Assessment of the Impact of Vibration Indicators on the Foundation of the Existing Building During Pile Driving

Rauan E. Lukpanov[iD]**, Serik B. Yenkebayev**[iD]**,
Duman S. Dusembinov**[iD]**, and Denis V. Tsygulyov**[iD]

Abstract The paper presents the results of vibromonitoring, the purpose of which was to determine the vibration parameters on the existing residential building from pile driving. Pile driving was assumed in conditions of dense urban development, near the building. The main evaluation parameters of vibration were: vibration displacement (amplitude), vibration velocity, frequency, and vibration acceleration. Vibration parameters were measured at different distances from the excitation source: in the vicinity of the pile, at a distance of 5, 15, 40 m, and near the building. According to the results of the measurements, the relationships of the vibroparameters changes by the driving time were obtained, based on the analysis of which the dependence of the vibroparameters changes depending on the distance from the excitation source was determined. Also, the paper presents statistical data of the obtained results, based on which the analysis of the relationship of the obtained particular values of vibration indicators was carried out. In the conclusion the calculation of the permissible distance of pile driving, made based on the vibration attenuation coefficient, determined by the results of actual measurements, is presented.

Keywords Pile driving · Piles · Vibration monitoring · Vibration acceleration · Displacement amplitude

1 Introduction

Vibromonitoring, designed to assess the maximum permissible pile driving distance, in conditions of dense urban development, has wide application in modern urban planning [1–6]. One of the main techniques for determining the permissible pile driving distance is a theoretical calculation regulated by the All-Union Scientific Research Institute [7–10]. The calculation is based on data on

R. E. Lukpanov · S. B. Yenkebayev · D. S. Dusembinov · D. V. Tsygulyov (✉)
L.N. Gumilyov Eurasian National University, Munaitpassov str, 13, Nur-Sultan 010008, Kazakhstan

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engineering-geological conditions of construction, structural features of adjacent buildings and structures, and, of course, the conditions of pile driving [11–15]. The data on the engineering-geological conditions are necessary to assess the propagation of vibration indicators through the soil thickness, the design features of the building are necessary to assess the conditions of vibration loadings perception, and the driving data are necessary to assess the initial parameters of the excitation source vibration [16–20].

The object of vibromonitoring is a construction site "Residential complex with detached commercial buildings and parking lot, located in Nur-Sultan".

2   Methods

The vibration monitoring program included the following tasks:

- analysis of initial data: adjacent buildings and structures, pile field, driving conditions, engineering and geological conditions;
- calculation of the permissible distance for pile driving based on theoretical data according to code (VSN 40-97) [21];
- experimental measurements of vibration effects of pile driving on the existing buildings (by several control measurements, subject to the closest pile driving to the inspected object);
- experimental measurements of the vibration effects of pile driving on the soil base (by differently spaced control measurements);
- calculation of the permissible distance for pile driving based on the obtained vibromonitoring data.

Software package "Program for the calculation of foundations and foundations, StroyExpertiza" was used for the automated calculation. The calculation is based on the methodology regulated by VSN 40-97. As the initial data the pile driving parameters, ground conditions, and the characteristic of the object, relative to which the influence of pile driving is estimated, are taken. The automated calculation is used as a preliminary estimation of groundmass vibration propagation (during pile driving), it is necessary to determine the reference points of experimental measuring of vibration influence of pile driving on the ground base.

The measurements were made in two stages:

The first stage—conducting experimental measurements of the vibration effects of pile driving on the existing building;

The second stage—conducting experimental measurements of the vibration effects of pile driving on the subsoil.

Conditions of the first stage:

1. To conduct experimental measurements of the impact on the foundation of the building from pile driving, the worst (unfavorable) condition—the closest possible location of the source of excitation of shock and vibration effects from the building—is taken.

2. To avoid the negative impact of shock and vibration load from pile driving on the existing buildings and structures, the number of measurements should be minimal, but sufficient to obtain reliable results. Thus, to analyze the impact of pile driving on the foundation of the existing building, at least 2 tests are performed (to compare the results). In case of a large gap between the two results, a 3rd control measurement was carried out to eliminate one of the erroneous data.

3. Install the vibration sensors depending on the availability of the structure according to the following mutually exclusive priority: on the foundation structure, on the most massive basement wall structure, on the staircase of the entrance group (facing the source of excitation). Sensors to be installed on the bare structure, according to all the requirements of the manual of the measuring instrument.

