Stan Yeh - Re: San Gabriel - Geotech Report

From:
To: "Stan Yeh"
Date: 8/15/2007 3:57 PM
Subject: Re: San Gabriel - Geotech Report
CC: , ,
Attachments: , ,

Stan:

These are the geotechnical reports:

- Dames & Moore, May 1, 1951, Report of Foundation Investigation, Proposed Etiwanda Steam Station
- Dames & Moore, May 18, 1951, Report of Testing of Compacted Fill, Proposed Etiwanda Steam Station
- URS, April 12, 2005, Summary Report of Geophysical Utility Survey and Surface Wave Investigation, Etiwanda Steam Station

The first 2 are attached to this email. The 2005 report will be sent in 3 emails (since it has color photos and is a big file)

Regards,

Anne
(See attached file: 0032 Report of Foundation Investigation.pdf)(See attached file: 0033 Report of Compacted Fill.pdf)

"Stan Yeh" <Syeh@energy.state.ca.us>

"Stan Yeh"
<Syeh@energy.state.ca.us>
08/15/2007 10:23 AM

To<Anne_Connell@URSCorp.com[redacted]
cc
SubjectSan Gabriel - Geotech Report

Anne,

In Appendix A, under section 3.1.1, you mention a geotechnical investigation. Can you please provide me with this report.

Thanks,
Stan

URS

April 12, 2005

Mr. Dan Kocunik
SARGENT & LUNDY, LLC.
55 East Monroe St.
Chicago, Illinois 60603-5780

Subject: ***Summary Report of Geophysical Utility Survey and Surface Wave Investigation***
Etiwanda Steam Station
Rancho Cucamonga, California
for Sargent & Lundy LLC

Dear Mr. Kocunik:

The URS Corporation (URS) is pleased to present this Summary Report, documenting field activities associated with the Geophysical Utility Survey and Surface Wave Investigation conducted at Etiwanda Steam Station, Rancho Cucamonga, California (Project Site).

Geophysical Utility Survey

On March 23, 2005, prior to survey activities, Reliant Energy Representatives Glenn Whritenour and Tim Burnette, conducted a site walk with URS and Geovision personnel to identify the seven proposed borehole locations. During the site walk Reliant representatives provided as-built utility maps to aid in the identification of underground utility/service lines. At each location a temporary borehole location was marked on the ground based on the exclusive use of as-built utility maps. At the completion of the site walk, Geovision conducted a geophysical survey using four types of ground penetrating radar (GPR) to locate any unidentified utility/service lines within a 15-foot perimeter around the seven temporary borehole locations. Appendix A is the Geophysical Survey Maps created by Geovision during the survey. Final borehole locations were adjusted to accommodate a minimum 5-feet perimeter clearance of any identified utility/service line. Borehole #6 was the only location that required a significant adjustment. The original location was within a major utility service corridor thus the location for borehole #6 was moved approximately 40 ft west of the originally proposed location. Appendix B is a boring location map identifying the final seven cleared boring locations.

Final boring locations were marked using green and orange spray paint on asphalt surfaces and on gravel surfaces the use of green feathered nails was used. Appendix C is a photo-log showing the vicinity and markers for each borehole location.

Surface Wave Measurements

During the same period of time, Geovision also conducted surface wave investigation to be used for UBC site classification. Active and passive surface wave techniques were utilized during the investigation. Active surface wave techniques included Spectral Analysis of Surface waves (SASW) and Multi-Channel Analysis of Surface Waves (MASW). Passive surface wave techniques included array and refraction micro-tremor methods. Appendix D is the Final Report and Conclusions provided by Geovision of the Surface Wave Measurement Investigation.

We appreciate this opportunity to be of continued service to Sargent & Lundy, LLC. We trust this report meets your needs. If you should have any questions concerning this report, please contact the undersigned at (909) 980-4000.

Very truly yours,
URS CORPORATION

Cynthia Gabaldon P.E.
Senior Engineer

Jose De Loera
Staff Geologist

APPENDICES

Appendix A Geophysical Survey Maps

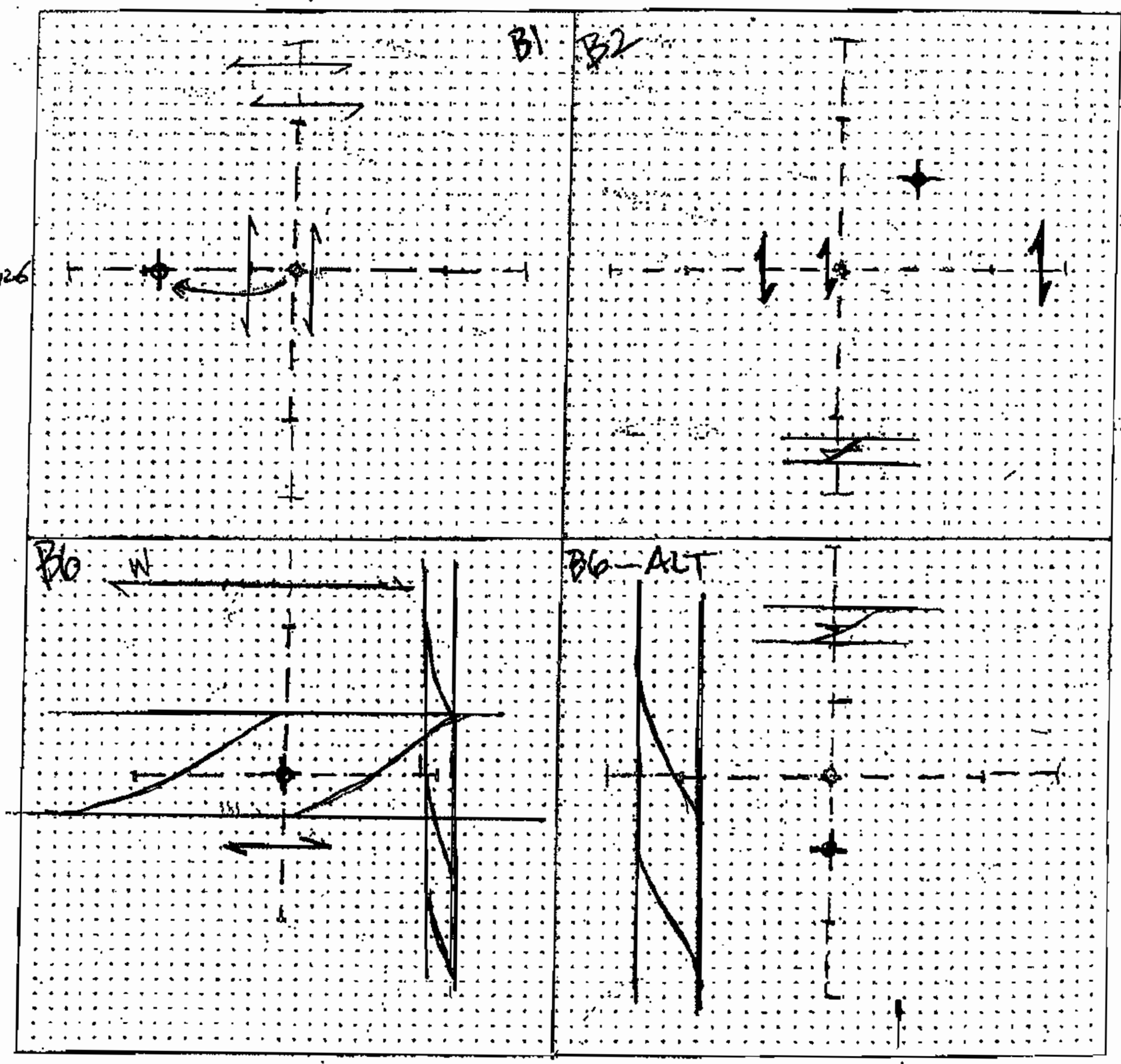
Appendix B Boring Location Map

Appendix C Photographs

Appendix D Surface Wave Measurements Report

APPENDIX A

GEOPHYSICAL SURVEY MAP



LEGEND

GEOPHYSICAL TRAVERSE

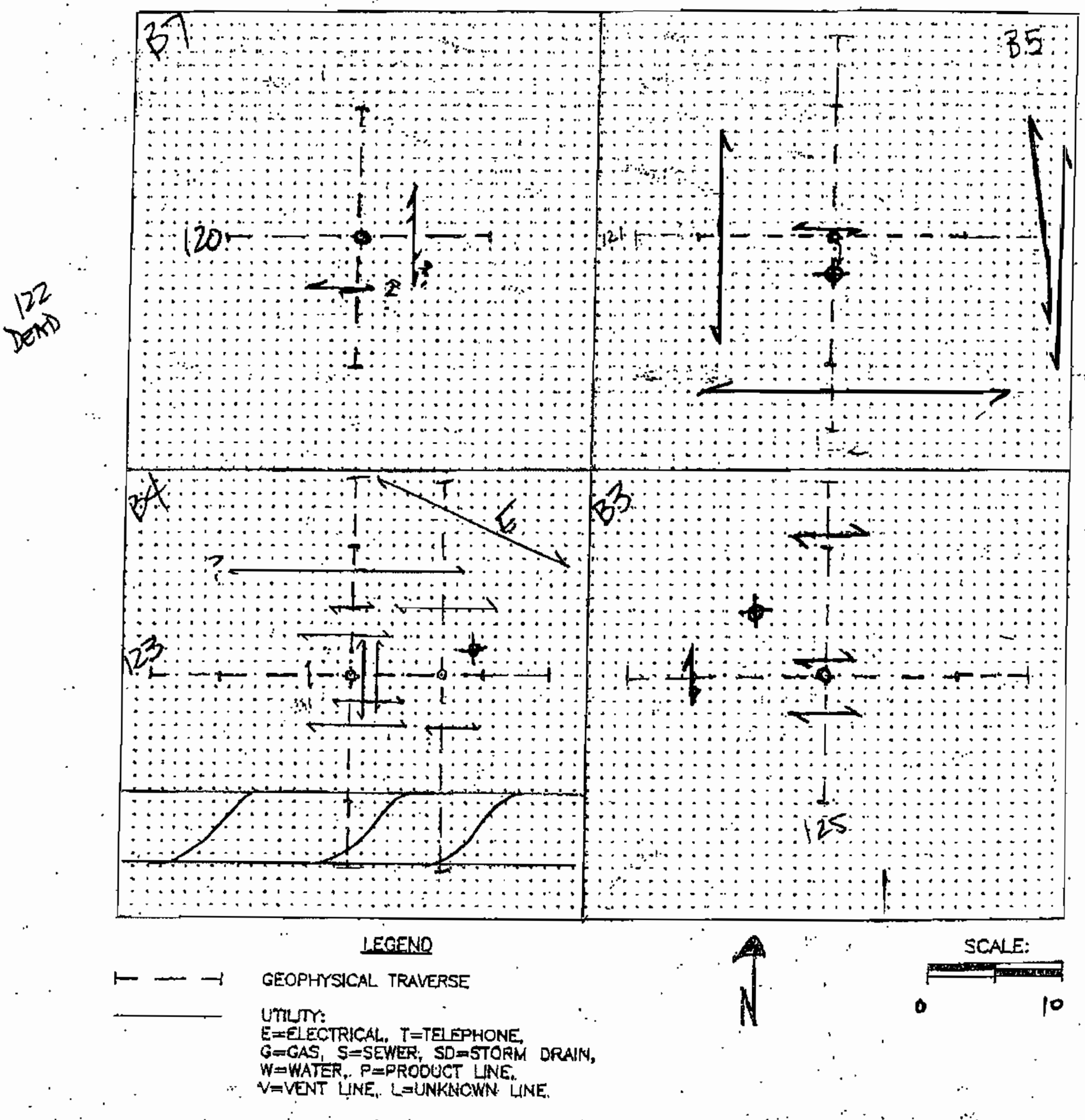
UTILITY:
E=ELECTRICAL, T=TELEPHONE,
G=GAS, S=SEWER, SD=STORM DRAIN,
W=WATER, P=PRODUCT LINE,
V=VENT LINE, L=UNKNOWN LINE

