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Cite as: AIP Conference Proceedings **2559**, 050004 (2022); https://doi.org/10.1063/5.0100336
Published Online: 16 August 2022

D. K. Orazova, R. E. Lukpanov, L. V. Gorshkova, et al.

Assessment of the Reliability of the Operated Ereymentau Wind Power Plant Based on the Results of Field Observations During the Construction Period

D. K. Orazova[1, a)], R. E. Lukpanov[2], L. V. Gorshkova[1], Zh. M. Omarov[1], L. T. Malayeva[1]

[1] *Toraighyrov Pavlodar State University, 64 Lomov Street, Pavlodar, 140000, Kazakhstan*
[2] *L.N. Gumilyov Eurasian National University, 2 Satbaeva street, Nur-Sultan, 010000, Kazakhstan*

[a)] Corresponding author: dinarzhan_84@mail.ru

Abstract. This article presents the results of vibration monitoring of the wind power plant (WPP). The analysis of the vibration effect from the pulsating loads of the tower on the foundation of the wind power plant is given based on the results of field researches. In the automated mode, the actual vibration parameters of the tower foundation were determined. The results of the research are presented by the graphical dependence of the vibration characteristics (frequency, amplitude, acceleration) on the intensity of the wind pressure. An extrapolation of the potential forces arising in the foundation at the maximum wind loads of the area is given. In order to predict the potential stress-strain state of the foundation, the obtained monitoring parameters were used for numerical modeling in the Plaxis 2D software package. The simulation results made it possible to make a prediction of the stress-strain state according to the maximum vibration indices. Recommendations on the choice of the optimal foundation in the engineering-geological and climatic conditions of the wind power plant are also given.

INTRODUCTION

Kazakhstan has all the necessary resources for the operation of wind power plant (WPP). And given the shortage of electricity in the country, especially in the southern regions, wider use of alternative sources is of particular importance. Inefficiency of centralized power supply on the vast territory of Kazakhstan, occupying 2.7 million square kilometers, and low population density (5.5 people per square kilometer) leads to significant energy losses during its transportation. Therefore, the use of renewable energy sources will reduce the cost of providing electricity to remote settlements, and significantly save on the construction of new power lines [1].

Wind power engineering is the most dynamically developing type of renewable energy sources, and wind power generators are becoming increasingly popular [2].

After studying the energy potential of wind in Kazakhstan, the Government of the Republic of Kazakhstan in collaboration with the United Nations Development Program “Kazakhstan – the Development Initiative of Wind Power Engineering Market” identified the Ereymentau district of Akmola region as the most promising for the construction of wind power plants. This program contributed to the development of the wind energy market in Kazakhstan by removing existing barriers and reducing the cost of implementing wind energy projects by [3]:

- helping the government to develop a cross-sectoral national wind energy program;
- providing information and building local capacity to design;
- promoting the construction of the first "demonstration" wind plant to pave the way for further investments and reduce risks;
- monitoring, evaluating and reporting on experiences and lessons learned from the program.

The first steps to implement the program were carried out in Ereymentau city in Akmola region.

Proceedings of the International Conference on Engineering Research 2021 (ICER 2021), Moscow, Russia
AIP Conf. Proc. 2559, 050004-1–050004-6; https://doi.org/10.1063/5.0100336
Published by AIP Publishing. 978-0-7354-4379-2/$30.00

For the present, 22 wind power plants (WPP) have been put into operation, which are connected to Ekibastuz electric power line and supply electricity to Ereymentau city, Yerkenshilik village, as well as partially to Nur-Sultan [4].

The main aim of the study was to assess the stress-strain state of the foundation, at maximum wind forces. In order to achieve the aim of the study, the following tasks were carried out:

- in-situ measurements of vibration load of a functioning wind turbine;
- calculations of the stress-strain state of the foundation of a wind turbine using the finite element method, taking into account the data obtained from in-situ measurements.

MATERIALS AND METHODS

The construction sites of WPP are located on a territory, which is free from development. The main forms of relief are dome-shaped hills, composed of dense rocks. The hills are separated by dendroid dry galleys and lowlands of blind creeks, which are confined to less stable rocks. The relative heights of the hills range from 30 to 110 meters [5-8].