Conditions of the second stage:

1. To conduct experimental measurements of shock and vibration effects on the subsoil from pile driving, the worst (unfavorable) condition is taken: the closest possible location of the source of excitation of shock and vibration effects.

2. To avoid the negative impact of shock and vibration load from pile driving on existing buildings and structures, the number of measurements should be minimal, taken equal to one for a single reference point. Detection of random error is performed by comparing the results of measurements on: control points of different distances; equidistant control points of two objects; the results of subsequent measurements at a distance from the existing buildings and structures.

3. For a more detailed analysis of the impact of pile driving (as well as to identify the random error of p. 3) additional tests were conducted at remote sites, in which the vibration impact of the pile driven on the building is minimal. The main condition is the similarity of the geotechnical structure. The additional tests include a greater number of measurements required to compare with the previously obtained results (if necessary, their correction).

4. Vibration sensors are installed on a reinforced concrete slab, the inertia of which allows resisting shock and vibration effects and surface vibrations of the ground. Sensors are installed on the bare structure, according to all the requirements of the manual of the measuring instrument.

Measurements of vibration impact were made by 2 devices Vibrotest-MG4.01 in parallel on 2 control points respectively. Fixing vibration sensors on the control points of the building structures and the groundmass is carried out using anchoring of supporting plates. Figure 1 shows diagrams of the first and second stages with the location of the excitation source (hammering) and control points of measurements. Figure 2a shows the positions of sensors installed on reinforced concrete structures, and Fig. 2b shows the installation of vibration sensors on a reinforced concrete slab of sufficient inertness.

Determination of the minimum permissible pile driving distance to the existing building is performed according to the method of the All-Union Scientific Research
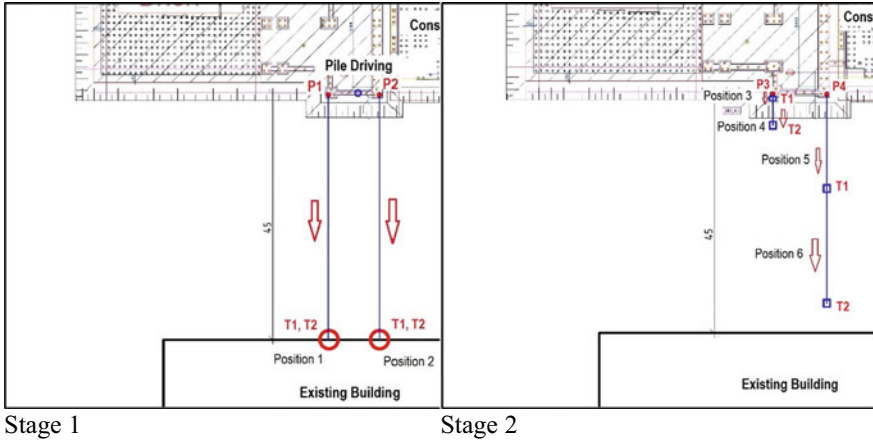
Fig. 1 Layout of vibromonitoring checkpoints

Fig. 2 Installation of vibration monitoring sensors

Institute [3], based on the obtained vibromonitoring data. The calculation technique is reduced to the determination of two coefficients λ and δ. The coefficient λ characterizes the initial acceleration, depending on the impact energy of the hammer and the ground conditions of the site. The coefficient δ characterizes the effect of attenuation of vibration indicators during the passage of the shock wave through the soil thickness, determined based on the Bouguer-Lambert law.

3 Results

Figure 3 shows the dependences of changes in the measured vibration parameters over time of pile immersion. In Fig. 3a—change in acceleration over time, Fig. 3b —speed over time, Fig. 3c—frequency over time, Fig. 3d—amplitude over time.

