PURDUE GEOTECHNICAL SOCIETY WORKSHOP

GEOTECHNICS AND SUPPLYING FUTURE ENERGY NEEDS

Monday, May 7, 2007

GEOTECHNICAL GEOPHYSICS FOR POWER DEVELOPMENT

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DESIGN BASED ON STRAIN

What we can do but usually don't.

Let's catch up to the Civil World.

Easy to measure moduli insitu.

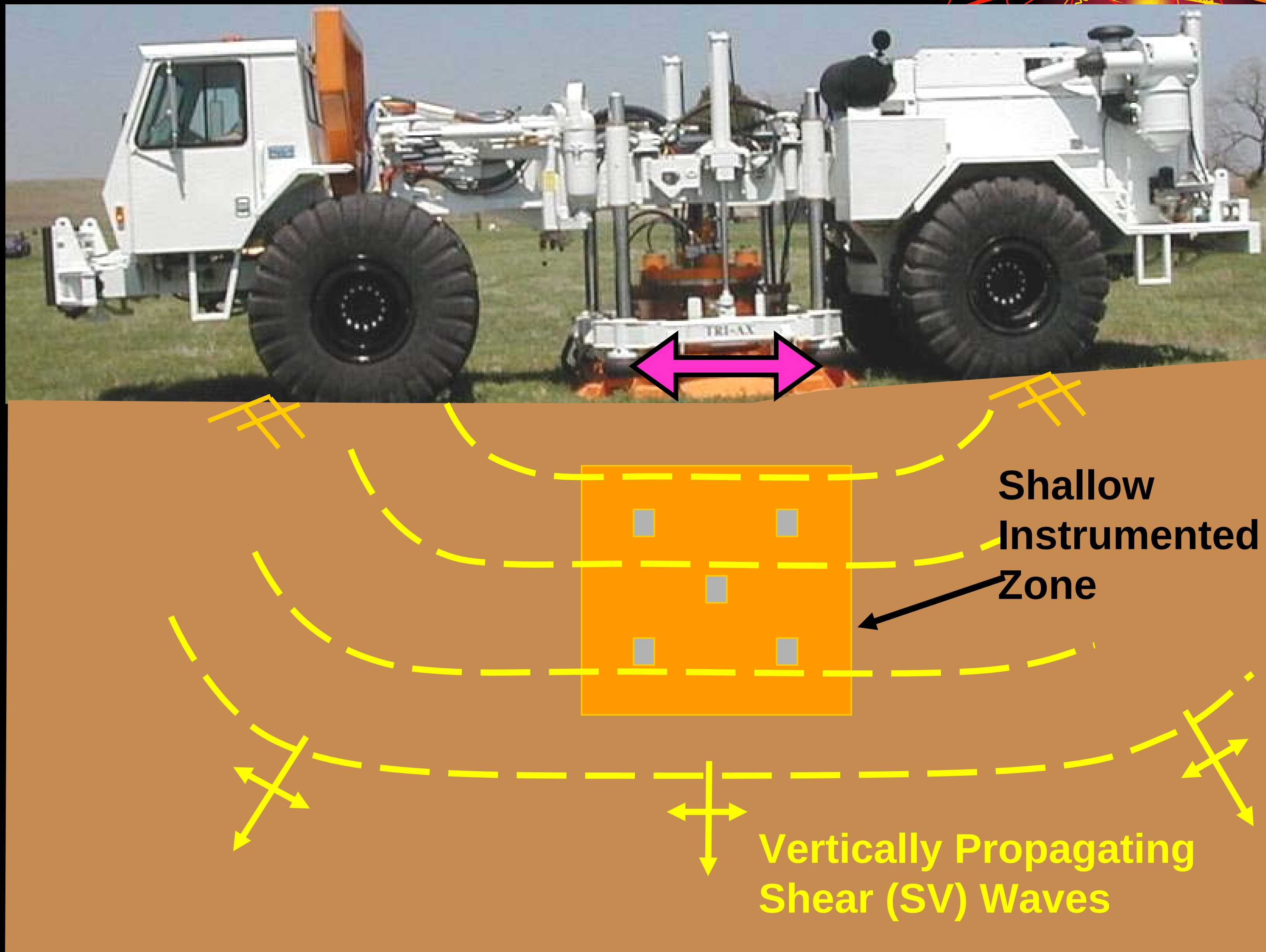
1st to do it: Bill Swiger 1974 - - Nuclear Power

- Stone and Webster heavily into nuclear power development.
- Used G/E from seismic waves to design for settlement.
- TAMU Settlement Conference, several settlement methods used In prediction challenge including seismic modulus.

TAMU SETTLEMENT CHALLENGE, 1994

Predicting Foundation Settlements

T-Rex: Loading with Shear (SV) Waves



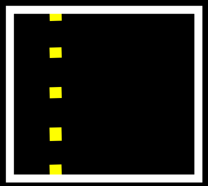
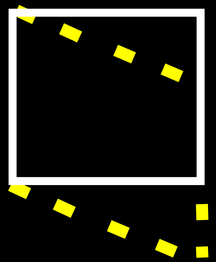
Solutions - Static Conditions

- foundation settlements
- retaining wall movements

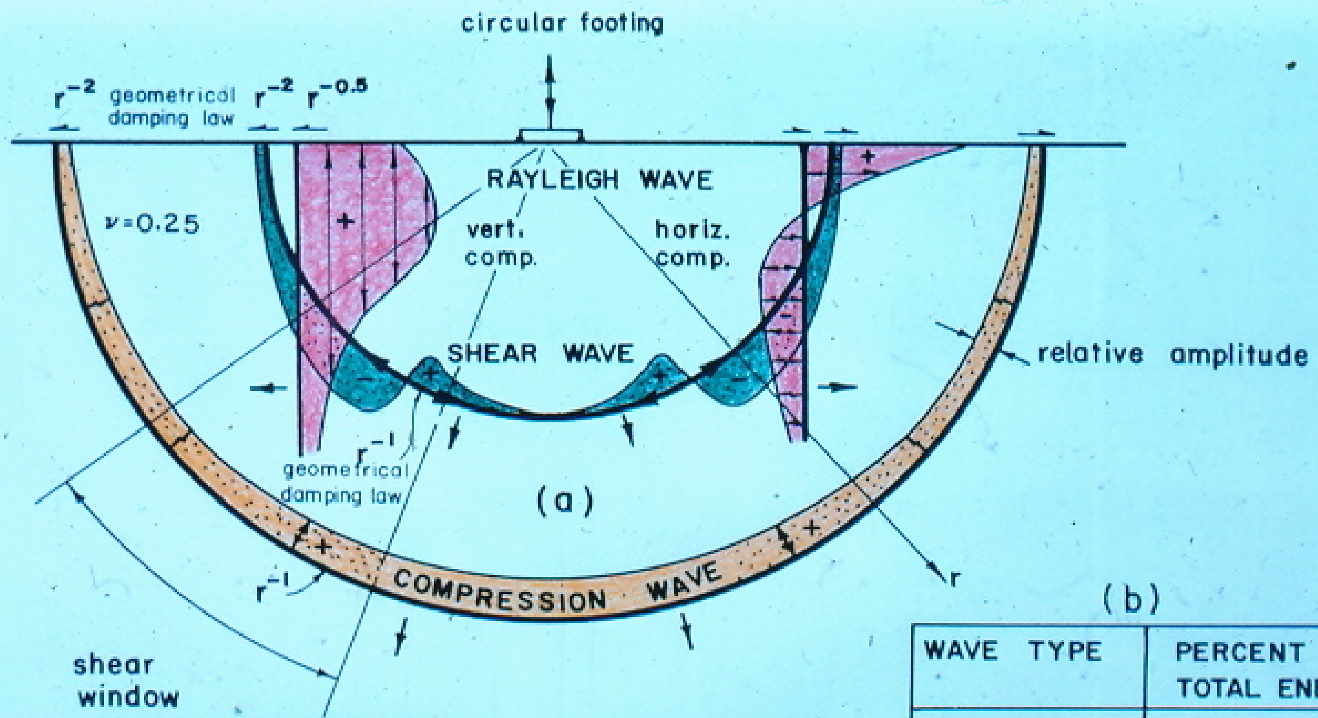
- layering, ground water table, etc.
- underground cavity detection
- tunnel investigations
- pavement studies

- grouting evaluations
- ground improvement studies
- areas of deterioration

Field Measurements with Compression (P) and Shear (S) Waves

Wave Type	Particle Motion	Distortion	Wave Velocity	Small-Strain Modulus
P	↔		V_p	$M_{max} = \frac{\gamma_t}{g} V_p$
S	↕		V_s	$G_{max} = \frac{\gamma_t}{g} V_s$

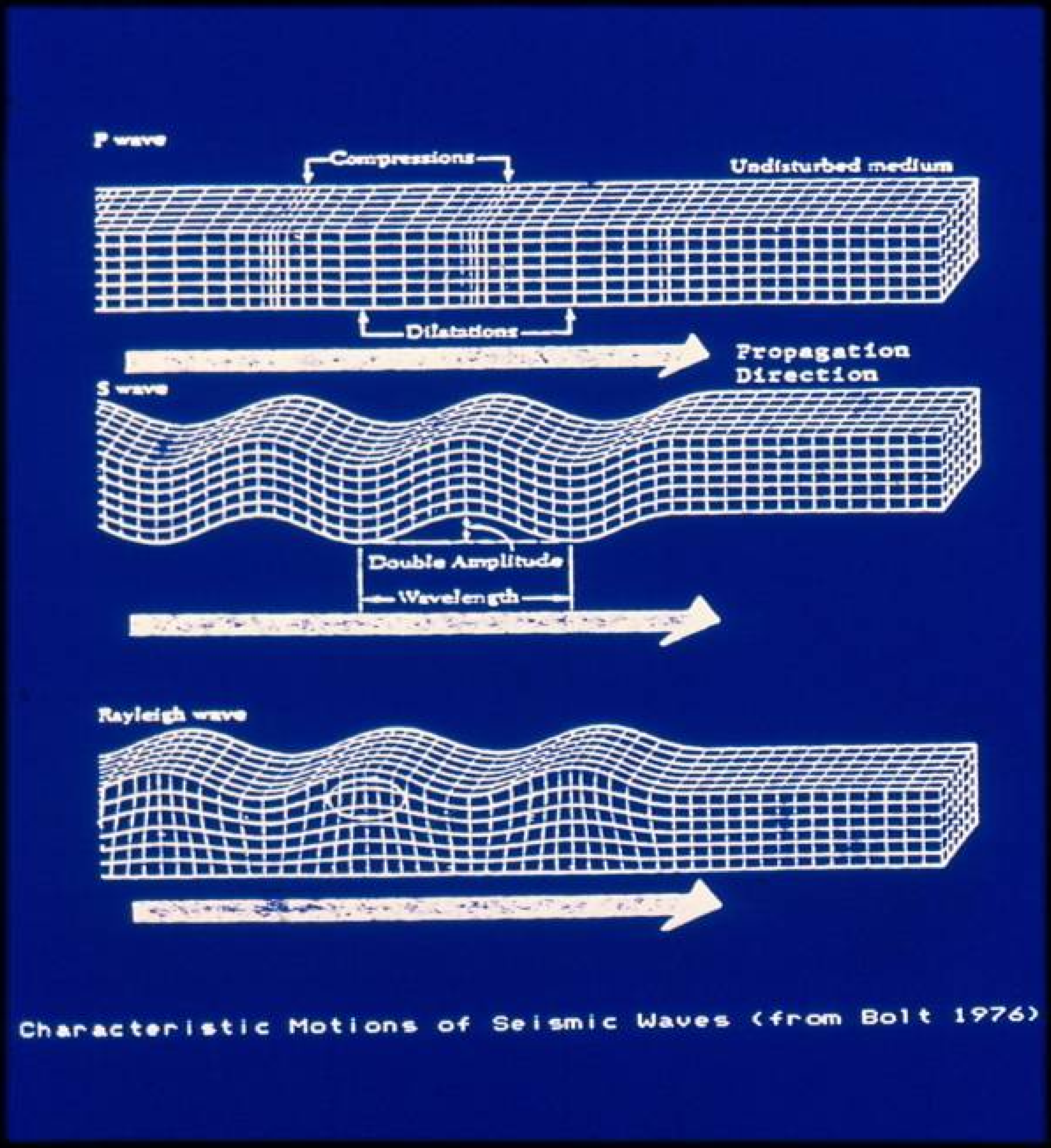
TOTAL WAVE FIELD



(b)

WAVE TYPE	PERCENT OF TOTAL ENERGY
RAYLEIGH	67
SHEAR	26
COMPRESSION	7

FIG. 3-18.— DISTRIBUTION OF DISPLACEMENT WAVES FROM A CIRCULAR FOOTING ON A HOMOGENEOUS, ISOTROPIC, ELASTIC HALF SPACE


P wave
Compressions
Undisturbed medium
Dilatations
Propagation Direction
S wave
Double Amplitude
Wavelength
Rayleigh wave
Characteristic Motions of Seismic Waves (from Bolt 1976)

