100-TON TEST AT TRINITY
REPORT ON EARTH VELOCITY MEASUREMENTS

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ABSTRACT

Elastic earth motion at 800, 1500, and 9000 yards from the 100-ton Trinity shot was measured with velocity-type geophones. The report includes descriptions of the apparatus, the field layout, miscellaneous testing, and the method of analysis. Earth particle velocities, displacements, and periods are given, and a rough method for predicting elastic earth motion for charges not buried.

PURPOSE OF MEASUREMENTS

It was desired to obtain values of earth particle velocity, and wave propagation velocity in both the vertical and the horizontal plane for a number of stations on two sides of the 100-ton shot which was located at "Z." The principal value of the data was for comparison with similar values to be obtained on the gadget shot at a later date, in order to measure the energy released at that time. From the velocities obtained, earth particle displacements and accelerations could be computed.

A secondary use for the data was for defense against possible law suits for property damage.

INSTRUMENTATION

The apparatus used included two similar types of low-frequency balanced-beam geophones or pickups, Type 810 cathode-follower amplifiers, an alternating-current-operated control box for turning off the A supply of the amplifiers and for operating the calibration relays, and a balancing panel for neutralizing the direct-current output of the amplifiers. Records were taken by three Heiland Type A-401R 6-trace oscillographs, and the time break or t₀ signal was impressed on one camera by means of a thyratron circuit.

Of the geophones used, 4 were Geophysical Research Corporation Type SG-3 modified to have a longer period, and the remaining 8 were the Ens. Geo. T. Reynolds' modification of the GRC Type SG-3 with longer beams.
In the appended figures (Fig. 3) will be found a diagrammatic sketch of the SG-3 geophone (see Page 2 in NDRC Report No. A-238 for a description of operation of the geophone). It was found to be necessary to use the Reynolds type of geophone for all horizontal units, because of its decreased sensitivity to levelling. The undamped natural period of the geophones fell within the limits of 2.0 and 2.2 sec, while the sensitivity at 70 per cent critical damping varied from 15 to 80 mv/cm/sec. The field strength of the geophone magnets varied between 1500 and 3500 gauss, while each of the two pickup coils consisted of 1100 turns of No. 40 enameled wire with a resistance of 450 ohms. The CRC SG-3 geophones had a moment of inertia of about 20,000 gm cm$^2$, while the Reynolds type instruments had a value of 60,000 gm cm$^2$. The phase angle of the geophones rises to 40 deg for long periods of 1 sec.

The Model 810 cathode-follower amplifiers and their auxiliary equipment were designed by Matt Sands and were built by G-4 under his supervision. Built into each amplifier were relays for placing a calibration potential on the cathode of the first vacuum tube, and for turning off the A supply to all tubes. It was desired to have the control of the A supply independent of any possible pickup, so the relay circuit was designed to require a direct current of 8 ma to open the circuit. A current of 4 ma was used to close the calibration relay. Curves of frequency response and linearity for typical amplifiers will be found in Figs. 1 and 2. It will be noted that the amplifiers were flat in their response from 0.5 to 10 cps, but that for a 0.99-mv signal the galvanometer deflections were 1.75 cm for a positive pulse and 1.60 cm for a negative signal. This nonlinearity is typical.

The Type A-401R Heiland Oscillographs were equipped with 6 galvanometers, of which the ones used to record the signals from the geophones were Type B with sensitivities of 6 cm/ma, and flat response from zero up to 40 cps. At Shelter A (N10,000 yd) Type C galvanometers were used to record the $t_0$ signal, whereas at Shelter B (S10,000 yd) the $t_0$ signal was impressed on one of the Type B galvanometers, which recorded earth velocities, by means of a thyatron circuit designed by E. W. Titterton and built by G-4. The timing interval of the Heiland Oscillograph is 0.01 sec, and the record speed is 1 ft/sec.

**TESTING AND CALIBRATING**

All geophones, both horizontal and vertical, were calibrated on a cart type of shake table (Fig. 8) which rolled on ways inclined at 45 deg from the horizontal. Simple harmonic motion was obtained from a spring suspension, and the initial static deflection was measured prior to cutting a wire which released the table and permitted it to vibrate. Records were taken on a Heiland Recorder, and sensitivity values were computed from the amplitude of the wave and the known sensitivity of the amplifier.

