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Performing horizontal to vertical ratio testing in stiff soils in and around Grand Teton National Park

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Abstract Horizontal to vertical spectral ratio (HVSR) testing was completed at two cross sections in and around GTNP. The HVSR testing produced reliable estimates of the fundamental frequencies for many of the sites tested. The goal of the testing was to determine a depth of soil above competent bedrock. However the fundamental frequencies recorded yielded predicted depths that are much shallower than expected. Also the predicted depths did not increase at greater distance from the Teton Range, which would be expected at these sites. Based on these predictions the authors do not believe the frequencies recorded are a good indication of the depth of the soil above bedrock but instead it is believed that the depths correspond with a layer of softer topsoil/overburden above a stiffer gravel layer. Although the goal of measuring the depth of soil above bedrock was not met, HVSR produced results that may be useful to others for determination of a fundamental frequency of resonance at our testing locations.

Introduction

Depth of bedrock is an important design consideration in terms of seismic modeling and foundation design. Although the depth of bedrock in the Snake River floodplain has not been well documented, borings for the Jackson Wilson bridge over the Snake River have proven its depth is greater than 30 m. The goal of this project was to determine the depth of the soil over competent bedrock and although this goal was not met, valuable frequency data was recorded and will be presented herein.

One method to determine depth of soil above bedrock is the horizontal to vertical spectral ratio (HVSR) method. This method uses ambient vibration data to determine a fundamental frequency at the location tested. In turn the frequency data can be used to determine the depth of the soil above a significant velocity (stiffness) contrast. This method has been shown to work well in conditions of soft soil over hard rock (Rodriguez and Midorikawa, 2002; Haghshenas et al., 2008). The sites tested are likely to have subsurface conditions of sand and gravel deposits. These subsurface conditions are known not to be ideal for HVSR testing; however, it is hoped that by recording data near the Teton Range (where the subsurface should be relatively shallow) and moving towards the Snake River (bedrock depths likely significantly deeper) a trend in the fundamental frequency data will reveal an increase in bedrock depth.

HVSR data was collected from near the Teton Range to the Snake River at two cross-section locations as presented in Figure 1. Location A is located within the southern GTNP boundaries while the Snake River Ranch owns most of the land surrounding location B. The National Park Service (NPS) and the Snake River Ranch, respectively, permitted testing at both locations. The data was recorded using six trillium compact broadband 3-component seismometers. The seismometers record ambient wave field vi-

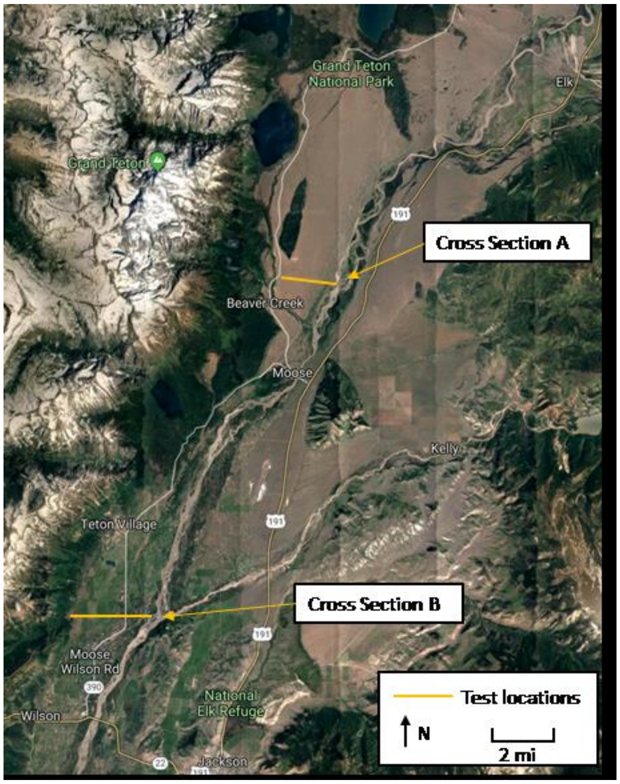

Figure 1. HVSR testing cross sections for the two chosen locations.

brations so no seismic source was used.

