ENERGY- CONTENT AND SPECTRAL ANALYSES OF SHOTS FOR OPTIMUM SEISMOGRAM GENERATION IN THE NIGER DELTA

Alaminokuma G.I. and *Emudianughe J.E.
Department of Earth Sciences, Federal University of Petroleum Resources Effurun,
P.M. B. 1221, Effurun, Nigeria
*Author for Correspondence

ABSTRACT
Energy content and spectral analyses of shots were conducted in the Central Niger Delta. Charge sizes of 0.4kg, 0.8kg, 1.2kg and 2.0kg units of dynamite were detonated respectively in two pattern holes configuration and eight single-deep holes arranged equally on the inner and outer circumferences of two circles. Seismogram quality was verified by computer-aided visualization and analyses of monitor records. Analyses of the seismograms for pattern shots show that increasing the charge size from 0.4kg to 1.2kg at same depth enhances strong energy but reduces frequency. The 5-hole x 3.5m x 2.0kg pattern shot configuration was observed to depict the best seismogram quality. In highly built-up areas where non-seismic objects are unavoidably present, the adoption of a 3-hole x 3.5m x 1.2kg pattern is necessary in order not to loose the near bin population about these structures. Guided by the energy components, distinctive frequency and signal-to-noise ratio, 5-hole x 3.5m x 1.2kg or 5-hole x 3.5m x 2.0kg shot records are comparable to same charges loaded at 15m or 40.0m deep holes. This research is important for better acquisition and interpretation of seismic data to improve reservoir characterization and increase hydrocarbon production.

Keywords: Energy-Content, Spectral Analyses, Pattern Hole, Single-Deep Hole, Seismogram, Niger Delta

INTRODUCTION
The energy content and frequency required to record seismic reflections is variable and depends on many factors, including the depth of the target and its thickness (Knapp and Steeples, 1986).

The signal-to-noise ratio of seismograms increases as the seismogram quality improves. Feroci et al., (2000) compared different sources in one particular area. They found that even if there are no substantial differences in frequency content, significant signal-to-noise ratio (S/N) differences are observed; suggesting that the source can dramatically influence the S/N. Seismogram quality depends on the charge size and charge depth. Large charge sizes involve loss of high frequency components as evidenced by the lower amplitude from 45Hz and the reduction in peak frequency from 36 to 31Hz. Charge depths usually affect the frequency content of the record and the ratio of signal-to-shot generated noise (Dale, 1994).

The energy of a seismic wave can be quantified by the energy density (energy per unit volume). Energy density (E) is proportional to the square of the frequency (f) within the same medium: $E = 2\pi f^2 A^2$ where $\rho$ is the density of the medium and A is the amplitude (Sheriff, 1975; Telford et al., 1990).

Since seismic resolution is directly related to the dominant frequency of the signal, it is important to find seismic sources capable of generating adequate high frequency energy which is the purpose of this paper. High resolution seismograms are necessary for better interpretation of seismic data to improve reservoir characterization and increase hydrocarbon production.

Field Location and Layout for Shots Configuration
The study area is located in the Central part of the Niger Delta between Latitude 10º00’ N and 14º00 N and Longitude 39º00 E and 42º50 E (Figure 1.0).

Two types of the linear spread of the Pattern Shot points were symmetrically spread about the peg position in two circles of radii 5 and 10 m respectively. These were the 3-hole and 5-hole patterns as shown in Figure 2.0. A separation of 10m distance was maintained between each shot hole. Five shot
points were established on each of the circles at angles of 60° and 45° making a total of 10 shot points as shown in Figure 2.0. All the established points on the 5m radius circle were labeled alphabetically from A to E. The single-deep hole on the inner circle was shot before the deep holes on the outer circle to ensure quality of signal reflection. Two geophone strings of nine jugs in series were laid out linearly at 2.78m spacing about the peg position along the receiver line for effective noise cancellations and enhanced S/N ratio for better data quality. Receiver station interval was 50m and 200 channels per line. A total of 6 receiver lines were deployed. All the experimental shots were acquired with full receiver spread (1200 stations). The shot log generated is shown in Table 1.0. The recorded raw monitors were processed on site.

Analyses of Monitor Records and Results
A time window of 2200 – 2300ms was used for the analyses within the shallow, mid and deep reflections for different shot configurations without applying Automatic Gain Control (AGC) which has the capability of boosting signal as well as noise. This time window was observed to display most coherent frequencies than adjacent windows.