BOLT WAVES

WIND FARMS

CURRENT APPLICATION OF FOUNDATION DESIGN

S
P
A
I
N

EARLY WINDFARM

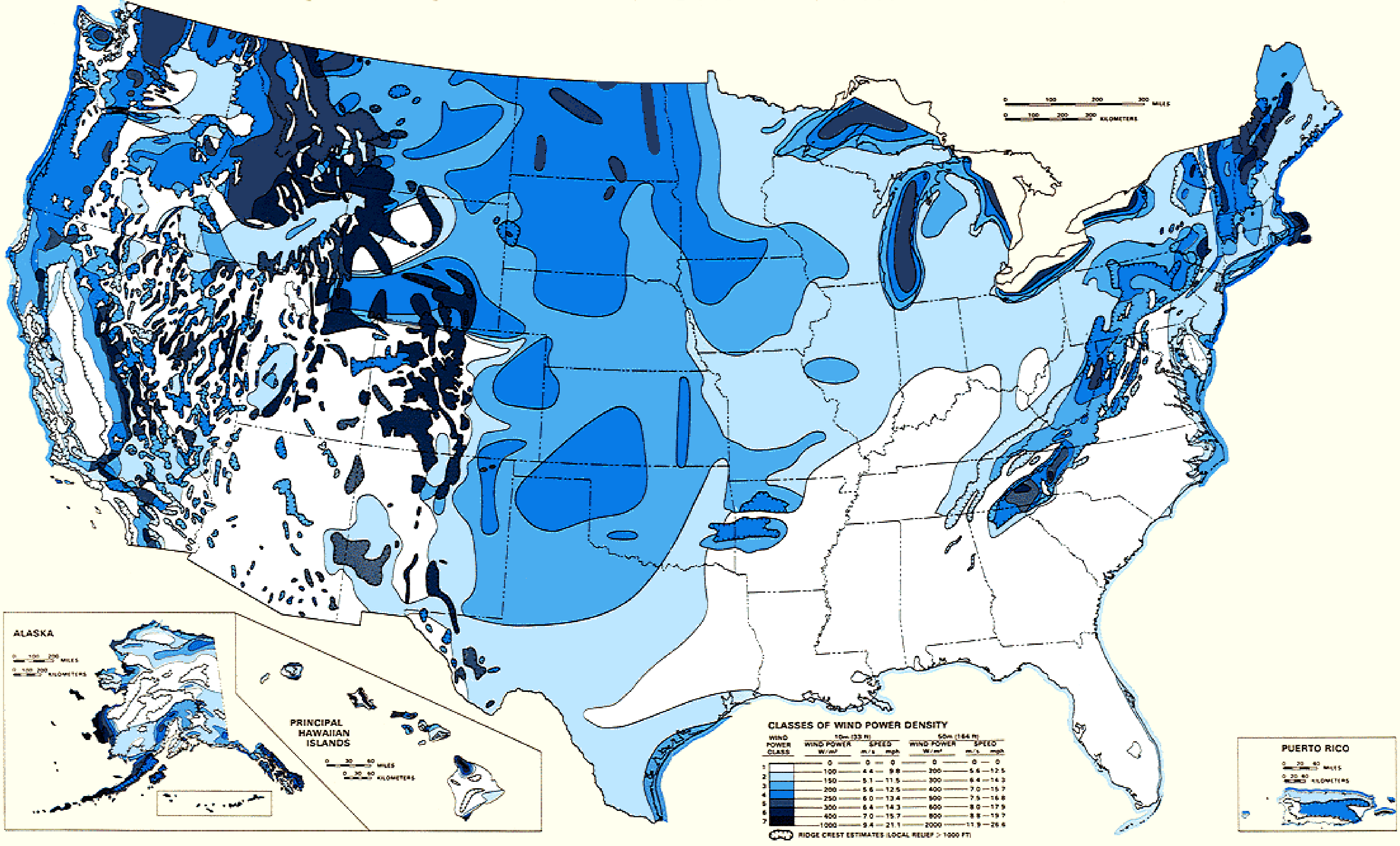
G
R
E
E
N
P
A
R
K

UK

WIND POWER FACTS

- WORLDWIDE: 74,000 MW, 2006
- ALTAMONT PASS: USA FAMOUS SITE, 6000 TURBINES @ 20 kW ea
- NEW MODELS 100 kW ea minimum
- COST $1600 per kW installed
- COST COMPETETIVE: GAS $52.50, COAL $53.10, and WIND $55.80/MWh
- POWER AVAILABLE % TIME: Nuclear 90%, Coal 70%, Wind 35%

UNITED STATES ANNUAL AVERAGE WIND POWER

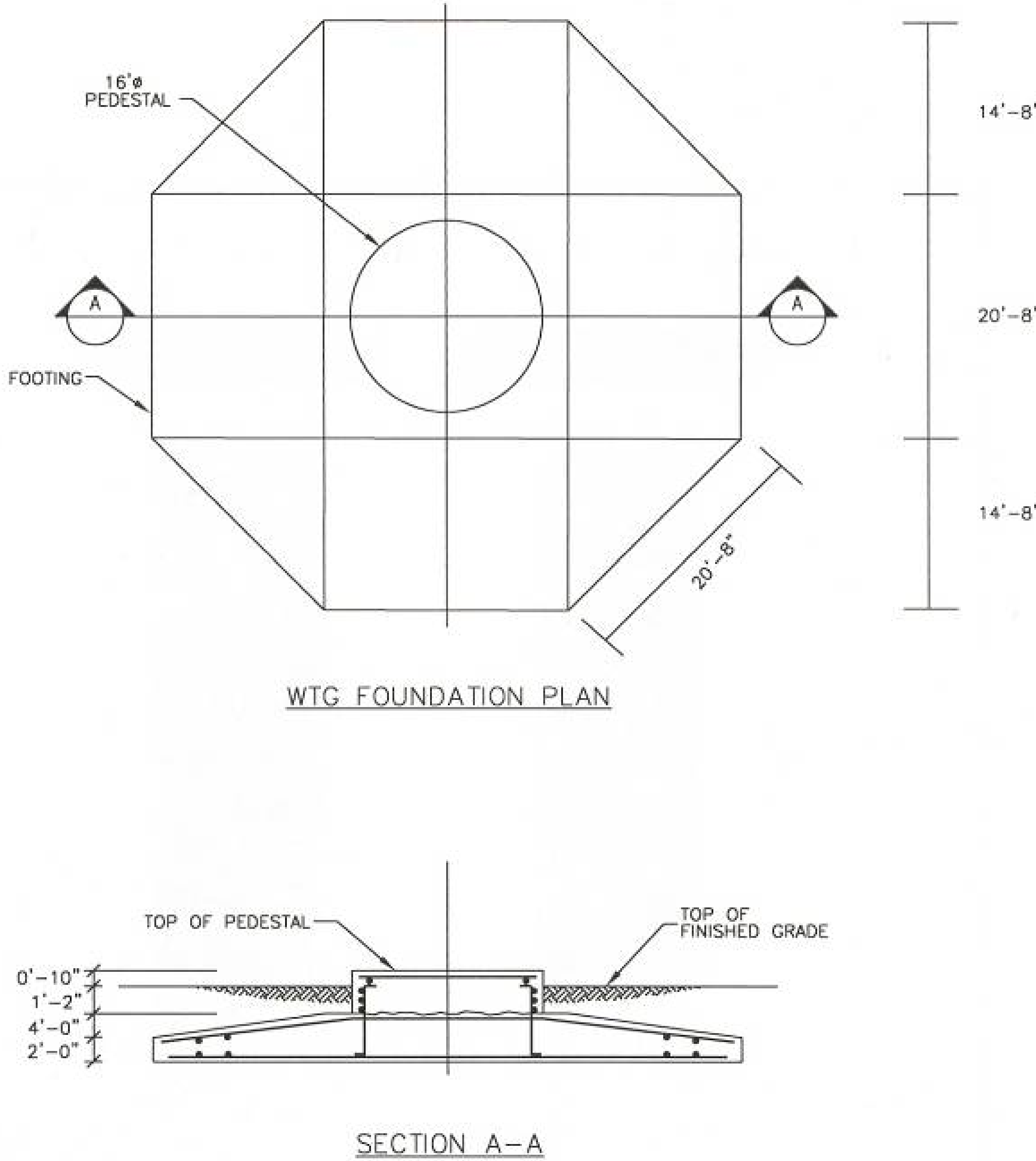


WIND-ALTAMONT
Altamont Pass, CA

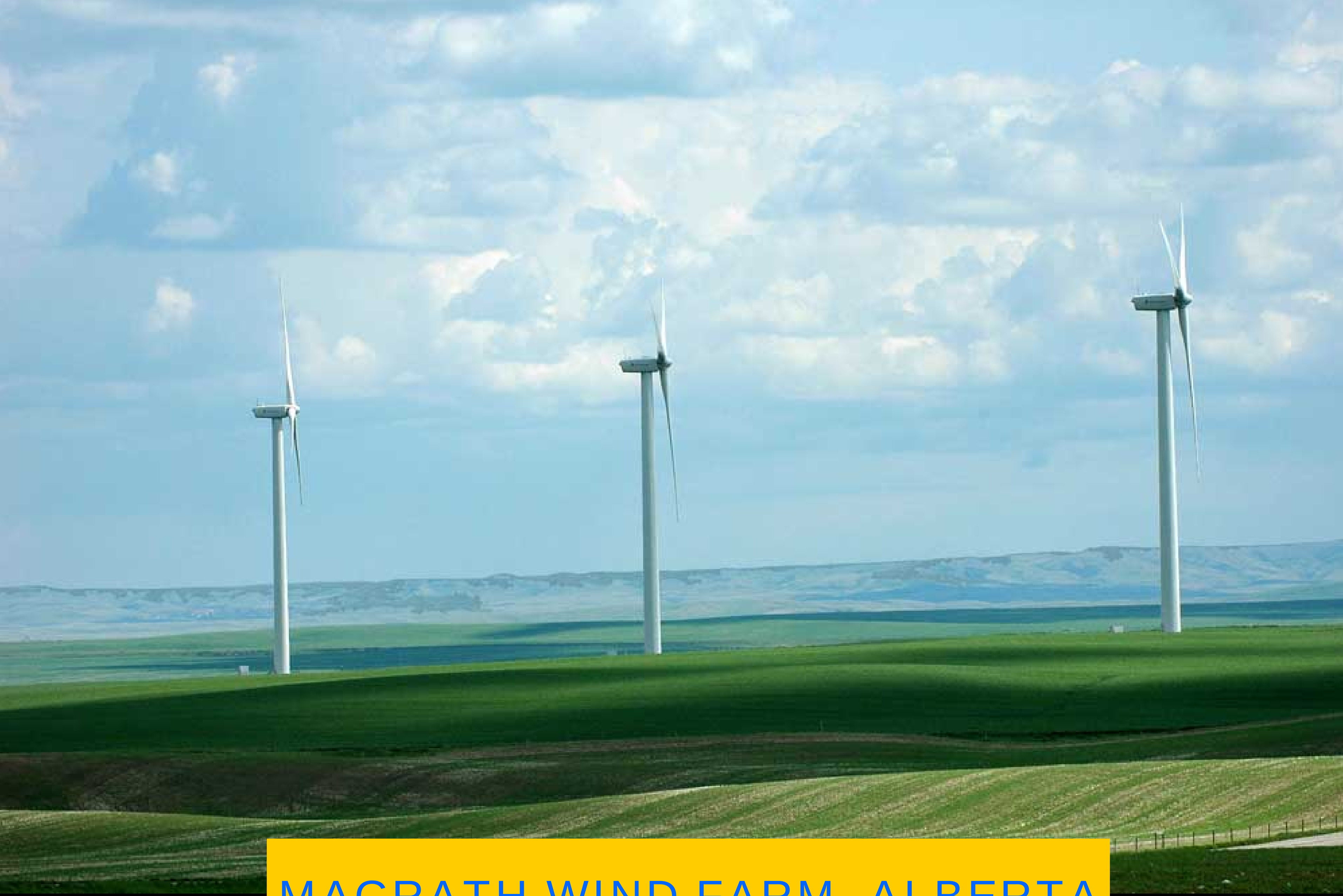
6000 @ 20kW = 125 MW & Annual bird kill

ECONOMIES

- Groups of footings could be designed individually based on ground profile
- Each footing could be customized to minimize cost