N

SCALE:
0 10

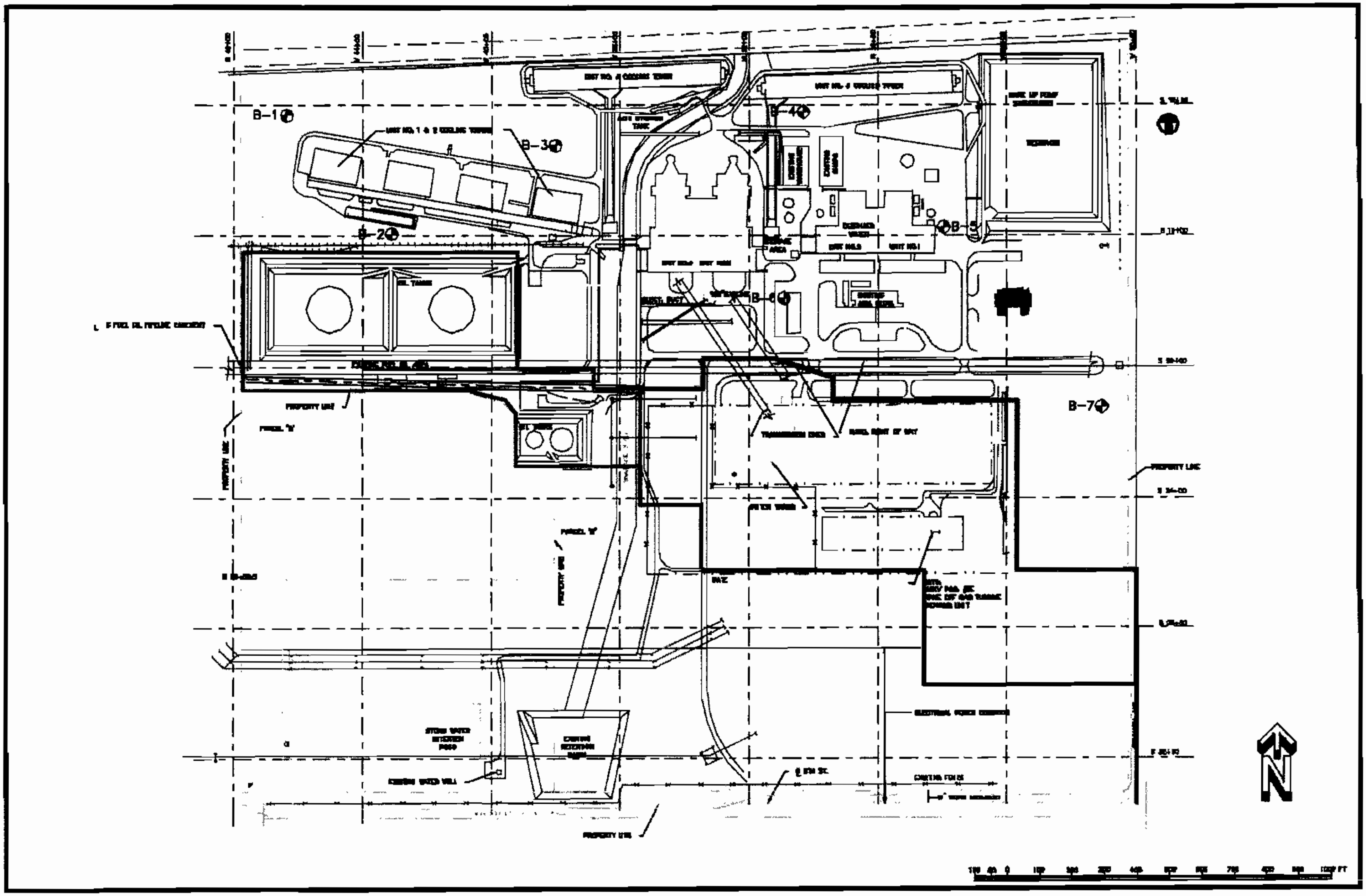
NOTE: All geophysical methods have limitations dependent on instrumentation used, soil conditions, and local cultural noise and other interference. The geophysical conditions interpretation presented above comprises a declaration of the geophysicist's professional judgment using methods and a degree of care and skill ordinarily exercised, under similar circumstances, by reputable members of their profession practicing in the same or similar locality. It does not constitute a warranty or guarantee, expressed or implied, nor does it relieve any other party of its responsibility to abide by contract documents, applicable codes, standards, regulations or ordinances. If you require further information about the limitations of the instruments and/or methods used on this project please contact GEOVision Geophysical Services.

GEOPHYSICAL SURVEY MAP



NOTE: All geophysical methods have limitations dependent on instrumentation used, soil conditions, and local cultural noise and other interference. The geophysical conditions interpretation presented above comprises a declaration of the geophysicist's professional judgment using methods and a degree of care and skill ordinarily exercised, under similar circumstances, by reputable members of their profession, practicing in the same or similar locality. It does not constitute a warranty or guarantee, expressed or implied, nor does it relieve any other party of its responsibility to abide by contract documents, applicable codes, standards, regulations or ordinances. If you require further information about the limitations of the instruments and/or methods used on this project please contact GEOVision Geophysical Services.

APPENDIX B



BORING LOCATION MAP

URS

SARGENT & LUNDY, LLC.

ETIWANDA STEAM STATION

RANCHO CUCAMONGA, CALIFORNIA

FIGURE 1

URS Project No. 38000866

MARCH 24, 2005

APPENDIX C

URS

PHOTOGRAPHIC LOG

Sargent & Lundy, LLC.	Etiwanda Steam Station Geophysical Survey	URS Project No. 38000866

Photo No.	Date:
1	3/23/2005

Direction Photo Taken:

Description:

Borehole #1 Vicinity

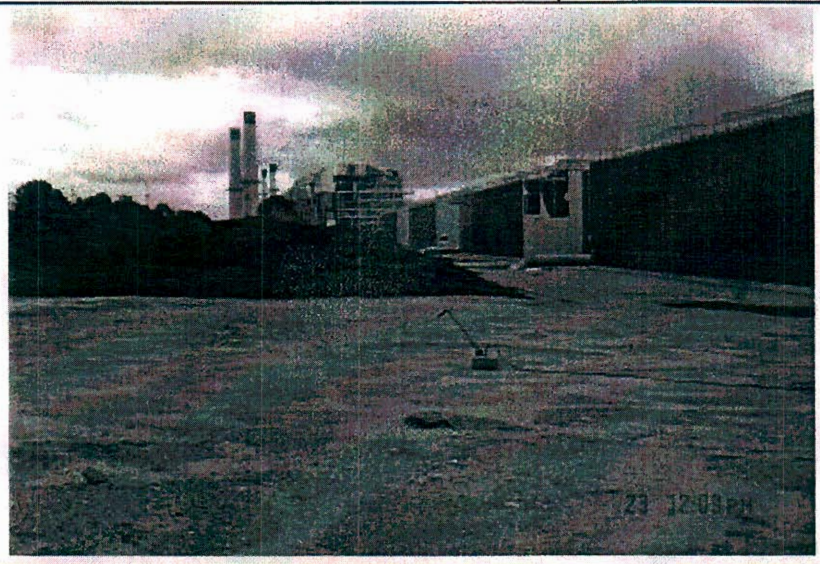


Photo No.	Date:
2	3/23/2005

Direction Photo Taken:

Description:

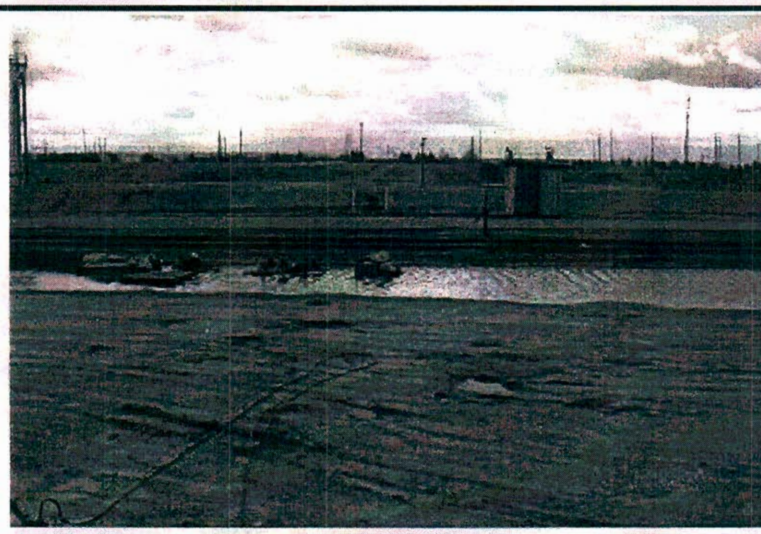
Borehole #1 Marker

Photo No.	Date:
3	3/23/2005

Direction Photo Taken:

Description:

Borehole #2 Vicinity



URS	PHOTOGRAPHIC LOG	
Sargent & Lundy, LLC.	Etiwanda Steam Station Geophysical Survey	**URS Project No.** 38000866

Photo No.	**Date:**
4	3/23/2005

Direction Photo Taken:

Description:

Borehole #2 Marker

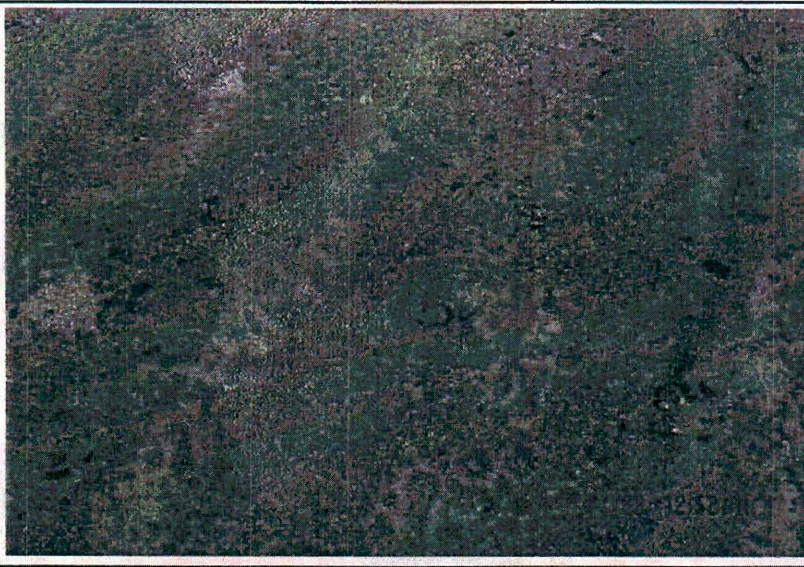


Photo No.	**Date:**
5	3/23/2005

Direction Photo Taken:

Description:

