Final Technical Report
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ST. LOUIS METRO AREA SHEAR WAVE VELOCITY TESTING

External Grant Award Number: 06HQGR0026

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Key Words: Amplification, Surficial Deposits, Database

ABSTRACT

This project used the Multi-Channel Analysis of Surface Waves (MASW) geophysical technique to acquire 20 shear wave velocity profiles of surficial materials and/or bedrock to a depth of approximately 30 meters on the Wentzville 7.5' quadrangle in the St. Louis, Missouri urban area. These data are needed to map and characterize the surficial materials and their earthquake shaking soil amplification potential. A preliminary investigation indicated no publicly available shear wave velocity data existed for the Wentzville 7.5' quadrangle area prior to the initiation of this investigation.

St. Louis is a bi-state major urban area and is one of two cities that are the focus of the USGS Earthquake Hazard Program (EHP) current Five Year Science Plan in the Central and Eastern United States (CEUS). Shear wave velocity data is a critical component of the USGS plans to produce urban earthquake hazard maps and risk evaluations for the St. Louis area. The St. Louis urban study area currently encompasses 29 standard USGS 7.5' quadrangles. The Wentzville 7.5' quadrangle is one of the 29 quadrangles in the St. Louis urban study area and one of the 4 priority quadrangles designated for initial earthquake hazard mapping.

The efficiency and relatively low cost of the MASW technique permitted acquiring the 20 shear wave velocity profile test data needed to characterize all of the surficial materials units on the Wentzville 7.5' quadrangle. The non-invasive nature of the MASW technique and the very limited footprint of the technique also make it ideal for the complexities and test site limitations of the urban areas. Sampling locations were targeted based on mapped surficial geology unit distributions, availability of nearby geotechnical borings for correlation and trying to maintain a relatively uniform coverage of the area. Coordination with other investigators, both within and external to the USGS, who have or planned to collect shear wave velocity data in the St. Louis area

using other techniques was continued so that unplanned duplication of test sites did not occur and so as to maximize test data coverage.

1. INTRODUCTION

This project used the Multi-Channel Analysis of Surface Waves (MASW) geophysical technique to acquire 20 shear wave velocity (Vs) profiles of surficial materials and/or bedrock to a depth of approximately 30 meters on the Wentzville 7.5’ quadrangle in the St. Louis, Missouri urban area. These data are needed to map and characterize the surficial materials and their earthquake shaking soil amplification potential. A preliminary investigation indicated no publicly available shear wave velocity data existed for the Wentzville 7.5’ quadrangle area prior to the initiation of this investigation.

St. Louis is a bi-state major urban area and is one of two cities that are the focus of the USGS Earthquake Hazard Program (EHP) current Five Year Science Plan in the Central and Eastern United States (CEUS). Shear wave velocity data is a critical component of the USGS plans to produce urban earthquake hazard maps and risk evaluations for the St. Louis area. The St. Louis urban study area currently encompasses 29 standard USGS 7.5’ quadrangles (Figure 1). The Wentzville 7.5’ quadrangle is one of the 29 quadrangles in the St. Louis urban study area and one of the 4 priority quadrangles designated for initial earthquake hazard mapping.

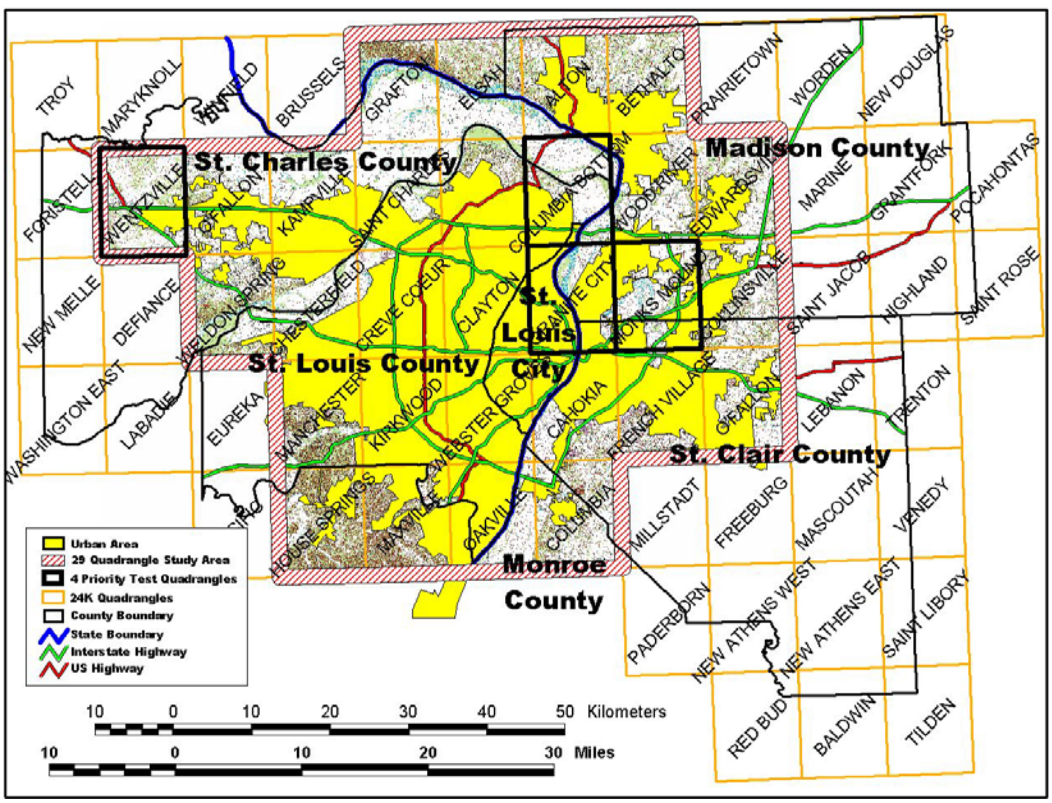


Figure 1. 29 quadrangle St. Louis urban study area and 4 priority quadrangles.

2. STUDY AREA

The Wentzville 7.5' quadrangle study area is located in western St. Charles County and the western part of the St. Louis urban area.

3. SHEAR WAVE VELOCITY TEST SITE SELECTION

Existing surficial materials geologic mapping data for the Wentzville 7.5' quadrangle were collected and used to guide the site selection for the Vs testing. The surficial materials geologic mapping data were digitized, georeferenced, and entered in a Geographic Information System (GIS) to aid in the site selection process (Figure 2). The Vs site selection was based on the need to characterize the surficial materials geologic map units, availability of nearby geotechnical borings for correlation, attempting to achieve a relatively uniform distribution of test sites, having 20 test sites on the quadrangle, and avoiding duplicate testing of sites that are being tested by others. GIS topographic maps air photos and property ownership overlays were used as an office tool to identify suitable physical and ownership conditions at test sites. A field visit was made to each site to insure its suitability, to verify site ownership and if necessary to obtain permission to test the site. The locations of sites selected for testing are shown on Figure 3 and the sites identification number, name, ownership, latitude, longitude and location description are listed in Tables 1 and 2. All sites were located on public property, such as highway and road right-of-ways.

Coordination with other investigators, both within and external to the USGS, who are collecting additional Vs data in the St. Louis area using other techniques, was continued so no unintentional duplication of test sites occur and to maximize test data coverage. Other known Vs investigators working or planning to work in the St. Louis area who have been contacted include the USGS Denver geophysics group (Jack Odum), the Association of Central United States Earthquake Consortium State Geologists' (CUSEC-SG) states of Illinois (Bob Bauer) and Missouri (Jim Palmer), and Saint Louis University seismologists (Bob Herrmann). Regular contact is also maintained with several people at the Missouri Department of Transportation (MoDOT), which does SCPT for select bridge design projects in the St. Louis area.

The surficial materials of the Wentzville 7.5' quadrangle are quite varied in composition and thickness (Figure 2). Major material types include silty, clayey, sandy and gravely alluvium in the small river valleys, silty and clayey loess on the uplands, and clayey, gravelly and silty residuum on the uplands. Surficial material thickness can change quite rapidly over short distances on the uplands especially where underlying bedrock is jointed and soluble carbonate.

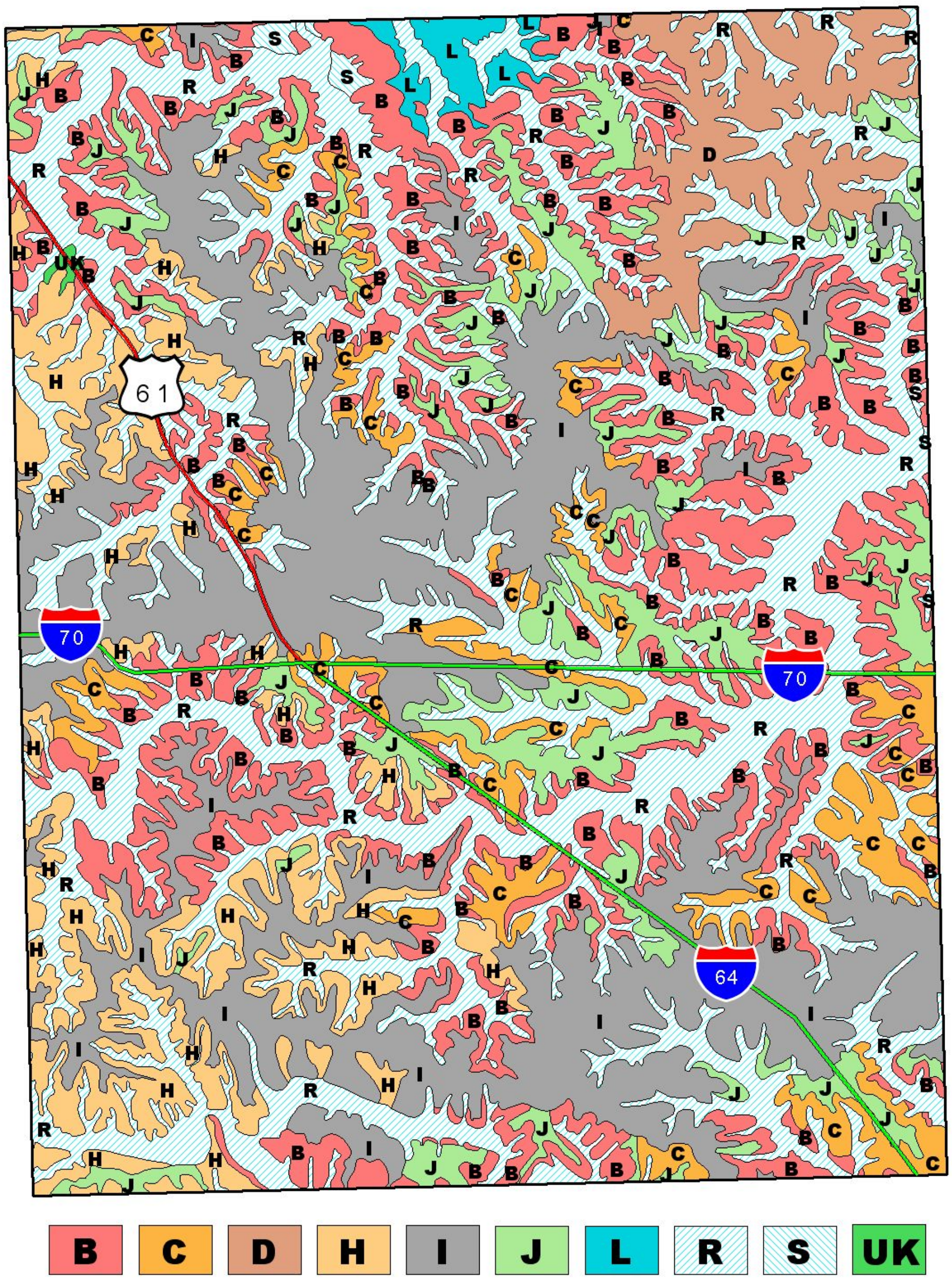


Figure 2. Wentzville 7.5’ quadrangle study area surficial materials geology: B = 0'-1' silt loam, 1'-4' residuum, 4' bedrock; C = 0'-5' silt loam, 5'-7' residuum, 7' bedrock; D = 0'-13' silt loam, 13'-15' residuum, 15' bedrock, H = 0'-4' silt loam, 4'-7' clay, 7'-12' clay loam, 12'-13' silt loam, 13'-18' loam, 18'-19' residuum; I = 0'-3' silt & silty clay loam, 3'-12' clay & clay loam, 12'-25' loam, 25'-50' clay loam; J = 0'-2' silt loam & silty clay, 2'-5' silty clay loam, 5'-7' silty clay, 7'-17' silty clay loam, 17'-20 residuum; L = 0’-2’ silty loam, 2’-5’ silty clay loam, 5’-31’ silty loam, 31’-34’ silty clay loam, 34’-38’ silty loam, 38’-40’ silty clay loam, 40’ bedrock; R = 0'-10' silt loam, 10'-15' silty clay loam; S = 0’-10’ silty loam, 10’-17’ silty clay loam, 17’-20’ silty clay loam & bedrock; UK = unknown.

