



Effect of Varying Source Charge Size on Seismogram Data Quality in Kwale, Niger Delta, Nigeria

IFEANYI IKECHUKWU CHUKWUEMEKA AGBODIKE^{1*} and
EMMANUEL AZUBUIKE OZOGBU²

¹Department of Physics, Imo State University, PMB, Owerri, Nigeria.

²Department of Science Laboratory Technology, Federal Polytechnic, Ngodo-Isuoch, Abia State Nigeria.

*Corresponding author E-mail: emmaozogbu@gmail.com

<http://dx.doi.org/10.13005/OJPS10.02.09>

(Received: April 08, 2025; Accepted: July 16, 2025)

ABSTRACT

This study investigates the effect of varying seismic source charge sizes on seismograms in Kwale, a hydrocarbon-rich region of the Niger Delta, Nigeria. High-resolution seismic data acquisition is critical for accurate subsurface imaging and the source energy plays a very important role in determining data quality. Field experiments were conducted using different charge sizes ranging from 2.0 kg, 2.5 kg and 3.0 kg as seismic energy sources at a fixed depth of 20.0m to assess their impact on key seismogram attributes, including signal-to-noise ratio (SNR), depth of reflection events and continuity. The results demonstrates a clear correlation between charge size and data quality: larger charges generally enhanced signal-to-noise ratio and depth of reflection events as well as event continuity. Geological conditions in Kwale, including lithological variability further influenced the energy transmission and recording. The study concludes that careful calibration of seismic source parameters is essential to balance energy penetration with noise control in the Niger Delta's complex subsurface environment. These findings provide a practical framework for charge size optimization in seismic data acquisition strategies in similar geologic settings.

Keywords: Charge size, Niger Delta, Nigeria, Reflection events; Seismic amplitudes.

INTRODUCTION

One of the main problems of seismic survey is seismic charge optimization. Seismic charge optimization involves determining the optimal amount of explosive energy to be released in a seismic survey so as to achieve the best possible data quality while minimizing costs and impact on the environment. There has always been the need for

improved Seismic methods that depend on the right configuration of explosives capable of converting a greater proportion of its potential energy into seismic wave at the optimal charge size. This study aims to determine the relationship between seismic source charge size and seismic data quality (seismic energy amplitude, signal-to-noise ratio and depth of signal penetration, that is, depth of reflection events) as well as provide insight on solving optimization problems



in seismic surveys. This study demonstrates by field records that the increased seismic source charge size produces a higher ratio of reflected energy to ground roll interference than the small source charge size does. It also showed that increased seismic source charge sizes produce greater reflected wave to low frequency random noise ratio. Frequency and signal-noise ratio of seismic data controls seismic vertical and lateral resolutions.² Hence, vertical and lateral seismic resolution are as well affected by varying source charge size. Explosive source has unequalled impulse of energy that is rich in all useful seismic frequencies. Similarly, charge size and charge depth are very important parameters for acquiring good quality seismic data in a land seismic survey using explosive sources.⁶

The importance of examining the relationship between charge size and seismogram characteristics, providing insights and practical guidelines for optimizing seismic source parameters is what this research aims to achieve. Understanding the optimal charge size required to produce high-quality seismograms under different geological conditions would reduce chances of overcharging that could lead to environmental concerns and unnecessary costs. On the other hand, undercharging would result in weak signals and poor seismic data quality that could negatively impact the subsurface imaging intended. The findings aims to assist geophysicists, geologists and field engineers in making informed decisions that could enhance data quality while balancing economic and environmental considerations. Therefore, a systematic analysis of the effect of varying seismic source charge sizes on seismogram quality is essential.

The scope of the work is delimited by the geographical and subsurface geology of the study area, Kwale, Delta State in Niger Delta region of Nigeria. The scope is also delimited by use of seismic explosive source type and use of simplified model assumptions. The simplified models assumptions include: linear relationship between charge size and seismic data quality, no scattering, no anisotropy, no dispersion and Gaussian distribution of errors which may not accurately represent real-world error distribution.

Area of Study and its Geology

The area of this study is Kwale, Delta State,

located in latitude 50 42' 27" N and Longitude 60 26' 2" E in Niger Delta, Nigeria. The geology of the Niger Delta Basin to which Kwale belongs is already well established. The early Niger Delta is dominated with river but its post Oligocene is wave-dominated, having mangrove and freshwater swamps with tidal channels, beach ridges and shore sands.³ It shows a transition from Akata Formation upwards through Agbada Formation to Benin Formation.

