A comparison of three seismic methods in the arid environment

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A comparison of three seismic methods in the arid environment

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University of Nevada, Las Vegas, 1989
A COMPARISON OF THREE SEISMIC METHODS IN THE ARID ENVIRONMENT

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science in

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Department of Geoscience
University of Nevada, Las Vegas
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ABSTRACT

Eight locations in the vicinity of Las Vegas, Nevada, were noise tested using a shotgun, high frequency geophones, and an engineering seismograph. The noise spreads were examined for reflection events to determine shotpoint to geophone offset for an optimum window reflection profile. No reflection events were observed in the noise spreads. Trial optimum offset lines were run at location 1 and location 8. The resulting profiles contain spurious reflecting horizons that appear to be teal reflectors. At the eighth location, a delay time profile and a series of over-lapping refraction soundings were performed at the site of the optimum offset line. The delay time profile contains false structure that is an artifact of error accumulation in data reduction. The over-lapping refraction soundings produced a useful low resolution profile of an alluvial contact approximately five to ten feet deep.

The surface geologic environment in the southwestern desert was found to be unfavorable to the optimum offset reflection profiling method and the delay time method. Both yield misleading results when applied to shallow targets in the desert southwest. The refraction sounding technique provided useful profiles and should continue to be used in the southwest for profiling shallow refraction targets.
INTRODUCTION

OBJECTIVES

A thorough geologic and geophysical description is critical to site characterization in engineering, hydrologic, and hazardous waste studies. Seismic exploration techniques can serve as guidelines for field personnel to indicate whether actual physical sampling methods, such as borehole exploration, need to be applied. Seismic methods available for these applications include refraction soundings, delay time profiling, and optimum offset reflection profiling. The objective of this project was to evaluate the performance of seismic exploration methods in a desert environment.

The desert environment of the southwest has diverse surface conditions. Surface materials may include dune fields, desert pavement, evaporites and poorly sorted sand and gravel. The immediate subsurface may contain unique stratigraphic features such as dry sand and caliche deposits. The water table is often deep and sometimes not readily identifiable. All these factors must be considered when using seismic exploration techniques. Variability in the texture of the surface materials can result in irregular geophone coupling factors. Variations in stratigraphy, in particular the degree of water saturation, affects the
acoustic velocities and the kinds of waves that are propagated.

Seismic noise spreads, refraction soundings, delay time profiles, and optimum offset reflection profiles were conducted at a variety of sites in the Las Vegas, Nevada area. The results indicate that seismic methods developed and demonstrated in more favorable environments, such as river deltas and glacial tills, should not be used in the southwest.

BACKGROUND

Seismology is the most highly developed branch of geophysics. It is a rapidly advancing field that includes earthquake seismology, seismotectonics, and exploration seismology (Sharma, 1978). Seismic methods may be classified into two major divisions depending on the energy source of the seismic waves. Earthquake seismology is dependent on natural shock waves from the earth. These waves allow us to infer the physical properties and structure of the earth’s interior. Exploration seismology is dependent on artificial waves generated by controlled explosions or similar techniques, and is used to obtain information about regional or local structures. Exploration seismology has been used as a tool in oil exploration since the 1920’s. Subsurface
geological conditions that have been assessed by seismic techniques include:

1. depth to bedrock
2. depth, thickness, dip, and density of lithologic units
3. horizontal and vertical extent of geologic structures (folds, faults, and fractures)
4. the approximate depth of the water table
5. the porosity and permeability of lithologic units

These techniques have also been used to delineate the boundaries of subsurface bulk waste trenches and depth of landfills.

The refraction method of exploration seismology utilizes principals similar to Snell's Law of optics. The refraction technique was first developed in Germany in 1919. In the beginning of seismic prospecting the refraction method was the only technique available and it was used extensively for locating salt domes. The basic data for refraction soundings and delay time profiling are the minimum source-to-receiver travel times. These are plotted as time versus distance, in refraction soundings, and then fit to a model of multiple homogeneous layers. The thicknesses and velocities of the layers and the apparent dip between the layers are the model variables. Delay time profiling adjusts the receiver spacing
to resolve a multiple layer interference. Both refraction sounding and delay-time profiling are described in introductory geophysical texts (Zohdy et.al. 1974; Dobrin 1976; Telford et.al. 1976; Kearey and Brooks, 1984).

The reflection seismic method has been used more extensively than any other geophysical method for mapping underground structures in the sedimentary section, particularly in connection with oil exploration. The underlying principle is similar to that of echo-sounding. Optimum-offset reflection profiling uses seismic waves reflected from stratigraphic contacts to produce a cross-sectional acoustic image of the stratigraphic layering along the profile line. The optimum-offset reflection profiling method has been used by the Geologic Survey of Canada in unique settings. At Quyon, Quebec, profiles on water-saturated glacial till overlying bedrock (Hunter et.al., 1985) acquired excellent definition of the till-bedrock contact. In British Columbia, traverses were conducted on the Fraser River delta (Pullan, 1987). The sources and the receivers were submerged in water on the bottom of irrigation ditches. High resolution profiles delineating bottom set, foreset, and topset deltaic sediments were collected.

An alternative to optimum-offset profiling is the common depth point (CDP) method. High resolution CDP profiling has
been described by several investigators including Hoffman and Waldner (1985), Knapp and Steeples (1986), and Senior (1987). CDP profiling requires more sophisticated data processing than optimum offset profiling and was not included in this study.
EQUIPMENT

Equipment for high resolution seismic surveys usually requires instrumentation that operates in high frequency ranges (over 100 hertz) for short time intervals (<1000 milliseconds). These constraints affect both the source and recording equipment. Low acoustic frequencies need to be eliminated because they are not capable of providing high resolution. Various combinations of equipment were tested in the field and low-frequency contributing components were systematically eliminated. Frequency filters were also used to suppress low frequency noise. These analog filters are located in the recording equipment described below.

