Investigating radiation patterns and power spectra from spherically symmetric explosive sources

CREWES Tech Talk
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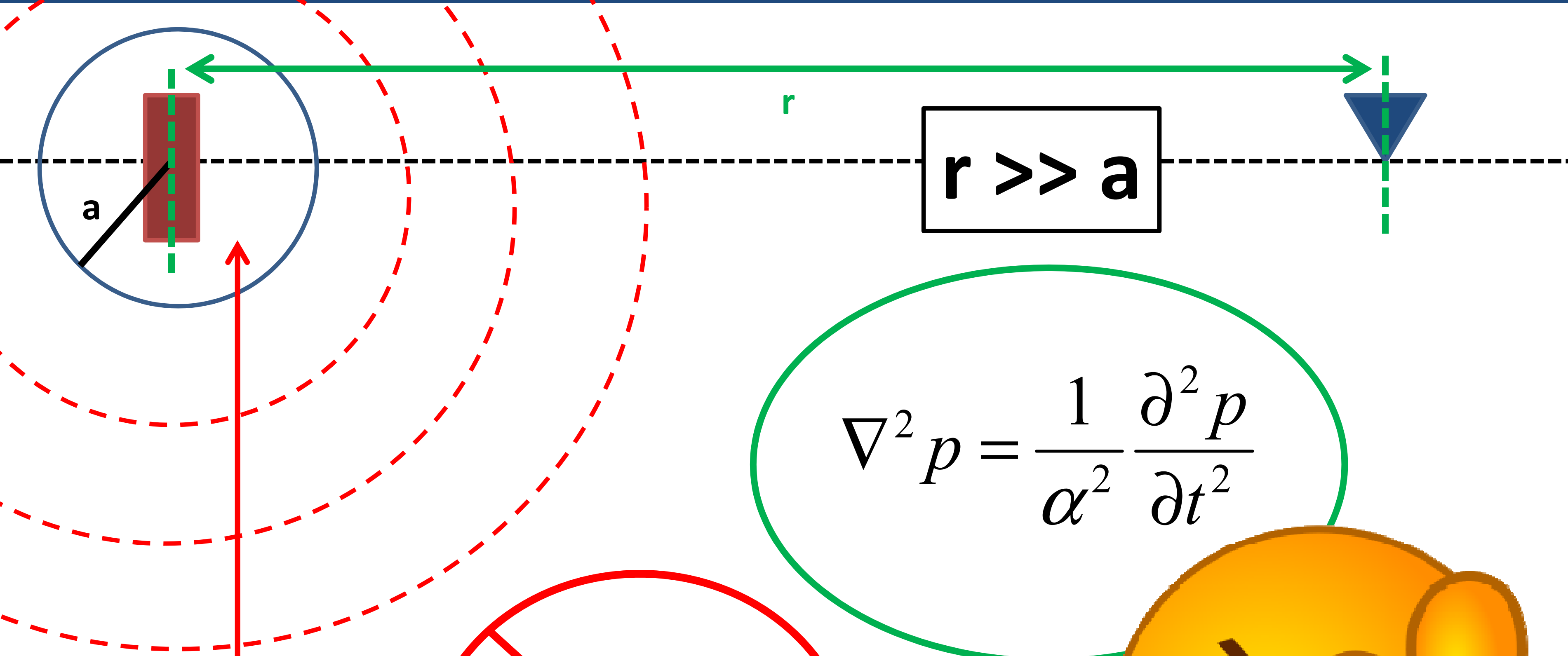
Introduction

- Dynamite is a commonly used tool in exploration seismology to image the subsurface.
- The reflection component is of particular interest as it contains valuable information regarding the subsurface.
- Several models currently exist to theorize the radiation patterns emitted from a dynamite explosion.
- We present the <u>spherical model</u> for dynamite and examine the effect of charge size on power and frequency spectra in a seismogram.

Theory



$$\nabla^2 p = \frac{1}{\alpha^2}\frac{\partial^2 p}{\partial t^2}$$

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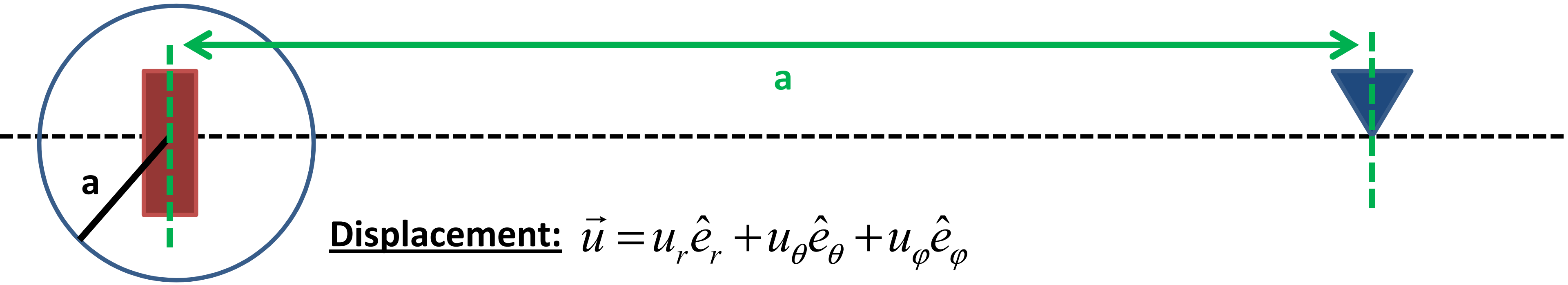


