



Shear Wave Structure of Umbria and Marche, Italy, Strong Motion Seismometer Sites Affected by the 1997 Umbria-Marche, Italy, Earthquake Sequence



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Shear Wave Structure of Umbria and Marche, Italy, Strong Motion Seismometer Sites Affected by the 1997-98 Umbria-Marche, Italy, Earthquake Sequence

INTRODUCTION

A long sequence of earthquakes, eight with magnitudes between 5 and 6, struck the Umbria and Marche regions of central Italy between September 26, 1997 and July 1998. The earthquake swarm caused severe structural damage, particularly to masonry buildings, and resulted in the loss of twelve lives and about 150 injuries. The source of the events was a single seismogenic structure that consists of several faults with a prevailing northwest-southeast strike and crosses the Umbria-Marche border. The focal mechanism of the largest shocks indicate that the events were the product of shallow extensional normal faulting along a NE-SW extension perpendicular to the trend of the Apennines.

The network of analog seismometer stations in the Umbria and Marche regions recorded motions of the main September and October 1997 events and a dense array of mobile digital stations, installed since September 29, recorded most of the swarm. The permanent national network Rete Accelerometrica Nazionale (RAN) is administered and maintained by Dipartimento delle Protezione Civile (DPC: Civil Protection Department); the temporary array was managed by Servizio Sismico Nazionale (SSN) in cooperation with small agencies and Universities (SSN, 2002) .

Most of the temporary and permanent stations in the Italian seismic network have little or no characterization of seismic velocities. In this study, we investigate 17 Italian sites using an active-source approach that employs low frequency harmonic waves to measure the dispersive nature of surface waves in the ground. We use the Spectral Analysis of Surface Wave (SASW) approach, coupled with an array of harmonic-wave electro-mechanical sources that are driven in-phase to excite the ground. An inversion algorithm using a non-linear least-squares best-fit method is used to compute shear wave velocities for the upper 100-200 meters of the soil column.

1997-98 Umbria-Marche, Italy, Earthquake Sequence

The regions of Umbria and Marche were shaken by two strong motion events on September 26, 1997 near Colfiorito on the Umbria-Marche border. Temporary stations were deployed in the epicentral region and recorded two large shocks on October 3 and 6. Later on October 12, 14, and November 9, swarms of quakes occurred in the vicinity of the town of Sellano.

After almost five months of relative seismic quiescence, two strong motion events occurred in the northern part of Umbria (Gualdo Tadino area) on March 26 and April 3 1998 (Decanini et al., 2002) with magnitudes of 5.6 and 5.3. The September events were the largest with magnitudes of M5.8 and M6.0. The two October quakes near Colfiorito were of M5.3 and the Sellano swarm had several major shocks that ranged from M4.5 to 5.7. In Colfiorito, the largest peak accelerations recorded were 0.38g and 0.44g horizontal and 0.33g vertical. In Nocera Umbra, the largest peak accelerations were 0.56g and 0.50g horizontal and 0.42g vertical (Trobiner et al., 1997).

The geologic setting of the rock in the mountainous Apennines of the Umbria-Marche regions consists of folded and thrust-faulted Mesozoic and Cenozoic marl, marl clays, and limestone. Valley alluvium of Pleistocene and Holocene age fill the drainages and lowland areas. In general, the region is dissected by a suite of NNW-trending Cenozoic thrust faults, now undergoing extension. The setting of faulted marine units has been the source of over a score of shallow damaging earthquakes in the past 800 years.

The Umbria-Marche earthquake swarm severely damaged hundreds of architecturally and culturally important structures, including the Basilica of St. Francesco in the town of Assisi, as well as palaces, towers, churches and historically important residences. In Foligno and Nocera Umbra, the towns' medieval towers collapsed, and numerous city gates were damaged. Severe damage was found, almost exclusively, in the stone masonry constructed structures. Strong-motion stations located within these towns, and the temporary stations set up after the initial events in more rural settings, were the object of our SASW testing program. All of the sites tested using SASW were temporary and permanent stations set up in or near the hilltop towns.

Velocity Measurements

The 17 strong-motion instrument sites were measured for velocity structure using a controlled sine wave source and the spectral analysis of surface waves (SASW) method. The SASW method of testing is a portable, inexpensive, and efficient means of non-invasively estimating the stiffness properties of the upper 100 meters of the ground. Prior to the development of non-invasive surface wave methods, shear waves were measured in cased boreholes in rock or by penetration tests, both costly methods, using a conventional travel-time approach. For all of the sites we studied in Umbria and Marche regions, the penetration method could not sound to useful depths, and boreholes would be prohibitively expensive. The surface wave test apparatus is highly portable allowing us to measure in remote locations where only small all-wheel-drive vehicles can go: for example, site 263GBB, Gubbio Park Collo.

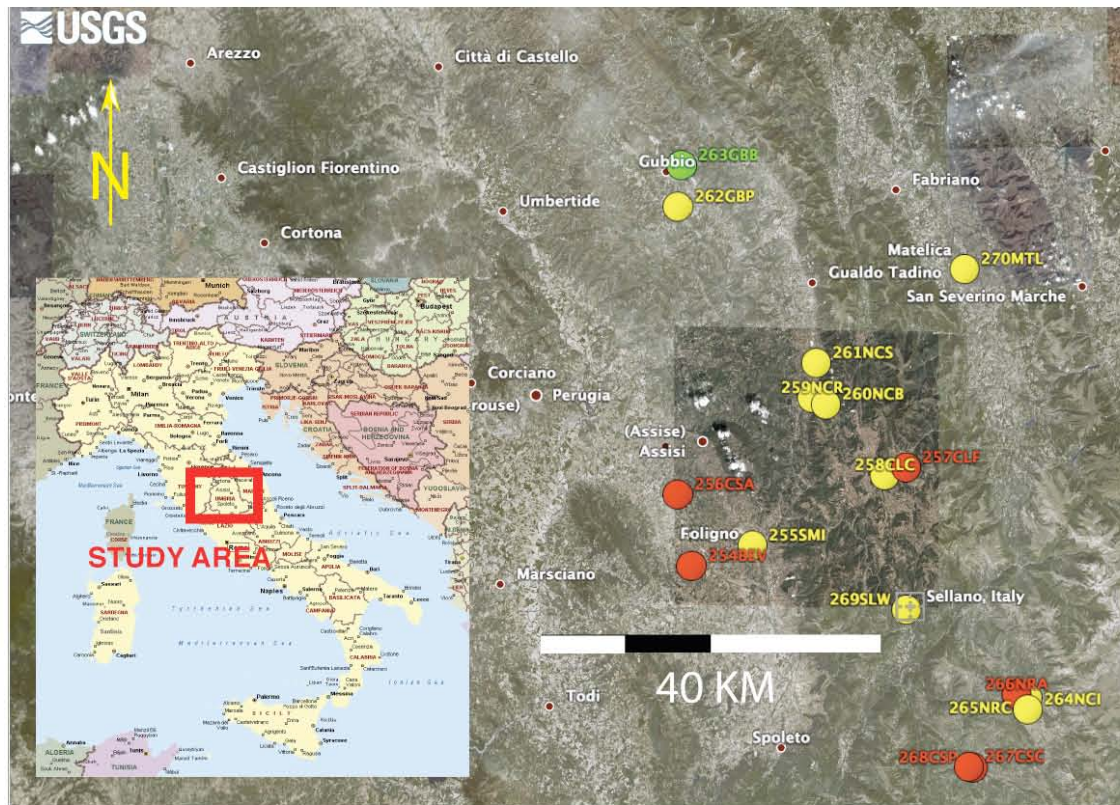


Figure 1. The seventeen Italian sites tested in this study are located in the regions of Umbria and Marche. The color of the site marker indicates NEHRP classification for D (Red), C (Yellow), and B (Green) V_{s30} velocities. Refer to Table 1 for site and velocity classification data.

For the seventeen Italian sites, we use a surface wave testing system and a crew of two people to collect dispersion data. The test apparatus consist of 1-Hz seismometers, a low frequency spectrum analyzer, two computer-controlled electro-mechanical harmonic-wave sources (shakers) and their amplifiers, cables and approximately 4.0 kW of total electrical output from generators made available in each test region. The 1-Hz Kinometrics receivers we use are designed for capturing vertical motions and cover the frequency range of interest in the active-source surface-wave test. For a source, the spectrum analyzer produces a sine wave signal that is split into a parallel circuit and by two separate power amplifiers to produce an in-phase continuous harmonic-wave. Two arrayed APS Dynamics Model 400 electro-mechanical shakers receive the input waveform and oscillate in vertical motion to excite the ground. The receivers record the waves and a fast Fourier transform (FFT) is performed on each of the two receiver signals. In near-real time, the linear spectra, cross-power spectra, and coherence are computed. The ability to perform near real-time frequency domain calculations and monitor the progress and quality of the test allows us to adjust various aspects of the test to optimize the capture of the phase data. These aspects include the source-wave generation, frequency step-size between each sine-wave burst, number of cycles-per-frequency, total frequency range of all the steps, and receiver spacing.

The dual shaker-sources are arrayed orthogonally to the SASW seismometer line. The test steps through a suite of frequencies, and for each frequency phase computations are made. This method of swept-sine surface wave testing sweeps through a broad range of low frequencies in order to capture the

surface wave-dispersion characteristics of the ground. This approach is a modification of the Continuous Sine Wave Source Spectral Analysis of Surface Waves (CSS-SASW) test presented by Kayen and others (2004a; 2005).

Spacing of the receivers stepped geometrically from 1 meter to 160 meters. The two seismometers are separated by a given distance, d , and the source is usually placed at a distance of d from the inner seismometer (Figure 6). Rayleigh wave wavelengths (λ) are computed by relating the seismometer spacing (δ) and the phase angle (θ , in radians determined from the peak of the cross-power spectrum) between the seismometers:

$$\lambda = 2\pi d/\theta \tag{1}$$

The Rayleigh wave surface wave velocity, V_r , is computed as the product of the frequency and its associated wavelength:

$$V_r = f\lambda \tag{2}$$



Figure 2. Configuration of the USGS surface wave testing system at site 262GBP Gubbio Soil Site Piana (43.314°N,12.59°E) composed of 1-Hz vertical motion sensors and two-100 kg electro-mechanical harmonic wave shakers. The shaker apparatus are arrayed in a parallel circuit and synchronized in phase for controlled swept-sine analysis.

Computing the average dispersion curve for a site requires that we collect a suite of individual data sets that relate Rayleigh wave phase velocities to their corresponding frequencies and wave-lengths. Regardless of the array dimensions, we routinely compute phase velocities for phase angles between 120 degrees and 1080 degrees, corresponding to wavelengths of $3d$ and $d/3$ respectively. If the data are noisy, the range is narrowed to 180 degrees and 720 degrees, or $2d$ and $d/2$. For example, if the array separation was 3 meters, velocities are inverted for Rayleigh wavelengths of 1m-to-9meters. Longer wavelengths sound more deeply into the ground and are needed to extend profile depths. These long wavelength data are associated with low frequencies. Figure 3 presents a plot of a group of eight individual dispersion curves that together cover a range of wavelengths from 0.6 meters–to-400 meters. The averaged dispersion curve from these eight profiles is used to invert the velocity structure of the ground.

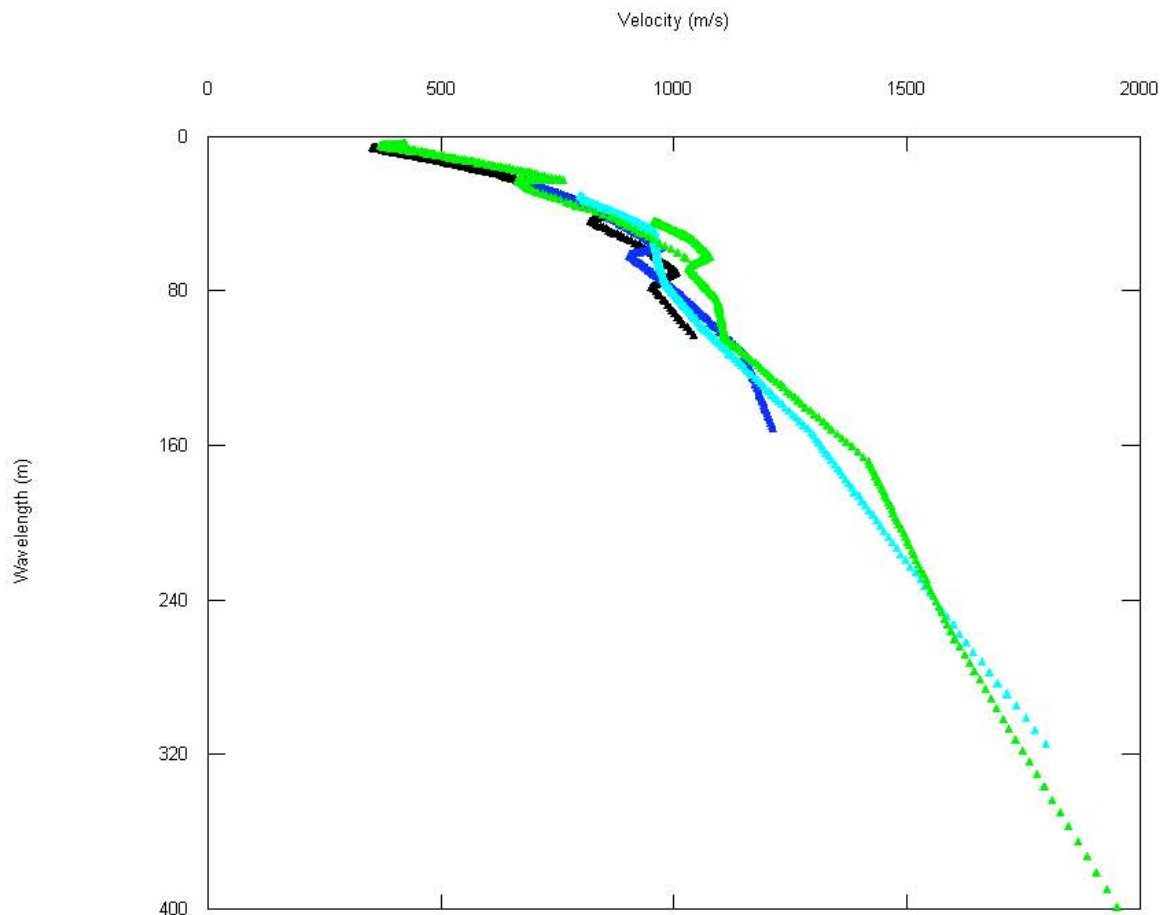


Figure 3. A group of eight dispersion curves covering a wavelength range of 1 meter to 400 meters (Site 267CSC, Cascia, Umbria).

The inversion process is used to estimate the soil stiffness model having a computed *theoretical*-dispersion curve that is a best-fit with the experimental dispersion data collected in the field. That is, we invert shear wave velocity profiles using an inversion code that hunts for the best-fit shear wave velocity profile whose theoretical dispersion curve is the closest match with the averaged field dispersion curve. The term “best-fit” refers to the minimum sum of the squares of residuals from the differences between the theoretical and experimental dispersion curves. The inversion algorithm, WaveEq of OYO Corp. (Hayashi and Kayen, 2003) uses an automated-numerical approach that employs a constrained least-squares fit of the theoretical and experimental dispersion curves. For the Cascia, Umbria site, noted above in Figure 3, we invert a shear wave velocity structure that rapidly climbs in stiffness from less than 300 m/s at the surface to in excess of 1900 m/s at 40 meters. The averaged $V_{s,30}$ value for this site is 540 m/s.