Methods

The HVSR method was first introduced by Nogoshi and Igarashi (1971) but was not popularized until the work by Nakamura (1989) (Haghshenas et al., 2008). The HVSR method uses recorded microtremor (i.e. ambient noise) surface wave data which contains both Shear and Rayleigh wave information. Nakamura (1989) proposed that the spectral ratio between horizontal and vertical components could be used as the transfer function of the site. It has since been shown that while the HSVR can help determine a reliable fundamental frequency, and hence bedrock depth, HVSR is not a transfer function for every site (Volant et al., 1998; Zaré et al., 1999; Haghshenas et al., 2008).

The best results from HVSR testing are accomplished by burying the sensors in the ground and allowing the sensors to collect data for enough time to capture high and low frequency data. If a site is likely to have very soft soils, longer recording times and lower sampling frequencies are acceptable. Similarly, a very stiff shallow site would necessitate a higher sampling frequency and may produce acceptable results with data recorded over less time. All data collected for this work were recorded at a sampling frequency of 100 Hz and each station included sampling times of at least 30 mins. At each location, burying the sensors was not possible because property owners (GTNP, and Snake River Ranch) would not allow holes to be dug on their property. In order to record ambient signals and provide proper coupling with the soil, sensors were placed in buckets of sand. At each testing location a sensor was placed and leveled in a two gallon bucket, then surrounded by sand. Each sensor was then covered by a five gallon bucket placed upside down to protect it from wind, sun other small disturbances.

HVSR data is stored in seg2 file format and was analyzed using matlab code developed at the University of Wyoming. Other available software was also used to analyze the HVSR data and verify the authors matlab code. All data was analyzed using 120 sec time windows.

Preliminary results

HVSR data is analyzed in the frequency domain and results are plotted as HVSR versus frequency as presented in the Figures 2 and 3. If HVSR data yields acceptable results, like those shown in Figures 2 and 3, primary frequencies can be determined. This frequency is assumed to corresponds to the site's fundamental natural frequency. HVSR data was collected at 60 sites (24 for A, 36 for B; Fig 1) and plots like Figures 2 and 3 were produced for each site. The primary frequency was determined by an analyst using an iterative process to determine the local maxima for each site. The chosen fundamental frequency is listed in each figure caption. Some sites (not shown) did not produce an HVSR peak that is distinguishable. In these cases the data were not included in further analyses.

