USE OF REFRACTION MICROTREMOR (REMI) DATA FOR SHEAR WAVE VELOCITY DETERMINATION AT AN URBAN BRIDGE REHABILITATION SITE

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ABSTRACT

A refraction microtremor (ReMi) survey was conducted to determine site specific shear wave velocities for seismic hazard evaluation at a bridge rehabilitation site in St. Louis, Missouri. The bridge, located within a highly urbanized area, is approximately 1,200 feet (360 meters) long with fourteen spans and three driving lanes in each direction. The rehabilitation will include widening of the existing abutments, superstructure and deck, replacement of various foundations, and seismic retrofit of the existing piers and superstructure. The bridge is situated within approximately 70 feet (20 meters) of fill, clay and clayey gravel, underlain by limestone bedrock.

The ReMi survey methodology, developed by John Louie of the University of Nevada, Reno, is a quick, non-intrusive method for determining a one-dimensional shear wave velocity profile by recording and analyzing surface waves. ReMi data were collected by a two-person crew in one day at two different locations, one at each end of the bridge. The surveys were conducted by establishing a 24-geophone spread along a straight line at each location and recording random surface wave energy. The random energy was primarily provided by street and railroad traffic; an artificial seismic source was not required. The data were processed and modeled using SeisOpt ReMi software (Optim, LLC, 2004).

The shear wave velocity profiles were constrained using drill data which provided depth to bedrock and standard penetration test results at each of the survey locations. The results were used to identify the AASHTO soil profile type and establish seismic design parameters in accordance with AASHTO guidelines.

Notable benefits in using the ReMi method included the ability to collect data quickly with a two-person crew and the ability to collect the seismic data in a noisy urban environment.

INTRODUCTION

The Grand Avenue Bridge, located in a highly developed area of south central St. Louis, Missouri, is currently planned for rehabilitation by the City of St. Louis. The rehabilitation will include widening the structure and replacing various foundations. The bridge is located in a topographically low-lying area known as Old Mill Creek Valley and overlies significant thicknesses of fill and alluvial deposits. Shear wave data are desired to assist in evaluating seismic effects on the design of the new structural elements.

Shear wave data may be obtained indirectly or directly using a variety of methods. Shear wave velocities may be estimated indirectly using standard penetration tests (N) or cone penetrometer results, but these results may be less reliable and provide less depth of exploration as compared to results obtained by measuring seismic energy directly (Malovichko, *et. al.*, undated and Anderson and Fennessey, 2005*)*. Direct shear wave measurements obtained performing a crosshole seismic survey, or downhole seismic survey, require the use of cased boreholes that add time and expense to a project. Shear wave velocity profiles can be modeled from the direct measurement of surface waves using the methods known as Spectral Analysis of Surface Waves (SASW), Multi-Spectral Analysis of Surface Waves (MASW), and Refraction MicroTremor (ReMi). SASW requires specialized equipment and, along with MASW, normally requires the use of an artificial source which can sometimes result in lower quality data when collected in an area with significant background noise. The ReMi method involves recording surface waves generated by surrounding background “noise” using typical seismic refraction equipment. The method has been successfully used for mapping coarse-grained deposits, characterization of bedrock, characterization of fill, and detection of low-velocity zones (Rucker, Undated, ----------, Undated (b), and Louis, 2001). Without adding significant time or expense to the Grand Avenue Bridge project, we used the ReMi method to develop shear wave velocity profiles. This geophysical survey was conducted in addition to performing geotechnical borings, laboratory testing, and engineering analyses for the project. The subsurface drilling data were used to help refine the shear wave velocities.

PROJECT DESCRIPTION

Figure 1. Grand Avenue Bridge project area.

The project includes rehabilitation of the Grand Avenue Bridge located between Chouteau Avenue to the south and Interstate 64 to the north in St. Louis, Missouri. The site location is shown in Figure 1. The central part of the bridge crosses various sets of railroad tracks used by Missouri-Pacific Railroad, Burlington Northern-Santa Fe Railroad and the MetroLink public transportation system. MetroLink operates a passenger station directly beneath the bridge with pedestrian access to the bridge deck (Figure 2). In addition, the bridge crosses Bernard and Scott Streets on the north end and Gratiot and Papin Streets toward the south end. Areas beneath and adjacent to the southern end of the bridge are used for storage by various industrial entities.