Borehole #3 Vicinity

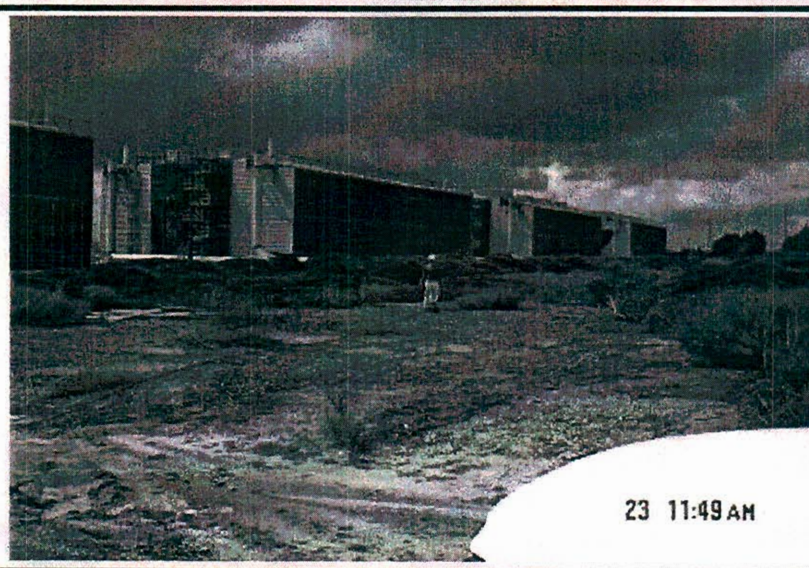


Photo No.	**Date:**
6	3/23/2005

Direction Photo Taken:

Description:

Borehole #3 Marker

URS		PHOTOGRAPHIC LOG
Sargent & Lundy, LLC.	Etiwanda Steam Station Geophysical Survey	**URS Project No.** 38000866

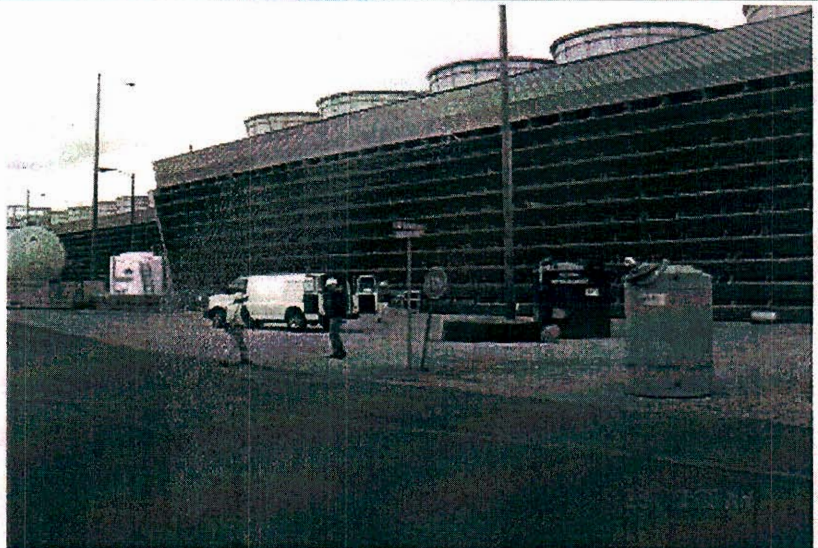
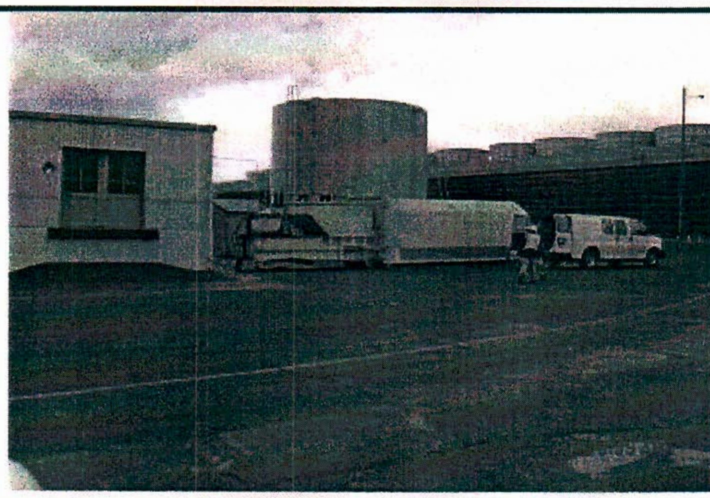
Photo No.	**Date:**	
7	3/23/2005	
Direction Photo Taken:		
Description: Borehole #4 Vicinty		

Photo No.	**Date:**	
8	3/23/2005	
Direction Photo Taken:		
Description: Borehole #4 Marker		

Photo No.	**Date:**	
9	3/23/2005	
Direction Photo Taken:		
Description: Borehole #5 Vicinty		

URS | **PHOTOGRAPHIC LOG**

Sargent & Lundy, LLC.	Etiwanda Steam Station Geophysical Survey	URS Project No. 38000866

Photo No. 10 **Date:** 3/23/2005

Direction Photo Taken:

Description:

Borehole #5 Marker

Photo No. 11 **Date:** 3/23/2005

Direction Photo Taken:

Description:

Borehole #6 Vicinty

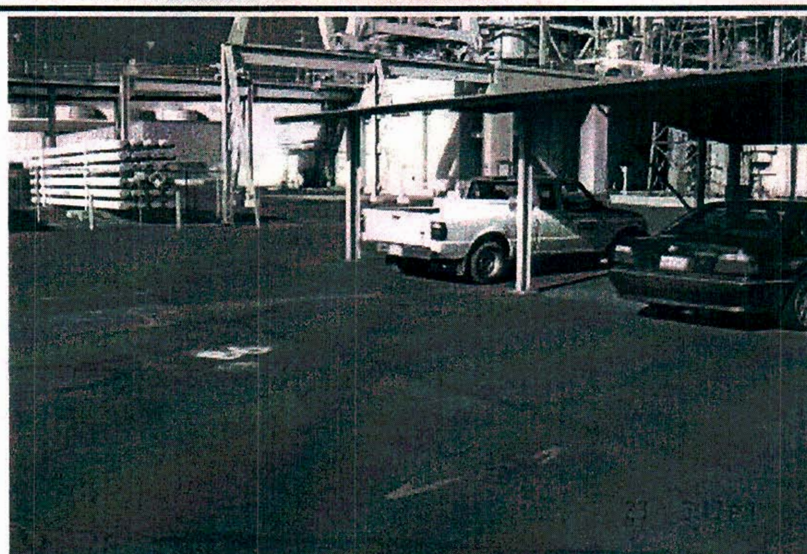
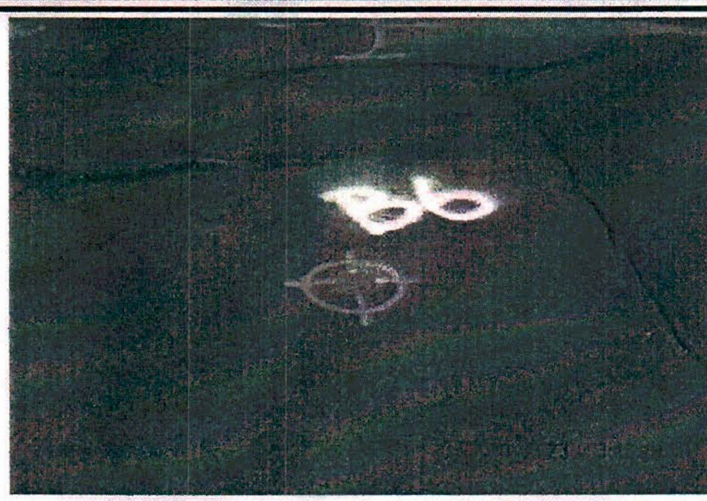


Photo No. 12 **Date:** 3/23/2005

Direction Photo Taken:

Description:

Borehole #6 Marker



URS	PHOTOGRAPHIC LOG	
Sargent & Lundy, LLC.	Etiwanda Steam Station Geophysical Survey	**URS Project No.** 38000866

Photo No. 13	**Date:** 3/23/2005	
Direction Photo Taken:		
Description: Borehole #7 Vicinity		

Photo No. 14	**Date:** 3/23/2005	
Direction Photo Taken:		
Description: Borehole #7 Marker		

Photo No. 15	**Date:** 3/23/2005	
Direction Photo Taken:		
Description: Vicinity of Surface Wave Measurements		

URS	PHOTOGRAPHIC LOG

Sargent & Lundy, LLC.	Etiwanda Steam Station Geophysical Survey	URS Project No. 38000866

Photo No. 16	Date: 3/23/2005

Direction Photo Taken:

Description:

Surface Wave Array Set-Up

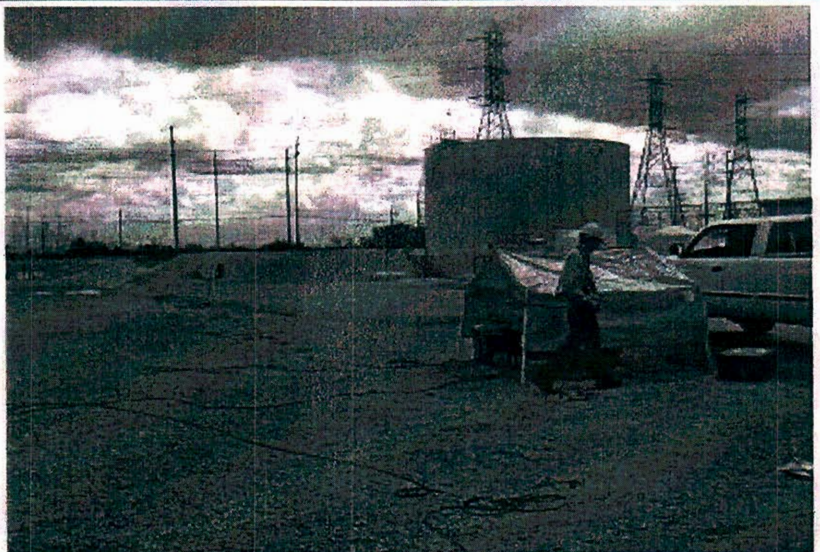


Photo No. 17	Date: 3/23/2005

Direction Photo Taken:

Description:

Surface Wave Sensor Close-up

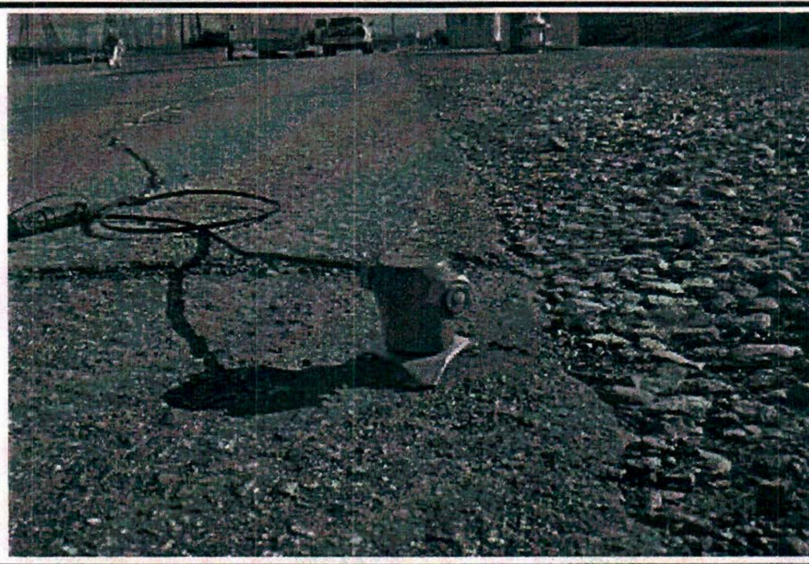


Photo No. 18	Date: 3/23/2005

Direction Photo Taken:

Description:

APPENDIX D

GEOVision
geophysical services
a division of Blackhawk GeoServices

FINAL REPORT

SURFACE WAVE MEASUREMENTS

Reliant Energy Power Plant
8996 Etiwanda Avenue
Rancho Cucamonga, California

Prepared for

URS Corporation
10723 Bell Court
Rancho Cucamonga, CA 91730

Prepared by

GEOVision Geophysical Services
1151 Pomona Road, Unit P
Corona, California 92882
(951) 549-1234

Report 5248-01
April 1, 2005

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

In-situ seismic measurements using active and passive surface wave techniques were performed at the Reliant Energy Power Plant, 8996 Etiwanda Avenue, Rancho Cucamonga, California on March 23, 2005. The purpose of this investigation was to provide a shear (S) wave velocity profile to a depth of 30 meters (100ft), to be used for UBC site classification. Active surface wave techniques utilized during this investigation included the spectral analysis of surface waves (SASW) and multi-channel analysis of surface waves (MASW) methods. Passive surface wave techniques utilized included both the array and refraction microtremor methods.

