Determination of Seismic Blast Vibrations and Damage to Structures in the Niger Delta Region of Nigeria using Peak Particle Velocity

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Abstract
This work measured the peak particle velocity of the ground vibrations induced by the detonation of seismic explosives to estimate the magnitude of possible impacts on buildings. The findings are aimed at serving as reference for future seismic exploration design where explosives will be used. The seismograph recording instrument was deployed and 44 shots of 2kg, 3kg, 4kg, and 5kg charges sizes were taken and monitored at distances that ranged from 50m to 300m. This will help in resolving the many controversies about claims of property damage by communities against seismic companies in the Niger Delta area. Longitudinal, transverse and vertical components of the peak particle velocity and their frequencies were monitored and recorded. The scaled distance and the resultants of the peak particle velocity were calculated and also recorded. The vertical peak particle velocities were plotted against the longitudinal peak particle velocities to predict the likelihood of the blast impacts on the neighbouring buildings. It was discovered that no major damage would be impacted on the buildings within 50m to 300m from an explosive blast of 2kg to 5kg. Peak particle velocities for the different charge sizes were also plotted against the scaled distance to determine the geologic and soil site constants $k$ and $\alpha$. The average values obtained for the constants were 13.29 and 0.58 respectively. The United States Bureau of Mines (USBM) and Office for Surface Mines (OSM) standards were employed as guide for data analysis and interpretation. The peak particle velocities were much lower than the USBM limits. 2 H3kg charge sizes detonated in the area at distances of 50m to 300m to a structure may cause no damage but a 4 H5kg of explosive sizes may cause threshold damages to buildings.

Keywords: charge, detonate, damage, peak particle velocity, scaled distance

INTRODUCTION
The continued use of explosives as seismic exploration energy source in the Niger Delta for over 60 decades has caused some concerns as to their effects on the environment. With growing awareness on environmental issues, vis-à-vis the legal and health implications amongst the oil host communities, there have been more speculative assertions on the damages to surface and underground structures by the use of seismic explosives in the area of seismic surveys. It has therefore, become necessary to determine the blasting parameters to be specifically applied in the Niger Delta with the aid of ground vibration standards and the Peak Particles Velocity (PPV), which is the most significant dominant response of ground vibrations.

Rock or soil properties that influence blasting results are strength, density, sonic velocity, and structure (Telford et al., 1990). The blast effects on surrounding earth materials and structures can be divided into the permanent and transient degradation, and displacements. Permanent degradation is normally described by cracking intensity. Displacement can be produced by either delayed gas pressures or by vibration-induced shaking. Transient structural response effects result from the vibratory nature of the ground motion and airborne disturbances that propagate outwards from a blast. A soil particle disturbed from equilibrium by explosive blast executes vibratory motion as a result of the elastic restoring forces of the soil medium. The blast induced ground motions on the elastic soil can be linearly oscillatory or vibratory or cyclic in all and/or any of the three mutually perpendicular components, longitudinal (Y-direction), transverse (X-direction) and vertical (Z-direction), (Dowding, 1996). The ground motions can be measured by any of the three perpendicular directions or dimensions in terms of displacement (m), velocity (m/sec) or acceleration (m/sec²). Most current damage criteria are based solely on Peak Particle Velocity (PPV). This work has as its objectives the determination of the soil response to explosive detonation and the possibility of damage to structures at various distance to the structure and with various charge weights.
STUDY LOCATION AND SURFACE GEOLOGY

This study was conducted in an area located between Latitudes 4°41' N – 4°51' N and Longitudes 7°16'E– 7° 27' E in the Niger Delta region of Nigeria. Geologically, the Niger Delta is a sedimentary basin whose origin dates back to the Eocene period of about 40-50 million years ago. The topsoil of the area consists of black muddy clays frequently submerged in the waters of the periodic high tides. Borehole data show that the clays continue to an average depth of about 15 m. The clay is underlain by white fine sand, which grade gradually into gravelly sand. Seismic refraction studies show that the area is characterised by weathered and sub-weathered or consolidated particle velocity (PPV) and scaled distance data pairs.

METHODOLOGY

A purpose built-in vibration monitoring digital seismograph, fitted with vibration transducer with tri-axial recording characteristics with high impulse sensitivity, low frequencies particularly in the ranges 1-100Hz, a signal processor with fast spectrum analysis and good storage characteristics and a transient signal recording and display system was used for recording the particle velocities and frequencies of the detonation. The longitudinal, vertical and transverse components of the ground vibration were recorded on three channels. The Peak Particle Velocities (PPV) of all three components was obtained and recorded at varying distances ranging 2000 m/s respectively (Eze et al., 2003).