The geological structure of the described territory includes sedimentary and metamorphic rocks of the Proterozoic and Paleozoic, broken by intrusions in the north-eastern part of the city, and overlapped with a cover of eluvial-deluvial quaternary deposits, represented by loams, sandy loams and clays with gravel and crushed stone, clay and loamy saprolites, rubble-gruss and gruss-rubble soils with sandy and loamy aggregate [9].

The framework of the wind power plant should be maximally stable, since it needs to withstand wind gusts of any strength. To ensure this parameter, it is necessary to mount the mast correctly, especially its base. The working efficiency and safety of the wind power plant will depend on which type of supporting element is chosen. The foundation for the wind power plant is the key to the stability and strength of a massive structure. The size and type of foundation for the wind power plant depends on the parameters of the mast, engineering and geological surveys, and loads working on the mast. Three types of foundations were considered in the project of the Ereymentau wind power plant – slab, pile-slab on driven piles and pile-slab on bored piles [10-14].

It was found that the basis of the construction site of the Ereymentau wind power plant is an inhomogeneous soil massif. Therefore, the calculation and comparison of the foundation options were performed for the most unfavorable area of the construction site, composed of weakly bearing clay soils.

All design conceptions of the wind power plant foundations are taken from the same conditions of reliability in terms of load-bearing capacity, precipitation and overall stability. However, based on these conditions, the cost indicators for material consumption and labor intensity referring to slab foundation significantly exceed the other two types of foundations. In this regard, it is recommended to use a pile-slab foundation as a more economical and reliable type of foundation for this project. This type of foundation was approved by the Customer as the foundation of a wind power plant under appropriate ground conditions [15, 16].

During the construction of the Ereymentau wind power plant, field observations were carried out in building the foundations.

Field observations, as well as measurements of the vibration effect on the foundation of the wind power plant were carried out using the VIBRA Profound device. The device allows to determine the speed, acceleration, frequency of vibrations, as well as the movement of the foundation caused by wind pressure.

The device system meets the national and international standards SBR 2002, DIN 4150 and DIN 45669.

The measurements were carried out in the following sequence:

1. Vibration impact measurements were carried out at the Ereymentau site from September 26 to 27, 2015.
2. The measurement standard meets the international standards DIN 4150 and DIN 45669.
3. Intermediate measurements were counted every 10 seconds.

RESULTS AND DISCUSSION

Annual measurements of speed and direction of wind were made at the site within the framework of the United Nations Development Program in wind power engineering. They were made in accordance with the international standards in the field of wind speed measurements for the assessment of wind potential (IEA/IEC) [2].

The wind speed distributions, the Weibull parameters at the height of 51 m (the gondola axis) for the site of Ereymentau WPP are shown in Fig. 1.

The wind direction rose shows that the predominant part of the wind has a direction from the southeast. The distribution of wind energy shows that the main part of wind energy comes from the southeast direction [3].

Based on the results of wind pressure measurements, a diagram of the seasonal distribution of wind speed is made; it demonstrates the nature of the change in the wind flow speed by months in relation to the average annual wind speed (Fig. 2).

At the construction site, the foundation of the wind power plant was tested for vibration effects using the VIBRA Profound device.

Before starting the measurement, the vibration sensors are installed on the foundation of the WPP at a distance of 100 mm from the WPP tower, in order to avoid direct contact with the excitation source (tower) (Fig. 3). The second stage was the installation of a sensor on the WPP tower.

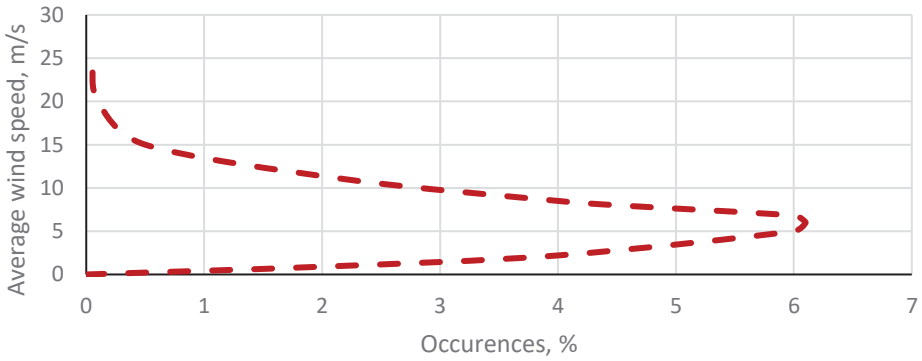

FIGURE 1. Wind speed distribution and the Weibull parameters at the height of 51 m

