BASIC AND APPLIED RESEARCH IN THE EARTH SCIENCES

DISTANCE ATTENUATION OF RESPONSE SPECTRA FROM UNDERGROUND NUCLEAR DETONATIONS

BY
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JULY 1973

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Prepared for the U. S. ATOMIC ENERGY COMMISSION
NEVADA OPERATIONS OFFICE
Contract No. AT(29-2)-1163

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Available from the
National Technical Information Service
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Printed copy price: }	1 - 50 pages	\$4.00
	51 - 150 pages	\$5.45
	Microfiche	\$0.95

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ABSTRACT

Response spectral data covering the period range 0.05 to 2.469 seconds are analyzed using the statistical model of analysis of covariance to determine distance scaling exponents. Data grouped according to two event areas, Pahute Mesa and Yucca Flat, are analyzed separately and as a combined sample. The analysis shows that the distance scaling exponents are period dependent and range in value from approximately -1.0 for periods greater than 1.0 second to approximately -1.5 at 0.10 seconds. The average deviation from the expected value of data for 13 stations is computed. It is shown that most stations consistently deviate from the expected value and that at certain stations and periods, the average deviations are as much as a factor of 5 above or a factor of 4 below the expected value.

CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

The objective of this research report is to show how seismic waves generated by underground nuclear detonations attenuate with distance. A statistical technique known as covariance analysis is employed to determine distance scaling exponents as a function of period using 5% damped pseudo relative velocity spectra derived from recorded ground motion velocity.

1.2 OVERVIEW

The propagation of seismic energy generated from an underground nuclear detonation is a very complex process. Energy from essentially a point source radiates in all directions and attenuates due to geometrical spreading of the wave front. At the interface of various near surface, crustal and upper mantle layers, the amplitude, direction of propagation, and spectral composition are altered by reflection and refraction. In addition, wave conversion occurs at these geologic interfaces with compressional waves converting to shear waves and vice versa. Some of the energy impinging at the earth's surface is converted to a surface wave which subsequently propagates in a channel bound by the surface of the earth. Frequency dependent energy loss due to inelastic effects also occur.

The seismic wave train observed at a recording station, therefore, depends on both the physical phenomena associated with wave propagation and the structure and physical properties of the earth between the source and receiver. In most practical situations, information on the earth's structure and properties is either unknown or known in gross detail only.

However, in such circumstances, much can be learned about the propagation of seismic waves by analyzing observed seismograms which are, in effect, "exact solutions" to particular wave propagation problems.

As might be expected on the basis of the foregoing discussion, seismograms are complex functions of amplitude and time. The duration of significant motion varies from a few seconds near ground zero to several minutes at distances of a few hundred kilometers. All seismograms exhibit oscillatory motion over a wide range of frequencies with the dominant spectral composition being a function of device yield, distance from detonation point, type of motion, and local geologic configuration.

A primary use of ground motion predictions is in assessing the response of structures to nuclear generated seismic disturbances. Since structures exhibit the phenomenon of resonance and damped oscillatory motion, it is desirable to extract these important characteristics. From recorded ground motion a quantity called a response spectrum is derived from ground motion data and meets this requirement. It corresponds to the peak response of an ensemble of simple harmonic oscillators (mass-spring systems with viscous damping) to an observed ground motion velocity. Velocity recordings are routinely processed to obtain 40 spectral values in the period range of 0.05 to 2.469 seconds with a damping value of 5% of critical.

1.3 PREVIOUS REGRESSION ANALYSES

The attenuation of PSRV with distance was previously examined using a general statistical model involving both yield (W) and distance (R) as independent variables in the following power law relationship:

$$\widehat{\text{PSRV}}_i = A_i W^{B1_i} R^{B2_i} ; \sigma_i$$

where

i = period index ($i = 1, 2, \dots, 40$)

$\widehat{\text{PSRV}}_i$ = expected value

A_i = amplitude coefficient

$B1_i$ = yield scaling exponent

$B2_i$ = distance scaling exponent

σ_i = geometric standard error of estimate

Sample estimates of the above constants for Nevada Test Site events detonated in Pahute Mesa (Lynch, 1969) are shown in Table 1.1. Estimates for detonations in Yucca Flat (Lynch and Williams, 1972), are shown in Table 1.2. Plots of the distance scaling exponents and geometric standard errors of estimate are shown respectively in Figures 1.1 and 1.2.

Distance scaling exponents derived from both Pahute Mesa and Yucca Flat event data have approximately the same trend over the entire period range. Yucca Flat shows greater attenuation for periods greater than approximately 0.2 seconds. Both event data sets exhibit the greatest attenuation between periods of 0.10 to 0.20 seconds. For periods less than about 0.15 seconds, the attenuation rate decrease. This feature contradicts theory; therefore, the exponents in this period range are conditionally acceptable at this time. Poor signal-to-noise ratios of short period seismic energy is the probable cause of the discrepancy.

With the exception of a few periods, the analysis indicates that the standard errors of estimate (σ) for Pahute Mesa data are greater than those for Yucca Flat data. The greatest differences in σ occur at the short period end of the spectrum.

TABLE 1.1

REGRESSION PARAMETERS FOR PAHUTE MESA DATA SAMPLE

Period	Amplitude Coefficient	Yield Exponent	Distance Exponent	Standard Error of Estimate
.050	2.69E+00	.491	-1.340	3.06
.055	3.69E+00	.479	-1.395	2.87
.061	5.00E+00	.483	-1.447	2.85
.067	6.76E+00	.474	-1.486	2.84
.075	8.87E+00	.463	-1.515	2.88
.082	1.08E+01	.457	-1.533	2.85
.091	1.18E+01	.468	-1.546	2.98
.101	1.29E+01	.475	-1.558	2.96
.111	1.53E+01	.480	-1.582	2.97
.123	1.89E+01	.480	-1.600	2.98
.136	2.18E+01	.468	-1.591	3.02
.150	2.48E+01	.466	-1.597	2.98
.166	2.06E+01	.478	-1.555	2.87
.183	2.01E+01	.479	-1.533	2.84
.203	1.67E+01	.480	-1.469	2.82
.224	1.21E+01	.498	-1.399	2.82
.248	1.21E+01	.509	-1.395	2.72
.274	1.10E+01	.504	-1.354	2.65
.302	1.13E+01	.508	-1.342	2.62
.334	8.65E+00	.528	-1.303	2.66
.369	6.82E+00	.555	-1.263	2.62
.408	7.15E+00	.572	-1.276	2.62
.451	6.40E+00	.583	-1.255	2.49
.499	3.63E+00	.601	-1.150	2.54
.551	2.96E+00	.632	-1.134	2.54
.609	2.93E+00	.636	-1.134	2.59
.673	2.76E+00	.645	-1.121	2.55
.744	2.02E+00	.665	-1.085	2.54
.822	1.59E+00	.698	-1.060	2.52
.908	1.72E+00	.713	-1.083	2.54
1.004	2.08E+00	.732	-1.133	2.62
1.110	1.83E+00	.748	-1.128	2.69
1.226	1.56E+00	.771	-1.129	2.75
1.355	1.66E+00	.775	-1.160	2.74
1.498	1.61E+00	.753	-1.145	2.74
1.655	1.59E+00	.749	-1.143	2.78
1.829	1.96E+00	.732	-1.168	2.76
2.022	2.35E+00	.719	-1.181	2.72
2.234	2.37E+00	.701	-1.165	2.72
2.469	2.40E+00	.699	-1.137	2.72