The depth of the soil above bedrock was determined

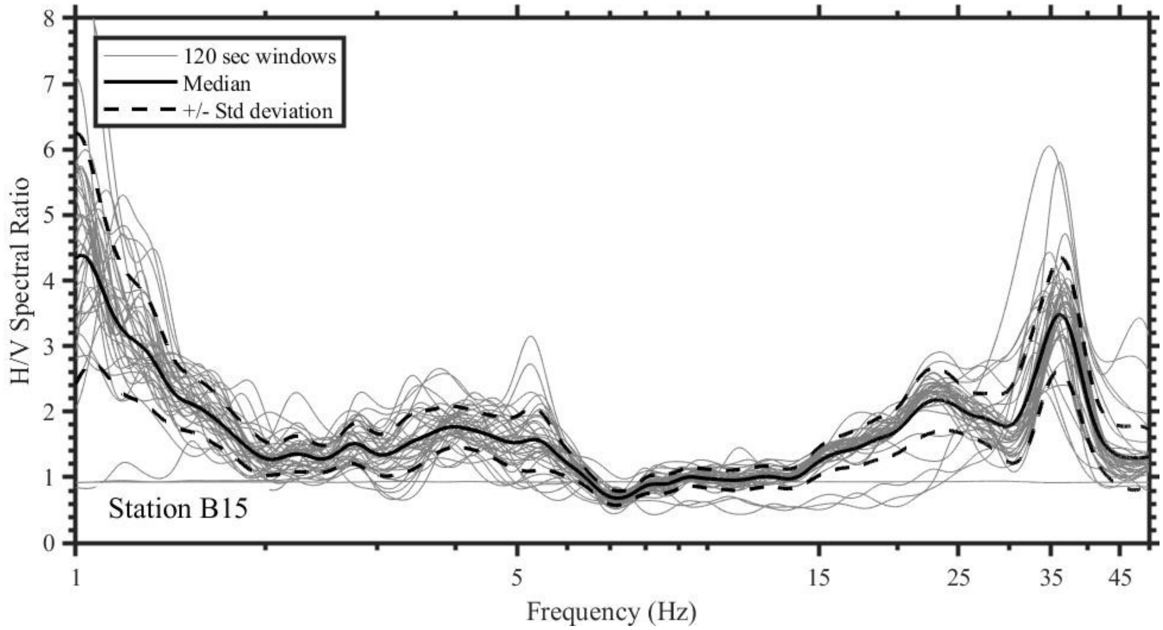

Figure 2. Station B15 HVSR data with chosen primary peak of 36.4 Hz.

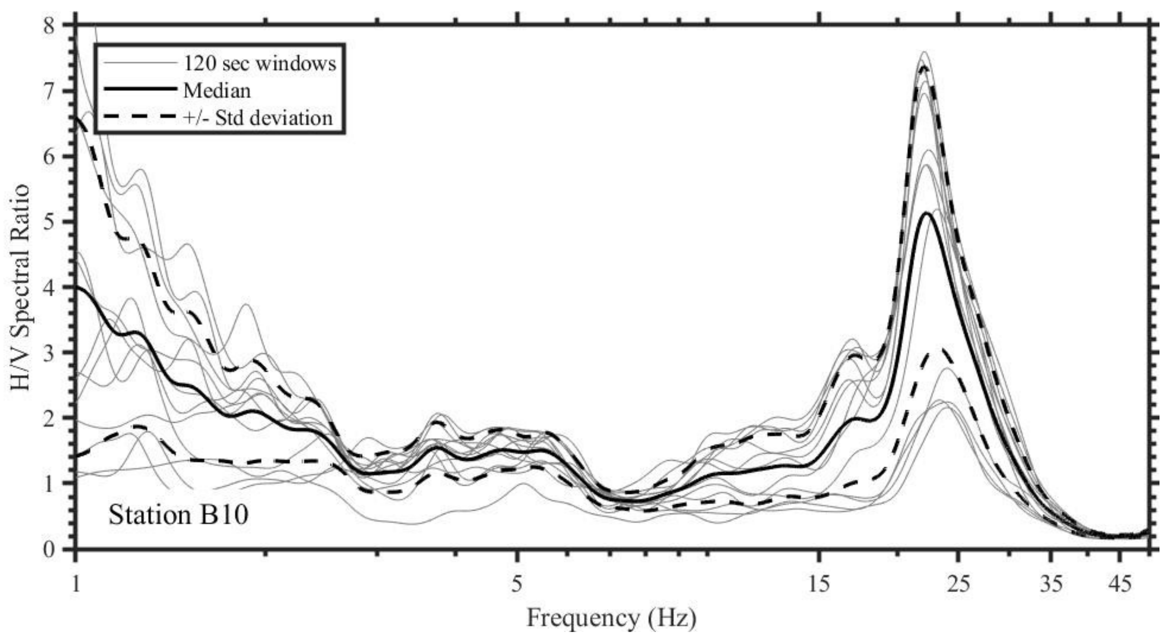

Figure 3. Station B10 HVSR data with chosen primary peak of 22.3 Hz.

using a well known estimate of natural frequency and an equation that related the shear wave velocity, depth of the soil above bedrock and fundamental frequency of a site as presented in Equation 1.

$$H = V_s/4 \times f_0 \tag{1}$$

Where f_0 is the fundamental frequency determined from the HVSR primary peak, V_s is the shear wave velocity (assumed) and H is the depth of the soil above bedrock.