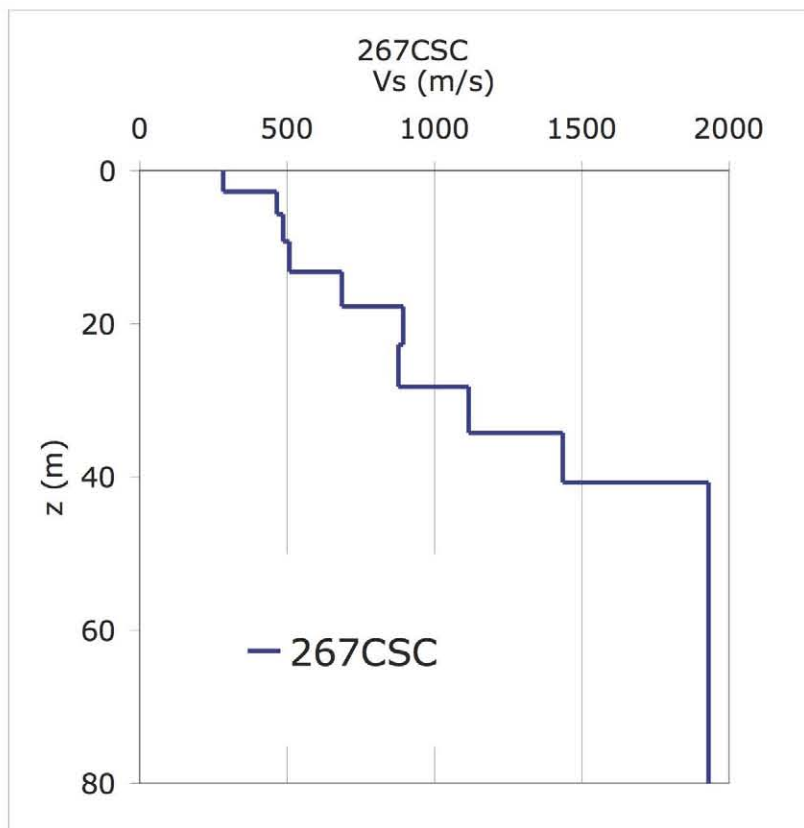


Figure 4. Shear wave velocity profile for Cascia, Umbria site 267CSC.

The testing program investigated seventeen sites in Umbria and Marche. These sites are listed in the order they were tested in Table 1. Typically, the strong motion recording (SMR) stations are located in residential or light industrial sites outside the town center, parks, or on private farm land. We located the testing system next to the SMR stations, or the GPS location of the site if we could not observe the SMR station.

SITE	SITE NAME	TOWN	REGION	LAT	LON	NEHRP	Vs_30 (m/s)	NEHRP(SUB)	VS_100 (m/s)
254BEV	BEVAGNA CHURCH ST	BEVAGNA	UMBRIA	42.932	12.611	D	182	D-	278
255 SMI	MARIA CASTEL	FOLIGNO	UMBRIA	42.954	12.699	C	395	C-	527
256CSA	NUOVO ASSISI	ASSISI	UMBRIA	43.008	12.591	D	293	D+	440
257CLF	COLFIORITO COLFIORITO-	COLFIORITO	UMBRIA	43.037	12.921	D	317	D+	719
258CLC	CASERMETTE	COLFIORITO	UMBRIA	43.029	12.890	C	405	C-	720
259NCR	NOCERA STATION-B	NOCERA	UMBRIA	43.111	12.785	C	428	C-	938
260NCB	BISCONTIN STATION-C	UMBRA - B NOCERA	UMBRIA	43.104	12.805	C	442	C-	823
261NCS	GRAVEL ROAD GUBBIO SOIL	UMBRA - C	UMBRIA	43.148	12.791	C	694	C+	1170
262GBP	SITE PIANA GUBBIO -	GUBBIO	UMBRIA	43.314	12.590	C	492	C+	864
263GBB	PARK COLLO NORCIA INDUSTRIAL	GUBBIO	UMBRIA	43.358	12.595	B	922	B-	1759
264NCI	PARK	NORCIA NORCIA	UMBRIA	42.780	13.097	C	551	C+	546
265NRC	NORCIA SITE C NORCIA TEMP.	SITE C	UMBRIA	42.792	13.097	C	677	C+	1148
266NRA	STA. A	NORCIA	UMBRIA	42.796	13.081	D	218	D-	264
267CSC	CASCIA CASCIA PETRUCCI	CASCIA	UMBRIA	42.719	13.012	C	540	C+	993
268CSP	APTMTS SELLANO	CASCIA	UMBRIA	42.718	13.018	D	339	D+	488
269SLW	WEST	SELLANO	UMBRIA	42.886	12.922	C	509	C-	713
270MTL	MATELICA	MATELICA	MARCHE	43.248	13.008	C	437	C-	767

Table 1. Italian station locations and their corresponding SASW and SMR site identifier. The computed 30- and 100-meter average shear wave velocities and site codes are presented as V_{S30} , V_{S100} and NEHRP.

The inversion of a theoretical velocity profile was performed using the inversion code Wave-EQ. Typically, a ten to fifteen layer model was used for the inversion, with layer thicknesses geometrically expanding with depth. The increasing layer thicknesses correspond with decreasing dispersion information in the longer wavelength (deeper) portion of the dispersion curve. The profiles generally increase in stiffness with depth, though low velocity layers are present in several of the profiles.

The simplest way of characterizing the overall site condition is to use the average shear wave velocity in the uppermost 30 meters or 100 meters of the subsurface (V_{s30} from the IBC, 2002; V_{s100}). Equation 3 is used to compute this average velocity based on the unit layer thickness (d_i) and the corresponding interval-velocity (V_{Si}).

$$V_{S\text{-depth-averaged}} = \frac{\sum_{i=1}^n d_i}{\sum_{i=1}^n \frac{d_i}{V_{Si}}} \quad (3)$$

The Italian SMR averaged velocities for the upper 30 meters ranged from 182 to 922 m/s. The velocities fall within NEHRP categories “D”-through- “B”.

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Appendix 1.

Seismic s-wave velocity profiles, and dispersion curve data sets for the seventeen Italy stations.

UMBRIA-MARCHE, ITALY SMR Stations

Site ID 254BEV

NEHRP CLASS: D

Vs30 182 (m/s)

SUB-CLASS D-

Vs100 278 (m/s)

Location

SMR Station SMI

State UMBRIA

Description

POSITION BEVAGNA

LAT (N) 42.9324

LON (E) 12.6111

Data Type

SWEPT-SINE SASW

KAYEN, SCASSERRA

11-Nov-2006

TEST METHODS

PARALLEL-ARRAY SOURCES;

CONTINUOUS HARMONIC

WAVE-SASW; 3D AMBIENT

MICROTREMOR ANALYSIS

PROJECT NAME

UMBRIA-MARCHE

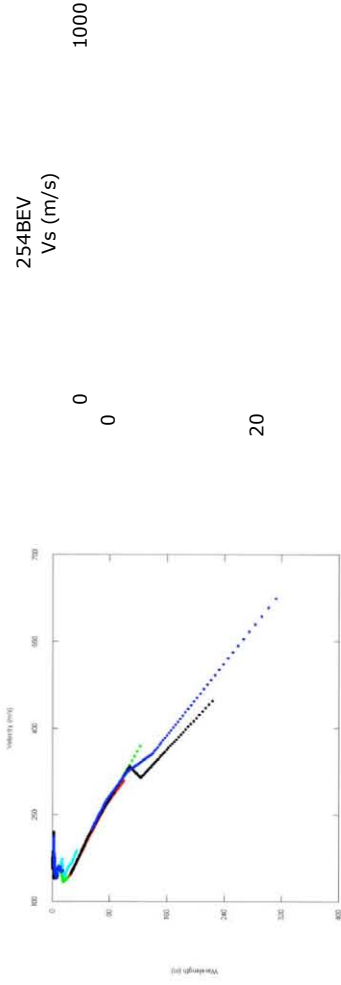
SMR CHARACTERIZATION

PEER, UNIV OF ROME

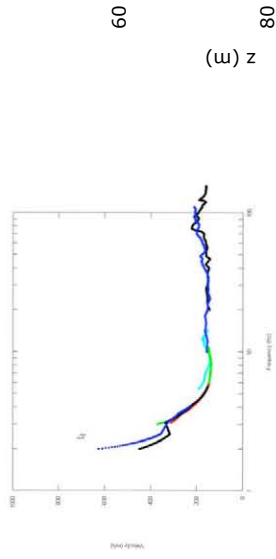
SPONSOR

SITE SUB CLASS:

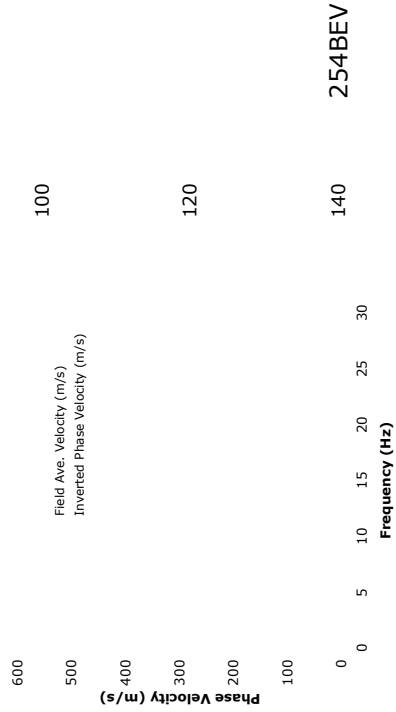
- A > 1500 m/s
 - B+ 1080 < Vs30 ≤ 1500 m/s
 - B- 720 < Vs30 ≤ 1080 m/s
 - C+ 540 < Vs30 ≤ 720 m/s
 - C- 360 < Vs30 ≤ 540 m/s
 - D+ 270 < Vs30 ≤ 360 m/s
 - D- 180 < Vs30 ≤ 270 m/s
 - E < 180 m/s
- Special Soil Conditions: Liquefiable soils; quick clays; soft/medium stiff clays thicker than 36m; and high permeability collapsible cemented soils; very soft/medium stiff clays thicker than 6m; soft/medium stiff clays thicker than 36m.



(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,



(D) Shear Wave Velocity SASW

254BEV	DISPERSION DATA		INVERSION PROFILE	
Site Disp. Vr (m/s)	Theoretical Disp. Vr (m/s)	Frequency (Hz)	Inversion Vs (m/s)	Depth (m)
540.0	522.9	1.9	160.8	0.0
375.0	393.4	2.5	160.8	2.8
275.9	244.3	3.6	151.6	2.8
148.5	157.1	6.4	151.6	5.8
144.7	148.5	9.7	144.2	5.8
157.5	147.5	13.6	144.2	9.3
159.8	147.7	16.5	147.9	9.3
152.5	148.2	19.9	175.8	13.3
149.0	148.5	23.0	175.8	13.3
150.7	148.8	26.3	175.8	17.8
151.7	148.9	29.5	210.7	17.8
149.4	148.9	32.6	210.7	22.8
152.1	148.6	35.8	277.3	22.8
153.8	148.4	38.8	277.3	28.3
155.7	148.0	42.4	230.2	28.3
145.8	147.8	45.5	230.2	34.3
155.3	147.5	48.7	264.8	34.3
160.2	147.3	52.3	264.8	40.8
158.6	147.2	54.9	288.6	40.8
157.3	147.0	58.5	288.6	52.8
			347.6	52.8
			347.6	66.3
			396.4	66.3
			396.4	82.8
			589.2	82.8
			589.2	100.8
			619.4	100.8
			619.4	120.3
			683.5	120.3
			683.5	150.3
			683.5	150.3
			Vs30	181.8

UMBRIA-MARCHE, ITALY SMR Stations

Site ID 255 SMI

NEHRP CLASS: C

Vs30 395 (m/s)

SUB-CLASS C-

Vs100 527 (m/s)

Location

SMR Station SMI

State UMBRIA

Description CHURCH ST MARIA

POSITION FOLIGNO

LAT (N) 42.95417

LON (E) 12.69892

Data Type

Investigators KAYEN, SCASSERRA

Date collected 12-Nov-2006

TEST METHODS

PARALLEL-ARRAY SOURCES;
CONTINUOUS HARMONIC
WAVE-SASW; 3D AMBIENT
MICROTREMOR ANALYSIS

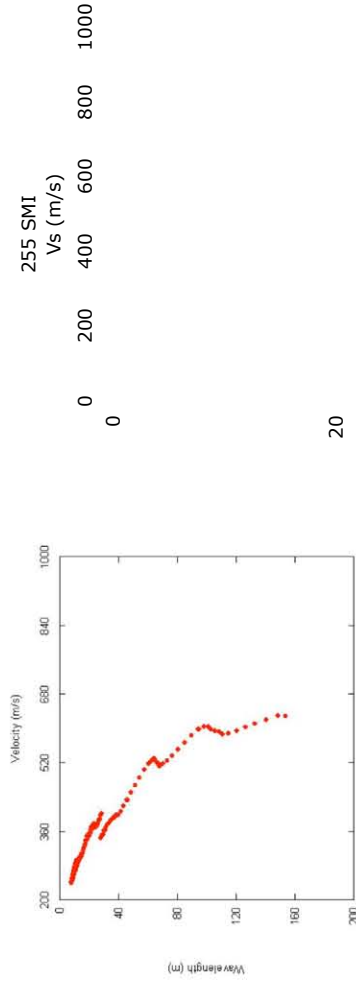
PROJECT NAME

UMBRIA-MARCHE
SMR CHARACTERIZATION
PEER, UNIV OF ROME

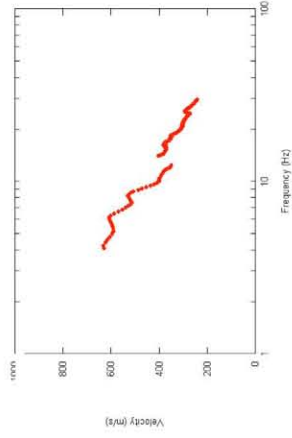
SPONSOR

SITE SUB CLASS:

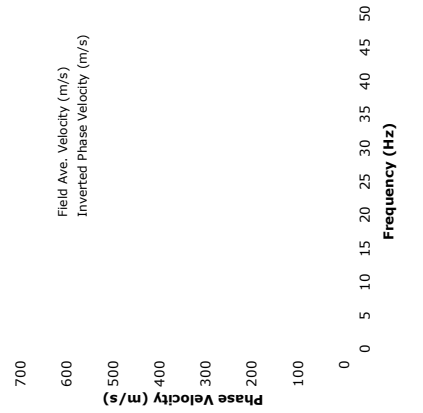
- A > 1500 m/s
 - B+ 1080 < Vs30 ≤ 1500 m/s
 - B- 720 < Vs30 ≤ 1080 m/s
 - C+ 540 < Vs30 ≤ 720 m/s
 - C- 360 < Vs30 ≤ 540 m/s
 - D+ 270 < Vs30 ≤ 360 m/s
 - D- 180 < Vs30 ≤ 270 m/s
 - E < 180 m/s
- Special Soil Conditions: Liquefiable soils; quick
and high permeability clay, collapsible cemented soils,
very soft soils, and soils with high plasticity
soft/medium stiff clays thicker than 36m.