TABLE 1.2

REGRESSION PARAMETERS FOR YUCCA FLAT DATA SAMPLE

Period	Amplitude Coefficient	Yield Exponent	Distance Exponent	Standard Error of Estimate
.050	1.471E-01	.918	-1.358	2.190
.055	1.681E-01	.924	-1.380	2.175
.061	2.002E-01	.921	-1.398	2.186
.067	2.349E-01	.926	-1.416	2.185
.075	2.847E-01	.939	-1.450	2.159
.082	3.071E-01	.957	-1.462	2.129
.091	3.681E-01	.965	-1.479	2.151
.101	4.474E-01	.973	-1.504	2.107
.111	5.793E-01	.968	-1.534	2.094
.123	7.288E-01	.967	-1.554	2.081
.136	8.338E-01	.967	-1.553	2.086
.150	1.075E+00	.954	-1.570	2.059
.166	1.160E+00	.934	-1.546	2.035
.183	1.518E+00	.917	-1.562	2.015
.203	1.996E+00	.882	-1.553	1.977
.224	2.445E+00	.826	-1.516	1.960
.248	3.265E+00	.791	-1.521	1.945
.274	3.775E+00	.757	-1.495	1.956
.302	3.633E+00	.759	-1.464	2.039
.334	2.913E+00	.786	-1.421	2.031
.369	2.700E+00	.791	-1.385	2.019
.408	2.176E+00	.807	-1.332	2.039
.451	2.097E+00	.818	-1.325	2.027
.499	2.163E+00	.834	-1.341	2.041
.551	1.850E+00	.888	-1.341	2.083
.609	1.416E+00	.934	-1.319	2.157
.673	9.882E-01	.975	-1.275	2.141
.744	7.946E-01	1.012	-1.267	2.197
.822	6.262E-01	1.069	-1.268	2.299
.908	4.294E-01	1.139	-1.239	2.365
1.004	3.172E-01	1.192	-1.209	2.422
1.110	2.421E-01	1.245	-1.191	2.445
1.226	2.381E-01	1.250	-1.200	2.459
1.355	2.172E-01	1.229	-1.182	2.461
1.498	2.581E-01	1.186	-1.197	2.476
1.655	2.990E-01	1.170	-1.223	2.445
1.329	2.282E-01	1.237	-1.200	2.530
2.022	1.492E-01	1.340	-1.181	2.672
2.234	1.079E-01	1.409	-1.174	2.810
2.469	6.535E-02	1.450	-1.108	2.884

Figure 1.1 Distance Exponents from Regression Analysis

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Figure 1.2 Standard Error of Estimate from Regression Analysis

1.4 ANALYSIS OF COVARIANCE MODEL

In the general regression analysis, the yield of events is explicitly accounted for in the regression equation. As the yield is the same for all stations recording a single event, the attenuation of PSRV with distance for each event can be analyzed using the single independent variable regression equation

$$\widehat{\text{PSRV}}_{ij} = A_{ij} R^{B_{2ij}} ; \sigma_{ij}$$

where

i = period index

j = event subscript

$\widehat{\text{PSRV}}_{ij}$ = expected value of PSRV for event j at period i

A_{ij} = amplitude coefficient for event j at period i

B_{2ij} = distance scaling exponent for event j at period i

σ_{ij} = standard error of estimate for event j at period i

The yield of the event is implicitly accounted for in the amplitude coefficient, A_{ij} . Thus, with the above equation, the attenuation of PSRV with distance can be examined independent of source conditions. Using this approach, one will obtain at each period a statistical estimate of the distance scaling exponent for each separate event. The exponents will differ from event to event because of uncertainty associated with statistical estimates based on small data samples.

If one assumes a single distance scaling exponent at each period, a statistical model of the following form results:

$$\widehat{\text{PSRV}}_{ij} = A_{ij} R^{B_{2i}} ; \sigma_i$$

where

i = period index

j = event subscript

A_{ij} = amplitude coefficient for event j at period i

B_{2i} = distance scaling exponent common to all events at period i

σ_i = standard error of estimate common to all events at period i

The unique characteristics of each event, i.e., yield and source parameters, will again be implicitly accounted for in the coefficient A_{ij} . The advantage of this approach is that the statistical estimate of the distance scaling exponent, B_{2i} , is obtained from a large data sample and is thus a better statistical estimate.

The model described above is known as analysis of covariance (Lynch, 1971). This statistical model was used in this research to analyze the relationship between PSRV and yield for data samples recorded at individual stations.

1.5 REPORT ORGANIZATION

In Chapter 2, analysis of covariance with distance is applied separately to events occurring in Pahute Mesa and Yucca Flat areas at the Nevada Test Site. Chapter 3 considers a combined Pahute Mesa and Yucca Flat sample. From the covariance analysis results of Chapter 3, the average deviations of PSRV recorded at individual stations are analyzed in Chapter 4. Conclusions are given in Chapter 5.

CHAPTER 2

COVARIANCE ANALYSIS OF INDIVIDUAL PAHUTE MESA AND YUCCA FLAT DATA SAMPLES

2.1 DATA SAMPLE

This chapter will consider the separate analysis of data samples from events detonated at the Pahute Mesa and Yucca Flat areas of the Nevada Test Site. The names of the events and number of recording stations for both event areas are given in Table 2.1. The Pahute Mesa data sample consists of 21 events and 295 recordings. The Yucca Flat sample has 12 events and 103 recordings. With few exceptions, the data were recorded within the distance range of 10 to 200 km.

Response spectra (PSRV, 5% damping) were derived from the two horizontal components of recorded velocity. In greater than 98% of the recordings, the orientations of the seismic instruments to the nuclear detonations were in the radial and transverse directions.

2.2 ANALYSIS RESULTS

The distance scaling exponents obtained from covariance analysis of the Pahute Mesa and Yucca Flat data samples are tabulated in Table 2.2 and shown graphically in Figure 2.1. In general, the exponents show the same trend across the period range. For periods greater than 0.20 seconds, the Yucca Flat generated seismic data attenuate more rapidly than the Pahute Mesa seismic data, except at 2.469 seconds. The greatest relative difference occurs at approximately 0.70 seconds. Again, the decrease in distance scaling exponents noted in Chapter 1 for periods less than approximately 0.10 seconds occurs and is attributed to unfavorable signal-to-noise characteristics of the velocity recordings.

TABLE 2.1

EVENTS AND NUMBER OF RECORDING STATIONS

Pahute Mesa Events	Number of Recording Stations	Yucca Flat Events	Number of Recording Stations
Buteo	5	Bronze	5
Rex	13	Buff	4
Duryea	8	Lampblack	5
Chartreuse	8	Purple	3
Halfbeak	3	Piranha	5
Greeley	11	Dumont	9
Scotch	6	Tan	6
Knickerbocker	7	Commodore	6
Cabriolet	4	Zaza	11
Stinger	13	Lanpher	7
Scroll	3	Clarksmobile	17
Boxcar	27	Calabash	<u>25</u>
Rickey	23	12 Events	103
Chateaugay	15		
Sled	14		
Schooner	14		
Benham	13		
Purse	21		
Jorum	29		
Pipkin	12		
Handley	<u>46</u>		
21 Events	295		

TABLE 2.2

DISTANCE EXPONENTS AND STANDARD ERRORS OF
ESTIMATE FOR PAHUTE MESA AND YUCCA FLAT

Period	<u>Pahute Mesa</u>		<u>Yucca Flat</u>	
	Distance Exponent	Standard Error of Estimate	Distance Exponent	Standard Error of Estimate
.050	-1.233	2.11	-1.319	1.76
.055	-1.263	2.12	-1.348	1.69
.061	-1.284	2.11	-1.369	1.67
.067	-1.300	2.09	-1.396	1.65
.075	-1.347	2.10	-1.430	1.63
.082	-1.413	2.13	-1.456	1.61
.091	-1.462	2.13	-1.489	1.65
.101	-1.493	2.14	-1.527	1.67
.111	-1.527	2.19	-1.539	1.65
.123	-1.545	2.22	-1.509	1.68
.136	-1.542	2.26	-1.474	1.71
.150	-1.530	2.25	-1.490	1.69
.166	-1.502	2.17	-1.459	1.61
.183	-1.479	2.15	-1.485	1.60
.203	-1.422	2.13	-1.479	1.59
.224	-1.406	2.10	-1.459	1.59
.248	-1.407	2.09	-1.447	1.57
.274	-1.363	2.05	-1.445	1.57
.302	-1.332	2.03	-1.443	1.57
.334	-1.285	2.02	-1.403	1.59
.369	-1.237	2.02	-1.376	1.62
.408	-1.238	2.01	-1.329	1.69
.451	-1.217	2.00	-1.317	1.69
.499	-1.140	1.99	-1.345	1.71
.551	-1.119	1.98	-1.326	1.79
.609	-1.078	1.99	-1.287	1.84
.673	-1.044	2.03	-1.243	1.83
.744	-1.012	2.03	-1.289	1.88
.822	-1.008	2.02	-1.298	1.91
.908	-1.018	2.04	-1.214	1.92
1.004	-1.005	2.08	-1.115	1.96
1.110	-1.000	2.13	-1.060	1.99
1.226	- .991	2.17	-1.037	2.03
1.355	- .988	2.21	-1.011	2.04
1.498	- .997	2.25	-1.015	1.95
1.655	- .997	2.31	-1.068	1.85
1.829	-1.003	2.34	-1.096	1.91
2.022	-1.005	2.29	-1.058	2.07
2.234	-1.027	2.23	-1.005	2.15
2.469	-1.015	2.21	-1.892	2.20

Figure 2.1 Distance Exponents from Covariance Analysis

A comparison of the data in Figure 2.1 with the results from regression analysis given in Figure 1.1 shows approximately the same trend across the period range. The regression analysis exponents are less at periods around 0.13 seconds and are greater for periods greater than about 1.0 seconds than the covariance exponents.