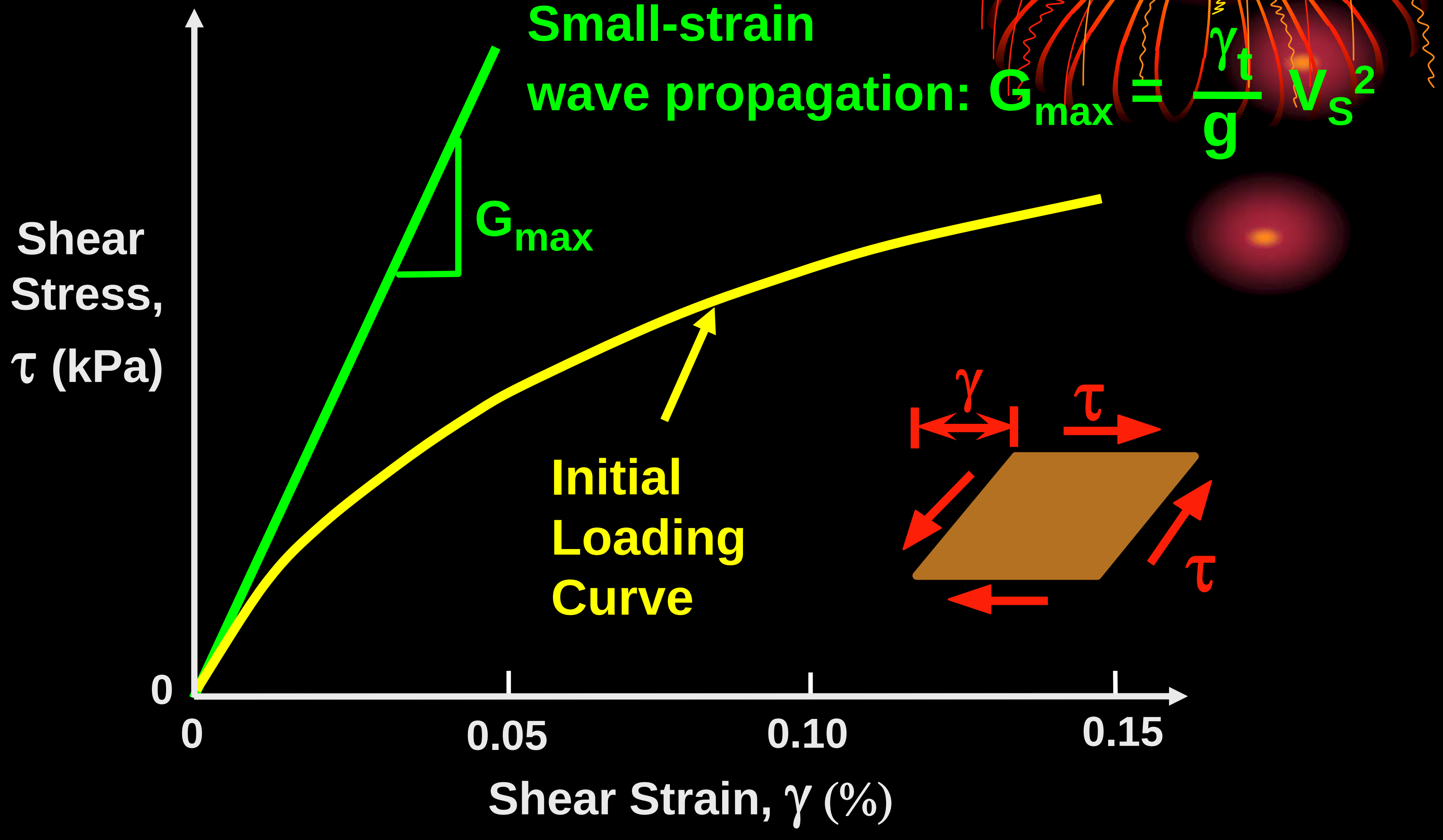

16'ø
PEDESTAL
A
A
FOOTING
14'-8"
20'-8"
14'-8"
20'-8"
WTG FOUNDATION PLAN
TOP OF PEDESTAL
TOP OF
FINISHED GRADE
0'-10"
1'-2"
4'-0"
2'-0"
SECTION A-A

EXAMPLE



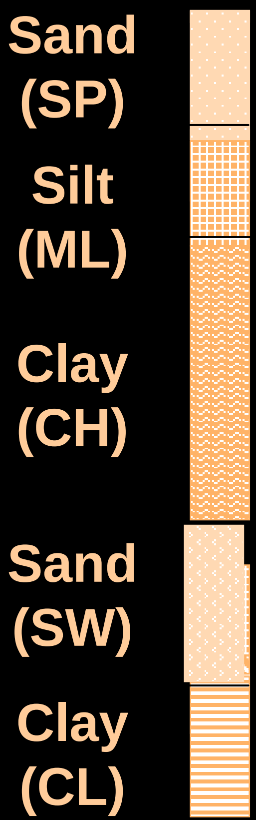
MAGRATH WIND FARM, ALBERTA
REVISED SPACING

Small-Strain Seismic Measurements

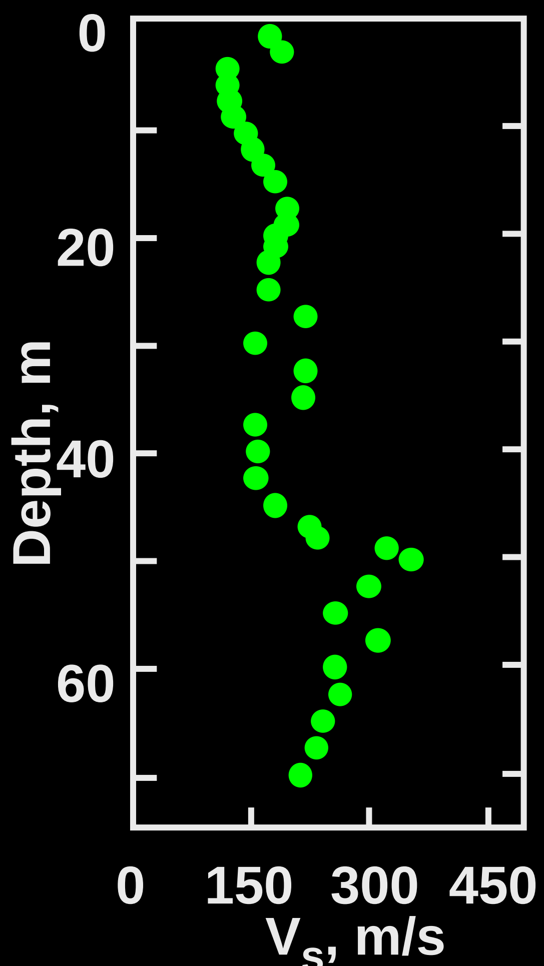


Role of Stress Wave Measurements

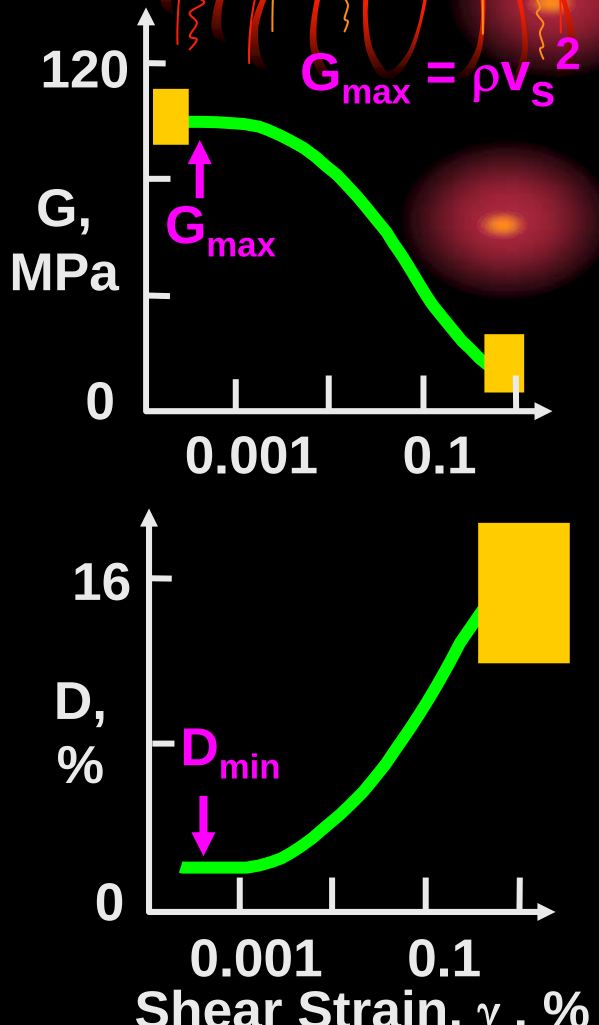
1. Soil Profile



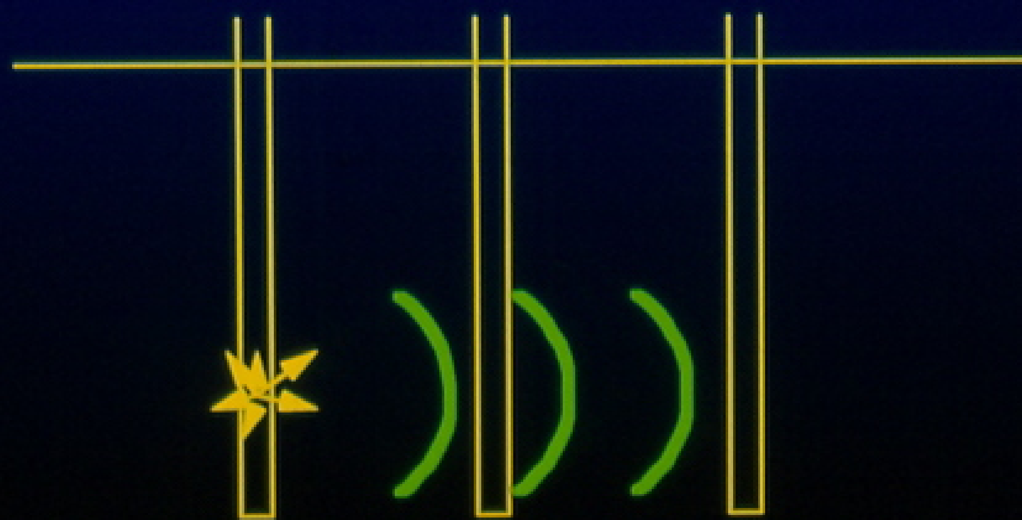
2. Field: Linear V_s (and V_p)



3. Lab: Linear and Nonlinear G and D

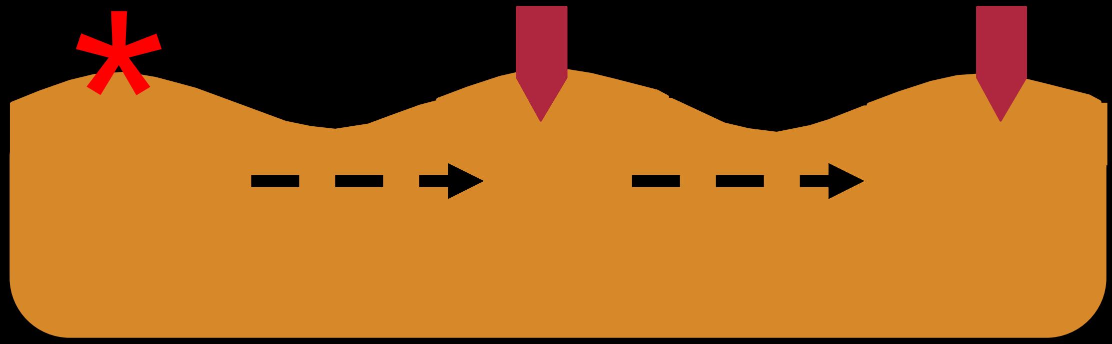


CROSS-HOLE



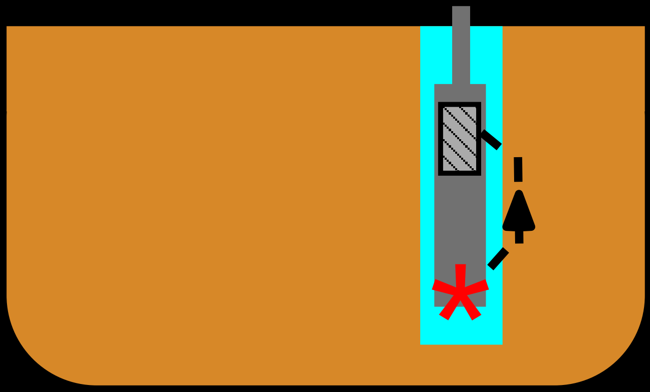
Recent Field Methods (1990s)