3.1 Energy-Frequency Content Analysis
3.1.1 For Pattern Records
Two Pattern configuration records were analyzed for energy-frequency content. From the analysis, the frequency and energy levels are stronger in the 5-hole shot configuration record compared to the 3-hole records. Reflection was also observed to be distinct and continuous in the 5-hole configuration record between 2.7 and 3.1s while on the 3-hole shot configuration, reflection is less distinct and continuous as shown in the square with red border in Figures 3.1a – 3.1b.

3.1.2 For Single Deep Hole (SDH) Records
The energy-frequency contents were analyzed for shallow, mid and deep layers. Two SDH shot types (15m and 40m) were analyzed at varying charge sizes: 0.4kg, 0.8kg, 1.2kg and 2.0kg.

a) 15 m SDH
Between the time slice of 1.8 and 2.1s shown in Figure 3.1c (0.4kg), the energy and frequency are not strong, while the reflections are continuous. However, the energy and frequency are weak between 2.7 and 3.1s. Here, signal coherency was the most deciding factor that guided the choice of time windows. Comparing the energy and frequency components of Figure 3.1c and 3.1d with those of Figures 3.1e and 3.1f, a sharp change in frequency and energy level can be observed. Energy and S/N are better, distinctive and comparable for both 1.2 kg and 2.0kg shot records.

b) 40 m SDH
From Figure 3.1g (0.4kg) charge between the time slice of 1.8 and 2.1s, the energy and frequency components are fair, while the reflections are continuous. However, the energy and frequency are poor between 2.7 and 3.1s. From Figure 3.1h (0.8kg), the frequency component is good with continuous reflections. However, between 2.7 and 3.1s, the energy is weak with an improved frequency component. Comparing the energy and frequency components of Figure 3.1g and 3.1h with those of Figures 3.1e with 1.2kg charges and Figure 3.1j with 2.0kg charges, there is a sharp change in frequency and energy level. Energy and S/N are better, distinctive and comparable for both 1.2kg and 2.0kg shot records loaded at 40m.

The above analyses show that either the 1.2kg or 2.0kg loaded at 40 m Top of Charge (TOC) provided a good quality seismogram.

3.1.3 Same Depth Different Charge Size
At the same depth, when the charge size is increased, the energy return is increased while the frequency is reduced (Figures 3.2a and 3.2b).

3.2 Spectral Analyses
3.2.1 Pattern Hole
Between the time windows of 2200 and 2300ms, a spectral analysis of Pattern Hole configuration was conducted on trace 470 (Figures 3.3a and 3.3b). Figure 3.3a analyzes the amplitude spectrum for 3.5m x 3-hole x 1.2kg and shows that the dominant frequency is about 17Hz and the frequency bandwidth is...
narrow for both the 1st and 2nd order peak frequencies. The main bandwidth is narrow for 5-hole shot configuration loaded at 3.5m with 2.0kg charge and the main frequencies are similar to Figure 3.3a. The spectral analysis of 5-hole is favourable when compared to 3-hole shot configuration because of reduced amplitude in 3-hole. The results are shown on Table 2.1.

Table 1.0: Experiment Shot Log [3-hole x 3.5m Pattern ad 4kg (15m) Deep Hole Shots around Inner Circle of 5m radius; 5-hole x 3.5m Pattern ad 4kg (40m) Deep Hole Shots around Inner Circle of 10m radius]

<table>
<thead>
<tr>
<th>Shot code</th>
<th>Type</th>
<th>Charge size(kg)</th>
<th>Pattern/charge configuration per hole</th>
<th>Effective shot depth (m)</th>
<th>Shot lines</th>
<th>Shot location</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Control</td>
<td>2.0</td>
<td>5-hole pattern 0.4kg/hole</td>
<td>3.5</td>
<td>2150</td>
<td>SP 4461</td>
</tr>
<tr>
<td>B</td>
<td>Shallow pattern</td>
<td>1.2</td>
<td>3-hole pattern 0.4kg/hole</td>
<td>3.5</td>
<td>2150</td>
<td>SP 4461</td>
</tr>
<tr>
<td>5</td>
<td>SDH</td>
<td>0.4</td>
<td></td>
<td></td>
<td>15</td>
<td>SP 4461</td>
</tr>
<tr>
<td>1</td>
<td>SDH</td>
<td>0.8</td>
<td></td>
<td></td>
<td>15</td>
<td>SP 4461</td>
</tr>
<tr>
<td>4</td>
<td>SDH</td>
<td>1.2</td>
<td></td>
<td></td>
<td>15</td>
<td>SP 4461</td>
</tr>
<tr>
<td>3</td>
<td>SDH</td>
<td>2.0</td>
<td></td>
<td></td>
<td>15</td>
<td>SP 4461</td>
</tr>
<tr>
<td>E</td>
<td>SDH</td>
<td>0.4</td>
<td></td>
<td></td>
<td>40</td>
<td>SP 4461</td>
</tr>
<tr>
<td>A</td>
<td>SDH</td>
<td>0.8</td>
<td></td>
<td></td>
<td>40</td>
<td>SP 4461</td>
</tr>
<tr>
<td>D</td>
<td>SDH</td>
<td>1.2</td>
<td></td>
<td></td>
<td>40</td>
<td>SP 4461</td>
</tr>
<tr>
<td>C</td>
<td>SDH</td>
<td>2.0</td>
<td></td>
<td></td>
<td>40</td>
<td>SP 4461</td>
</tr>
</tbody>
</table>