A plot of the standard errors of estimate (σ) from the Pahute Mesa and Yucca Flat covariance analyses is given in Figure 2.2. At all periods, the σ values for Pahute Mesa exceed those for Yucca Flat. The Yucca Flat σ values range from 1.57 to 2.20 while the values for Pahute Mesa range from 1.97 to 2.33. The Pahute Mesa data show less relative variation across the period range than does Yucca Flat values.

Comparison of σ values from covariance with value from regression analysis (Figure 1.2) shows a significant reduction in variance associated with the covariance σ 's throughout the entire period range. Maximum and minimum values from each analysis for each event area are summarized below:

	Pahute Mesa		Yucca Flat	
	Max σ	Min σ	Max σ	Min σ
Covariance	2.33	1.97	2.20	1.57
Regression	3.06	2.54	2.88	1.94

The reduction in σ values can be attributed to the elimination of variance associated with source parameters.

2.3 DISCUSSION

The above analyses indicate different results between test areas and between types of analysis. Differences in distance scaling exponents

Figure 2.2 Standard Error of Estimate from Covariance Analysis

for the two test areas are preserved in both regression and covariance analysis. For instance, Yucca Flat exponents are more negative at most periods below about 0.20 seconds than Pahute Mesa exponents. Covariance analysis does, however, give less negative exponents at periods greater than approximately 1.0 second.

From a practical standpoint, small differences in exponents are probably not significant. For instance, if one compares the relative attenuation above and below some reference distance, say 50 km, for differences in scaling exponents of the order of 0.1, the result produces small differences in attenuation. This can be shown by using the formula

$$A = \left(\frac{R}{R_r} \right)^{B_2}$$

where

R = distance

R_r = reference distance

Results for R_r = 50 km over the distance range of 10 to 250 km for exponents of -1.2 and -1.3 are as follows:

<u>Distance Exponents</u>	<u>R</u>	<u>A</u>
-1.2	10	6.8986
-1.3	10	8.10
-1.2	250	.1449
-1.3	250	.1234

The relative difference in A for distance factors of 5 above and below the reference distance gives ratios in A of .85 to 1.17 for a change of 0.1 in distance scaling exponent. When these ratios are compared with the standard errors of estimate (which range from 1.57 for Yucca Flat covariance

analysis to 3.06 for Pahute Mesa regression analysis) then small differences in distance scaling exponents are not significant from a practical view point.

CHAPTER 3

COVARIANCE ANALYSIS OF COMBINED DATA SAMPLE

3.1 COMBINING SUBSAMPLES

In a previous analysis, Lynch and Williams (1972) showed that yield scaling exponents derived from Pahute Mesa and Yucca Flat data samples are significantly different due mainly to the emplacement media for the two test areas. Detonations at Pahute Mesa occur primarily in rhyolite and interbedded tuffs while those at Yucca Flat occur in alluvium or tuff (wet or dry) depending on the depth of burial of the device. Thus, it is not feasible to combine data samples from these two areas in regression analyses since it is a basic assumption in that type of analysis that subsamples come from the same parent population and follow the same scaling laws.

The two data samples can be combined to examine attenuation of PSRV data with distance in covariance analysis since the yield of the device and source media properties do not appear explicitly in the statistical equations. This is the major advantage of this type of analysis. The only assumption made in covariance analysis is that the relationship between PSRV and distance must be the same for the two subsamples. The fact that the yield scaling relationships differ for the two subsamples is of no consequence.

3.2 COVARIANCE ANALYSIS RESULTS

Distance scaling exponents and standard errors of estimate derived from covariance analysis with distance for the combined Pahute Mesa and Yucca Flat data samples are tabulated in Table 3.1. The distance scaling exponents are shown graphically in Figure 3.1. The general shape of this

TABLE 3.1

COMBINED PAHUTE MESA AND YUCCA FLAT ANALYSIS

Period	Distance Exponent	Standard Error of Estimate
.050	-1.242	2.02
.055	-1.270	2.00
.061	-1.293	1.99
.067	-1.312	1.98
.075	-1.355	1.98
.082	-1.407	1.99
.091	-1.450	2.00
.101	-1.486	2.02
.111	-1.515	2.05
.123	-1.518	2.08
.136	-1.506	2.12
.150	-1.505	2.11
.166	-1.477	2.03
.183	-1.465	2.02
.203	-1.428	1.99
.224	-1.409	1.98
.248	-1.407	1.97
.274	-1.375	1.93
.302	-1.353	1.92
.334	-1.316	1.91
.369	-1.273	1.92
.408	-1.258	1.93
.451	-1.238	1.92
.499	-1.194	1.92
.551	-1.177	1.93
.609	1.137	1.96
.673	-1.107	1.98
.744	-1.094	1.99
.822	-1.090	2.00
.908	-1.078	2.01
1.004	-1.044	2.04
1.110	-1.026	2.08
1.226	-1.017	2.13
1.355	-1.009	2.16
1.498	-1.012	2.17
1.655	-1.025	2.19
1.829	-1.033	2.22
2.022	-1.028	2.23
2.234	-1.027	2.20
2.469	- .990	2.20

Figure 3.1 Distance Exponents from Covariance Analysis of the Total Sample

curve is very similar to the curves obtained from the individual analyses of the subsamples. The greatest attenuation ($R^{-1.518}$) occurs at a period of 0.123 second. Between periods greater than approximately 0.15 seconds to 1 second, the distance exponent increase in a regular manner. For periods greater than 1.0 second, the exponents are essentially constant and approximately equal to -1.0.

The standard errors of estimate for the combined sample are shown graphically in Figure 3.2.

3.3 COMPARISON OF COMBINED AND INDIVIDUAL SAMPLES

Figure 3.3 gives a plot of distance exponents for the combined and individual Pahute Mesa and Yucca Flat data samples. As would be expected, the exponents from the combined data sample fall between those from the individual samples over most of the period range. Again, as might be expected from the fact that the Pahute Mesa data sample is approximately twice the size of the Yucca Flat sample, the combined sample exponents are more nearly like those for Pahute Mesa.

Plots of the standard errors of estimate are shown in Figure 3.4. The values for the combined sample fall between those of the individual samples but are closer to the Pahute Mesa values for the same reasons as stated above.

Figure 3.2 Standard Error of Estimate from Covariance Analysis of the Total Sample

Figure 3.3 Comparison of Distance Exponents

Figure 3.4 Comparison of Standard Errors of Estimate

CHAPTER 4

STATION DEVIATION ANALYSIS

4.1 INTRODUCTION

The purpose of this chapter is to examine the deviation of PSRV spectra at 13 recording sites from the predicted value based on covariance analysis. Since the first ground motion measurements, it has been noted that some stations consistently record ground motion above or below what might be expected based upon the distance from the detonation point. Large frequency dependent relative ground motion amplification due to the local geologic configuration has been documented for a number of sites by deploying adjacent alluvium and hardrock stations. Theoretical models have been developed which describe the relative body and surface wave amplification as a function of period due to resonance in the surface layers (Murphy and Davis, 1969, Murphy, et al., 1971). The present covariance analysis examines the average station deviation as a function of period. These data estimate the effect of the total transmission path between NTS and the individual recording stations.