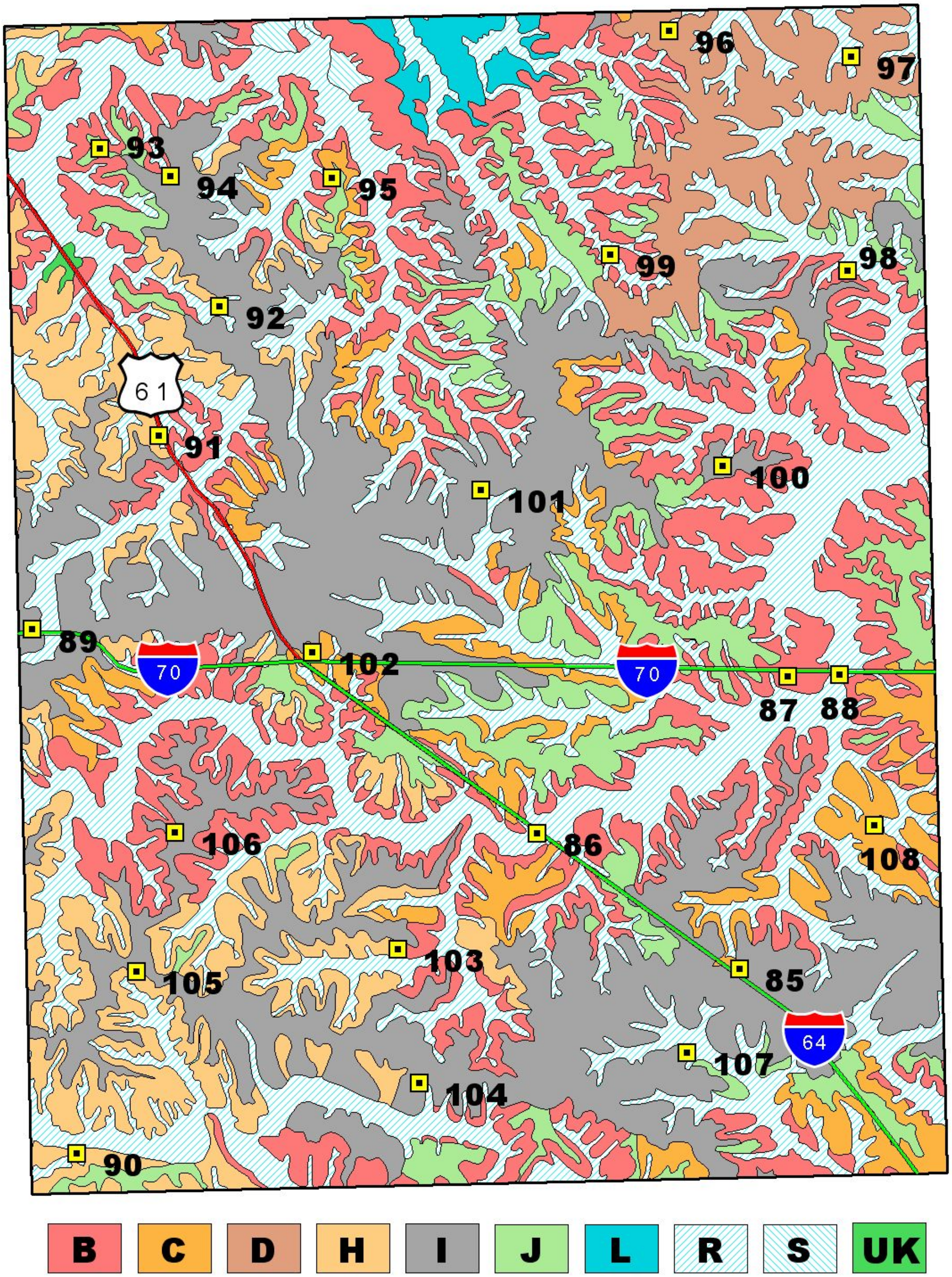


Figure 3. Wentzville 7.5' quadrangle 20 shear wave velocity test sites and surficial materials geology.

Table 1. Wentzville 7.5' quadrangle Vs test site number, names and ownership.

ID	Site Name	Owner
85	I-64 at Route 364	MO Dept. of Transportation
86	I-64 at Peruque Creek bridge	MO Dept. of Transportation
87	I-70 at Lake St. Louis Blvd.	MO Dept. of Transportation
89	I-70 at Wentzville Parkway	MO Dept. of Transportation
90	Old Hwy Z at Little Dardenne Creek	MO Dept. of Transportation
91	Hwy US 61service road at unnamed junc.	MO Dept. of Transportation
92	Mexico Rd at water tower	St. Charles County Highway Department
93	Mette Road at unnamed driveway	St. Charles County Highway Department
95	Parr Road at Cedar Gate	St. Charles County Highway Department
97	Church Road at treelike	St. Charles County Highway Department
98	Hwy P at Meadow Farm Road	MO Dept. of Transportation
100	Guthrie Road at Hancock & Feldewert Roads	St. Charles County Highway Department
101	Josephville Road at farm field entrance	St. Charles County Highway Department
102	Continental Drive at Econo Lodge motel	Wentzville City Street Department
103	Duello Road at Charity Drive	St. Charles County Highway Department
104	Hwy N at Hopewell Road	MO Dept. of Transportation
105	Hwy N at water tower near Hwy Z	MO Dept. of Transportation
106	Hwy Z at Perry Cate Blvd.	MO Dept. of Transportation
107	Hwy N at Sommers Road	MO Dept. of Transportation
108	Lake St. Louis Blvd. at Quail Ct.	Lake St. Louis Street Department

Table 2. Wentzville 7.5' quadrangle Vs test site number, latitude, longitude and location description.

ID	Latitude	Longitude	Location
85	38.77216	-90.77752	I-64 at Route 364 interchange - northeast quadrant
86	38.78716	-90.80473	I-64 at Peruque Creek bridge - east bound shoulder north of bridge
87	38.80339	-90.77023	I-70 at Lake St. Louis Blvd. interchange - southeast quadrant
89	38.81032	-90.87337	I-70 at Wentzville Parkway interchange - northeast quadrant
90	38.75428	-90.86869	Old Hwy Z at Little Dardenne Creek - between old & new Hwy Z south of creek
91	38.83088	-90.85535	US 61west service road ~2/3 mi. north of Hwy A at unnamed junc.
92	38.84450	-90.84629	Mexico Rd at water tower near High Country Dr.
93	38.86181	-90.86240	Mette Road ~0.4 mi. north of Hwy P at unnamed driveway to east (at zigzag)
95	38.85799	-90.83081	Parr Road east side ~1/3 mi. south of Hwy P at Cedar Gate road
97	38.86947	-90.75919	Church Road north side ~2/3 mi. east of Freymuth Road at field road & tree line
98	38.84665	-90.76041	Hwy P north side just west of Meadow Farm Road
100	38.82599	-90.77828	Guthrie Road east side just north of Feldewert & Hancock Roads
101	38.82391	-90.81142	Josephville Road east side ~0.3 mi. north of Hwy A at farm field entrance
102	38.80717	-90.83478	Continental Drive north side at Econo Lodge motel
103	38.77517	-90.82413	Duello Road south side ~1 mi. north Hwy N at Charity Drive (Twin Fawn Estate)
104	38.76097	-90.82198	Hwy N south side just east of Hopewell Road
105	38.77342	-90.85987	Hwy N north side ~0.2 mi. east of Hwy Z & just west of water tower
106	38.78819	-90.85448	Hwy Z east side just north of Perry Cate Blvd. (Stone Meadows subdivision)
107	38.76332	-90.78522	Hwy N south side just east of Sommers Road
108	38.78714	-90.75897	Lake St. Louis Blvd. west side just north of Quail Ct.

4. SHEAR WAVE VELOCITY TESTING

Some Vs testing techniques such as SCPT are not usable in gravelly areas such as the upland areas of gravelly residuum. The MASW technique used is suitable for testing in all the geologic settings. The efficiency and relatively low cost of the MASW technique permitted acquiring the 20 Vs profile test data needed to characterize all of the surficial materials units in the Wentzville 7.5' quadrangle study area. The non-invasive nature of the MASW technique and the very limited footprint of the technique also make it ideal for the complexities and test site limitations of the urban areas.

The "active" MASW technique involves the acquisition of Rayleigh wave (surface wave) data using a high-amplitude impact source, 4.5 Hz geophones and a 24-channel engineering seismograph. At each test site, the surface waves generated using an offset impact source are recorded (Figure 4). These data are processed and analyzed using software developed and marketed by the Kansas Geologic Survey (SURFSEIS). SURSEIS is designed such that each acquired set of Rayleigh wave data (24 channel data set for each station location) is transformed from the time domain into the frequency domain using Fast Fourier Transform (FFT) techniques. The field-based data are used to generate site-specific dispersion curves ($\mathbf{V_R(f)}$ versus $\boldsymbol{\lambda_R(f)}$) for each site location. The site-specific dispersion curves generated from field-acquired Rayleigh wave data are then transformed into site-specific vertical shear wave velocity profiles (Figure 5).