Figure 2. View towards the west beneath Grand Avenue Bridge showing the MetroLink passenger station.

The existing bridge is approximately 1,200 feet (360 meters) in length, includes fourteen spans and has three driving lanes in each direction. The general site topography slopes downward from the abutments toward the central, east-west trending valley of Mill Creek. The creek has been piped underground and the valley was filled to form the rail yard. Maximum relief is approximately 50 feet (15 meters), between Elevation 510 feet (155 meters) msl near Chouteau Avenue and Elevation 460 msl in the rail yard. Grade is about Elevation 490 feet (150 meters) near the Interstate 64 off-ramp.

General features of the bridge rehabilitation include widening of the existing north and south abutments, widening of ten piers, replacement of various foundations, widening of portions of the superstructure and deck, seismic retrofitting of existing piers and superstructure, and installing various amenities and aesthetic features.

GEOLOGIC SETTING

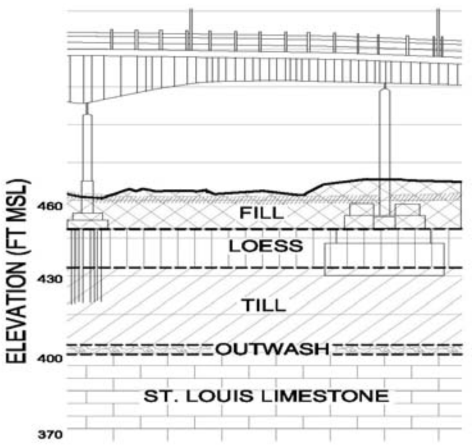

Figure 3. Typical geologic profile for the Grand Avenue Bridge area.

The near surface geology in the vicinity of the site is dominated by sediments related to Pleistocene glaciation. Glacially-derived soils in the region consist of till and outwash deposits overlain by modified loess (post-glacial windblown sediments comprised of silt and clay). At the project site, surficial fill is present in most areas, as a result of previous grading in the Mill Creek valley. The underlying soil deposits include, from younger to older, Pleistocene-age loess, glacial till, and glacial outwash. Bedrock is generally Mississippian age carbonates. A typical geologic profile for the project site is shown in Figure 3.

At the bridge site, fill extends to depths of 8 to 18 feet (2.5 to 5 meters) and typically consists of lean and fat clay with sand, gravel, and variable amounts of cinders, brick fragments, concrete, and glass. Loess deposits occur below the fill and extend to depths of 18 to 28 feet (5 to 8 meters). The loess has been modified by weathering and consists of brown to gray, lean and fat clay. Glacial till and outwash deposits occur below the loess and extend to bedrock at depths of 33 to 77 feet (10 to 23 meters). The till and outwash deposits are comprised of fat and lean clay with sand and silt layers, underlain by silt and/or clayey sand and gravel.

Bedrock in the area is Mississippian-age limestone of the Meramecian Series. The bedrock generally dips to the northeast away from the Ozark uplift centered in southeastern Missouri (i.e., St. Francois Mountains) and towards the Illinois Basin centered in east-central Illinois. Bedrock at the subject site is St. Louis Limestone which is composed of gray to brown, lithographic to finely crystalline, medium-bedded to massive limestone. Blue and bluish-gray shale seams occur throughout the formation. The St. Louis Limestone is about 180 feet (50 meters) thick in the St. Louis area; however, at the project site, much of the formation has been removed by erosion. Karst features are prevalent in the formation, with solution voids and pinnacles that may penetrate 20 feet (6 meters) or more into the rock. Experience indicates weathering is typically in the range of 3 to 7 feet (1 to 2 meters). Underlying the St. Louis Limestone is the Salem Formation which is a 100- to 160-foot thick, bluish-gray to gray, argillaceous, oolitic limestone. The Salem is conformable with and difficult to differentiate from the overlying St. Louis Limestone.