4.2 MULTI-EVENT RECORDING STATION

In order to insure an adequate data sample in determining average station deviation, a minimum of 5 recorded events at a station was used as a selection criterion. This resulted in the selection of 13 recording stations which are listed in Table 4.1 together with the number of recorded events. The smallest data sample is associated with the Alamo hardrock station while the largest sample is associated with the station at the University of Nevada at Las Vegas (SE-6). The total number of PSRV spectra for these 13 stations is 375 (190 radial components and 185 transverse components). This is slightly less than half of the total data sample which

TABLE 4.1

MULTI-EVENT RECORDING STATIONS

Recording Stations	Number of Events Recorded	
	R Component	T Component
Alamo (Alluvium)	13	13
Alamo (Hardrock)	6	5
Beatty (Alluvium)	16	16
Beatty (Hardrock)	15	15
Control Point #1 (CP-1), NTS	9	9
Administration Building, NRDS	15	13
Mercury, Q-25	13	12
Indian Springs, SE-2	14	14
Kyle Canyon, SE-4	10	10
University of Nevada, Las Vegas, SE-6	25	23
Squires Park, Las Vegas	13	13
Tonopah (Church)	22	21
Tonopah (Silver Queen Motel)	19	21

indicates the importance of this 13 station subsample. The locations of these stations with respect to the Pahute Mesa and Yucca Flat event areas at the Nevada Test Site are shown in Figure 4.1.

4.3 COMPUTATIONAL FORMULAS

The geometric deviation is defined as the ratio of observed to predicted PSRV. Let the subscripts i, j, k and l refer respectively to period, event, station and component. Then the geometric deviation, d_{ijkl} , is given by

$$d_{ijkl} = \frac{\text{PSRV}_{ijkl}}{\widehat{\text{PSRV}}_{ijkl}}$$

where PSRV_{ijkl} = observed value

$$\widehat{\text{PSRV}}_{ijkl} = A_{ijl} R_{jk}^{B_i}; \text{ predicted geometric mean value (from covariance analysis)}$$

For a particular period, i, and component, l, the geometric mean deviation at station k is defined as the n_j^{th} root of the product of deviations from all events.

$$\bar{d}_{ikl} = \left(\prod_{j=1}^{n_j} d_{ijkl} \right)^{1/n_j}$$

(n_j = number of events recorded)

The scatter of the individual deviation about the geometric station mean is given by the geometric standard error of estimate

$$\sigma_{ikl} = \log^{-1} \left(\left[\frac{1}{n_j - 1} \left\{ \sum_{j=1}^{n_j} \left(\log \frac{d_{ijkl}}{\bar{d}_{ikl}} \right)^2 \right\} \right]^{\frac{1}{2}} \right)$$

Figure 4.1 Locations of Multi-Event Recording Stations

The $\bar{d}_{ikl}$ is interpreted as the average factor above ($\bar{d}_{ikl} > 1$) or below ($\bar{d}_{ikl} < 1$) the mean prediction from covariance analysis. The interval defined by $\bar{d}_k \sigma_k$ and $\bar{d}_k / \sigma_k$ defines the dispersion of observed deviations about the station mean value.

4.4 ANALYSIS RESULTS

The geometric mean deviations for the 13 stations are presented graphically in Figure 4.2 and are listed in the Appendix (Tables A.1 to A.13) together with the computed standard errors of estimate. Examination of the graphical data indicates that both components of stations Alamo hard-rock and NRDS Administration Building and the radial component of Beatty alluvium, consistently recorded near the general covariance prediction across the entire period range. The maximum mean deviation of 5.39 occurs on the radial component for the Tonopah Motel station while the minimum mean deviation of 0.248 occurs on the transverse component for Beatty hardrock. Stations Beatty hardrock, CP-1 and SE-4 show mean deviations below 1.0 for both components over the entire period range. The same is true for the Mercury station (Q-25) except for a few periods on the transverse component. The Las Vegas stations, Squires Park and SE-6, have mean deviations on the order of 2 to 3 at long periods which encompasses the period range of fundamental mode resonance of many highrise structures in Las Vegas. Thus, the above data indicate that consistent deviation from the average is common and that the deviation can be quite large.

The maximum and minimum values of the geometric standard errors of estimate, σ_{ikl} , for each station and component are summarized in Table 4.2 for comparison with the maximum and minimum geometric standard errors of estimate, 2.02 and 1.909 respectively, from covariance analysis with distance from the combined Pahute Mesa and Yucca Flat data sample. As can be seen

Figure 4.2 Geometric Mean Deviation for 13 Stations

(continued)

Figure 4.2 Geometric Mean Deviation for 13 Stations

TABLE 4.2

MAXIMUM AND MINIMUM STANDARD ERROR
OF ESTIMATE AT EACH STATION

Station	Radial		Transverse	
	Maximum	Minimum	Maximum	Minimum
Alamo (Alluvium)	1.869	1.261	1.910	1.258
Alamo (Hardrock)	3.097	1.606	3.473	1.977
Beatty (Alluvium)	1.950	1.493	1.966	1.560
Beatty (Hardrock)	1.962	1.336	1.755	1.399
Control Point #1 (CP-1), NTS	1.670	1.251	1.895	1.150
Administration Building, NRDS	1.613	1.329	1.575	1.149
Mercury, Q-25	2.560	1.550	2.245	1.554
Indian Springs, SE-2	1.590	1.243	1.545	1.237
Kyle Canyon, SE-4	1.560	1.165	1.596	1.194
University of Nevada, Las Vegas, SE-6	1.715	1.407	1.744	1.423
Squires Park, Las Vegas	1.956	1.147	1.883	1.142
Tonopah (Church)	2.200	1.242	2.063	1.270
Tonopah (Silver Queen Motel)	1.917	1.298	1.979	1.270

from Table 4.2, and as would be expected, the individual station σ_{ikl} values are in general smaller than the total sample σ values. Of the 26 station maximum σ_k values, 6 exceed that of the total sample. Only one minimum value exceeds the total sample minimum. Slightly less than half (45%) of all σ_{ikl} listed in the Appendix (Tables A.1 to A.13) have values less than 1.5 and 88% have values less than the 1.902 minimum from the total data sample analysis.

4.5 MODIFIED SAMPLE

The results of the previous section indicate that the statistical covariance model for the expected value should have the form

$$\widehat{PSRV}_{ijkl} = A_{ijl} R_{jk}^{B_i} \bar{d}_{ijk} ; \sigma_{ijk}$$

This form reflects the fact that stations deviate consistently from the expected value, as given by the term $A_{ijl} R_{jk}^{B_i}$. An analysis utilizing the above equation will not be attempted for this report. However, it is of interest to determine the effect of removing $\bar{d}_{ijk}$ from the 13 station data samples since this subsample represents near $\frac{1}{2}$ of the total sample. The magnitude of the $\bar{d}_{ijk}$ and the size of the subsample indicate a possible large bias in the covariance analysis. Consequently, the 13 station subsample of observed $PSRV_{ijkl}$ were divided by the appropriate $\bar{d}_{ijk}$, combined with all other station data, and analyzed using the covariance with distance model.