(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,

255 SMI

(D) Shear Wave Velocity SASW

255 SMI	DISPERSION DATA		Frequency (Hz)	INVERSION PROFILE	
Site Disp. Vr (m/s)	Theoretical Disp. Vr (m/s)		Inversion Vs (m/s)	Depth (m)	
629.4	578.0	4.1	254.3	0.0	
631.3	576.8	4.3	254.3	5.5	
621.5	575.4	4.4	416.8	5.5	
611.7	573.9	4.6	416.8	11.5	
604.0	572.4	4.8	370.0	11.5	
596.1	570.8	4.9	370.0	18.5	
589.6	569.1	5.1	519.8	18.5	
587.9	567.2	5.3	519.8	26.5	
593.5	565.3	5.5	628.1	26.5	
596.2	563.1	5.6	628.1	35.5	
600.2	560.7	5.8	615.1	35.5	
605.2	558.1	6.0	615.1	45.5	
605.8	555.3	6.2	631.3	45.5	
600.2	552.0	6.3	631.3	56.5	
585.0	548.5	6.5	615.2	56.5	
567.8	544.6	6.7	615.2	68.5	
552.0	540.1	6.9	575.4	68.5	
537.7	535.1	7.0	575.4	81.5	
526.0	529.9	7.2	631.3	81.5	
518.0	524.1	7.4	631.3	100.0	
513.4	518.0	7.6			
518.7	511.7	7.7			
521.6	504.9	7.9			
525.3	497.6	8.1			
530.3	490.1	8.2			
524.7	483.1	8.4			
519.2	475.9	8.6			
504.9	468.9	8.8			
486.1	462.2	8.9			
469.2	455.9	9.1			
451.7	449.6	9.3			
434.4	443.7	9.5			
			Vs30		395.2

UMBRIA-MARCHE, ITALY SMR Stations

Site ID 256CSA

NEHRP CLASS: D
Vs30 293 (m/s)

SUB-CLASS D+
Vs100 440 (m/s)

Location

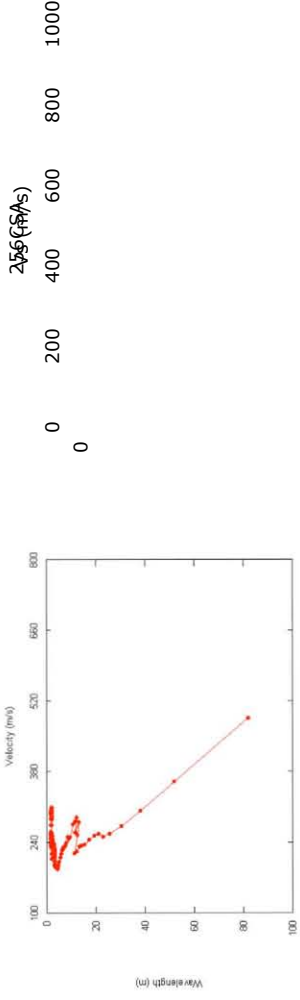
SMR Station CSAD
State UMBRIA
Description CASTEL NUOVO ASSISI
POSITION ASSISI
LAT (N) 43.0081
LON (E) 12.5905

Data Type SWEPT-SINE SASW
Investigators KAYEN, SCASSERRA
Date collected 12-Nov-2006

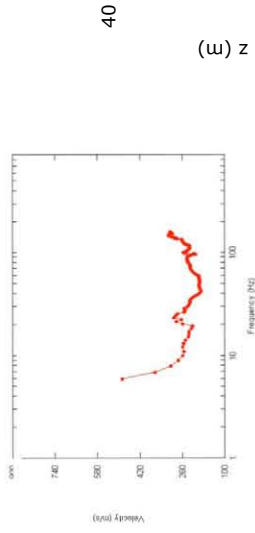
TEST METHODS PARALLEL-ARRAY SOURCES;
 CONTINUOUS HARMONIC
 WAVE-SASW; 3D AMBIENT
 MICROTREMOR ANALYSIS

PROJECT NAME UMBRIA-MARCHE
SMR CHARACTERIZATION
SPONSOR PEER, UNIV OF ROME

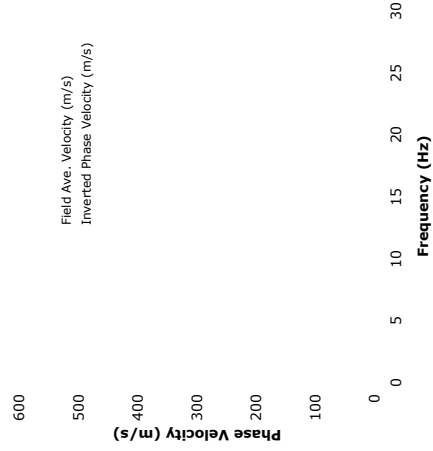
SITE SUB CLASS: **Vs30 (m/s)**
 A >1500 m/s
 B+ 1080 < Vs30 ≤ 1500 m/s
 B- 720 < Vs30 ≤ 1080 m/s
 C+ 540 < Vs30 ≤ 720 m/s
 C- 360 < Vs30 ≤ 540 m/s
 D+ 270 < Vs30 ≤ 360 m/s
 D- 180 < Vs30 ≤ 270 m/s
 E <180 m/s
Special Soil Conditions: Liquefiable soils; quick
 clays; highly compressible cemented soils;
 and high permeability collapsible cemented soils;
 with weight 25% or greater of clay content 0m,
 soft/medium stiff clays thicker than 36m.



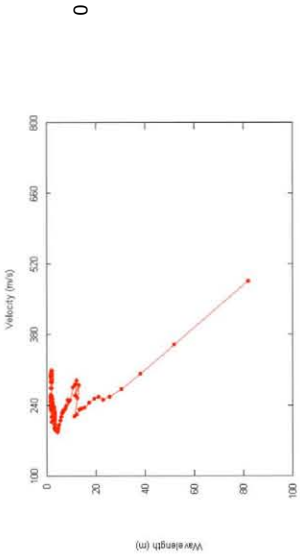
(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,



(D) Shear Wave Velocity SASW



256CSA	DISPERSION DATA				INVERSION PROFILE	
Site Disp. Vr (m/s)	Theoretical Disp. Vr (m/s)	Frequency (Hz)	Inversion Vs (m/s)	Depth (m)		
486.1	475.3	5.9	192.7	0.0		
360.5	367.6	6.9	192.7	2.8		
303.5	306.9	8.0	215.4	2.8		
273.0	279.2	9.0	215.4	5.8		
257.8	265.3	10.0	236.1	5.8		
252.1	258.2	10.9	236.1	9.3		
257.8	253.1	12.1	236.6	9.3		
253.7	250.5	13.1	236.6	13.3		
246.1	249.0	14.1	319.3	13.3		
246.1	248.1	15.2	319.3	17.8		
246.1	247.7	16.2	349.3	17.8		
246.1	247.5	17.2	349.3	22.8		
246.1	247.5	18.3	510.1	22.8		
232.7	247.5	19.3	510.1	28.3		
255.7	247.5	20.2	545.3	28.3		
251.4	247.5	21.4	545.3	34.3		
251.4	247.5	22.4	578.2	34.3		
251.4	247.3	23.4	578.2	40.8		
251.4	246.9	24.4	565.8	40.8		
251.4	246.2	25.5	565.8	54.1		
251.4	245.3	26.6	559.2	54.1		
246.9	243.9	27.6	559.2	69.1		
252.1	242.1	28.6	600.2	69.1		
240.1	239.6	29.6	600.2	100.0		
235.4	236.5	30.6				
231.1	232.9	31.6				
229.5	228.9	32.6				
231.8	224.7	33.7				
228.4	220.6	34.8				
224.0	217.0	35.8				
218.1	213.7	36.8				
211.3	210.5	37.8				
			Vs30	293.2		

UMBRIA-MARCHE, ITALY SMR Stations

Site ID 257CLF

NEHRP CLASS: D

Vs30 317 (m/s)

SUB-CLASS D+

Vs100 719 (m/s)

Location

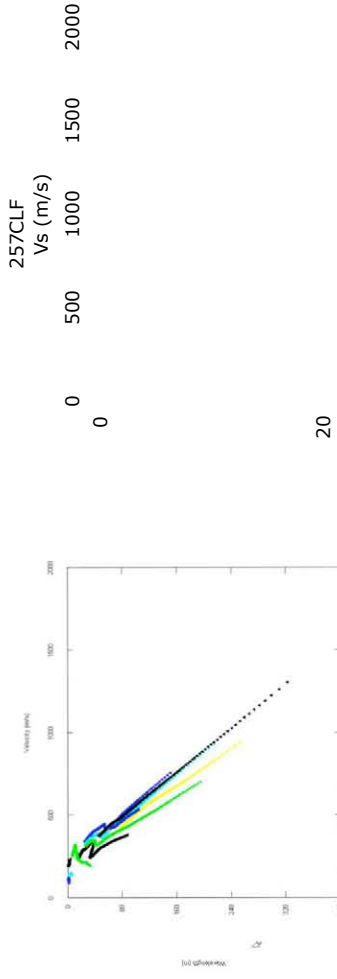
SMR Station CLF
State UMBRIA
Description COLFIORITO-NR.MARCHE BRDR
POSITION COLFIORITO
LAT (N) 43.03737
LON (E) 12.92118

Data Type SWEPT-SINE SASW
Investigators KAYEN, SCASSERRA
Date collected 11/13/200

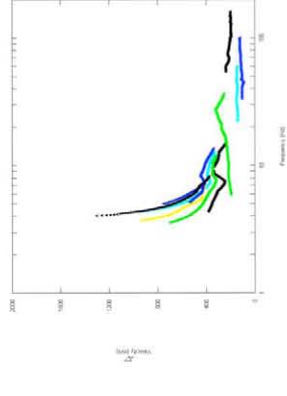
TEST METHODS PARALLEL-ARRAY SOURCES;
 CONTINUOUS HARMONIC
 WAVE-SASW; 3D AMBIENT
 MICROTREMOR ANALYSIS

PROJECT NAME UMBRIA-MARCHE
SMR CHARACTERIZATION
SPONSOR PEER, UNIV OF ROME

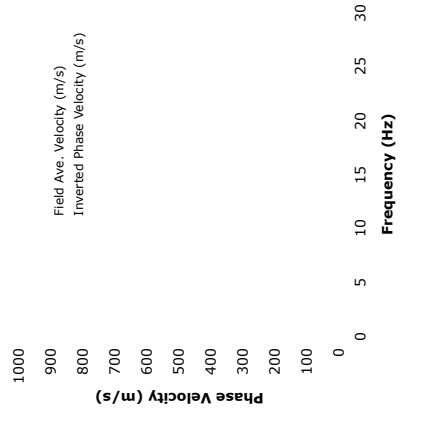
SITE SUB CLASS: **Vs30 (m/s)**
 A >1500 m/s
 B+ 1080 < Vs30 ≤ 1500 m/s
 B- 720 < Vs30 ≤ 1080 m/s
 C+ 540 < Vs30 ≤ 720 m/s
 C- 360 < Vs30 ≤ 540 m/s
 D+ 270 < Vs30 ≤ 360 m/s
 D- 180 < Vs30 ≤ 270 m/s
 E <180 m/s
Special Soil Conditions: Liquefiable soils; quick
 and high permeability clay; collapsible cemented soils;
 and soils with Vs30 or Vs100 greater than 360 m/s;
 soft/medium stiff clays thicker than 36m.



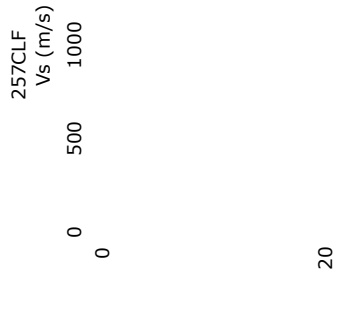
(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,



(D) Shear Wave Velocity SASW



UMBRIA-MARCHE, ITALY SMR Stations

Site ID 257CLF

NEHRP CLASS: D

Vs30 317 (m/s)

SUB-CLASS D+

Vs100 719 (m/s)

Location

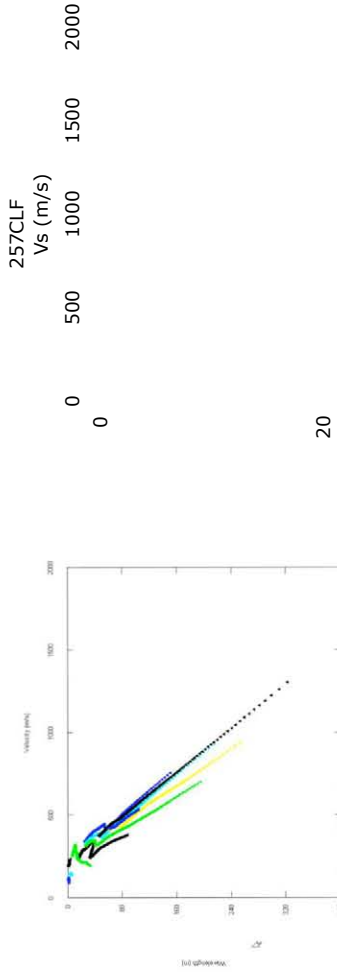
SMR Station CLF
State UMBRIA
Description COLFIORITO-NR.MARCHE BRDR
POSITION COLFIORITO
LAT (N) 43.03737
LON (E) 12.92118

Data Type SWEPT-SINE SASW
Investigators KAYEN, SCASSERRA
Date collected 11/13/200

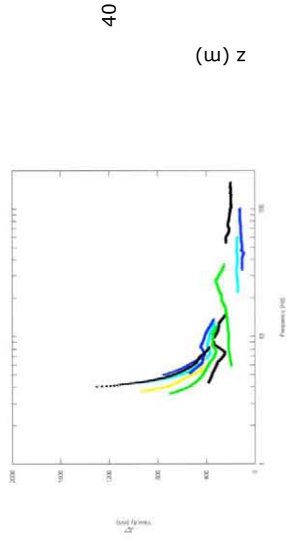
TEST METHODS PARALLEL-ARRAY SOURCES;
 CONTINUOUS HARMONIC
 WAVE-SASW; 3D AMBIENT
 MICROTREMOR ANALYSIS

PROJECT NAME UMBRIA-MARCHE
SMR CHARACTERIZATION
SPONSOR PEER, UNIV OF ROME

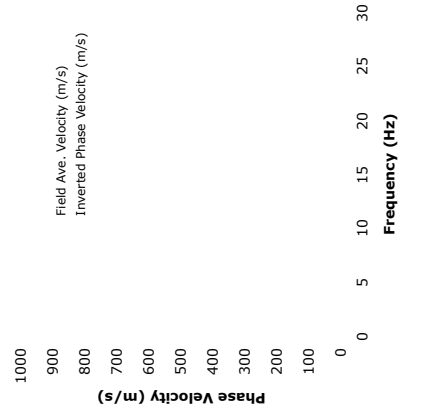
SITE SUB CLASS: **Vs30 (m/s)**
 A >1500 m/s
 B+ 1080 < Vs30 ≤ 1500 m/s
 B- 720 < Vs30 ≤ 1080 m/s
 C+ 540 < Vs30 ≤ 720 m/s
 C- 360 < Vs30 ≤ 540 m/s
 D+ 270 < Vs30 ≤ 360 m/s
 D- 180 < Vs30 ≤ 270 m/s
 E <180 m/s
Special Soil Conditions: Liquefiable soils; quick
 and high permeability clay; collapsible cemented soils;
 and soils with Vs30 or Vs100 greater than 1250 or
 soft/medium stiff clays thicker than 36m.