The average shear wave velocity of the upper 30m (V_S30) is used in the NEHRP provisions and the 1997 Uniform Building Code (UBC) to separate sites into classes for earthquake engineering design (BSSC, 1994). The average shear wave velocity of the upper 100ft (V_S100) is used in the 2000 International Building Code (IBC) for site classification. These site classes are as follows:

Class A – hard rock – $V_S30 > 1500$ m/s (UBC) or $V_S100 > 5{,}000$fps (IBC)
Class B – rock – $760 < V_S30 \leq 1500$ m/s (UBC) or $2{,}500 < V_S100 \leq 5{,}000$fps (IBC)
Class C – very dense soil and soft rock – $360 < V_S30 \leq 760$ m/s (UBC)
or $1{,}200 < V_S100 \leq 2{,}500$fps (IBC)
Class D – stiff soil – $180 < V_S30 \leq 360$ m/s (UBC) or $600 < V_S100 \leq 1{,}200$fps (IBC)
Class E – soft soil – $V_S30 < 180$ m/s (UBC) or $V_S100 < 600$fps (IBC)
Class F – soils requiring site-specific evaluation

At many sites active surface wave techniques (SASW and MASW) with the utilization of portable energy sources, such as hammers and weight drops, are sufficient to obtain a 30m/100ft S-wave velocity sounding. At sites with high ambient noise levels and/or very soft soils, these energy sources may not be sufficient to image to 30m and a larger energy source such as a bulldozer is necessary. Alternatively, passive surface wave techniques such as the refraction microtremor method of Louie, 2001 or the array microtremor technique can be used to extend depth of investigation at sites that have adequate noise levels.

This report contains the results of the active and passive surface wave measurements conducted along two arrays at the site. An overview of the surface wave methods is given in Section 2. Field and data reduction procedures are discussed in Sections 3 and 4, respectively. Interpretation and results are presented in Section 5. Section 6 presents our conclusions. References and our professional certification are presented in Sections 7 and 8, respectively.

2 OVERVIEW OF THE SURFACE WAVE METHODS

A discussion of active and passive surface wave methods is provided in the technical note included as Appendix A. Active surface wave techniques include the spectral analysis of surface waves (SASW) and multi-channel array surface wave (MASW) methods. Passive surface wave techniques include the refraction and array microtremor methods.

The basis of surface wave methods is the dispersive characteristic of Rayleigh waves when propagating in a layered medium. The phase velocity, V_R, depends primarily on the material properties (V_S, mass density, and Poisson's ratio or compression wave velocity) over a depth of approximately one wavelength. Waves of different wavelengths, λ, (or frequencies, f) sample different depths. As a result of the variance in the shear stiffness of the layers, waves with different wavelengths travel at different phase velocities; hence, dispersion. A surface wave dispersion curve, or dispersion curve for short, is the variation of V_R with λ or f.

The SASW and MASW methods are in-situ seismic method for determining shear wave velocity (V_S) profiles [Stokoe et al., 1994; Stokoe et al., 1989; Park et al., 1999a and 1999b, Foti, 2000]. Surface wave techniques are non-invasive and non-destructive, with all testing performed on the ground surface at strain levels in the soil in the elastic range (< 0.001%). SASW testing consists of collecting surface wave phase data in the field, generating the dispersion curve, and then using iterative forward or inverse modeling to calculate the shear stiffness profile. MASW testing consists of collecting multi-channel seismic data in the field and applying a wavefield transform to obtain the dispersion curve and data modeling.

A detailed description of the SASW field procedure is given in Joh [1996]. A vertical dynamic load is used to generate horizontally-propagating Rayleigh waves. The ground motions are monitored by two, or more, vertical receivers and recorded by the data acquisition system capable of performing both time and frequency-domain calculations. Theoretical as well as practical considerations, such as attenuation, necessitate the use of several receiver spacings to generate the dispersion curve over the wavelength range required to evaluate the stiffness profile. To minimize phase shifts due to differences in receiver coupling and subsurface variability, the source location is reversed.

After the time-domain motions from the two receivers are converted to frequency-domain records using the Fast Fourier Transform, the cross power spectrum and coherence are calculated. The phase of the cross power spectrum, ϕ_w (f), represents the phase differences between the two receivers as the wave train propagates past them. It ranges from $-\pi$ to π in a wrapped form and must be unwrapped through an interactive process called masking. Phase jumps are specified, near-field data (wavelengths longer than three times the distance from the source to first receiver), and low-coherence data are removed. The experimental dispersion curve is calculated from the unwrapped phase angle and the distance between receivers by:

$$V_R = f * d_2/(\Delta\phi/360°),$$

where V_R is Rayleigh wave phase velocity, f is frequency, d_2 is the distance between receivers, and $\Delta\phi$ is the phase difference in degrees.

WinSASW V1, a program developed at the University of Texas at Austin, or WinSASW V2 (Joh, 2002) is used to reduce SASW data and interpret the dispersion curve.

A detailed description of the MASW method is given by Park, 1999a and 1999b. Ground motions are recorded by 24, or more, geophones spaced 1 to2 m apart and aligned in a linear array and connected to a seismograph. A wavefield transform, such as the f-k or τ-p transform, is applied to the time history data to isolate the surface wave dispersion curve. PICKWIN95, software developed by Oyo Corporation is typically used to process the MASW data and obtain the dispersion curve.

The refraction microtremor technique is a passive surface wave technique developed by Dr. John Louie at University of Nevada, Reno. A detailed description of this technique can be found in Louie, 2001. The refraction microtremor method differs from the more established array microtremor technique in that it uses a linear receiver array rather than a triangular or circular array. Unlike the SASW method, which uses an active energy source (i.e. hammer), the microtremor technique records background noise emanating from ocean wave activity, wind noise, traffic, industrial activity, construction, etc. Refraction microtremor field procedures consist of laying out a linear array of 24, 4.5 to 8Hz geophones and recording 10, or more, 15 to 60 second noise records. These noise records are reduced using the software package SeisOpt® ReMi™ v2.0 by Optim™ Software and Data Services. This package is used to generate and combine the slowness (p) – frequency (f) transform of the noise records. The surface wave dispersion curve is picked at the lower envelope of the surface wave energy identified in the p-f spectrum.

A detailed discussion of the array microtremor method can be found in Okada, 2003. This technique uses 4 to 24 receivers aligned in a 2-dimensional array. Triangle, circle, semi-circle and "L" shaped arrays are commonly used, although any 2-dimensional arrangement of receivers can be used. Receivers typically consist of 1- to 4.5-Hz geophones. The triangle array, which consists of several embedded equilateral triangles, is often used as it provides good results with a relatively small number of geophones. With this array the outer side of the triangle should be at least equal to the desired depth of investigation. The "L" array is useful at sites located at the corner of perpendicular intersecting streets. Typically 10 to 20, 30-second noise records are acquired for analysis. The surface wave dispersion curve is estimated by calculating the spatial autocorrelation (SPAC) function for the time-history data. A first-order Bessel function is fit to the SPAC function to obtain the dispersion curve (phase velocity at each frequency). PICKWIN95, software developed by Oyo Corporation is typically used to process the array microtremor data and obtain the dispersion curve.

The active and passive surface wave techniques compliment one another as outlined below:

- SASW/MASW techniques image the shallow velocity structure which cannot be imaged by the microtremor technique and is needed for an accurate V_S30/V_S100' estimate.
- Microtremor techniques work best in noisy environments where SASW/MASW depth investigation may be limited.
- In a noisy environment the microtremor technique will usually extend the depth of an SASW/MASW sounding.

- The degree of fit in the overlapping portion of the dispersion curves from the two techniques provides a level of confidence in the results.

The dispersion curves generated from the active and passive surface wave soundings are generally combined and modeled. Typically, WinSASW V1 or V2 is used to model the data, whereby through iterative forward and/or inverse modeling, a V_S profile is found whose theoretical dispersion curve is a close fit to the field data.

The final model profile is assumed to represent actual site conditions. Several options exist for forward modeling: a formulation that takes into account only fundamental-mode Rayleigh wave motion (called the 2-D solution), and one that includes all stress waves and incorporates receiver geometry (3-D solution) [Roesset et al., 1991].

The theoretical model used to interpret the dispersion assumes horizontally layered, laterally invariant, homogeneous-isotropic material. Although these conditions are seldom strictly met at a site, the results of active and/or passive surface wave testing provide a good "global" estimate of the material properties along the array. The results may be more representative of the site than a borehole "point" estimate.

Based on our experience at other sites, the shear wave velocity models determined by surface wave testing are within 20% of the velocities that would be determined by other seismic methods [Brown, 1998]. The average velocity of the upper 30m or 100ft, however, is much more accurate than this, often to better than 5%, because it is less sensitive to the layering in the model.