The distance scaling exponents and geometric standard errors of estimate for the modified sample are listed in Table 4.3. The distance scaling exponents are shown graphically in Figure 4.3 together with the exponents derived from the individual Pahute Mesa and Yucca Flat samples without modification. As is evident, the exponents from the modified sample

TABLE 4.3

DISTANCE EXPONENTS AND STANDARD ERROR OF
ESTIMATE FOR THE MODIFIED SAMPLE

Period	Distance Exponent	Geometric Standard Error of Estimate
.050	-1.333	1.749
.055	-1.359	1.740
.061	-1.375	1.728
.067	-1.390	1.704
.075	-1.428	1.693
.082	-1.472	1.689
.091	-1.508	1.676
.101	-1.538	1.670
.111	-1.571	1.673
.123	-1.565	1.684
.136	-1.556	1.706
.150	-1.560	1.705
.166	-1.538	1.687
.183	-1.533	1.684
.203	-1.509	1.668
.224	-1.494	1.661
.248	-1.494	1.657
.274	-1.470	1.640
.302	-1.443	1.629
.334	-1.413	1.600
.369	-1.376	1.601
.408	-1.362	1.594
.451	-1.338	1.585
.499	-1.309	1.580
.551	-1.295	1.588
.609	-1.263	1.611
.673	-1.242	1.628
.744	-1.240	1.643
.822	-1.227	1.634
.908	-1.204	1.631
1.004	-1.169	1.640
1.110	-1.151	1.662
1.226	-1.141	1.668
1.355	-1.129	1.687
1.498	-1.126	1.675
1.655	-1.129	1.690
1.829	-1.128	1.723
2.022	-1.121	1.743
2.234	-1.122	1.752
2.469	-1.082	1.775

Figure 4.3 Distance Exponents for Individual Event Samples and the Modified Sample

closely approximate those from Yucca Flat except for periods greater than approximately 1.0 second. Below 1.0 second, the modified sample gives slightly more negative exponents than do either of the other samples analyzed.

The geometric standard errors of estimate, σ_i , given in Table 4.3, range from 1.580 to 1.775 which are significantly below the 1.909 to 2.230 range from the unmodified total sample. The values are shown graphically in Figure 4.4. Since slightly less than half the total sample was modified by removing $\bar{d}_{ijk}$ values, a greater reduction in σ values could be obtained if means were available for estimating $\bar{d}$ for the unmodified part of the sample. The self-imposed criterion of a minimum of 5 spectra at a station can be relaxed to possibly 2 spectra so as to increase the number of stations for which $\bar{d}_{ijk}$ can be computed.

Figure 4.4 Standard Error of Estimate from the Modified Sample

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 SUMMARY

The objective of this report was to determine attenuation with distance of response spectral data using a statistical technique known as covariance analysis. The data sample consists of two horizontal response spectra at 40 periods derived from 398 velocity recordings from 21 Pahute Mesa and 12 Yucca Flat detonations.

The statistical equation for the expected value is

$$\widehat{\text{PSRV}}_{ijkl} = A_{ijl} R_{jk}^{B_i}$$

where i, j, k, l refer respectively to period, event, station and component. A_{ijl} is a constant particular to event j , R_{jk} is the distance from event j to station k , and B_i is the distance scaling exponent. The dispersion of observations about the expected value, $\widehat{\text{PSRV}}_{ijkl}$, is given by the geometric standard error of estimate, σ_i .

Individual data samples from Pahute Mesa and Yucca Flat were analyzed separately and then analyzed as a combined sample. From the results of the combined data sample analysis, deviations of data recorded at 13 stations were analyzed to determine the geometric mean deviation, $\bar{d}_{ikl}$, from the expected value, $\widehat{\text{PSRV}}_{ijkl}$. In addition, the geometric standard error of estimate, σ_{ikl} , which measures the dispersion of data about $\bar{d}_{ikl}$, was computed.

5.2 OBSERVATIONS AND CONCLUSIONS

Distance scaling exponents from the Pahute Mesa and Yucca Flat individual analysis show approximately the same trend across the period range.

Distance exponents range from about -1.55 at 0.1 second period to -1.0 at periods greater than 1.0 second. The Yucca Flat exponents are, however, in general more negative for periods greater than 0.2 seconds. This same trend was noted in a previous analysis using a more general regression equation which included yield as an independent variable, i.e., $\widehat{PSRV}_i = A_i W^{B_{1i}} R^{B_{2i}}$.

The geometric standard errors of estimate, σ_i , for the Yucca Flat sample are smaller across the period range than those from Pahute Mesa. However, the σ_i from the covariance analysis were smaller than those from general regression analysis which included yield as a variable.

From the combined sample of Pahute Mesa and Yucca Flat data, both the distance scaling exponents and the geometric standard errors of estimate assumed values intermediate between those from the individual samples.

From an observation that certain stations consistently experience ground motion significantly above or below what is expected based on their distance from the event detonation point, an analysis was performed to determine the geometric mean deviation at 13 recording stations. The results verify that most stations do deviate significantly from the expected value. The computed geometric mean deviations ranged from 5.39 at Tonopah Motel to 0.247 at the Beatty hardrock station. Based on these results, it is important that individual station geometric mean deviations be taken into account in statistical analysis models.

A covariance analysis of a modified sample in which the observed $PSRV_{ijk}$ were divided by $\bar{d}_{ijk}$ resulted in distance scaling exponents

similar to those obtained from an individual analysis of the Yucca Flat data sample, except for periods greater than 1.0 second where the modified sample gave slightly more negative values.

From this last analysis, it is concluded that the total sample is probably biased by the relatively large Pahute Mesa sample and by the 13 station subsamples. However, the techniques described in this report permit this bias to be partially removed leading to a better estimate of seismic attenuation with distance.

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APPENDIX

TABLES OF STATION GEOMETRIC MEAN
AND STANDARD ERROR OF ESTIMATE

<u>Station</u>	<u>Table</u>
Alamo (Alluvium)	A.1
Alamo (Hardrock)	A.2
Beatty (Alluvium)	A.3
Beatty (Hardrock)	A.4
Control Point #1 (CP-1), NTS	A.5
Administration Building, NRDS	A.6
Mercury, Q-25	A.7
Indian Springs, SE-2	A.8
Kyle Canyon, SE-4	A.9
University of Nevada, Las Vegas, SE-6	A.10
Squires Park, Las Vegas	A.11
Tonopah (Church)	A.12
Tonopah (Silver Queen Motel)	A.13

TABLE A.1

STATION GEOMETRIC MEAN AND
STANDARD ERROR OF ESTIMATE;
ALAMO (ALLUVIUM)

Period	Radial Component		Transverse Component	
	$\bar{d}_k$	σ_k	$\bar{d}_k$	σ_k
.050	1.387	1.869	1.498	1.905
.055	1.299	1.783	1.420	1.857
.061	1.254	1.753	1.399	1.769
.067	1.249	1.628	1.328	1.684
.075	1.186	1.614	1.281	1.614
.082	1.193	1.578	1.276	1.668
.091	1.281	1.573	1.315	1.608
.101	1.303	1.592	1.404	1.525
.111	1.361	1.575	1.550	1.453
.123	1.395	1.523	1.590	1.577
.136	1.511	1.578	1.674	1.616
.150	1.514	1.639	1.659	1.542
.166	1.573	1.594	1.787	1.555
.183	1.617	1.736	1.870	1.613
.203	1.680	1.750	1.915	1.655
.224	1.740	1.715	2.089	1.724
.248	1.759	1.807	2.332	1.811
.274	1.875	1.737	2.342	1.797
.302	1.956	1.818	2.274	1.833
.334	1.875	1.834	2.319	1.839
.369	2.056	1.641	2.524	1.910
.408	2.054	1.622	2.577	1.850
.451	1.903	1.661	2.329	1.773
.499	1.792	1.645	2.146	1.693
.551	1.887	1.615	2.179	1.669
.609	1.790	1.507	2.261	1.691
.673	1.520	1.439	2.135	1.593
.744	1.332	1.441	1.745	1.657
.822	1.344	1.478	1.652	1.695
.908	1.288	1.575	1.772	1.735
1.004	1.186	1.514	1.434	1.590
1.110	1.149	1.681	1.318	1.588
1.226	1.149	1.749	1.254	1.688
1.355	1.010	1.783	1.247	1.681
1.498	.930	1.738	1.183	1.574
1.655	.933	1.616	1.040	1.413
1.829	.938	1.523	.953	1.401
2.022	.910	1.261	1.034	1.258
2.234	1.031	1.297	1.156	1.346
2.469	.998	1.409	1.209	1.436

TABLE A.2

STATION GEOMETRIC MEAN AND
STANDARD ERROR OF ESTIMATE;
ALAMO (HARDROCK)

