi analysis was performed in order to add a comparative model to our results of 2D Passive and Active methods already discussed above.

Summary of Shear Wave Data and HVSR Processing:

Values obtained from the above methods were combined and plotted for averaging of the site's Vs30 and layered models. Initial Vs30 values ranged from between 301 m/sec to 336 m/sec depending on which model was used. The difference of these is low. Neighboring sites have values in the range of 250 m/sec (within 1.5 miles on flat similar terrain - USGS, 2017). Based on this a new Vs30 = 301 m/sec is reasonable. This value was subsequently reviewed and combined using a weighted averaging techniques to address none conformance of the models, and was combined to make a final layer profile.

In the 2D Passive/Active-MASW, the layering was deeper and determinable up to about 100 meters below ground surface. In general, ReMi tends to underestimate Vs30 for sites, due to its inability to distinguish fundamental modes from subsequent order energy modes. However, in this case Remi and 2D Passive methods better predicted the expected values based on geologic background review. Through understanding these differences and analytical review of the data, we developed the final average value for Vs30 = 301 m/sec. The estimated error for this is 7.3 %, or 22 m/sec. This error is moderate to low and is based on the likely variation in the sample mean from the population mean, which we have reviewed in some detail. This Vs30 gives the site a borderline Site Class D designation. However, in considering the nature of the liquefaction potential in the region, as well as the lower Vs30 values for neighboring sites, additional verification with by means of geotechnical drilling and exploration is warranted.

Taking this data into account and comparing against the HVSR data, we were able to calculate a depth to bedrock interface of 84 meters. The equation for this is f0 = Vs4z, where Vs is assumed to be Vs30 in meters, f0 is HVSR in Hz, and z is depth in meters. This depth seems to be reasonable for what would be considered a bedrock material at this location based on our geological review, and considering that there is a nearby mountain to the southwest that is within 1 mile of the site.

Legend

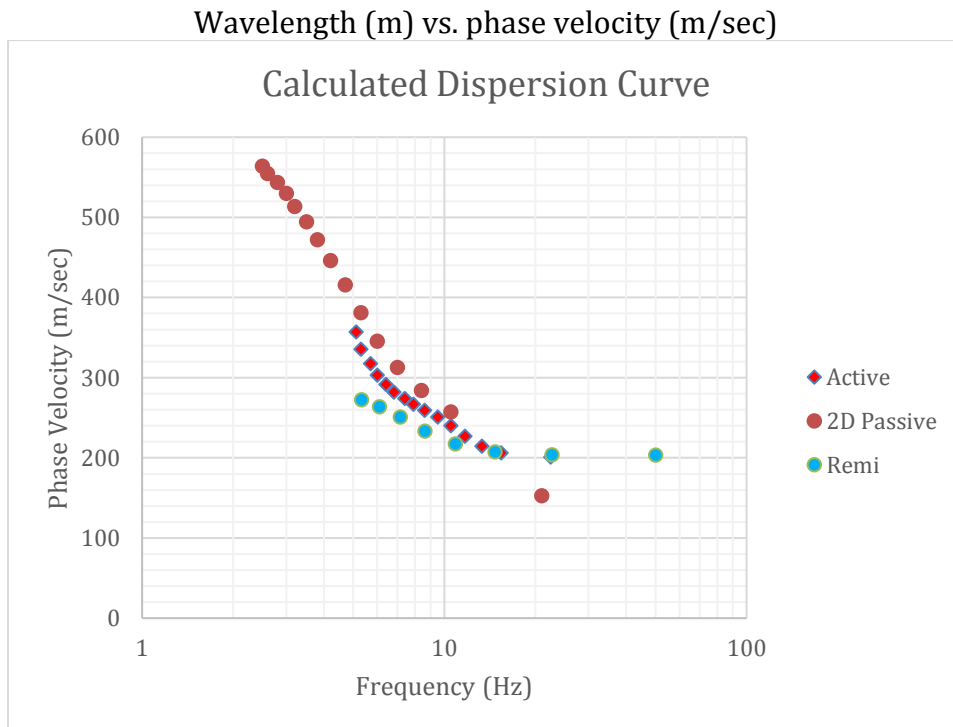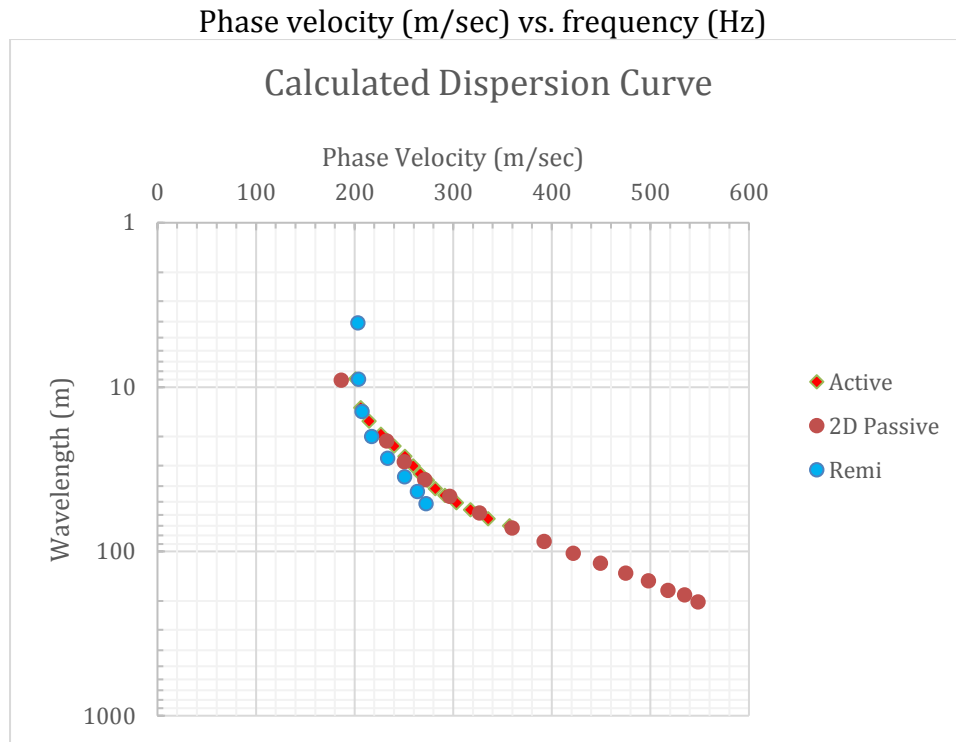|	
SMIP Station 23542	
Coordinate Grid	
HVSR Station	
MASW Array	
Passive Line 1	
Passive Line 2	