The primary energy source used for this study was a conventional 12-gauge shotgun shell. Two versions of detonating equipment were used: a fabricated "buffalo gun" consisting of a pipe and "droprod", and a commercially available seismic gun called the "Betsy Seisgun".

The buffalo gun (Figure 1), was constructed according to guidelines established by the Geologic Survey of Canada (Pullan and MacAulay, 1985). It is constructed of a length
12 GAUGE BUFFALO GUN
(AFTER GAGNE, 1985)
of 3/4 inch steel pipe connected by a coupler to a 3/4 inch nipple. The detonator consists of a steel droprod made of threaded stock rod. The droprod fit loosely inside the 3/4 inch pipe. A protruding pin welded onto the end of the droprod served as the firing pin. A 12-gauge shotgun shell was placed in the nipple and the gun was fired by dropping the rod down the pipe. The pipe end containing the shell, was placed in a 1-foot deep hole and buried prior to detonation. The buffalo gun misfired many times proving to be unreliable as well as a safety hazard.

The Betsy Seisgun (Figure 2), is similar to the buffalo gun but is built with machined steel parts. The Betsy differs from the buffalo gun by having a built-in firing rod which detonates the shotgun shell when it is hit on the upper end with a hammer. The Betsy proved to be more reliable and safe.

A sledge hammer and striking plate were used as alternate energy sources. The system was simple and was found to produce a frequency spectrum comparable to the shotgun source.

The shotgun energy sources were coupled to the recording equipment by a trigger switch and cable. The trigger was an accelerometer switch that produced a current during the shot.
Triggering was slightly different for both guns due to the difference in the firing mechanisms. The buffalo gun triggered the recorder when the gun barrel was accelerated upward by the detonating shell. The Betsy gun triggered when the gun was impacted by the firing hammer.

Triggering for the sledge hammer was accomplished with an extra geophone planted adjacent to the impact point. The geophone was connected to the triggering circuit of the recorder with a cable adapter.

Mark Products 100 hertz (model L-40A-2) geophones (Figure 3) were used as the primary source of data collection for this study. Ten hertz geophones were also available. Both are conventional spike plant, moving coil, geophones which respond to vertical ground motion by showing changes in electrical voltage output.

The difference in the two types of geophones used in the filtering provided in the system. The 10 hertz geophones pass frequencies of lower range to the recorder than the 100 hertz geophones. The frequency-response curves of the 10 and 100 hertz geophones is shown in the appendix, Figure A1. The geophones were connected to the recorder by a cable. Maximum spacing of the geophones is limited to ten feet by the cable takeouts.
GEOPHONES

Figure 3
The data recorder unit was a Model 8012A seismograph manufactured by Bison Instruments (Figure 4). The unit records twelve geophone traces that are digitized by the 8012A and displayed on a monitor. The monitor allows for expansion of the waveforms for better resolution and is equipped with two movable time cursors. The display lists the time elapsed for each channel from triggering to the position of the time cursor. Data can also be transferred from the registers to permanent solid state memory boards.

The Bison 8012A seismograph is equipped with gain controls to amplify the signals from the geophones. The gain is adjustable from 24db to 102db in increments of 6db. The sweep time may be set at 48, 96, 192, 480, 960, 1920, or 4800 milliseconds.

Frequency filtering options include high pass, notch and low pass filters. The frequency response curves for the 8012A are shown in the appendix, Figures A2-A4.

The filtered geophone traces are digitized into 959 samples of eight bits each. A record of 480 milliseconds is sampled every 0.0005 seconds, thus, two samples are taken every 0.001 seconds. Two samples are required for each wavelength to avoid aliasing the wave form. Aliasing is undersampling a high frequency wave; therefore, the highest
SEISMOGRAPH

Figure 4
frequency that can be digitized without aliasing the signal is 1000 hertz. Signal frequencies above 1000 hertz must be removed by low pass analog filters.

Data storage in the Bison is a solid state digital memory powered by internal batteries. The memory storage capacity is 119 kilobytes per twelve channel record. The digitized waveform traces for each twelve channel geophone spread was stored in the seismograph as a file. Raw data was transferred to a Compaq computer and stored on 5 1/4 inch floppy disks. Software to transfer the data to the computer and to display the data on the computer screen was modeled after programs available from the New Jersey Geologic Survey (Hoffman and Waldner, 1985). Data plots consisting of time domain traces were made on a Model DMP-42 pen plotter manufactured by Houston Instruments. Software was developed to drive the plotter from the Compaq computer using BASIC graphics.

TECHNIQUES

Four techniques were included in this study: noise spreads, refraction soundings, delay-time profiling, and optimum-offset reflection profiling. Each is described separately below.
Noise Spread

Noise spreads, or walkways, are used to determine the seismic response of a site and to establish the optimum parameters for subsequent surveys. Noise spreads show the arrival times and relative energy of all seismic events as a function of shot-to-receiver separation. Noise spreads also allow a qualitative assessment of the uniformity of the geophone-to-ground coupling. The noise spreads are as essential as the processed reflection sections for the interpretation of optimum-offset reflection data.