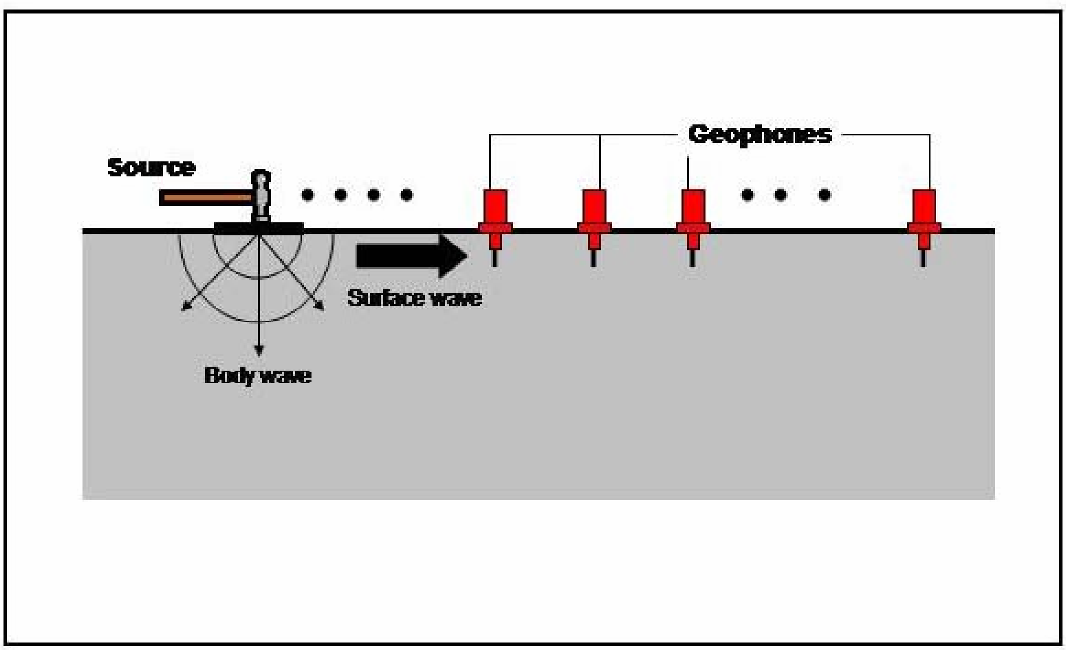


Figure 4. Field configuration. Each Rayleigh wave data set was recorded using an array of 24 low-frequency geophones spaced 1.52 meters apart. The near shot-receiver offset was 9.14 meters.

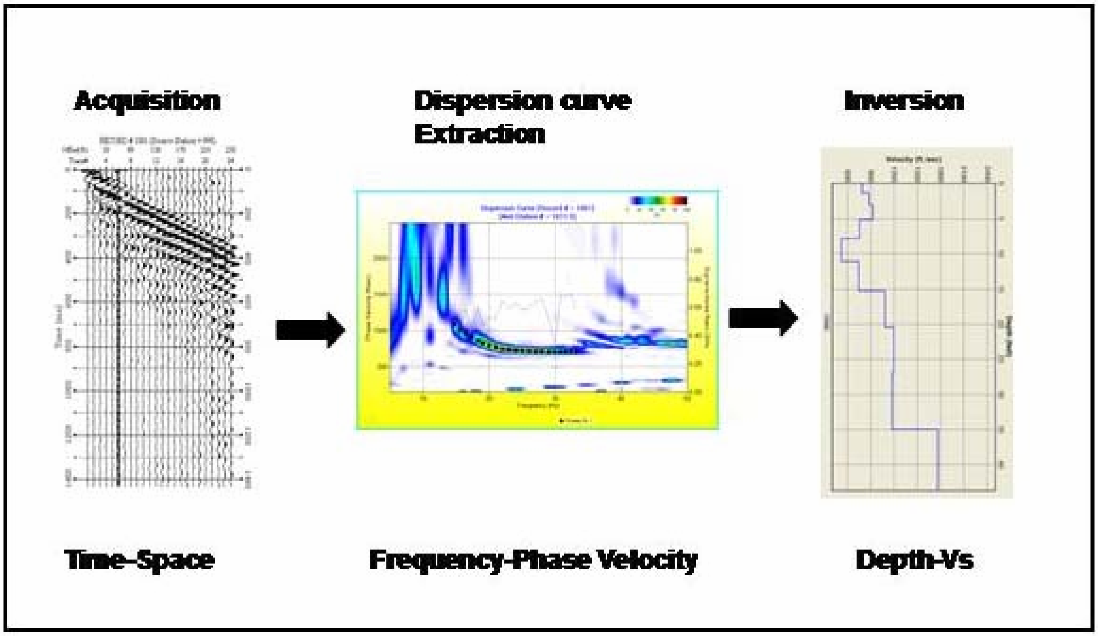


Figure 5. Dispersion curves were generated for each acquired Rayleigh wave data set. Each dispersion curve was transformed (inversion) into a shear-wave velocity vs. depth curve.

5. SHEAR WAVE VELOCITY TEST DATA

The MASW technique and data processing used divides the sampled interval in to 10 layer of greater thickness with depth and produces a Vs value for each of the 10 layers. The tabular results of the 20 Vs tests in the Wentzville 7.5' quadrangle are given in Tables 3 through 22 and plots of Vs verses depth are shown in Figures 6 through 25.

Table 3. Shear wave velocity verses depth for Site 85.

Layer	1	2	3	4	5	6	7	8	9	10
Depth (m)	-0.6	-1.3	-2.2	-3.3	-4.7	-6.4	-8.6	-11.3	-14.7	-18.4
Vs (m/sec)	163	145	177	157	202	294	353	412	498	677

Table 4. Shear wave velocity verses depth for Site 86.

Layer	1	2	3	4	5	6	7	8	9	10
Depth (m)	-0.7	-1.6	-2.8	-4.2	-6.0	-8.2	-11.0	-14.4	-18.8	-23.4
Vs (m/sec)	253	201	150	193	310	376	373	472	586	893

Table 5. Shear wave velocity verses depth for Site 87.

Layer	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Depth (m)	-1.1	-2.5	-4.2	-6.4	-9.1	-12.5	-16.8	-22.1	-28.7	-35.9
Vs (m/sec)	383	208	312	363	507	605	793	944	1092	1696

Table 6. Shear wave velocity verses depth for Site 89.

Layer	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Depth (m)	-0.6	-1.4	-2.4	-3.7	-5.2	-7.1	-9.5	-12.6	-16.3	-20.4
Vs (m/sec)	202	178	110	239	272	285	345	409	450	649

Table 7. Shear wave velocity verses depth for Site 90.

Layer	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Depth (m)	-1.0	-2.3	-3.9	-5.9	-8.4	-11.6	-15.5	-20.4	-26.5	-33.2
Vs (m/sec)	317	335	276	216	346	454	531	590	605	884

Table 8. Shear wave velocity verses depth for Site 91.

Layer	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Depth (m)	-0.9	-1.9	-3.3	-5.0	-7.1	-9.7	-13.0	-17.2	-22.3	-27.9
Vs (m/sec)	487	410	397	548	623	630	844	1027	1153	1589

Table 9. Shear wave velocity verses depth for Site 92.

Layer	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Depth (m)	-0.7	-1.6	-2.7	-4.0	-5.7	-7.9	-10.5	-13.8	-18.0	-22.5
Vs (m/sec)	202	162	162	277	325	271	319	445	519	726

Table 10. Shear wave velocity verses depth for Site 93.

Layer	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Depth (m)	-1.4	-3.1	-5.2	-7.9	-11.3	-15.5	-20.7	-27.2	-35.4	-44.3
Vs (m/sec)	303	183	382	412	531	700	843	957	1028	1540

Table 11. Shear wave velocity verses depth for Site 95.

Layer	1	2	3	4	5	6	7	8	9	10
Depth (m)	-1.0	-2.3	-3.9	-5.8	-8.3	-11.4	-15.2	-20.1	-26.1	-32.6
Vs (m/sec)	302	230	265	419	540	666	837	881	974	1552

Table 12. Shear wave velocity verses depth for Site 97.

Layer	1	2	3	4	5	6	7	8	9	10
Depth (m)	-0.9	-2.1	-3.5	-5.3	-7.5	-10.3	-13.8	-18.2	-23.6	-29.5
Vs (m/sec)	190	149	161	265	324	386	498	592	683	921

Table 13. Shear wave velocity verses depth for Site 98.

Layer	1	2	3	4	5	6	7	8	9	10
Depth (m)	-0.9	-2.0	-3.3	-5.0	-7.2	-9.8	-13.1	-17.3	-22.5	-28.1
Vs (m/sec)	205	179	148	259	302	391	483	561	675	889

Table 14. Shear wave velocity verses depth for Site 100.

Layer	1	2	3	4	5	6	7	8	9	10
Depth (m)	-0.9	-2.0	-3.4	-5.2	-7.4	-10.2	-13.6	-18.0	-23.3	-29.2
Vs (m/sec)	330	198	309	456	414	518	694	816	859	1185

Table 15. Shear wave velocity verses depth for Site 101.

Layer	1	2	3	4	5	6	7	8	9	10
Depth (m)	-0.7	-1.6	-2.7	-4.0	-5.7	-7.9	-10.5	-13.9	-18.0	-22.5
Vs (m/sec)	221	220	119	150	251	313	378	453	542	731

Table 16. Shear wave velocity verses depth for Site 102.

Layer	1	2	3	4	5	6	7	8	9	10
Depth (m)	-1.2	-2.6	-4.4	-6.7	-9.6	-13.1	-17.6	-23.1	-30.1	-37.6
Vs (m/sec)	319	344	228	230	414	481	508	657	714	1072

Table 17. Shear wave velocity verses depth for Site 103.

Layer	1	2	3	4	5	6	7	8	9	10
Depth (m)	-1.7	-3.9	-6.5	-9.9	-14.1	-19.3	-25.9	-34.0	-44.3	-55.3
Vs (m/sec)	278	220	248	404	494	486	537	644	722	1024

Table 18. Shear wave velocity verses depth for Site 104.

Layer	1	2	3	4	5	6	7	8	9	10
Depth (m)	-1.1	-2.5	-4.2	-6.4	-9.1	-12.5	-16.8	-22.1	-28.7	-35.8
Vs (m/sec)	251	244	281	234	394	476	546	604	624	921

Table 19. Shear wave velocity verses depth for Site 105.

Layer	1	2	3	4	5	6	7	8	9	10
Depth (m)	-1.4	-3.1	-5.2	-7.9	-11.3	-15.5	-20.7	-27.3	-35.5	-44.3
Vs (m/sec)	217	184	194	211	211	312	384	444	517	713

Table 20. Shear wave velocity verses depth for Site 106.

Layer	1	2	3	4	5	6	7	8	9	10
Depth (m)	-0.5	-1.2	-2.0	-3.0	-4.3	-5.9	-7.9	-10.3	-13.4	-16.8
Vs (m/sec)	242	174	206	296	223	326	401	378	414	691

Table 21. Shear wave velocity verses depth for Site 107.

Layer	1	2	3	4	5	6	7	8	9	10
Depth (m)	-0.6	-1.5	-2.5	-3.7	-5.3	-7.3	-9.7	-12.8	-16.6	-20.8
Vs (m/sec)	211	108	207	199	213	344	408	449	518	734

Table 22. Shear wave velocity verses depth for Site 108.