1. Surface Wave (SASW) Test



Measure Rayleigh (R) Waves

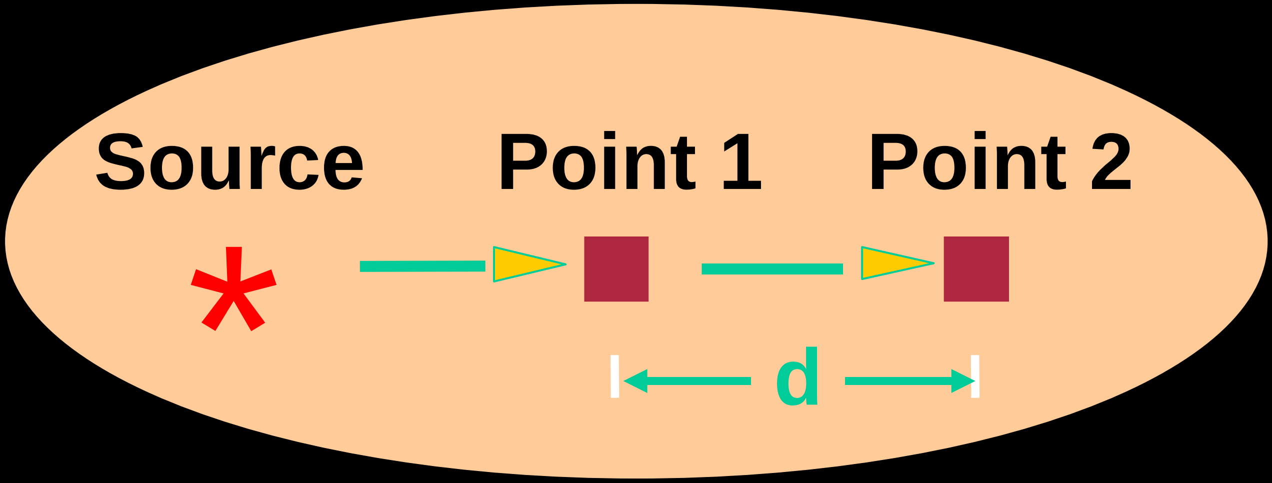
2. P-S Suspension Logger



Direct P and S Waves

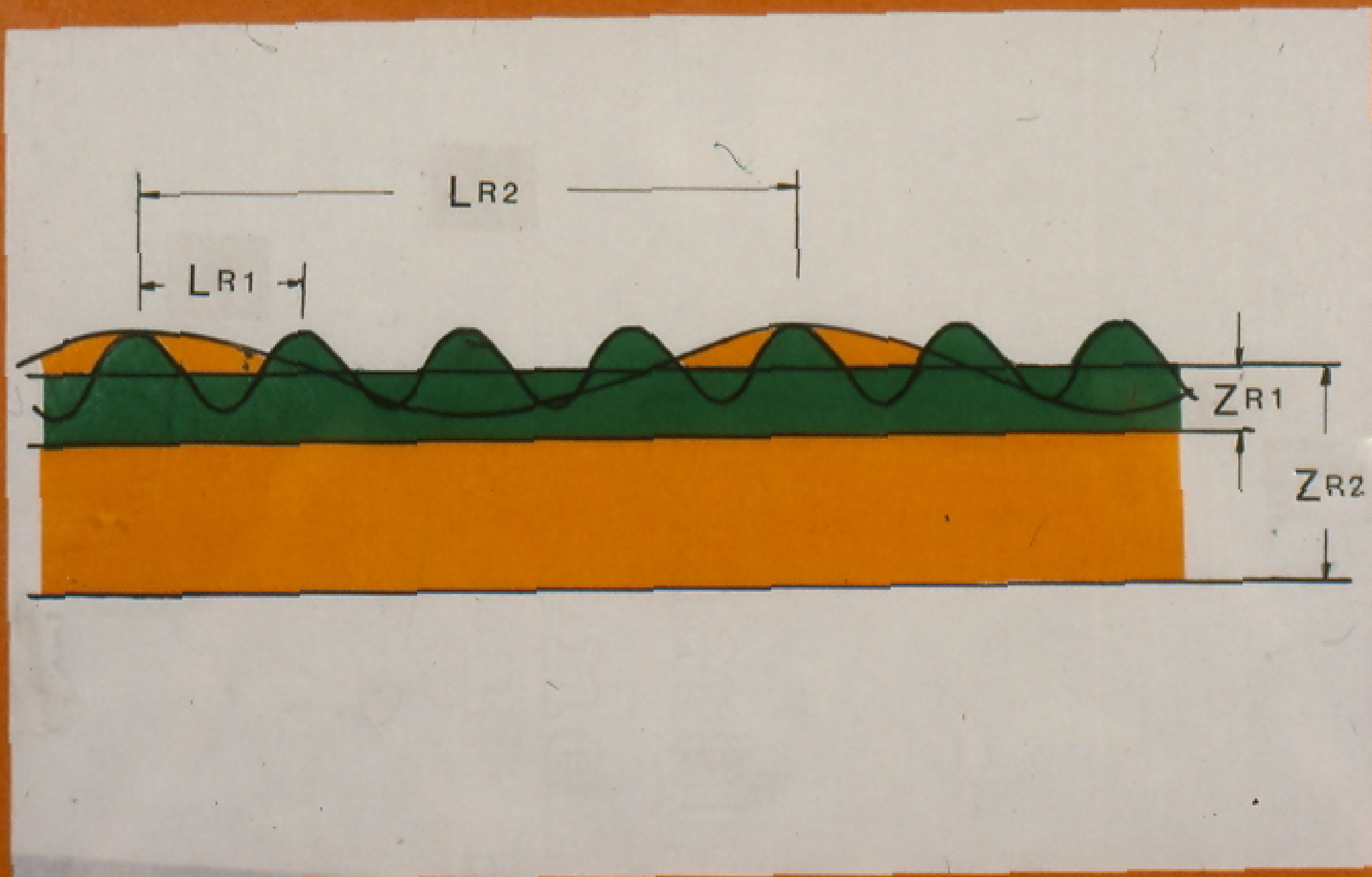
Stress Wave (Seismic) Measurements in the Field

Objective: measure time, t, for a given stress wave to propagate a given distance, d ... then velocity = d/t



Key characteristic: small-strain (linear) measurements

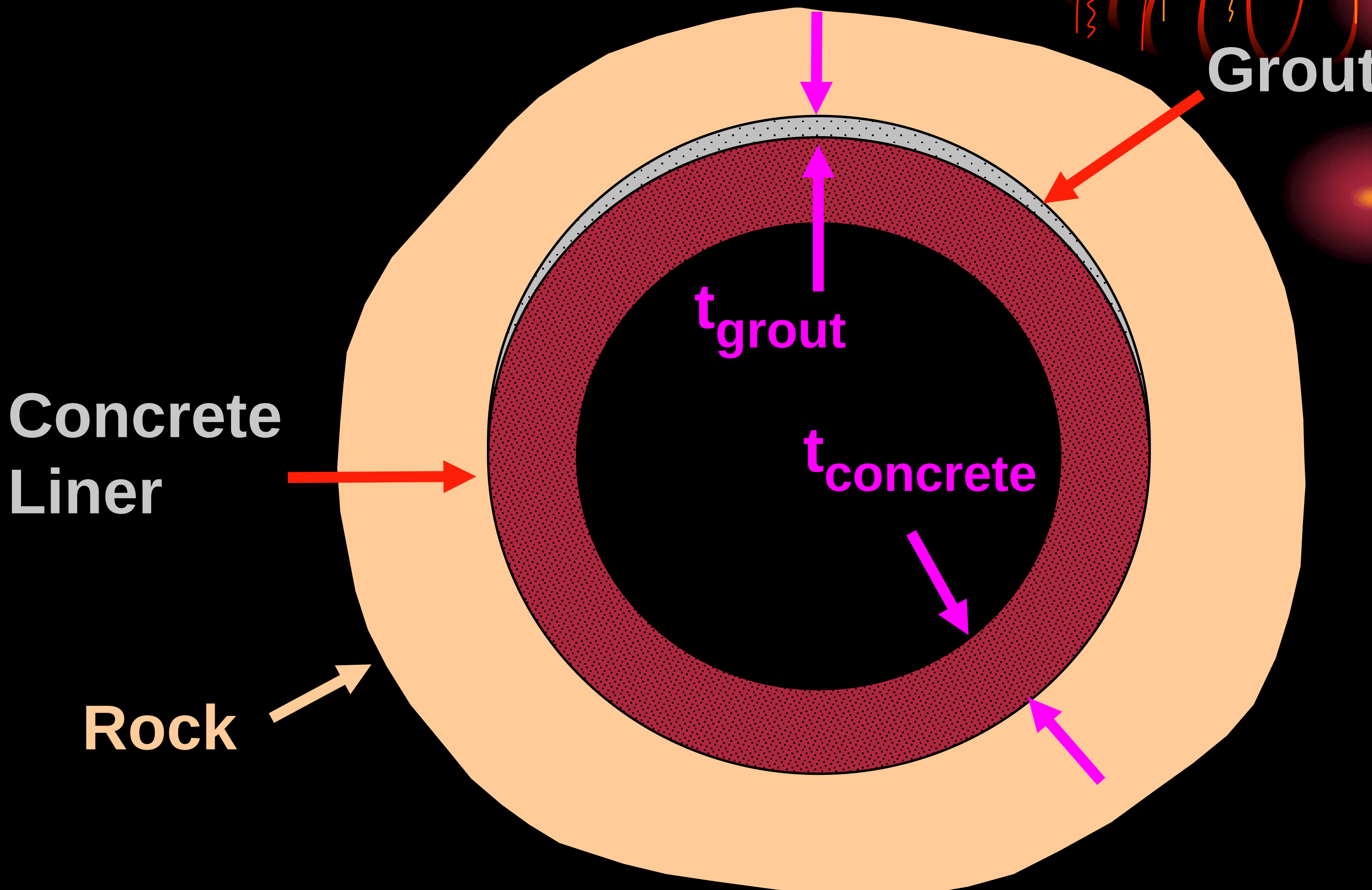
SPECTRAL–ANALYSIS OF SURFACE–WAVES (SASW)