3 FIELD PROCEDURES

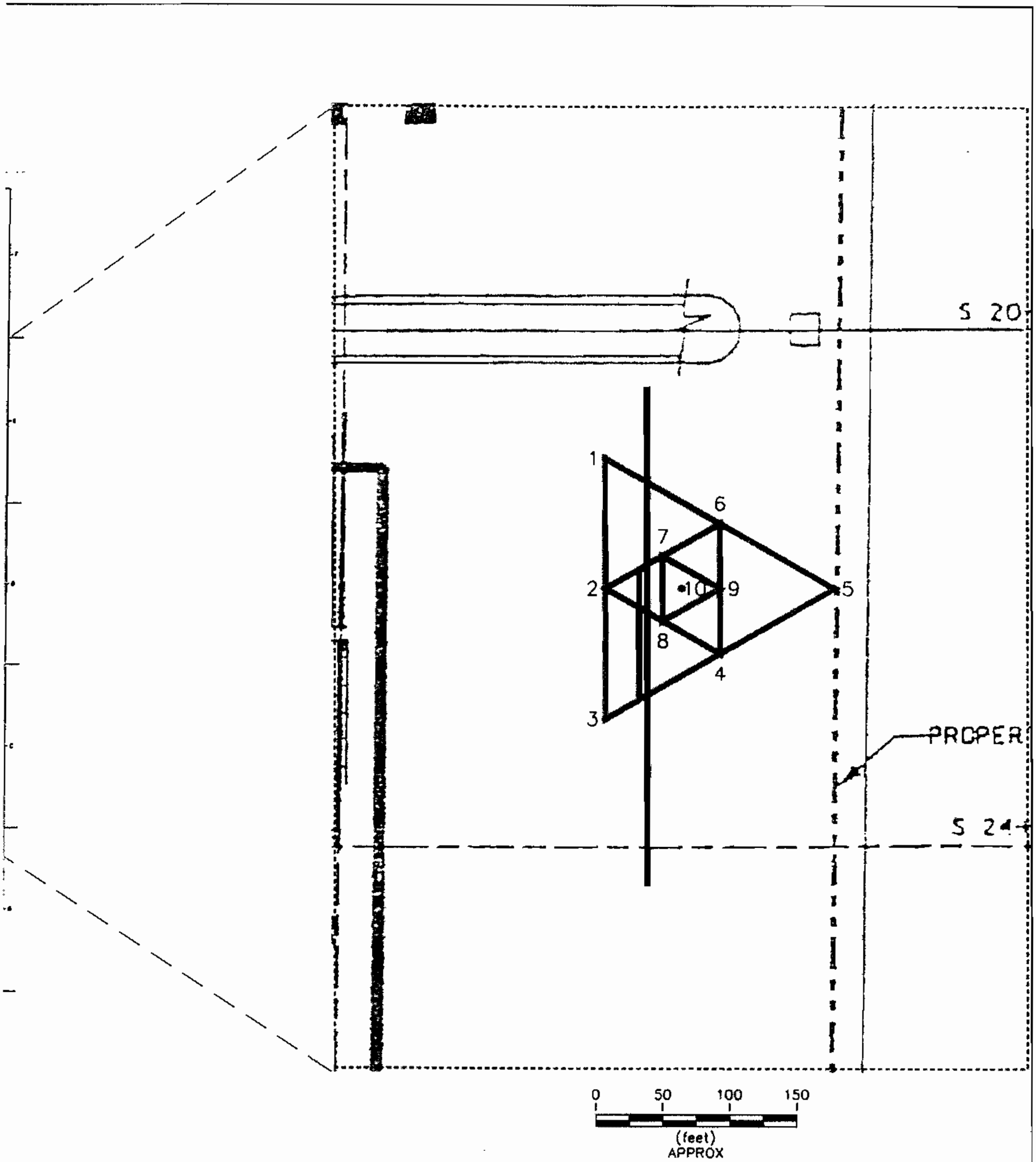
SASW, MASW and array and refraction microtremor data were collected at a single location at the site, as shown in Figure 1. The site consisted of an open dirt area bound by the property line and Etiwanda Avenue to the east, ponds to the south, a switch yard to the west and the main entrance into the facility to the north.

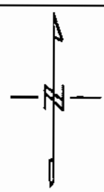
A typical SASW field layout is shown in Appendix A. The SASW data were collected with base receiver spacings of 2, 4, 8, 12, 16 and 20m (6.6, 13.1, 39.4, 52.5 and 65.6ft). These receiver spacings generally provided adequate overlap of dispersion data over a wavelength range of 1 to 40m. Data could not be obtained at larger receiver spacings due to high ambient noise levels from the adjacent Etiwanda Ave. Generally, the high frequency (short wavelength) surface waves were measured across the short spacings and the low frequency (long wavelength) surface waves were measured with the large receiver spacings. The dispersion data averaged across longer distances are often smoother as the affects of localized heterogeneities are averaged. For each receiver spacing, reversed source locations were occupied with a common centerline, where possible. Rock hammers, 3lb hammers and 12- and 20-lb sledgehammers and an accelerated weight drop (AWD) were used as energy sources. Data from the transient impacts (hammers) were averaged 10 to 20 times to improve the signal-to-noise ratio. Surface waves were monitored by two Oyo Geospace 1 Hz and/or 4.5 Hz geophones and recorded by an HP 35670A dynamic signal analyzer. Photographs of typical SASW equipment are presented in Appendix A.

A typical MASW field layout is shown in Appendix A. MASW equipment used during this investigation consisted of a Geometrics Geode signal enhancement seismograph, 4.5 Hz vertical geophones, seismic cable with 25-foot takeouts, a rock hammer, 20 lb sledge hammer and aluminum plate, and an AWD. MASW data was acquired along a linear array with 1m (3.3 ft) geophone spacing. Shot points were typically located 1, 5, 12 and 25m (3.3, 16.4, 39.4 and 82ft) from the end geophone locations. Both the rock hammer and 20lb sledge hammer were used for the 1m offset source. The 20lb sledge hammer was used for the 5m source offset and the AWD was used for the remaining shot points. Data from the transient impacts (hammers and AWD) were averaged 5 to 10 times to improve the signal-to-noise ratio. Surface waves were monitored by 24 Oyo Geospace 4.5 Hz geophones and recorded by a Geometrics Geode signal enhancement seismograph. Photographs of typical MASW equipment are presented in Appendix A. All field data was saved to hard disk and documented on field data acquisition forms.

Refraction microtremor measurements were made along a linear array of 24, 4.5Hz geophones with a 5m (16.4ft) geophone spacing. A typical field layout is shown in Appendix A. A Geometrics Geode, 24 bit, 24-channel seismic recording system was used to record thirty 30.96s noise records using a 2ms sample rate. Data were stored on a laptop computer for later processing.

Array microtremor measurements were made along a 10-channel triangle array using 4.5Hz geophones with a maximum spacing of 60m (197ft). The field layout is shown in Figure 1 and Appendix A. A Geometrics Geode, 24 bit, 24-channel seismic recording system was used to record thirty 30.96s noise records using a 2ms sample rate. Data were stored on a laptop computer for later processing.





(APPROX)

GEOVision
geophysical services
a division of Blackhawk GeoServices

Project #	5248
Date	Mar 31,2005
Developed by	A MARTIN
Drawn by	T RODRIGUEZ
Approved by	
File	Z:\5248\5248-1.dwg

FIGURE – 1
SITE LOCATION MAP

RELIANT ENERGY POWER PLANT
8996 ETIWANDA AVENUE
RANCHO CUCAMONGA, CALIFORNIA

PREPARED FOR
URS CORPORATION

4 DATA REDUCTION AND MODELING

The SASW data was reduced using WinSASW and the following steps:

- Input forward and reverse-direction phase spectrum and coherence for a receiver spacing
- Enter receiver spacing, geometry and wavelength restrictions (max. wavelength = 2 times the receiver spacing)
- Mask phase data (either the forward and reverse directions individually or the average)
- Generate dispersion curve
- Repeat for all receiver spacings and merge all dispersion curves

The MASW data were reduced using the software PICKWIN95 developed by Oyo Corporation and the following steps:

- Input seismic record into software.
- Enter receiver spacing, geometry and wavelength restrictions, as necessary.
- Apply wavefield transform to seismic record to convert the data to phase velocity – frequency space.
- Identify and pick dispersion curve.
- Repeat for all shot records and merge dispersion curves.
- Convert dispersion curves to WinSASW format for modeling.

The refraction microtremor data were reduced using the Optim™ Software and Data Services SeisOpt® ReMi™ v2.0 data analysis package. Data reduction steps included the following:

- Conversion of SEG-2 format field files to SEG-Y format.
- Data preprocessing which includes trace-equalization gaining and DC offset removal.
- Erasing receiver geometry present in the file header.
- Computing the velocity spectrum of each record by p-f transformation.
- Combining the individual p-f transforms into one image.
- Picking and saving the velocity spectrum image.
- Conversion of the dispersion curve to WinSASW format.

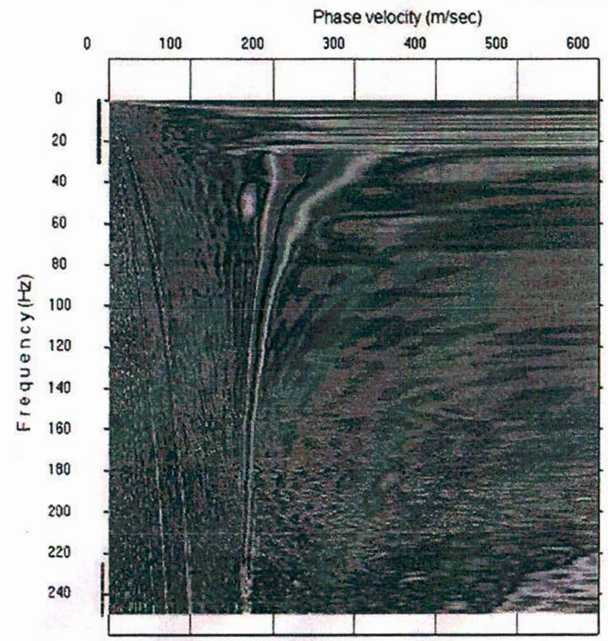
The array microtremor data were reduced using the software PICKWIN95 developed by Oyo Corporation and the following steps:

- Input all seismic records into software.
- Enter receiver spacing, geometry and wavelength restrictions, as necessary.
- Calculate the SPAC function for each seismic record and average.
- For each frequency calculate the degree of fit of a first-order Bessel function to the SPAC function for a multitude of phase velocities.
- Identify and pick dispersion curve as the best fit of the Bessel function for each frequency.
- Convert dispersion curves to WinSASW format for modeling

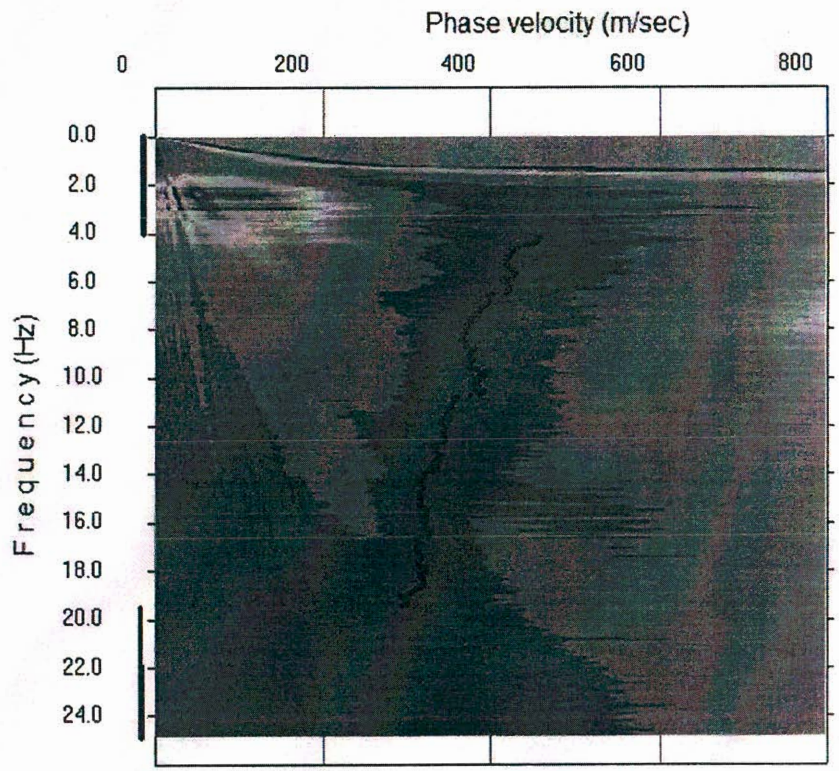
Example wavefield transforms of the MASW and microtremor data are presented in Figure 2. The surface wave dispersion curves from the active and passive surface wave data were combined and an iterative forward modeling process was used to generate an S-wave velocity model for the sounding. During this process an initial velocity model was generated based on general characteristics of the dispersion curve. The theoretical dispersion curve was then generated using the 2-D modeling algorithm (fundamental mode Rayleigh wave dispersion module) and compared to the field dispersion curve. Adjustments are then made to the thickness and velocities of each layer and the process repeated until an acceptable fit to the field data is obtained.

