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Testing the viability of the Sharpe Hollow Cavity Model in modelling explosive pressure sources

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Summary

We investigate the viability of utilizing the Sharpe Hollow Cavity Model (SHCM) for modelling explosive pressure sources, specifically dynamite. The SHCM is used to make several predictions regarding the frequency content and amplitude responses for test charges used in two recent CREWES field experiments. It was found that the SHCM was able accurately predict the behaviour of the emitted waves in both field experiments, suggesting that this model could be a very useful tool in designing field experiments.

Introduction

Dynamite is a commonly used tool in exploration seismology and is therefore worthwhile to develop a theoretical basis for modeling dynamite explosions. One of the major challenges associated with modelling an explosion is the fact that the emitted waves that propagate in close proximity to the source do not behave linearly. This phenomenon presents a significant hurdle from a theoretical perspective since wave motion in this region cannot be predicted by the linear wave equation. The SHCM introduced by Joseph Sharpe in the late 1940's (Sharpe, 194XX?) assumes that an explosion can be modelled as a pressure pulse on the inner wall of a hollow cavity.The waves within the cavity do not behave linearly but are assumed to result in a pressure pulse of some possibly prescribable form. Thus the nonlinearity is hidden and replaced with the need to prescribe the transient form of the pressure pulse. Using this assumption, the problem can be reduced to a configuration where elastic waves are emitted directly from the outside walls of the cavity in response to application of a pressure pulse acting on the inside walls of the cavity. In this study, we investigate the validity of such an assumption by applying it to a series of test charges used in the Hussar 2011 and Priddis 2012 experiments conducted by CREWES (Margrave et al., 2012).

Theory

Figure 1 shows a graphical depiction of the SHCM as described by Sharpe in his first paper. The dynamite (shown in red) is enclosed inside a hollow cavity of radius a, wherein the waves are assumed to behave in a nonlinear fashion. The dynamite is replaced by a pressure pulse that acts uniformly on the inside walls of the cavity which results in the emission of elastic waves from the surface of the cavity; these emitted waves (shown as red dotted lines) are assumed to behave linearly, and so their motion can be predicted by the elastic wave equation. The displacement in this model is given by:

$$u = \frac{a^2 p_o}{2\sqrt{2}\mu R} e^{-\omega t/\sqrt{2}} \sin \omega t \tag{1}$$

where R is the distance from the center of source to the point of measurement, a is the radius of the cavity, p_o is a uniform pressure pulse, ω is the angular frequency of the emitted waves, and t is the time. For pratical purposes, we assume that the cavity volume is proportional to charge size and hence expect that the radius will be proportional to the cube-root of the charge size. Thus the cavity radius increases with larger charge sizes. Sharpe uses several assumptions with this model which are important to note: (1) The Lame parameters of the subsurface are assumed to be equal. (2) The waves emitted from the outside walls of the cavity are strictly compressional; this model does not account for the production of shear waves in the subsurface. (3) The dynamite is assumed to be in an infinite homogenous medium. (4) This model is strictly a far-field approximation.

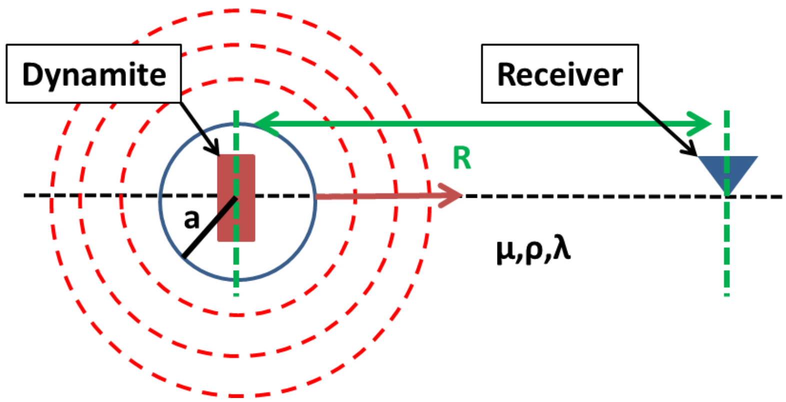

Figure 1: Graphical depiction of the SHCM.