Layer	1	2	3	4	5	6	7	8	9	10
Depth (m)	-1.7	-3.9	-6.5	-9.9	-14.1	-19.3	-25.8	-34.0	-44.2	-55.3
Vs (m/sec)	646	437	694	996	1245	1519	1950	2331	2385	3661

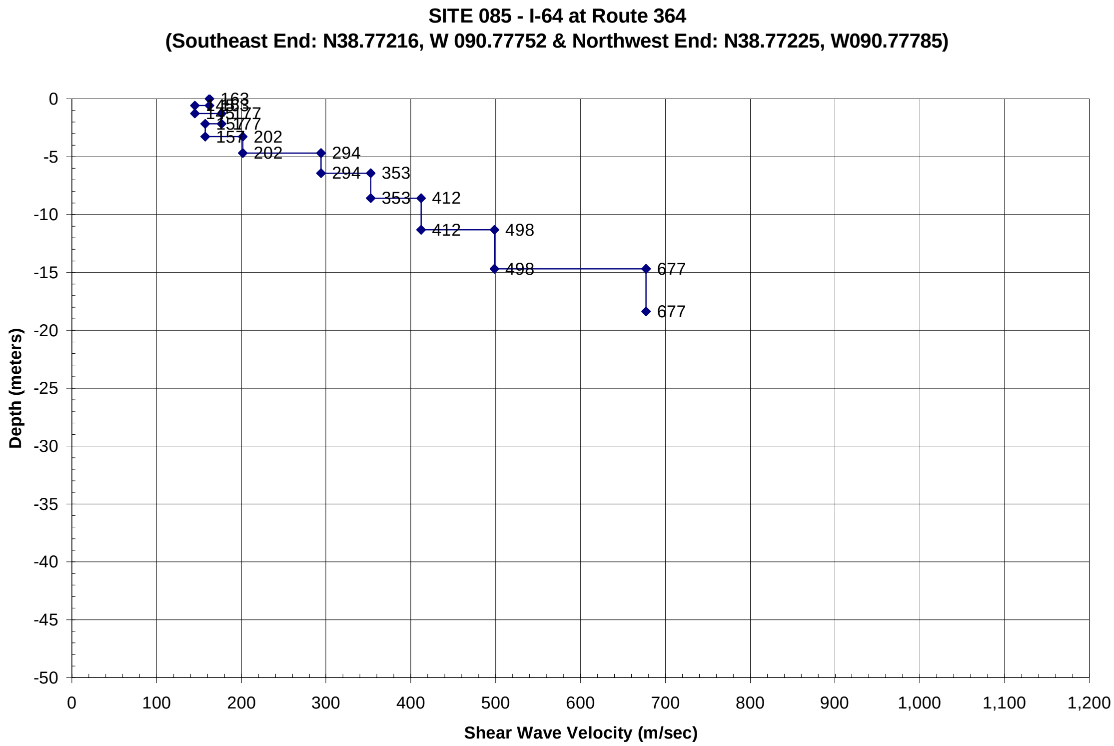
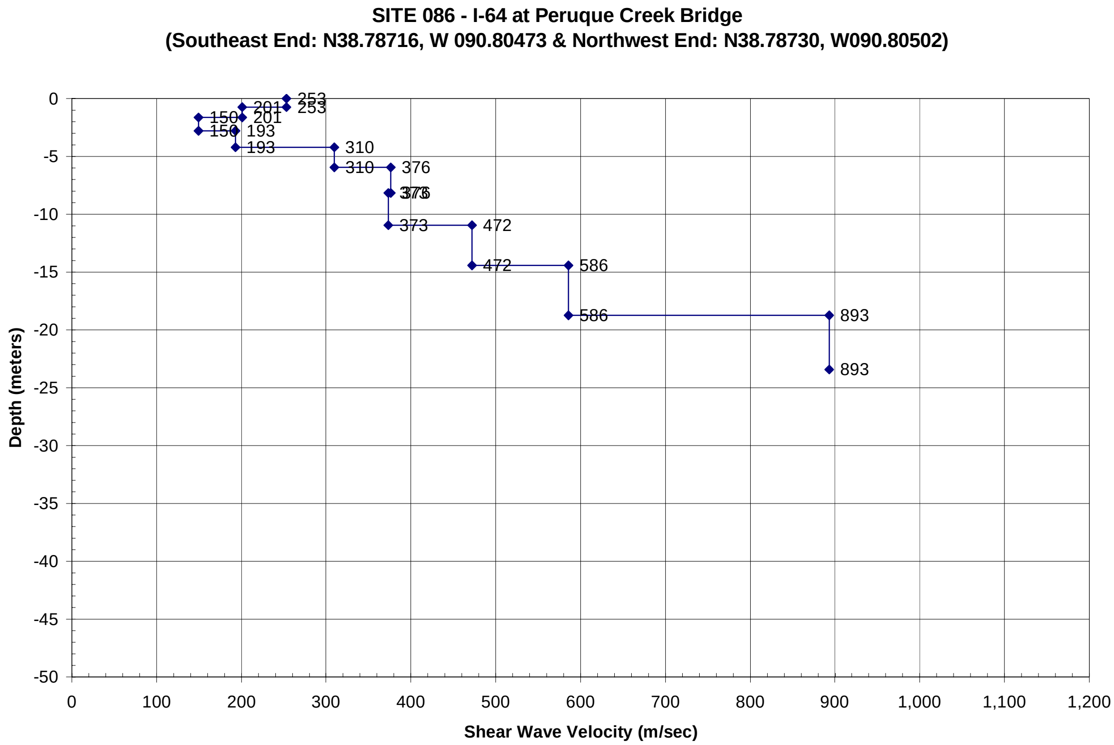


Figure 6. Shear wave velocity verses depth for Site 85.



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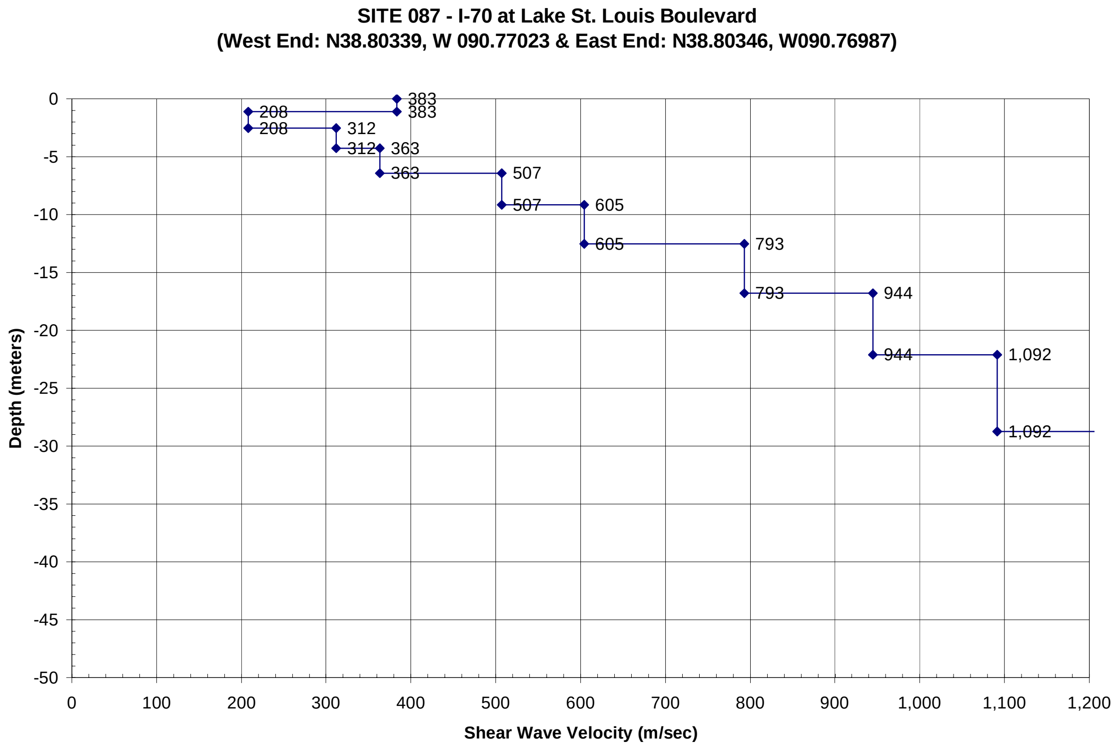

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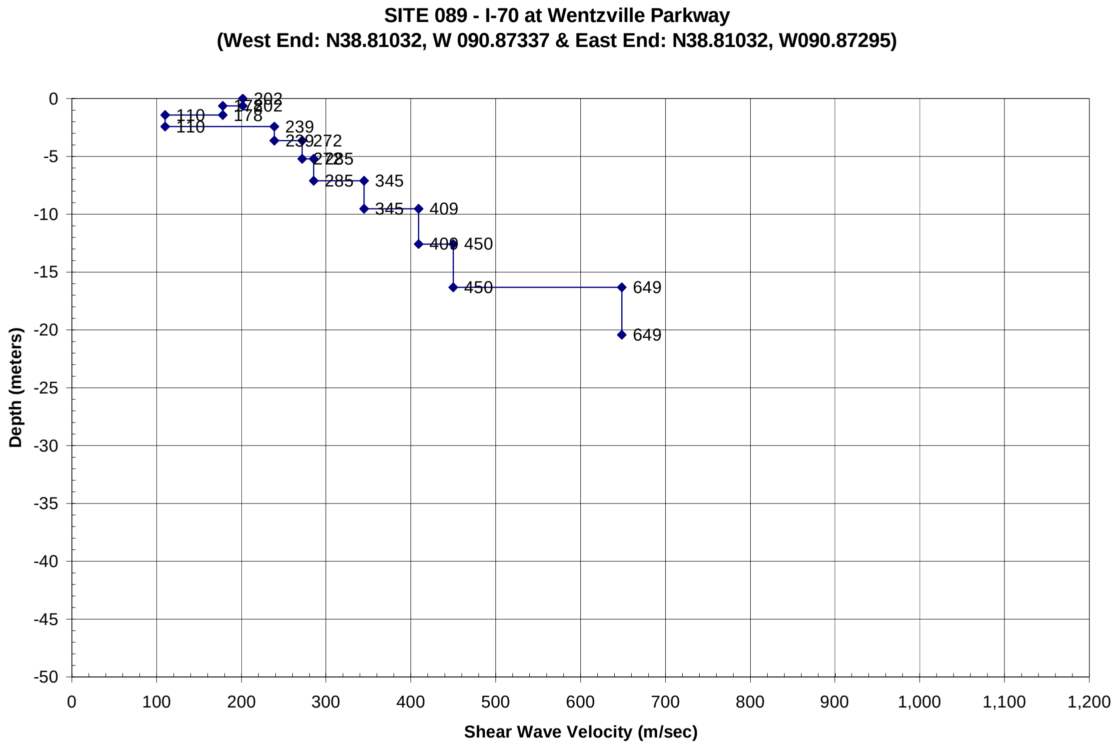

