Continued work on using the horizontal-to-vertical spectral ratio (HVSR) passive seismic method for determining Quaternary sediment thickness in Minnesota

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County Geologic Atlas and State Special Appropriations of the Minnesota Legislature



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The HVSR method measures vertical and two horizontal (north-south and east-west) components of ambient seismic noise, which includes microtremors induced by wind, ocean waves, and anthropogenic activity.

The ratio of the averaged horizontal-tovertical frequency spectrum is used to determine the fundamental site resonance frequency (shear-wave), which can be used to estimate depth to bedrock via empirical calibration conducted at control points.



Eye-shaped spectral structures arise from stratigraphic sources.



WAVE MECHANISMS FOR HVSR SIGNATURES

Shear-Wave Trapping Mechanism

The primary resonance frequency for a uniform, low-velocity surface layer is associated with a wave length that is 4x the surface layer thickness



Surface-Wave Mechanisms



Airy phase Love waves



Assumptions:

EARTH SCIENCES

- The sediment is soft
- The bedrock is hard
- The bedrock-sediment interface is
 - a horizontal plane



REGIONALLY THICK GLACIAL SEDIMENT COVERBUT HOW THICK AND WHERE?







CONVENTIONAL (MULTI-CHANNEL) SEISMIC METHODS



Expensive! \$5,000-\$10,000 per hole, sometimes more Cheaper, but not cheap! 3-4 CREW MEMBERS 2-3 VEHICLES 1-4 SOUNDINGS/DAY





PASSIVE SEISMIC DATA ACQUIRED BY THE MGS AS OF 05/15/2015

1431 Stations acquired,446 of which are within200m of a Bedrockcontrol point



HVSR CALIBRATION: METRO AREA











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HVSR CALIBRATION: METRO AREA







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Pk. Fq.=6.88 Hz // Est. D= 10.7 m (35 ft.)

HVSR

Pk. Fq.=1.81 Hz

HVSR



Pk. Fq.=10.63 Hz

S 4 N 0 8 9 4 N 0 œ 9 4 N 0 8 9 4 N 0 8 6 4 N 0

Est. D= 6.1 m (20 ft.)

HVSR

Pk. Fq.=2.94 Hz

Est. D= 32 m (105 ft.)

HVSR

Pk. Fq.=2.06 Hz

Est. D= 50.6 m (166 ft.)

HVSR













PROBLEMS FOR THE USING HVSR METHOD TO MAP BEDROCK DEPTH AND ELEVATION (HVSR can be derailed!)

-- Lack of a strong acoustic impedance contrast at the sediment-bedrock interface

-- Strong acoustic impedance contrast within the sediments above the bedrock surface

-- Uneven bedrock surface

-- Pronounced variations in Vs near the surface can negate the calibration curve approach

Iron Range Research Center Chisolm, Minnesota

Science N Engineering





Soft sediment? Hard Bedrock?

RED = WELLS ENCOUNTERING FRESH BEDROCK

BLACK=WELLS ENCOUNTERING SOFT BEDROCK (CRETACEOUS SEDIMENTS, SAPROLITE)

> Source: County Well Index MN Department of Health MN Geological Survey



HVSR CALIBRATION IN SOUTH CENTRAL MINNESOTA:

Some Results Good, Some Not So Good



UNIVERSITY OF MINNESOTA Driven to Discover





Max. H/V at 3.06 ± 0.04 Hz. (In the range 0.0 - 64.0 Hz).



Max. H/V at 6.56 ± 0.13 Hz. (In the range 0.0 - 64.0 Hz).



HVSR CALIBRATION: SOUTH CENTRAL AREA



White Circles: 29 "Ideal" Points (No Cretaceous, no saprolite) used for calibration





Ibs-von Seht and Wohlenberg, 1999

Log Observed Depth to Bedrock (m)

Log Observed Depth to Bedrock (m)





Log HVSR Peak Frequency (Hz)



Log HVSR Peak Frequency (Hz)





UNEVEN BEDROCK SURFACE: ARROWHEAD PROJECT NORTHERN ISABELLA AREA STATION AR137

HORIZONTAL TO VERTICAL SPECTRAL RATIO (HVSR)









METRO AREA CALIBRATION AND VELOCITY CURVES





Using Calibration Curves: Beware of near-surface Velocity variations!

Case in point: The Arrowhead Project







Loon Poo: (Organic Deposits) Extremely Low Vs

Outwash and Fluviolacustrine Deposits: Low to Intermediate Vs

Dense, Rocky Till: High Vs





ARROWHEAD AREA NEAR ISABELLA DENSE, ROCKY TILL NEAR SURFACE

HORIZONTAL TO VERTICAL SPECTRAL RATIO (HVSR)



Exposure of dense, rocky till, Mesabi Range

Photo-Mark Jirsa

Station CDC-9



ARROWHEAD AREA OLD TOMAHAWK TRAIL: EFFECT OF ORGANIC SEDIMENTS



HORIZONTAL TO VERTICAL SPECTRAL RATIO (HVSR)





frequency [Hz]



Arrowhead Project Area HVSR Depth Calibration at 17 Bedrock Drill-holes

Image: Constrained of the second of the s

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CONTROL POINTS:

Blue – Outwash , Fluviolacustrine and Ice-Contact Deposits Red – Supra- and Sub-Glacial Tills





Science Engineering

Northern Becker County: Compilation of a Color-Coded HVSR Section





(2) Bdrk Elev=Surf. Elev-z

Grid the converted Spectra to produce a HVSR section



Conclusions on using the HVSR passive seismic method for determining Quaternary sediment thickness in Minnesota:

Strengths of the HVSR Method

- -It's Cheap
- -It's Fast
- -It seems to thrive in culturally noisy areas
- -It should be useful to a variety of geological and
- geo-engineering investigations

Limitations of the HVSR Method

- -It's only for rough estimates
- -Conditions within the sediments or at the bedrock
- surface can complicate or even preclude useful
- results
- -It should never be used blindly, always consult local geology and conduct readings at control sites





Further Work:

- -Continue applying the method in a variety of geological conditions (MGS)
- -Investigate the effect of ambient noise levels (MGS?)
- -Independent studies of shear-wave velocities for local materials (Help!)
- -Investigate processing of passive seismic data to improve results (Help!)
- -Use the method to investigate the thickness of very near-surface materials like fill or organic sediments (MGS?)





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