Displacement: $\vec{u} = u_r \hat{e}_r + u_\theta \hat{e}_\theta + u_\varphi \hat{e}_\varphi$

Spherical Symmmetry: $u_\theta = u_\varphi = 0 \Rightarrow \boxed{u = u_r}$

$$u = \frac{\partial \varphi}{\partial r} \Rightarrow \boxed{u_s(t_r) = \frac{a^2 p_o \sqrt{1-2\sigma}}{2\mu} \frac{e^{-ct_r}}{r} \sin(\chi t_r)}$$

where $\chi = \frac{\alpha}{a} \frac{\sqrt{1-2\sigma}}{1-\sigma}$ $\quad c = \frac{\alpha}{a}\left(\frac{1-2\sigma}{1-\sigma}\right)$ $\quad t_r = t - \frac{r-a}{\alpha}$

Observations

Displacement

$$\boxed{u_s(t_r) = \frac{a^2 p_o \sqrt{1-2\sigma}}{2\mu} \frac{e^{-ct_r}}{r} \sin(\chi t_r)}$$

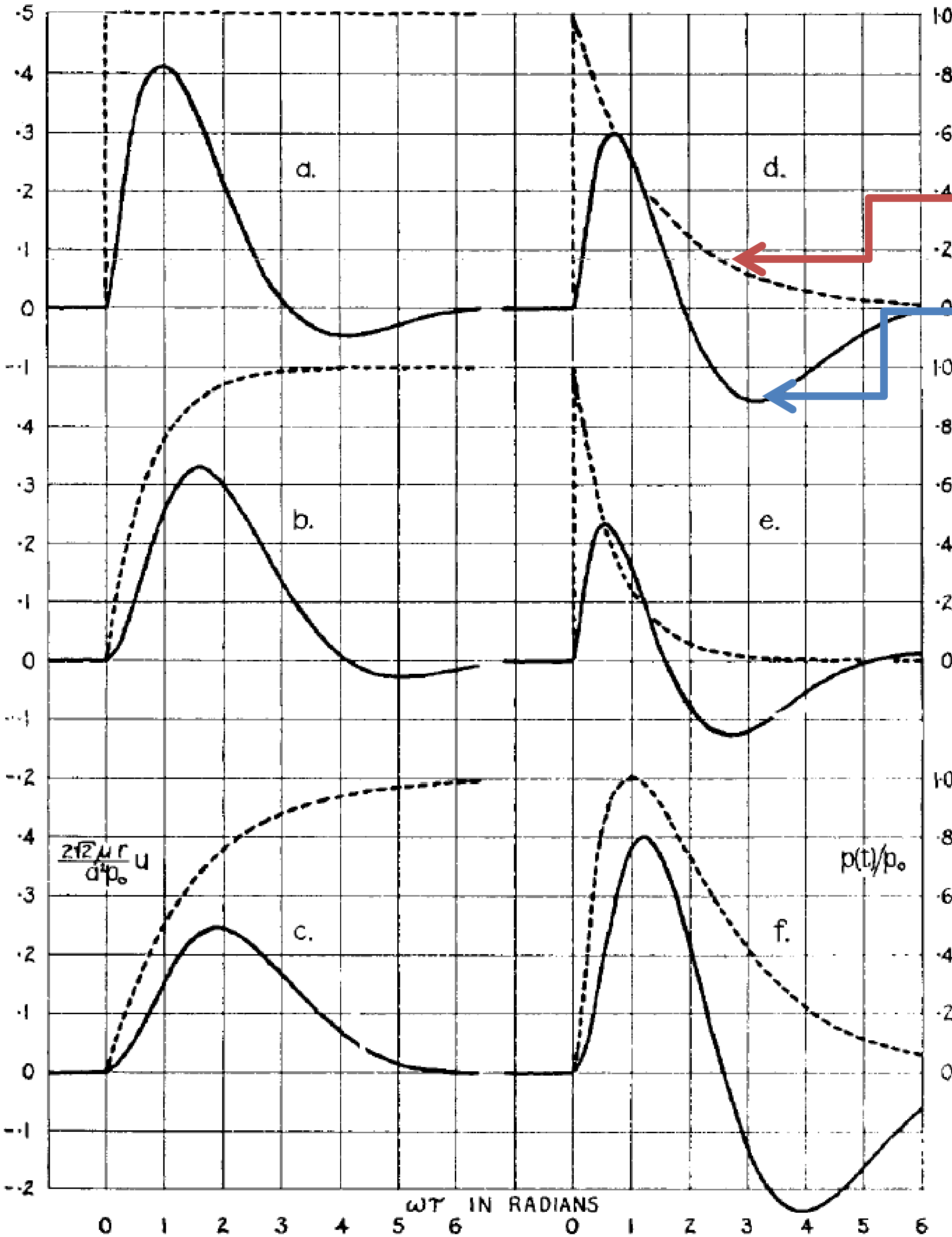
Frequency spectrum of u is:

$$\boxed{f_o = \left[\frac{\sqrt{1-2\sigma}}{2\pi(1-\sigma)}\right]\frac{\alpha}{a}}$$

$$\boxed{m \sim a} \quad \boxed{u \sim a} \quad \boxed{f \sim \frac{1}{a}}$$

Key Observations (Sharpe, 1942)

- **Radius of the equivalent cavity, a, is proportional to the charge size.**
- **Particle displacement is proportional to the charge size.**
- **The dominant frequency of the emitted waves is inversely proportional to the charge size.**
- **The relationship between m and a is difficult to establish due to the nature of energy transfer when dynamite explodes.**



Pressure pulse (dotted line)

Displacement (solid line)

Images taken from Sharpe, 1942.