Figure 4 shows the dependences of the maximum and average values of the vibration parameters by distance from the excitation source. In Fig. 3a—change of acceleration by distance, Fig. 3b—velocity by distance, Fig. 3c—frequency by distance, Fig. 3d—amplitude by distance. To assess the magnitude of the attenuation of the vibration effect, the changes of private values are shown on the absolute time scale, multiples of 10 s. Table 1 shows the maximum values of vibration indices depending on the distance of pile driving.
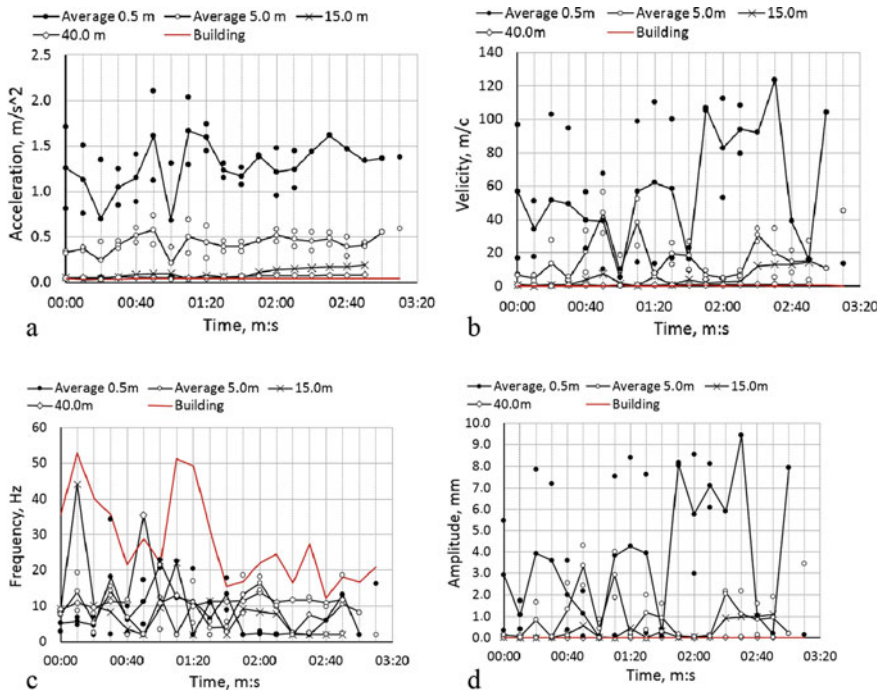

Fig. 3 Variation of vibration indicators by time of measurement (hammering)
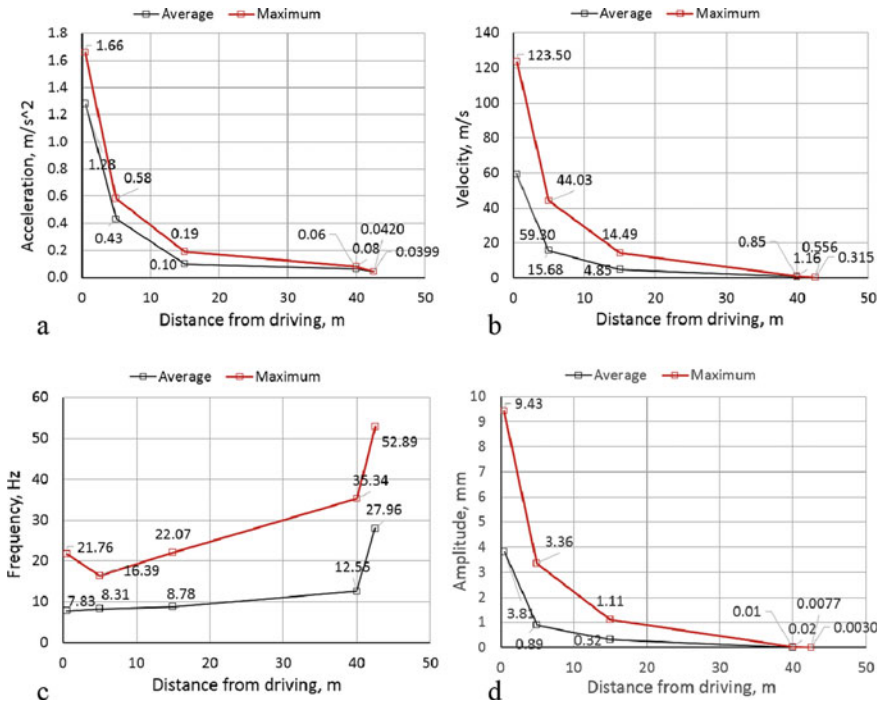
Fig. 4 Variation of maximum and average vibration values depending on the distance to the excitation source (pile driving)

According to the obtained diagrams, all the indicators, except for the frequency, have a logical inverse proportionality of the dependence of the values on the distance from the excitation source, which is also evidenced by the correlation coefficients presented in Table 1. The high values indicate the existing regularity, and the negative values indicate the inverse proportionality. The direct proportionality of the frequency change can be explained by the fact that the frequency of the building natural vibration, equal to 52.89 Hz (maximum), as well as the natural frequency of the soil base of 35.34 Hz (no influence of hammering at 40 m distance), exceeds the frequency of the ground vibration from pile driving, approximating the value of 21.76 Hz (maximum). All other intrinsic vibration indicators are lower than the vibration indicators caused by pile driving.