The twelve geophones were deployed on-line at ten-foot intervals to achieve the noise spreads. There were four shot points off one end of the line with the shot-to-near-receiver offsets either at 10, 12.5, 15, or 17.5 foot intervals or 100, 102.5, 105, 107.5 foot intervals depending on the range being investigated (Figure 5).

Signals were digitized at one millisecond intervals and recorded for 480 milliseconds. The gains were individually adjusted for maximum trace amplitude without clipping and the filters were out. Usually the 100 hertz land phones and a 12-gauge seisgun source were used. The complete record or trace from each of the 48 shot-plus-receiver pairs are plotted in order of increasing shot-to-receiver distance.
LONG OFFSET NOISE TEST

short #1

shot #2

shot #3

shot #4

--- 100' ---

100 ft.

SHORT OFFSET NOISE TEST

short #1

shot #2

shot #3

shot #4

--- 100' ---

100 ft.

Figure 5

Noise test configuration
Appendix Figure A5 is a representative example from a site.

The noise spread technique provided 48-trace spatial coverage with only one deployment of the 12 geophones. Interpretation of the data is straight-forward once the characteristics of the different seismic events are understood. Figure 6 (not drawn to scale) is an ideal earth-model simulation consisting of 2 feet of unconsolidated surficial material, a water table at 20 feet, a stratigraphic reflector, and an alluvium/bedrock interface at 400 feet. Figure 7 is the same simulation with seismic velocities and ray paths illustrated. Figure 8 is the corresponding noise spread showing arrival times of seismic events expected in this model. These include the air wave, direct wave, a shallow refracted wave, reflections from the water table from the stratigraphy, and from the alluvium/bedrock interface. The band corresponding to the phase velocities of the frequency-dispersed, fundamental mode Rayleigh waves within the sediments is also shown as ground-roll.

The frequencies of Rayleigh waves affecting the basement at 400 feet should be below the response of the geophones. Fundamental-mode Rayleigh waves are generally the strongest components of ground roll (Dobrin, 1976).
GROUND MODEL FOR SEISMIC WAVES

Figure 6
Figure 7
Seismic model derived from figure 6
Figure 8

Travel time – distance plot derived from figure 7
Noise spreads are essential in determining whether an optimum-offset reflection survey can be conducted at a particular site. Reflection hyperbolas similar to those plotted in Figure 8 must be observed in the noise spread. The reflection hyperbola is used to determine the optimum shot-to-receiver offset and the time window of reflections at this offset. Figure 8 indicates that reflection arrivals are more flat and horizontal than the other events. The reflected waveform comes up from below and arrives nearly simultaneously at all receivers. Reflected events have very high apparent velocities. Figure 8 also indicates that reflections arrive simultaneously with other events including the shallow refractions and low frequency ground-roll. The noise spread is examined to find a shot-to-receiver offset at which reflections are the strongest events. When reflection events, as indicated by their apparent velocities, are not the strongest events within the time window being investigated, then the other events will dominate the processed reflection section. These other events are indistinguishable from reflected events.

Noise spreads also allow a qualitative assessment of the uniformity of the geophone-to-ground coupling. When the coupling is irregular, the character of the events (i.e., the wiggle shape) will tend to change every fourth trace (four traces per geophone) instead of gradationally. Appendix
Figure A6 is an example of irregular coupling from Site 3. The events on an optimum-offset reflection section will be discontinuous if the coupling is irregular.

**Refraction Method**

The refraction method of seismic exploration uses a linear array of geophones with shot points at each end of the array. When a shot is fired, energy arrives at the geophones in the form of elastic waves in the earth. The waves are three-dimensional body waves that propagate away from the energy source on wavefronts. Lines that are normal to the wavefronts are rays. The rays travel on paths that are determined by the velocity structure of the subsurface. The refraction exploration method uses arrival times of the rays to model the subsurface. Additional information concerning the refraction method of seismic exploration can be found in Dobrin (1976) and also in Kearey and Brooks (1984).

When encountering any separation of the shot point and geophone, there is a specific path that the ray can follow that will minimize the travel time of the ray. The energy carried by the ray will be the first-arriving ground disturbance detected by the geophone. The "first break" is the earliest arriving disturbance on the geophone output record. Rays arriving at the geophones are considered
"direct arrivals" when the ground is uniform and unlayered. Direct arrival rays travel a straight path through the earth. When the surface layer is underlain by a higher velocity bed then another path between the source and the geophone is possible. The second ray path originates when a downward traveling ray is critically refracted at the top of the higher velocity layer. A ground model containing two layers is shown in Figure 9A. The seismic model showing the critically refracted ray is shown in Figure 9B. The critically refracted ray travels on top of the high speed bed with the velocity of that bed. Rays are generated in the overlying low-velocity bed as the wave propagates. These waves emerge from the base of the low-velocity bed at the same critical angle of refraction. The refracted ray has a higher average velocity than the direct ray because it travels with the velocity of the high-speed bed for a part of its path. The crossover distance is the shotpoint-to-geophone spacing that allows the velocity advantage of the refracted ray to make it the first arrival. The possibility exists for additional raypaths that follow deeper refracted paths if there are higher velocity beds below the shotpoint. Deeper beds are detected by increasing the distances between the shotpoint and the geophones. This may be accomplished by using additional geophones on a longer line, or by moving the geophones. For this study, moving the geophones required multiple shots at the same shotpoints.
Figure 9A
TWO LAYER GEOLOGIC MODEL