Data and Field Acquisition

- **Data was obtained during the Hussar Low Frequency experiment conducted by CREWES in 2011.**
- **Groups of test charges, ranging in size between 1 and 4 kg, were buried at a depth of 15 m at 3 separate locations located along the seismic line (Margrave et al. 2011).**
- **Data was recorded by a 5-component geophone array; we used the vertical component of the 10 Hz receiver to conduct this study.**
- **The geophone and sample interval where Δx = 10 m and Δt = 2 ms.**
- **Data was collected for a total of 17 shots along the seismic line, however, this discussion will be limited to data from the first location.**

Power Analysis

- We were primarily interested in examining the power distribution in the first breaks, reflection data, and the ground roll.
- Each component of the seismogram was isolated using time windows represented by straight lines in x-t space.
- After each component was isolated, the power was computed by summing the squares of the traces contained within these windows.
- This procedure was carried out for all 17 shot records obtained from all the test charges.

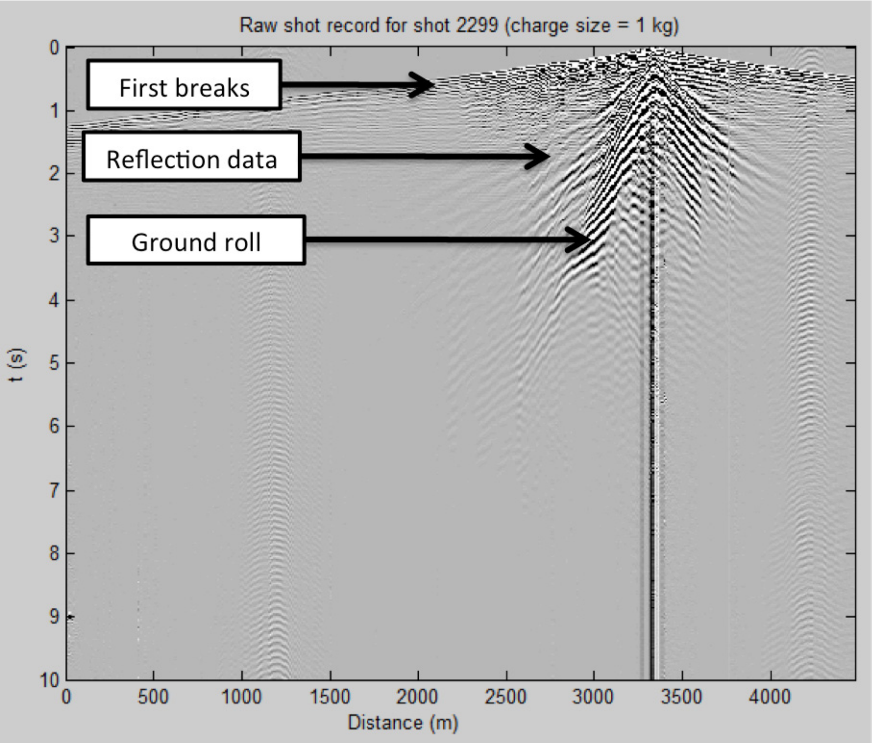
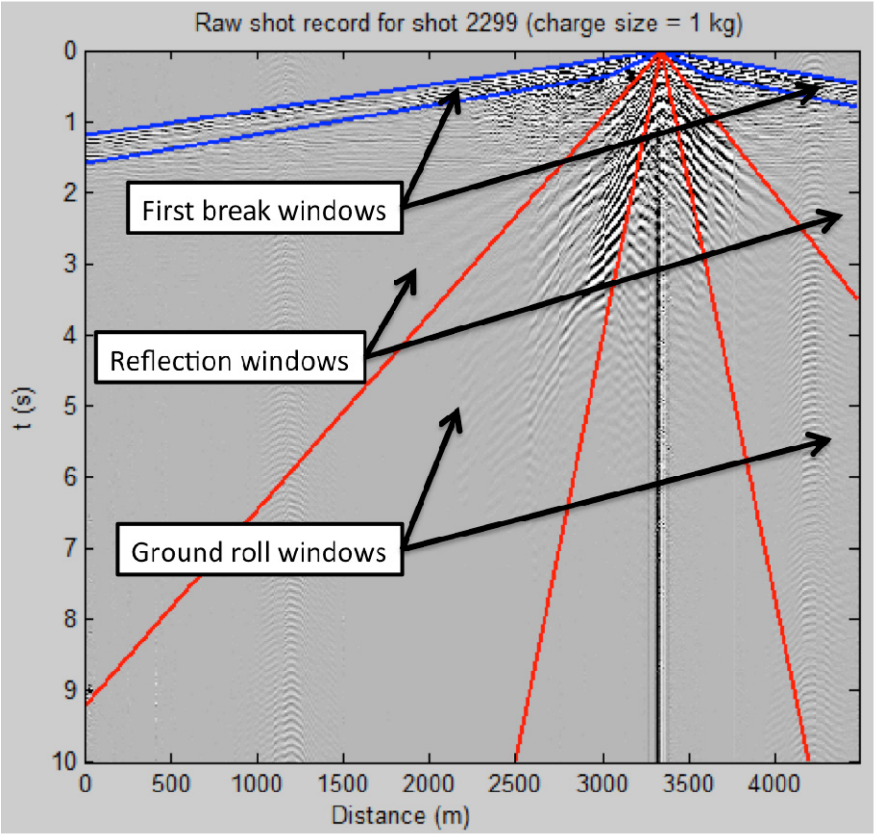
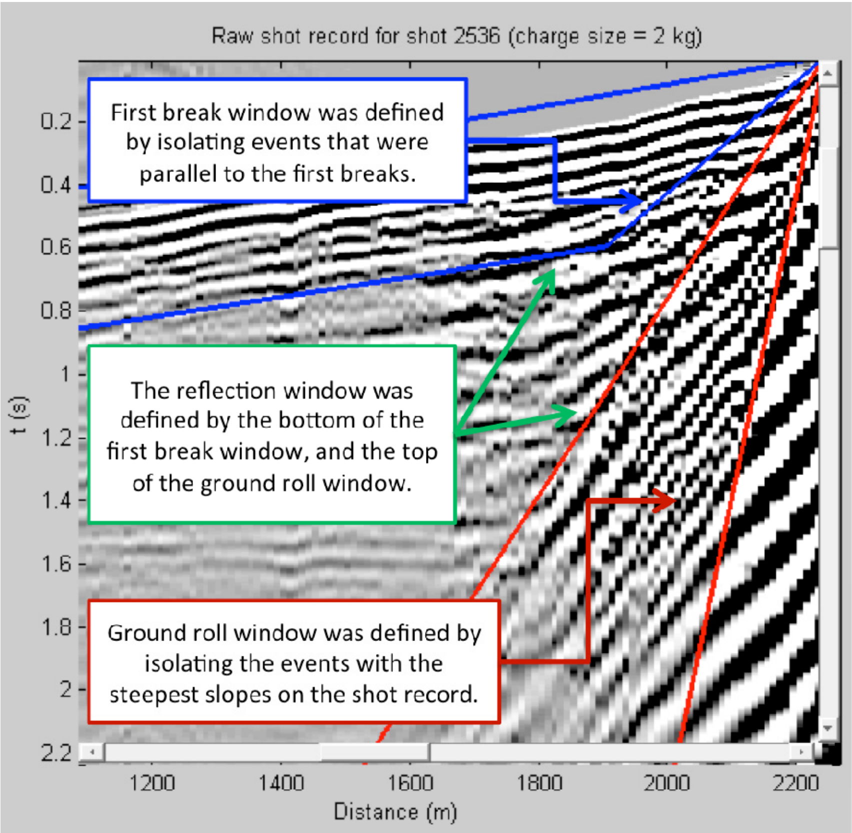