Amplifier linearity tests were made by impressing several direct-current positive and negative potentials on the amplifier input and
recording the galvanometer deflections. Calibration records were taken with the built-in calibration circuit for all important shots.

Test shots of scaled sizes were fired near each geophone station of the final setup for verifying over-all sensitivities and for checking direction of breaks.

A series of 5-pound charges of pentolite was fired at various heights from 0 to 10 ft above the ground for checking the height scaling estimates made by Ens. Geo. T. Reynolds. A similar series of 25-lb charges of Composition B was fired on the surface at distances varying from 150 to 600 ft to check the Lampson curves.

Records of 41-lb charges of Composition B taken on Two-Mile Mesa with amplifiers in open pits, and 1000-ohm resistors across their inputs, showed that the shock mounted amplifiers were unduly sensitive to air blasts. This difficulty was eliminated by the addition of felt in the amplifier boxes and between plywood chamber covers, and principally by a layer of 12 in. of loose dirt over the chamber cover.

EQUIPMENT LAYOUT FOR 100-TON SHOT

Horizontal and vertical geophones were planted in pits 2 ft deep at stations 800, 1500, and 9000 yd from Z along lines from "0" to "A" and from "0" to "B" (see Fig. 6). In order to measure the desired components of earth motion, the geophones had to be planted so that their coil axes were parallel to the direction of propagation of the component. This was accomplished by orienting the horizontal instruments with their bases perpendicular to the line of shot, and the vertical units with their bases downward. Except at Stations CS-1 and CN-1, the geophone pits were located 75 yd from the pole line in order to minimize noise from that source. At CS-1, a branch pole line made it necessary to cut this distance to 35 yd, and at CN-1 the distance was increased to 200 yd to get away from the foundation pits at "0." Amplifiers and power supplies were mounted in pairs in wooden boxes which were suspended by springs from a beam across the top of each amplifier chamber (see Fig. 4). In addition to shock mounting inside the metal amplifier cases, the wooden boxes were lined with sponge rubber and felt. A 12-in. layer of loose earth on top of the amplifier chamber cover completed the protection against air blast.

Signals were transmitted from the two amplifiers at each station along twisted-pair telephone lines to the Heiland Recorder at Stations A or B. The twisted pairs were laid along the ground from pits to the pole line, after which they were carried on knob insulators on the cross arms. A single control line was used to send calibration relay signals and turn off relay signals to the three stations on each profile line by means of parallel taps.

CHARACTER OF TRACES

The photographic records of Fig. 7 give earth particle velocity at the position of the geophone as a function of time. The general character of
a trace is as follows. The first earth shock or primary wave appears some time after the explosion, and subsequent waves increase both as to particle velocity and period until a point on the record is reached which corresponds to a propagation velocity of 1500 to 2500 ft/sec, at which time the major component of the earth motion is probably a Rayleigh wave. At later times the amplitude decreases until the air wave approaches the ground where the geophones are buried. As the air wave approaches the geophone location, the ground motion increases, and when the air wave reaches the ground directly above the geophones, both the frequency and the particle velocity increase considerably. The decrease in ground motion between the arrival of the Rayleigh wave and the air wave is more distinct for the far stations than for the near.

EVALUATION OF TRACES

Figure 7 is the record of the signals from the south line of geophones. The two upper lines record signals from the 800-yd station, the next two lines from 1500-yd station, etc. The upper line of each pair records the vertical component and the lower line the horizontal-radial component. The stepwise signal of the lowermost trace indicates the time of the explosion.

Earth particle velocities are calculated from the record and calibration data by the relation:

\[ v = \frac{h}{\alpha g_0} \]

where  
- \( v \) = earth particle velocity in cm/sec.  
- \( h \) = centimeter deflection on Heiland trace.  
- \( \alpha \) = geophone sensitivity in millivolts per unit velocity.  
- \( g_0 \) = gain of amplifier - galvanometer combination in cm/mv.