Constant mass density values of 1.8 to 2.0 g/cc were used in the profile for subsurface soils. Within the normal range encountered in geotechnical engineering, variation in mass density has a negligible effect on surface wave dispersion. During modeling the compression wave velocity, V_P, was estimated using a Poisson's ratio, ν, of 0.33 and the relationship:

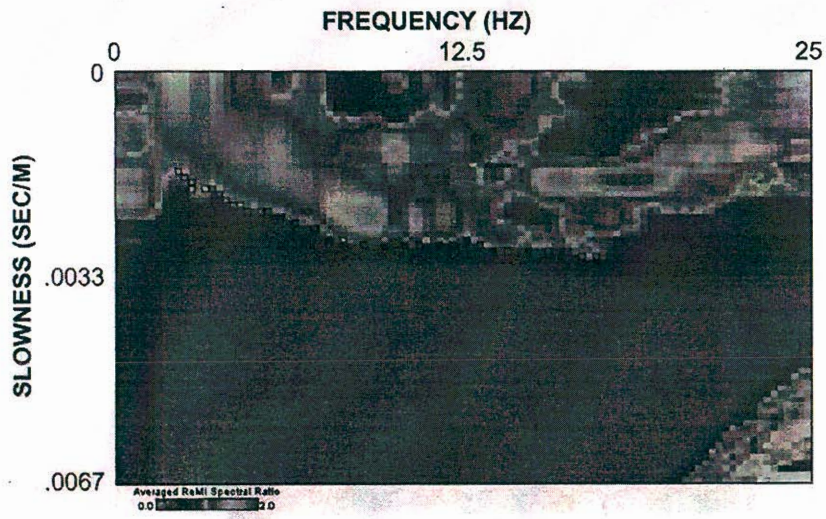
$$V_P = V_S\,[(2(1-\nu))/(1-2\nu)]^{0.5}.$$



WAVEFIELD TRANSFORM OF MASW DATA



WAVEFIELD TRANSFORM OF ARRAY MICROTREMOR DATA



WAVEFIELD TRANSFORM OF REFRACTION MICROTREMOR DATA

GEOVision geophysical services a division of Blackhawk GeoServices	FIGURE 2 EXAMPLE WAVEFIELD TRANSFORMS OF MASW AND MICROTREMOR DATA
Project # 5248	RELIANT ENERGY POWER PLANT 8996 ETIWANDA AVENUE RANCHO CUCAMONGA, CALIFORNIA
Date: APRIL 1, 2005	
Drawn By: A MARTIN	
Approved By:	PREPARED FOR URS CORPORATION
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5 INTERPRETATION AND RESULTS

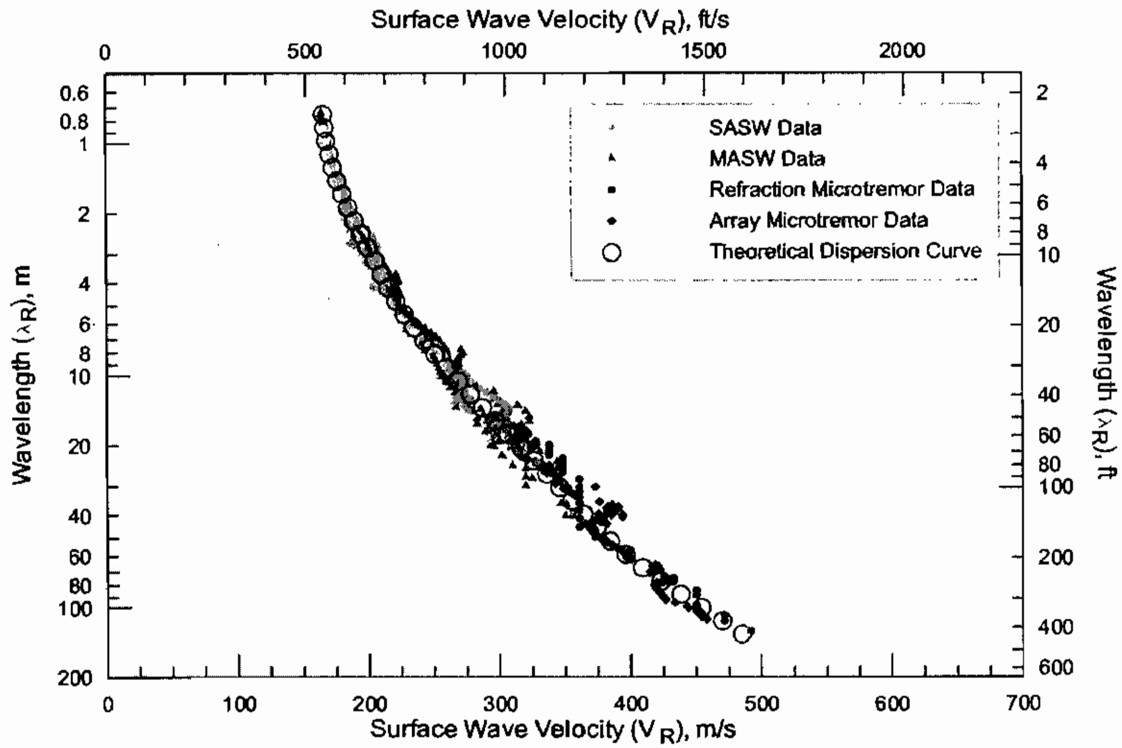
The fit of the theoretical dispersion curve to the experimental data collected at the site and the modeled V_S profile is presented in Figure 3. The resolution decreases gradually with depth, because of loss of sensitivity of the dispersion curve to changes in V_S at greater depth. The V_S profile used to match the field data is provided in tabular form as Table 1.

Table 1 Velocity Model for Surface Wave Array

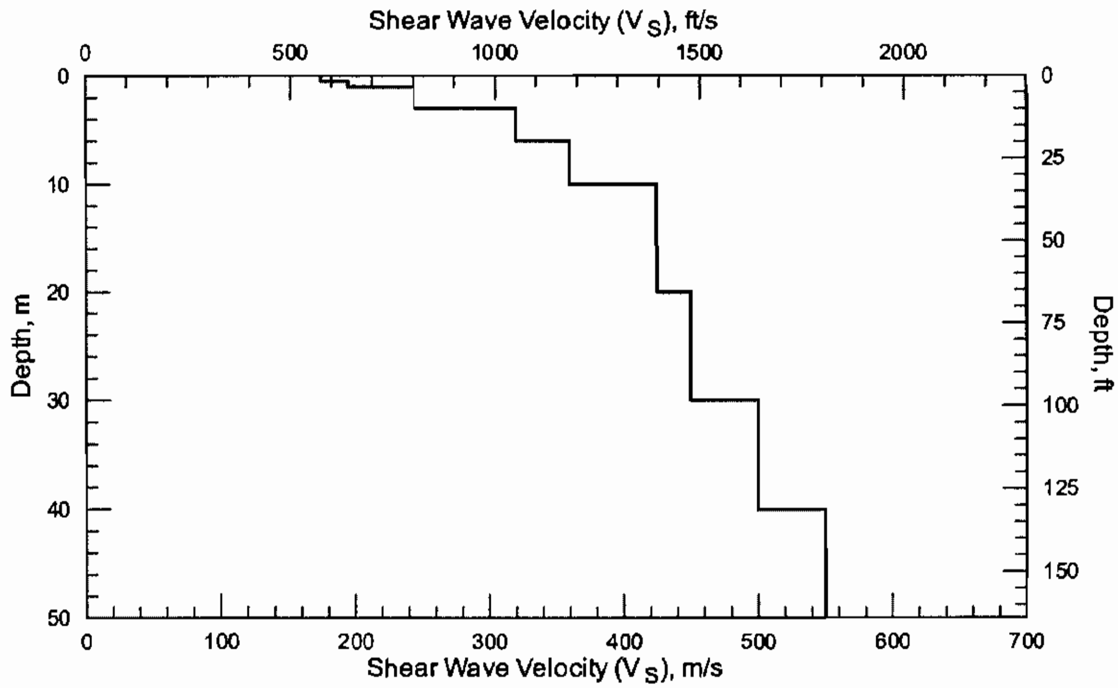
Depth to Top of Layer		Layer Thickness		S-Wave Velocity		P-Wave Velocity	
m	ft	m	ft	m/s	ft/s	m/s	ft/s
0	0.0	0.5	1.6	175	574	350	1148
0.5	1.6	0.5	1.6	195	640	390	1280
1	3.3	2	6.6	245	804	490	1608
3	9.8	3	9.8	320	1050	640	2100
6	19.7	4	13.1	360	1181	720	2362
10	32.8	10	32.8	425	1394	850	2788
20	65.6	10	32.8	450	1476	900	2952
30	98.4	10	32.8	500	1640	1000	3281
40	131.2	>10	>32.8	550	1804	1100	3609

The dispersion curves derived from the SASW and MASW data are very similar, demonstrating that these techniques can be used interchangeably. The dispersion curves from the refraction microtremor and array microtremor data are also very similar. The surface wave phase velocities from the microtremor measurements are in very good agreement with those from the SASW and MASW data in the region of overlapping wavelength. The estimated depth of investigation for the combined active and passive surface wave sounding is over 50m (164ft).

The shear wave velocity model consists of about 2 m (6.6 ft) of loose soil with velocity of about 175 to 245 m/s (574 to 804 ft/s) overlying denser soils with velocity generally increasing with depth from 320 to 550 m/s (1,050 to 1,804 ft/s) at a depth of about 40 m (131 ft). Average shear wave velocity to a depth of 30 m, V_S30, is 376 m/s (1,233 ft/s) at the location of the surface wave array.



Comparison of Field Experimental Data and Theoretical Dispersion Curve from Active and Passive Surface Wave Array



V_S Profile from Active and Passive Surface Wave Array

GEOVision geophysical services a division of Blackhawk GeoServices	FIGURE 3 VELOCITY MODEL FOR ACTIVE AND PASSIVE SURFACE WAVE ARRAY
Project # 5248	RELIANT ENERGY POWER PLANT 8996 ETIWANDA AVENUE RANCHO CUCAMONGA, CALIFORNIA
Date: APRIL 1, 2005	
Drawn By: A MARTIN	
Approved By:	PREPARED FOR URS CORPORATION
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6 CONCLUSIONS

Active and passive measurements using the SASW, MASW, refraction microtremor and array microtremor techniques were made at a single location at the Reliant Energy Power Plant, 8996 Etiwanda Avenue, Rancho Cucamonga, California to characterize shear-wave velocity of the upper 30m (98.4ft). The locations of the active and passive surface wave sounding arrays are presented in Figure 1. The shear wave velocity profile determined by these methods is presented in this report as Figure 3 and Table 1.