(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,



(D) Shear Wave Velocity SASW



UMBRIA-MARCHE, ITALY SMR Stations
Site ID 258CLC
NEHRP CLASS: C
Vs30 405 (m/s)
SUB-CLASS C-
Vs 80 720 (m/s)
Location

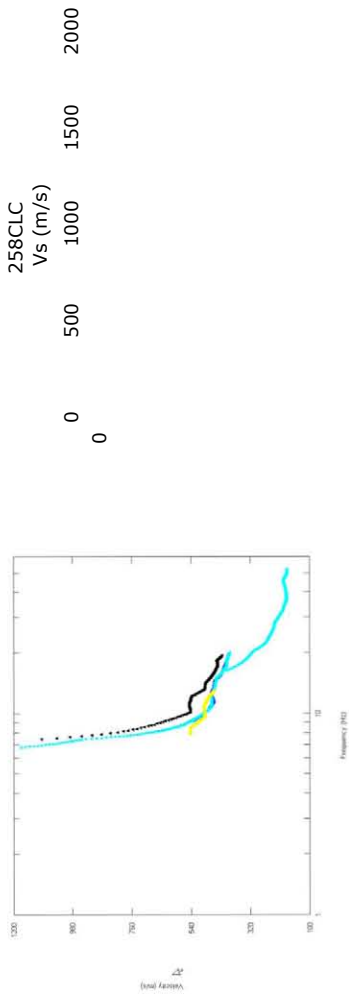
SMR Station CLF
State UMBRIA
Description COLFIORITO-CASERMETTE
POSITION COLFIORITO
LAT (N) 43.02865
LON (E) 12.89037

Data Type SWEPT-SINE SASW
Investigators KAYEN, SCASSERRA
Date collected 11/13/200

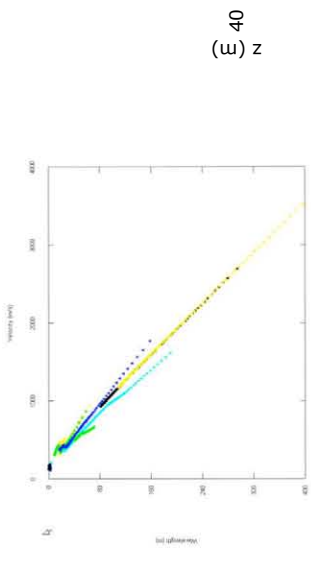
TEST METHODS
 PARALLEL-ARRAY SOURCES;
 CONTINUOUS HARMONIC
 WAVE-SASW; 3D AMBIENT
 MICROTREMOR ANALYSIS

PROJECT NAME UMBRIA-MARCHE
SMR CHARACTERIZATION
SPONSOR PEER, UNIV OF ROME

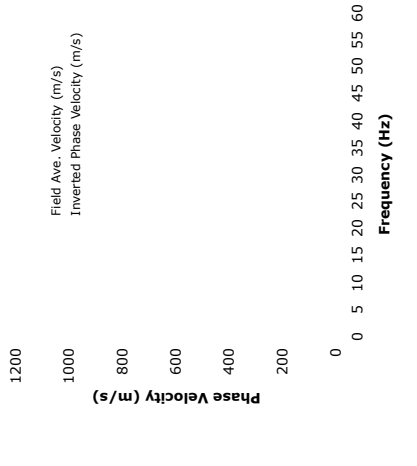
SITE SUB CLASS: **Vs30 (m/s)**
 A >1500 m/s
 B+ 1080 < Vs30 ≤ 1500 m/s
 B- 720 < Vs30 ≤ 1080 m/s
 C+ 540 < Vs30 ≤ 720 m/s
 C- 360 < Vs30 ≤ 540 m/s
 D+ 270 < Vs30 ≤ 360 m/s
 D- 180 < Vs30 ≤ 270 m/s
 E <180 m/s
 F Special Soil Conditions: Liquefiable soils; quick
 and high permeability clay; collapsible cemented soils;
 very soft soils; soft soils with thin clay
 partings; soft/medium stiff clays thicker than 36m.



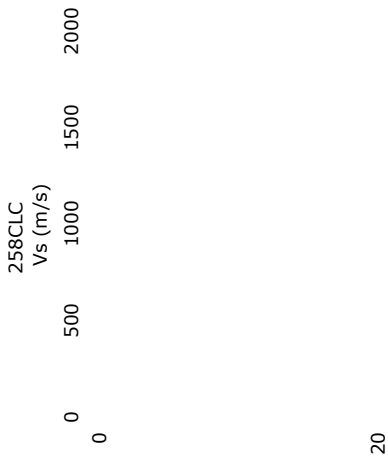
(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,



(D) Shear Wave Velocity SASW

258CLC	DISPERSION DATA		INVERSION PROFILE	
Site Disp. Vr (m/s)	Theoretical Disp. Vr (m/s)	Frequency (Hz)	Inversion Vs (m/s)	Depth (m)
1171.0	858.0	6.8	180.5	0.0
1110.7	844.3	6.9	180.5	2.8
997.7	808.2	7.2	273.0	2.8
916.4	776.4	7.5	273.0	5.8
721.5	746.8	7.9	366.0	5.8
624.3	723.3	8.1	366.0	9.3
588.7	699.2	8.5	435.0	9.3
569.1	676.5	8.8	435.0	13.3
541.9	654.9	9.1	373.5	13.3
526.4	635.1	9.4	373.5	17.8
508.6	613.0	9.7	683.1	17.8
496.3	590.4	10.0	683.1	22.8
491.4	567.8	10.3	755.1	22.8
484.9	544.7	10.6	755.1	28.3
482.3	521.8	10.9	700.3	28.3
478.3	501.2	11.2	700.3	34.3
476.7	482.9	11.5	1029.2	34.3
476.3	466.5	11.8	1029.2	40.8
473.2	452.4	12.1	1597.3	40.8
471.7	440.3	12.4	1597.3	80.0
464.0	429.7	12.7		
461.8	420.7	13.0		
459.9	411.4	13.4		
457.4	404.0	13.6		
457.0	397.3	13.9		
454.3	390.7	14.3		
453.3	384.7	14.6		
449.5	379.1	14.9		
442.9	374.0	15.2		
437.3	368.8	15.5		
431.1	364.1	15.8		
428.3	359.5	16.1		
			Vs30	404.7

UMBRIA-MARCHE, ITALY SMR Stations

Site ID 259NCR
NEHRP CLASS: C
Vs30 428 (m/s)
SUB-CLASS C-
Vs100 938 (m/s)

Location

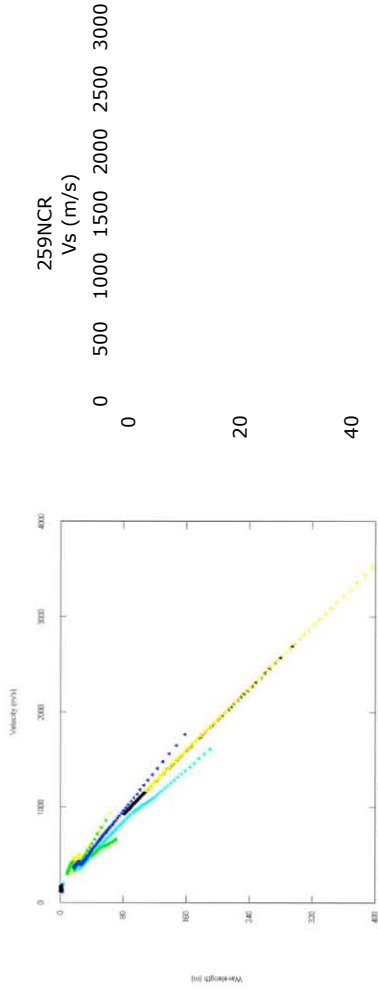
SMR Station NCR
State UMBRIA
Description NOCERA
POSITION NOCERA
LAT (N) 43.11134
LON (E) 12.78467

Data Type SWEPT-SINE SASW
Investigators KAYEN, SCASSERRA
Date collected 14-Nov-2006

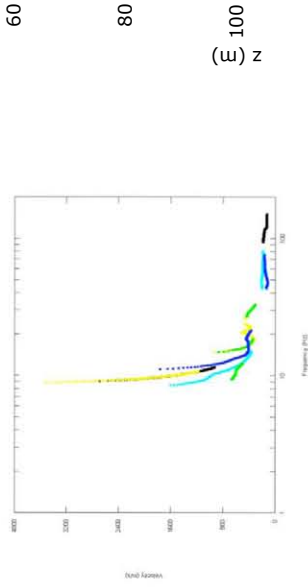
TEST METHODS
 PARALLEL-ARRAY SOURCES;
 CONTINUOUS HARMONIC
 WAVE-SASW; 3D AMBIENT
 MICROTREMOR ANALYSIS

PROJECT NAME UMBRIA-MARCHE
SMR CHARACTERIZATION
SPONSOR PEER, UNIV OF ROME

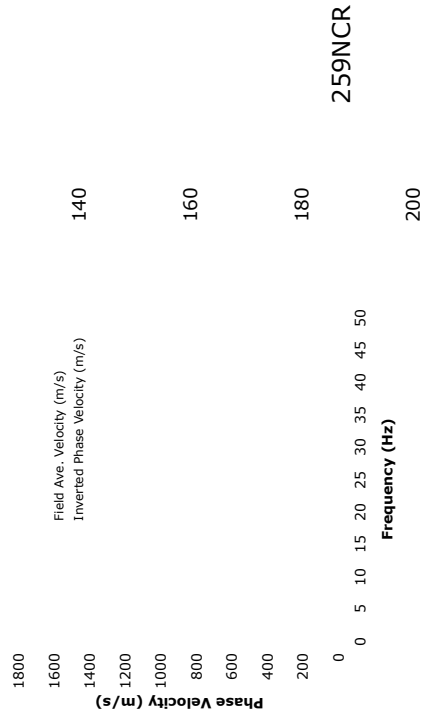
SITE SUB CLASS: **Vs30 (m/s)**
 A >1500 m/s
 B+ 1080 < Vs30 ≤ 1500 m/s
 B- 720 < Vs30 ≤ 1080 m/s
 C+ 540 < Vs30 ≤ 720 m/s
 C- 360 < Vs30 ≤ 540 m/s
 D+ 270 < Vs30 ≤ 360 m/s
 D- 180 < Vs30 ≤ 270 m/s
 E <180 m/s
Special Soil Conditions: Liquefiable soils; quick
 and high permeability clay; collapsible cemented soils;
 and highly compressible soils with high plasticity
 (liquid limit > 75% or water content > 25% or
 soft/medium stiff clays thicker than 36m).



(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,



(D) Shear Wave Velocity SASW

259NCR	DISPERSION DATA		INVERSION PROFILE	
Site Disp. Vr (m/s)	Theoretical Disp. Vr (m/s)	Frequency (Hz)	Inversion Vs (m/s)	Depth (m)
2000.0	1713.5	6.7	175.5	0.0
1600.0	1538.5	7.3	175.5	2.8
1559.8	1494.7	7.4	386.7	2.8
1403.4	1199.7	8.5	386.7	5.8
1318.9	1037.8	9.4	443.7	5.8
1218.6	927.9	10.3	443.7	9.3
885.3	848.4	11.3	446.6	9.3
646.4	781.9	12.2	446.6	13.3
537.8	714.3	13.2	466.1	13.3
525.6	638.7	14.2	466.1	17.8
517.3	549.6	15.1	446.5	17.8
434.0	466.2	16.1	446.5	22.8
393.3	421.1	17.1	721.9	22.8
380.2	395.5	18.0	721.9	28.3
404.3	378.6	19.0	1275.9	28.3
403.2	367.5	20.0	1275.9	34.3
409.8	359.9	20.9	1601.2	34.3
408.7	353.8	22.0	1601.2	40.8
398.9	349.5	22.9	1666.2	40.8
406.3	347.3	23.5	1666.2	56.8
402.7	340.4	26.2	2090.6	56.8
407.0	339.4	26.8	2090.6	74.8
402.3	338.0	27.7	2307.8	74.8
403.3	336.8	28.7	2307.8	94.8
386.2	335.8	29.6	2337.3	94.8
357.2	335.0	30.6	2337.3	116.8
333.0	335.0	31.6	2298.2	116.8
0.0	0.0	0.0	2298.2	140.8
0.0	0.0	0.0	2289.1	140.8
0.0	0.0	0.0	2289.1	166.8
0.0	0.0	0.0	2289.1	166.8
0.0	0.0	0.0	Vs30	427.9

UMBRIA-MARCHE, ITALY SMR Stations

Site ID 260NCB
NEHRP CLASS: C
Vs30 442 (m/s)
SUB-CLASS C-
Vs100 823 (m/s)

Location

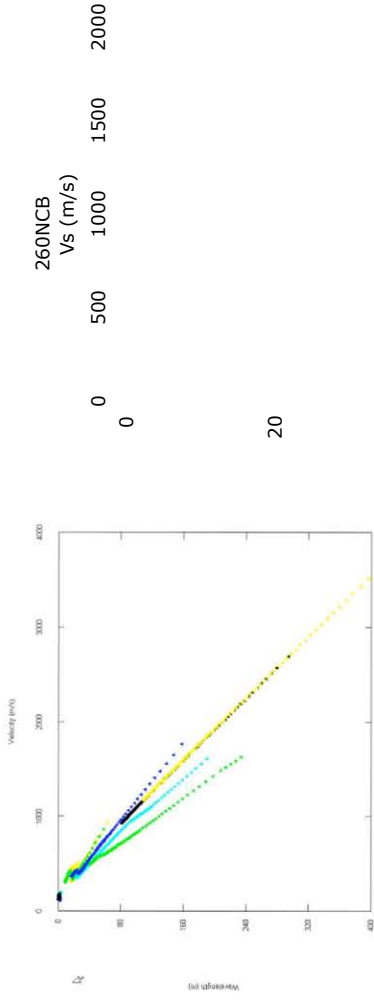
SMR Station NCB
State UMBRIA
Description STATION-B BISCONTIN
POSITION NOCERA UMBRA - B
LAT (N) 43.10358
LON (E) 12.80518

Data Type SWEPT-SINE SASW
Investigators KAYEN, SCASSERRA
Date collected 14-Nov-2006

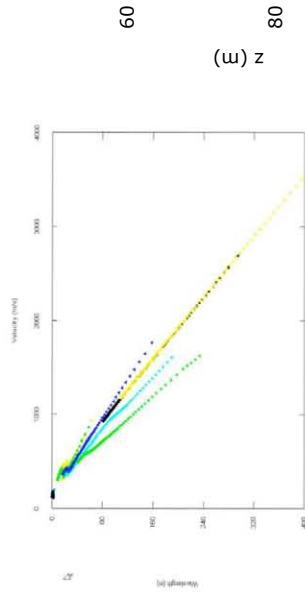
TEST METHODS
 PARALLEL-ARRAY SOURCES;
 CONTINUOUS HARMONIC
 WAVE-SASW; 3D AMBIENT
 MICROTREMOR ANALYSIS

PROJECT NAME UMBRIA-MARCHE
SPONSOR SMR CHARACTERIZATION
 PEER, UNIV OF ROME

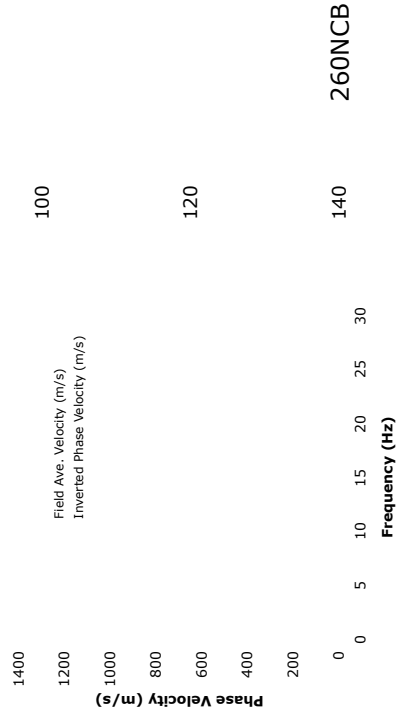
SITE SUB CLASS: **Vs30 (m/s)**
 A >1500 m/s
 B+ 1080 < Vs30 ≤ 1500 m/s
 B- 720 < Vs30 ≤ 1080 m/s
 C+ 540 < Vs30 ≤ 720 m/s
 C- 360 < Vs30 ≤ 540 m/s
 D+ 270 < Vs30 ≤ 360 m/s
 D- 180 < Vs30 ≤ 270 m/s
 E <180 m/s
Special Soil Conditions: Liquefiable soils; quick
 and high permeability clay; collapsible cemented soils;
 and soils with Vs30 per vertical extent greater than 6m,
 soft/medium stiff clays thicker than 36m.