Thus, the PPV obtained from elemental charge (q x dx) becomes

\[ \delta v = K q^\alpha \left( \frac{dx}{\sqrt{R_0^2 + (z - x)^2}} \right)^\alpha \]  

The elemental PPV at ‘X’ direction obtained from elemental charge (q x dy) becomes:

\[ \delta v_x = K q^\alpha \left( \frac{dy}{\sqrt{R_0^2 + (y - z)^2}} \right)^\alpha \cos \theta \]  

While the elemental PPV at ‘Y’ direction obtained from elemental charge (q x dy) becomes:

\[ \delta v_y = K q^\alpha \left( \frac{dy}{\sqrt{R_0^2 + (y - z)^2}} \right)^\alpha \sin \theta \]  

This is usually reported as the ‘peak true resultant particle velocity’ (summing the three orthogonal components coincident with time. The resultant PPV at ‘X’ and ‘Y’ direction becomes

\[ ppv_x = K q^\alpha \left( \sum_{y=0}^{h} \left( \frac{dy}{R_0^2 + (z - y)^2} \right)^\alpha \cos \theta \right) \]  

and

\[ ppv_y = K q^\alpha \left( \sum_{y=0}^{h} \left( \frac{dy}{R_0^2 + (z - y)^2} \right)^\alpha \sin \theta \right) \]  

The resultant peak particle velocity, PPV, expressed in equation 1 is obtained as the vector sum

\[ PPV = K \times Q^\alpha \times D^\beta \]  

A general form of PPV predictor equation is shown in eq. (1). Holmberg and Persson (1978) have obtained a first approximation of the resulting PPV by integrating the generalized equation for the total charge length as:

\[ v = K q^\alpha \int_0^h \frac{dx}{\sqrt{R_0^2 + (Z - x)^2}} \]  

where,

V=peak particle velocity
K, α, β are empirical site constants to be established through far-field monitoring, q=linear charge concentration (kg/m)
h=total charge length in hole (m) and
x=position of the elemental charge from bottom of the hole.

Aroro and Dey (2010) have shown that the above mathematical equation can be solved for β=2α and the resultant PPV can be obtained as given by

\[ v = K q^\alpha \int_0^h \left( \tan^{-1} \frac{Z}{R_0} - \tan^{-1} \frac{Z - h}{R_0} \right) \]  

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where,

V=peak particle velocity
K, α, β are empirical site constants to be established through far-field monitoring, q=linear charge concentration (kg/m)
h=total charge length in hole (m) and
x=position of the elemental charge from bottom of the hole.
The vector sum of resultant $PPV$ becomes
\[ PPV_R = (ppvx)^2 + (ppvy)^2 \]  \hspace{1cm} (9)
Where $\delta px$, $\delta py$ = the elemental peak particle velocity along ‘X’ and ‘Y’ co-ordinate axes, 
$ppvx$, $ppvy$ = component of peak particle velocity along ‘X’ and ‘Y’ co-ordinate axes, 
$PPV_R$ = resultant $PPV$ or vector sum of $ppvx$, $ppvy$.  
$K$, $\alpha$, $\beta$ are the empirical site constants.

$R_0$ = horizontal distance between blast hole axis and point of interest (m) = $(x_2-x_1)$
$Z$ = vertical distance between the blast hole bottom and the point of interest (m) = $(y_2-y_1)$
$q$ = linear charge concentration $(kg/m)$,
$h$ = total charge length in hole (m)
$y$ = position of the elemental charge from bottom of the hole (m), and
$\theta$ = angle with the ‘X’ axis so that
\[
\cos \theta = \frac{R_y}{\sqrt{R_0^2 + (Z-y)^2}} \\
\sin \theta = \frac{(Z-y)}{\sqrt{R_0^2 + (Z-y)^2}} 
\]

RESULTS AND DISCUSSIONS
The resultant peak particle velocities for the different charges at calculated at different distances from the charges are shown in Table 1. The results show that $PPV_R$ increase with charge size and decreases with distance. The resultant of the PPV components has the highest value of 2.14 mm/s at 50m from 5kg of explosive size. The soil site constants ‘$a$’ and ‘$a’ listed in Table 2 were obtained. The mean value of the soil site constant ‘$a$’ is 0.58 while the mean of the constant ‘$k$’ is 13.29. These site constants can be regarded as characteristic of the Niger Delta soil and can be used to determine the safe blasting distance for known charge size and depth in the area. The resultant peak particle velocity of all the charges against the scaled distance are below both the maximum USBM reference line and the USBM mean reference line (Figure 1). This implies that the ground induced vibrations from the blasts of 2kg to 5kg at a depth of 40m are not likely to cause any damage to buildings within 50m to 300m in the Niger Delta region. However, buildings in the Niger Delta region may generally have lower integrity compared to those used in the formulation of the USBM standard.