Note that that SHCM assumes that the waves emitted from the source are strictly compressional, so shear waves cannot be modelled using the assumptions presented here. Equation 1 uses a uniform pressure pulse, which is not necessarily representative of a dynamite explosion. Different pressure pulses can be assigned to this model by convolving an arbitrary pressure pulse with the expression shown in Equation 1 and then differentiating, as follows:

$$U(t) = \frac{d}{dt}\int_0^t p(n)u(t-n)dn \qquad (2)$$

where p(n) is an arbitrary pressure pulse, and u(t) is the displacement obtained using Equation 1. Figure 2 shows a series of displacements that result from different pressure pulses, and Figure 3 shows the frequency spectra that result from these displacements. The choice of pressure pulse plays an important role in the SHCM as different pulses result in significantly different frequency spectra, most notably in the low frequency content. In this particular study, a decaying exponential seems to best represent a dynamite pulse since a significant portion of energy is released at first, which then decays in time over a short period.

The cavity radius also plays a significant role in the resulting frequency spectra, which can be seen in Figure 3. Amplitude in this case increases with charge size however, the dominant frequency appears to decrease with larger charge sizes in the SHCM.

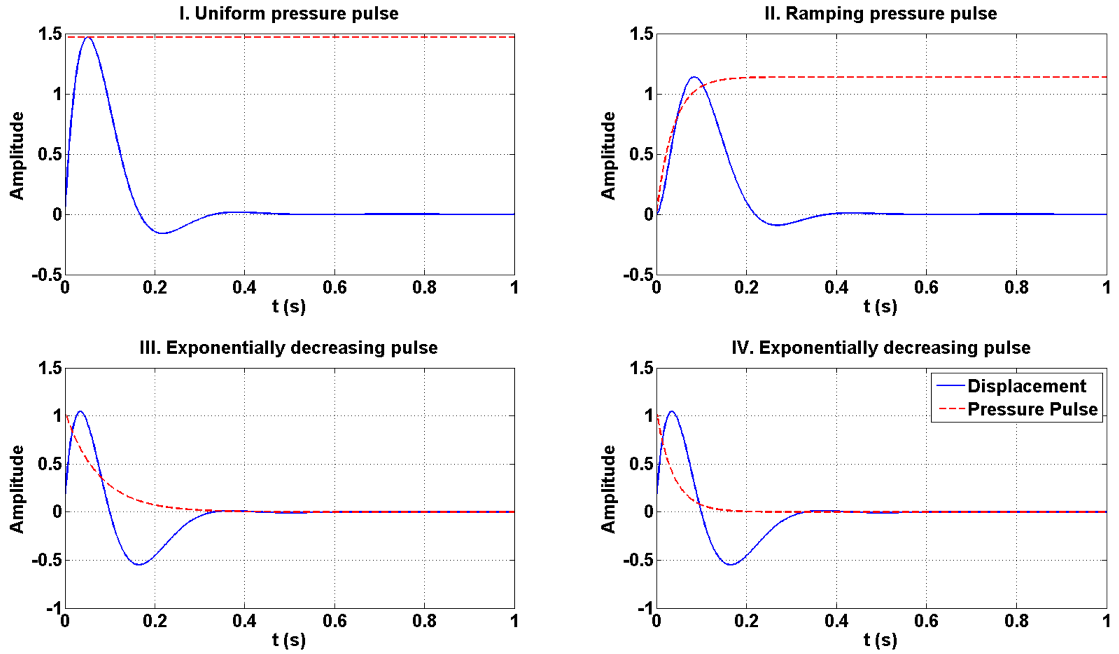

Figure 2: Displacements that result from various pressure pulses in the SHCM. Note that in each case the pressure pulses have been scaled to the maximum amplitude of the displacement. (I) Particle displacement that results from application of a uniform pressure pulse, ie, a pressure pulse that is one at all points in time. (II) Particle displacement that results from application of a pressure pulse that is increasing with time. (III) Particle displacement that results from application of an exponentially decreasing pressure pulse with time. (IV). Particle displacement that results from the exponentially decreasing pressure pulse shown in III, however in this case the decay constant is much larger.