Table 2.1: Spectral Analysis for 3-Hole and 5-Hole Pattern Shots

<table>
<thead>
<tr>
<th>Time Window (ms)</th>
<th>Shot Configuration</th>
<th>Charge Size (kg)</th>
<th>Main Frequency (Hz)</th>
<th>Frequency Bandwidth</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>2200 - 2300</td>
<td>3.5 m X 5-Hole</td>
<td>0.4 kg x 5</td>
<td>17</td>
<td>Narrow</td>
<td>Favourable</td>
</tr>
<tr>
<td>2200 - 2300</td>
<td>3.5 m X 3-Hole</td>
<td>0.4 kg x 3</td>
<td>17</td>
<td>Narrow</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.2: Spectral Analysis for 3-Hole and 5-Hole Pattern Shots

<table>
<thead>
<tr>
<th>Time Window (ms)</th>
<th>Charge Size (kg)</th>
<th>Main Frequency (Hz)</th>
<th>Frequency Bandwidth</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>2200 - 2300</td>
<td>0.4</td>
<td>35</td>
<td>Wider</td>
<td></td>
</tr>
<tr>
<td>2200 - 2300</td>
<td>0.8</td>
<td>24</td>
<td>Narrow</td>
<td></td>
</tr>
<tr>
<td>2200 - 2300</td>
<td>1.2</td>
<td>24</td>
<td>Narrow</td>
<td></td>
</tr>
<tr>
<td>2200 - 2300</td>
<td>2.0</td>
<td>24</td>
<td>Narrow</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.3: Spectral Analysis for 3-Hole and 5-Hole Pattern Shots

<table>
<thead>
<tr>
<th>Time Window (ms)</th>
<th>Charge Size (kg)</th>
<th>Main Frequency (Hz)</th>
<th>Frequency Bandwidth</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>2200 - 2300</td>
<td>0.4</td>
<td>30</td>
<td>Wide</td>
<td></td>
</tr>
<tr>
<td>2200 - 2300</td>
<td>0.8</td>
<td>24</td>
<td>Fairly wide</td>
<td></td>
</tr>
<tr>
<td>2200 - 2300</td>
<td>1.2</td>
<td>24</td>
<td>Wide</td>
<td></td>
</tr>
<tr>
<td>2200 - 2300</td>
<td>2.0</td>
<td>24</td>
<td>Wide</td>
<td></td>
</tr>
</tbody>
</table>
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Figure 1.0: Location of the Study Area

Figure 2.0: Field Layout for Shots Configuration
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Figure 3.1a: Energy Content Analysis of 3.5m x 3 Holes 1.2kg (SL2150/4461) Y-axis is Time in ms

Figure 3.1b: Energy Content Analysis of 3.5m x 5 Holes 2.0kg (SL 2150/4461) Y-axis is Time in ms

Figure 3.1c: Energy Content Analysis of 15m x 0.4kg (SL 2150/4461) Y-axis is Time in ms
Figure 3.1d: Energy Content Analysis of 15m x 0.8kg (SL 2150/4461) Y-axis is Time in ms

Figure 3.1e: Energy Content Analysis of 15m x 1.2kg (SL 2150/4461) Y-axis is Time in ms

Figure 3.1f: Energy Content Analysis of 15m x 2.0kg (SL 2150/4461) Y-axis is Time in ms
Figure 3.1g: Energy Content Analysis of 40m x 0.4kg (SL 2150/4461) Y-axis is Time in ms

Figure 3.1h: Energy Content Analysis of 40m x 0.8kg (SL 2150/4461) Y-axis is Time in ms

Figure 3.1i: Energy Content Analysis of 40m x 1.2kg (SL 2150/4461) Y-axis is Time in ms
Figure 3.1j: Energy Content Analysis of 40m x 2.0kg (SL 2150/4461) Y-axis is Time in ms