FIG.1. Raw shot record showing the individual components of the shot record that were analyzed in this investigation.

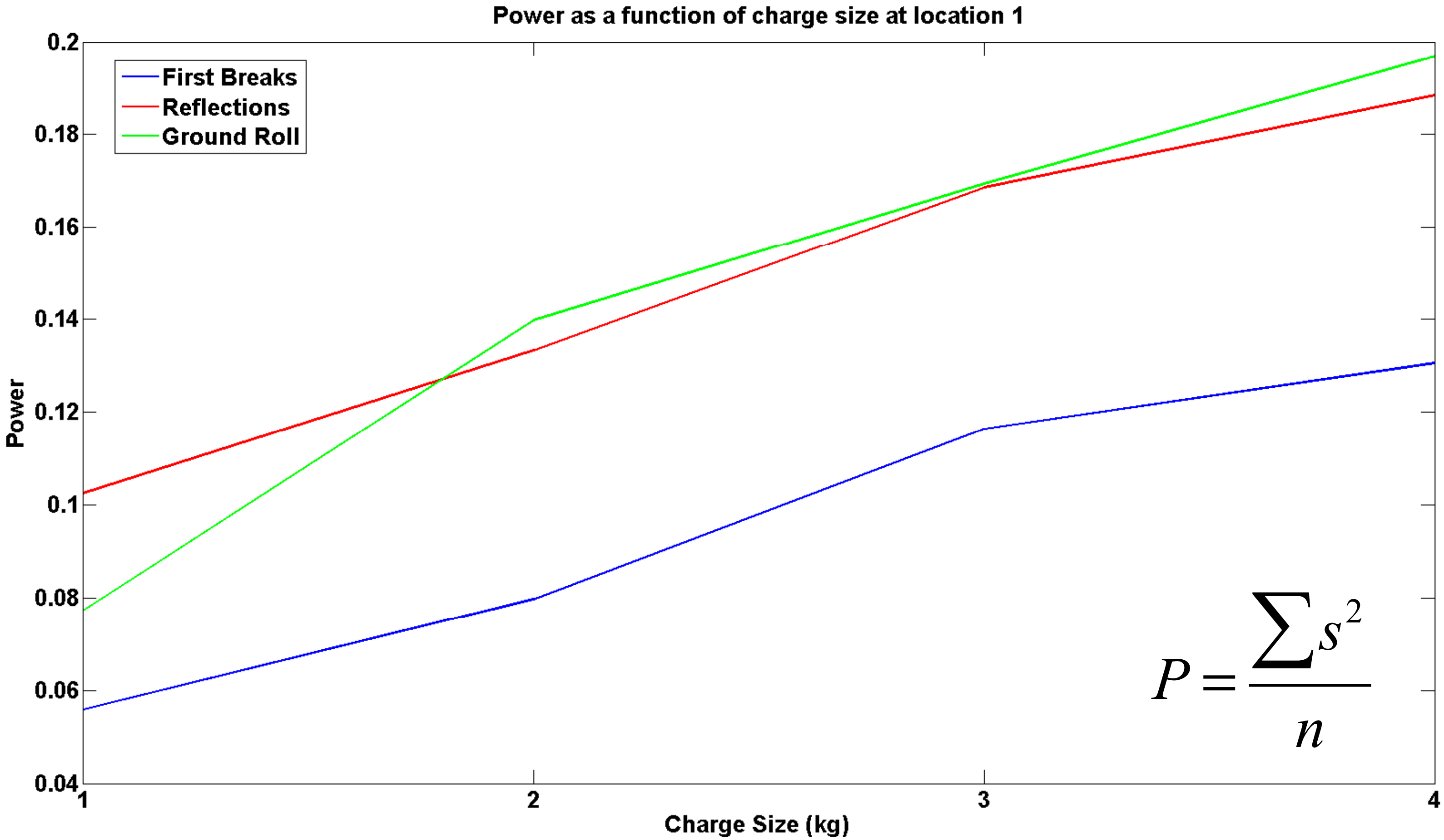
Power Analysis





(Left) FIG.2. Raw shot record showing the time windows used to isolate each component of the shot record.
(Right) FIG.3. Criterion used to isolate the components from the remainder of the seismogram.

Power Analysis



$$P = \frac{\sum s^2}{n}$$