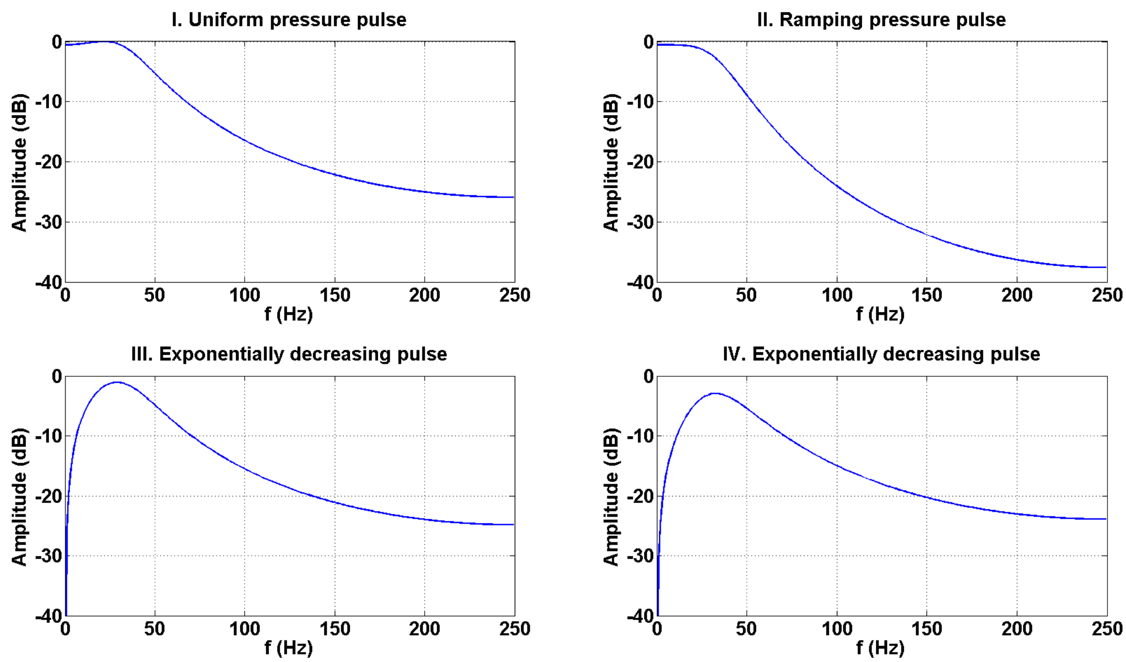

Figure 3: Frequency spectra that result from the displacements shown in Figure 2. In I and II there does not appear to be a low frequency roll-off present in the spectra, however, in III and IV there appears to be a roll-off in frequency below the dominant frequency.

