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ATTENUATION OF BLASTING VIBRATIONS IN SOUTH FLORIDA, PART II

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ABSTRACT

In this paper, the measured vibrations are plotted in terms of the individual PPV components versus Scaled Distance (SD) on logarithmic scales. The maximum PPV is plotted on a separate graph and equations are presented to predict the maximum PPV based on sealed distance and prediction level using power fits. The prediction levels include a 99.9% curve, which encompasses the data points and provides an envelope formula for determining the maximum PPV at South Florida sites. The dominant frequency distribution is established for the PPV components.

INTRODUCTION

Several large limestone quarrying projects recently occurred in Miramar, Florida. The Seismologist of Record and Broward County closely monitored blasting in accordance with County and City regulations. In addition to this monitoring, the City of Miramar employed The Pepper Engineering Group, Inc., to provide additional spot cheek monitoring and to review the records of the other two parties on a routine basis.

Broward County ordinances require that the location of each shot and the nearest protected structure be recorded along with seismograph measurement of each shot at the nearest protected structure. Over 600 shots, which are the subject of this study? were measured both by the County, the Seismologist and, on many occasions The Pepper Engineering Group. The result of this process was that at least two, and many times three, seismographs recorded the measurements of vibrations at the nearest structure to the shot. As such, the vibration data was constantly crosschecked for consistency. The positions of the blasts and nearest protected structures were determined using GPS .

PURPOSE

This study has four primary purposes:

1. The prediction, within a specified degree of certainty, of the maximum PPV at a site distant from the point of the detonation of the explosive charge based on the charge weight per delay of explosive and the distance to the point of interest.

2. The prediction, within a specified degree of certainty, of the maximum PPV at a site distant from the point of seismographic measurement to another location, based on the distance from the point of

detonation to the measurement point and the distance from the point of detonation to the point of interest.

3. Provide a comparison of the attenuation of the individual components of the vibrations (longitudinal, tangential, and vertical) and with the. maximum PPVs. These attenuation curves may also be compared to the attenuation curve for the RPPVs presented by the authors in reference 1.

4. Provide an understanding of the. dominant frequencies of blasting vibrations in South Florida. An understanding of these frequencies may provide assistance in determining the dynamic response of South Florida structures to blasting vibrations.

CORRELATION OF COMMON VIBRATION PARAMETERS:

The primary vibration parameters in&de the square root sealed distance (SD), the peak particle velocity (PPV) and the dominant frequency. A correlation analysis was preformed using Microsoft Excel to determine whether the vibration parameters are associated with one another. A correlation of 1.0 or –1.0 indicates that the parameters are definitely related, positively or negatively, respectively. A summary of the correlation analysis is provided in the following table:

Correlation Summary

PPV	SD - PPV Correlation	SD - Freq. Correlation	PPV - Freq. Correlation
Longitudinal	-0.5705	0.0009	0.0948
Tangential	-0.4223	-0.0538	0.1110
Vertical	-0.5745	0.1516	-0.1448

As expected, no correlation was found between scaled distance and frequency and between PPV and frequency. A negative correlation between sealed distance and PPV was found, which means that the PPV decreases as the scaled distance increases.

The amplitude of the vibration is primarily a function of distance from the blast and the energy of the blast. To a lesser extent, attenuation is affected by the geology, which includes such factors as porosity, water table, degree of consolidation, fracturing and overburden. The effects of geometrical attenuation are far greater than the effects of geological attenuation.

DOMINANT FREQUENCY

A frequency histogram was plotted for each of the vibration components. (Figure 1) For all components it was found that the dominant frequencies were typically less than 12 Hz. These low frequencies are largely a function of the South Florida geology and most often are very close to the natural frequency of the typical South Florida home.