Theoretical Background

Understanding explosion source processes is very important in seismic event characterization. Seismic exploration and monitoring rely heavily on the quality of recorded seismograms, which are influenced by the source characteristics, particularly the charge size. The amplitude, frequency content, and waveform clarity generated by this artificial seismic energy source depend significantly on the energy released, which is directly related to the size of the explosive charge. The amplitude of seismic wave and the signature of the source are affected by both the explosive yield, thermodynamic behavior of gaseous yields and the detonation velocity.⁸ The peak ground vibration amplitude is positively correlated with TNT explosive mass.⁵ The peak seismic amplitude increases with explosive mass, confirming a direct relationship between charge size and received vibration level.⁴ It is established that seismic amplitude from explosions often follows a cube-root scaling law, meaning that the amplitude, A , is directly proportional to the cube root of explosive energy, W .⁹ Similarly, the signal-to-noise ratio (SNR) increases with explosive yield, improving detection capabilities for larger events.¹

Additionally, the frequency content of the seismogram can be affected by charge size. Smaller charges tend to produce higher frequency waves that are more susceptible to attenuation, while larger sizes yield more low-frequency content, which can penetrate deeper but might reduce resolution in near-surface imaging.

MATERIALS AND METHODS

The method used involved loading of explosives (dynamite and detonators) charge sizes of 2.0 kg, 2.5 kg and 3.0 kg as seismic energy sources in three different drilled holes of constant depth of 20.0m within the same location. The three

shot holes were drilled as single deep holes (SDH) to 20m depths using motorized pump. The loaded source holes were backfill and properly tamped to minimize energy loss through blowout when the seismic shot is taken. These seismic sources were then shot into a seismic symmetric split-spread consisting of eight receiver lines of 1568 (196*8) active channels per shot, with 50m receiver spacing, 50m source spacing, 300m receiver line spacing and 350m source line spacing giving a nominal fold of 56. The acquisition parameters remained same except for the changing charge sizes throughout the course of this study. This methodology is consistent with the method described by Stewart *et al.*, which demonstrated that seismic signal quality, especially in terms of amplitude and frequency content is significantly influenced by source energy and coupling conditions.⁷ The charge sizes are the independent variables while the observed amplitude variations were the dependent variables.

RESULTS

The effect of varying seismic source charge on seismogram quality was systematically analyzed by deploying controlled charges ranging from 2.0 kg through 2.5 kg to 3.0 kg at same test site. All the sources were detonated at a consistent depth of 20 meters to reduce variability from surface coupling effects. The primary metrics for evaluating seismogram quality included seismic energy return and signal amplitude, depth of penetration, waveform clarity and signal-to-noise ratio as well as consistency of arrival times.

Amplitude and Seismic Energy Return

Seismogram generated using 3.0 kg charge size showed the highest recorded seismic energy return and hence amplitude. This decreased as the charge size decreased from 3.0 kg to 2.0 kg through 2.5 kg at consistent charge depth of 20m.

Signal-to-Noise Ratio and Waveform Clarity

The clarity of first arrivals and subsequent phases improved with increased charge size. At 2.0 kg charge size, the first arrivals and subsequent phases were much more obscured by ambient noise. The ground roll also obscured much of the reflection events. Thus reflection events could not be seen clearly beyond 2.1s. At 2.5 kg charge size, reflection events could be seen on monitor records down to

2.3s only but reached 2.9s at charge size of 3.0 kg. This represents increasing signal-to-noise ratio with increasing charge size.

Depth of Penetration

Depth of penetration of seismic signal is represented by two-way travel time of reflection events. Longer time of reflection event implies deeper penetration of the seismic signals barring possible multiple reflections in the subsurface. Thus, it was observed that with 3.0 kg charge size, the two-way travel time of the reflection event could be clearly seen down to 2.9s while with 2.5 kg charge size, the clearly seen reflection event time reduced to 2.3s and later to 2.1s at 2.0 kg charge size.

Consistency of Arrival Times

Arrival times for each phase remained stable across all charge sizes, indicating that charge size did not affect the timing of wave propagation in any significant manner.