Period	Radial Component		Transverse Component	
	$\bar{d}_k$	σ_k	$\bar{d}_k$	σ_k
.050	.815	3.097	.961	2.938
.055	.793	3.090	.933	3.061
.061	.702	2.997	.766	2.944
.067	.671	2.910	.714	2.918
.075	.632	2.938	.660	2.849
.082	.596	2.995	.611	3.024
.091	.582	2.900	.597	2.839
.101	.616	2.709	.601	3.030
.111	.675	2.690	.659	3.221
.123	.698	2.286	.680	3.473
.136	.694	2.370	.731	3.225
.150	.664	2.976	.739	3.154
.166	.807	2.612	.847	2.910
.183	.799	2.636	.812	2.711
.203	.827	2.718	.850	2.905
.224	.938	2.920	.869	3.210
.248	.925	2.825	.908	3.119
.274	.849	2.219	.850	3.328
.302	.861	2.350	.844	2.918
.334	.915	2.278	.987	3.046
.369	1.010	2.296	1.060	3.036
.408	.976	2.325	1.107	3.135
.451	.950	2.321	1.027	2.845
.499	.959	2.597	1.033	2.449
.551	1.028	2.376	1.239	2.355
.609	1.062	2.124	1.134	2.264
.673	.989	2.183	1.010	2.258
.744	.914	1.942	.999	2.229
.822	.846	1.895	1.126	2.074
.908	.845	2.191	1.159	1.977
1.004	.827	2.079	1.097	2.045
1.110	.834	1.932	1.077	2.303
1.226	.778	1.809	.871	2.297
1.355	.754	1.606	.810	2.211
1.498	.700	1.675	.763	2.297
1.655	.660	2.042	.641	2.213
1.829	.642	2.193	.610	2.171
2.022	.569	2.104	.617	2.297
2.234	.597	1.942	.762	2.534
2.469	.581	2.121	.920	2.650

TABLE A.3

STATION GEOMETRIC MEAN AND
STANDARD ERROR OF ESTIMATE;
BEATTY (ALLUVIUM)

Period	Radial Component		Transverse Component	
	$\bar{d}_k$	σ_k	$\bar{d}_k$	σ_k
.050	.967	1.590	.911	1.743
.055	.978	1.562	.974	1.658
.061	.990	1.519	1.057	1.654
.067	1.028	1.541	1.118	1.605
.075	1.082	1.555	1.110	1.636
.082	1.201	1.550	1.105	1.648
.091	1.231	1.572	1.197	1.767
.101	1.101	1.729	1.218	1.729
.111	1.031	1.750	1.140	1.773
.123	1.053	1.775	1.220	1.813
.136	1.082	1.831	1.301	1.826
.150	1.060	1.833	1.375	1.808
.166	.973	1.767	1.241	1.762
.183	.999	1.655	1.167	1.886
.203	1.011	1.570	1.058	1.864
.224	1.089	1.553	1.019	1.763
.248	1.269	1.585	1.028	1.658
.274	1.228	1.474	1.131	1.724
.302	1.258	1.493	1.272	1.800
.334	1.283	1.516	1.331	1.786
.369	1.315	1.564	1.296	1.704
.408	1.357	1.509	1.426	1.584
.451	1.520	1.502	1.471	1.687
.499	1.382	1.599	1.236	1.684
.551	1.339	1.498	1.140	1.715
.609	1.225	1.501	1.034	1.618
.673	1.107	1.581	.935	1.625
.744	1.034	1.645	.823	1.560
.822	1.021	1.717	.788	1.691
.908	1.134	1.679	.771	1.785
1.004	1.158	1.627	.775	1.893
1.110	1.079	1.590	.708	1.966
1.226	1.021	1.572	.732	1.846
1.355	1.013	1.748	.826	1.849
1.498	1.026	1.887	.838	1.771
1.655	1.073	1.893	.938	1.833
1.829	1.103	1.877	.959	1.755
2.022	1.199	1.896	.852	1.730
2.234	1.237	1.877	.775	1.761
2.469	1.236	1.950	.723	1.882

TABLE A.4

STATION GEOMETRIC MEAN AND
STANDARD ERROR OF ESTIMATE;
BEATTY (HARDROCK)

Period	Radial Component		Transverse Component	
	$\bar{d}_k$	σ_k	$\bar{d}_k$	σ_k
.050	.465	1.399	.436	1.416
.055	.510	1.391	.444	1.431
.061	.514	1.348	.463	1.455
.067	.526	1.369	.482	1.515
.075	.525	1.394	.516	1.480
.082	.511	1.344	.481	1.462
.091	.486	1.372	.469	1.411
.101	.483	1.383	.469	1.411
.111	.437	1.417	.442	1.467
.123	.460	1.519	.427	1.463
.136	.468	1.513	.469	1.532
.150	.463	1.615	.469	1.642
.166	.434	1.465	.468	1.659
.183	.386	1.575	.445	1.659
.203	.352	1.561	.410	1.573
.224	.321	1.540	.369	1.569
.248	.307	1.552	.355	1.571
.274	.317	1.596	.350	1.563
.302	.326	1.614	.329	1.626
.334	.326	1.450	.292	1.446
.369	.324	1.399	.277	1.399
.408	.345	1.336	.248	1.549
.451	.419	1.403	.264	1.629
.499	.410	1.467	.276	1.536
.551	.442	1.520	.300	1.409
.609	.439	1.539	.325	1.520
.673	.418	1.585	.349	1.503
.744	.448	1.678	.344	1.640
.822	.487	1.658	.391	1.670
.908	.478	1.833	.407	1.704
1.004	.673	1.962	.398	1.755
1.110	.735	1.889	.383	1.702
1.226	.673	1.848	.416	1.643
1.355	.620	1.725	.459	1.578
1.498	.601	1.612	.487	1.640
1.655	.728	1.622	.543	1.618
1.829	.800	1.668	.638	1.613
2.022	.829	1.679	.674	1.666
2.234	.793	1.853	.653	1.543
2.469	.842	1.924	.585	1.551

TABLE A.5

STATION GEOMETRIC MEAN AND
STANDARD ERROR OF ESTIMATE;
CONTROL POINT #1 (CP-1), NTS

Period	Radial Component		Transverse Component	
	$\bar{d}_k$	σ_k	$\bar{d}_k$	σ_k
.050	.382	1.601	.412	1.895
.055	.357	1.627	.399	1.727
.061	.358	1.670	.383	1.761
.067	.370	1.578	.400	1.663
.075	.386	1.595	.381	1.480
.082	.388	1.511	.413	1.315
.091	.387	1.400	.418	1.369
.101	.438	1.400	.403	1.299
.111	.464	1.419	.392	1.303
.123	.481	1.468	.409	1.391
.136	.444	1.438	.456	1.416
.150	.468	1.532	.427	1.393
.166	.511	1.530	.464	1.373
.183	.499	1.438	.493	1.464
.203	.484	1.316	.457	1.356
.224	.435	1.251	.426	1.223
.248	.416	1.366	.428	1.200
.274	.461	1.432	.470	1.277
.302	.463	1.304	.436	1.237
.334	.430	1.495	.398	1.150
.369	.486	1.460	.416	1.264
.408	.535	1.549	.464	1.340
.451	.544	1.472	.438	1.349
.499	.534	1.416	.450	1.481
.551	.513	1.465	.442	1.365
.609	.537	1.589	.423	1.446
.673	.567	1.463	.465	1.323
.744	.555	1.409	.469	1.288
.822	.537	1.390	.483	1.515
.908	.523	1.520	.528	1.531
1.004	.513	1.605	.631	1.561
1.110	.562	1.535	.638	1.375
1.226	.614	1.574	.613	1.464
1.355	.720	1.400	.660	1.394
1.498	.798	1.369	.689	1.444
1.655	.760	1.349	.639	1.524
1.829	.817	1.477	.686	1.598
2.022	.710	1.385	.737	1.531
2.234	.664	1.277	.701	1.429
2.469	.749	1.436	.767	1.534

