A modern industrial establishment is usually a grouping of buildings and structures with complex above-ground and subsurface interconnecting elements. Under these difficult conditions, the installation of pile foundations closer than 20-25 m from existing buildings and structures requires special investigations to estimate ground vibrations excited during pile driving. This report presents certain results of experimental studies of ground vibrations, which were obtained during the driving of 30 × 30 cm piles with an S-330 hammer at various Ufa construction sites.

Ground-surface vibrations were recorded by an N-700 oscillograph and SVI-10 earthquake-shock receivers at various distances $r$ from the piles and at different depths $l$ of pile embedment during normal hammer operations. Timing marks were introduced at 0.1-sec intervals. Figure 1 shows the arrangement of the earthquake-shock receivers.

Figure 2 shows recordings of ground vibrations at the No. 1 site; the physicomechanical properties of the soils indigenous to this site are listed in Table 1. It is apparent from the oscillograms that ground vibration is virtually completely damped in the interval between blows. The duration of vibrations excited by a blow does not exceed 1.5–3 periods; this is 2–3 times shorter than the cycle of vibrations necessary to achieve resonance with the majority of buildings and structures [1]. The vibrations noted on the oscillogram prior to and after the blow are the result of the engine of the S-878 pile-driving unit.

It also follows from the oscillograms that the frequency of ground vibrations due to individual blows is independent of the distance to the pile. It depends on the resistance $R$ of the soil to static probing below the cutting point of the pile (Fig. 3). For cohesive soils with $R = 460–2400$ kN/m$^2$, this relationship takes the form

$$f = 0.00463 R + 8(\text{Hz}).$$

![Fig. 1. Diagram showing arrangement of earthquake-shock receivers. 1) Pile; 2) earthquake-shock receivers; 3) connecting cables.](image_url)
Fig. 2. Oscillograms of ground-surface vibrations.

Fig. 3. Variation of frequency of ground-surface vibrations as function of end resistance R of soil to static probe. Triangles represent site No. 1, dark circles site No. 2, and light circles No. 3.

**TABLE 1**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Site No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Density, tons/m³</td>
<td>2.7 ± 0.2</td>
</tr>
<tr>
<td>Bulk mass, ton/km²</td>
<td>2.8 ± 0.2</td>
</tr>
<tr>
<td>Natural moisture content, %</td>
<td>30.7 ± 2.6</td>
</tr>
<tr>
<td>Degree of saturation</td>
<td>0.8 ± 0.2</td>
</tr>
<tr>
<td>Plasticity index</td>
<td>20.6 ± 0.5</td>
</tr>
<tr>
<td>Consistency</td>
<td>0.02 ± 0.05</td>
</tr>
<tr>
<td>Porosity</td>
<td>0.5 ± 0.1</td>
</tr>
<tr>
<td>Void ratio</td>
<td>0.35 ± 0.03</td>
</tr>
<tr>
<td>Cohesion, kN/m²</td>
<td>60 ± 0.2</td>
</tr>
<tr>
<td>Angle of internal friction, degrees</td>
<td>15 ± 0.1</td>
</tr>
</tbody>
</table>

**TABLE 2**

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Depth of pile embed-ment, m</th>
<th>Resistance of soil to probing 10^5 kN/m²</th>
<th>Standard pile resistance, kN</th>
<th>Amplitude of ground vibrations at distance of 5 m, 10^-2 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-2</td>
<td>10-15</td>
<td>85-120</td>
<td>0.5-1.5</td>
</tr>
<tr>
<td>1-4</td>
<td>10-15</td>
<td>80-130</td>
<td>120-290</td>
<td>1.5-2.5</td>
</tr>
<tr>
<td>7</td>
<td>20-25</td>
<td>50-100</td>
<td>250-400</td>
<td>2.0-3.5</td>
</tr>
<tr>
<td>1-2</td>
<td>6-12</td>
<td>0.15-0.35</td>
<td>50-180</td>
<td>1.0-1.5</td>
</tr>
<tr>
<td>3-4</td>
<td>8-10</td>
<td>0.5-0.15</td>
<td>270-230</td>
<td>1.0-1.5</td>
</tr>
<tr>
<td>7-8</td>
<td>20-25</td>
<td>0.35-0.3</td>
<td>340-350</td>
<td>1.0-1.5</td>
</tr>
<tr>
<td>9-10</td>
<td>40-40</td>
<td>0.65-0.8</td>
<td>435-375</td>
<td>1.0-1.5</td>
</tr>
<tr>
<td>11-12</td>
<td>76-76</td>
<td>0.55-0.65</td>
<td>490-499</td>
<td>1.0-1.5</td>
</tr>
<tr>
<td>2</td>
<td>1-2</td>
<td>9-5.5</td>
<td>60-80</td>
<td>0.5-0.5</td>
</tr>
<tr>
<td>3-4</td>
<td>9-8</td>
<td>0.15-0.3</td>
<td>115-160</td>
<td>0.5-1.1</td>
</tr>
<tr>
<td>7-8</td>
<td>16-11.5</td>
<td>0.5-0.3</td>
<td>210-240</td>
<td>1.5-2.0</td>
</tr>
<tr>
<td>3</td>
<td>60-60</td>
<td>2.4</td>
<td>960</td>
<td>1.4</td>
</tr>
</tbody>
</table>

The amplitude and acceleration of the ground-surface vibrations dampen as one proceeds further from the pile-driving zone (Fig. 4). This damping is rather accurately described by B. Golitsyn's relationship (broken line) [2].

The amplitude of ground vibrations increases with increasing height of the hammer drop (Fig. 5). The amplitude varies linearly with pile refusal that are close to elastic, and in accordance with a curve that asymptotically approaches a straight line with a constant abscissa during embedment when inelastic