Figure 9B
REFRACTION SURVEY

$V = 1500 \text{ FT/SEC}$
$V = 3500 \text{ FT/SEC}$

$\theta = \sin^{-1}\left(\frac{V_1}{V_2}\right) = 25.38^\circ$

$0^\circ$ 5' 10' 15' 20' 25' 30' 35' 40' 45' 50' 55' 60' 65'

$0^\circ$ 10'$^\circ$ 5' 10' 15' 20' 25' 30' 35' 40' 45' 50' 55' 60' 65'

FOREWARD MODELING EQUATIONS

$0 = \sin^{-1}\left(\frac{V_1}{V_2}\right) = 25.38^\circ$

$\theta = 4.41^\circ$

$Z = 3 \text{ FEET}$

$Z = 8 \text{ FEET}$

Figure 9
Refraction ground model and seismic model
Data acquisition for a refraction survey requires recording the first arriving wave on each geophone trace. The plot of ray travel time versus geophone distance from the energy source is an important step in the interpretation of the data. Directly arriving rays plot as straight lines through the origin on a time versus distance plot, and have a slope equal to the reciprocal of the apparent velocity of the surface bed. The refracted ray plot intercepts the time axis at a value called the "intercept time". The analysis of the model illustrated in Figure 9A is shown in Figure 10.

The thickness of the structure can be calculated from the slopes and intercept times of the time-distance plots using only one shot when the velocity structures in the subsurface are known to be horizontal. It is necessary, however, to shoot from each end of the geophone line and plot travel time versus distance each way from the shot if the structure has dip. Two sets of apparent slopes and intercept times are found for each structure. This procedure allows the dip angle of the structures as well as the thickness to be calculated. The refraction method of seismic exploration has the advantage of simplicity and provides a precise geometrical model of the subsurface velocity structures. Some disadvantages of refraction exploration are as follows:
TRAVEL TIME PLOT

INVERSION EQUATIONS

\[
\theta = \frac{1}{2} \left( \sin^{-1} \left( \frac{V_1}{V_D} \right) + \sin^{-1} \left( \frac{V_1}{V_U} \right) \right)
\]

\[
\gamma = \frac{1}{2} \left( \sin^{-1} \left( \frac{V_1}{V_D} \right) - \sin \left( \frac{V_1}{V_U} \right) \right)
\]

\[
V_2 = \frac{V_1}{\sin(\theta)}
\]

\[
Z = \frac{V_1 t_1}{2 \cos(\theta)}
\]

\[
Z^1 = \frac{V_1 t_1^1}{2 \cos(\theta)}
\]

_Figure 10_

Refraction travel time – distance plot
1) Success depends on the extent to which geology can be approximated as a sequence of homogenous layers separated by the planar interfaces and for which velocity increases with depth.

2) It is blind to thin beds.

3) It is blind to beds with lower wave velocities than the overlying beds.

**Delay Time Method**

The delay time method is a high-resolution seismic profiling technique. The name of the method is derived from the use of the delay time to calculate depths to refracting horizons. The delay time is a difference in travel time between two rays, one real and one imaginary. The real ray traverses a path from the source to the receiver by way of the refracting bed. The imaginary ray path is along the top of the refracting bed between the projections of the source and receiver onto the bed. The real and imaginary rays are shown in Figure 11 by the segments "SMNG" and "PMNQ".

The delay time method uses the delay times of three rays to calculate the depth to a point on a subsurface refractor.
\[ \delta = t_{SMNG} - \frac{PQ}{V_2} \]

\[ = \left( \frac{SM+NG}{V_1} + \frac{MN}{V_2} \right) - \frac{PQ}{V_2} \]

\[ = \frac{SM+NG}{V_1} - \frac{PM+NQ}{V_2} \]

\[ = \left( \frac{SM}{V_1} \frac{PM}{V_2} \right) + \left( \frac{NG}{V_1} \frac{NQ}{V_2} \right) \]

\[ = \delta_{SHOT} + \delta_{GEOPHONE} \]

**Figure 11**

*Definition of delay time*
The three rays are shown in Figure 12. The distance labeled in Figure 12 is important in the design of the survey. It is the surface separation between source "B" and receiver "Q" that corresponds to the critical distance in refraction surveying.

The ray traveling downward from "B" to "N" enters the high speed refracting bed at the same point the ray traveling upwards from "N" to "Q" leaves the bed. The critical distance, \( d \), and the critical angles are determined by a refraction sounding.

The goal of the delay time method is to isolate the travel times associated with leg NQ in Figure 12. This is done by adding the delay time of path AQ to the delay time of path BR, and subtracting the delay time of path AR. The remainder is the delay time of BN plus NQ. The NQ delay time is known because BN equals NQ. \( Z \) is computed from the NQ delay time, \( V_1 \), and the cosine of the critical angle.

The field procedure to acquire a delay time profile uses two shot points and two geophone plants for each profile point. It is convenient to place the shot points and geophones on a spacing corresponding to the "d" distance indicated in Figure 12. The array is walked across the surface as sequential shots are made. The actual data point
DELAY TIME PROFILING

\[ \delta_{AQ} = \delta_{AM} + \delta_{NQ} \]
\[ \delta_{AR} = \delta_{AM} + \delta_{PR} \]
\[ \delta_{AQ} - \delta_{AR} = \delta_{NQ} - \delta_{PR} \]
\[ \delta_{BR} = \delta_{BN} + \delta_{PR} \]

IF \( \delta_{BN} = \delta_{NQ} \)
THEN \( \delta_{BR} = \delta_{NQ} + \delta_{PR} \)

ADDING

\[ \delta_{NQ} = \frac{1}{2} (\delta_{AQ} - \delta_{AR} + \delta_{BR}) \]

ALSO

\[ \delta_{NQ} = \frac{\frac{NQ}{V_1} - \frac{1}{2} \delta_{OQ}}{V_2} \]

\[ = \frac{z}{V_1 \cos \theta} - \frac{z \tan \theta}{V_2} \]

\[ = \frac{z}{V_1 \cos \theta} \left( 1 - \frac{V_1}{V_2} \sin \theta \right) \]

\[ = \frac{z \cos \theta}{V_1} \]

THEN

\[ z = \frac{V_1}{2 \cos \theta} \left( \delta_{AQ} - \delta_{AR} + \delta_{BR} \right) \]

**Figure 12**

Calculation of depth from delay time
for the depth to the irregular refracting surface is the mid-point of the array.