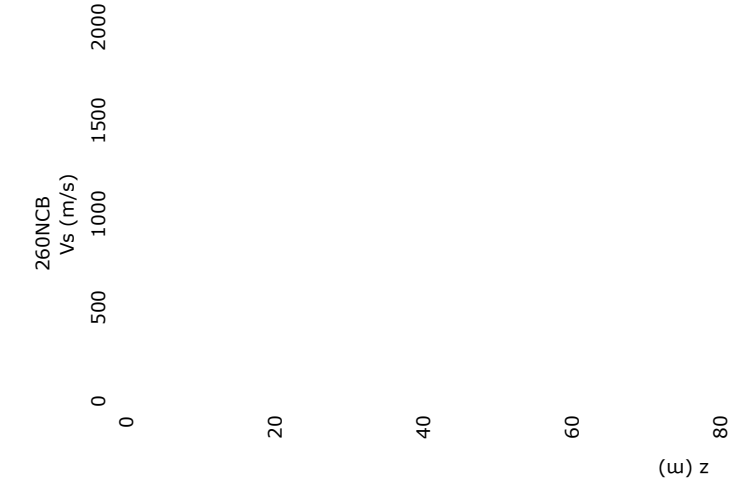
(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,



(D) Shear Wave Velocity SASW

260NCB	DISPERSION DATA				INVERSION PROFILE	
Site Disp. Vr (m/s)	Theoretical Disp. Vr (m/s)	Frequency (Hz)	Inversion Vs (m/s)	Depth (m)		
1300.0	1271.3	5.0	198.1	0.0		
1259.8	1190.7	7.4	198.1	2.8		
1103.4	1116.2	8.5	246.8	2.8		
1018.9	1037.9	9.4	246.8	5.8		
1018.6	946.5	10.3	326.0	5.8		
885.3	824.7	11.3	326.0	9.3		
646.4	654.2	12.2	447.2	9.3		
537.8	522.2	13.2	447.2	13.3		
425.6	466.4	14.2	537.7	13.3		
517.3	440.2	15.1	537.7	17.8		
434.0	424.8	16.1	699.8	17.8		
405.0	416.5	17.1	699.8	22.8		
404.0	411.8	18.0	1056.1	22.8		
404.3	409.1	19.0	1056.1	28.3		
400.0	407.8	20.0	1161.5	28.3		
400.0	407.4	20.9	1161.5	34.3		
395.0	407.4	22.0	1235.8	34.3		
398.9	407.2	22.9	1235.8	40.8		
398.9	406.5	23.5	1313.6	40.8		
398.9	376.3	26.2	1313.6	49.8		
398.9	366.2	26.8	1318.5	49.8		
398.9	349.8	27.7	1318.5	64.8		
398.9	331.7	28.7	1317.3	64.8		
386.2	311.8	29.6	1317.3	81.3		
357.2	289.1	30.6	1345.2	81.3		
333.0	266.3	31.6	1345.2	99.3		
312.5	245.7	32.6	1334.4	99.3		
310.0	180.3	33.0	1334.4	118.8		
305.0	179.1	35.0	1357.0	118.8		
295.0	177.9	37.0	1357.0	99118.8		
285.0	176.7	39.0	1357.0	99118.8		
280.0	175.7	40.0	Vs30	441.5		

UMBRIA-MARCHE, ITALY SMR Stations

Site ID 261NCS

NEHRP CLASS: C

Vs30 694 (m/s)

SUB-CLASS C+

Vs100 1170 (m/s)

Location

SMR Station NCS

State UMBRIA

Description STATION-C GRAVEL ROAD

POSITION NOCERA UMBRA - C GRAVEL RD

LAT (N) 43.14835

LON (E) 12.79134

Data Type

Investigators KAYEN, SCASSERRA

Date collected 15-Nov-2006

TEST METHODS

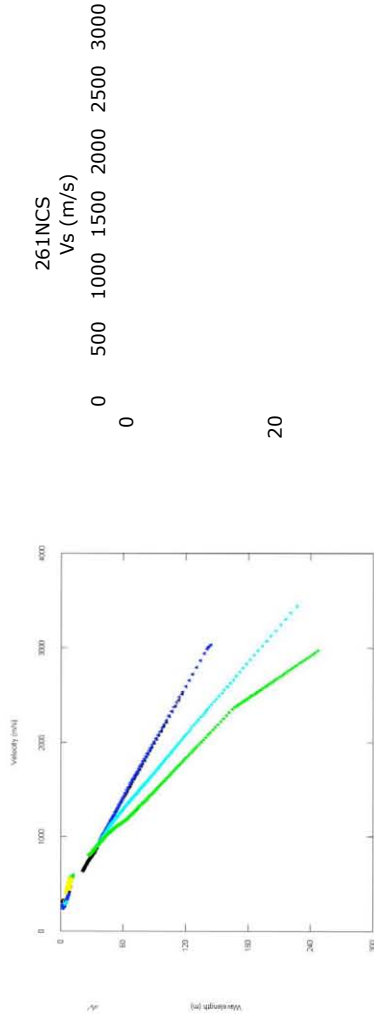
PARALLEL-ARRAY SOURCES;
CONTINUOUS HARMONIC
WAVE-SASW; 3D AMBIENT
MICROTREMOR ANALYSIS

PROJECT NAME

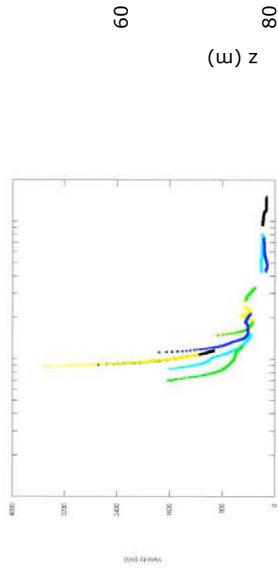
UMBRIA-MARCHE
SMR CHARACTERIZATION
PEER, UNIV OF ROME

SITE SUB CLASS:

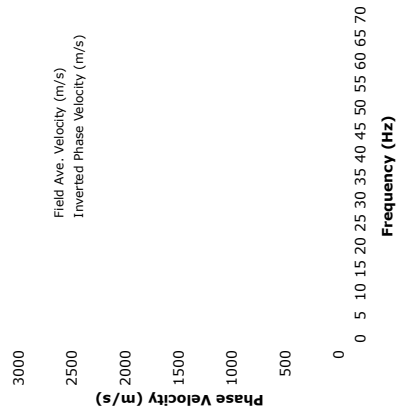
- A > 1500 m/s
 - B+ 1080 < Vs30 ≤ 1500 m/s
 - B- 720 < Vs30 ≤ 1080 m/s
 - C+ 540 < Vs30 ≤ 720 m/s
 - C- 360 < Vs30 ≤ 540 m/s
 - D+ 270 < Vs30 ≤ 360 m/s
 - D- 180 < Vs30 ≤ 270 m/s
 - E < 180 m/s
- Special Soil Conditions: Liquefiable soils; quick
and high permeability clay; collapsible cemented soils;
very soft soils; soft soils; soft soils with thin 0m,
soft/medium stiff clays thicker than 36m.



(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,

140 261NCS

(D) Shear Wave Velocity SASW

261NCS	DISPERSION DATA		INVERSION PROFILE	
Site Disp. Vr (m/s)	Theoretical Disp. Vr (m/s)	Frequency (Hz)	Inversion Vs (m/s)	Depth (m)
2778.8	2689.8	12.6	200.6	0.0
2482.0	2531.5	13.7	200.6	2.8
2213.7	2314.7	14.8	350.3	2.8
2175.0	2062.9	15.9	350.3	5.8
1776.2	1776.8	17.0	785.7	5.8
1526.3	1538.4	18.1	785.7	9.3
1360.8	1372.2	19.2	1198.8	9.3
1272.1	1255.7	20.3	1198.8	13.3
1188.7	1164.4	21.4	1270.8	13.3
1184.4	1100.8	22.5	1270.8	31.3
1126.9	1043.7	23.6	1541.1	31.3
1015.9	995.1	24.7	1541.1	51.3
894.6	956.3	25.7	1721.9	51.3
832.1	916.0	26.9	1721.9	73.3
795.4	882.2	28.0	1667.9	73.3
754.6	851.2	29.1	1667.9	97.3
686.0	832.3	29.8	2523.5	97.3
593.6	457.0	46.8	2523.5	123.3
497.6	440.4	48.0	2516.8	123.3
511.1	426.9	49.0	2516.8	133.3
476.5	414.2	50.1		133.3
464.8	403.4	51.1		133.3
402.7	392.3	52.3		133.3
380.5	383.5	53.4		133.3
379.0	375.0	54.5		133.3
386.7	367.7	55.6		133.3
384.5	361.4	56.6		133.3
387.2	355.5	57.8		133.3
387.2	350.2	58.9		150.0
387.2	345.6	60.0		150.0
387.2	341.4	61.1		
387.2	337.6	62.2	Vs30	693.7

UMBRIA-MARCHE, ITALY SMR Stations

Site ID 262GBP

NEHRP CLASS: C

Vs30 492 (m/s)

SUB-CLASS C+

Vs100 864 (m/s)

Location

SMR Station GBP

State UMBRIA

Description GUBBIO SOIL SITE PIANA

POSITION GUBBIO

LAT (N) 43.314

LON (E) 12.59

Data Type

Investigators KAYEN, SCASSERRA

Date collected 17-Nov-2005

TEST METHODS

PARALLEL-ARRAY SOURCES;
CONTINUOUS HARMONIC
WAVE-SASW; 3D AMBIENT
MICROTREMOR ANALYSIS

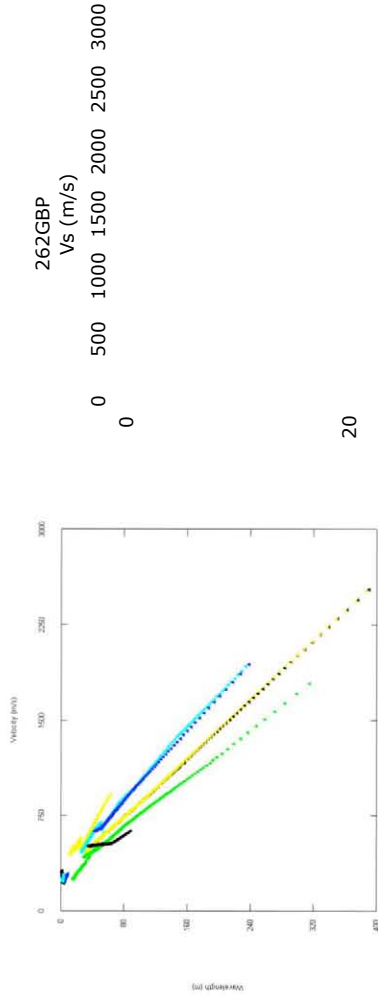
PROJECT NAME

UMBRIA-MARCHE
SMR CHARACTERIZATION
PEER, UNIV OF ROME

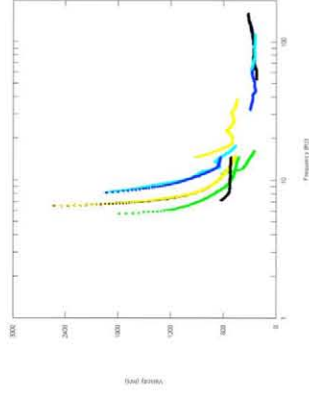
SPONSOR

SITE SUB CLASS:

- A >1500 m/s
 - B+ 1080 < Vs30 ≤ 1500 m/s
 - B- 720 < Vs30 ≤ 1080 m/s
 - C+ 540 < Vs30 ≤ 720 m/s
 - C- 360 < Vs30 ≤ 540 m/s
 - D+ 270 < Vs30 ≤ 360 m/s
 - D- 180 < Vs30 ≤ 270 m/s
 - E <180 m/s
- Special Soil Conditions: Liquefiable soils; quick
and high permeability clay, collapsible cemented soils,
very soft soils, soft soils, soft soils with thin 0m,
soft/medium stiff clays thicker than 36m.



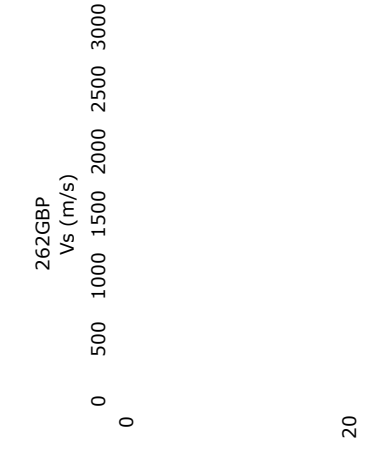
(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,



(D) Shear Wave Velocity SASW

262GBP	DISPERSION DATA		INVERSION PROFILE	
Site Disp. Vr (m/s)	Theoretical Disp. Vr (m/s)	Frequency (Hz)	Inversion Vs (m/s)	Depth (m)
2510.0	2229.3	5.9	296.0	0.0
1634.1	1567.2	6.3	296.0	5.5
1193.3	1136.2	7.3	531.9	5.5
963.5	976.1	8.3	531.9	11.5
826.7	867.7	9.3	567.3	11.5
691.5	781.7	10.4	567.3	18.5
608.7	711.6	11.4	531.2	18.5
543.8	646.2	12.4	531.2	26.5
528.4	573.3	13.5	940.1	26.5
525.1	498.4	14.5	940.1	35.5
540.8	431.8	15.6	976.6	35.5
533.1	392.3	16.6	976.6	45.5
502.5	369.3	17.5	1165.3	45.5
499.8	348.1	18.7	1165.3	56.5
495.0	335.2	19.8	1225.6	56.5
495.0	325.7	20.8	1225.6	68.5
495.0	318.6	21.9	1335.4	68.5
495.0	313.2	22.9	1335.4	81.5
495.0	308.9	24.0	1911.0	81.5
495.0	305.7	25.0	1911.0	100.0
487.4	302.9	26.0	1911.0	99081.5
477.9	300.7	27.0		99081.5
484.8	298.9	28.1		99081.5
484.8	297.4	29.2		99081.5
484.8	296.1	30.2		99081.5
484.8	295.1	31.3		99081.5
452.2	294.2	32.3		99081.5
430.1	293.5	33.3		99081.5
420.0	292.8	34.3		150.0
416.8	292.3	35.4		150.0
408.2	291.8	36.5		
403.9	291.4	37.5	Vs30	491.9

UMBRIA-MARCHE, ITALY SMR Stations

Site ID 263GBB

NEHRP CLASS: C

Vs30 922 (m/s)

SUB-CLASS C+

Vs100 1759 (m/s)