**Figure 1: Site Map
SMIP Station 23542**

Figure 2 – HVSR Results: Representative HVSR Curve from data obtained at a sampling frequency of 200 Hz and processed with a high pass filter at 1 Hz.
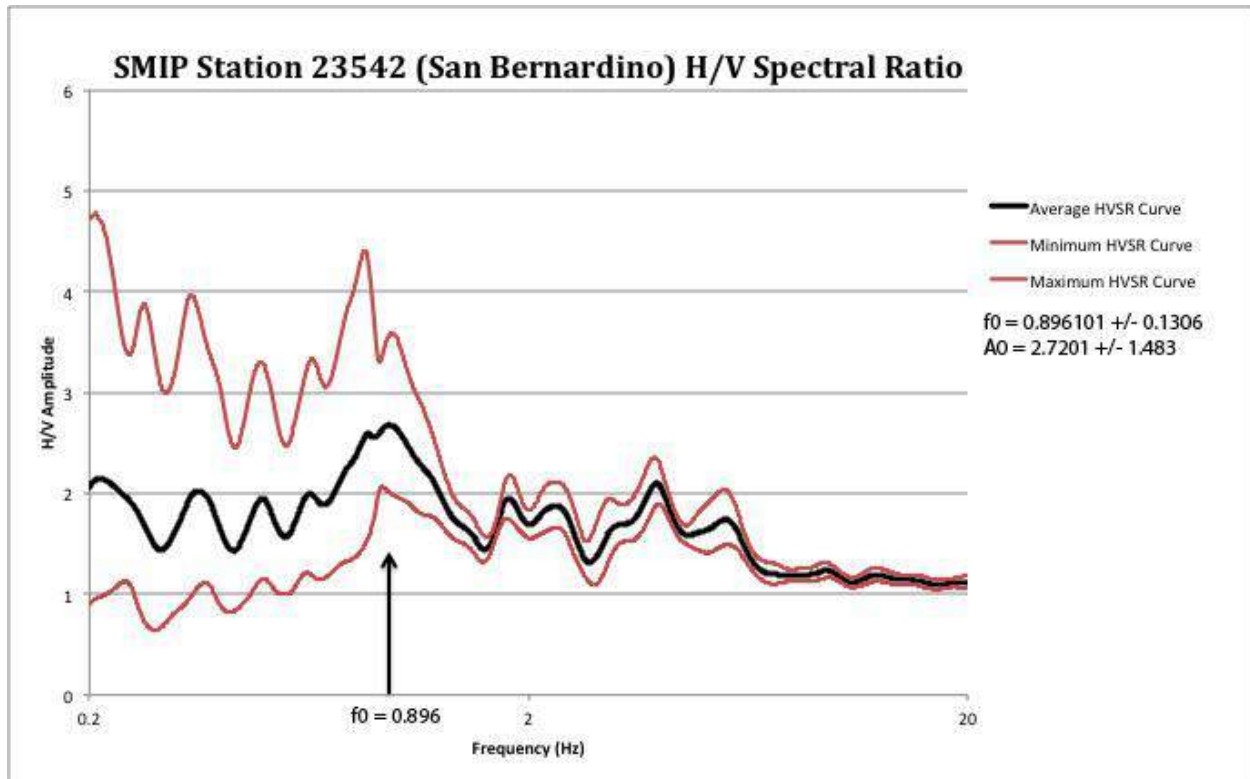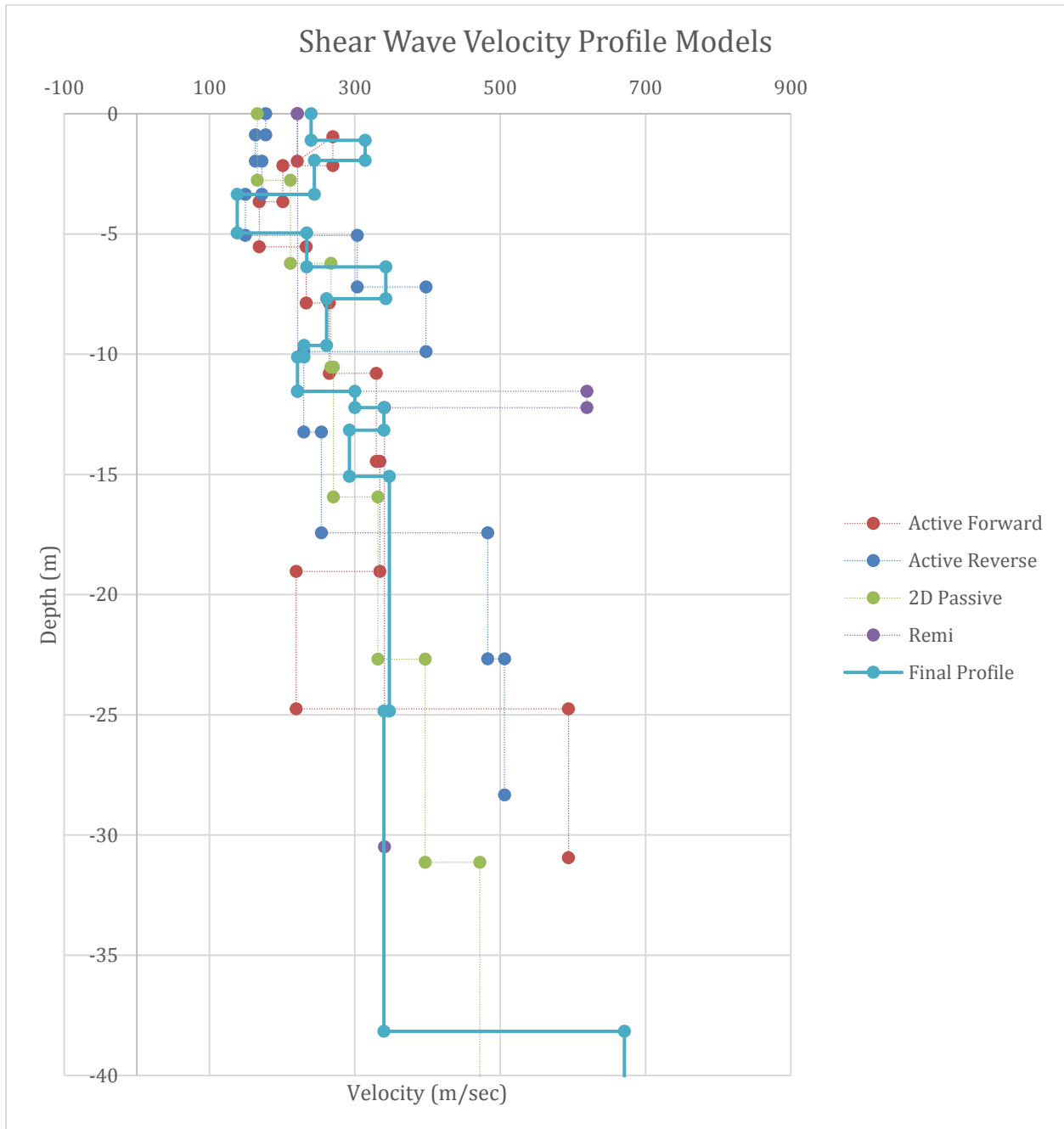
Figure 3 – Dispersion Curves: Final picked dispersion curve values for all methods.