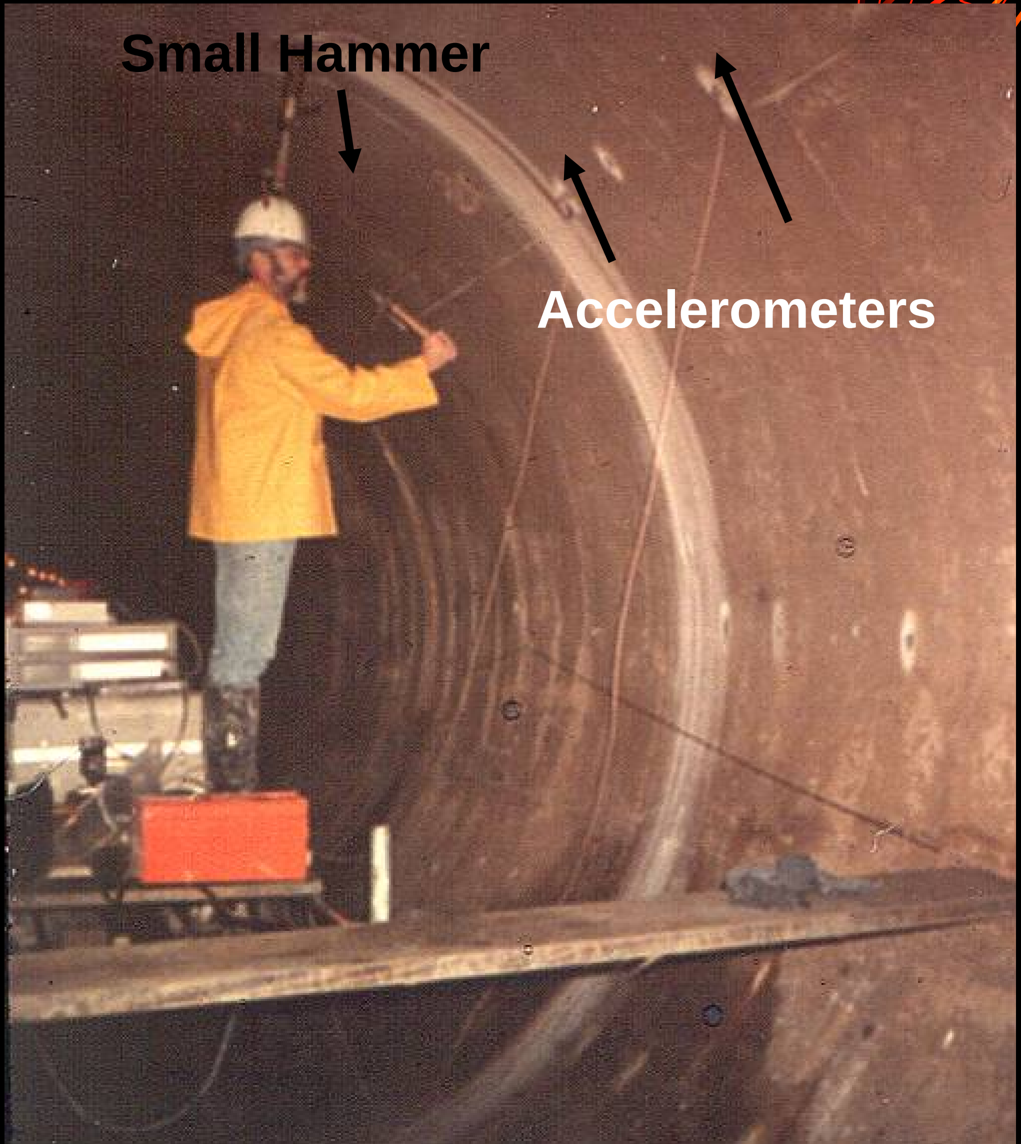
LR2
LR1
ZR1
ZR2

VARIABLE SCALE

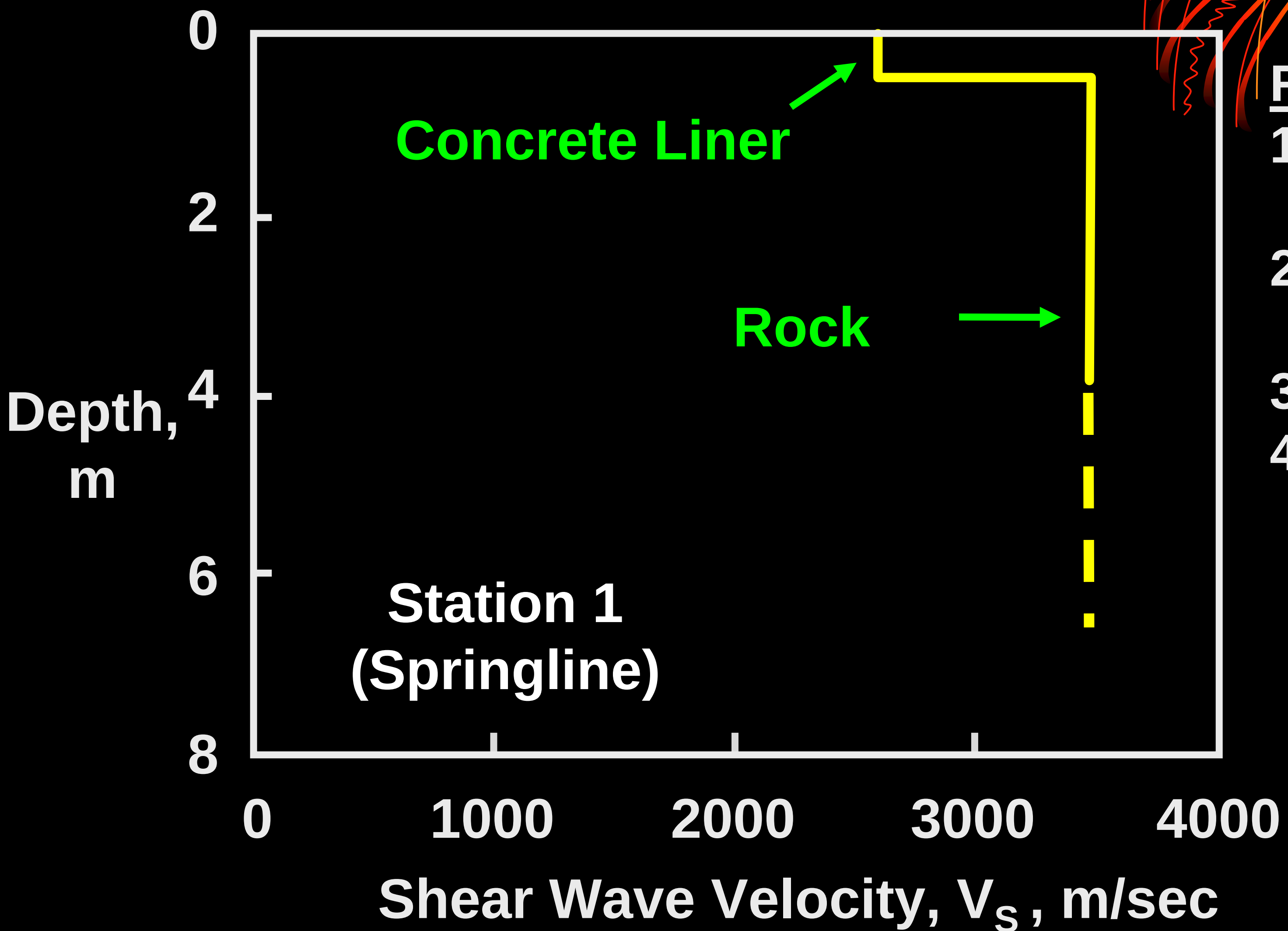
Tunnel Investigation



Conducting SASW Tests



Interpreted V_S Profile Behind Tunnel Wall at Springline



Results:

1. high-quality concrete
2. thickness ~ 0.3 m
3. no voids
4. rock stiffer than liner

Some Questions

1. Quality of concrete liner?
2. Thickness of concrete liner?
3. Quality of grout in crown?
4. Thickness of grout in crown?
5. Any voids behind liner?
6. Stiffness of rock behind liner?

(Answered all Questions)

VINCENT THOMAS BRIDGE, Liquefaction

CRAWLER VEHICLE AS SOURCE

VIBROSEIS

Solutions - Dynamic Conditions

Site response, soil-structure interaction, liquefaction, etc.

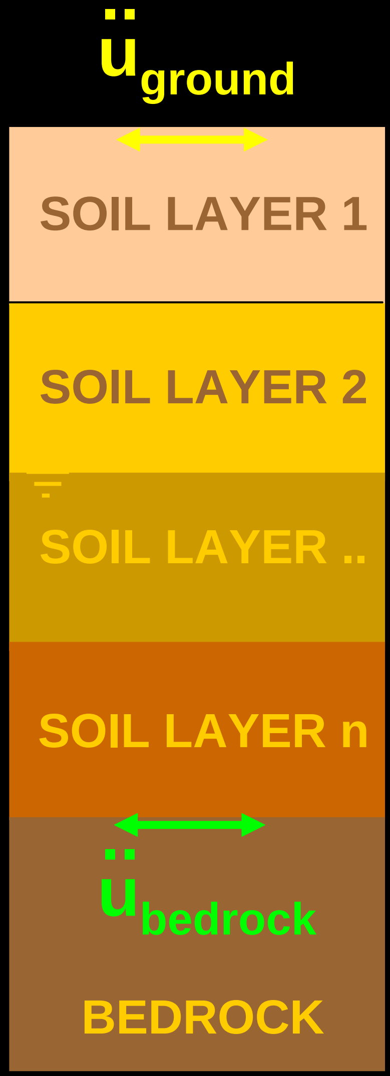
POWER PLANT SITING

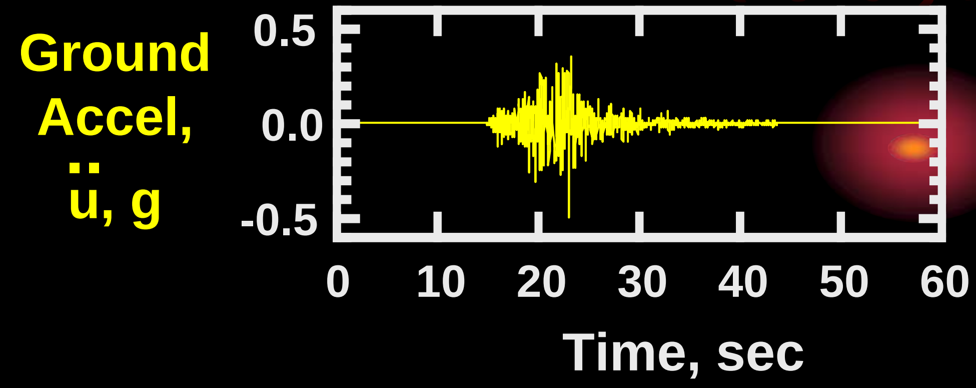
-EATHQUAKE HAZARD-

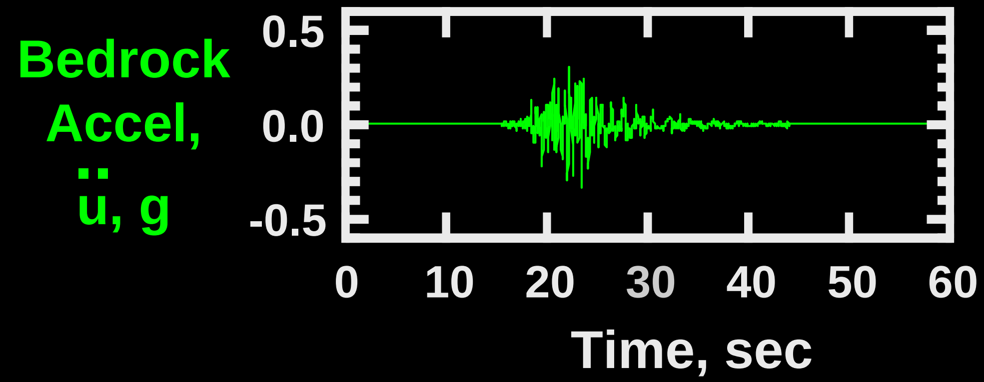
SEISMOMETER SITES ARE

USUALLY NOT WELL CHARACTERIZED

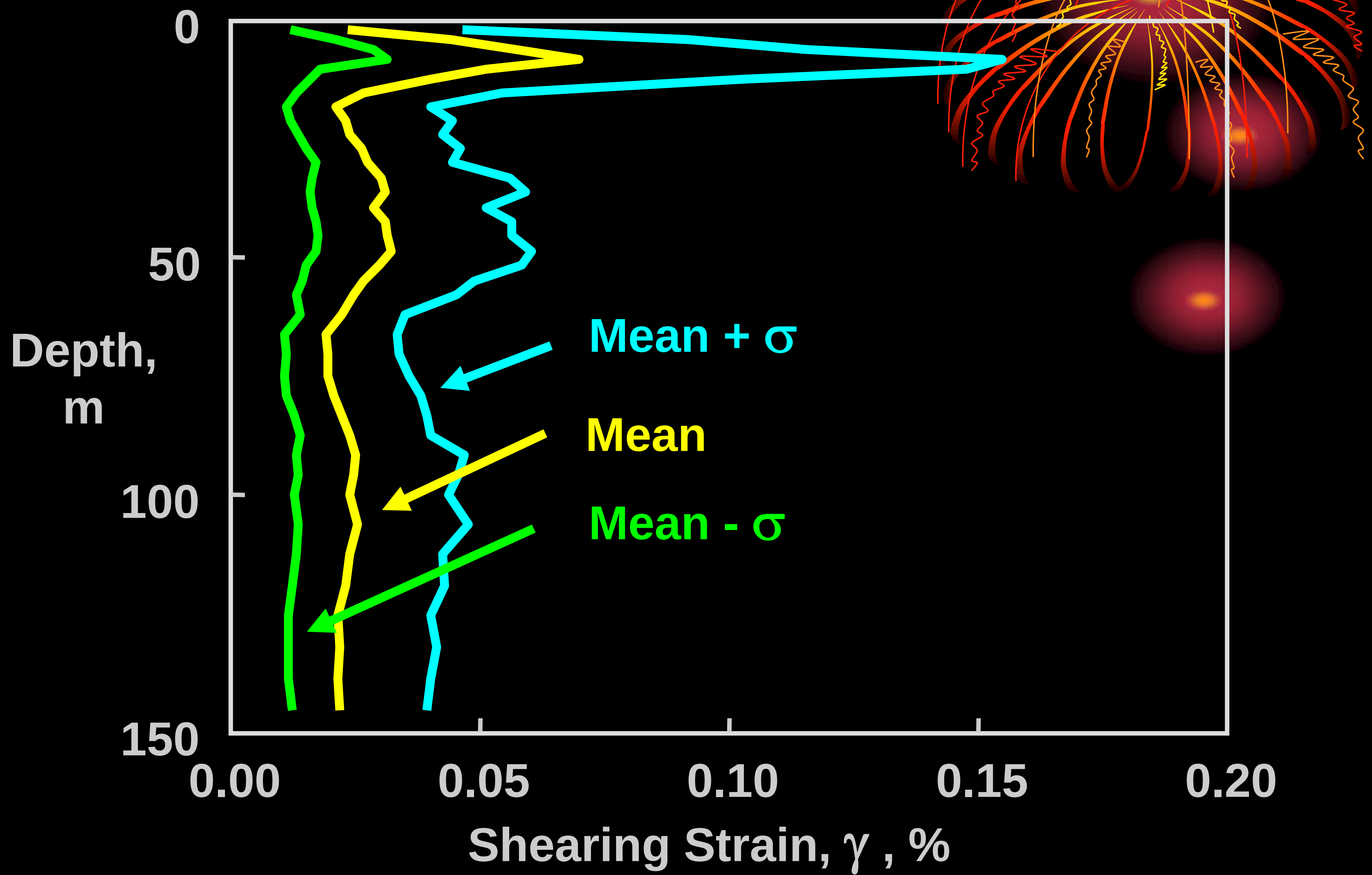
Predict Ground Motions During Earthquake Shaking