In general, the South Florida geology consists of a soft limestone, called Miami Limestone or Miami Oolite over the Ft. Thompson Formation and the underlying Tamiami Formation. The Miami Oolite extends from mean sea level to about –10' to –20 feet. The Ft. Thompson Formation is a sandy limestune and extends to approximately -60' to -80'. The top layers of the soil (3' to 5' thick), above the Miami Oolite, consist of sand, peat and muck, which are typically removed and suitable fill provided for the foundations for houses and other low-rise structures.

The frequency of the vibration is a function of the distance from the blast, the blast design and the geology. The higher frequency waves are attenuated quickly as a result of the weak, less consolidated limestones in the Miami Oolite and Ft. Thompson Formation layers. As a result, the low frequency surface waves are. dominant at farther distances from the blast.

PREDICTION PEAK PARTICLE VELOCITY BASED UN EXPLOSIVE CHARGE

The prediction of particle velocity requires that average and upper bound values be well known. For the bounds to be established, site-specific studies must be made.

The method we used to predict maximum PPV based on the charge weight per delay is standard. We plotted Scaled Distance (SD) on the X ordinate and RPPV on the Y ordinate. Scaled Distance is a function of the distance (D) from the nearest point of the shot to the seismograph and the Charge Weight per Delay (W) defined as follows:

$$SD=(D/W^{1/2})$$

The data for each vibration component was plotted and the 50% line was fitted using a power fun&on. This is shown in Figure 2 along with a plot of the maximum PPV 50% curve. The plot indicates that the vertical component is dominant and is close to the maximums PPV curve.

The vertical PPVs are typically higher than the longitudinal PPVs. However, the longitudinal PPVs are most important in assessing the potential for damage to structures because the vertical component is not amplified by the structure. It is evident that, for this reason, the use of the maximum PPV curve for predicting vibration amplitudes is conservative and provides an additional factor of safety.

The maximum PPV data was then plotted separately. At this point, the analysis deviates slightly from the standard ones in that statistical techniques were applied to **obtain** the degrees of certainty. Figure 3 shows the estimated 95% 99% and 99.9% upper bounds. Using either Figure 3 or the equations provided, the maximum PPV at a given distance from the nearest hole of the detonation may be estimated.

PREDICTION OF MAXIMUM PPV BASED UN SEISMOGRAPH MEASUREMENT

In order to predict the maximum PPV based on the reading of a seismograph at a known location in relation to the shot, the slope of the attenuation curve must be known, The slope of the attenuation curve must be statistically supported and mechanistically explained. Given a known blast, location of the seismograph and distance from the blast to the structure in question, the particle velocity may be predicted by the following formula:

$$V_h = V_s (D_h/D_s)^{-b}$$

V_h = particle velocity at the structure or house (ips)
Vs = particle velocity measured by the seismograph (ips)
D_h = distance from the blast to the structure (ft)
D_s= distance from the blast to the seismograph (ft)
$-_b$ = the slope of the attenuation curve

In this study, the slopes of the prediction curves are consistent with the slope presented in reference 1.

The slope of the 99.9% upper bound predictive curve, which encompasses all the data points, is basically the same as the slope of the RPPV curves previously presented. The predictive equation, in a simplified form, is as follows:

$$V_h = V_s\,(D_s/D_h)^{0.80}$$

STATISTICAL ANALYSIS

Statistical analysis of blasting data used the results of approximately 600 events (shots). The classical relationship between these variables is given by:

$$PPV= a\,SD^b,$$

where the parameters a and b are to be estimated from the data. We assume that the data is in the form (PPV_i, SD_i) for i = 1, 2, ..., n (the number of data points). In addition to finding least squares estimates of a and b using standard statistical fitting methods, we also provide in this section prediction limits. Hence, given a particular scaled distance, we offer a best guess as to the PPV as well as upper 95%, 99% and 99.9% prediction limits below which we expect future blasts to occur.

The basic scheme for obtaining the best fit and prediction limits is provided in Appendix 1 and describes the steps necessary to generate the PPV to SD best-fit relationship along with 95%, 99% and 99.9% prediction limits. The upper 99.9% prediction limit is:

$$UL = 10^{c + d\,w + 3.090232\,SE}$$

A numerical example was also presented in reference 1 and is not repeated here.