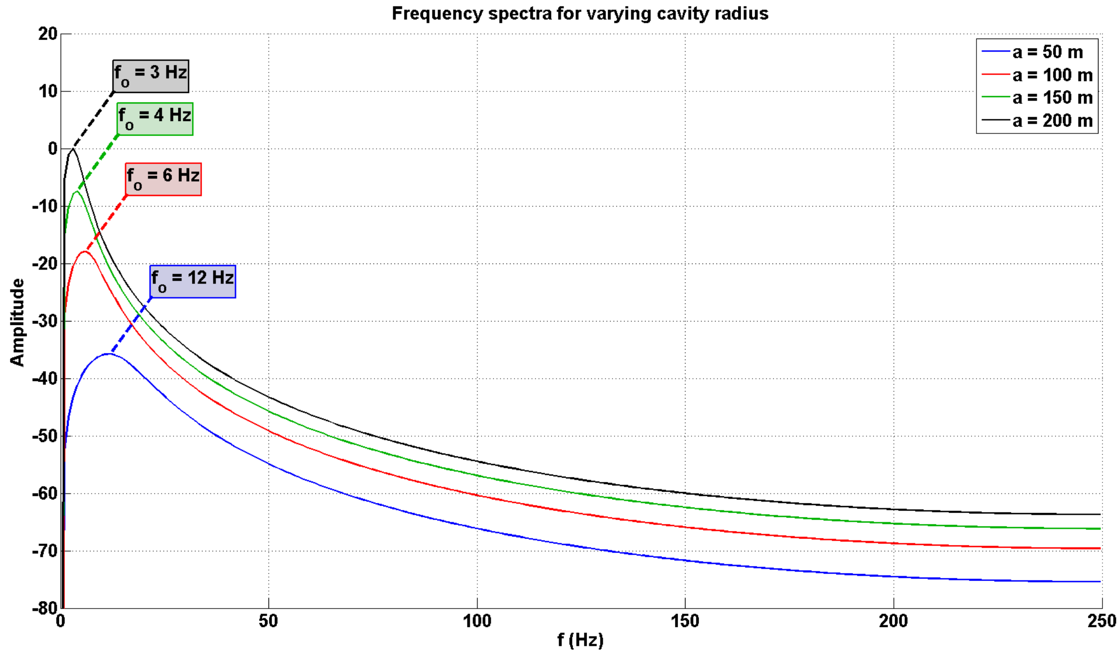

Figure 4: Frequency spectra that result from different cavity radius.

Observation of Figures 2 through 4 shows some specific criteria that have to be present in real data in order for the SHCM to be a viable model for modelling dynamite: (1) a low-frequency roll off should be present, (2) amplitude should increase with charge size, (3) dominant frequency should decrease with larger charge sizes, and (4) a loss in high frequency content should be observed for smaller charges.

Examples

Figures 5 and 6 show the frequency spectra for test charges used in the Hussar 2011 and Priddis 2012 test shoots. These spectra were computed as the average frequency spectra over the entire shot record, using the full length of the time window. These spectra include all body waves and have not been filtered in any way. In both cases a low-frequency roll off occurs, there is a decrease in dominant frequency with larger charge sizes, amplitude increases with larger charges, and there is a loss in high-frequency content with smaller charges. These match the predictions of the SHCM which provides strong evidence that this model provides a viable means of modelling dynamite explosions.