Phase velocity (m/sec) vs. frequency (Hz)

Wavelength (m) vs. phase velocity (m/sec)

Figure 4 – Representative and Calculated Dispersion Curves: Representative and calculated/theoretical dispersion curves. The field data used in the creation of the representative curve is also shown.
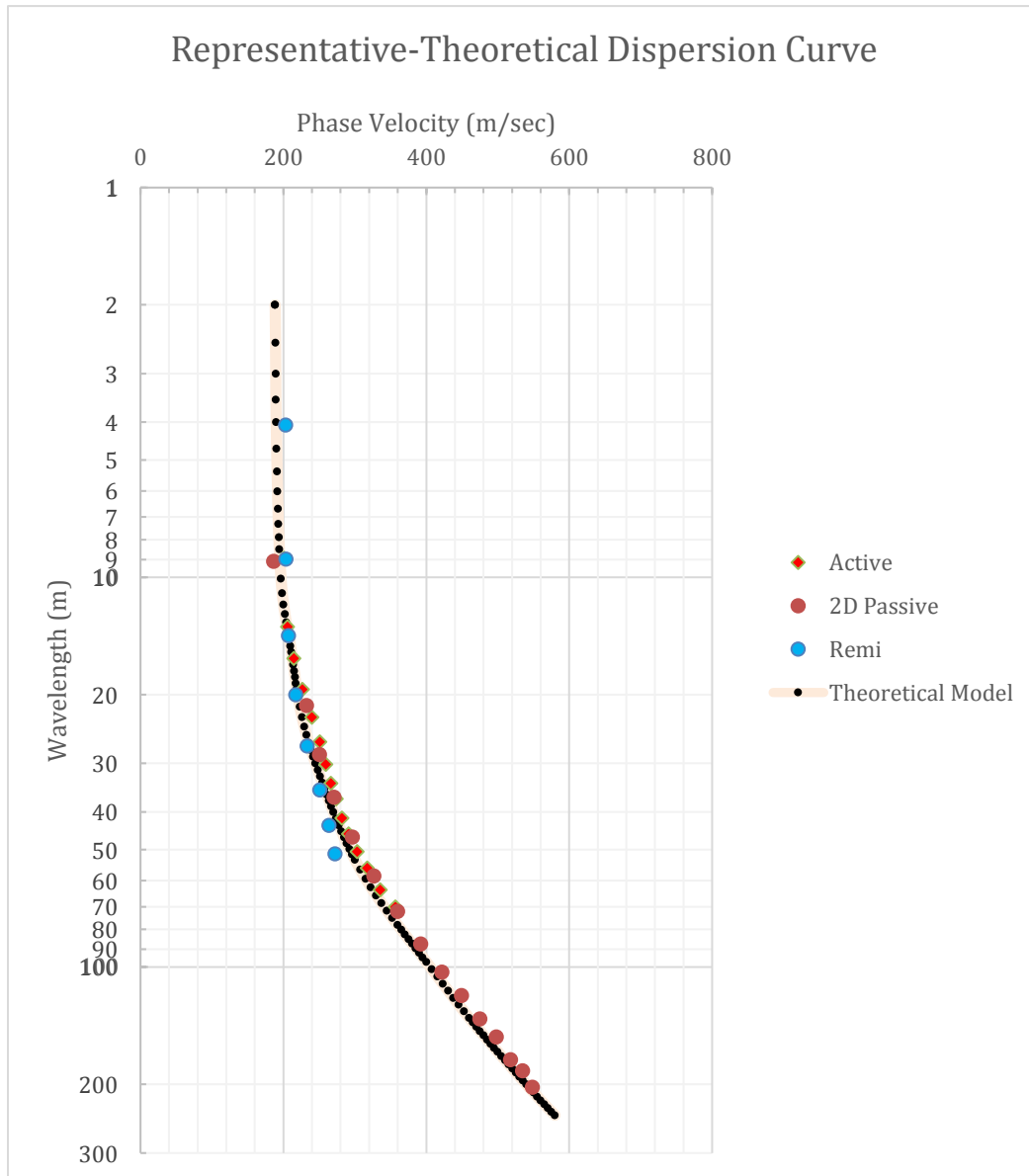
Figure 5 – Shear Wave Velocity Profile: Various profile models used to assess site and determine Vs30 and most likely layering scenario.

Tables:

Table 1: GPS Location Chart – Locations in latitude and longitude for MASW and 2D Passive lines – Shows location of start and end points.

Site 12 - 23542 San Bernardino E & Hospitality

Method	Start (DD) Lat.	Start (DD) Long.	End (DD) Lat.	End (DD) Long.
MASW	34.06541770200	-117.29297766000	34.06504420600	-117.29234603100
Line 1 2D Passive	34.06496881400	-117.29220606700	34.06554296600	-117.29312610400
Line 2 2D Passive	34.06567532600	-117.29315867700	34.06581624600	-117.29215705500
	(DD) Lat.	**(DD) Long.**	**-**	**-**
HVSR	34.065609	-117.293091	**-**	**-**

Site Photos
Site 12 - 23542 San Bernardino E & Hospitality

Figure 22 – View of equipment layout.

Figure 23 – View of MASW layout.

References

Bortugno, E.J. and Spittler, T.E., 1998, Geologic Map of the San Bernardino Quadrangle, California: State of California Division of Mines and Geology, Regional Map Series, San Bernardino Quadrangle, Map No. 3A, Scale 1:250,000.