Additional information concerning the delay time method may be found in Dobrin (1976) and Palmer (1980).

Optimum Offset Reflection Method

Reflection profiling utilizes acoustic wave energy that has penetrated the subsurface and has been reflected back to the surface. The reflection of the wave energy occurs at boundaries between layers with contrasting acoustic impedance. The acoustic impedance is the product of rock density and the acoustic wave velocity in the rock. A change in rock density or wave velocity accompanying a change in lithology or moisture content results in reflection. The reflection of the wave energy follows the same geometric law that a light reflection follows; the angle of incidence equals the angle of reflection.

Reflections are recognized in a noise spread by the hyperbolic profile of the adjacent amplitude peaks. The hyperbolic shape results from the geometry of the ray paths. The travel time can be calculated from the overburden velocity, the shot-geophone offset distance, and the depth
to the reflecting surface. These variables can be related in the following expression:

\[ t^2 = x^2 + 4Z^2 \]

\[ \frac{\phantom{1}}{v^2} \]

where \( t \) = the travel time of the wave from the shot to the receiver
\( x \) = the horizontal distance between the shot and the receiver
\( Z \) = the depth to the reflector
\( V \) = the velocity of the overburden

The increase in wave travel time caused by increasing \( x \) when \( Z \) is constant is called the "normal move out". Conventional reflection data processing removes the effect of normal move out by subtracting the horizontal time component from the total travel time. The correction for normal move out is not necessary in optimum offset profiling because the shot-geophone separation is constant. Horizontal reflectors appear as flat alignment of wave forms, not as hyperbolas.

The field acquisition of an optimum offset reflection profile is preceded by a noise spread. The noise spread
locates the optimum offset where reflections occur. The reflection survey requires a line of shotpoints and a line of geophones. The separation between shotpoints is equal to the separation between geophones and determines the resolution of the survey. Each shot is recorded by only one geophone and that is the geophone located at the optimum offset distance. The optimum offset distance is maintained by advancing the shotpoint and the active geophone across the ground surface.

The traces of the geophone response to ground movement are saved as digitized data in the seismograph. The traces may be plotted on paper for interpretation. The location of the mid-point between the shot and receiver is the horizontal axis of the plot. The elapsed time after the shot is the vertical axis.

Additional information about optimum offset reflection profiling may be found in Hunter et.al., (1984).

SITE DESCRIPTION AND ACTIVITIES

The comparison of the three seismic methods in the desert environment was conducted at eight locations near Las Vegas, Nevada. The locations are shown on Figure 13.
The eight sites were chosen to provide a variety of geological environments for seismic investigation. A range of desert surroundings were tested since a technique that works in one specific geological environment may not be successful in another desert area.

Site 1 is located in a trash dump in the Las Vegas Wash. The surface soil was disturbed by grading and filling. The soil is fine grained and dry in contrast to water saturated soils where optimum offset reflection profiling has been previously applied (Pullan and Hunter, 1987). The site is located east of Highway 95 approximately 0.7 miles east of the Las Vegas Silverbowl.

Work at Site 1 included multiple noise spreads to evaluate the droprod seisgun, source-to-geophone offset distances, geophones, and recording filters. The droprod gun was tried with 10 hertz geophones, both with and without frequency filtering. This combination provided more high frequency energy, but did not suppress the low frequency noise. The offset distance between the energy source and the geophones was also varied, including offsets of 10, 20, and 100 feet. The greatest success in recording high frequency signals was achieved using the droprod gun, the 100 hertz geophones, and 70 hertz bypass filters in the seismograph.
Site 2 is located on mud flats in Searchlight Playa approximately 15 miles south of Las Vegas on Highway 95. The surface consists of fine, compacted silt. The surface was expected to propagate seismic waves more rapidly than the loose soil at Site 1. This was expected to create an optimum window after the arrival of the surface waves. Digging two feet into the subsurface revealed a layer of wet silt. The wet subsurface created a zone of low wave velocity and made this site blind to shallow refraction surveying.

Site 2 test noise spreads were shot to find the refraction and reflection properties of the site. The shot-receiver offset was tried at 10 and 100 foot intervals. The 10 and 100 hertz geophones were tried with 70 hertz high-pass filters in and out. The droprod gun and sledge hammer energy sources were used. Only direct arrivals were obtained, so refraction sounding was not successful at the site. The geophone spacing was three feet and the source was offset three feet from the end of the line.