FIG.3. Shot power as a function of charge size at location one. The power, and thus displacement amplitude, appears to increase with charge size as predicted by Sharpe, 1942.

Frequency Analysis

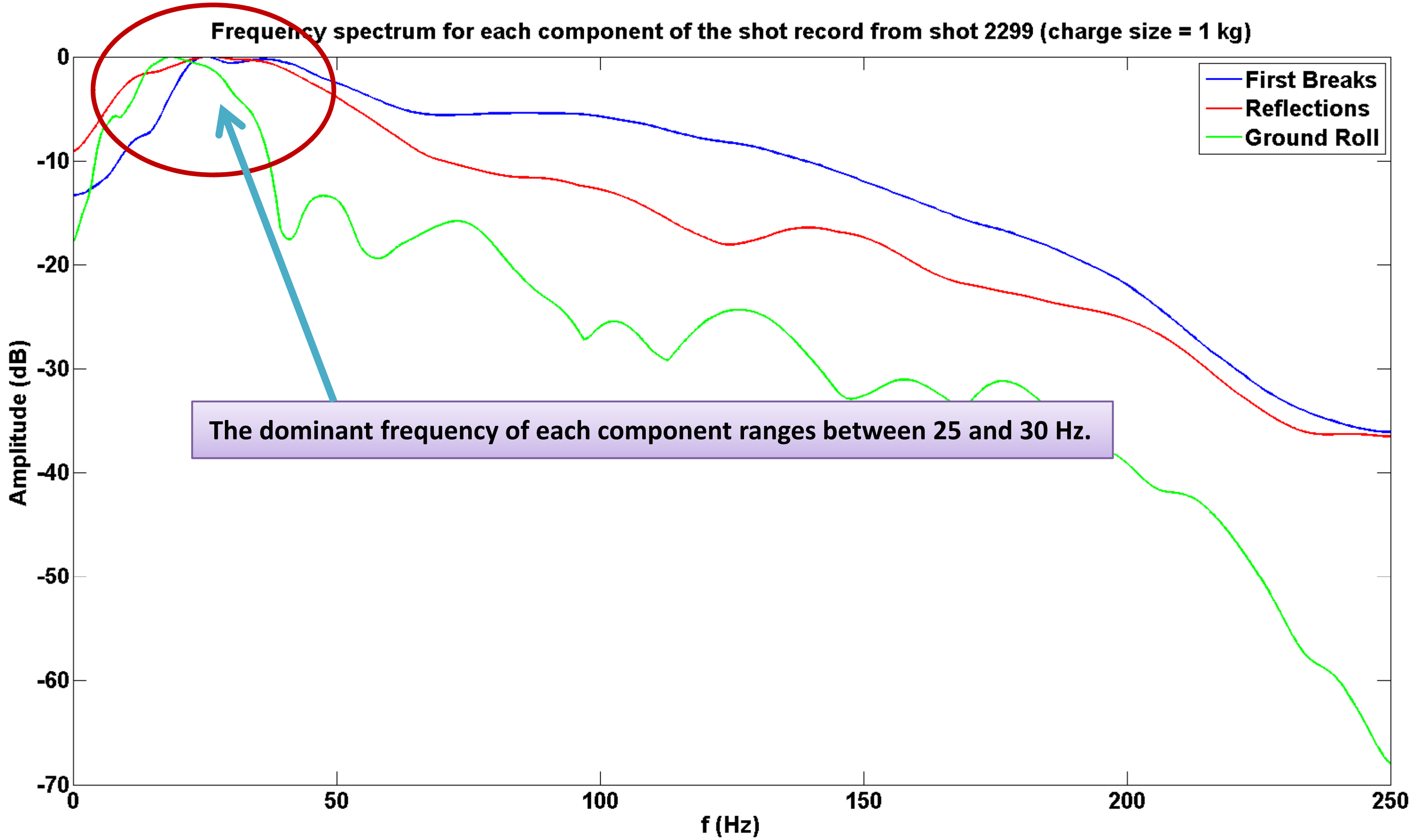


FIG.4. Frequency spectra for each of the components of the shot record for shot 2299. These were obtained via the fxtran_new code using the time windows for tmin and tmax.