City of San Bernardino, 2005, Safety Element: City of San Bernardino General Plan, http://www.sbcity.org/pdf/DevSvcs/General%20Plan%20Document.pdf.

Geopsy Software, 2017, SESAME European Research Project: Release 0.0.0-snapshot-20170109, geopsy.org.

KGS, 2017, Kansas Geological Survey, Surfseis Version 5.3.

Morton, D.M. and Bovard, K.R., 2003, Preliminary Geologic Map of the Fontana 7.5' Quadrangle, San Bernardino and Riverside Counties, California: U.S. Geological Survey in cooperation with California Geological Survey, Open-File Report 03-418, Scale 1:24,000.

Optim Software, 2017, SeisOpt - ReMi Refraction Microtremor Analysis.

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Report on Site Characteristics for
SMIP Station

22791

Station Name: Big Bear Lake – Fire Station   **Station Number:** 22791

Location: Big Bear Fire Department – Moonridge Station
          42610 Rathbun Drive
          Big Bear Lake, CA 92315

Latitude: 34.2411   **Longitude**: -116.8724
V_{S30}: **335 m/sec**   **Estimated Error for V_{S30}: +/- 55 m/sec**

Site Geology

The site is located south of Big Bear Lake in an area dominated by Miocene sedimentary rocks. These rocks include siltstone, fine to coarse-grained sandstone, pebbly sandstone, and some minor amount of greenish mudstone (Miller and Cossette, 2004). These deposits overlie basement rocks throughout most of the surrounding area and the Big Bear Valley groundwater basin, within which the site is located, and are usually well consolidated and range from thinly to thickly bedded (Flint and Martin, 2012).

Site Conditions

The site is located in a suburban, flat environment, though the surrounding area is quite mountainous. Specifically, the station is in a dirt lot next to Big Bear City Moonridge Fire Station in an area that does not appear to have much traffic.

Description of Geophysical Methods and Locations of Arrays:

HVSR, MASW, and 2D Passive field procedures were performed for the site. The location of the respective test methods are shown in Figure 1, and were field surveyed using a Trimble GeoExplorer 6000 capable of sub-meter accuracy. Subsequent differential GPS corrections were made to the location files using Trimble Pathfinder to increase the accuracy of the start and end points of survey lines. Survey lines were laid out using a 300-foot tape, and bearings were taken using a Brunton Compass. Any major elevation changes were determined in the field using a hand level and measuring rod. See Table 1 for detailed Latitudes and Longitudes.

HVSR readings were recorded after an equipment installation and warmup period of 20 minutes. Readings were taken using 500 Hz, 200 Hz, 100 Hz, and 1Hz sampling frequency settings. The total HVSR recording time for the site was roughly 2 hours in total length.

Equipment used included a Kinemetrics Q330 Digitizer in combination with a 120 sec to 160 Hz Metrozet MBB-2 triaxial broadband sensor (an effective equivalent to the Trillium-120). The sensor was buried in a small hole and covered with a thermal insulator and bucket to decrease surface noise interference and temperature variations.

The MASW line was placed along the same lineal path as one of the Passive 2D lines. Geophones were placed at 5 foot (1.524 meter) intervals, with a total line length of 235 feet (71.6 meters) using 48 channels/geophones (4.5 Hz). Off-end shots were performed at 100, 70, 40, and 10 feet (30.48, 21.34, 12.20, and 3.048 meter). Surveys were conducted in forward and reverse, with an additional shot taken at 1.5 feet (0.457 meters) on each end, and in the center of the array. The off-end shots were performed using a stack of 5 hits per record, with a 16-lb sledge-hammer. A single jack (4-lb hammer) was used at the 1.5 (0.457 meters) foot off-end shots to add a higher frequency noise content to the overall record. Recordings were triggered using a hammer switch and taken using a sampling rate of 1 milliseconds (ms) for a total time of 2 seconds (s).

The 2D Passive lines were arranged roughly perpendicular to each other. At each line geophones were placed at 15 foot (4.57 meter) intervals, with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 1, and at 15 foot (4.57 meter) intervals with a total line length of 345 feet (105.2 meters) using 24 channels/geophones (4.5 Hz) for line 2. Using this length of survey line we were able to achieve 40+ meter depth estimate. Between the two lines, a total of 48 channels were utilized for the 2D Passive survey. Recordings were triggered automatically and taken using a sampling rate of 2 ms for a total time of 30 seconds (30 records were taken in total). We did additional recording using a sampling rate of 1 ms for a total time of 15 seconds (30 records total as well). For both seismic line surveys two separate 24-Channel Geodes (by Geometrics) were combined and used for recording.

HVSR Data Processing and Results:

Ambient noise data was recorded as MiniSEED files and processed using Geopsy software's H/V toolbox to create a characteristic HVSR curve and determine the fundamental frequency of the site. Data was loaded into Geopsy with vertical and horizontal components and sampling frequencies (100 Hz, 200 Hz, and 500 Hz) specified. Data at these frequencies were processed separately. HVSR curves were calculated over the entire recording time, using a window lengths of 50 s. The signals were first processed using a high-pass filter at 0.2 Hz in order to decrease scattered low frequency noise. Time windows containing transients (nearby foot and vehicular traffic or industrial sources) or segments yielding poor quality results were excluded from the analysis. The time windows were picked automatically using an anti-triggering algorithm applied to avoid transients. Some windows were then manually removed because the signals appeared to contain notable transients within those windows that may have affected the results. For each time window, Fourier amplitude spectra were calculated and smoothed by the Konno and Ohmachi filter with a smoothing constant of 40. The HVSR was calculated for each time window and averaged to produce a characteristic HVSR curve. After calculating standard deviation of the HVSR amplitudes for all windows,

the average HVSR curve is divided and multiplied by the standard deviation to produce the minimum and maximum HVSR spectra (SESAME, 2004).

Each of the HVSR curves exhibited two peaks (Figure 2). The only peak to meet the minimum reliability criteria occurred at an average frequency of 0.54 Hz. This peak does have an amplitude greater than 10, but these higher amplitudes occur over a short enough frequency range that the peak is still considered valid. Moreover, this peak met at least five out of the six clarity criteria for a clear peak. The lower peak frequency at f1 = 0.2 fails to meet all of the reliability criteria. However, the peak appears to be relatively stable with different processing parameters since proportional and decreased smoothing do not remove the peak. Such unclear low frequency peaks may sometimes be an artefact of the site geology, given thick stiff sedimentary deposits. Given the site geology of thickly bedded well-consolidated sandstones, this peak may in fact be a site characteristic. However, the sharp increase in amplitude as frequency approaches zero suggests that wind or a bad soil-sensor coupling may have influenced the data, and the peak does appear to narrow with less smoothing, suggesting a possible industrial origin. This, combined with the fact that the lower frequency peak does not meet the reliability criteria, means that 0.54 Hz is the best estimate for the fundamental frequency of the site.