All velocity values given in Table 1 are the average of two values computed from two successive deflections on the trace. This procedure enables one to compute the earth particle displacement by assuming the wave is a sine wave with displacement amplitude equal to \( d/2 \), where \( d = vT/\pi \), and \( T \) is the period; \( d \) is thus the total earth motion from one extreme to the other. Errors in this assumption are usually not more than 10 or 20 per cent. Asymmetry of the amplifier response with respect to positive and negative deflections was accounted for by calibration signals of both signs, but nonlinearity was not accounted for, and errors of 10 or 20 per cent can thereby be introduced.

Table 1 of results fails to give values for some of the stations for the reason that the corresponding records were off-scale, or, in the one case of the vertical geophone at 9000 south, the geophone was out of adjustment.
Predictions of the elastic earth movement previous to the present measurements were based on the Lampson formulas* which were derived from data on a large number of charges buried at the "optimum depth" \( d = \frac{2W}{3} \). To predict earth shock from charges not buried Reynolds† estimated that the weight of a charge elevated to a scaled height \( h = 0.47W^{1/3} \) should be reduced by a factor 100 as compared to a charge buried at the "optimum depth" and that the weight of a surface charge should be correspondingly reduced by a factor of 5. To check these estimates, after the 100-ton shot, test shots with 5 lb of pentohip were taken to determine the effect of charge height above ground level. Figure 5 shows the results, and shows an increase rather than decrease, in earth particle velocity with charge height up to about 10 ft. This correlates with the fact that, because of the Mach effect, there is an optimum height for effectiveness of an exploding charge in creating destruction on the ground. According to W. G. Penney this optimum height is about \( 4.8 \frac{W}{3} \), or 8 ft for 5 lb.

In order to try to estimate ground motion for the purpose of setting gains for further test shooting and the gadget shot, an attempt has been made to correlate the results of the 100-ton shot with the results of four 25-lb Comp. B shots and two 40-lb Comp. B shots taken on Trinity ground. The data are sketchy and the correlation admittedly crude. However, within about a factor of 3 the values pertaining to maximum earth wave previous to arrival of air blast obey the following relations:

\[
\begin{align*}
d_{2v} & = \frac{W}{3}^{1/3}(32\lambda^{-3} + 0.080\lambda^{-1}) \\
d_{2h} & = \frac{W}{3}^{1/3}(120\lambda^{-3} + 0.055\lambda^{-1}) \\
T_2 & = 0.0022 \frac{\lambda^{1/2}}{W^{1/16}} \\
v_2 & = \frac{\pi}{T} d_v \\
v_{2h} & = \frac{\pi}{T} d_h
\end{align*}
\]

where \( \frac{W}{3} = (1/3)W \) and \( \lambda = \frac{r}{\frac{W}{3}} \). \( W \) is pounds charge weight in TNT equivalence and \( r \) is horizontal distance from charge in feet. The other symbols are defined in Table 1. The above expressions for displacements are the Lampson formulas, modified by reducing the charge weight by a factor of 3 to obtain an effective charge weight. These expressions will probably apply about equally well to ground charges and to charges elevated up to twice the scaled height.

A program of shots at Trinity before the coming gadget test is planned for the sake of testing the foregoing relations and also for testing the relative effect of buried, surface, and elevated charges.