Frequency Analysis

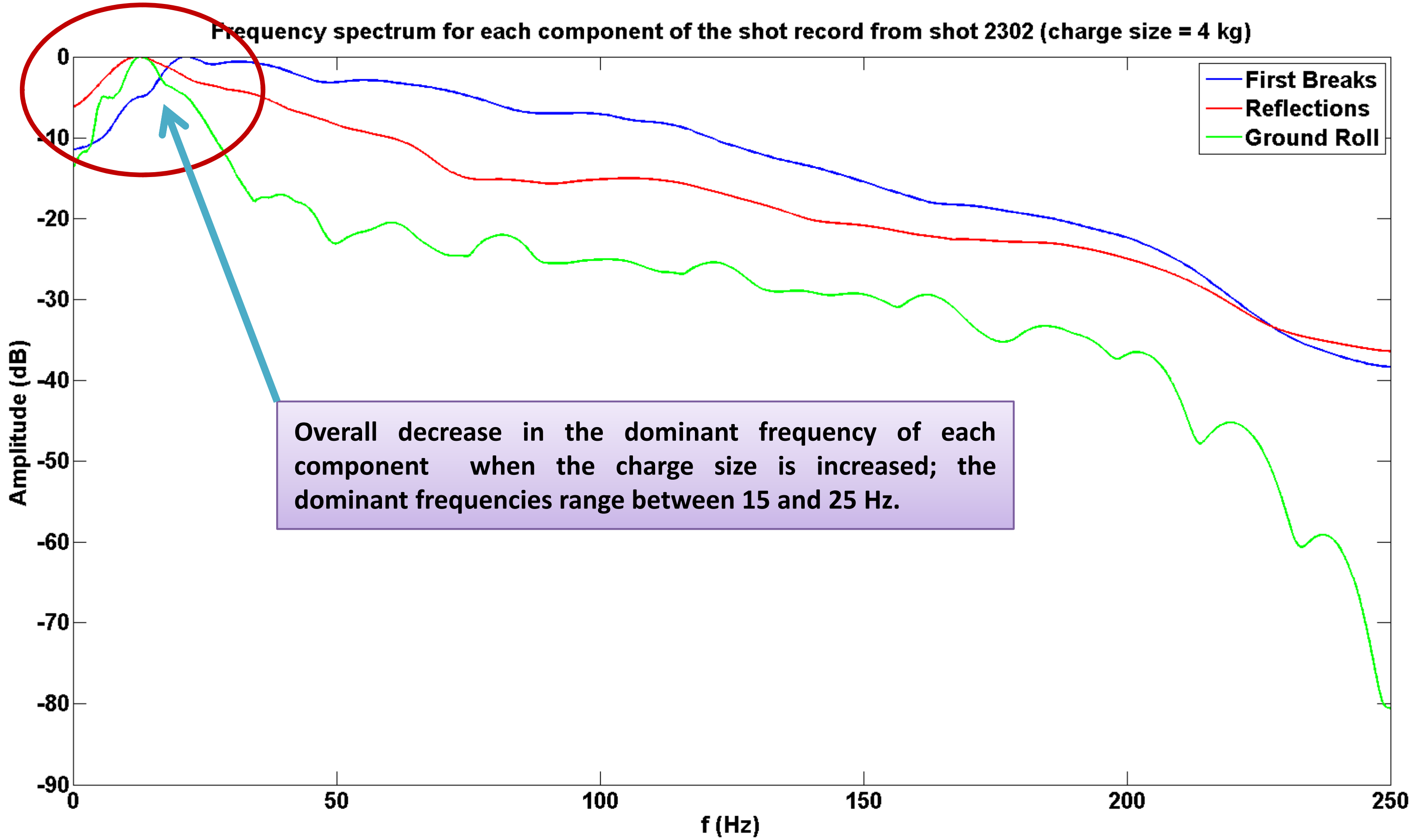


FIG.5. Frequency spectra for each of the components of the shot record for shot 2302. Note the decrease in frequency of each component with the increased charge size.