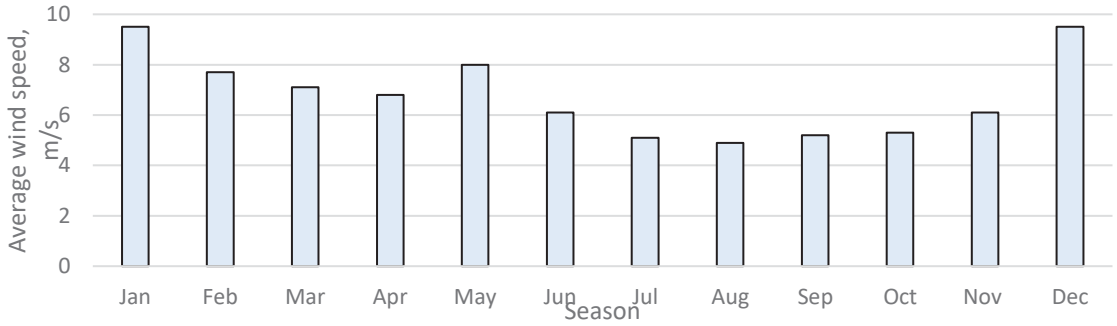

FIGURE 2. Monthly average wind speeds at the height of 50 m

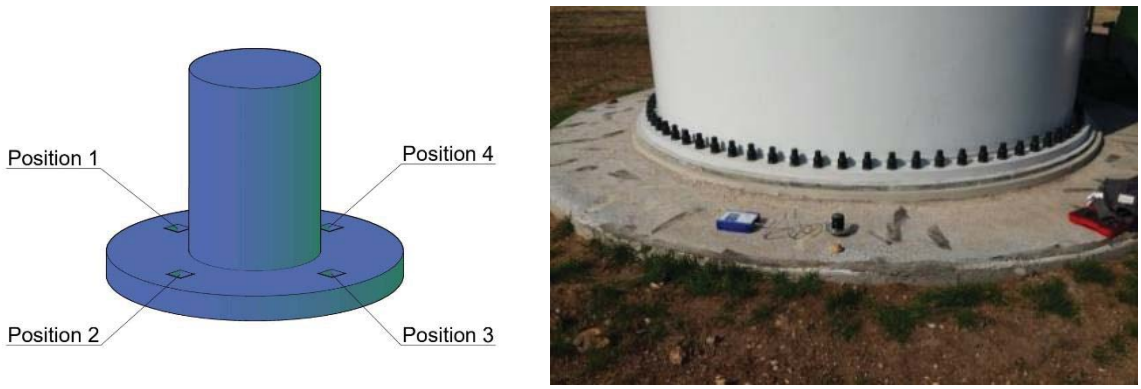

FIGURE 3. Installation of a vibration sensor on the WPP foundation

With the help of the device, a graph of the dependence of the absolute movements of the foundation and time at this site is obtained (Fig. 4). The maximum values of movements for each position are visible on the graph. For the 1st position, the maximum values of movements are 0.1 mm, for the 2nd and 3rd positions, the maximum values of movements are 0.2 mm, for the 4th position, respectively, the values are 0.3 mm with a maximum wind pressure of 4.75 m/s.

The second stage was the installation of a vibration sensor directly on the excitation source (tower) of the wind power plant. The results of vibration measurements are shown on the graphs of the dependence of displacement, accelerations, vibration frequency, velocity of vibration on wind speed (Fig. 5).