MASW Processing and Results:

Multichannel Analysis of Surface Waves (MASW) was performed using Surfseis Version 5.3 (KGS, 2017). The active method operation was chosen to evaluate the SEG-2 field files. A frequency overtone generator was used to develop a Phase Velocity-Frequency Image. Frequency ranges were allowed to span from 1 Hz to 50 Hz, with an allowed Phase Velocity window of 20 and 2,000 meters per second (m/sec). An automatic evaluation was performed which yielded a surface wave velocity range of 10 and 500 m/sec, with a dominant frequency of surface waves of 5 Hz. The risk of contamination by higher modes was considered to be low, and the overall quality of input data was excellent. The site had a significant amount of traffic that reduced overall quality of the data, as well as the nearby freeway.

From this process dispersion curves were generated for both forward and reverse geometries along the line using the 100, 70, 40, and 10 foot (30.48, 21.34, 12.20, and 3.048 meter) offsets. These individual dispersion curves were combined to create a single averaged curve for subsequent dispersion value (phase velocity vs. frequency) picking and extraction. Inversion was performed on the picked/extract values in order to create a layer model for comparison and integration with other methods to obtain a best fit shear-wave approximation for the site. The model was allowed to run through the inversion process for 10 iterations, with a final model that reached a total depth of 40+ meters. All data obtained from this processing was used to assist in developing an appropriate dispersion curve and a representative layer profile model, and for calculating the Vs30 for site class designation (Figures 3, 4, and 5).

2D Passive Processing and Results:

2-Dimensional (2D) Passive data was analyzed using Surfseis Version 5.3 (KGS, 2017). The passive-remote mode operation was chosen to evaluate incoming surface wave velocity and frequency because it allows for the use of multiple evaluation points versus pairs or singular values, thus reducing ambiguities related to dispersion curves (DC) that are based on only one or two geophone recordings. Rather this method allows for all geophone signals to be incorporated into the DC and subsequent models. Individual geophone locations were converted to UTM coordinates and tabulated for use with the program. The geometry input file was then uploaded along with the 30 records for subsequent dispersion curve extraction. The files were preprocessed, and an automatic dispersion curve pick was achieved using similar settings as the active method described previously. Each pick was reviewed and modified prior to the extraction of a final dispersion curve. The final DC was then created from the combined records and analyzed for the extraction of the fundamental-mode. An inversion process was then run on the DC curve to create a shear wave velocity profile. In addition to this method, Refraction Microtremor modeling was performed using ReMi (SeisOpt, 2017). ReMi analysis was performed in order to add a comparative model to our results of 2D Passive and Active methods already discussed above.

Summary of Shear Wave Data and HVSR Processing:

Values obtained from the above methods were combined and plotted for averaging of the site's Vs30 and layered models. Initial Vs30 values ranged from between 249 m/sec to 535 m/sec depending on which model was used. The difference of these is high. There are no neighboring sites which have values to compare against. Across the valley there is one site with a Vs30 = 356 m/sec (within 4 miles on flat similar terrain - USGS, 2017). Based on this a new Vs30 = 335 m/sec is reasonable. This value was subsequently reviewed and combined using a weighted averaging techniques to address none conformance of the models, and was combined to make a final layer profile.

In the 2D Passive/Active-MASW, the layering was deeper and determinable up to about 100 meters below ground surface. In general, ReMi tends to underestimate Vs30 for sites, due to its inability to distinguish fundamental modes from subsequent order energy modes. However, in this case Remi and 2D Passive methods better predicted the expected values based on geologic background review. Through understanding these differences and analytical review of the data, we developed the final average value for Vs30 = 335 m/sec. The estimated error for this is 16.5 %, or 55 m/sec. This error is moderate and is based on the likely variation in the sample mean from the population mean, which we have reviewed in some detail. This Vs30 gives the site a Site Class D designation.

Taking this data into account and comparing against the HVSR data, we were able to calculate a depth to bedrock interface of 155 meters. The equation for this is f0 = Vs4z, where Vs is assumed to be Vs30 in meters, f0 is HVSR in Hz, and z is depth in meters. This depth seems to be somewhat high for what would be considered a bedrock material at this location based on our geological review. However, we do not have local depth to bedrock data to compare against, and the site is within a drainage basin, so alluvial infill in this spot could amount to this depth to bedrock potentially.
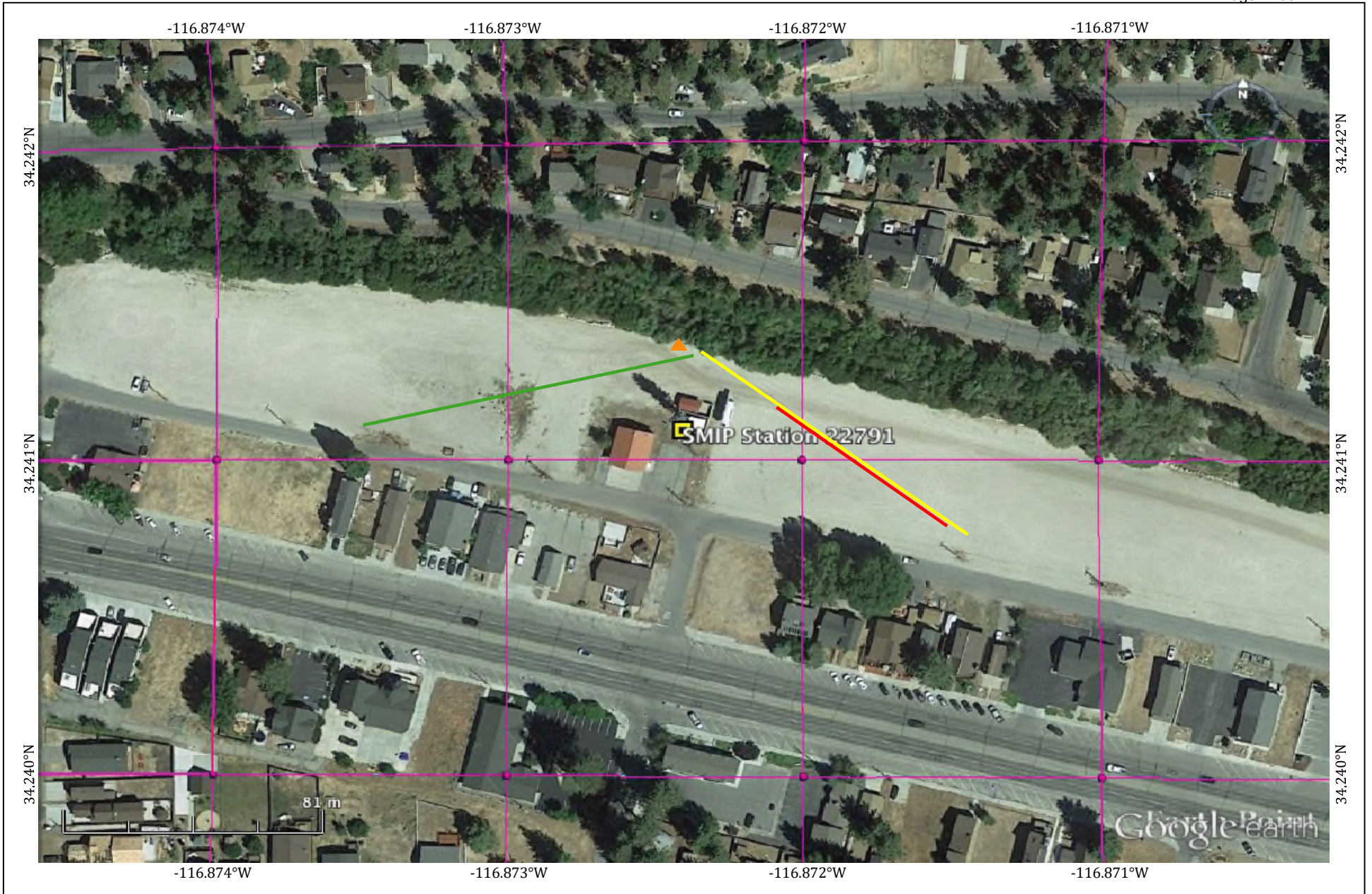
Figure 1: Site Map
SMIP Station 22791