Frequency Analysis

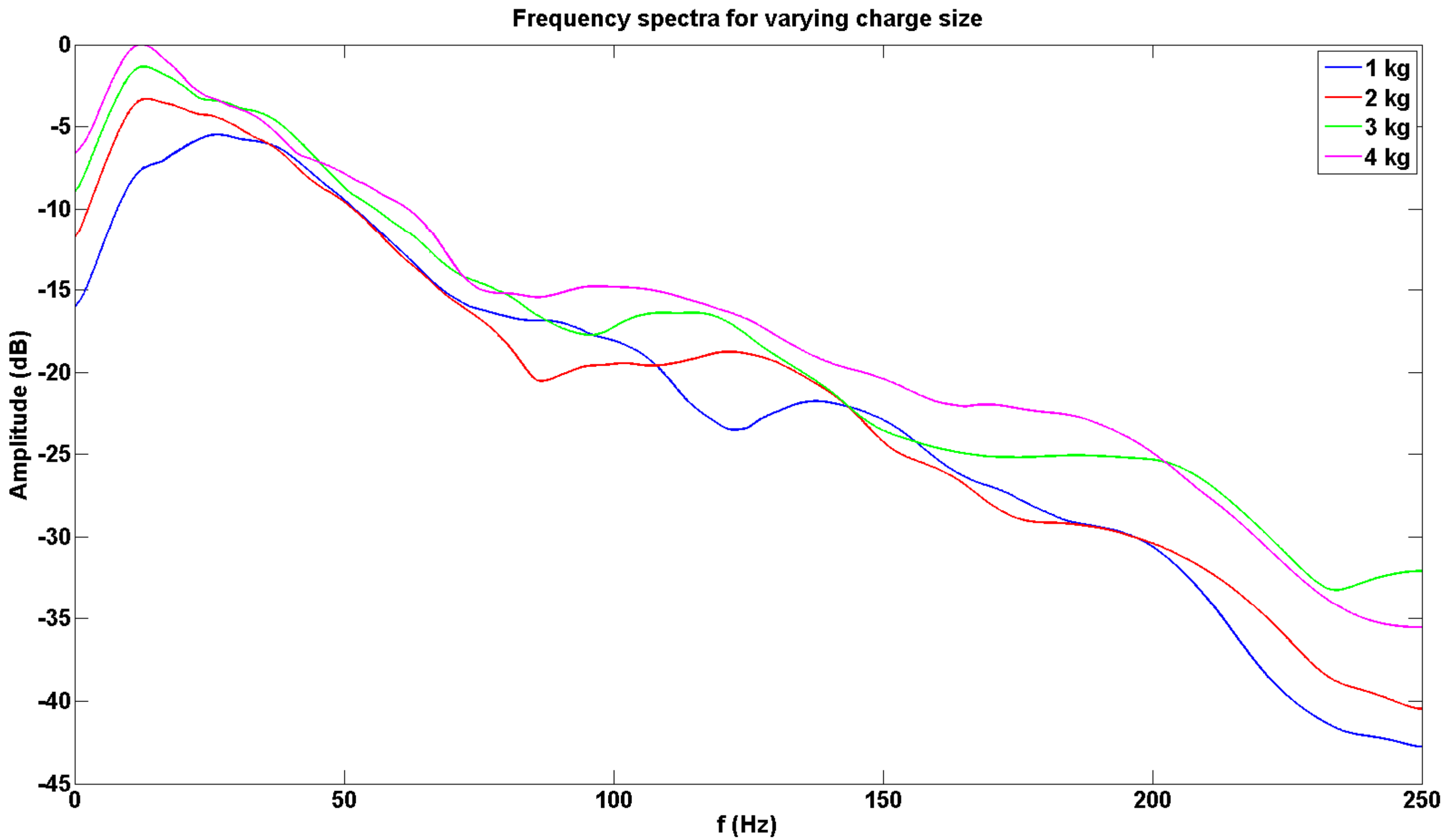


FIG.6. Frequency spectra for the reflections that result from different charge sizes. The dominant frequency appears to decrease with increased charge size as predicted by Sharpe, 1942.

Frequency Analysis

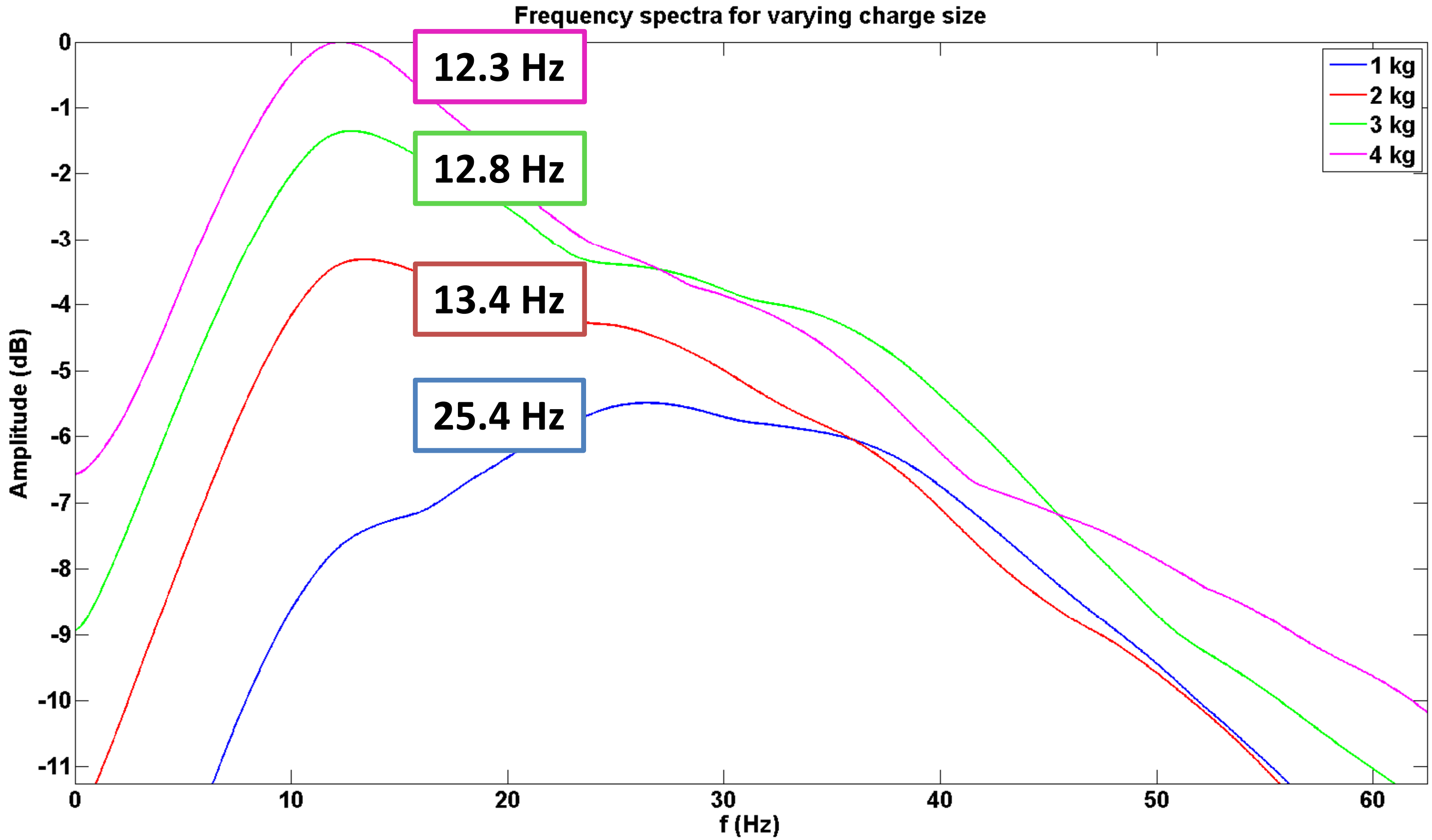


FIG.7. Closer view of the peaks in the frequency spectra for the reflection data. The decrease in frequency appears to be most drastic for the 1 and 2 kg charge sizes.