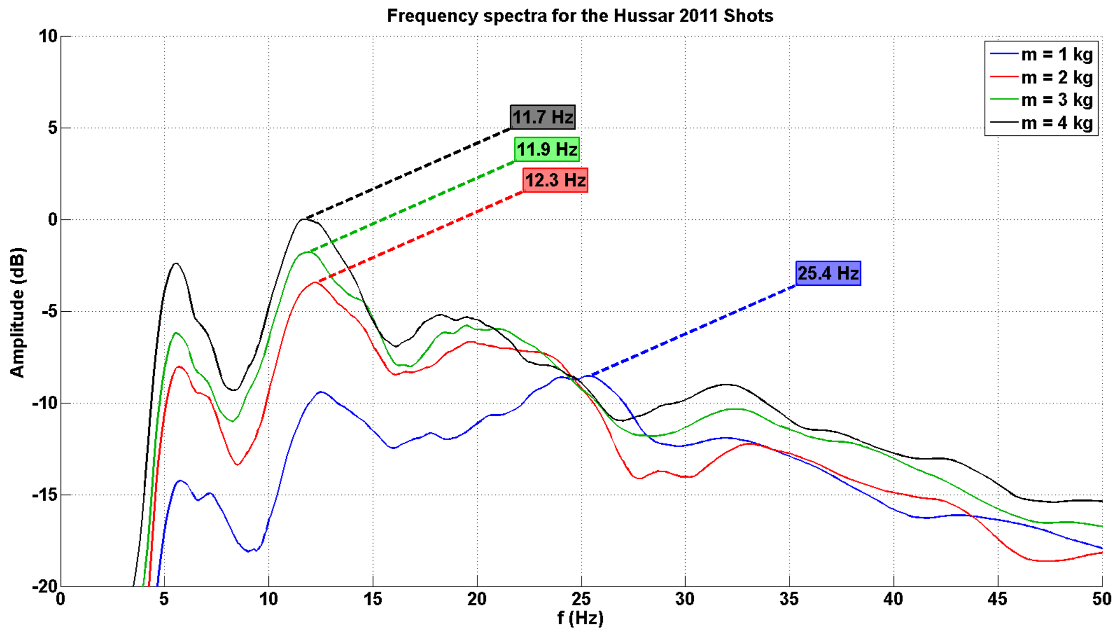

Figure 5: Data from the Hussar 2011 field experiments.

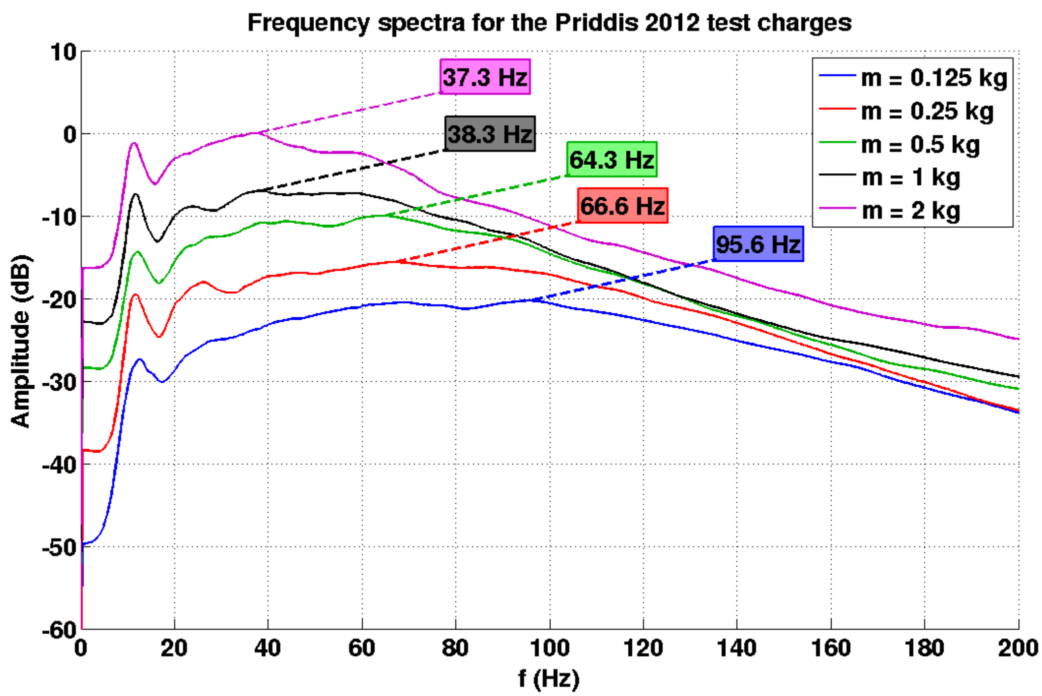

Figure 6: Data from the Priddis 2012 experiments.

Conclusions

The data obtained in both the Hussar and Priddis experiments seem to match the predictions set forth by the SHCM, which suggests that this model can be applied to dynamite surveys in general. Currently, there is no link between charge size and cavity radius which significantly limits this model at this time.

Future work includes a more accurate means of linking charge size and cavity radius, and obtaining more data to further test this model.

Acknowledgements

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References

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