Site 3 is located in Henderson, Nevada, near the Pittman Lateral. The site was accessed by Sunset Road east of Boulder Highway. The surface consists of unvegetated, dry, alluvial fan sands and gravels. This dry, uncompacted nature of the surface was expected to result in low surface wave velocity which creates a wider window for reflections.
The Site 3 noise spread was performed by use of the 100 hertz geophones, the droprod gun, and 70 hertz high pass filters. The shot-receiver distance was 10 feet, and the geophone spacing was 10 feet. Results of the noise spread were disappointing. Little coherent signal was recorded, making interpretation difficult. The lack of success at the Pittman Lateral is attributed to the soil conditions. The poorly sorted soil included pebble-sized clasts in a loose sandy matrix. The presence of metal, glass, and plastic cultural material interspersed in the soil complicated the natural inhomogeneity. The geophone plants, the shot hole-ground couplings, and the earth transmission are unfavorable to seismic methods at this site. Nevertheless, a successful refraction survey was undertaken. No reflection work was attempted at Pittman Lateral.

Site 4 is located at the corner of Patrick Lane and Harrison Street in an empty lot. The site was chosen for seismic investigation because the loose sandy surface is underlain with dense caliche. The caliche was exposed near one end of the geophone line. The near-surface caliche was thought to be a faster conductant of surface waves, thus causing the surface waves to pass the geophones before the reflected waves. The surface was loose, dry sand which created good geophone to ground coupling. A velocity inversion such as that experienced at the Searchlight Playa
was not expected due to the dry conditions.

Data collected at Site 4 was unfortunately more noisy than as anticipated due to jet airplane disturbances. Work on Site 4 consisted of a noise spread showing cultural noise. Additional attempts for quality data from this site were abandoned.

Site 5 was located in a low, wet area of Las Vegas Wash approximately one mile north of the Las Vegas Silverbowl. This site was chosen for seismic testing because it is a low land area that is moist to within inches of the surface. Preparation of shot holes showed standing water approximately one foot below the surface. The soil was covered with low, grassy vegetation.

Noise spreads and a refraction sounding were completed at Site 5. The noise spreads were conducted using the droprod seisgun, 100 hertz geophones, and 70 hertz high pass filters. Geophone spacing was 10 feet, and both 10 and 100 foot shot point offsets were performed. The noise spreads did not show reflections on either offset, so no reflection lines were attempted. The refraction line was performed with the sledge hammer, the 100 hertz geophones, and no filters. Geophones were spaced two feet apart with a two foot source offset.
Site 6 was also located in Las Vegas Wash approximately 1.5 miles north of the Las Vegas Silverbowl. This site was chosen because of its moist condition. The soil was saturated to within a foot of the surface and was covered with grass and brush.

The work at Site 6 consisted of a single noise spread. The noise spread was shot with the droprod seisgun, 100 hertz geophones, and 70 hertz pass filters. The geophone spacing was 10 feet and the shot point offset was 100 feet. The site produced no reflections on the noise spread, so a reflection profile was not attempted.

Site 7 is located near the Boulder City airport in the Eldorado Valley. This site is a large sandy area located on the east side of Highway 95. The subsurface was excavated and contains scattered pebbles which are more abundant with depth. The loose, sandy surface was expected to propagate seismic surface waves slowly enough to provide an optimum window for reflection profiling. The absence of cultural noise was expected to enhance the visibility of reflection events for the noise spread.

Site 7 work included a noise spread shot with the droprod seisgun, 100 hertz geophones and 70 hertz high pass
filters. Geophone spacing was 10 feet and the source offset was 100 feet. A refraction line was also shot using the droprod seisgun, 100 hertz geophones with filters out. The geophones were spaced on three foot centers and were shot forward and reverse.

Site 8 was chosen because the surface is typical of a desert trash dump site. The land's surrounding urban areas will be developed into housing tracts and recreational areas in the near future. Assessment of dump sites for construction is an important application of shallow seismic exploration. The surface was littered with cultural debris and had been graded and compacted. The surficial soil extends to a pebbly layer five to ten feet below the surface. The site was accessed by dirt roads off Highway 95 in East Las Vegas. For this study, the site is in a good location for comparison of reflection, refraction and delay-time profiling results.

The work at Site 8 was the most intensive of all site studies. A 400 foot long section was investigated using noise spreads, refraction, reflection, and delay time methods. The shots at site 8 were made with the Betsy Seisgun, using 100 hertz geophones.

The noise spread shots at Site 8 used a 100 foot shot-
receiver offset and 10 foot receiver spacing. Based on the results of the noise spread, an optimum offset reflection profile was performed. The reflection profile consists of 132 geophone traces on 3 foot intervals. The noise spread and the reflection profile were recorded with 70 hertz high pass filters. The reflection profile was enhanced using the normalizing and smoothing programs called "NORM" and "SMOOTH".

The refraction sounding at Site 8 was successful. Ten overlapping lines were shot with the Betsy Seisgun using three foot spacing. The 100 hertz geophones were used without seismograph filtering. Each line was shot forward and reverse and consisted of three geophone string layouts totaling 108 feet.

The delay time survey conducted at Site 8 was designed to provide high resolution profiles using refracted rays. The selection of geophone spacing and shotpoint offset was based on the refraction survey shot at the location. The delay time survey required 48 shots with the Betsy Seisgun. The shot and receiver spacing was ten feet.

The delay time survey covered the 400 foot strip also profiled by the refraction and reflection lines. The method was designed to provide better resolution than the refraction
line, but less resolution than the reflection line. The resolution for delay time and reflection profiling is directly related to receiver spacing.
RESULTS

The attempts to acquire reflections at Site 1 were totally unsuccessful. The noise spreads from the location (appendix, Figures A5 and A7) were closely inspected for reflection events, but none were found. A short optimum offset reflection line was run at the location to provide data for computer enhancement and plotting. The plot of the reflection profile, shown in the appendix, Figure A8, illustrates events that appear to be reflection geologic horizons, however these events are spurious. The optimum offset method collimates the noise from trace to trace and gives the illusion of continuous reflecting surfaces. This is a consequence of the constant separation of the source and the receiver.