SUMMARY and CONCLUSION

A method has been presented that allows the estimation of vibrations due to quarrying operations in South Florida based on both charge weight per delay as well as seismographic measurements at other locations.

As shown in Figure 5, the results indicate that the slope of the attenuation equation is approximately -0.80. The suggested equation for the attenuation of blast vibrations in South Florida, when SD is known, is as follows:

$$\text{Maximum PPV } (99.9\%) = 21.25\,(SD)^{-0.80}$$

This predictive equation produces a conservative PPV at the house, in that it results in a higher amplitude because it is largely a function of the dominating vertical component. The longitudinal PPV component? which is responsible for the structural response, is less than the vertical component and the maximum PPV.

The suggested equation when a seismographic reading is known is:

$$V_h = V_s\,(Ds/Dh)^{0.80}$$

The dominant frequency of blast vibrations in South Florida have been found to be low and very close to the natural frequencies of the typical South Florida home. The presentation of the dynamic response of South Florida homes to blasting vibrations was beyond the scope of this paper.

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APENDIX 1 - STATISTICAL ANALYSIS

The classical relationship between the variables PPV and SD is given by:

$$PPV = a\, SD^b,$$

where the parameters a and b are to be estimated from the data, We assume that the data is in the form (PPV_i, SD_i) for i = 1, 2, . . . , n (the number of data points). In addition to finding least squares estimates of a and b using standard statistical fitting methods we also provide in this section prediction limits. Hence, given a particular scaled distance, we offer a best guess as to the PPV as well as upper 95%, 99% and 99.9% prediction limits below which we expect future blasts to occur.

The basic scheme for obtaining the best fit and prediction limits is given, as follows:

1. Log10 transformation.

   Let $z_i = \log10(PPV_i)$. Let $w_i = \log10(SD_i)$.

2. Linear regression.

   Fit the data using least squares for the relation $z = c + d\, w$, where c is the intercept and d is the slope of the resultant fit. 'This is the best-fit curve in the log-log-transformed space.

3. Auxiliary calculations.

   Compute the following three auxiliary values necessary for later prediction limit determinations:

   $$MSE = \Sigma\, (z_i - c + d\, w_i)^2,$$

   $$Ave(w) = (\Sigma\, w_i) / n,$$

   $$WSS = \Sigma\, (w_i - Ave(w))^2,$$

   where the summations are each from 1 through the number of data points n.

4. Best fit curve.

   Transforming back to the original scale (which is to be plotted on log-log paper), the appropriate best-fit function is:

   $$PPV = 10^c\, (SD)^d$$

5. Upper prediction limits.

For a given SD value, let w = log10(SD) and compute the following quantity:

$$SE = [MSE\ (1 + (1/n) + (w - Ave(w))^2 / WSS\ )]^{1/2}$$

The upper 95% prediction limit is:

$$UL = 10^{c + d\,w - 1.645\ SE}$$

The upper 99% prediction limit is:

$$UL = 10^{c + d\,w + 2.326\ SE}$$

The upper 99% prediction limit is:

$$UL = 10^{c + d\,w + 3.090232\ SE}$$

These quantities are suitable for plotting on log-log paper.

The procedure given above describes the steps necessary to generate the RPPV to SD best-fit relationship along with 95%, 99% and 99.9% upper prediction limits.