Location

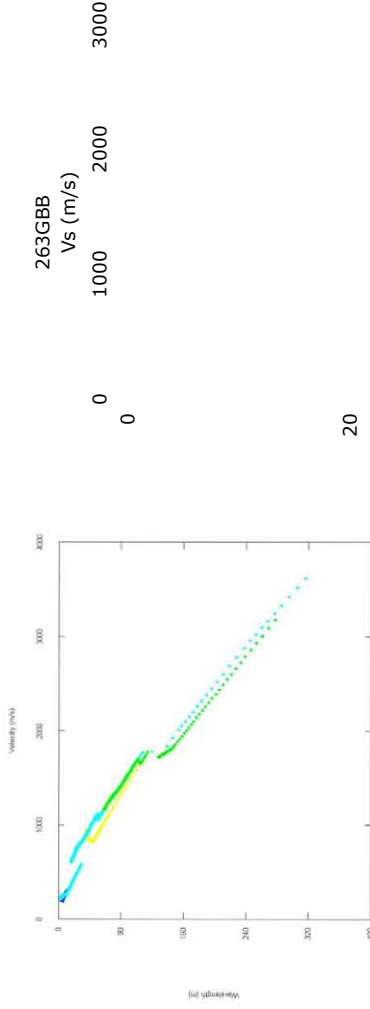
SMR Station GBB
State UMBRIA
Description GUBBIO - PARK COLLO
POSITION GUBBIO
LAT (N) 43.35786
LON (E) 12.5947

Data Type SWEPT-SINE SASW
Investigators KAYEN, SCASSERRA
Date collected 17-Nov-2005

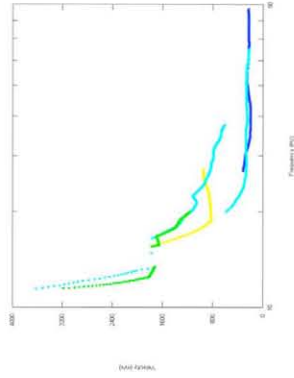
TEST METHODS PARALLEL-ARRAY SOURCES;
 CONTINUOUS HARMONIC
 WAVE-SASW; 3D AMBIENT
 MICROTREMOR ANALYSIS

PROJECT NAME UMBRIA-MARCHE
SPONSOR SMR CHARACTERIZATION
 PEER, UNIV OF ROME

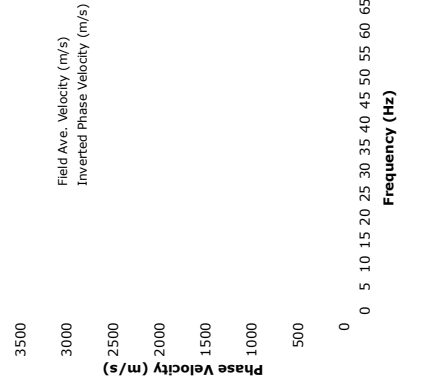
SITE SUB CLASS: **Vs30 (m/s)**
 A >1500 m/s
 B+ 1080 < Vs30 ≤ 1500 m/s
 B- 720 < Vs30 ≤ 1080 m/s
 C+ 540 < Vs30 ≤ 720 m/s
 C- 360 < Vs30 ≤ 540 m/s
 D+ 270 < Vs30 ≤ 360 m/s
 D- 180 < Vs30 ≤ 270 m/s
 E <180 m/s
Special Soil Conditions: Liquefiable soils; quick
 and high permeability clay; collapsible cemented soils;
 and high plasticity clay; collapsible cemented soils;
 and high plasticity clay; collapsible cemented soils;
 soft/medium stiff clays thicker than 36m.



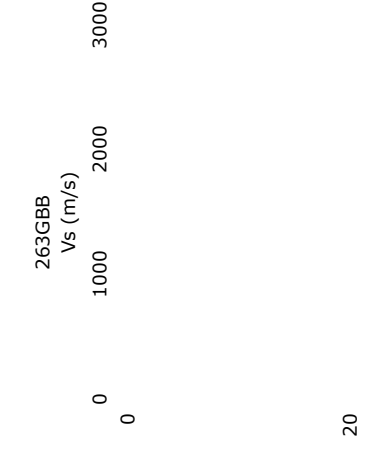
(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,



(D) Shear Wave Velocity SASW

263GGB	DISPERSION DATA				INVERSION PROFILE	
Site Disp. Vr (m/s)	Theoretical Disp. Vr (m/s)	Frequency (Hz)	Inversion Vs (m/s)	Depth (m)		
2923.5	2229.3	11.7	224.8	0.0		
2299.0	1567.2	12.2	224.8	2.8		
1943.0	1136.2	12.7	683.9	2.8		
1788.4	976.1	13.2	683.9	5.8		
1720.7	867.7	13.5	1248.2	5.8		
1776.1	781.7	14.8	1248.2	9.3		
1680.6	711.6	15.7	1275.4	9.3		
1628.0	646.2	16.2	1275.4	13.3		
1597.5	573.3	16.7	1254.5	13.3		
1461.5	498.4	17.2	1254.5	17.8		
1336.0	431.8	17.7	1734.3	17.8		
1266.6	392.3	18.2	1734.3	22.8		
1211.3	369.3	18.7	1990.2	22.8		
1171.5	348.1	19.2	1990.2	28.3		
1011.5	335.2	19.7	2327.7	28.3		
981.3	325.7	19.7	2327.7	34.3		
867.1	318.6	20.2	2923.5	34.3		
758.2	313.2	20.7	2923.5	40.8		
760.4	308.9	21.2	2923.5	40.8		
754.6	305.7	21.7	2923.5	100.0		
742.3	302.9	22.3				
752.0	300.7	22.8				
728.4	298.9	23.3				
712.0	297.4	23.8				
717.7	296.1	24.3				
716.0	295.1	24.8				
698.7	294.2	25.3				
713.2	293.5	25.8				
674.9	292.8	26.3				
567.1	292.3	26.8				
561.2	291.8	27.3				
539.0	291.4	27.8				
		28.3				
			Vs30	921.7		

UMBRIA-MARCHE, ITALY SMR Stations

Site ID 264NCI

NEHRP CLASS: C

Vs30 551 (m/s)

SUB-CLASS C+

Vs100 546 (m/s)

Location

SMR Station NCI

State UMBRIA

Description NORCIA INDUSTRIAL PARK

POSITION NORCIA

LAT (N) 42.77974

LON (E) 13.09729

Data Type

Investigators KAYEN, SCASSERRA

Date collected 18-Nov-2006

TEST METHODS

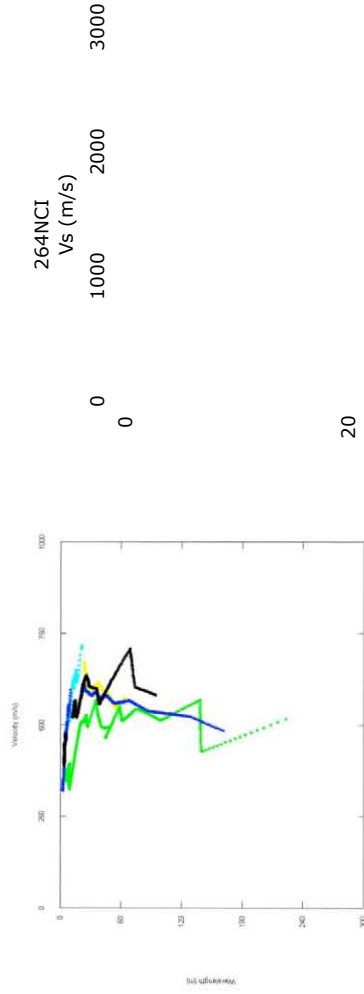
PARALLEL-ARRAY SOURCES;
CONTINUOUS HARMONIC
WAVE-SASW; 3D AMBIENT
MICROTREMOR ANALYSIS

PROJECT NAME

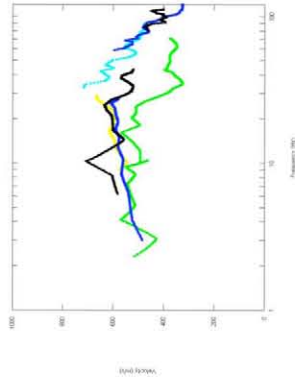
UMBRIA-MARCHE
SMR CHARACTERIZATION
PEER, UNIV OF ROME

SITE SUB CLASS:

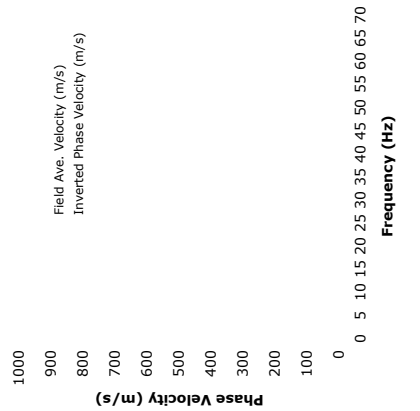
- A > 1500 m/s
 - B+ 1080 < Vs30 ≤ 1500 m/s
 - B- 720 < Vs30 ≤ 1080 m/s
 - C+ 540 < Vs30 ≤ 720 m/s
 - C- 360 < Vs30 ≤ 540 m/s
 - D+ 270 < Vs30 ≤ 360 m/s
 - D- 180 < Vs30 ≤ 270 m/s
 - E < 180 m/s
- Special Soil Conditions: Liquefiable soils; quick
and high permeability clay; collapsible cemented soils;
very soft soils; soft soils; soft soils with thin 0m,
soft/medium stiff clays thicker than 36m.



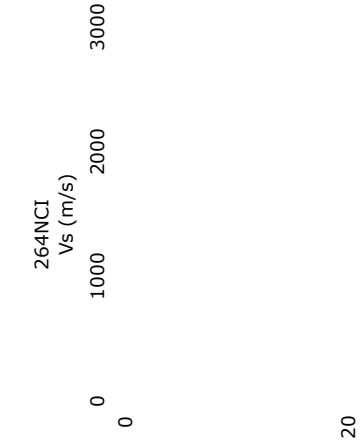
(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,



(D) Shear Wave Velocity SASW

264NCI	DISPERSION DATA				INVERSION PROFILE	
Site Disp. Vr (m/s)	Theoretical Disp. Vr (m/s)	Frequency (Hz)	Inversion Vs (m/s)	Depth (m)		
550.0	498.0	2.4	441.5	0.0		
555.4	498.2	2.6	441.5	5.5		
530.4	499.7	4.0	587.8	5.5		
527.2	500.6	5.0	587.8	11.5		
535.2	501.3	6.0	693.6	11.5		
553.7	501.7	7.0	693.6	18.5		
551.4	501.8	8.1	556.7	18.5		
567.9	501.6	9.2	556.7	26.5		
555.9	501.1	10.2	480.4	26.5		
576.4	500.3	11.3	480.4	35.5		
577.8	499.1	12.3	558.5	35.5		
573.4	497.6	13.4	558.5	45.5		
571.4	495.8	14.4	581.3	45.5		
581.0	493.6	15.5	581.3	56.5		
590.1	491.0	16.5	539.7	56.5		
583.8	488.0	17.6	539.7	68.5		
578.5	484.5	18.6	509.0	68.5		
580.5	480.6	19.7	509.0	81.5		
582.0	476.4	20.7	566.8	81.5		
585.2	471.8	21.8	566.8	100.0		
587.7	466.8	22.8				
587.7	461.5	23.9				
587.7	456.0	24.9				
587.7	450.4	26.0				
587.7	444.7	27.0				
579.0	439.4	28.0				
511.2	434.1	29.1				
511.2	429.1	30.2				
511.2	424.6	31.2				
511.2	420.4	32.3				
511.2	416.8	33.3				
511.2	413.5	34.4				
			Vs30			
				551.3		

UMBRIA-MARCHE, ITALY SMR Stations

Site ID 265NRC

NEHRP CLASS: C

Vs30 677 (m/s)

SUB-CLASS C+

Vs100 1148 (m/s)

Location

SMR Station NRC

State UMBRIA

Description NORCIA SITE C-CENTRAL DIST.

POSITION NORCIA SITE C-CENTRAL DIST.

LAT (N) 42.79223

LON (E) 13.097

Data Type

Investigators KAYEN, SCASSERRA

Date collected 18-Nov-2006

TEST METHODS

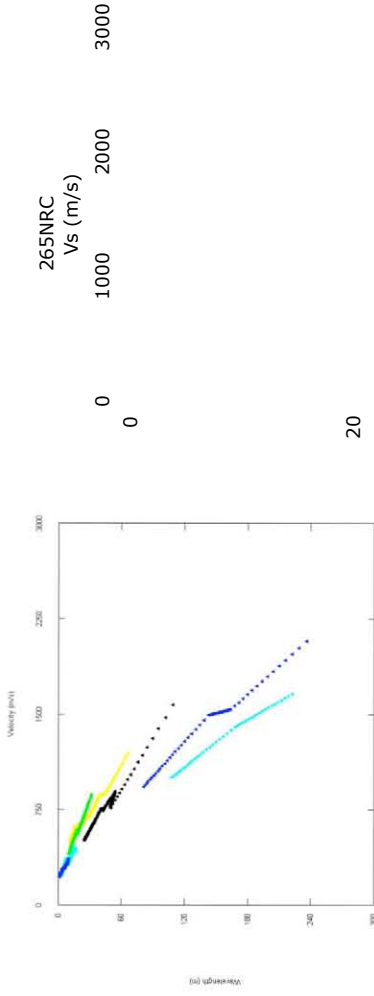
PARALLEL-ARRAY SOURCES;
CONTINUOUS HARMONIC
WAVE-SASW; 3D AMBIENT
MICROTREMOR ANALYSIS

PROJECT NAME

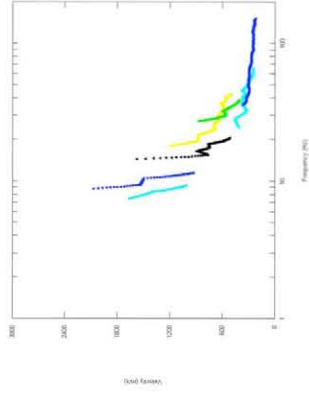
UMBRIA-MARCHE
SMR CHARACTERIZATION
PEER, UNIV OF ROME

SITE SUB CLASS:

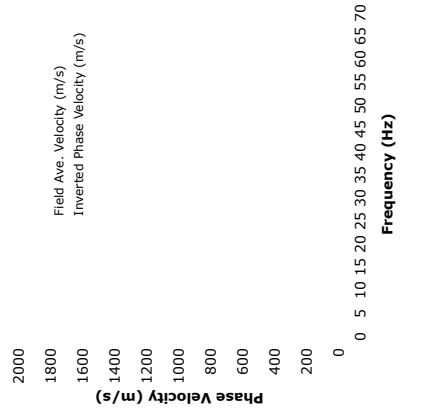
- A > 1500 m/s
 - B+ 1080 < Vs30 ≤ 1500 m/s
 - B- 720 < Vs30 ≤ 1080 m/s
 - C+ 540 < Vs30 ≤ 720 m/s
 - C- 360 < Vs30 ≤ 540 m/s
 - D+ 270 < Vs30 ≤ 360 m/s
 - D- 180 < Vs30 ≤ 270 m/s
 - E < 180 m/s
- Special Soil Conditions: Liquefiable soils; quick
and high permeability; collapsible cemented soils;
very soft soils; soft soils; soft soils with
soft/medium stiff clay thicker than 36m.