TABLE A.6

STATION GEOMETRIC MEAN AND
STANDARD ERROR OF ESTIMATE;
ADMINISTRATION BUILDING, NRDS

Period	Radial Component		Transverse Component	
	$\bar{d}_k$	σ_k	$\bar{d}_k$	σ_k
.050	1.054	1.537	1.063	1.450
.055	1.041	1.487	1.085	1.423
.061	1.016	1.453	1.071	1.346
.067	1.038	1.406	1.113	1.423
.075	1.081	1.386	1.125	1.453
.082	1.150	1.343	1.159	1.281
.091	1.182	1.336	1.150	1.249
.101	1.319	1.384	1.242	1.304
.111	1.307	1.378	1.371	1.283
.123	1.339	1.427	1.374	1.247
.136	1.350	1.416	1.273	1.265
.150	1.251	1.367	1.296	1.224
.166	1.238	1.402	1.261	1.203
.183	1.209	1.439	1.257	1.395
.203	1.160	1.396	1.368	1.422
.224	1.222	1.438	1.396	1.377
.248	1.140	1.459	1.459	1.318
.274	1.182	1.540	1.360	1.362
.302	1.207	1.500	1.379	1.477
.334	1.057	1.421	1.297	1.575
.369	.995	1.459	1.362	1.511
.408	.958	1.472	1.348	1.548
.451	1.127	1.526	1.313	1.547
.499	1.047	1.525	1.238	1.529
.551	1.089	1.437	1.202	1.427
.609	1.076	1.429	1.270	1.350
.673	.930	1.367	1.277	1.412
.744	.993	1.396	1.123	1.334
.822	1.036	1.459	1.138	1.350
.908	1.077	1.451	1.300	1.328
1.004	1.218	1.389	1.326	1.307
1.110	1.253	1.432	1.375	1.306
1.226	1.224	1.401	1.321	1.375
1.355	1.203	1.329	1.238	1.216
1.498	1.222	1.348	1.369	1.338
1.655	1.283	1.467	1.425	1.370
1.829	1.386	1.527	1.402	1.394
2.022	1.442	1.429	1.571	1.417
2.234	1.367	1.613	1.607	1.251
2.469	1.240	1.605	1.521	1.149

TABLE A.7

STATION GEOMETRIC MEAN AND
STANDARD ERROR OF ESTIMATE;
MERCURY, Q-25

Period	Radial Component		Transverse Component	
	$\bar{d}_k$	σ_k	$\bar{d}_k$	σ_k
.050	.883	2.560	.794	2.255
.055	.829	2.521	.778	2.199
.061	.839	2.360	.834	2.143
.067	.825	2.184	.814	2.000
.075	.866	1.965	.907	1.808
.082	.872	1.789	.918	1.794
.091	.956	1.686	.963	1.738
.101	.887	1.577	1.039	1.631
.111	.838	1.621	.994	1.662
.123	.849	1.550	.884	1.567
.136	.852	1.601	.781	1.572
.150	.785	1.643	.758	1.578
.166	.715	1.731	.779	1.686
.183	.776	1.746	.750	1.653
.203	.796	1.729	.711	1.554
.224	.837	1.777	.757	1.752
.248	.785	1.883	.755	1.794
.274	.759	1.714	.759	1.780
.302	.794	1.807	.765	1.749
.334	.909	1.817	.809	1.893
.369	.909	1.763	.913	1.812
.408	.857	1.829	.892	1.871
.451	.779	1.700	.816	1.844
.499	.809	1.727	.788	1.940
.551	.851	1.739	.720	1.865
.609	.829	1.983	.663	1.836
.673	.775	1.900	.627	1.813
.744	.685	1.773	.599	1.708
.822	.727	1.907	.627	1.781
.908	.673	1.819	.594	1.834
1.004	.646	1.833	.600	1.787
1.110	.612	1.758	.621	1.935
1.226	.629	1.675	.632	1.855
1.355	.599	1.774	.609	1.759
1.498	.652	1.751	.574	1.723
1.655	.699	1.783	.532	1.806
1.829	.668	1.905	.528	1.910
2.022	.656	1.895	.558	1.966
2.234	.634	1.952	.572	1.810
2.469	.697	1.825	.611	1.896

TABLE A.8

STATION GEOMETRIC MEAN AND
STANDARD ERROR OF ESTIMATE;
INDIAN SPRINGS, SE-2

Period	Radial Component		Transverse Component	
	$\bar{d}_k$	σ_k	$\bar{d}_k$	σ_k
.050	.911	1.414	.916	1.404
.055	1.071	1.363	1.065	1.429
.061	1.202	1.355	1.176	1.425
.067	1.414	1.269	1.287	1.426
.075	1.587	1.371	1.368	1.507
.082	1.604	1.384	1.510	1.502
.091	1.514	1.450	1.500	1.351
.101	1.426	1.584	1.407	1.416
.111	1.482	1.555	1.235	1.449
.123	1.501	1.591	1.042	1.545
.136	1.103	1.533	.874	1.444
.150	.819	1.578	.802	1.375
.166	.749	1.375	.825	1.498
.183	.805	1.282	.707	1.327
.203	.784	1.324	.689	1.244
.224	.710	1.273	.654	1.261
.248	.688	1.299	.724	1.325
.274	.697	1.243	.714	1.317
.302	.699	1.244	.703	1.344
.334	.653	1.279	.622	1.237
.369	.637	1.349	.599	1.351
.408	.577	1.290	.559	1.384
.451	.562	1.268	.551	1.351
.499	.588	1.291	.588	1.306
.551	.576	1.346	.607	1.360
.609	.574	1.320	.627	1.383
.673	.519	1.383	.568	1.345
.744	.479	1.288	.511	1.274
.822	.502	1.356	.535	1.357
.908	.502	1.331	.469	1.322
1.004	.459	1.317	.454	1.324
1.110	.428	1.327	.442	1.365
1.226	.443	1.331	.458	1.440
1.355	.430	1.376	.422	1.417
1.498	.448	1.350	.390	1.434
1.655	.496	1.301	.448	1.337
1.829	.509	1.319	.463	1.316
2.022	.521	1.425	.478	1.255
2.234	.551	1.379	.583	1.307
2.469	.600	1.361	.634	1.298

TABLE A.9

STATION GEOMETRIC MEAN AND
STANDARD ERROR OF ESTIMATE;
KYLE CANYON, SE-4

Period	Radial Component		Transverse Component	
	$\bar{d}_k$	σ_k	$\bar{d}_k$	σ_k
.050	.518	1.560	.456	1.596
.055	.471	1.487	.427	1.410
.061	.449	1.361	.401	1.301
.067	.417	1.346	.389	1.284
.075	.399	1.331	.373	1.285
.082	.384	1.403	.387	1.276
.091	.375	1.345	.381	1.210
.101	.362	1.379	.411	1.310
.111	.387	1.254	.416	1.287
.123	.352	1.267	.421	1.303
.136	.396	1.300	.463	1.319
.150	.398	1.253	.466	1.345
.166	.485	1.290	.469	1.383
.183	.474	1.303	.471	1.289
.203	.504	1.415	.533	1.254
.224	.574	1.423	.565	1.364
.248	.626	1.309	.563	1.531
.274	.561	1.277	.602	1.393
.302	.555	1.329	.601	1.437
.334	.579	1.417	.578	1.389
.369	.557	1.312	.540	1.445
.408	.531	1.309	.508	1.286
.451	.518	1.211	.486	1.316
.499	.535	1.177	.496	1.309
.551	.590	1.209	.503	1.358
.609	.544	1.238	.514	1.456
.673	.507	1.330	.462	1.363
.744	.469	1.251	.501	1.466
.822	.473	1.218	.454	1.499
.908	.417	1.205	.445	1.368
1.004	.414	1.206	.446	1.315
1.110	.464	1.225	.420	1.334
1.226	.420	1.210	.384	1.290
1.355	.406	1.292	.366	1.353
1.498	.410	1.323	.410	1.282
1.655	.410	1.322	.424	1.262
1.829	.438	1.165	.428	1.194
2.022	.419	1.219	.422	1.267
2.234	.389	1.232	.440	1.256
2.469	.415	1.266	.407	1.288