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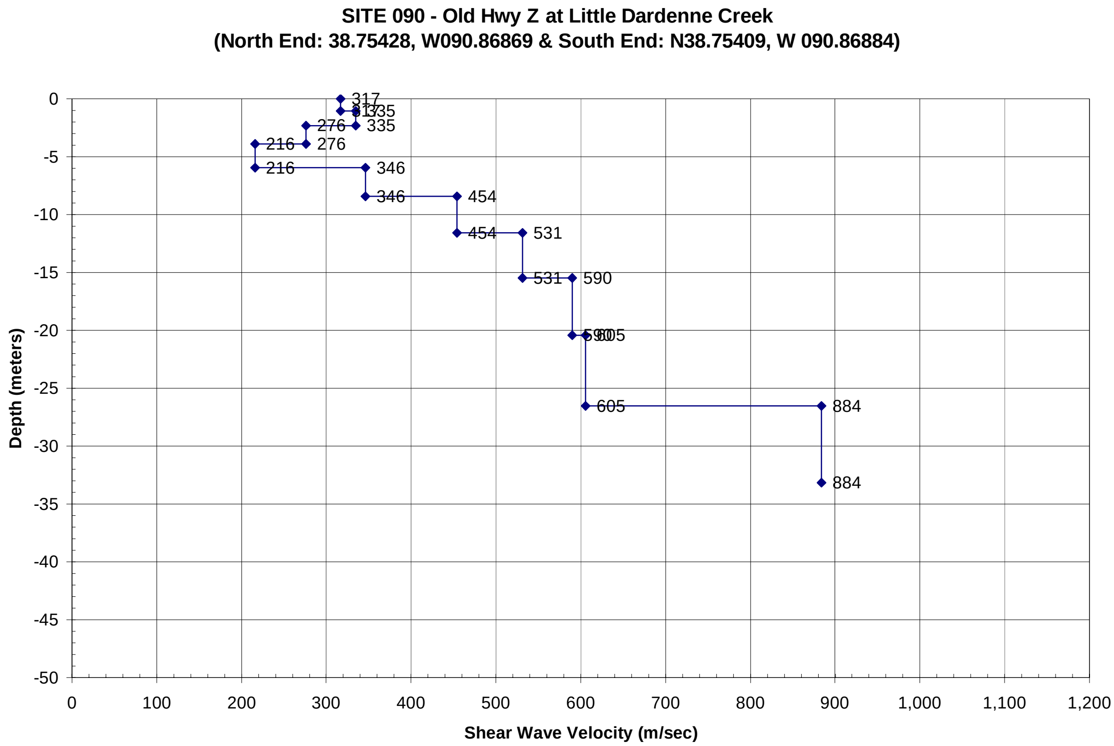

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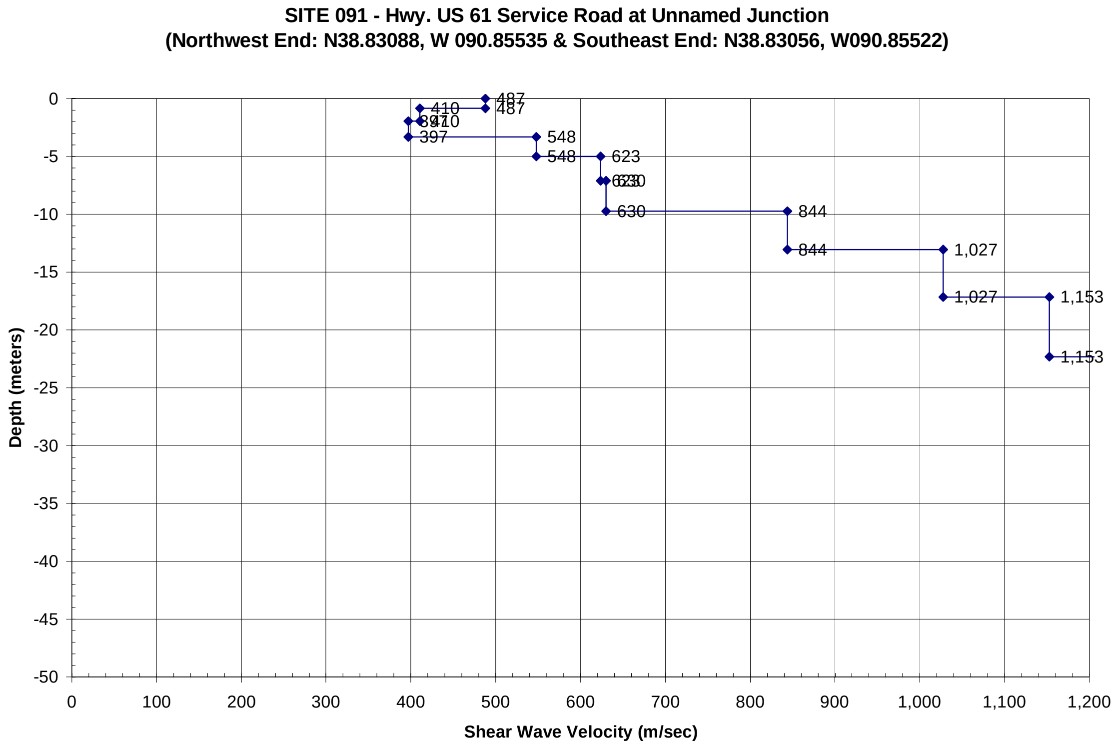

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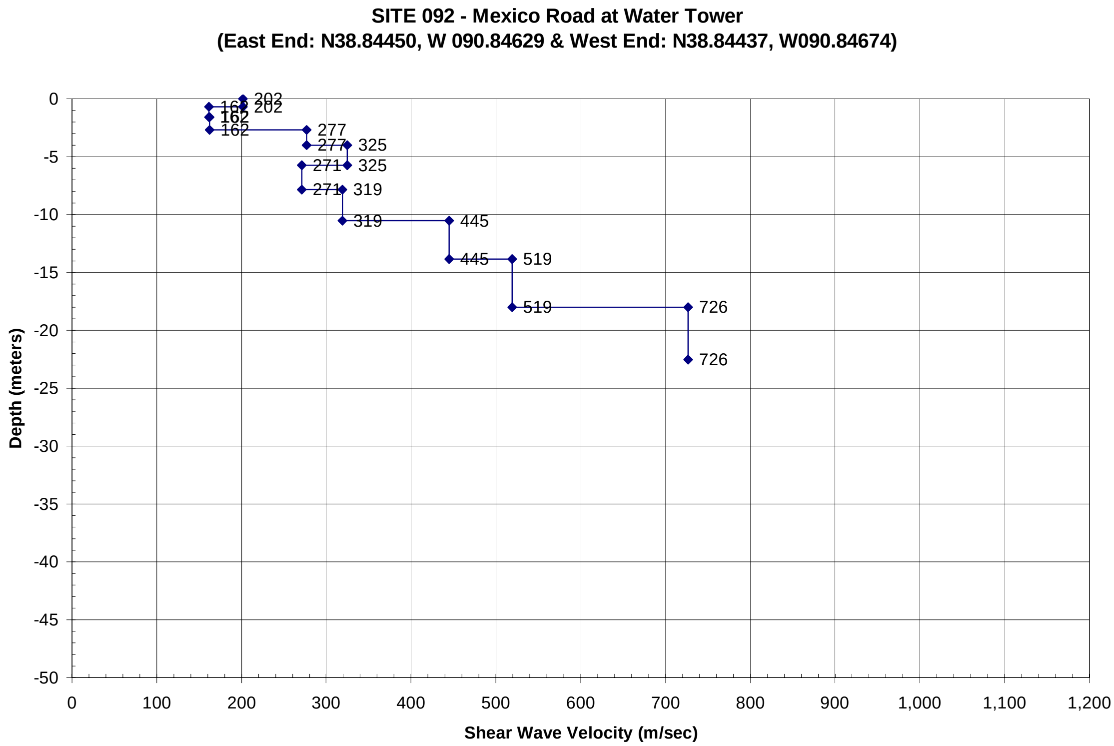
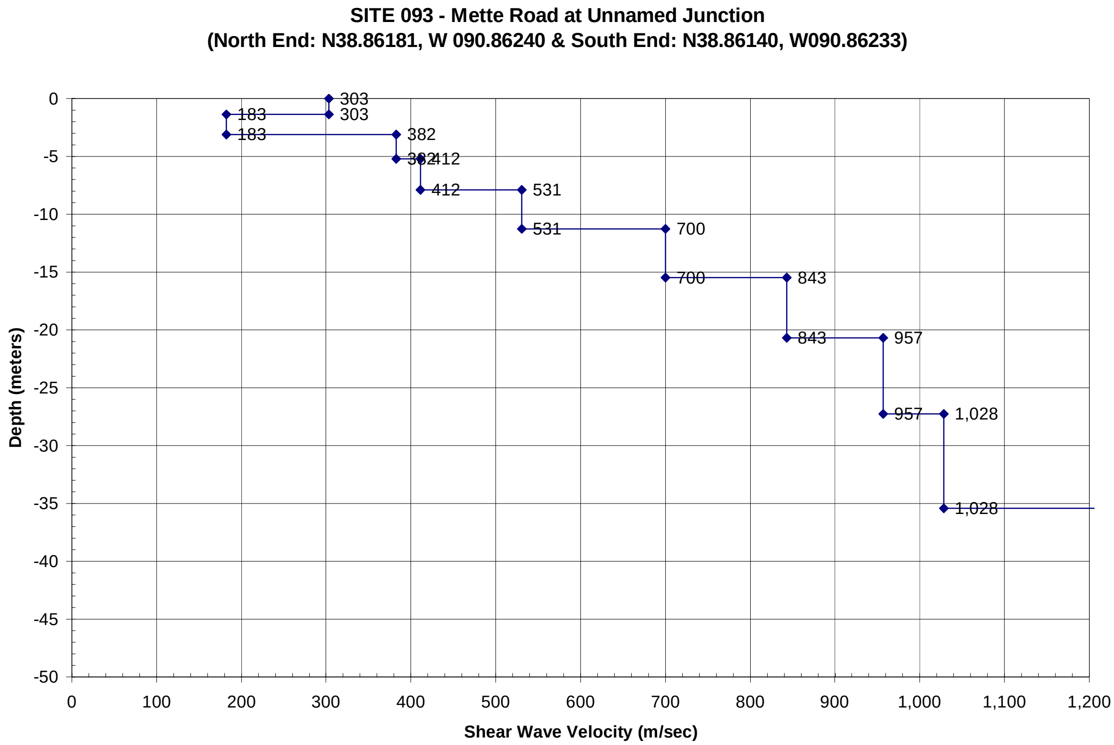


Figure 12. Shear wave velocity verses depth for Site 92.