(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,

265NRC

(D) Shear Wave Velocity SASW

265NRC	DISPERSION DATA		INVERSION PROFILE	
Site Disp. Vr (m/s)	Theoretical Disp. Vr (m/s)	Frequency (Hz)	Inversion Vs (m/s)	Depth (m)
1900.0	1723.6	6.3	259.8	0.0
1503.7	1632.0	7.9	259.8	2.8
1408.0	1550.6	9.0	531.7	2.8
1516.3	1465.8	9.9	531.7	5.8
1205.3	1378.1	10.9	560.2	5.8
1145.1	1331.6	11.4	560.2	9.3
1139.9	1040.8	14.8	699.0	9.3
810.7	920.2	15.7	699.0	13.3
841.3	833.4	16.7	882.4	13.3
815.6	776.1	17.7	882.4	17.8
844.5	740.2	18.6	893.9	17.8
708.2	711.6	19.6	893.9	22.8
725.6	691.0	20.5	1273.6	22.8
725.6	669.7	21.5	1273.6	28.3
725.6	653.3	22.5	1561.2	28.3
706.2	638.6	23.5	1561.2	34.3
629.7	624.1	24.5	1512.6	34.3
609.9	611.8	25.4	1512.6	40.8
598.5	598.9	26.4	1517.0	40.8
657.0	585.5	27.4	1517.0	100.0
625.2	573.9	28.4	1399.8	49.8
578.6	562.1	29.3	1399.8	59.8
558.0	550.3	30.3	1693.8	59.8
544.7	538.5	31.3	1693.8	70.8
546.5	526.4	32.2	1689.4	70.8
521.4	514.0	33.2	1689.4	82.8
513.4	501.2	34.2	1900.0	82.8
501.3	487.9	35.1	1900.0	95.8
488.3	473.3	36.1		
472.7	458.4	37.1		
447.7	443.4	38.1		
472.6	428.3	39.1		
			Vs30	676.7

UMBRIA-MARCHE, ITALY SMR Stations

Site ID 266NRA

NEHRP CLASS: D

Vs30 218 (m/s)

SUB-CLASS D-

Vs 80 264 (m/s)

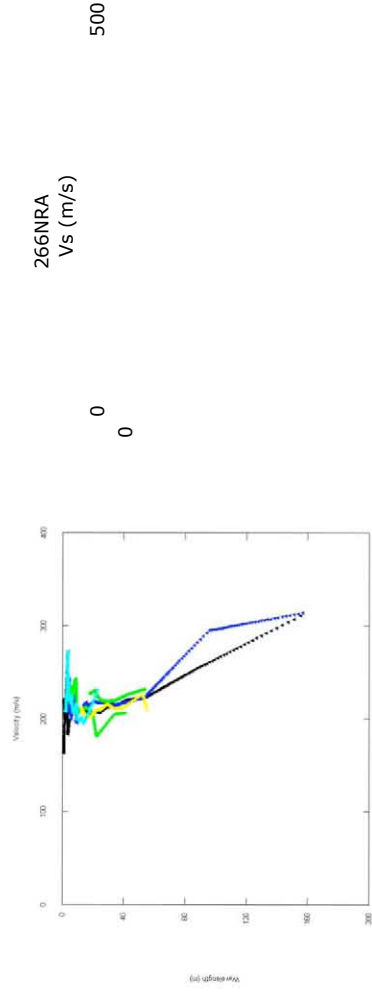
Location

SMR Station NRA
State UMBRIA
Description NORCIA TEMPORARY STATION A
POSITION NORCIA
LAT (N) 42.79556
LON (E) 13.08096

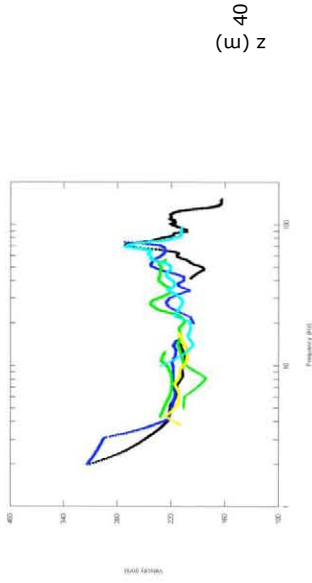
Data Type SWEPT-SINE SASW
Investigators KAYEN, SCASSERRA
Date collected 19-Nov-2006
TEST METHODS PARALLEL-ARRAY SOURCES;
 CONTINUOUS HARMONIC
 WAVE-SASW; 3D AMBIENT
 MICROTREMOR ANALYSIS

PROJECT NAME UMBRIA-MARCHE
SPONSOR SMR CHARACTERIZATION
 PEER, UNIV OF ROME

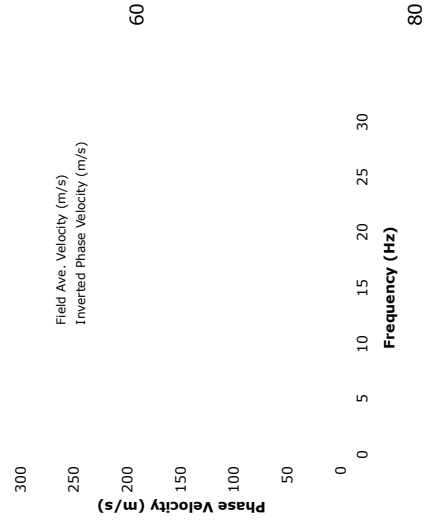
SITE SUB CLASS: **Vs30 (m/s)**
 A >1500 m/s
 B+ 1080 < Vs30 ≤ 1500 m/s
 B- 720 < Vs30 ≤ 1080 m/s
 C+ 540 < Vs30 ≤ 720 m/s
 C- 360 < Vs30 ≤ 540 m/s
 D+ 270 < Vs30 ≤ 360 m/s
 D- 180 < Vs30 ≤ 270 m/s
 E <180 m/s
Special Soil Conditions: Liquefiable soils; quick
 and high permeability; collapsible cemented soils;
 and high permeability; collapsible cemented soils;
 and high permeability; collapsible cemented soils;
 soft/medium stiff clays thicker than 36m.



(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,

(D) Shear Wave Velocity SASW

266NRA	DISPERSION DATA				INVERSION PROFILE	
Site Disp. Vr (m/s)	Theoretical Disp. Vr (m/s)	Frequency (Hz)	Inversion Vs (m/s)	Depth (m)		
310.0	285.5	1.8	215.0	0.0		
285.6	273.1	2.6	215.0	4.4		
233.8	236.2	3.9	226.7	4.4		
221.1	219.7	5.0	193.9	9.2		
215.2	213.1	6.2	193.9	9.2		
214.1	210.5	7.4	239.5	14.8		
212.4	209.3	8.6	239.5	14.8		
214.4	208.9	9.8	236.1	21.2		
214.7	208.8	11.0	236.1	21.2		
212.4	208.7	12.2	230.4	28.4		
210.0	208.7	13.4	230.4	28.4		
211.1	208.7	14.6	285.2	36.4		
207.9	208.6	15.9	285.2	36.4		
207.8	208.5	16.9	290.5	45.2		
205.5	208.4	18.2	290.5	45.2		
203.8	208.4	19.5	318.4	54.8		
203.0	208.3	20.7	318.4	54.8		
207.7	208.3	21.9	321.5	65.2		
213.8	208.3	23.0	321.5	65.2		
221.2	208.3	24.3	321.5	80.0		
226.2	208.3	25.5				
229.1	208.3	26.7				
226.8	208.3	27.9				
227.8	230.3	29.1				
224.2	207.5	30.3				
220.6	206.7	31.5				
218.2	205.9	32.7				
217.0	205.2	33.9				
219.2	204.4	35.1				
219.9	203.7	36.3				
221.8	203.0	37.5				
222.6	202.3	38.7				
			Vs30			
				223.0		

UMBRIA-MARCHE, ITALY SMR Stations

Site ID 267CSC

NEHRP CLASS: C

Vs30 540 (m/s)

SUB-CLASS C+

Vs 80 993 (m/s)

Location

SMR Station CSC

State UMBRIA

Description CASCIA

POSITION CASCIA

LAT (N) 42.71875

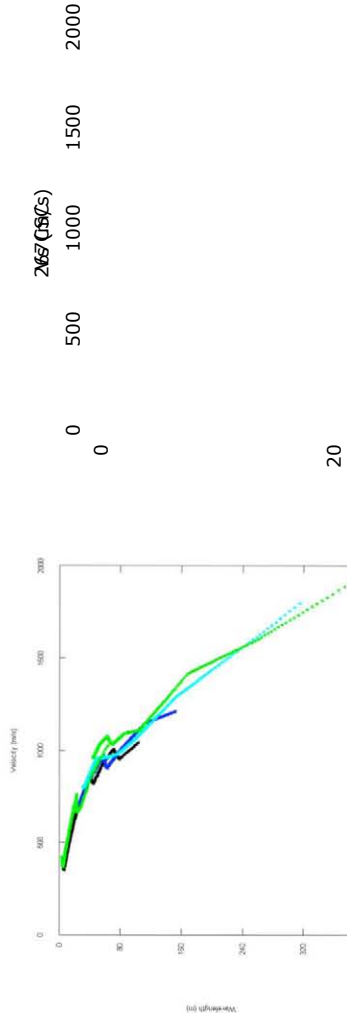
LON (E) 13.012

Data Type SWEPT-SINE SASW
Investigators KAYEN, SCASSERRA
Date collected 20-Nov-2006

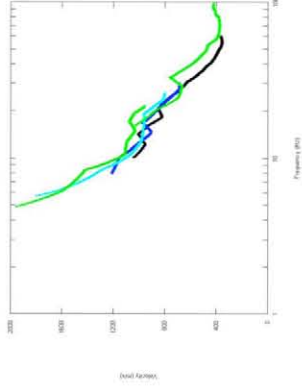
TEST METHODS PARALLEL-ARRAY SOURCES;
 CONTINUOUS HARMONIC
 WAVE-SASW; 3D AMBIENT
 MICROTREMOR ANALYSIS

PROJECT NAME UMBRIA-MARCHE
SMR CHARACTERIZATION
SPONSOR PEER, UNIV OF ROME

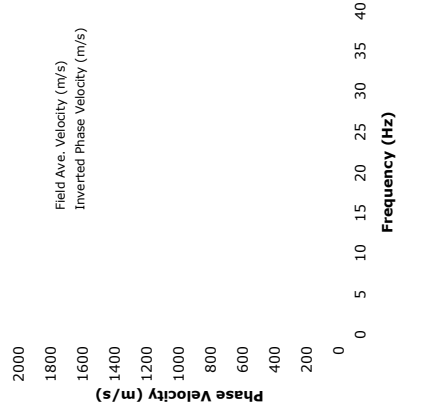
SITE SUB CLASS: **Vs30 (m/s)**
 A >1500 m/s
 B+ 1080 < Vs30 ≤ 1500 m/s
 B- 720 < Vs30 ≤ 1080 m/s
 C+ 540 < Vs30 ≤ 720 m/s
 C- 360 < Vs30 ≤ 540 m/s
 D+ 270 < Vs30 ≤ 360 m/s
 D- 180 < Vs30 ≤ 270 m/s
 E <180 m/s
Special Soil Conditions: Liquefiable soils; quick
 and high permeability clay; collapsible cemented soils;
 and soils with Vs30 per vertical extent greater than 6m,
 soft/medium stiff clays thicker than 36m.



(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,



(D) Shear Wave Velocity SASW

267CSC	DISPERSION DATA		INVERSION PROFILE	
Site Disp. Vr (m/s)	Theoretical Disp. Vr (m/s)	Frequency (Hz)	Inversion Vs (m/s)	Depth (m)
1950.0	1695.3	4.9	284.2	0.0
1859.0	1683.4	5.1	284.2	2.8
1718.7	1651.1	5.7	496.0	2.8
1603.5	1615.9	6.3	487.6	5.8
1499.4	1560.8	6.9	487.6	5.8
1410.3	1476.5	7.7	608.6	9.3
1288.8	1356.8	8.5	608.6	9.3
1199.5	1199.8	9.3	486.3	13.3
1111.1	1065.6	10.3	486.3	13.3
1054.4	990.7	11.4	894.5	17.8
1017.7	953.6	12.6	894.5	17.8
988.6	936.8	13.9	878.3	22.8
976.2	931.1	15.4	878.3	22.8
981.5	931.1	17.0	1116.4	28.3
948.8	932.0	18.8	1116.4	28.3
899.2	922.3	20.7	1438.4	34.3
809.1	841.5	23.0	1438.4	34.3
754.4	732.1	25.3	1620.8	54.3
683.2	664.6	28.0	1620.8	54.3
658.3	628.5	30.6	1843.4	76.3
607.3	591.4	34.2	1843.4	76.3
537.4	546.9	37.8	1950.0	100.3
478.5	484.6	41.7	1950.0	100.3
431.7	422.9	46.2	1950.0	126.3
402.0	372.8	51.0	1950.0	126.3
377.3	346.4	56.4		
377.5	346.4	61.6		
217.0	205.2	33.9		
219.2	204.4	35.1		
219.9	203.7	36.3		
0.0	0.0	0.0		
0.0	0.0	0.0	Vs30	575.3

UMBRIA-MARCHE, ITALY SMR Stations

Site ID 268CSP

NEHRP CLASS: D

Vs30 339 (m/s)

SUB-CLASS D+

Vs 80 488 (m/s)

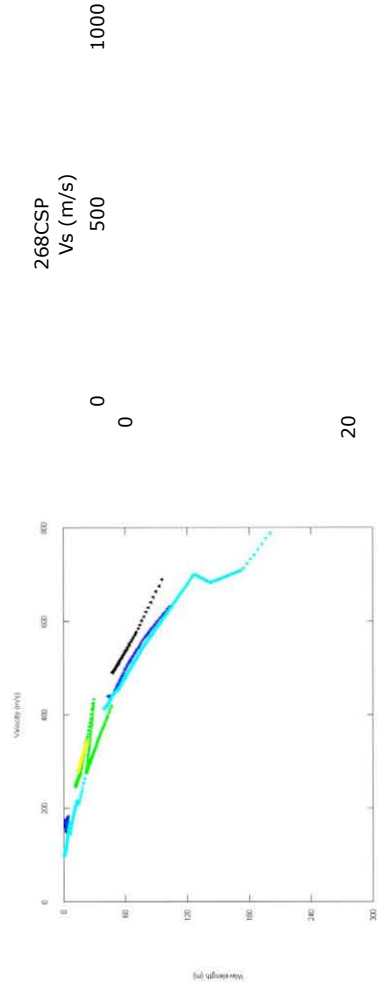
Location

SMR Station CSP
State UMBRIA
Description CASCIA PETRUCCI APARTMENTS
POSITION CASCIA
LAT (N) 42.71788
LON (E) 13.0184

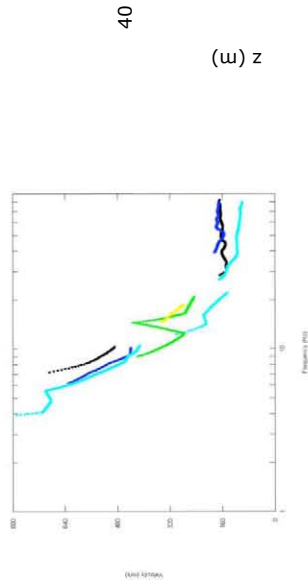
Data Type SWEPT-SINE SASW
Investigators KAYEN, SCASSERRA
Date collected 20-Nov-2006
TEST METHODS PARALLEL-ARRAY SOURCES;
 CONTINUOUS HARMONIC
 WAVE-SASW; 3D AMBIENT
 MICROTREMOR ANALYSIS

PROJECT NAME UMBRIA-MARCHE
SPONSOR SMR CHARACTERIZATION
 PEER, UNIV OF ROME

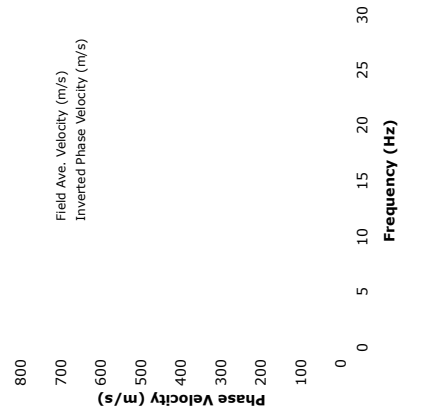
SITE SUB CLASS: **Vs30 (m/s)**
 A >1500 m/s
 B+ 1080 < Vs30 ≤ 1500 m/s
 B- 720 < Vs30 ≤ 1080 m/s
 C+ 540 < Vs30 ≤ 720 m/s
 C- 360 < Vs30 ≤ 540 m/s
 D+ 270 < Vs30 ≤ 360 m/s
 D- 180 < Vs30 ≤ 270 m/s
 E <180 m/s
Special Soil Conditions: Liquefiable soils; quick
 and high permeability clay; collapsible cemented soils;
 and high permeability clay cemented soils;
 and high permeability clay cemented soils;
 soft/medium stiff clays thicker than 36m.