Relationship between m and a

Assume a relationship between dominant frequency and cavity size to be:

$$\boxed{f_o = \lambda a^n}$$

where:

$$a \sim m$$
$$\lambda = const.$$

<u>*Can we establish a relationship between cavity size and charge size? (we can't control a)*</u>

$$\boxed{\log_{10} f_o = \log_{10} \lambda + n \log_{10} a}$$

Relationship between f and a

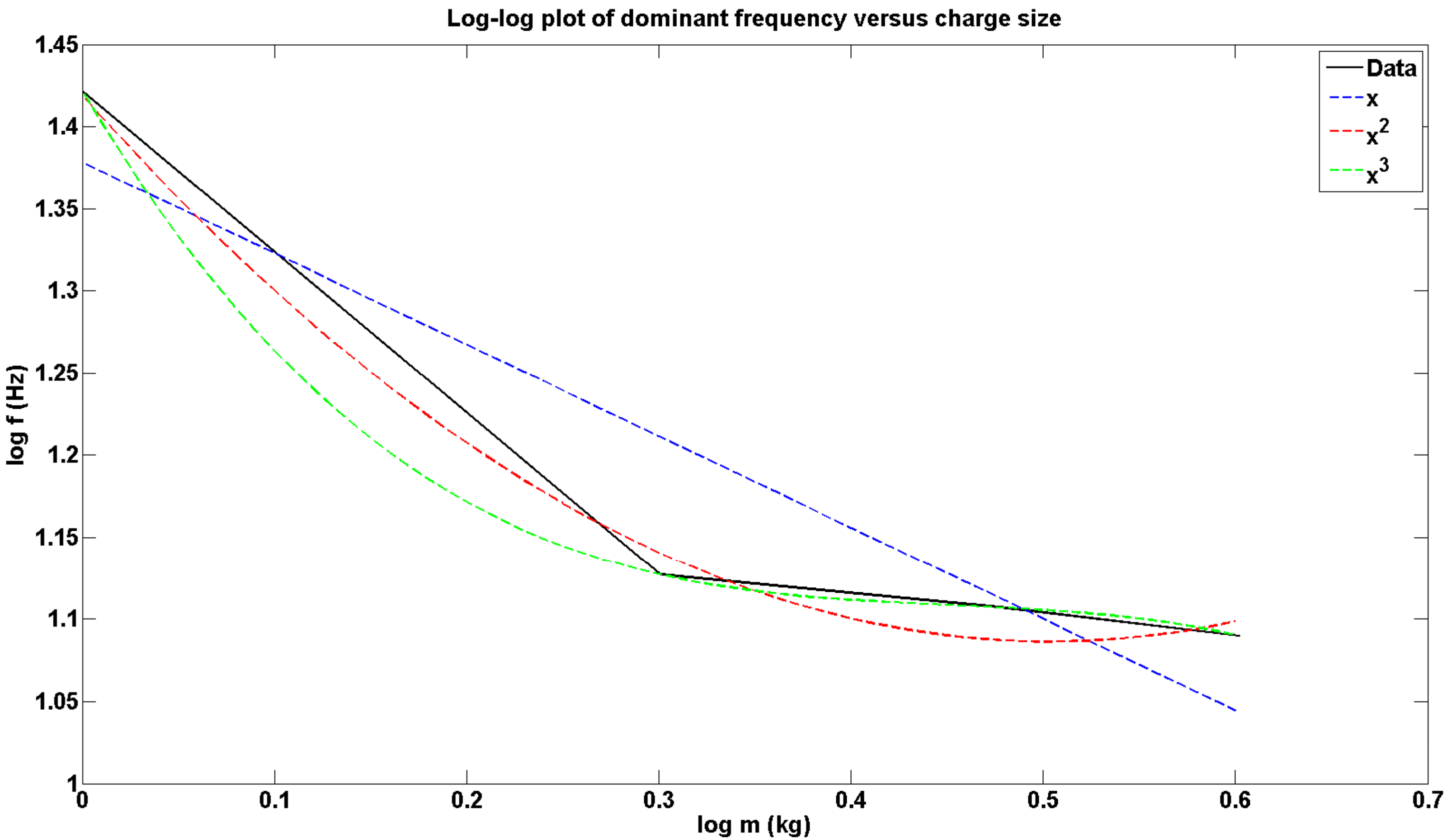


FIG.8. Log-log plot of dominant frequency and charge size. A series of polynomial fits which were computed based on the log of the charge size have been superimposed.

Conclusions

- The spherical model predicts that particle displacement increases with charge size.
- This model also predicts a decrease in dominant frequency with increased charge size.
- Increasing the size of the charge used will increase the power of reflection amplitudes.
- The dominant frequency of elastic waves emitted by a dynamite explosion decreases with charge size.

Acknowledgements

- **I would like to thank Gary Margrave for his assistance with this project.**
- **All of the CREWES sponsors, staff, and students.**