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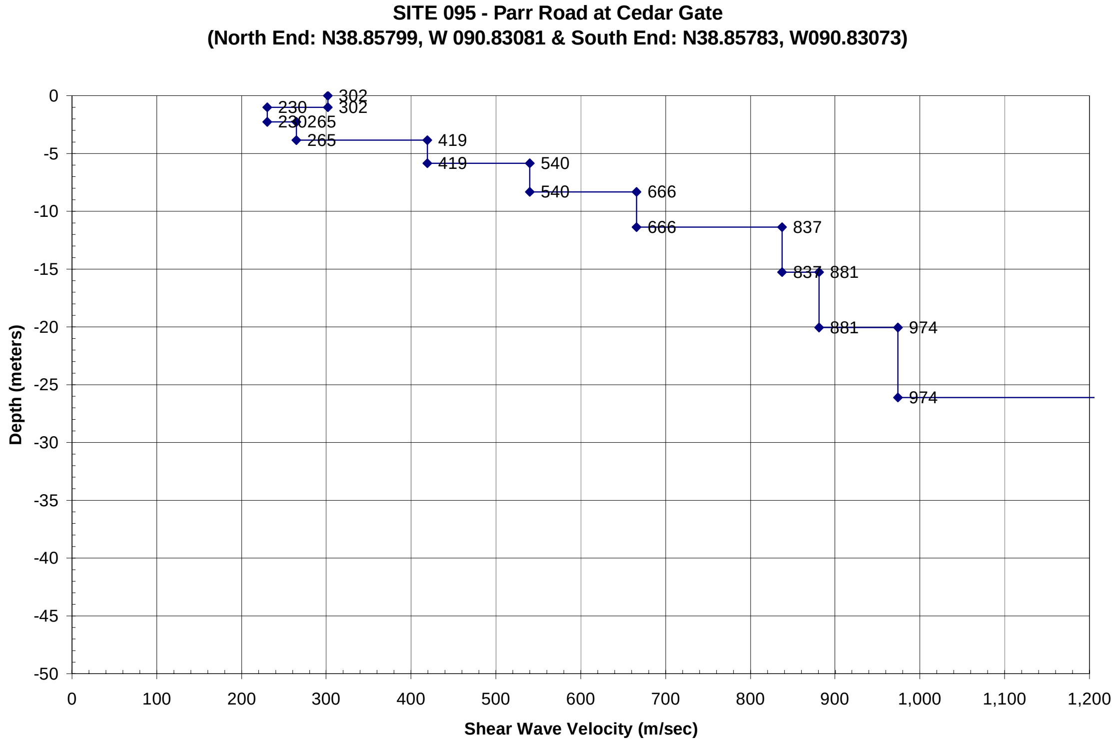
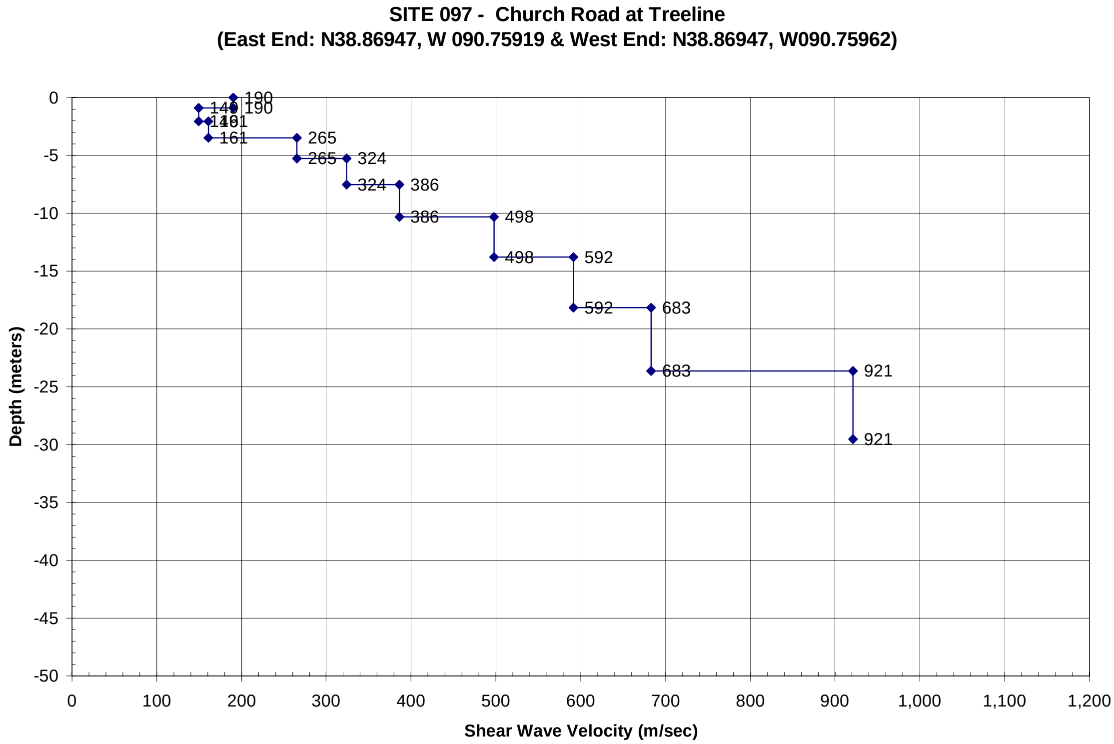


Figure 14. Shear wave velocity verses depth for Site 95.



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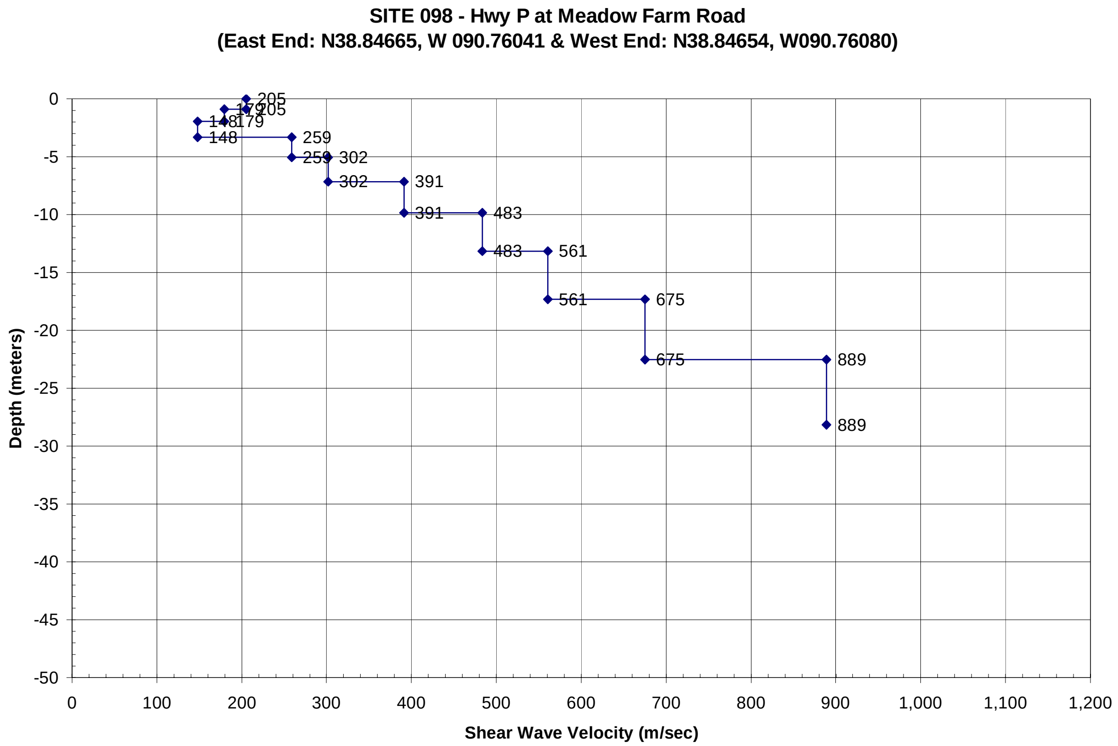

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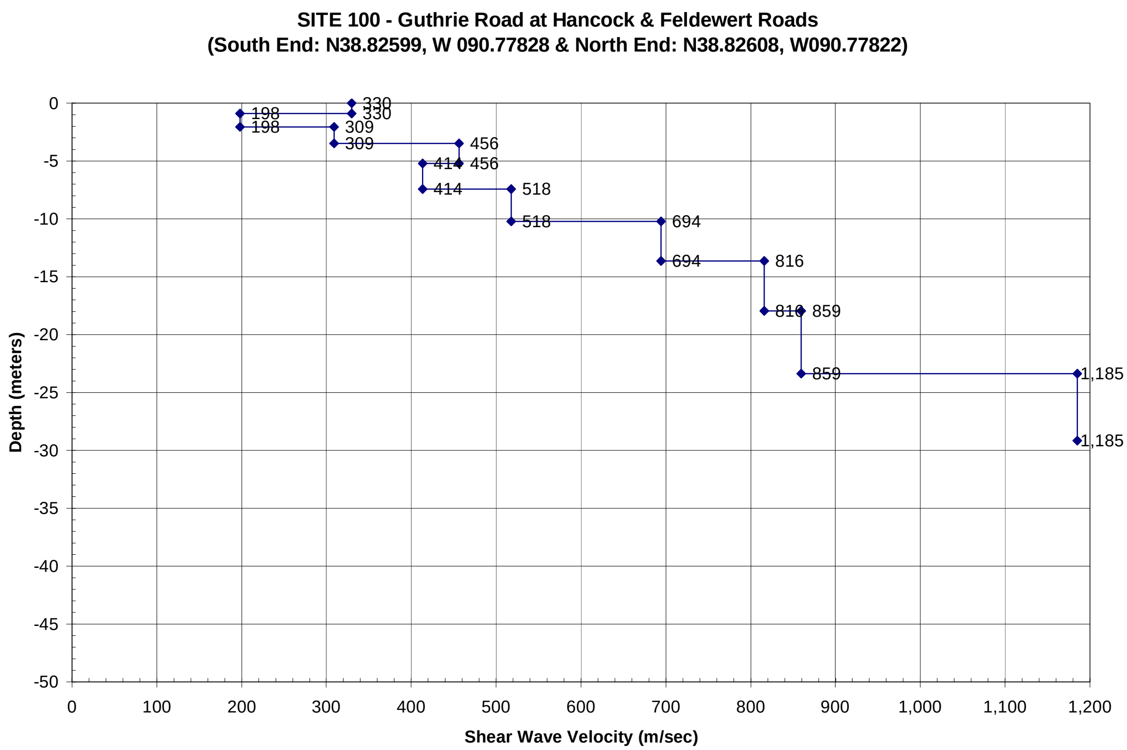

Figure 17. Shear wave velocity verses depth for Site 100.

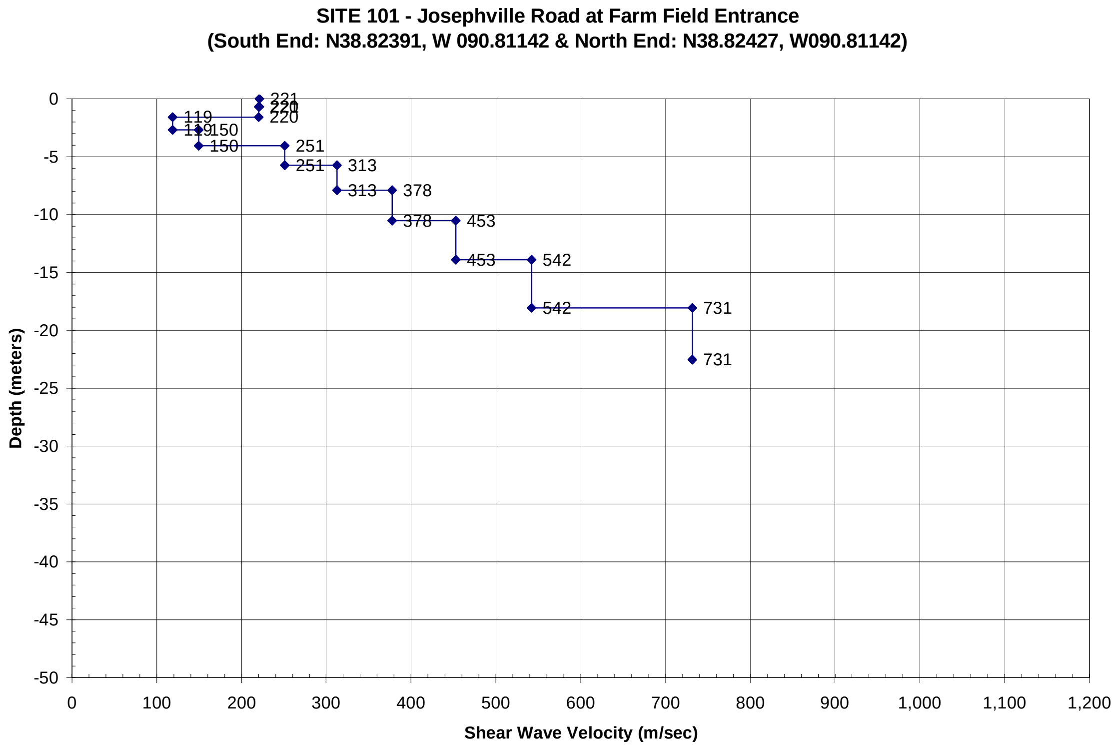

Figure 18. Shear wave velocity verses depth for Site 101.