REFRACTION MICROTREMOR METHOD

A refraction microtremor (ReMi) survey was performed to determine site specific shear wave velocities at the bridge location. The ReMi method utilizes the dispersive property of surface waves (Louis, 2001). ReMi data are collected by passively recording background surface wave “noise” such as the vibrations generated by passing vehicles, airplanes or trains, as well as added noise created by initiating impacts (via sledgehammer) at the ground surface. The surface waves are recorded using a seismic system comprised of geophones, cables and a seismograph. Shear wave velocity profiles are constructed by analyzing surface wave phase velocities and frequencies, and performing inversion modeling.

REMI DATA COLLECTION

Figure4. View along ReMi Line 1 showing 20-foot geophone spacings.

ReMi surveys were conducted by a two-person crew on November 21, 2005, using a Seistronix RAS24 engineering seismograph and 4.5-hz vertical geophones. Data recorded with a 24-channel system such as this provides better layer resolution than data recorded using a 12-channel system (Optim, LLC, 2004). ReMi data were collected along one east-west trending line parallel to the Metrolink tracks (ReMi Line 1), and one north-south trending line parallel to the eastern edge of the bridge in an industrial storage lot (ReMi Line 2). ReMi survey locations are shown in Figure 1. ReMi Line 1 extended 460 feet (140 meters), and ReMi Line 2 extended 440 feet (134 meters). Line lengths of approximately 600 feet would have been preferred to obtain information at greater depths, however, the line lengths were limited due to site conditions. Regardless, we were able to interpret velocity profiles to depths of at least 100 feet (30 meters). The lines were situated as far from concrete footings as possible. The ReMi method is based on the assumption of relatively continuous geologic layering across the survey line. Large footings, voids, or other discontinuous features in the immediate vicinity of the survey line would reduce the accuracy of the velocity interpretation. A 20-foot (6-meter) geophone spacing was used for each line (Figure 4). To assist in geophone coupling on ReMi Line 2, 1/4-inch (0.6-centimeter) diameter holes were hammer-drilled into the asphalt pavement and the geophones spikes were securely seated into each hole (Figure 5). The ReMi data were acquired by collecting approximately 20 background microtremor "noise" recordings using a time window (sampling length) of 30 seconds each. A 2-ms sampling rate was used and all filters were open. The "noise" recordings were supplemented with sledge hammer blows on a metal plate at the end of each line.

Figure 5. View of typical geophone secured into pavement prior to surveying.

REMI DATA PROCESSING

The data were processed and modeled using SeisOpt ReMi software developed by Optim LLC. Plots of inverse velocity (slowness) versus frequency were plotted for each line as shown in Figures 6 and 7. These plots were generated using all 20 recordings for each line.

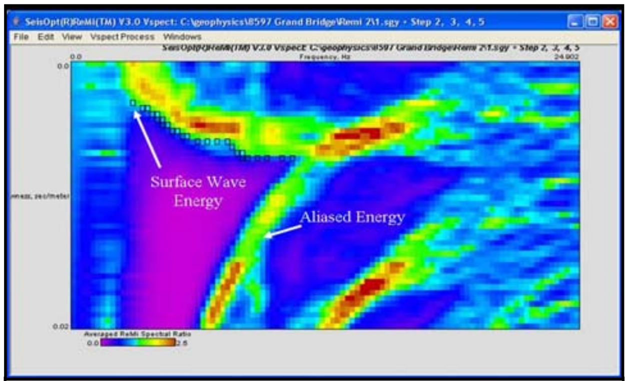

Figure 6. Dispersion curve (slowness versus frequency) of data recorded along ReMi Line 1.