TABLE A.10

STATION GEOMETRIC MEAN AND
STANDARD ERROR OF ESTIMATE;
UNIVERSITY OF NEVADA, LAS VEGAS, SE-6

Period	Radial Component		Transverse Component	
	$\bar{d}_k$	σ_k	$\bar{d}_k$	σ_k
.050	1.017	1.732	.847	1.633
.055	.988	1.732	.846	1.637
.061	.949	1.751	.839	1.667
.067	.922	1.738	.828	1.668
.075	.934	1.738	.824	1.736
.082	.889	1.755	.768	1.745
.091	.861	1.711	.738	1.714
.101	.831	1.690	.716	1.710
.111	.800	1.699	.714	1.645
.123	.791	1.715	.694	1.652
.136	.764	1.693	.702	1.658
.150	.803	1.666	.767	1.649
.166	.832	1.629	.765	1.620
.183	.854	1.626	.832	1.537
.203	1.008	1.538	.932	1.523
.224	1.068	1.571	1.002	1.552
.248	1.129	1.495	1.014	1.449
.274	1.195	1.451	1.087	1.442
.302	1.145	1.502	1.074	1.555
.334	1.189	1.488	1.193	1.538
.369	1.395	1.488	1.291	1.583
.408	1.529	1.435	1.326	1.423
.451	1.501	1.465	1.323	1.502
.499	1.507	1.459	1.368	1.502
.551	1.554	1.407	1.372	1.531
.609	1.609	1.409	1.483	1.580
.673	1.671	1.454	1.502	1.624
.744	1.702	1.486	1.624	1.590
.822	1.768	1.497	1.569	1.535
.908	1.910	1.536	1.569	1.547
1.004	2.232	1.508	1.726	1.539
1.110	2.296	1.409	1.821	1.509
1.226	2.237	1.425	1.868	1.516
1.355	2.265	1.467	1.783	1.564
1.498	2.255	1.476	1.797	1.442
1.655	2.020	1.562	1.924	1.514
1.829	1.901	1.490	1.942	1.555
2.022	2.027	1.497	1.866	1.509
2.234	1.903	1.532	1.866	1.536
2.469	1.888	1.636	2.001	1.593

TABLE A.11

STATION GEOMETRIC MEAN AND
STANDARD ERROR OF ESTIMATE;
SQUIRES PARK, LAS VEGAS

Period	Radial Component		Transverse Component	
	$\bar{d}_k$	σ_k	$\bar{d}_k$	σ_k
.050	1.352	1.868	1.450	1.760
.055	1.382	1.956	1.391	1.883
.061	1.344	1.922	1.402	1.826
.067	1.330	1.846	1.387	1.803
.075	1.194	1.933	1.301	1.839
.082	1.157	1.928	1.163	1.778
.091	1.102	1.841	1.110	1.769
.101	1.101	1.718	1.106	1.647
.111	1.048	1.690	1.088	1.629
.123	.957	1.598	1.023	1.551
.136	.906	1.486	.980	1.571
.150	.918	1.390	.926	1.552
.166	.917	1.399	.914	1.502
.183	.927	1.419	1.016	1.379
.203	.954	1.316	1.030	1.367
.224	.967	1.309	1.014	1.489
.248	1.018	1.294	1.063	1.481
.274	1.150	1.271	1.296	1.405
.302	1.155	1.316	1.264	1.406
.334	1.088	1.288	1.183	1.359
.369	1.163	1.244	1.282	1.382
.408	1.426	1.283	1.423	1.344
.451	1.645	1.241	1.886	1.360
.499	1.775	1.295	2.262	1.307
.551	1.916	1.365	2.254	1.331
.609	2.022	1.461	2.280	1.243
.673	1.930	1.269	2.168	1.231
.744	1.788	1.320	2.125	1.239
.822	1.900	1.357	2.258	1.195
.908	1.911	1.235	2.335	1.326
1.004	2.244	1.207	2.436	1.142
1.110	2.134	1.147	2.421	1.253
1.226	2.448	1.234	2.294	1.211
1.355	2.484	1.300	2.492	1.228
1.498	2.511	1.163	2.547	1.229
1.655	2.601	1.224	2.709	1.324
1.829	2.812	1.294	2.864	1.405
2.022	2.904	1.381	2.975	1.381
2.234	2.915	1.227	3.146	1.370
2.469	2.692	1.358	3.099	1.270

TABLE A.12

STATION GEOMETRIC MEAN AND
STANDARD ERROR OF ESTIMATE;
TONOPAH (CHURCH)

Period	Radial Component		Transverse Component	
	$\bar{d}_k$	σ_k	$\bar{d}_k$	σ_k
.050	.761	1.699	.948	1.901
.055	.809	1.774	.992	1.917
.061	.846	1.844	.977	1.946
.067	.889	1.903	1.025	1.982
.075	1.008	1.958	1.206	2.022
.082	1.109	2.053	1.323	2.063
.091	1.139	2.076	1.351	1.939
.101	1.090	2.117	1.230	2.056
.111	1.150	2.063	1.378	2.043
.123	1.164	2.129	1.333	1.995
.136	1.285	2.200	1.360	2.012
.150	1.307	2.084	1.375	2.050
.166	1.326	1.946	1.380	1.919
.183	1.250	1.863	1.323	1.831
.203	1.146	1.821	1.246	1.803
.224	1.192	1.743	1.163	1.650
.248	1.131	1.740	1.122	1.707
.274	1.044	1.634	1.035	1.678
.302	1.025	1.556	1.108	1.608
.334	1.049	1.561	1.034	1.538
.369	.996	1.497	.969	1.503
.408	.901	1.490	.903	1.442
.451	.915	1.386	.842	1.411
.499	.846	1.388	.762	1.371
.551	.700	1.330	.767	1.416
.609	.697	1.360	.766	1.364
.673	.785	1.398	.789	1.379
.744	.810	1.356	.745	1.309
.822	.708	1.242	.657	1.281
.908	.693	1.302	.657	1.270
1.004	.617	1.341	.660	1.289
1.110	.554	1.394	.636	1.310
1.226	.522	1.459	.569	1.315
1.355	.526	1.351	.563	1.326
1.498	.504	1.446	.522	1.333
1.655	.462	1.363	.458	1.347
1.829	.436	1.349	.451	1.368
2.022	.426	1.470	.458	1.317
2.234	.449	1.500	.471	1.353
2.469	.483	1.419	.466	1.400

TABLE A.13

STATION GEOMETRIC MEAN AND
STANDARD ERROR OF ESTIMATE;
TONOPAH (SILVER QUEEN MOTEL)

Period	Radial Component		Transverse Component	
	$\bar{d}_k$	σ_k	$\bar{d}_k$	σ_k
.050	1.759	1.842	1.485	1.979
.055	1.873	1.837	1.530	1.941
.061	1.992	1.803	1.602	1.923
.067	2.064	1.695	1.772	1.883
.075	2.302	1.593	2.010	1.771
.082	2.403	1.653	2.312	1.817
.091	2.860	1.674	2.447	1.792
.101	3.554	1.757	2.578	1.746
.111	4.058	1.821	2.764	1.626
.123	4.514	1.761	3.132	1.584
.136	5.394	1.869	3.262	1.595
.150	5.198	1.917	3.091	1.659
.166	3.941	1.709	2.769	1.599
.183	3.544	1.632	2.632	1.653
.203	2.978	1.680	2.260	1.624
.224	2.459	1.736	2.058	1.612
.248	1.957	1.704	1.717	1.601
.274	1.586	1.662	1.442	1.521
.302	1.530	1.484	1.388	1.411
.334	1.576	1.375	1.340	1.422
.369	1.393	1.438	1.203	1.424
.408	1.052	1.374	1.083	1.380
.451	.969	1.367	.962	1.318
.499	.837	1.343	.824	1.333
.551	.720	1.298	.763	1.379
.609	.700	1.414	.729	1.390
.673	.766	1.453	.717	1.435
.744	.796	1.451	.681	1.363
.822	.711	1.311	.609	1.363
.908	.700	1.324	.604	1.362
1.004	.592	1.387	.596	1.446
1.110	.536	1.317	.589	1.412
1.226	.475	1.410	.522	1.356
1.355	.482	1.359	.522	1.366
1.498	.462	1.393	.488	1.337
1.655	.434	1.385	.436	1.270
1.829	.394	1.442	.422	1.321
2.022	.363	1.540	.448	1.367
2.234	.439	1.511	.453	1.409
2.469	.446	1.410	.424	1.525

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