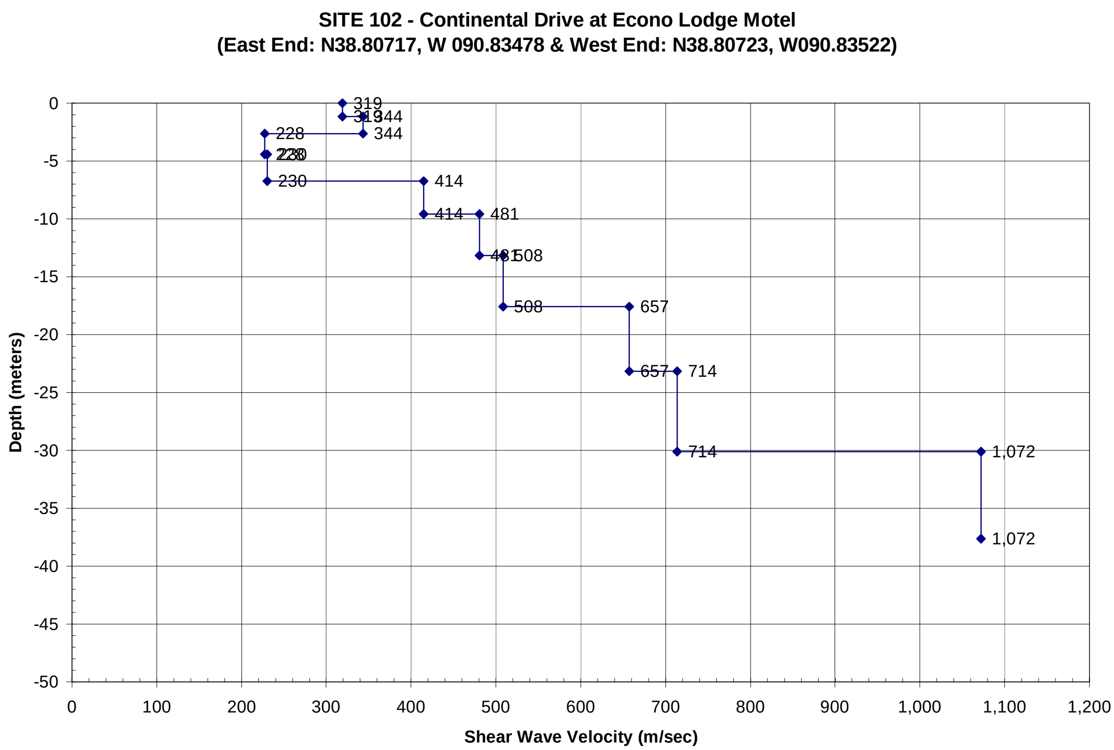

Figure 19. Shear wave velocity verses depth for Site 102.

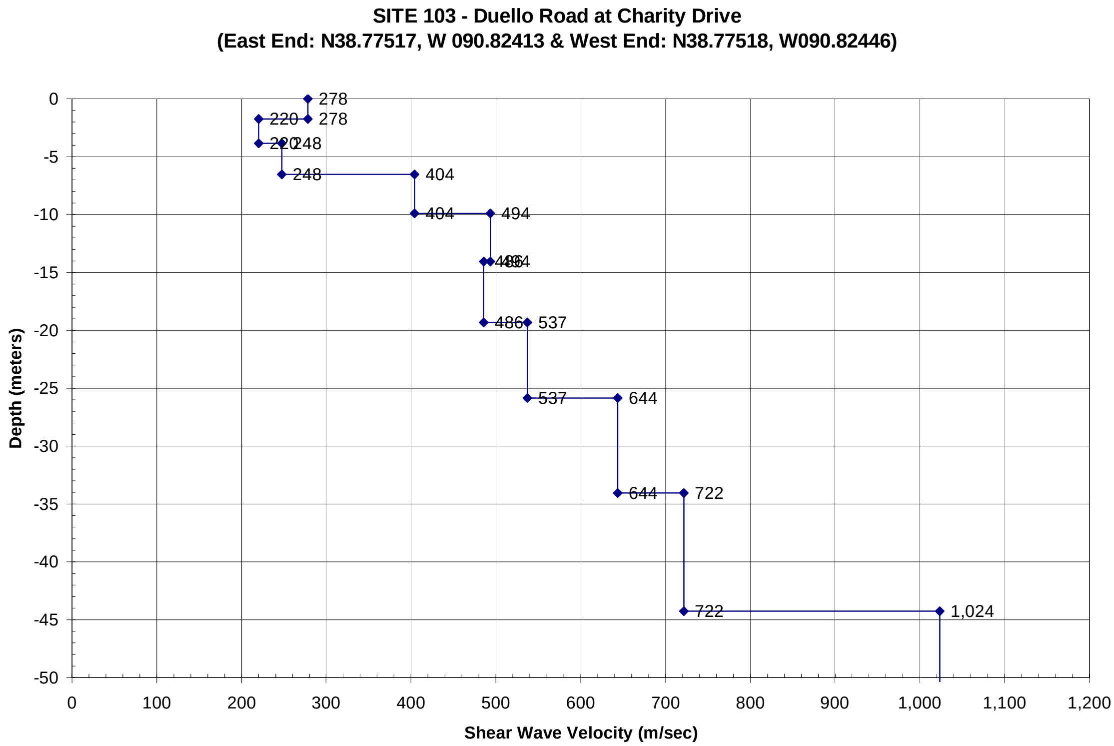

Figure 20. Shear wave velocity verses depth for Site 103.

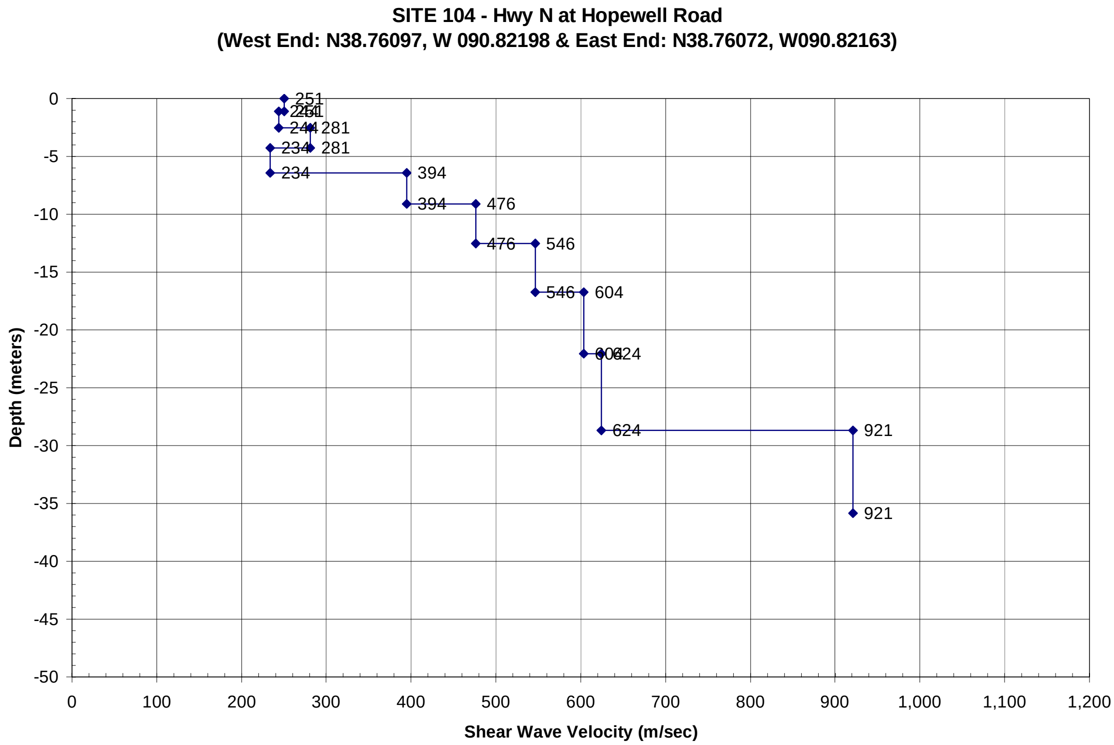

Figure 21. Shear wave velocity verses depth for Site 104.

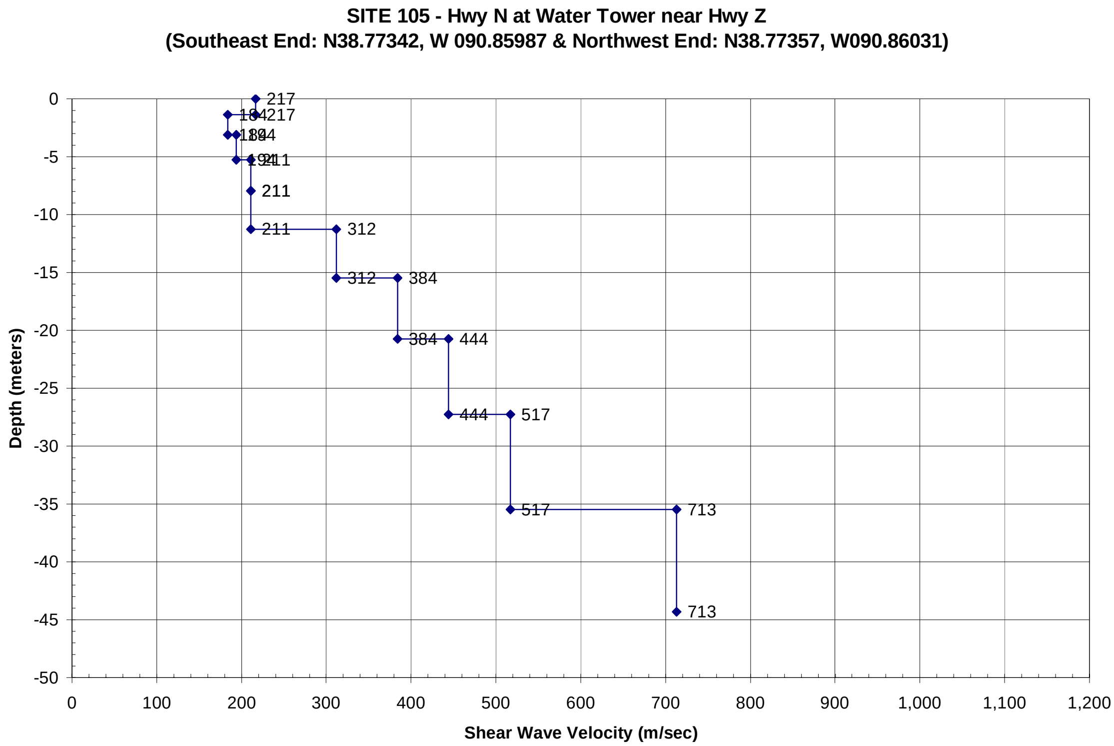

Figure 22. Shear wave velocity verses depth for Site 105.