Peak Shearing Strains: La Cienega



POWER PLANT SITING

HIDDEN GROUND CAVITIES

Davis Besey, Ohio

San Onofre, Cal

DRIC

E

DETROIT PROFILE

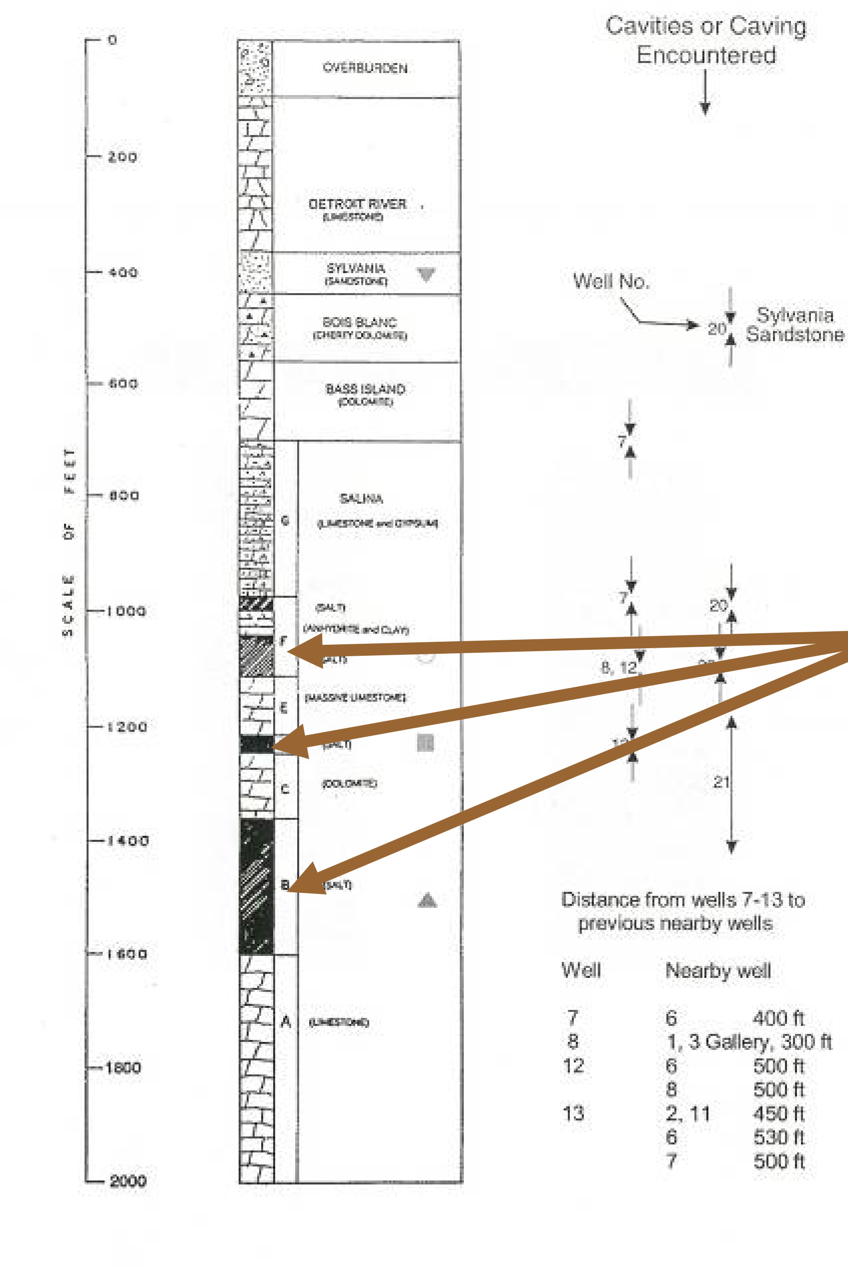


Figure A-5B, Comparison of Lithologic Log and Cavities encountered in wells. (After Russell, 1993)

SALT

SOLUTION MINING

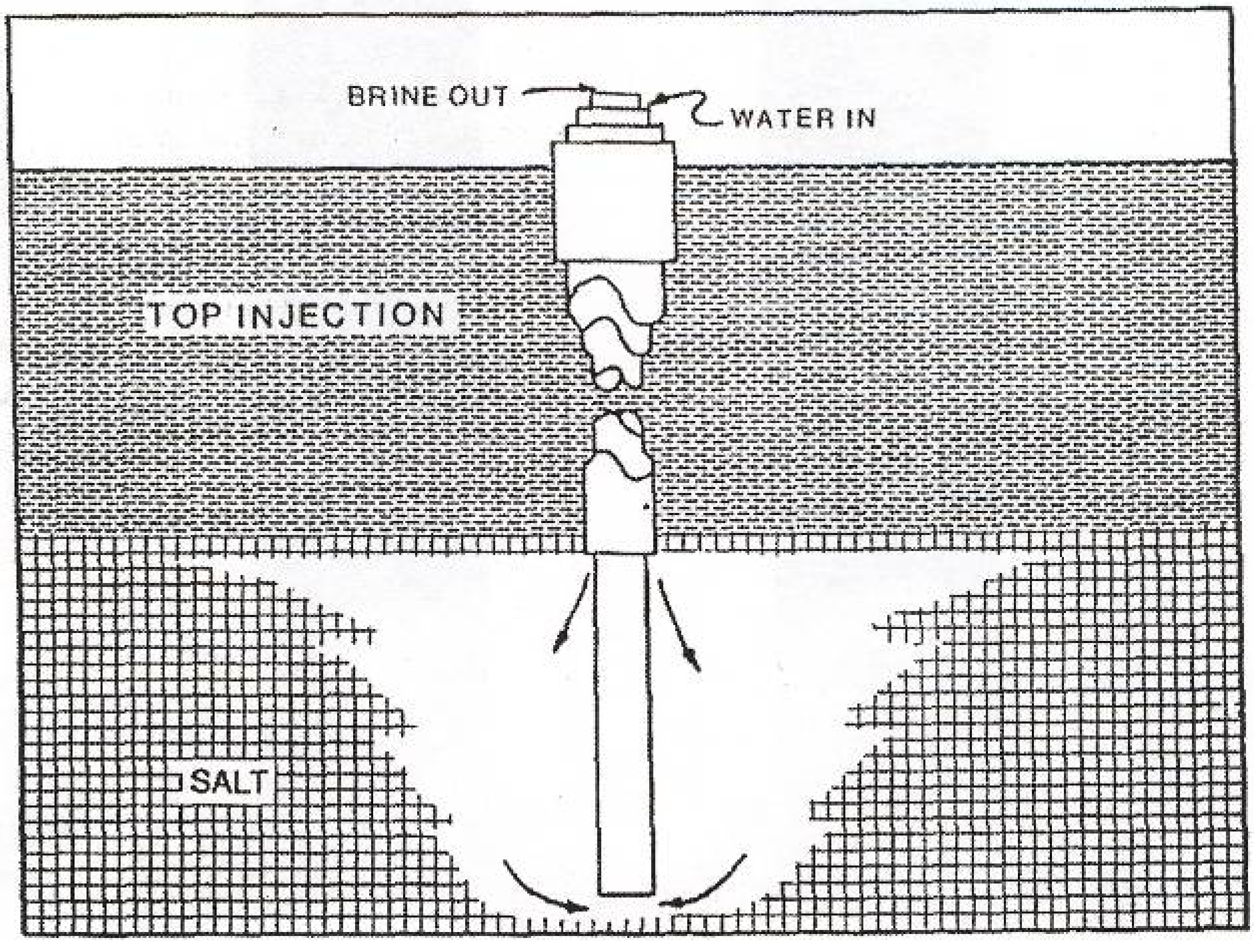


Figure A-1. Single well injection method of brine extraction and resulting "morning glory" cavity. (Russell, 1993)

CANADIAN SINKHOLES

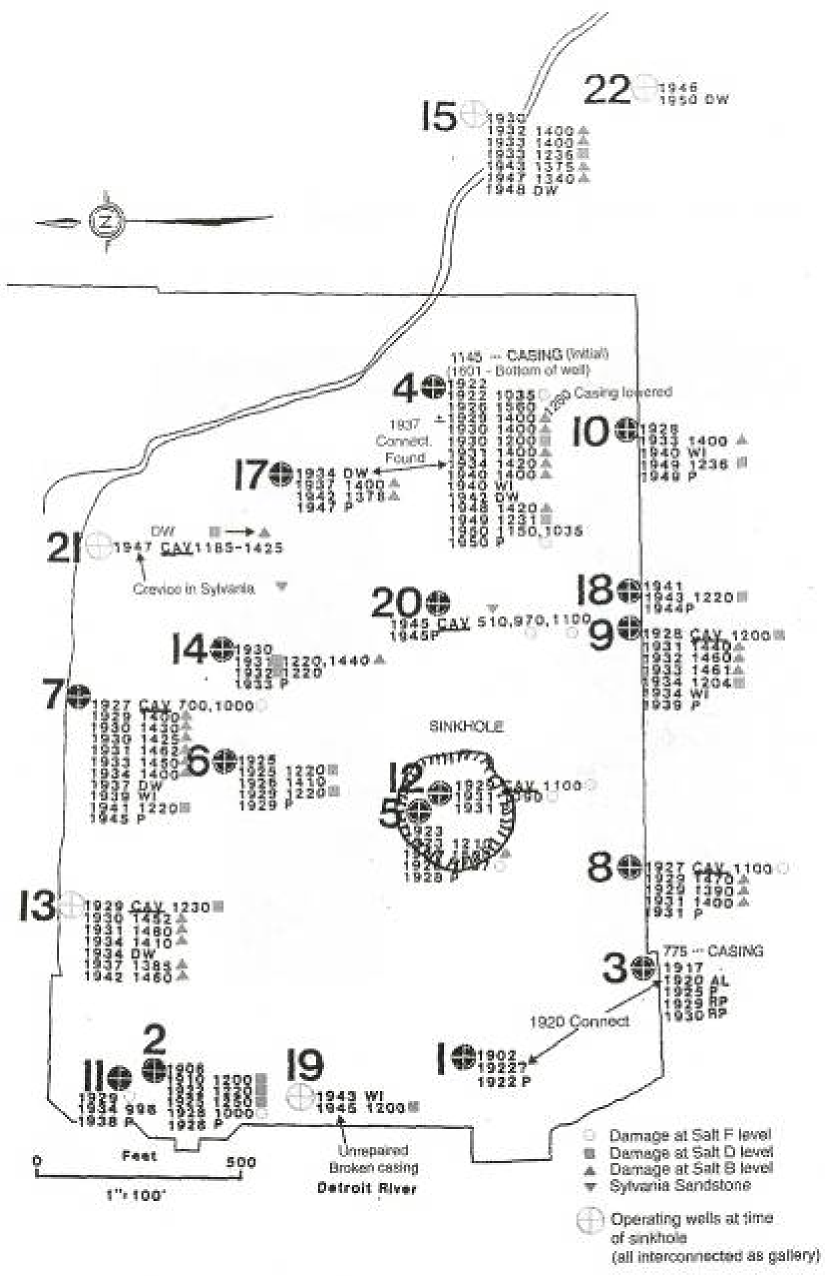
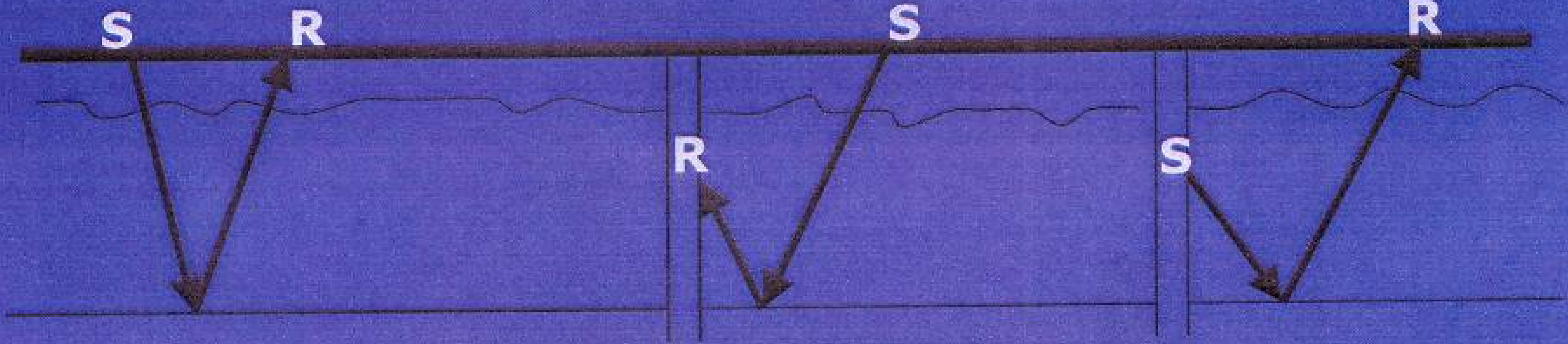


Figure A-5A. History of repairs at Windsor Brinefield, 1902 - 1954. First date is year of drilling. (Fernandez - Castro, 1996, After Russell, 1993)



Surface Seismic, Reflection Technique

Vertical Seismic Profiling (VSP)

Reverse Vertica Seismic Profilin (RVSP)

Target depths > 1,000ft.

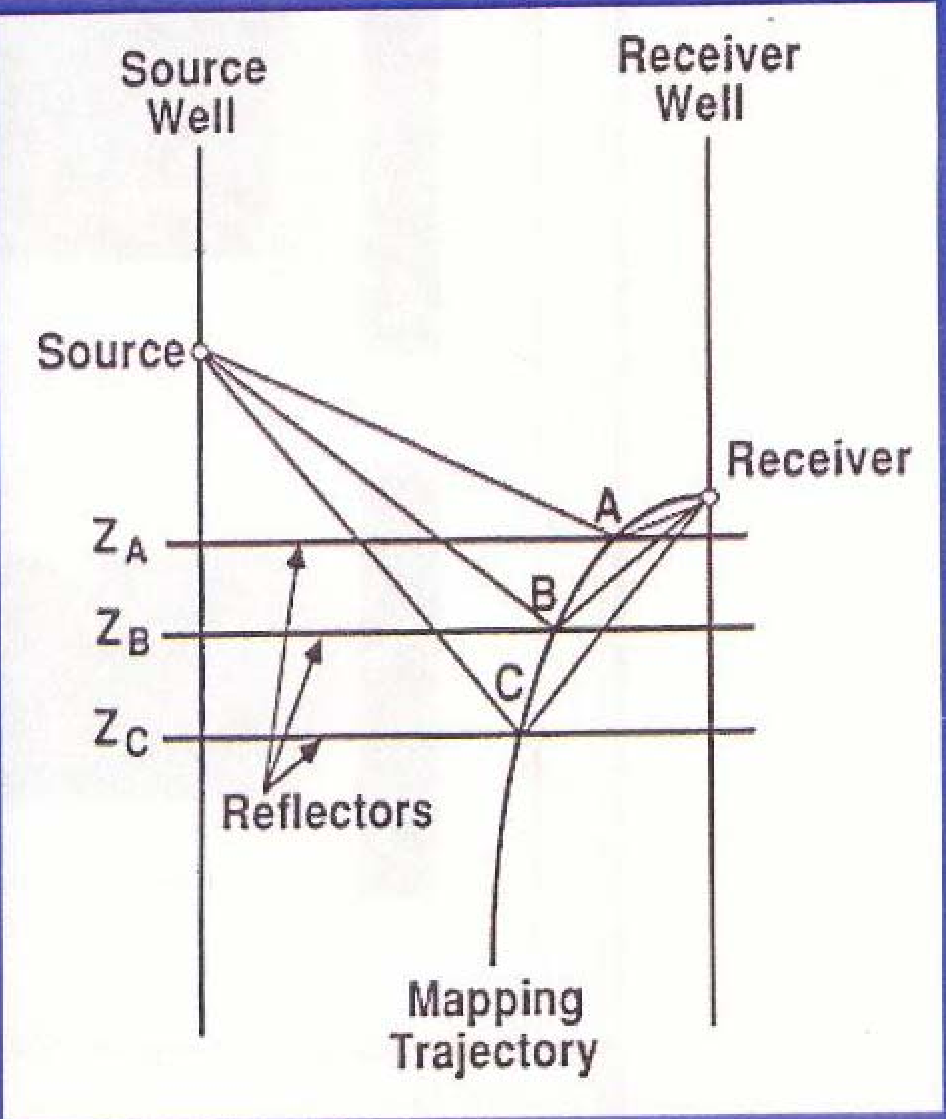
Frequency (peak) with available sources <= 100Hz.