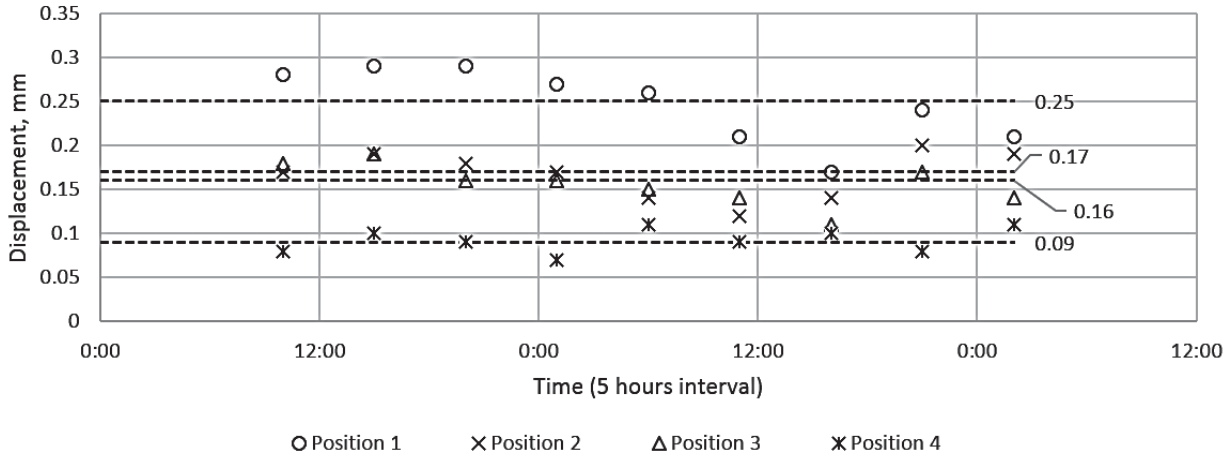

FIGURE 4. Graph of the dependence of movements on time

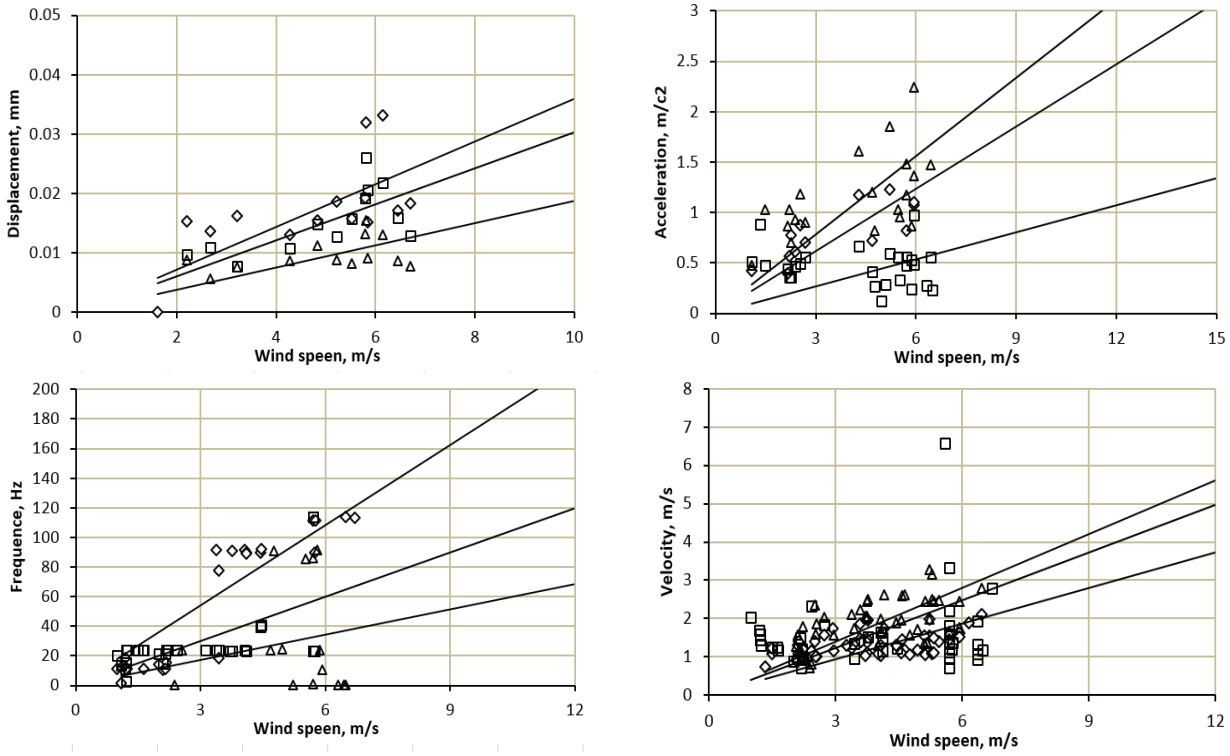

FIGURE 5. Graph of the dependence of wind parameters and wind speed

PLAXIS 2D software was used to assess the stress-strain state of the foundation of the wind power plant. The vibrations caused by the tower are transmitted through the foundation to the foundation. The main purpose of the calculation was to assess the effect of vibration effects transmitted to the foundation of the wind power plant from the tower. For the calculation we used the obtained vibration parameters of the tower, as well as statistical data on the wind load of the region. Figure 6 shows the calculation scheme, and Fig. 7 shows the results of acceleration values, the results of vibration velocity values and the graph of the vertical displacement versus time.