The shear wave velocity for each site was assumed to be 250 m/s. This value was not measured for each site, but based on the high fundamental frequencies (and hence shallow depths) and previous work in the Snake River Valley. The authors believe 250 m/s to be a reasonable assumption, however due to the high frequencies measured at most sites, depth estimates assuming 250 m/s and a much higher velocity of 500 m/s both produce depths much shallower than expected. While each site alone can be used to determine a depth of soil, the aggregate data and depths from all sensors along each cross section allow for analyses and depth determination across the entire cross section as presented in Figures 4 and 5 for locations A and B, respectively.

At location A, within the GTNP, the fundamental frequency results in depths of soil above bedrock of around 2 m along the entire cross section. It is important to note that the data quality at location A was worse than at location B. Also at location A the cross section was 2.3 km long, shorter than the 3.5 km long cross section at B, meaning much less data was collected at A than B. At location B, Snake River Ranch, the fundamental frequency results in depths of soil above bedrock of around 2 m along the entire cross section but varies from 1.5 m to 3 m. At both locations, if a shear wave velocity of 500 m/s is assumed, the depth of soil above bedrock would double from the estimates shown in Figures 4 and 5. This high a shear wave velocity is unlikely and reinforces the investigator's belief that the depths measured correspond to the depth of surficial soils above more compact gravels and cobbles.

One of the unforeseen challenges we faced in this research was gaining access to private property in order to place sensors in pre-determined locations. This was due to many of the private residences that only live in the area a portion of the year, and the protective nature of Wyoming land owners. Testing within the GTNP also had some challenges and, while access was granted, working in areas that were not next to established roads or trails was not acceptable and care was taken to leave no trace of the areas we did test.

Conclusions

Previous work approximately 25 km south of location A (6 km south of location B), indicated that subsurface soil conditions are likely to be composed of gravels and cobbles and that bedrock depth is greater than 30m. Previous work also indicates a surface layer less than 10 m deep yielded measured velocities less than 250 m/s.

While the HVSR data did not produce bedrock depths that are compatible with previous data and expected depths, they did produce measurable fundamental frequencies at many of the locations tested. The depths determined from the fundamental frequencies ranged from about 1.5 m to 3 m at both location A location B. The shallow depths that correspond to these frequencies is likely a near surface velocity contrast that differentiates top soil/surficial deposits from a stiffer gravel material. Better determination of what this velocity contrast might be would require more extensive surface wave testing to be completed.

Future work

At each site future work could include surface wave testing to confirm velocity contrasts and determine subsurface stiffness. This information may also be used to determine bedrock depths if seismic sources large enough to produce the long wavelengths could be used and permission from the GTNP could be obtained. This would require GTNP to allow testing devices to be placed in large arrays in remote locations. Repeated HVSR testing and sampling at greater frequencies could also improve data quality at some lo-