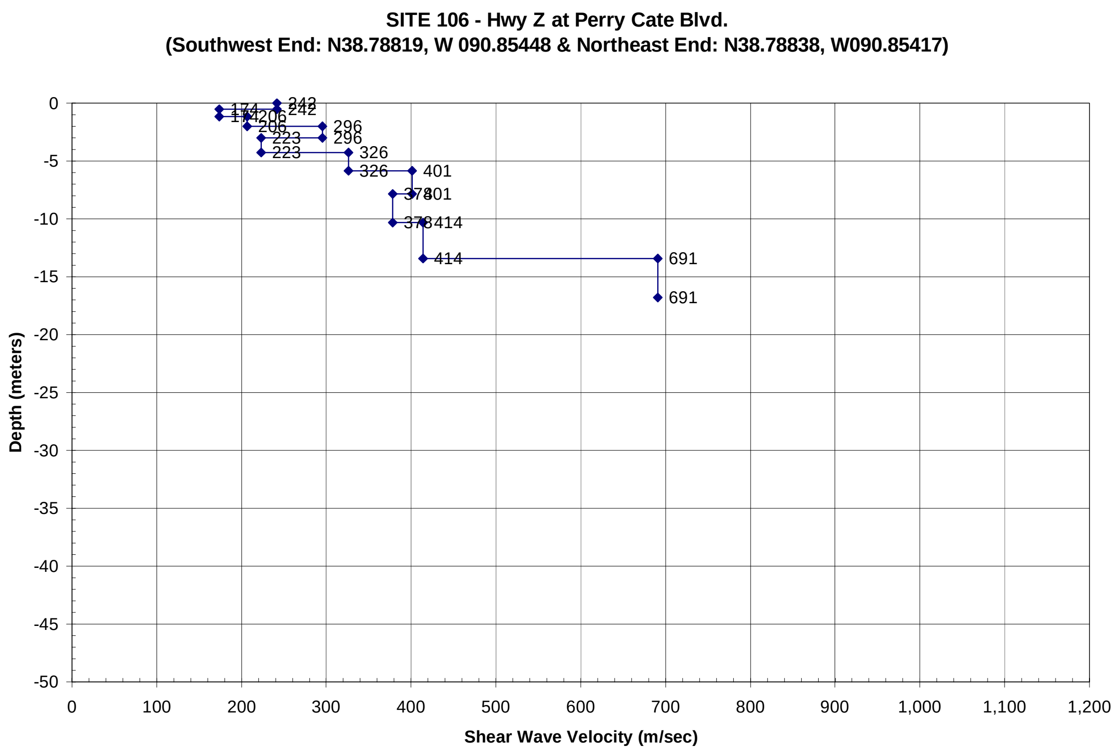

Figure 23. Shear wave velocity verses depth for Site 106.

SITE 107 - Hwy N at Sommers Road
(Southwest End: N38.76332, W 090.78522 & Northeast End: N38.76350, W090.78499)

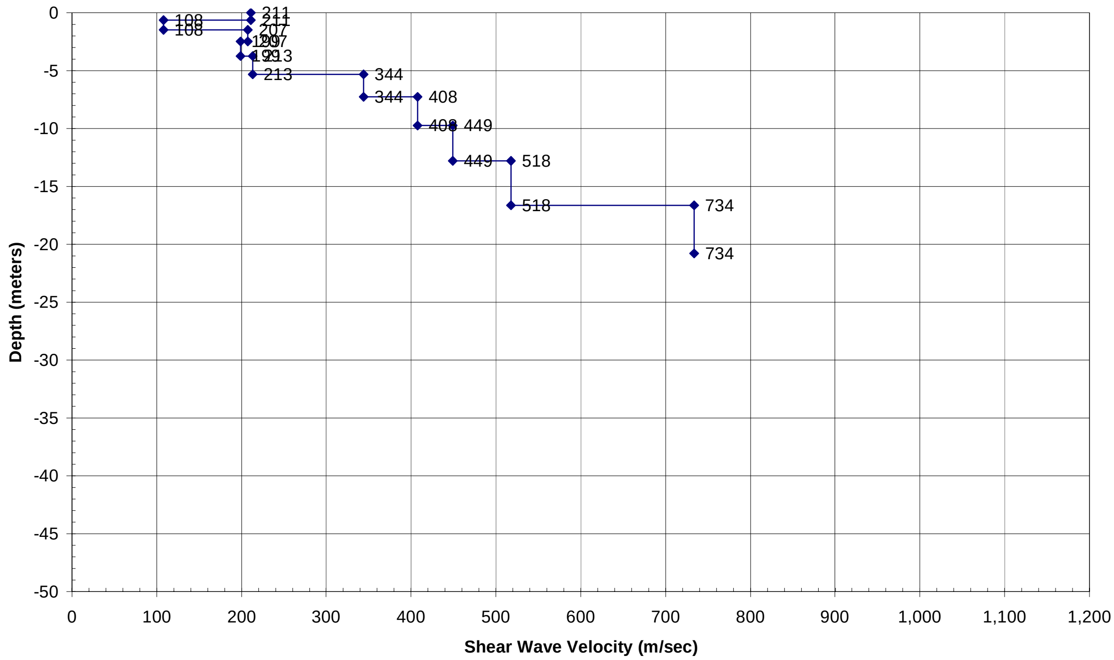

Figure 24. Shear wave velocity verses depth for Site 107.

SITE 108 - Lake St. Louis Blvd. at Quail Court
(Southwest End: N38.78714, W 090.75897 & Northeast End: N38.78730, W090.75861)

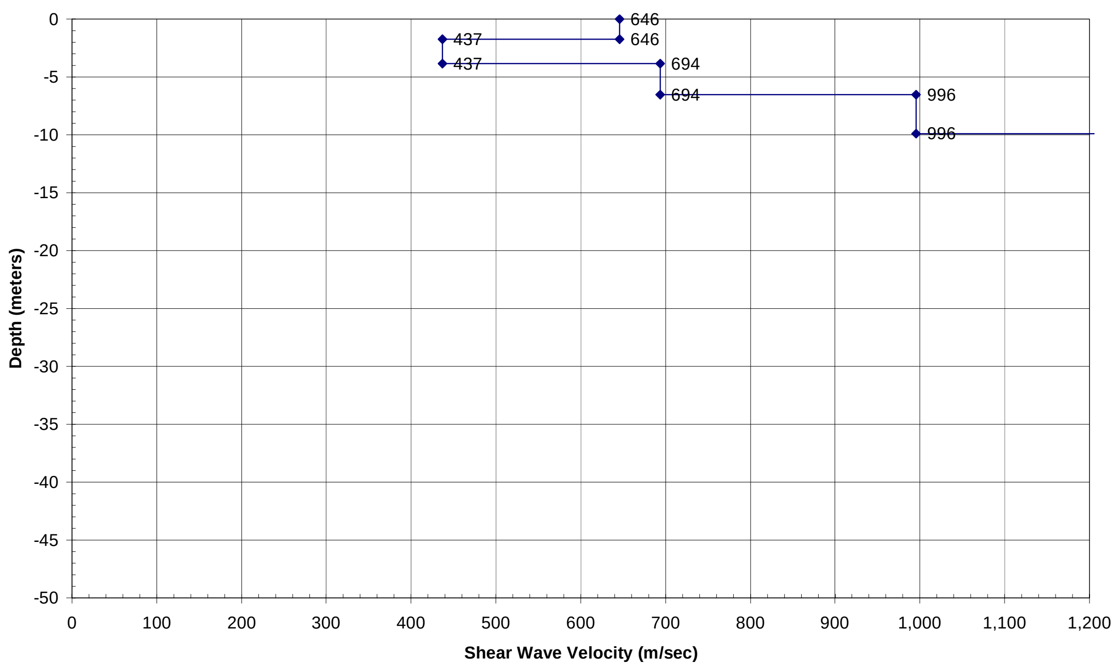

Figure 25. Shear wave velocity verses depth for Site 108.

6. AVERAGE SHEAR WAVE VELOCITY TO 30 METERS

The average shear wave velocity to a depth of 30 meters (Vs30) has been correlated to soil site amplification or NEHRP Soil Site Class. The Vs30 calculated for the 20 Wentzville 7.5' quadrangle Vs test sites are given in Table 23. In some cases where the MASW Vs data did not extend all the way to 30 meters depth the Vs for the unmeasured layer to 30 meters was estimated as that of the deepest measured layer. It should also be noted that Vs30 is intended for use with sites having 30 or more meters of surficial material above bedrock. At many locations on the Wentzville 7.5' quadrangle there are less than 30 meters of surficial materials which makes the calculation of Vs30 for those sites of questionable value.

Table 23. Average shear wave velocity to 30 meters for test sites in the Wentzville 7.5' quadrangle.

ID	Site Name	Vs 30m
85	I-64 at Route 364	397
86	I-64 at Peruque Creek bridge	436
87	I-70 at Lake St. Louis Blvd.	601
89	I-70 at Wentzville Parkway	384
90	Old Hwy Z at Little Dardenne Creek	454
91	Hwy US 61service road at unnamed junc.	840
92	Mexico Rd at water tower	406
93	Mette Road at unnamed driveway	555
95	Parr Road at Cedar Gate	631
97	Church Road at tree line	419
98	Hwy P at Meadow Farm Road	426
100	Guthrie Road at Hancock & Feldewert Roads	603
101	Josephville Road at farm field entrance	387
102	Continental Drive at Econo Lodge motel	448
103	Duello Road at Charity Drive	411
104	Hwy N at Hopewell Road	440
105	Hwy N at water tower near Hwy Z	293
106	Hwy Z at Perry Cate Blvd.	449
107	Hwy N at Sommers Road	409
108	Lake St. Louis Blvd. at Quail Ct.	1,123

7. AVAILABILITY OF DATA

A digital database of Vs test sites and profile results was developed for this project so that the data is easy to transfer and incorporate into public geotechnical databases being developed for the USGS St. Louis urban seismic hazards mapping project by other investigators. Coordination was maintained with the public geotechnical database developers at the Missouri and Illinois geological surveys and the Missouri University of Science and Technology to insure compatible data fields and formats are used.

The Vs data developed during this project have been transferred to and incorporate in the public geotechnical databases being developed for the USGS St. Louis urban seismic hazards mapping project by the Missouri Geological Survey (David Overhoff at 573-368-2182 or david.overhoff@dnr.mo.gov), the Illinois State Geological Survey (Robert Bauer at 217-244-2394 or bauer@isgs.uiuc.edu) and the Missouri University of Science and Technology (David Rogers at 573-341-6198 or rogersda@mst.edu). The Vs data has also been provided to the USGS Memphis, TN and Golden, CO coordinators for the St. Louis area earthquake hazard mapping project (Eugene Schweig and Robert Williams)   The Vs data can also be obtained from the principal investigator, David Hoffman, at 573-341-7608 or dhoffman@mst.edu.

8. SUMMARY

The result of this testing effort is the ready availability of a large volume of quality, quantitative, digital Vs data for the surficial materials in the Wentzville 7.5' quadrangle. The availability of this data is important to the success of the National Earthquake Hazard Reduction Program and EHP focus on St. Louis and the urban earthquake hazard reduction products that are being developed. The Vs test data will result in the production of higher quality soil amplification maps and other derivative products such as liquefaction susceptibility, landslide susceptibility, deterministic ground motion and probabilistic ground motion maps. Proper implementation of these derivative maps will reduce the losses in the St. Louis area from future earthquakes.

9. REPORTS PUBLISHED

No reports have been published yet.