Frequency (peak) special downhole source 150Hz.

Information from MTU Test Site

Crosswell Reflection Geometry

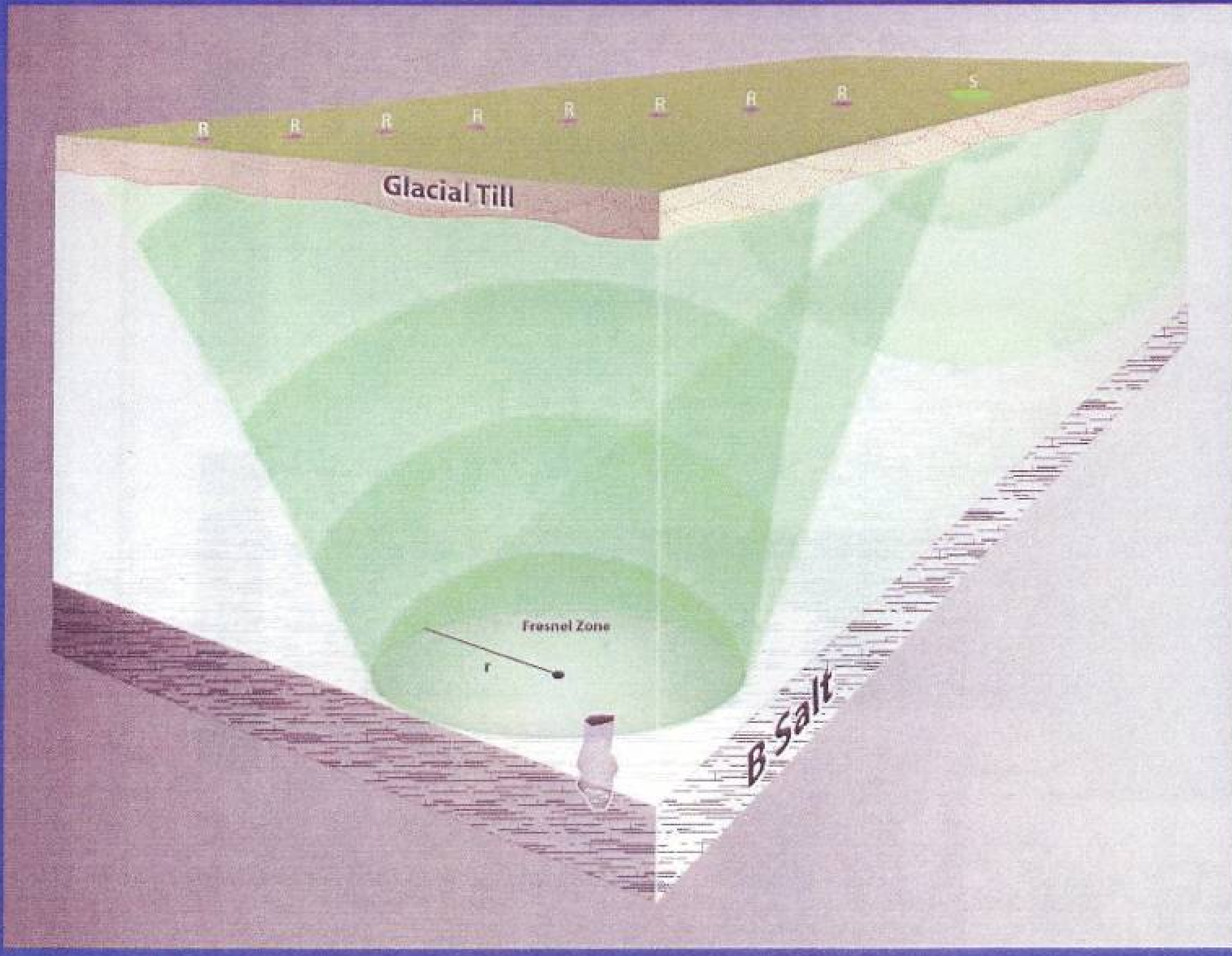
- All possible reflection points mapped
- Trajectory linking reflection points defined
- Samples mapped to reflection point corresponding to ray travel time



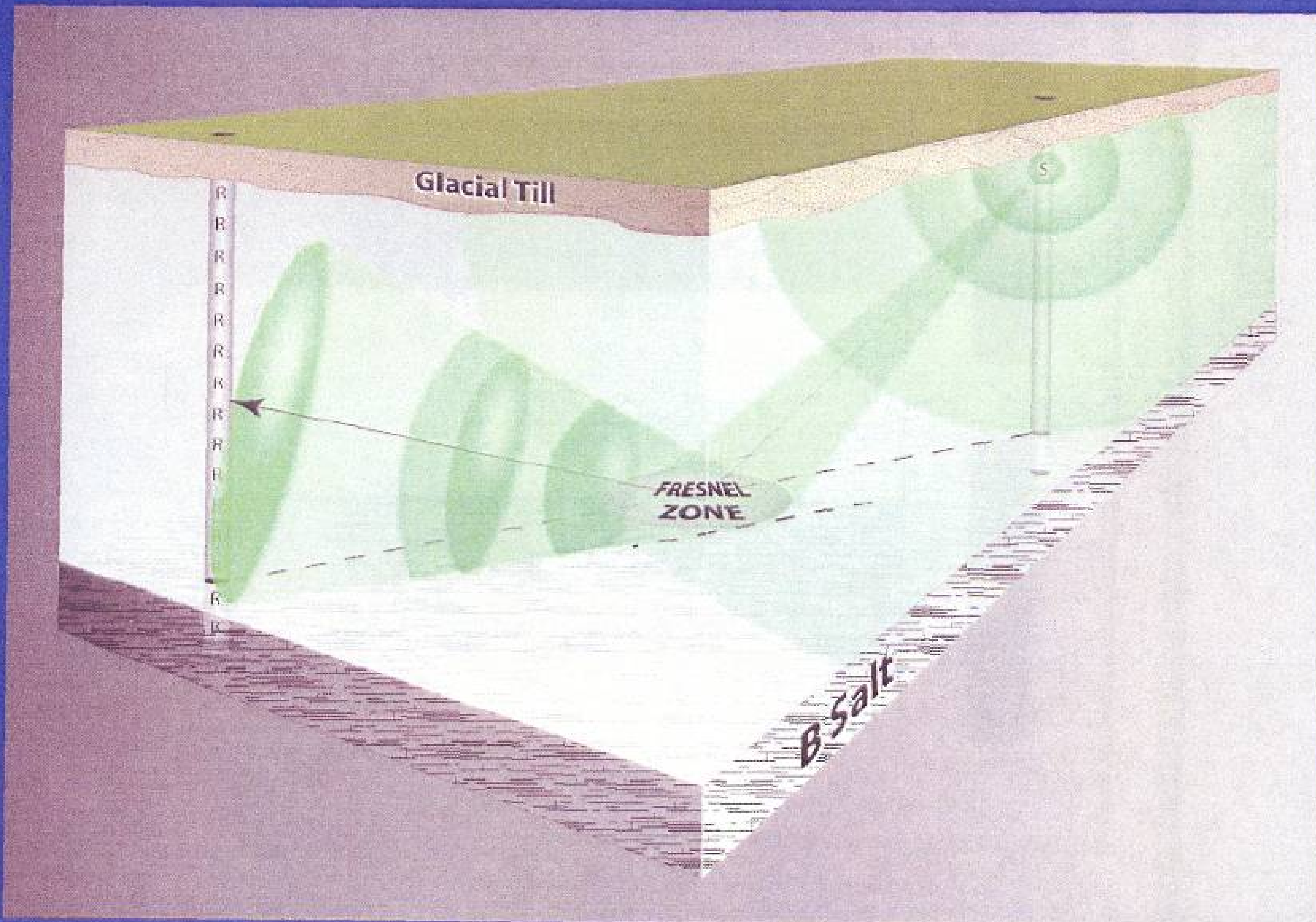
Introduction to the Fresnel Zone

The fresnel zone is defined as the part of the interface from which the energy returned to a receiver, within half a wavelength of the initial reflected arrival, interferes constructively to build up the reflected signal.

Geophysical Surface Methods Fresnel Zone



Crosswell Fresnel Zone



Crosswell Reflection Principles

- Routine data
  - Direct arrivals
  - Reflection information
- Additional data yields specific information (e.g. guided waves, converted waves)
- Result – 2-D or 3-D map (tomogram)

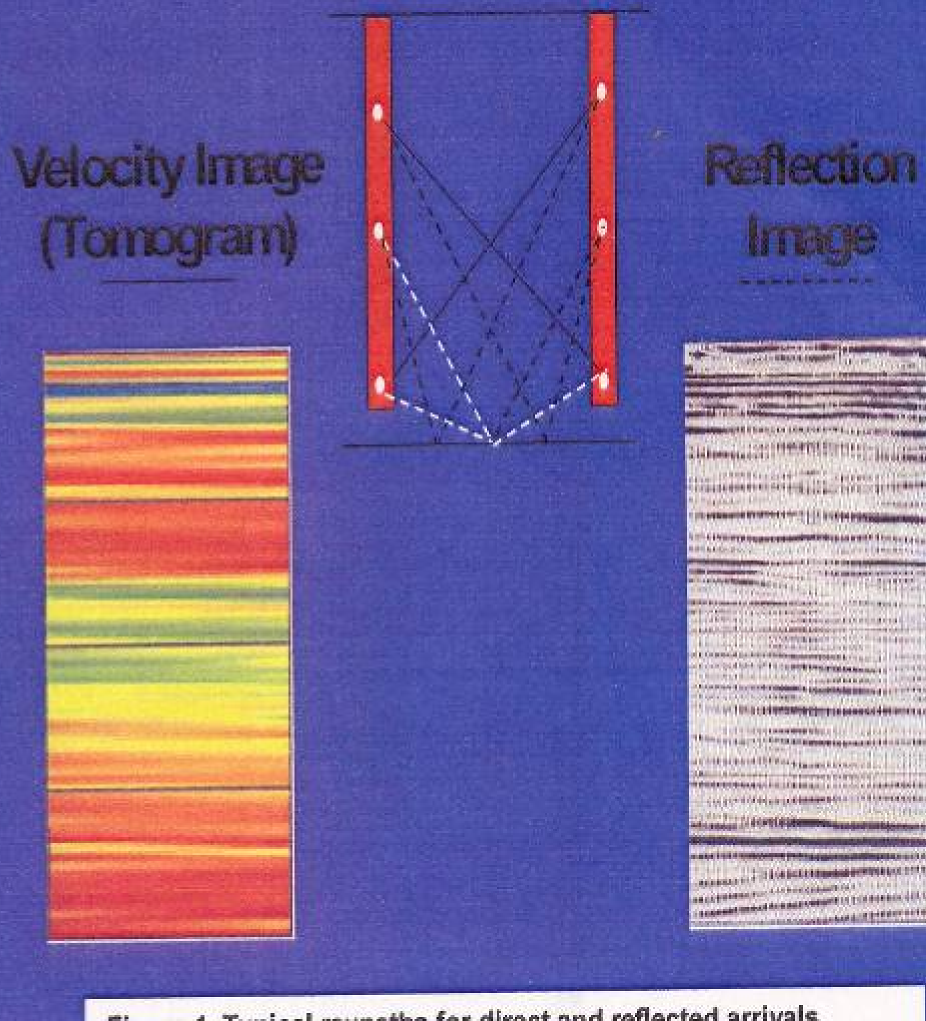


Figure 1. Typical raypaths for direct and reflected arrivals

Modeling Results for a 300-foot Diameter "Bulked Up" Cavity

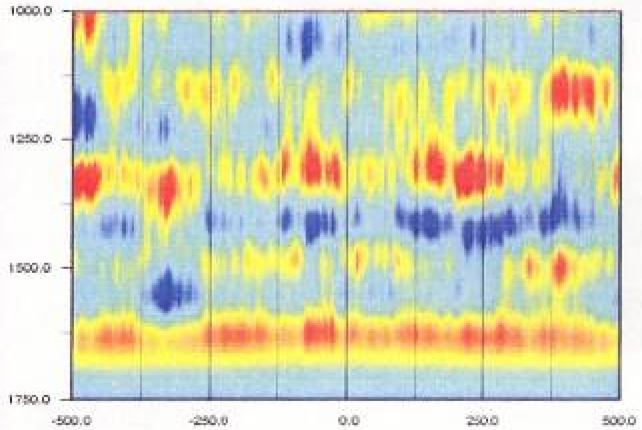


Figure 26. Surface seismic section for 300-foot bulked-up cavity.