Determination of the minimum allowable distance of pile driving to the existing building is performed according to the method of the VSN [2]. The value of the coefficient λ is:

$$\lambda = \frac{a_I}{\frac{A_f}{A_s} \alpha_0} = \frac{0.15}{0.7 \cdot 2.1} = 0.10$$

Table 1 Maximum values of vibration indicators

Parameters	Distance (L) from pile driving, m					Correlation coefficient, $\left(\frac{Distance\ (L)}{Parameter\ (a,v,f,A)}\right)$
	0.5	5.0	15.0	40.0	42.5	
	Soil	Soil	Soil	Soil	Soil	
Acceleration (a), m/s^2	1.66	0.58	0.19	0.08	0.042	−0.766/
Speed (v), m/s	123.50	44.03	14.49	1.16	0.556	−0.788
Frequency (f), Hz	21.76	16.39	22.07	35.34	52.89	0.908
Amplitude (A), mm	9.43	3.36	1.11	0.02	0.007	−0.791

Fig. 5 Nomogram for determining the maximum permissible pile driving distance
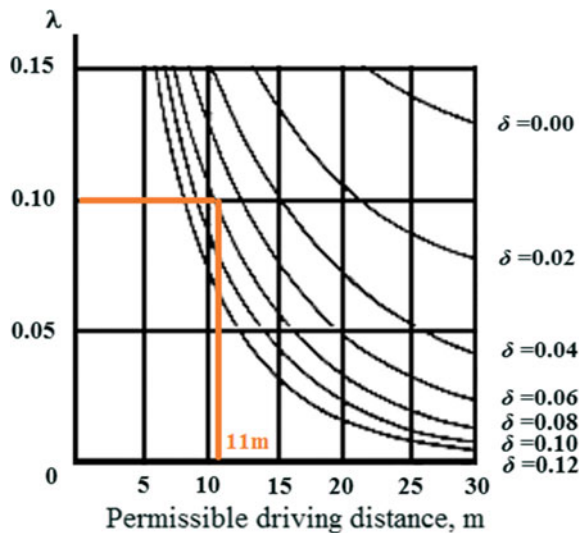
where a_l—allowable acceleration of vertical vibrations of the foundation, at which no additional deformation of the foundation occurs, taken according to [3], depending on the type of soil 0.15 m/s^2; α_0—maximum acceleration of soil vibrations at the distance of 0.5 m from the driven pile, taken 2.10 m/s^2 according to the vibromonitoring results; A_f—maximum amplitude of the foundation, equal to 0.055 mm according to vibromonitoring; A_s—maximum amplitude of the soil adjacent to the building, equal to 0.080 mm according to vibromonitoring.

The coefficient of damping of vibrations with distance δ for flowing and soft plastic loams we take 0.07.

The permissible distance is determined from the graph (Fig. 5). If the coefficient $\lambda]] > = 0.10$, and coefficient of damping $\delta = 0.08$, then the allowable distance from the piles to the building is 11 m, while the allowable distance according to the results of theoretical calculations based on engineering and geological data, the

parameters of pile driving equipment and design features of the building was 14 m. In both cases, the maximum permissible distance does not exceed the design distance of pile driving to the existing building of $\sim$35–40 m.

4   Conclusions

- Measurements of vibration indicators of natural vibrations and forced vibrations from pile driving were made. Measurements were made at different distances, to assess the effect of attenuation of vibration indices.
- According to the results of vibromonitoring values of vibration parameters of adjacent buildings and soil base, based on which the calculation of the maximum permissible distance of pile driving.
- Obtained maximum values of vibration accelerations are from 0.0322 to 0.0554 m/s^2, which does not exceed the maximum allowable value of 0.15 m/s^2. The maximum permissible distance based on theoretical calculations based on geotechnical data, pile-driving equipment parameters, and structural features of the building was 14 m. The maximum permissible distance based on the results of the actual vibration parameters was 11 m.
- It should be noted that the resulting maximum permissible distance of 11 m is valid under the condition of pile driving from the distance (or from distances at least) at which the measurements were made—35–40 m from the building. Driving the piles at closer distances requires repeated measurements of the vibration values to adjust the maximum permissible distance due to changes in the soil conditions in the vicinity of the building, and therefore changes in the spread of the vibration values through the soil strata.

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