V_S30 is approximately 376 m/s (1,233 ft/s) beneath the surface wave array. Therefore, according to the 1997 Uniform Building Code, the area in the vicinity of the array is classified as C, very stiff soil and soft rock.

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8 CERTIFICATION

All geophysical data, analysis, interpretations, conclusions, and recommendations in this document have been prepared under the supervision of and reviewed by a GEO***Vision*** California Registered Geophysicist.

4/01/05

Antony J. Martin
California Registered Geophysicist GP989
GEO*Vision* Geophysical Services

Date

* This geophysical investigation was conducted under the supervision of a California Registered Geophysicist using industry standard methods and equipment. A high degree of professionalism was maintained during all aspects of the project from the field investigation and data acquisition, through data processing interpretation and reporting. All original field data files, field notes and observations, and other pertinent information are maintained in the project files and are available for the client to review for a period of at least one year.

A registered geophysicist's certification of interpreted geophysical conditions comprises a declaration of his/her professional judgment. It does not constitute a warranty or guarantee, expressed or implied, nor does it relieve any other party of its responsibility to abide by contract documents, applicable codes, standards, regulations or ordinances.

APPENDIX A

TECHNICAL NOTE

ACTIVE AND PASSIVE SURFACE WAVE TECHNIQUES

ACTIVE AND PASSIVE SURFACE WAVE TECHNIQUES

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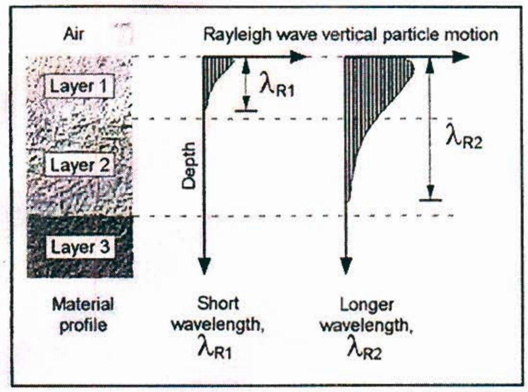
Overview

Active and passive surface wave techniques are relatively new in-situ seismic methods for determining shear wave velocity (V_S) profiles. Testing is performed on the ground surface, allowing for less costly measurements than with traditional borehole methods. The basis of surface wave techniques is the dispersive characteristic of Rayleigh waves when traveling through a layered medium. Rayleigh wave velocity is determined by the material properties (primarily shear wave velocity, but also to a lesser degree compression wave velocity and material density) of the subsurface to a depth of approximately 1 to 2 wavelengths. As shown in the adjacent diagram, longer wavelengths penetrate deeper and their velocity is affected by the material properties at greater depth. Surface wave testing consists of measuring the surface wave dispersion curve at a site and modeling it to obtain the corresponding shear wave velocity profile.



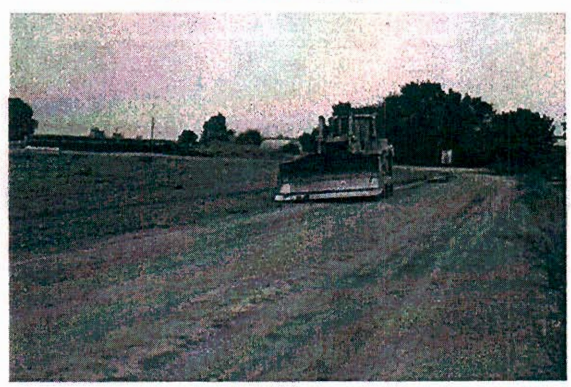
Active Surface Wave Techniques

Active surface wave techniques measure surface waves generated by dynamic sources such as hammers, weight drops, electromechanical shakers, vibroseis and bulldozers. These techniques include the spectral analysis of surface waves (SASW) and multi-channel array surface wave (MASW) methods.

Hammer Energy Sources

Accelerated Weight Drop

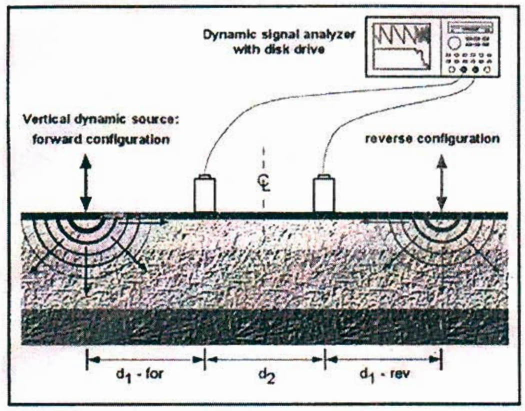
Electromechanical Shaker



Bulldozer Energy Source

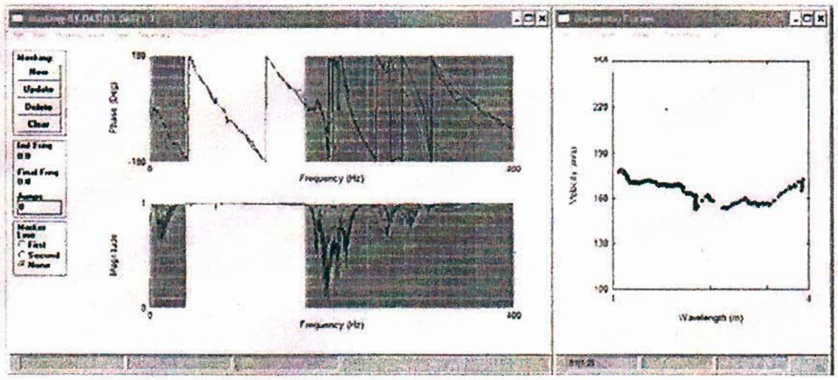
1151 Pomona Road, Corona, California 92882 ph. 951-549-1234 fx 951-549-1236 www.geovision.com

The SASW method is optimized for conducting V_S depth soundings. A dynamic source is used to generate surface waves of different wavelengths (or frequencies) which are monitored by two or more receivers at known offsets. An expanding receiver spread is used to avoid near field effects associated with Rayleigh waves and the source-receiver geometry is optimized to minimize body wave signal. A dynamic signal analyzer is typically used to calculate the phase and coherence of the cross spectrum of the time history data collected at a pair of receivers. During data analysis, an interactive masking process is used to discard low quality data and to unwrap the phase spectrum, as shown in the figure below. The dispersion curve (Rayleigh wave phase velocity versus frequency or alternatively wavelength) is calculated from the unwrapped phase spectrum.



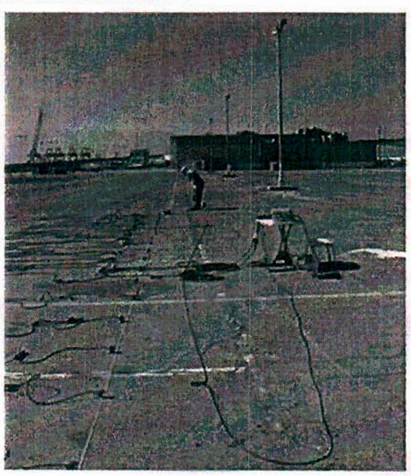
SASW Setup

HP Dynamic Signal Analyzer

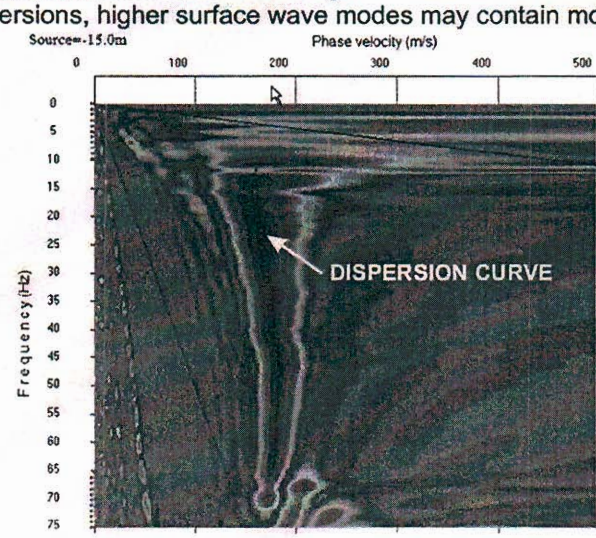


Masking of Wrapped Phase Spectrum and Resulting Dispersion Curve

The MASW field layout is similar to that of the seismic refraction technique. Twenty four, or more, geophones are laid out in a linear array with 1 to 2m spacing and connected to a multi-channel seismograph as shown below. This technique is ideally suited to 2D V_S imaging, with data collected in a roll-along manner similar to that of the seismic reflection technique. The source is offset at a predetermined distance from the near geophone and the Rayleigh wave dispersion curve is obtained by a wavefield transformation of the seismic record via the frequency-wavenumber (f-k) or slowness-frequency (p-f) transforms. These transforms are very effective at isolating surface wave energy from that of body waves. The dispersion curve is picked as the peak of the surface wave energy in slowness (or velocity) – frequency space as shown. One advantage of the MASW technique is that the wavefield transformation may not only identify the fundamental mode but also higher modes of surface waves. At some sites, particularly those with large velocity inversions, higher surface wave modes may contain more energy than the fundamental mode.



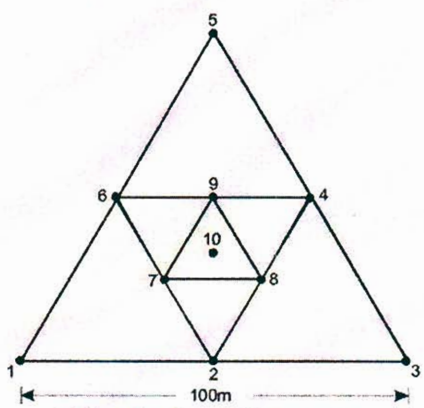
MASW Field Setup



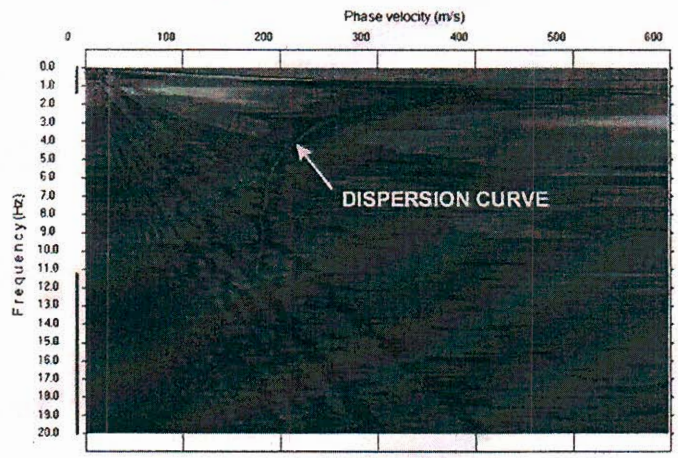
Wavefield Transform of MASW data

Passive Surface Wave Techniques
Passive surface wave techniques measure noise; surface waves from ocean wave activity, traffic, factories, wind, etc. These techniques include the array microtremor and refraction microtremor (REMI) techniques.