Image Source: Google Earth and Earth Point

Legend

SMIP Station 22791
Coordinate Grid
HVSR Station
MASW Array
Passive Line 1
Passive Line 2

Figure 2 – HSRV Results: Representative HVSR Curve from data obtained at 200 Hz and processed with a high pass filter at 0.2 Hz, depicting both the fundamental frequency and a secondary low frequency peak.
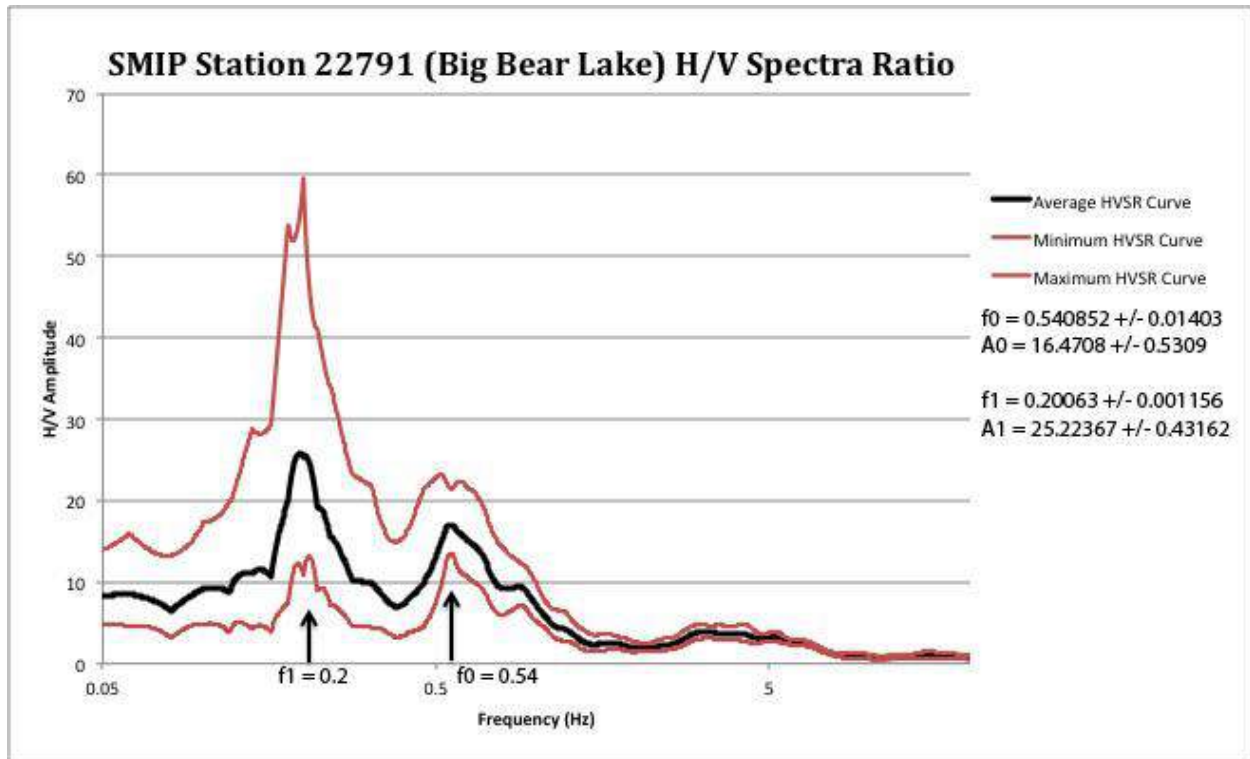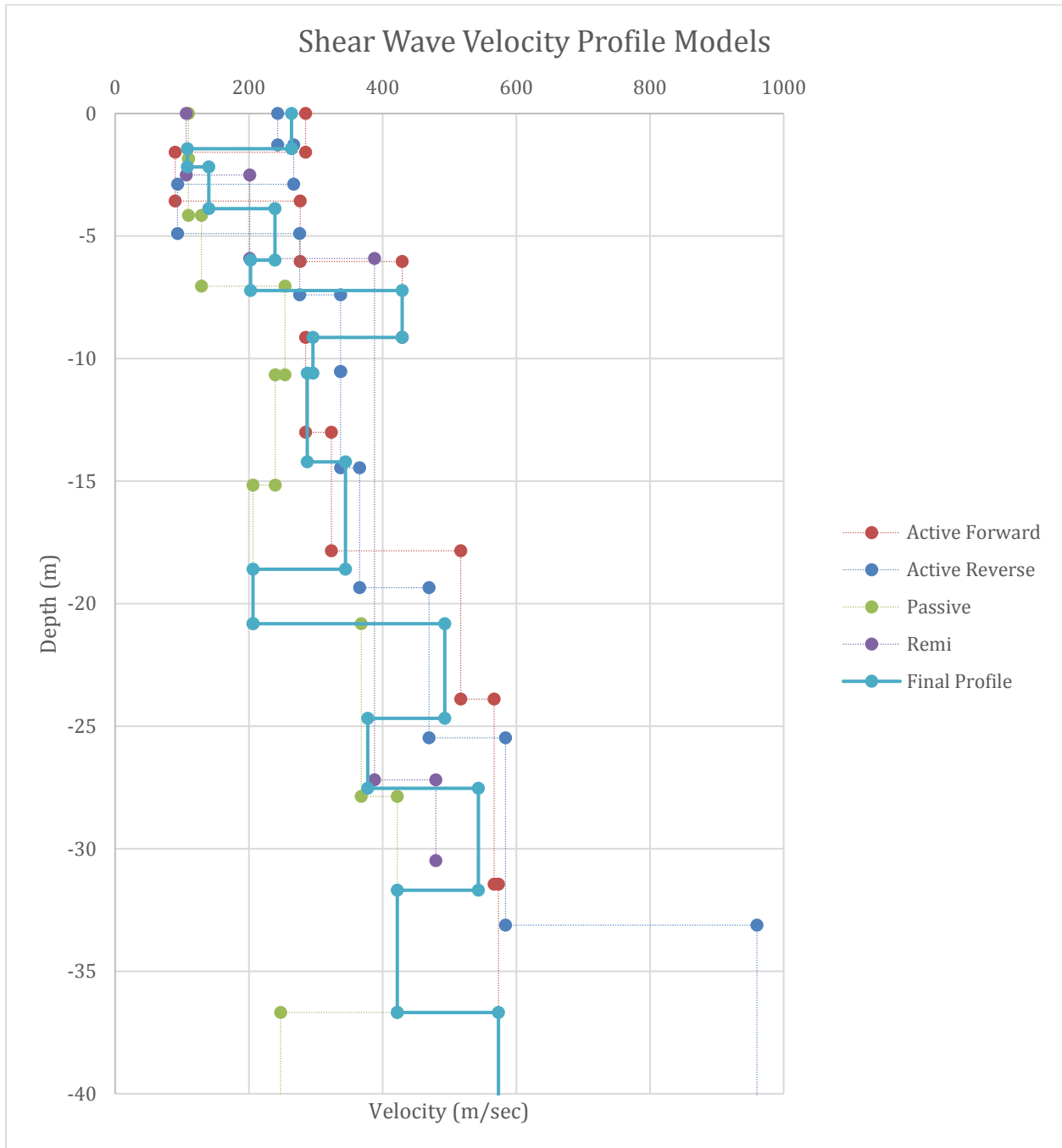
Figure 3 – Dispersion Curves: Final picked dispersion curve values for all methods.
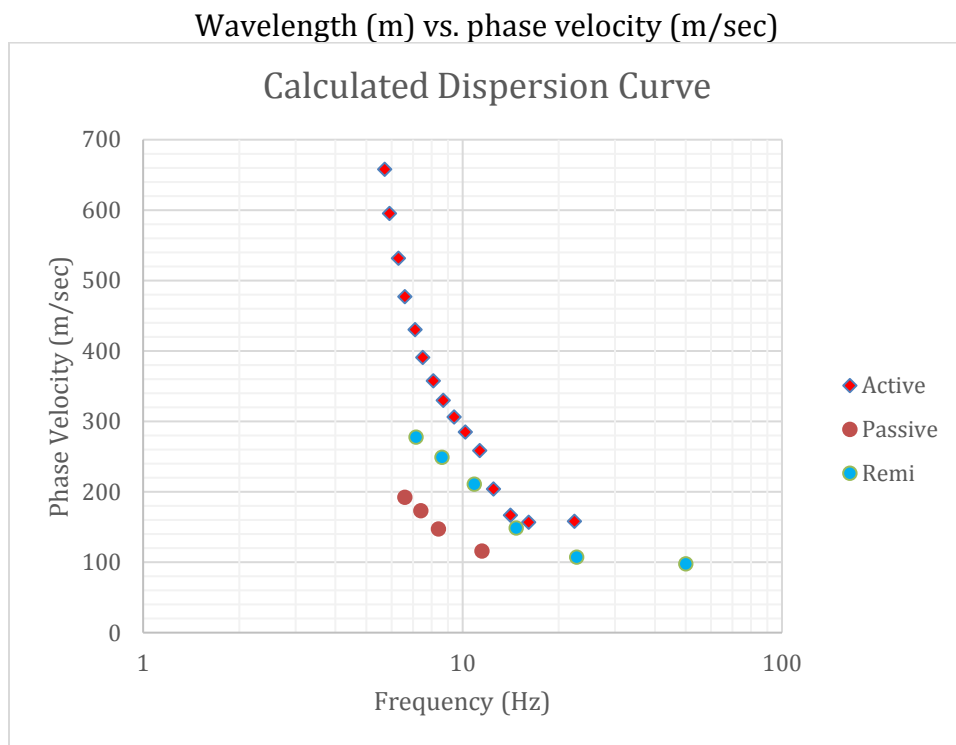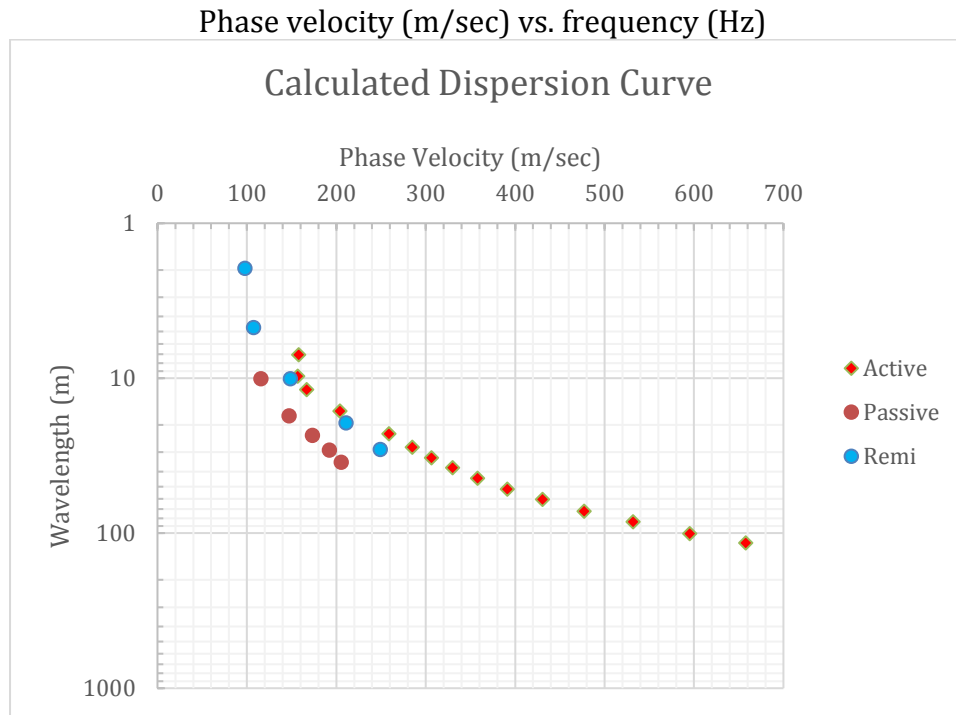
Phase velocity (m/sec) vs. frequency (Hz)