(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,

(D) Shear Wave Velocity SASW

268CSP	DISPERSION DATA		INVERSION PROFILE	
Site Disp. Vr (m/s)	Theoretical Disp. Vr (m/s)	Frequency (Hz)	Inversion Vs (m/s)	Depth (m)
800.0	713.3	3.8	144.4	0.0
723.2	706.6	4.1	144.4	2.8
690.2	694.2	4.6	236.0	2.8
688.7	674.5	5.1	236.0	5.8
681.3	640.5	5.6	356.4	5.8
613.1	590.1	6.2	356.4	9.3
567.5	540.8	6.9	331.9	9.3
533.3	497.9	7.6	331.9	13.3
483.7	461.5	8.4	443.4	13.3
445.1	425.6	9.3	443.4	17.8
413.4	394.1	10.2	455.0	17.8
362.7	356.2	11.4	455.0	22.8
349.2	330.3	12.7	520.2	22.8
333.4	311.5	13.9	520.2	28.3
314.1	291.3	15.4	547.5	28.3
273.4	264.2	17.1	547.5	34.3
247.0	234.8	18.8	653.7	34.3
206.2	206.5	20.6	653.7	40.8
184.8	189.9	22.1	683.4	40.8
169.4	161.1	26.7	683.4	50.8
156.9	155.6	28.4	680.6	50.8
145.7	149.4	31.3	680.6	61.8
136.9	145.1	34.6	685.1	61.8
138.6	142.0	38.6	685.1	73.8
146.3	140.2	42.5	772.6	73.8
143.2	138.9	47.0	772.6	86.8
141.9	138.1	51.9	901.6	86.8
145.5	137.5	57.5	901.6	100.0
144.8	137.2	63.7		
143.8	137.2	70.5		
0.0	0.0	0.0		
0.0	0.0	0.0	Vs30	338.9

UMBRIA-MARCHE, ITALY SMR Stations

Site ID 269SLW

NEHRP CLASS: C

Vs30 509 (m/s)

SUB-CLASS C-

Vs 80 713 (m/s)

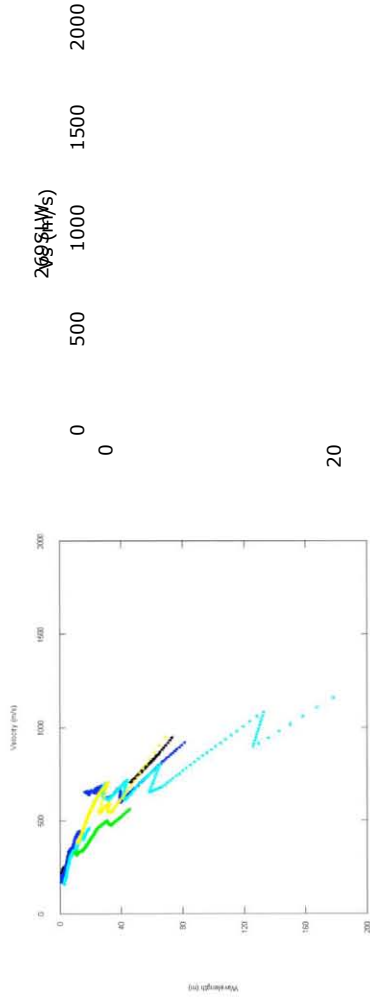
Location

SMR Station SLW
State UMBRIA
Description SELLANO WEST
POSITION
LAT (N) 42.886
LON (E) 12.922

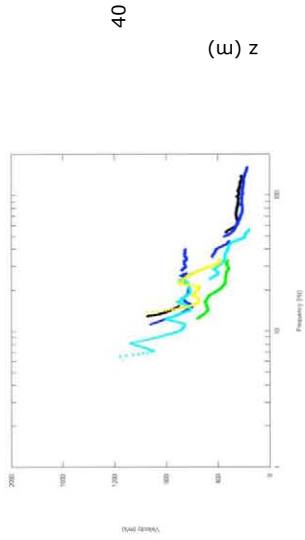
Data Type SWEPT-SINE SASW
Investigators KAYEN, SCASSERRA
Date collected 21-Nov-2006
TEST METHODS PARALLEL-ARRAY SOURCES;
 CONTINUOUS HARMONIC
 WAVE-SASW; 3D AMBIENT
 MICROTREMOR ANALYSIS

PROJECT NAME UMBRIA-MARCHE
SMR CHARACTERIZATION
SPONSOR PEER, UNIV OF ROME

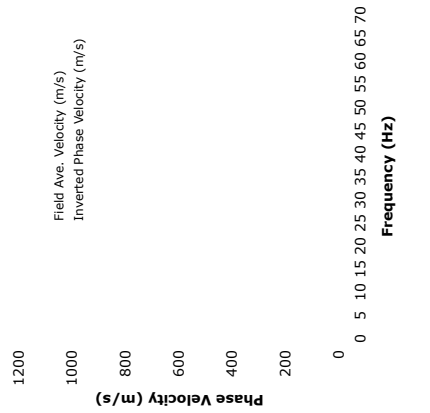
SITE SUB CLASS: **Vs30 (m/s)**
 A >1500 m/s
 B+ 1080 < Vs30 ≤ 1500 m/s
 B- 720 < Vs30 ≤ 1080 m/s
 C+ 540 < Vs30 ≤ 720 m/s
 C- 360 < Vs30 ≤ 540 m/s
 D+ 270 < Vs30 ≤ 360 m/s
 D- 180 < Vs30 ≤ 270 m/s
 E <180 m/s
Special Soil Conditions: Liquefiable soils; quick
 and high permeability clay; collapsible cemented soils;
 and soils with Vs30 or Vs80 greater than 360 m/s;
 soft/medium stiff clays thicker than 36m.



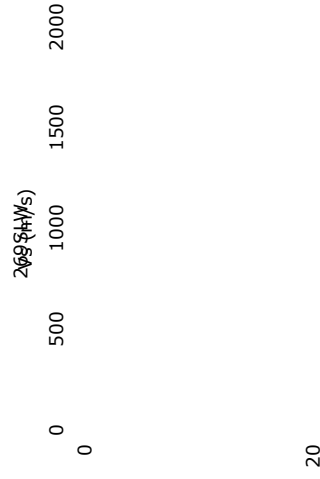
(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,



(D) Shear Wave Velocity SASW

269SLW	DISPERSION DATA		INVERSION PROFILE	
Site Disp. Vr (m/s)	Theoretical Disp. Vr (m/s)	Frequency (Hz)	Inversion Vs (m/s)	Depth (m)
1150.0	713.3	6.2	239.9	0.0
998.7	706.6	6.9	239.9	2.8
995.2	694.2	7.7	530.8	2.8
973.9	674.5	8.5	530.8	5.8
785.6	640.5	9.5	476.2	5.8
672.7	590.1	10.6	476.2	9.3
789.0	540.8	11.8	523.9	9.3
721.3	497.9	13.1	523.9	13.3
662.8	461.5	14.5	616.0	13.3
601.9	425.6	16.1	616.0	17.8
595.8	394.1	18.0	664.3	17.8
559.9	356.2	20.0	664.3	22.8
574.2	330.3	22.2	594.8	22.8
570.1	311.5	24.8	594.8	28.3
489.5	291.3	27.5	636.6	28.3
469.4	264.2	30.6	636.6	34.3
496.0	234.8	33.9	659.2	34.3
527.0	206.5	38.0	659.2	40.8
338.1	189.9	42.2	974.9	40.8
254.6	161.1	46.7	974.9	51.8
236.9	155.6	52.5	1041.6	51.8
254.6	149.4	57.8	1041.6	63.8
242.5	145.1	64.6	1141.5	63.8
236.7	142.0	72.0	1141.5	76.8
228.8	140.2	80.0	1304.8	76.8
227.5	138.9	88.9	1304.8	100.0
225.2	138.1	99.1		
220.9	137.5	110.3		
210.9	137.2	122.7		
201.8	137.2	135.6		
0.0	0.0	0.0		
0.0	0.0	0.0	Vs30	509.1

UMBRIA-MARCHE, ITALY SMR Stations

Site ID 270MTL

NEHRP CLASS: C
Vs30 437 (m/s)

SUB-CLASS C-
Vs 80 767 (m/s)

Location

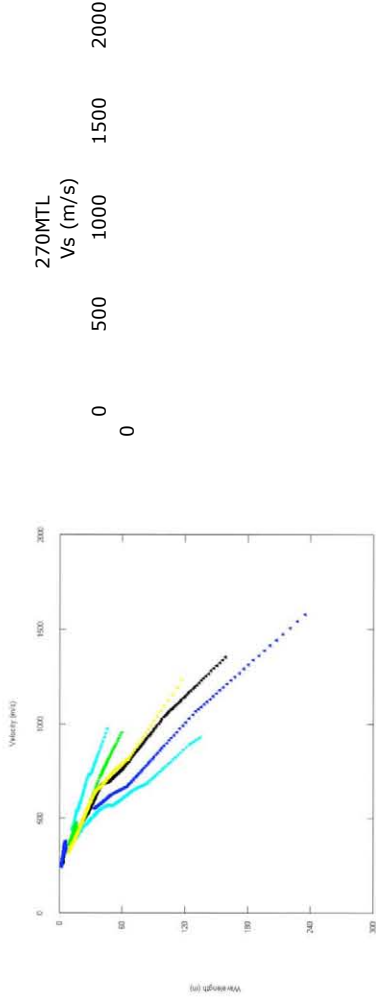
SMR Station MTL
State MARCHE'
Description MATELICA
POSITION
LAT (N) 43.24841
LON (E) 13.0079

Data Type SWEPT-SINE SASW
Investigators KAYEN, SCASSERRA
Date collected 21-Nov-2006

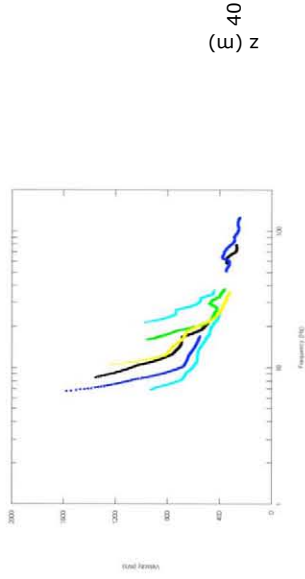
TEST METHODS
 PARALLEL-ARRAY SOURCES;
 CONTINUOUS HARMONIC
 WAVE-SASW; 3D AMBIENT
 MICROTREMOR ANALYSIS

PROJECT NAME UMBRIA-MARCHE
SPONSOR SMR CHARACTERIZATION
 PEER, UNIV OF ROME

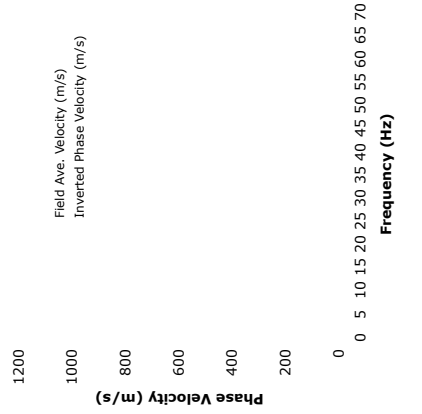
SITE SUB CLASS: Vs30 (m/s)
 A >1500 m/s
 B+ 1080 < Vs30 ≤ 1500 m/s
 B- 720 < Vs30 ≤ 1080 m/s
 C+ 540 < Vs30 ≤ 720 m/s
 C- 360 < Vs30 ≤ 540 m/s
 D+ 270 < Vs30 ≤ 360 m/s
 D- 180 < Vs30 ≤ 270 m/s
 E <180 m/s
 F Special Soil Conditions: Liquefiable soils; quick
 and high permeability; collapsible cemented soils;
 and soils with any of the following conditions:
 soft/medium stiff clays thicker than 36m,



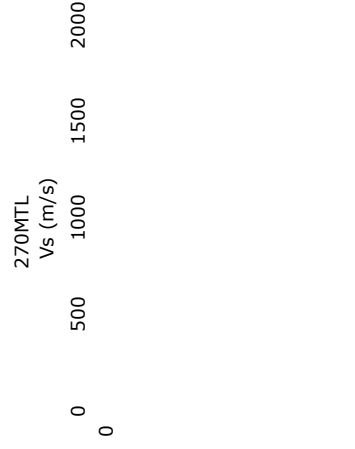
(A) Merged Field-LAMBDA Dispersion Curves



(B) Merged Field-Frequency Dispersion Curves



(C) Inversion-theoretical dispersion curve versus averaged field dispersion curve,



(D) Shear Wave Velocity SASW

270MTL	DISPERSION DATA		INVERSION PROFILE	
Site Disp. Vr (m/s)	Theoretical Disp. Vr (m/s)	Frequency (Hz)	Inversion Vs (m/s)	Depth (m)
1570.0	713.3	6.2	170.7	0.0
1136.8	706.6	7.2	170.7	2.8
909.8	694.2	7.9	175.4	2.8
921.6	674.5	8.8	175.4	5.8
839.2	640.5	9.5	524.7	5.8
789.1	590.1	10.3	524.7	9.3
761.1	540.8	11.1	535.9	9.3
704.2	497.9	11.9	535.9	13.3
672.7	461.5	12.7	605.2	13.3
650.9	425.6	13.5	605.2	17.8
633.2	394.1	14.3	779.2	17.8
615.3	356.2	15.1	779.2	22.8
619.0	330.3	16.0	978.6	22.8
636.5	311.5	16.7	978.6	28.3
614.1	291.3	17.5	978.6	28.3
583.3	264.2	18.3	978.6	33.8
546.8	234.8	19.1	1164.3	33.8
517.3	206.5	20.0	1164.3	39.8
517.3	189.9	20.8	1336.7	39.8
517.6	161.1	21.5	1336.7	46.3
489.9	155.6	22.3	1541.6	46.3
481.3	149.4	23.2	1541.6	80.0
467.0	145.1	24.0		
451.9	142.0	24.7		
451.9	140.2	25.6		
451.9	138.9	26.4		
451.9	138.1	27.2		
452.2	137.5	27.9		
459.6	137.2	28.7		
454.4	137.2	29.6		
438.3	203.0	30.4		
436.1	202.3	31.2		
			Vs30	437.2