The noise spreads shot at Site 2, shown in appendix Figures A9 and A10, did not succeed in recording reflections. The negative results on the noise spreads cancelled plans to do a reflection profile. Results of the refraction soundings are shown in Figure 14. The refraction sounding was successful in detecting the surface layer of dried mud but was blind to the underlying layer of wet mud found by digging at the location. Blindness to velocity inversions is unavoidable in refraction surveying because the waves are refracted deeper by low velocity zones.
Figure 14

Site # 2 Refraction survey
The work at Site 3 yielded a noise spread that contained no recognizable reflections. The section of the noise spread record that was expected to contain reflections was difficult to interpret. The phase of the waveforms undergo reversals from trace to adjacent trace, as shown in the appendix, Figure A6. This means that if reflections are present, they cannot be recognized.

The location at Site 4 produced too much cultural noise to acquire a quality noise spread (appendix, Figure A11). The cultural noise was expected to be a lower frequency than the seismograph recorded, and therefore not a problem; however, the cultural noise in the area did hide reflections that may have been present.

The noise spread at Site 5 did not produce reflections. The noise spread from Site 5 dominated by random noise (appendix, Figure A12). The refraction spread shot at Site 5 (Figure 15), successfully sounded the location.

Site 6 noise spread shots produced no reflections (appendix, Figure A13). Although standing water is near the surface at Site 6 making it the least arid of the sites, the noise spread is dominated by refraction events and ground-roll.
Figure 15

Site #5 Refraction survey
Reflections were not produced after Site 7 noise spread shots were made. The dry, sandy soil at the site is not favorable to optimum offset reflection profiling. The record from the site is dominated by ground-roll, which obscures any reflection that may have been present. The noise spread from Site 7 is shown in appendix Figure A14. A reflection profile was not attempted at the location because of the ground roll problem.

The noise spread from Site 8 (appendix, Figure A15), produced apparent reflections in a window centered near 200 feet of the source-receiver offset. The time window is around 250 milliseconds following the shot, where a false reflection event is present. The event is not a true reflection event because it is concave upward rather than downward. The optimum offset reflection line shot at Site 8 was normalized and filtered to enhance the plot. The optimum offset profile of Site 8 is shown in the appendix, Figures A16-A18.

The refraction soundings from Site 8 are shown in the appendix, Figure A19. The soundings were chained together to form the profile illustrated in Figure 16. The surface that was profiled ranged in depth from ten feet on the east end of the line, to 5 feet at the west end of the line. The wave velocities in the refracting layer are approximately
Figure 16
5000 feet per second which suggests dense alluvium. The upper 5 to 10 feet of material propagates waves at a velocity around 3000 feet per second, suggesting unconsolidated alluvium.

The shallow acoustic boundary profiled at Site 8 must originate at a soil contact. The change in soil causes an increase in propagation velocity that allows the refraction of the waves. The site was probed using a soil corer at the deep end of the seismic section. The findings corroborate the refraction sounding profile. A comparison of core description with seismic refraction sounding data is presented in the following table.
<table>
<thead>
<tr>
<th>DEPTH (feet)</th>
<th>DESCRIPTION</th>
<th>SEISMIC VELOCITY (ft/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 1</td>
<td>Argillaceous silt with reddish-brown very fine grained sand</td>
<td>3110</td>
</tr>
<tr>
<td>1 - 2</td>
<td>Predominately silt, slightly argillaceous, water saturated silt.</td>
<td></td>
</tr>
<tr>
<td>2 - 3</td>
<td>Slightly argillaceous as above</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>Standing water</td>
<td></td>
</tr>
<tr>
<td>3 - 4</td>
<td>Argillaceous silt as above with sand concretions</td>
<td></td>
</tr>
<tr>
<td>4 - 5</td>
<td>Argillaceous silt and sand concretions as above</td>
<td></td>
</tr>
<tr>
<td>5 - 9</td>
<td>Silty with sand concretions</td>
<td></td>
</tr>
</tbody>
</table>

Continued-
<table>
<thead>
<tr>
<th>DEPTH</th>
<th>SEISMIC VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>(feet)</td>
<td>DESCRIPTION (ft/sec)</td>
</tr>
<tr>
<td></td>
<td>of hand auger cuttings at site 8</td>
</tr>
</tbody>
</table>

9 - 10 High plasticity clay bounded by gravel and clay near base of the interval, gravel up to 2-3 cm

Velocity Interface

10 - 11 Limestone and sandstone gravel with sandy clay matrix, clay lenses 5460

The profile shown in Figure 16, therefore, follows the top of the gravel bed.

The delay time profile attempted at Site 8 produced poor results. The variation in depth between adjacent points is great enough to blur the surface being profiled. The depths calculated during the reduction of the data are approximately the same as the depths to bedrock indicated by the refraction
survey. This supports the belief that the top of the gravel layer is the surface being profiled. The plot of the delay time profile of Site 8 is shown in Figure 17. An analysis of sources of error inherent in the delay methods reveal limits to the resolution which may be attained.