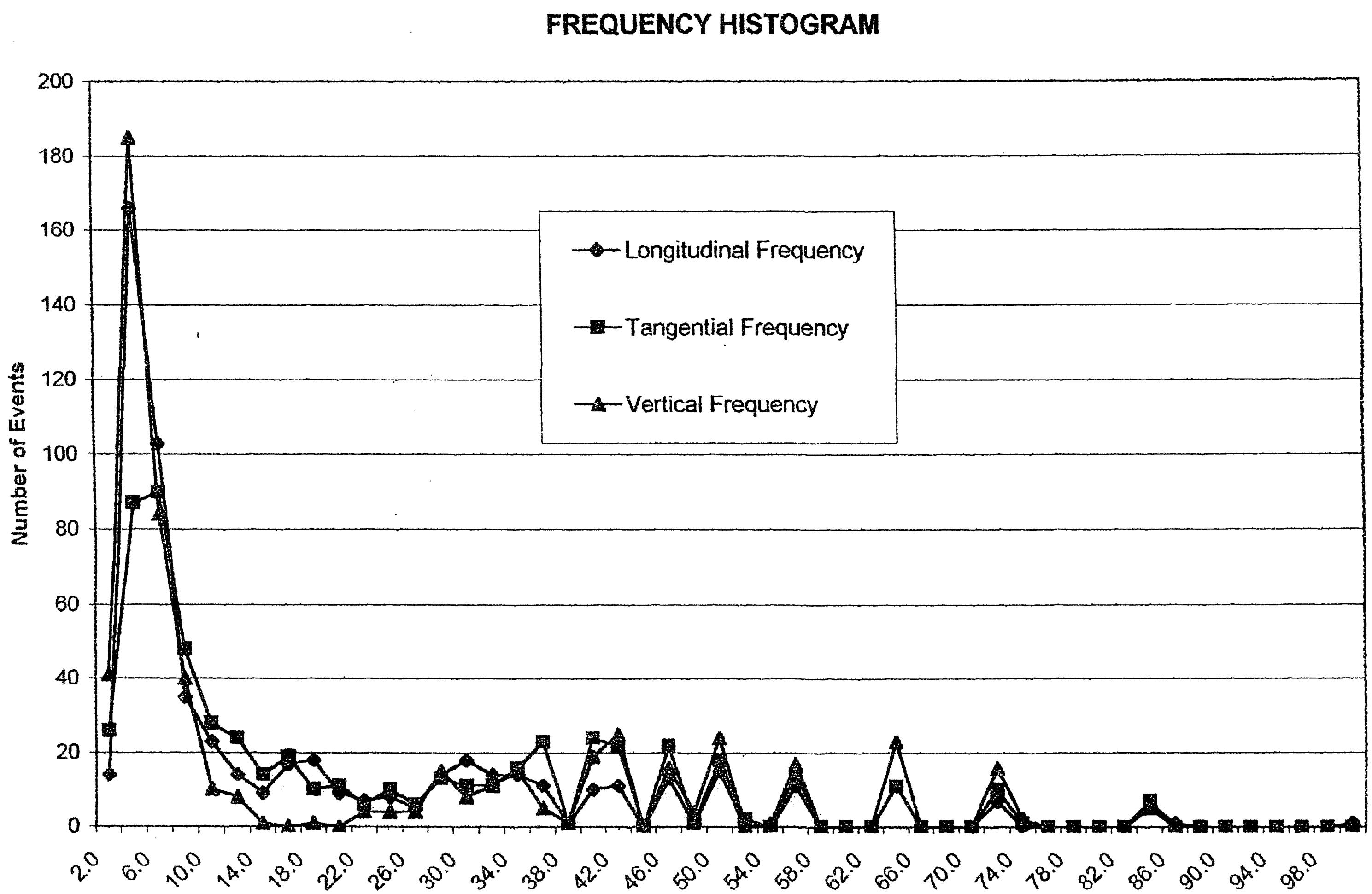
FREQUENCY HISTOGRAM
Longitudinal Frequency
Tangential Frequency
Vertical Frequency
Number of Events
200
180
160
140
120
100
80
60
40
20
0
2.0
6.0
10.0
14.0
18.0
22.0
26.0
30.0
34.0
38.0
42.0
46.0
50.0
54.0
58.0
62.0
66.0
70.0
74.0
78.0
82.0
86.0
90.0
94.0
98.0
Frequency (Hz)