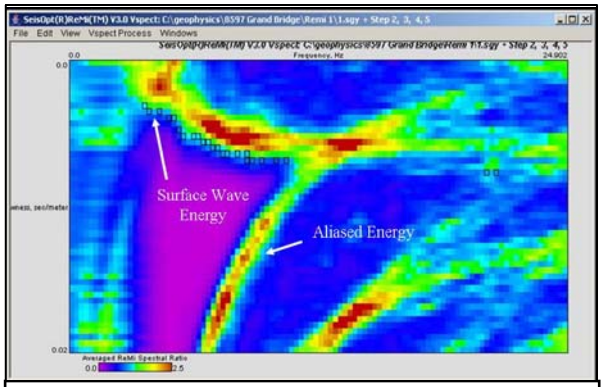

Figure 7. Dispersion curve (slowness versus frequency) of data recorded along ReMi Line 2.

The surface wave energy is easily identified as the high amplitude data trending from the upper left corner (high velocity and low frequency) toward the lower right corner (lower velocity and higher frequency). The lower edge of this data package was picked and used to develop a graph of phase velocity versus period (inverse frequency). The graphed data for each ReMi line is shown in Figures 8 and 9.

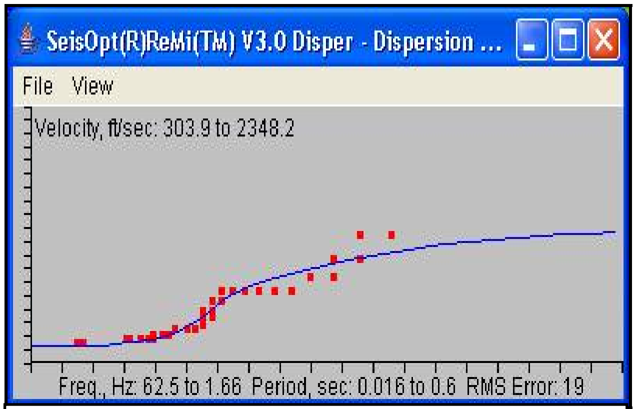

Figure 8. Graph of phase velocity versus period for ReMi Line 1 data.

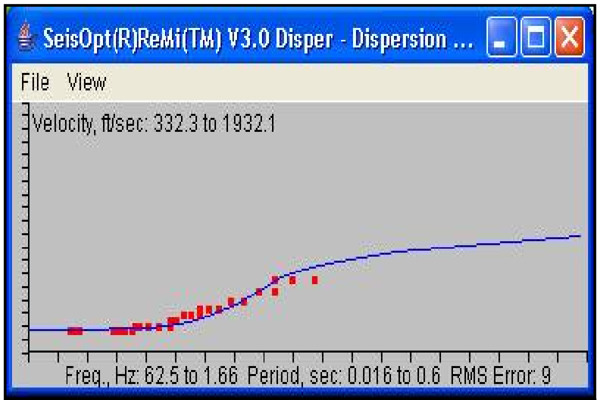

Figure 9. Graph of phase velocity versus period for ReMi Line 2 data.

These graphed data were used to develop models of shear wave velocity profiles centered at the location of each ReMi line. The models are developed by adjusting values of shear wave velocity and unit thicknesses with depth. Boring data available from the geotechnical exploration were used to help refine the shear wave velocity modeling results. Distinct layers of fill, loess, granular outwash, and limestone bedrock, identified during drilling, were used to constrain the thicknesses of the subsurface layers, and the velocities were adjusted to provide the best fit with the recorded and graphed data.

RESULTS AND CONCLUSIONS

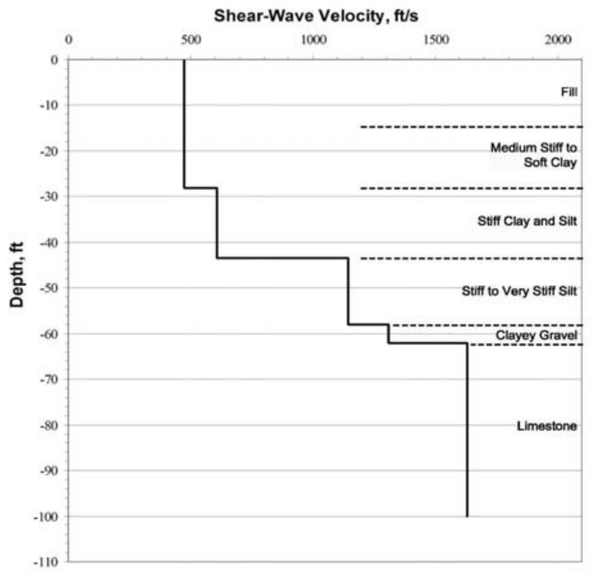

Figure 10. Shear wave velocity profile for ReMi Line 1.