*AM-670, Summary by C. W. Lampson
†LAMS-226
Table 1--100-Ton Results

Yards south and north

<table>
<thead>
<tr>
<th></th>
<th>800S</th>
<th>800N</th>
<th>1500S</th>
<th>1500N</th>
<th>9000S</th>
<th>9000N</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>( c_1 )</td>
<td>4800</td>
<td>4900</td>
<td>6100</td>
<td>6100</td>
<td>10000</td>
<td>9200</td>
<td>3</td>
</tr>
<tr>
<td>( c_2 )</td>
<td>2480</td>
<td>2400</td>
<td>2000</td>
<td>2050</td>
<td>2120</td>
<td>2390</td>
<td>20</td>
</tr>
<tr>
<td>( c_3 )</td>
<td>1400</td>
<td>----</td>
<td>1260</td>
<td>----</td>
<td>1139</td>
<td>1143</td>
<td>3</td>
</tr>
<tr>
<td>( v_{1v} )</td>
<td>0.54</td>
<td>0.40</td>
<td>0.25</td>
<td>0.40</td>
<td>---</td>
<td>0.0038</td>
<td>25</td>
</tr>
<tr>
<td>( v_{1h} )</td>
<td>0.16</td>
<td>0.08</td>
<td>0.077</td>
<td>0.12</td>
<td>0.0014</td>
<td>0.0016</td>
<td>25</td>
</tr>
<tr>
<td>( d_{1v} )</td>
<td>0.015</td>
<td>0.013</td>
<td>0.0088</td>
<td>0.014</td>
<td>---</td>
<td>0.00024</td>
<td>50</td>
</tr>
<tr>
<td>( d_{1h} )</td>
<td>0.0041</td>
<td>0.0031</td>
<td>0.0025</td>
<td>0.0042</td>
<td>0.0008</td>
<td>0.00011</td>
<td>50</td>
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<tr>
<td>( v_{2v} )</td>
<td>0.76</td>
<td>---</td>
<td>0.44</td>
<td>---</td>
<td>---</td>
<td>0.029</td>
<td>25</td>
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<tr>
<td>( v_{2h} )</td>
<td>0.74</td>
<td>---</td>
<td>0.30</td>
<td>---</td>
<td>0.013</td>
<td>0.026</td>
<td>25</td>
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<tr>
<td>( d_{2v} )</td>
<td>0.065</td>
<td>---</td>
<td>0.035</td>
<td>---</td>
<td>---</td>
<td>0.0055</td>
<td>50</td>
</tr>
<tr>
<td>( d_{2h} )</td>
<td>0.059</td>
<td>---</td>
<td>0.021</td>
<td>---</td>
<td>0.0036</td>
<td>0.0065</td>
<td>50</td>
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<tr>
<td>( T_{1v} )</td>
<td>0.09</td>
<td>0.10</td>
<td>0.11</td>
<td>0.11</td>
<td>0.18</td>
<td>0.20</td>
<td>10</td>
</tr>
<tr>
<td>( T_{1h} )</td>
<td>0.08</td>
<td>0.12</td>
<td>0.10</td>
<td>0.11</td>
<td>0.18</td>
<td>0.20</td>
<td>10</td>
</tr>
<tr>
<td>( T_{2v} )</td>
<td>0.27</td>
<td>---</td>
<td>0.25</td>
<td>---</td>
<td>---</td>
<td>0.60</td>
<td>10</td>
</tr>
<tr>
<td>( T_{2h} )</td>
<td>0.25</td>
<td>---</td>
<td>0.22</td>
<td>---</td>
<td>0.88</td>
<td>0.78</td>
<td>10</td>
</tr>
</tbody>
</table>

\( c_1 \) = average propagation velocity of first earth shock, ft/sec.
\( c_2 \) = average propagation velocity of maximum earth displacement shock previous to arrival of air wave, ft/sec.
\( c_3 \) = average propagation velocity of air wave over ground, ft/sec.

Propagation velocities are computed by dividing distance by arrival time.

\( v \) = earth particle velocity, cm/sec.
\( d \) = earth particle displacement equals twice the maximum displacement from rest; centimeters.
T = period of earth wave, sec.
Subscripts on v and d signify the following:
  v = vertical
  h = horizontal-radial.
  l = first earth shock.
  2 = maximum earth shock before arrival of air wave.
Fig. 1 — Frequency response of amplifier, Model 810, Serial No. 4.
Fig. 2—Amplifier linearity curve, Model 810, Serial No. 6.
Fig. 3—Schematic drawing of the Geophysical Research Corporation's Type SG-3 Velocity Geophone (from NDRC Report A-238, p.3).
Fig. 4 — Sketch of amplifier chamber and geophone pit.

Fig. 5 — Height scaling curves, relative geophone amplitude; charge 5 lb pentolite; horizontal distance 150 ft.
Fig. 6—Sketch of geophone station locations for 100-ton test.
Fig. 7—Record from south line of geophone stations at 800, 1500, and 9000 yd for 100-ton shot; calibration recorded at 10,000 yd south. Approximately half size.
Fig. 8--Vertical Reynolds geophone and shake table used for calibration.

END OF DOCUMENT