Figure 1

Blasting Vibration Attenuation
Component PPVs

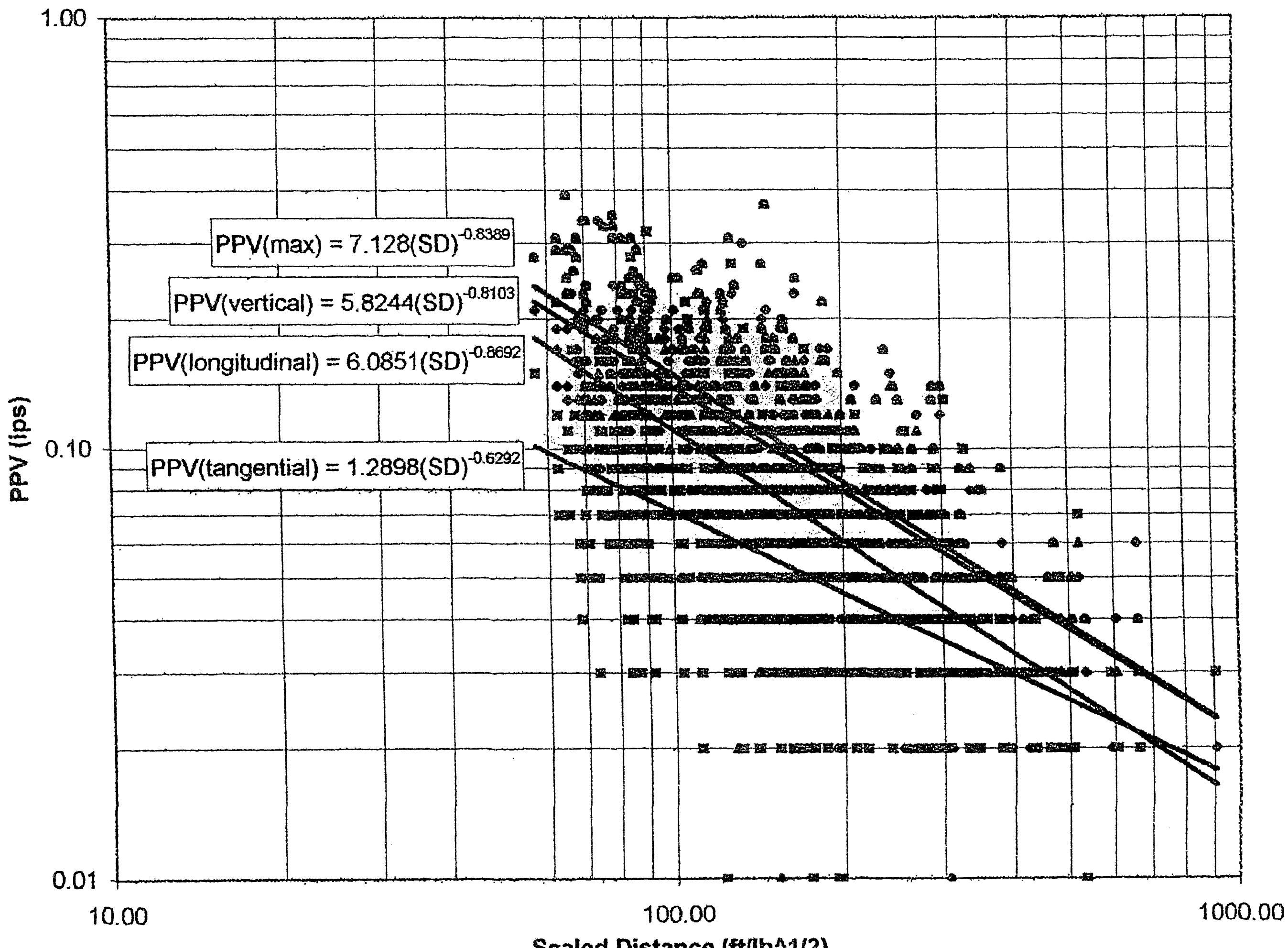