Figure 3.2a: Energy Content Analysis of 15m loaded at 0.4kg (SL 2150/4461) (Lower Energy, Stronger Frequency) Y-axis is Time in ms
Figure 3.2b: Energy Content Analysis of 15m loaded at 1.2kg (SL 2150/4461) (Stronger Energy, Lower Frequency) Y-axis is Time in ms

Figure 3.3a: Single Trace Spectral Analysis of 3.5m x 3 x 0.4kg Configuration CDP = Common Depth Point. Y-axis is Amplitude
Figure 3.3b: Single Trace Spectral Analysis of 3.5m x 5 x 0.4kg Configuration CDP = Common Depth Point. Y-axis is Amplitude

Figure 3.3c: Single Trace Spectral Analysis of 15m x 0.4kg Configuration CDP = Common Depth Point. Y-axis is Amplitude
Figure 3.3d: Single Trace Spectral Analysis of 15m x 0.8kg Configuration CDP = Common Depth Point. Y-axis is Amplitude

Figure 3.3e: Single Trace Spectral Analysis of 15m x 1.2kg Configuration CDP = Common Depth Point. Y-axis is Amplitude
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Figure 3.3f: Single Trace Spectral Analysis of 15m x 2.0kg Configuration CDP = Common Depth Point. Y-axis is Amplitude

Figure 3.3g: Single Trace Spectral Analysis of 40m x 0.4kg Configuration CDP = Common Depth Point. Y-axis is Amplitude
Research Article

Figure 3.3h: Single Trace Spectral Analysis of 40m x 0.8kg Configuration CDP = Common Depth Point. Y-axis is Amplitude

Figure 3.3i: Single Trace Spectral Analysis of 40m x 1.2kg Configuration CDP = Common Depth Point. Y-axis is Amplitude
3.2.2 Single Deep Hole Shots

a) 15m
Between the time windows of 2200 and 2300ms, spectral analyses of various charges sizes loaded at 15m were conducted on trace 470 (Figures 3.3c to 3.3f). Figure 3.3c analyzes the amplitude spectrum for 0.4kg and shows that the dominant frequency is about 35Hz and the frequency bandwidth is wide. In Figure 3.3d (0.8kg), the dominant frequency is about 24Hz and the frequency bandwidth is narrow for both the 1st and 2nd order peak frequencies. The spectral signature for both 1.2kg and 2.0kg records are similar and comparable. The dominant frequency for both records is about 24Hz and their frequency bandwidth are both narrow (Figures 3.3e and 3.3f). The results are shown in Table 2.2.

b) 40m
Between the time window of 2200 and 2300ms, a spectral analysis of various charge sizes loaded at 40m were conducted on trace 470 (Figure 3.3g to 3.3j). Figure 3.3g analyzes the amplitude spectrum for 0.4kg and shows that the dominant frequency is about 30 Hz and the frequency bandwidth is wide. In Figure 3.3h (0.8kg), the dominant frequency is about 24 Hz and the frequency bandwidth is fairly wide. The spectral signature for both 1.2kg and 2.0kg records are similar and comparable. The dominant frequency for both records is about 24Hz and their frequency bandwidths are both wide (Figures 3.3i and 3.3j). The results are as shown in Table 2.3.

Conclusion
Based on the energy content and spectral analyses, the control shot configuration of 3.5m x 5-hole x 2.0kg provided good seismogram quality capable of meeting geophysical objective. However, in special cases like highly built up areas where non-seismic objects become unavoidably present, the adoption of 3.5m x 3-hole x 1.2kg may become necessary in order not to lose the near bin population about these structures.
From the analyses, at the same depth when the charge size is increased from 0.4kg to 1.2kg, the energy is strong while the frequency is reduced. Hence, increase in charge size at the same depth does not translate to increment in frequencies. Spectral analysis however, shows that increase in depth results to widening of the frequency bandwidth. For optimum results, energy and frequency should balance. The 0.4kg and 0.8kg charge sizes loaded at either 15m or 40m would not provide good seismogram quality needed to achieve the geophysical objective. Guided by the energy components, distinctive frequency, better S/N either 1.2kg or 2.0 kg shot records are comparable for charges loaded at 1.5m or 40m. Both charge sizes and depth are favourable for geophysical objective. However, to ensure that the top of charge is met, a drill tolerance should be adopted. Based on these conclusions, the 15m SDH loaded with 1.2kg is herein recommended because the energy and frequency levels are comparable to single deep hole loaded with the 1.2kg or 2.0kg at 40m. However, the difference in depth range from 15 to 40m is too large that its adoption may be unnecessary. Hence, for best results, denser analyses between the ranges of 15 to 40m become necessary as to optimize the best depth. Therefore, confirmation of these results is subject to further analysis from other researches within the Niger Delta.

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REFERENCES