Beginning with the formula for depth:

\[ Z = V_1 \frac{(T_1 - T_2 + T_3)}{2 \cos \theta} \]

\[ \frac{Z}{2} \]

\[ \frac{Z}{2} \]

The error or uncertainty in \( Z \) can be found from:

\[ dZ = \pm \frac{dZ}{dT} \pm \frac{dZ}{dV_2} \pm \frac{dV}{d\theta} \]

\[ \frac{dT}{dT} \quad \frac{dV_2}{dV_2} \quad \frac{d\theta}{d\theta} \]
\[ = \pm V_2 \tan \theta \left( \frac{T_1 + T_2 + T_3}{2} \right) \]

\[ \pm \tan \theta (T_1 - T_2 + T_3) \frac{V_2 \pm V_2 (T_1 - T_2 + T_3) \sec^2 \theta}{2} \mathrm{d}\theta \]

substituting:

\[ T_1 = T_2 = T_3 = 0.0055 \text{ sec.} \]
\[ V_2 = 5300 \text{ ft/sec.} \]
\[ \tan \theta = 1.4 \]

where: \( \tan \theta, V_2, \) and the mean of \( T \) are taken from our refraction line, and the uncertainty in \( T \) from 1/6 period at 30Hz

we find: \[ dZ = \pm 1.82 \pm 0.41 \pm 6.76 = \pm 9 \text{ feet} \]
CONCLUSIONS

The optimum offset profiles acquired at Site 1 and Site 8 contain events which are easily misinterpreted as reflections from geologic strata. Inspection of the noise spreads reveal that no true reflections were recorded at either site. The continuity of the events originates from collimation of noise generated by the shot. The constant separation of the source and receiver is responsible for the collimation.

The delay time profile acquired at Site 8 lacks continuity. The calculated depths to the refracting bed are highly variable, giving the impression of irregular structure. It has been shown that the uncertainty in the measured depths accounts for this variability. The uncertainty visible at the 300 foot station, where a large discrepancy in depth occurs, is an example of the variability. The complicated structure is spurious and not an indication of true structure.

The refraction sounding acquired at Site 5 provided dependable depth and dip information on subsurface structure. The overlapping chained refraction profile acquired at Site 8 indicates the presence of structure on the refraction surface and provides information on the velocities of the
subsurface beds.

The method least adaptable to the desert environment is the delay time profiling method. It requires that a refraction sounding be run to find the delay time parameters, including critical refracting angle and wave velocities. This technique has no supporting records such as events on the noise spread. There is no check on the data to ascertain whether the profile of the velocity interface calculated by this method is real or spurious. Future high resolution studies in the desert environment should avoid the delay time method. The inherent uncertainty in estimating the survey parameters restricts the method to the study of deep, large targets, such as major fault or fold structures. The method provides precision but not accuracy in locating shallow refracting targets.

The optimum offset reflection profiling technique is not suited for desert environments. Optimum windows have not been found to exist in where water is not standing on the surface. In order for optimum windows to exist there must be water saturated, fine grained clayey soil at the surface. Increasing survey parameters, such as the geophone offset distance and the strength of the energy source may yield an optimum window for deeper reflectors, but will not assist in identifying reflections of shallow targets. This technique
does have the advantage of requiring recognition of reflection hyperbolas in the noise spread.

The technique best suited for the desert environment was found to be the refraction profiling method. The method is easy to use and yields an easily interpreted cross section of the subsurface velocity structure. The method is unavoidably low in resolution and is blind to the bases of beds which propagate waves more rapidly than underlying beds. A properly designed refraction survey will provide useful, accurate information on the subsurface velocity structure.
REFERENCES CITED


Kearey, p., and Brooks, M., An Introduction to Geophysical


APPENDIX : Figures A1-A19
10 HERTZ GEOPHONE RESPONSE CURVES

100 HERTZ GEOPHONE RESPONSE CURVES

Figure A1
KEY for High Pass Filter Frequency Response Graph

1 7 Hz Butterworth
2 8 Hz ChebyShev
3 15 Hz Bessel
4 15 Hz Butterworth
5 20 Hz ChebyShev
6 35 Hz Bessel
7 30 Hz Butterworth
8 40 Hz ChebyShev
9 75 Hz Bessel
10 70 Hz Butterworth

BISON 8012A SEISMOGRAPH ANALOG FILTER FREQUENCY RESPONSE CURVES

Figure A2
NOTCH FILTER FREQUENCY RESPONSE

BISON 8012A SEISMOGRAPH ANALOG FILTER FREQUENCY RESPONSE CURVES

Figure A3
LOW PASS FILTER FREQUENCY RESPONSE

KEY for Low Pass Filter Group Delay Graph & Frequency Response Graph

1  100 Hz Butterworth
2  100 Hz Bessel
3  175 Hz ChebyShev
4  200 Hz Butterworth
5  200 Hz Bessel
6  375 Hz ChebyShev
7  475 Hz Butterworth
8  440 Hz Bessel
9  825 Hz ChebyShev
10 1000 Hz Butterworth

BISON 8012A SEISMOGRAPH ANALOG FILTER FREQUENCY RESPONSE CURVES

Figure A4
Figure A5
Noise test: Site #1
Figure A6
Noise test: Site #3
Figure A7
Noise test: Site #1
Figure A8
Optimum offset reflection profile
Figure A9
Noise test: Site #2
Figure A10

Noise test: Site #2 with 100 foot offset
Figure A11
Noise test: Site #4
Figure A12
Noise test: Site #5
Figure A13
Noise test: Site #6
Figure A14
Noise test: Site #7
Figure A15
Noise test: Site #8
Figure A16
Site #8  Reflection profile, Part 1
Figure A17

Site # 8 Reflection profile, Part 2
Figure A18

Site #8 Reflection profile, Part 3
SITE NUMBER EIGHT REFRACTION LINE

Figure A19