The one-dimensional shear wave velocity profiles derived from ReMi Lines 1 and 2 are presented in Figures 10 and 11, respectively. The horizontal scale is shear wave velocity in feet per second and the vertical scale is depth in feet. Also shown on the profiles are representative soil and rock descriptions for borings located on each line. These boring logs were used to help constrain the ReMi models.

Along ReMi Line 1, top of bedrock was interpreted to occur at an approximate depth of 62 feet (19 meters) and the shear wave velocity of bedrock was interpreted to be approximately 1,630 ft/sec (497 m/sec). This line revealed a low shear wave velocity layer, approximately 476 ft/sec (145 m/sec), extending from the surface to a depth of approximately 28 feet (9 meters), which corresponds to the surficial fill and underlying loess. Data from two borings located on ReMi Line 1, generally agree with the interpretation.

Along ReMi Line 2, bedrock was interpreted to occur at an approximate depth of 64 feet (20 meters) and the shear wave velocity of bedrock was interpreted to be approximately 1,340 ft/sec (408 m/sec). This line also revealed a layer with low shear wave velocity, approximately 518 ft/sec (158 m/sec), extending from the surface to a depth of approximately 48 feet (15 meters), which corresponds to the surficial fill and underlying loess. Data from a boring located on ReMi Line 2, generally agrees with the interpretation.

AASHTO defines a Type IV Soil Profile as soft clays or silts greater than 40 feet (12 meters) in depth, which may be characterized by a shear wave velocity less than 500 ft/sec. Based on the results of the ReMi survey, the shallow layers of fill and loess along Line 1 were characterized as 28 feet (9 meters) thick with a shear wave velocity of 476 ft/sec (145 m/sec), and along Line 2 were characterized as 48 feet (15 meters) thick with a shear wave velocity of 518 ft/sec (158 m/sec). Based on the ReMi results and on boring data, the site did not satisfy the criteria for a Type IV Soil Profile. For this site, an AASHTO Soil Profile Type I was selected which corresponds to a Site Coefficient, S, of 1.0.

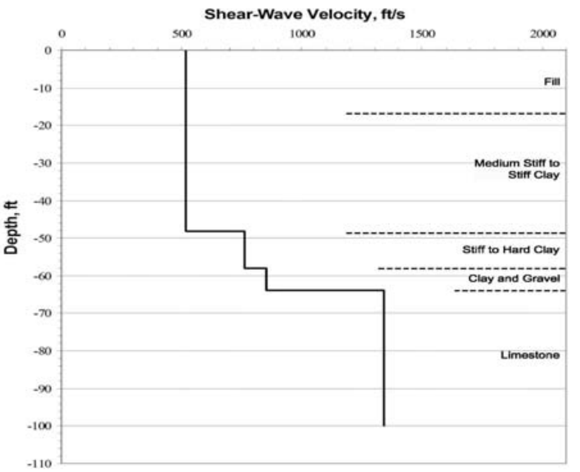

Figure 11. Shear wave velocity profile for ReMi Line 2.

CONCLUSIONS

Based on these results, the ReMi method appears to be a viable and low-cost method for developing shear wave velocity profiles in highly developed urban environments. ReMi data were collected at two locations within an area of high industrial and vehicular activity. A primary requirement for collecting ReMi data is the ability to extend survey lines approximately 400+ feet (122+ meters) in the vicinity of the area of interest. Although not required, boring data collected in the vicinity of the ReMi survey assists in constraining the shear wave velocity model.

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