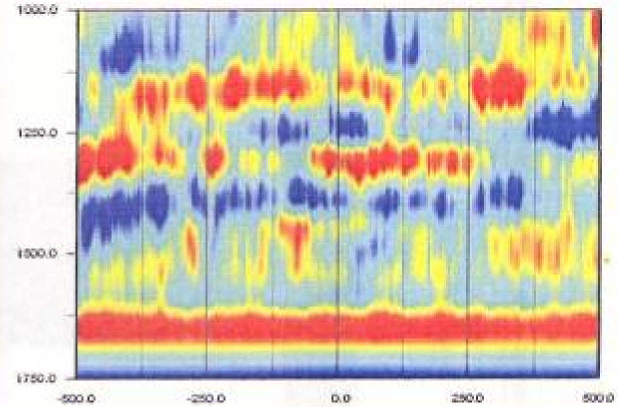


Figure 27. Reverse VSP seismic section for 300-foot bulked-up cavity.

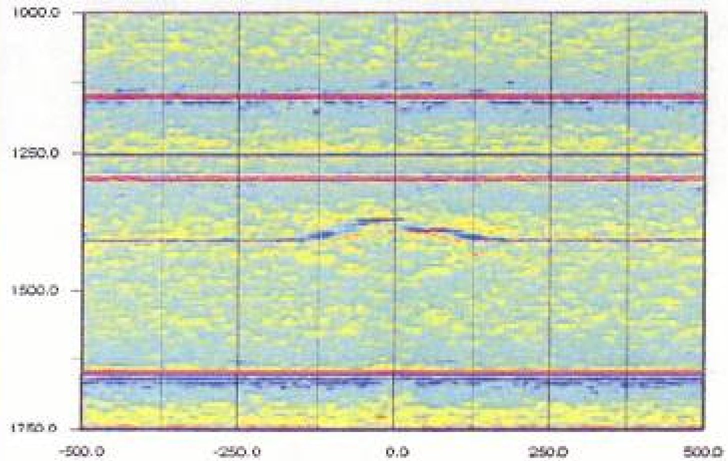


Figure 28. Crosswell seismic section for 300-foot bulked-up cavity.

Modeling Results for a 100-foot Diameter Brine Filled Cavity

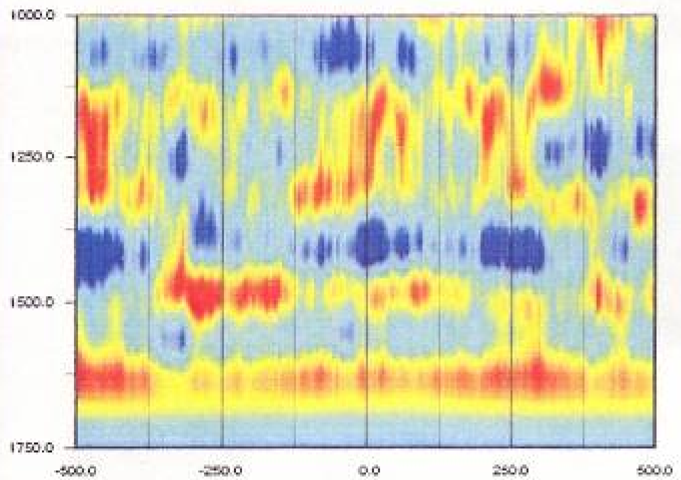


Figure 20. Surface seismic section for 100-foot brine-filled cavity.

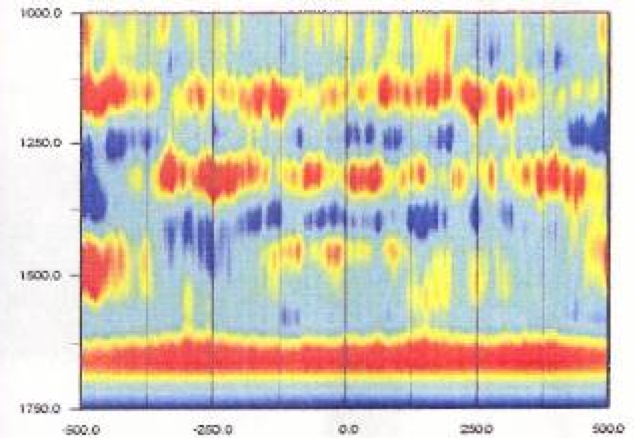


Figure 21. Reverse VSP seismic section for 100-foot brine-filled cavity.

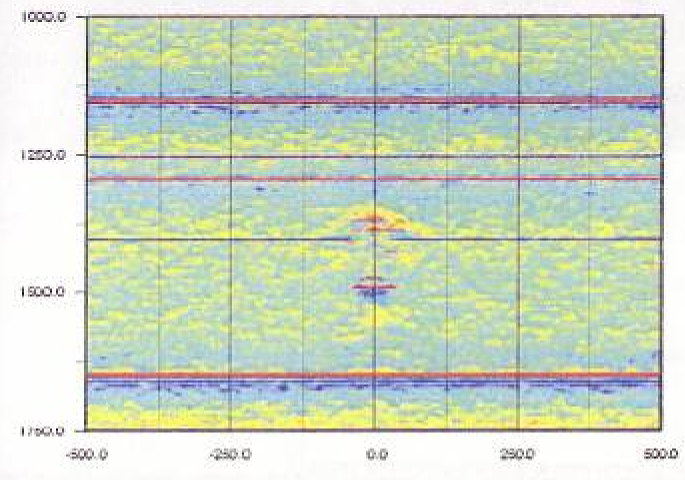


Figure 22. Crosswell seismic section for 100-foot brine-filled cavity.

Velocity Models

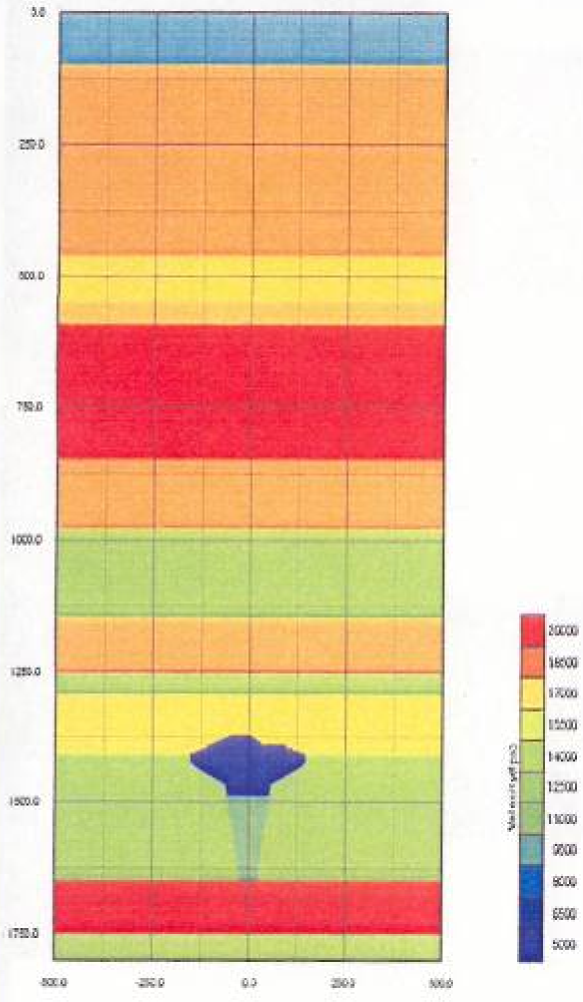


Figure 3. Velocity model for 300-foot diameter brine-filled cavity.

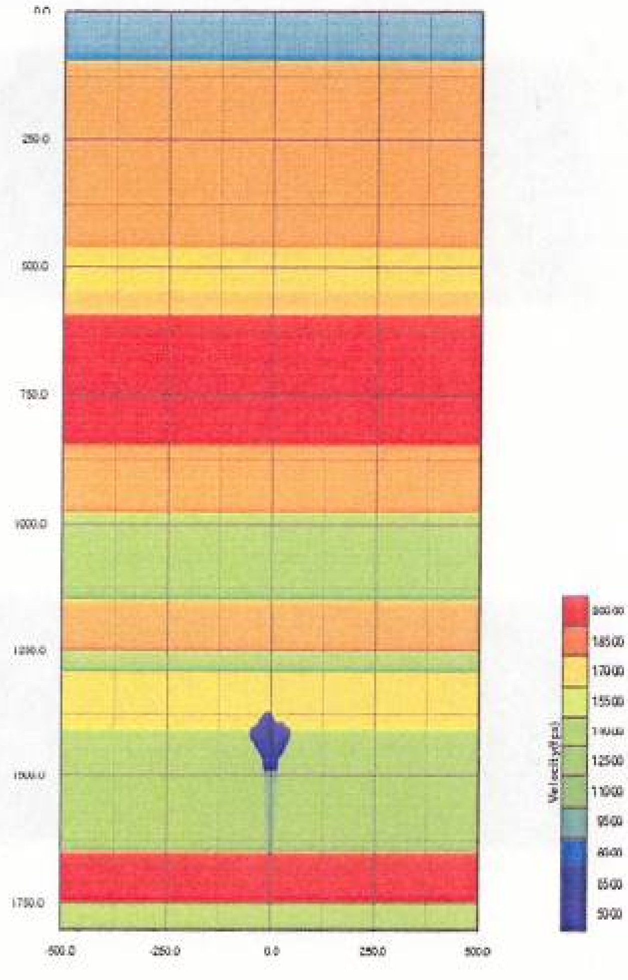


Figure 5. Velocity model for 100-foot diameter brine-filled cavity.

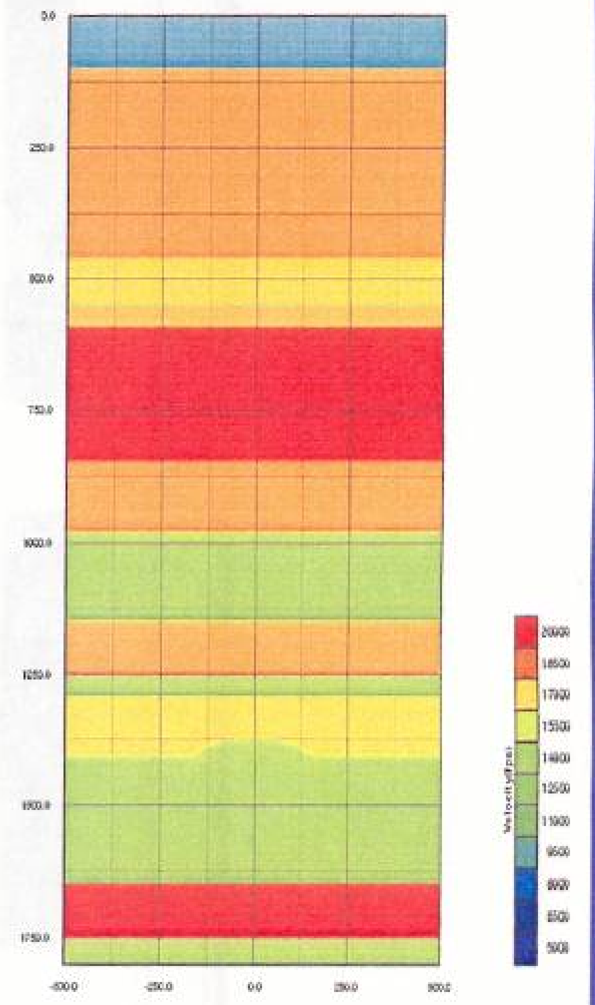


Figure 7. Velocity model for normal stratigraphy with B-salt structure.

Geophysics is Playing an Increasing Role in Solving General Geotechnical Engineering Problems

- static conditions
- dynamic conditions

Conclusions and Future Developments

- **Stress wave (seismic) measurements play an important role in geotechnical engineering.**
- **This role will continue to grow.**
- **The growth will involve four areas:**
  1. education, 2. integration, 3. automation, and 4. innovation.

USES OF GEOPHYSICS IN POWER DEVELOPMENT

- SMALL SCALE GEOTECHNICAL ACTIVITES – FOOTINGS FOR WIND FARMS

TO

- LARGE SCALE GEOTECHNICAL ACTIVITES – SITING FOR LARGE POWER PLANTS

MANY THANKS FROM ME TO:

- PURDUE GEOTECHNICAL SOCIETY FOR INCLUDING THIS "*IRISH WOLVERINE*"
- PROF. VINCENT DRNEVICH
- ALL IN ATTENDENCE