Wavelength (m) vs. phase velocity (m/sec)

Figure 4 – Representative and Calculated Dispersion Curves: Representative and calculated/theoretical dispersion curves. The field data used in the creation of the representative curve is also shown.
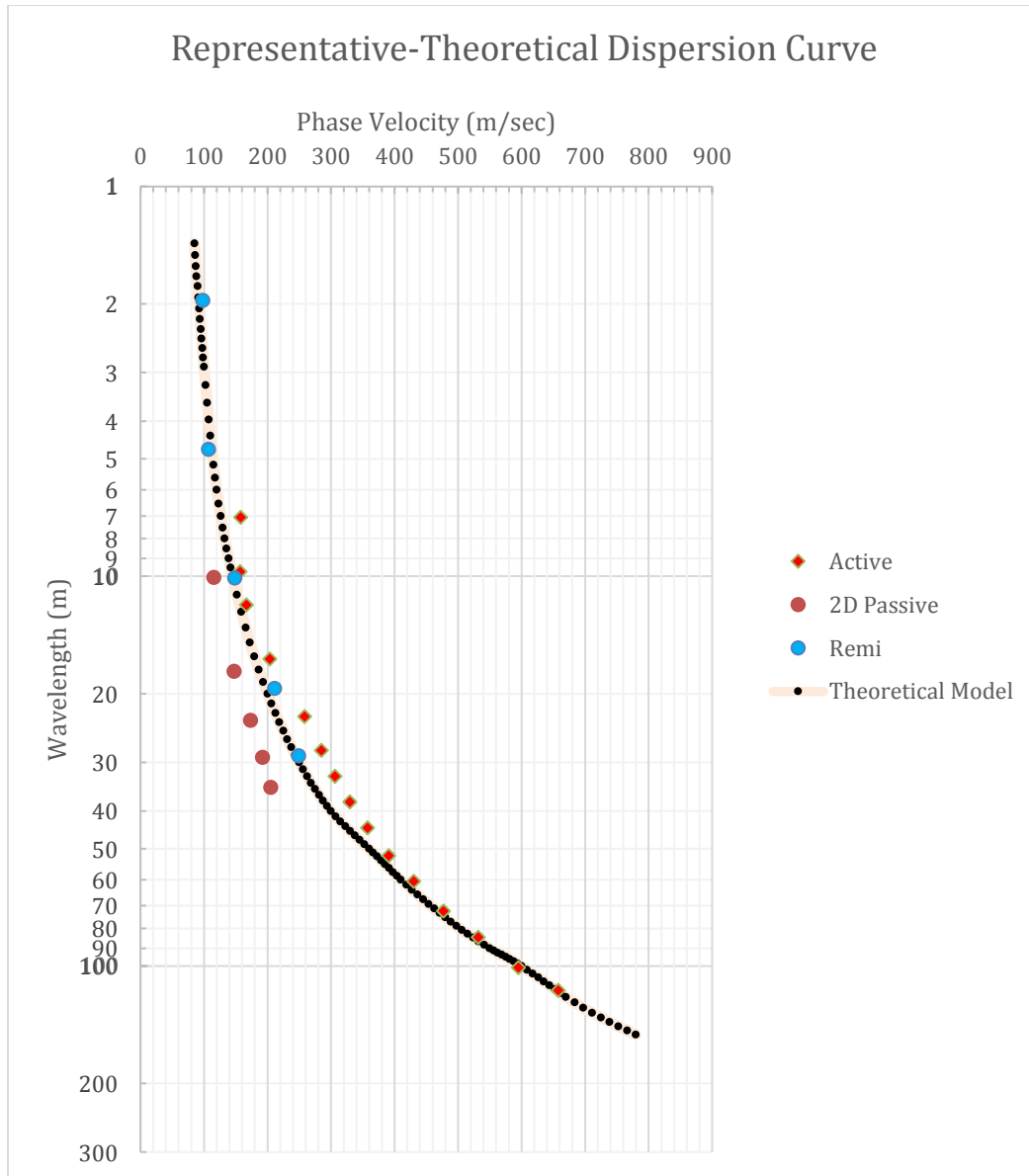
Figure 5 – Shear Wave Velocity Profile: Various profile models used to assess site and determine Vs30 and most likely layering scenario.

Tables:

Table 1: GPS Location Chart – Locations in latitude and longitude for MASW and 2D Passive lines – Shows location of start and end points.

Site 13 - 22791 Big Bear Lake - Fire Station

Method	Start (DD) Lat.	Start (DD) Long.	End (DD) Lat.	End (DD) Long.
MASW	34.24117782700	-116.87208212000	34.24079097400	-116.87145855200
Line 1 2D Passive	34.24112485500	-116.87345838500	34.24134180200	-116.87234902700
Line 2 2D Passive	34.24077811500	-116.87142971600	34.24134234000	-116.87234624700
	(DD) Lat.	(DD) Long.	-	-
HVSR	34.241363	-116.872406	-	-

Site Photos
Site 13 - 22791 Big Bear Lake - Fire Station

Figure 24 – View of 2D Passive layout.

Figure 25 – View of MASW layout.

References

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