Figure 2

South Florida Attenuation
Max PPV

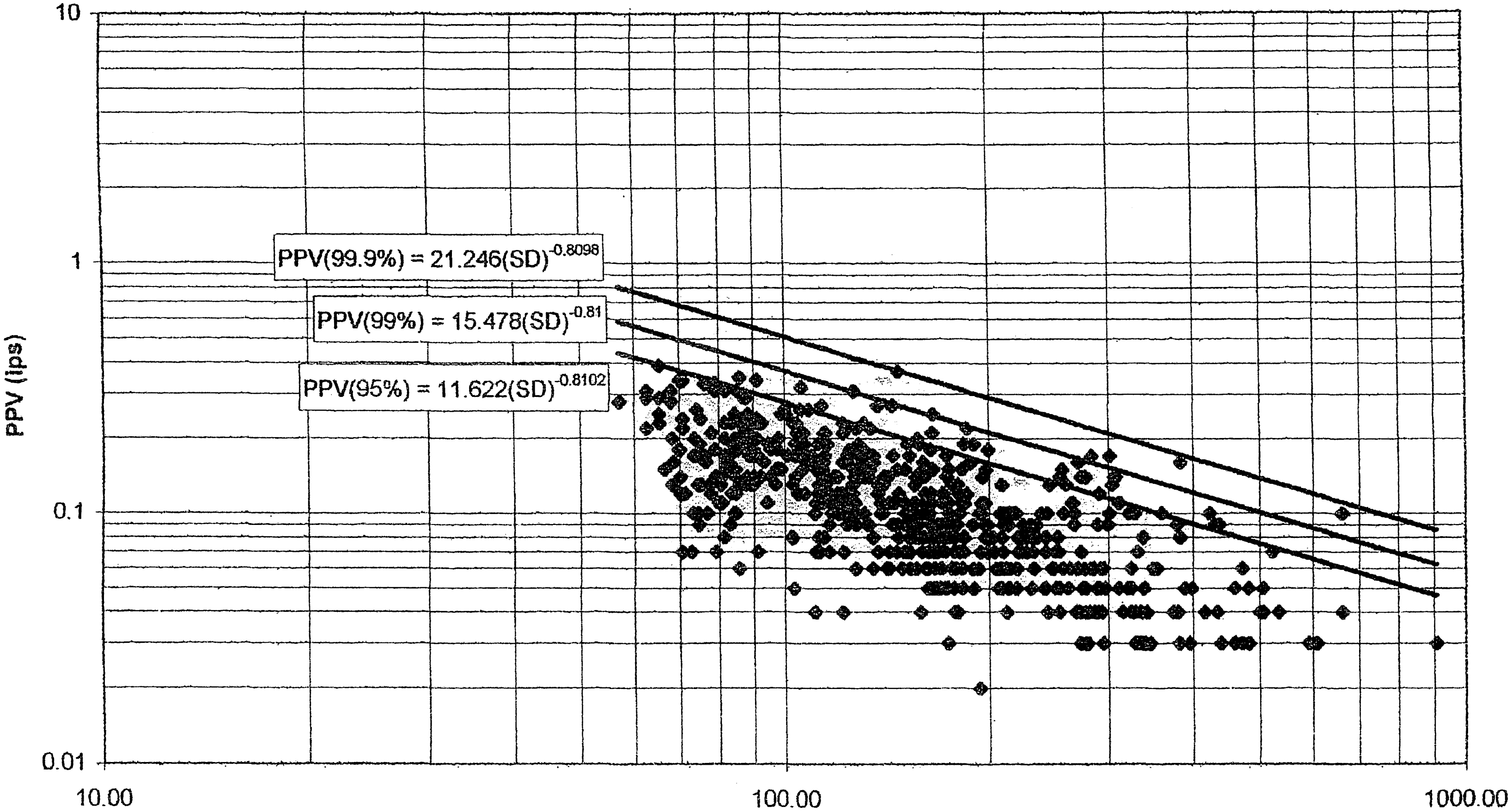

Figure 3