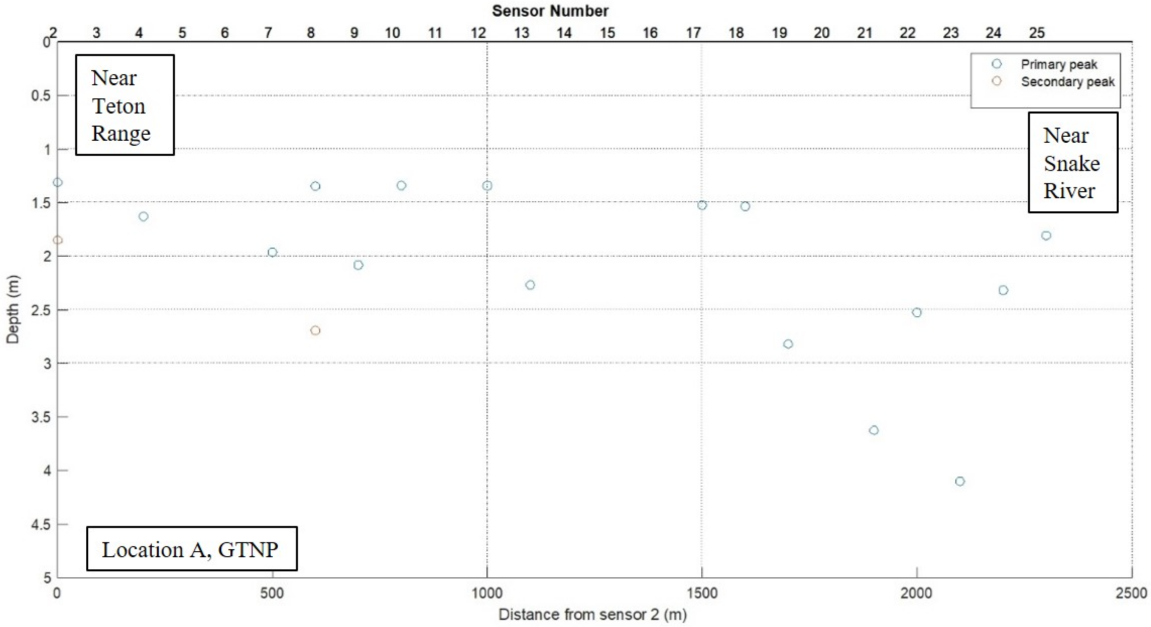

Figure 4. Estimate of the depth of soil above a strong velocity contrast or location A, GTNP.

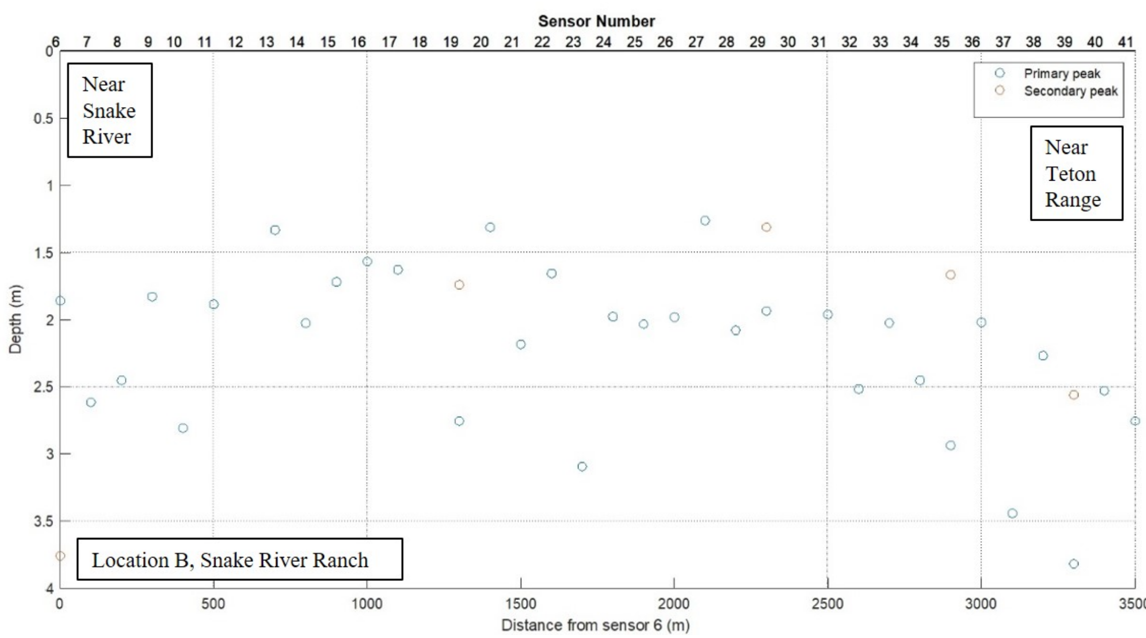

Figure 5. Estimate of the depth of soil above a strong velocity contrast or location B, Snake River Ranch.

cations. Higher frequency sampling would not produce greater depth (i.e. lower frequency) information but it may reveal higher frequency data that could result in modal or other important information. The investigators would also recommend that if tests where repeated, sensors be allowed to record data for time periods of at least one hour.

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