Figure 2 shows a cluster of the PPV’s from the 4-5kg charge sizes cluster within the threshold damage zone, while most of the 2-3kg explosives fell within the ‘no damage’ zones. The physical interpretation of each of the damage zone is shown in Table 3. Figure suggests that 2 -3kg charge sizes detonated in the area at distances of 50m to 300m to a structure may cause no damage while a 4-5kg of explosive sizes may cause threshold damages to buildings in the Niger Delta region especially within a distance of less than 100m.

CONCLUSIONS
As a conservative measure, buildings within the area should not be subjected to PPV values above 10mm/s because of the likelihood of damage to buildings within the associated frequency range of 2Hz to 12Hz. There is the need for further studies to establish the actual integrity range of the buildings in the Niger Delta region.

REFERENCES
**APPENDIX**

Table 1: Resultant Peak Particle Velocity for Different Charges at Different Shot Distances

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>2kg</th>
<th>3kg</th>
<th>4kg</th>
<th>5kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>1.05</td>
<td>1.51</td>
<td>1.76</td>
<td>2.14</td>
</tr>
<tr>
<td>75</td>
<td>0.90</td>
<td>1.40</td>
<td>1.62</td>
<td>1.96</td>
</tr>
<tr>
<td>100</td>
<td>0.85</td>
<td>0.85</td>
<td>1.37</td>
<td>1.85</td>
</tr>
<tr>
<td>125</td>
<td>0.60</td>
<td>0.60</td>
<td>1.00</td>
<td>1.57</td>
</tr>
<tr>
<td>150</td>
<td>0.46</td>
<td>0.70</td>
<td>0.97</td>
<td>1.27</td>
</tr>
<tr>
<td>175</td>
<td>0.46</td>
<td>0.78</td>
<td>0.87</td>
<td>1.16</td>
</tr>
<tr>
<td>200</td>
<td>0.48</td>
<td>0.48</td>
<td>0.96</td>
<td>1.50</td>
</tr>
<tr>
<td>225</td>
<td>0.28</td>
<td>0.28</td>
<td>1.75</td>
<td>1.39</td>
</tr>
<tr>
<td>250</td>
<td>0.30</td>
<td>0.70</td>
<td>0.80</td>
<td>1.04</td>
</tr>
<tr>
<td>275</td>
<td>0.35</td>
<td>0.49</td>
<td>0.70</td>
<td>1.88</td>
</tr>
<tr>
<td>300</td>
<td>0.26</td>
<td>0.43</td>
<td>0.71</td>
<td>1.10</td>
</tr>
</tbody>
</table>

**Table 2: Explosive Site Constants in the Niger Delta Region.**

<table>
<thead>
<tr>
<th>Explosive Size</th>
<th>α</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>-0.82</td>
<td>22.28</td>
</tr>
<tr>
<td>3.0</td>
<td>-0.75</td>
<td>17.69</td>
</tr>
<tr>
<td>4.0</td>
<td>-0.45</td>
<td>7.70</td>
</tr>
<tr>
<td>5.0</td>
<td>-0.31</td>
<td>5.48</td>
</tr>
<tr>
<td>Mean</td>
<td>-0.58</td>
<td>13.29</td>
</tr>
</tbody>
</table>

Figure 1: Resultant Peak Particle Velocity against Scaled Distance for the Charge Sizes

Figure 2: Predictive zones of damage

Table 3: Damage Classification of US Bureau of Mines

<table>
<thead>
<tr>
<th>S/No</th>
<th>Type of Damage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Threshold Damage</td>
<td>Loosing of paint and small plaster cracks; cause visual disturbance.</td>
</tr>
<tr>
<td>2</td>
<td>Minor Damage</td>
<td>Loosing and falling of plaster, hairline to 3-mm cracks and fall of loose mortar; cause discomfort. It does not affect strength of structure and load bearing capability of structural elements.</td>
</tr>
<tr>
<td>3</td>
<td>Major Damage</td>
<td>Forms permanent deformation in structures and weakens the structure and due to wide cracks in walls; rupture of opening vaults and fall of masonry.</td>
</tr>
</tbody>
</table>

*Source: Siskind et al., 1980*