The array microtremor technique typically uses 7 or more 4.5- or 1-Hz geophones arranged in a two-dimensional array. The most common arrays are the triangle, circle, semi-circle and "L" arrays. The triangle array, which consists of several embedded equilateral triangles, is often used as it provides good results with a relatively small number of geophones. With this array the outer side of the triangle should be at least as long as the desired depth of investigation. Typically, fifteen to twenty 30-second noise records are acquired for analysis. A technique called spatial autocorrelation (SPAC) is used to obtain the Rayleigh wave dispersion curve. For a particular frequency the phase velocity is equal to that which best fits a first order Bessel function to the SPAC function. The image shown is phase velocity versus frequency showing the degree of fitness of the Bessel function to the SPAC function for a wide velocity and frequency range. The dispersion curve, is the peak (best fit), as shown in the figure below.

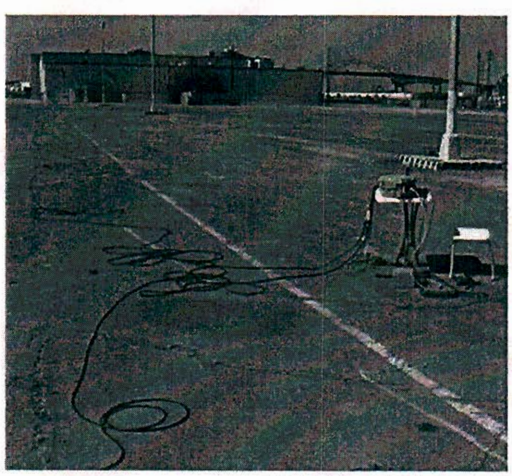


Triangle Array Geometry

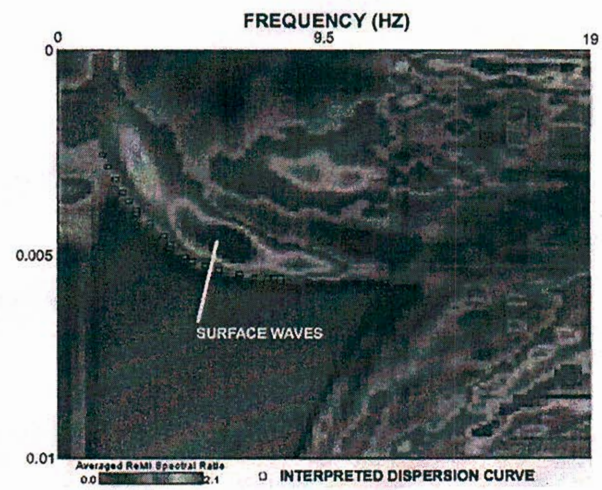


Dispersion Curve from Array Microtremor Measurements

The refraction microtremor (REMI) technique uses a field layout similar to the seismic refraction method (hence its name). Twenty-four, 4.5 Hz geophones are laid out in a linear array with a spacing of 6 to 8m and fifteen to twenty 30-second noise records are acquired. A slowness-frequency (p-f) wavefield transform or SPAC function is used to separate Rayleigh wave energy from that of other waves. Because the noise field can originate from any direction, the wavefield transform is conducted for multiple vectors through the geophone array, all of which are summed. The dispersion curve is defined as the lower envelope of the Rayleigh wave energy in p-f space. Because the lower envelope is picked rather than the energy peak (energy traveling along the profile is slower than that approaching from an angle), this technique may be somewhat more subjective than the others, particularly at low frequencies.



Refraction Microtremor Array Layout



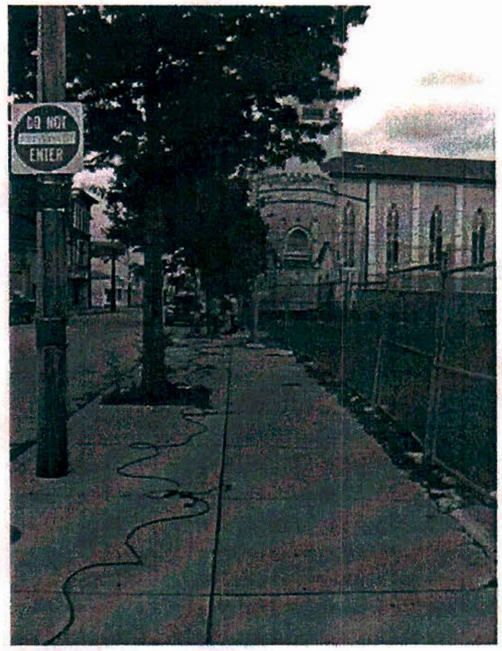
Wavefield Transform of REMI Data

Depth of Investigation

Active surface wave investigations typically use various sized sledge hammers to image the shear wave velocity structure to depths of up to 15m. Weight drops and electromechanical shakers can often be used to image to depths of 30m. Bulldozers and vibroseis trucks can be used to image to depths as great as 100m. Passive surface wave techniques can often image shear wave velocity structure to depths of over 100m, given sufficient noise sources and space for the receiver array. Large passive arrays, utilizing long-period seismometers with GPS clocks have been used to image shear wave velocity structure to depths of several kilometers.

Combined Active and Passive Surface Wave Testing

The combined use of active and passive techniques may offer significant advantages on many investigations. It can be very costly to mobilize large energy sources for 30m/100ft active surface wave soundings. In urban environments, the combined use of active and passive surface wave techniques can image to these depths without the need for large energy sources. We have found that dispersion curves from active and passive surface wave techniques are generally in good agreement, making the combined use of the two techniques viable. It is not recommended that passive surface wave techniques be applied alone for UBC/IBC site classification investigations. Microtremor techniques do not generally characterize near surface velocity, which may have a significant impact of the average shear wave velocity of the upper 30m or 100ft and so should always be used in conjunction with SASW or MASW. An SASW sounding to a depth of 30m requires at least a 60m linear array. If sufficient space is not available for this, it may be possible to use a 30m triangle array on the site or place a 100-200m long REMI array along an adjacent sidewalk or an "L" array at an adjacent street intersection.



Microtremor Measurements along Sidewalk

Modeling

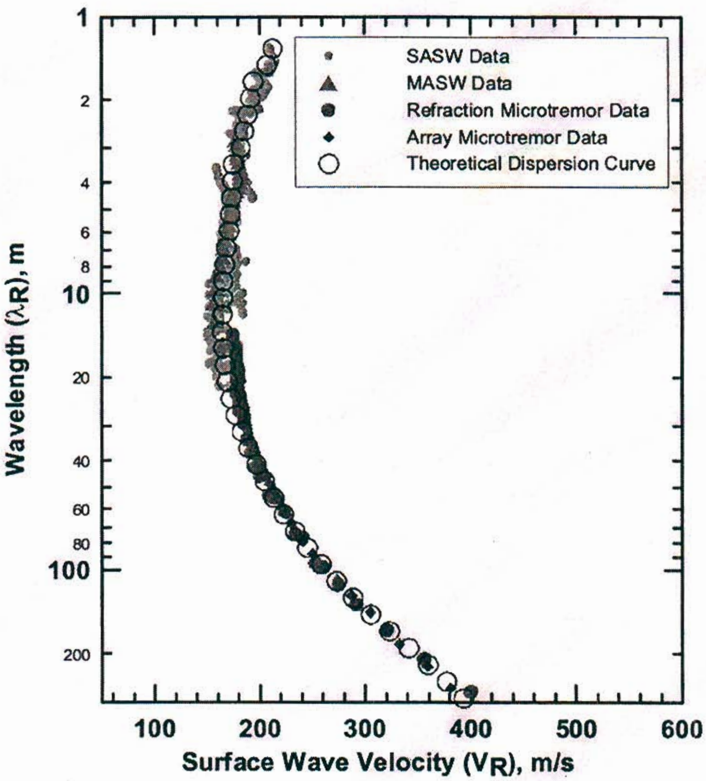
There are several options for interpreting surface wave dispersion curves, depending on the accuracy required in the shear wave velocity profile. A simple empirical analysis can be done to estimate the average shear wave velocity profile. For greater accuracy, forward modeling of fundamental-mode Rayleigh wave dispersion as well as full stress wave propagation can be performed using several software packages. A formal inversion scheme may also be used. With many of the analytical approaches, background information on the site can be incorporated into the model and the resolution of the final profile may be quantified.

Applications

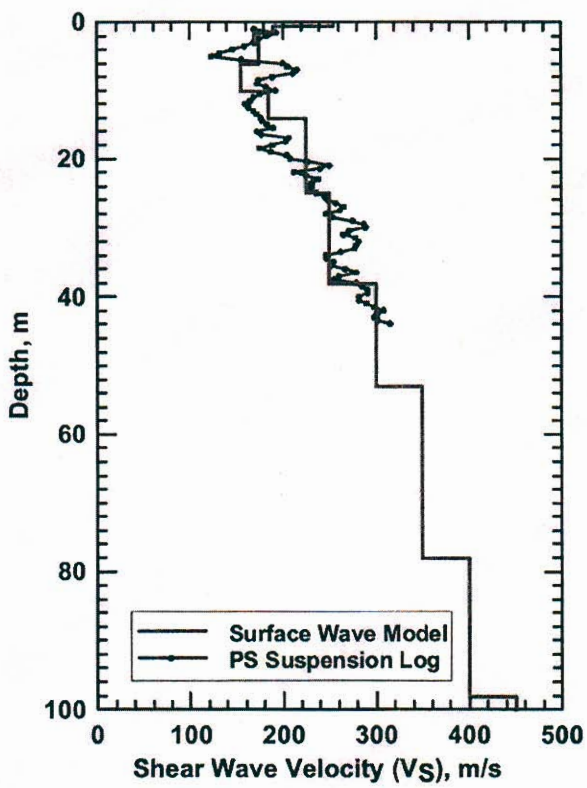
Active and passive surface wave testing can be used to obtain V_S profiles for:

- UBC/IBC site classification for seismic design
- Earthquake site response
- Seismic microzonation
- Liquefaction analysis
- Soil compaction control
- Mapping subsurface stratigraphy
- Locating potentially weak zones in earthen embankments and levees

Case History
The figures below show the surface wave dispersion curves and shear wave velocity model for a site in Los Angeles, California. All of the previous figures illustrating SASW, MASW, array and refraction microtremor techniques were from this site. The dispersion curves from all four methods are shown on the left along with the theoretical dispersion curve for the S-wave velocity versus depth model on the right. Conditions at this site were very poor for active surface wave techniques because of the presence of very low velocity hydraulic fill. In fact, with active surface wave techniques it was only possible to image to a depth of about 12.5m with energy sources typically capable of imaging to 30m. There is excellent agreement between all of the methods over the overlapping wavelength ranges. The minor differences probably result from variable velocity of the hydraulic fill within the sampling volume of the specific methods. The Vs versus depth model on the right agrees well with a shallow PS Suspension log and the average shear wave velocity (Vs30) from the PS log (185m/s) agrees well with that from the surface wave model (201 m/s). The differences in V_S30 between the two methods may easily result from the different sampling regimes (borehole versus larger area) rather than errors in either of the methods.



Field Data and Theoretical Dispersion Curve



V_s Model

In contrast to borehole measurements which are point estimates, surface wave testing is a global measurement, that is, a much larger volume of the subsurface is sampled. The resulting profile is representative of the subsurface properties averaged over distances of up to several hundred feet. Although surface wave techniques do not have the layer sensitivity or accuracy (velocity and layer thickness) of borehole techniques; the average velocity over a large depth interval (i.e. the average shear wave velocity of the upper 30m or 100ft) is very well constrained. Because surface wave methods are non-invasive and non-destructive, it is relatively easy to obtain the necessary permits for testing. At sites that are favorable for surface wave propagation, active and passive surface wave techniques allow appreciable cost and time savings.