DISCUSSIONS

The field experiment demonstrated a direct correlation between seismic source charge size and the resulting seismogram quality. The seismograms were evaluated based on the following primary parameters: Signal amplitude, depth of reflection events and its continuity and signal-to-noise ratio.

Signal Amplitude and Depth of Penetration

In line with our expectation and reviewed literature, larger charge sizes produced higher seismic wave amplitude and deeper reflection events. The increase in amplitude and depth of penetration was most pronounced at 3.0 kg charge size. At 3.0 kg, deeper reflection events could be clearly seen on the raw seismic records down to 2.9s on the monitor records while at 2.5 kg charge size, the reflection events could only be seen clearly down to 2.3s and at 2.0 kg, the reflection events is seen clearly down to only 2.1s. It should be noted here that travel time could be converted to depth if the wave velocity in the medium is determined by a method outside the scope of this research. Thus, longer two-way travel time on the monitor records corresponds to deeper depth of penetration (barring multiple reflections).

Signal-to-Noise Ratio

The signal-to-noise ratio improved consistently with increasing charge size up to the maximum charge of 3.0 kg used in this research. At 2.0 kg charge size, the ground roll was very strong masking data leading to very low reflection signal to ground roll ratio with reflection events shallower than 2.1s on the two-way travel time of axis the monitor record. The reflection signal to ground roll ratio improved at 2.5 kg charge size but was best at 3.0 kg source charge size. At 3.0 kg charge, the reflection signal to ground roll ratio was very strong as the reflection signal is seen cutting across the much weaker ground roll and clearly reaching a penetration depth equivalent in travel time of 2.9s on the monitor records.

Operational Considerations

From a practical standpoint and Oil Industry regulations in Nigeria, there are approved safe shooting distances to different types of structures for every charge size and charge depth. This has to be put into consideration when planning seismic survey using explosives as energy sources. Another consideration is technical consideration when source points need to be offset because of poor safe shooting distance resulting from larger than normal explosive size. Offsetting a source point has negative geophysical impact because near-trace offset contributions to the subsurface imaging are usually lost when source points are offset from their originally designed positions. Another consideration is that large charge sizes would require deeper depths to minimize impact on the environment. This also increases the cost of the seismic survey.

Interpretation and Implication

The result suggests that while increasing seismic charge size generally improves seismogram quality, the benefits are nonlinear and site-dependent. These findings align with earlier studies and contribute to a growing body of knowledge supporting tailored charge optimization based on geological conditions and imaging goals. Future work could explore charge effects in more complex lithologies.

CONCLUSION

This study has demonstrated a clear relationship between explosive seismic source

charge size and seismogram data quality. Larger charge sizes generally produce stronger energy returns, clearer signals, improving resolutions and penetration depth. However, increasing charge sizes introduces environmental concerns and associated costs. On the other hand, smaller charge sizes results in weaker and poor signal-to-noise ratio, especially in deeper or more complex subsurface conditions. This study offers insight into right explosive seismic source configuration that would give optimal seismic data quality while minimizing cost and environmental impact. From the analysis, it is seen that increasing the seismic source charge size results in increased energy returns on seismic record leading to greater ratio of reflected energy to ground roll interference and deeper reflection events (2.9s for 3.0 kg charge size, 2.3s for 2.5 kg charge size and just down to 2.1s for 2.0 kg clearly seen on raw monitor records on a fixed charge depth of 20.0m). These findings highlight the importance of explosive charge optimization based on specific geological settings and survey objectives. Ultimately, achieving high quality seismogram requires balancing signal clarity with operational safety, costs and environmental considerations.

ACKNOWLEDGMENT

The authors are grateful to lecturers in the Department of Physics, Imo State University, Owerri for their invaluable contribution to this study. The invaluable contributions and work of the Seismology Department of Sinopec Changjiang Engineering Services Limited during this data acquisition campaign is also very much appreciated.

Funding Source

The authors received no financial support for the research, authorship, and/or publication of this article.

Conflict of Interest

The authors do not have any conflict of interest

Data Availability Statement

This statement does not apply to this article

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Permission to reproduce material from other sources

Not applicable

Conceptualization, Methodology, Data Collection, Analysis, Writing-Original Draft and Editing after review.

Author Contributions

Emmanuel Azubuike Ozogbu:

Ifeanyi Ikechukwu Chukwuemeka Agbodiike

(PhD): Review and Funding

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