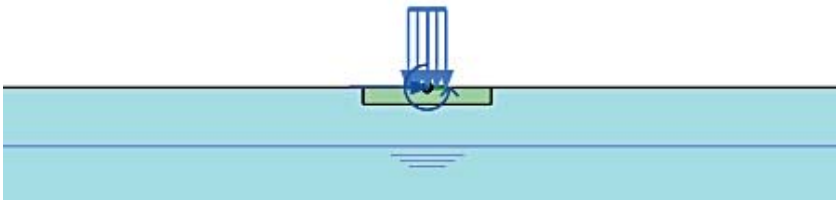

FIGURE 6. Design scheme

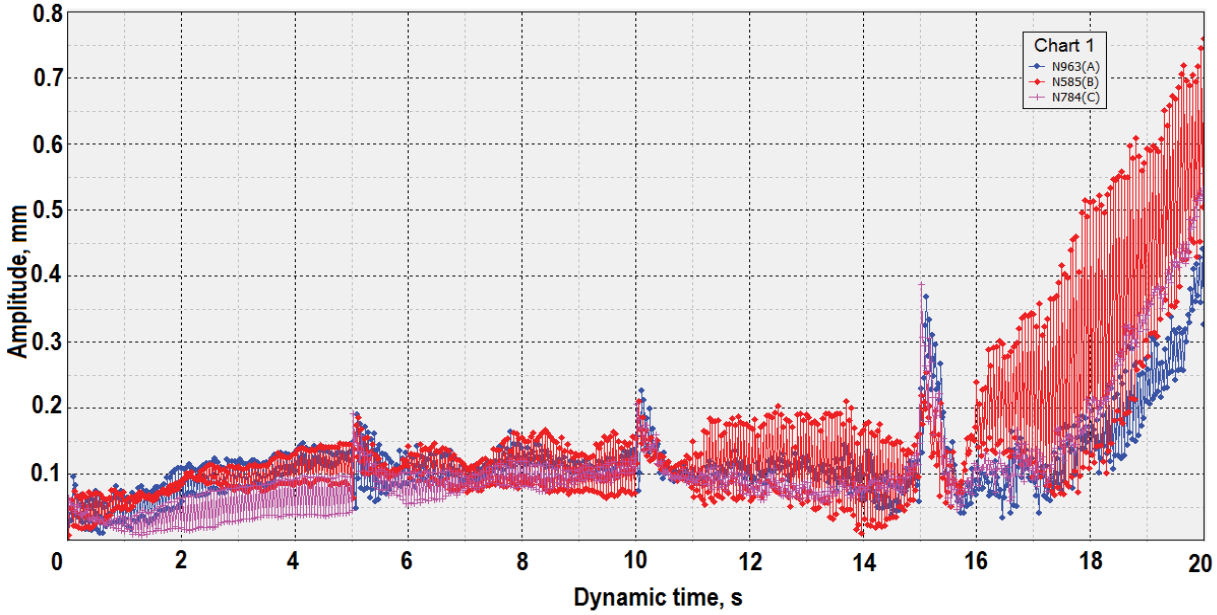

FIGURE 7. The graph of the vertical displacement vs. time for surface points at different distances from the oscillation source

CONCLUSION

Based on the measurement results, a forecast of the vibration parameters of the WPP foundation from the wind pressure was made. The maximum values of the parameters at the maximum wind pressure of this region are:

1. Maximum movement on X=0.09 mm, Y=0.076 mm, Z=0.048 mm.
2. Maximum acceleration on X=5.14 m/c^2, Y=2.24 m/c^2, Z=6.48 m/c^2.
3. The maximum vibration frequency on X=450 Hz, Y=200 Hz, Z=480 Hz.
4. The maximum vibration speed of X=7.8 mm/s, Y=9 mm/s, Z=11.8 mm/s.

According to the received graphs of the device, the collection of control points data was obtained. After analyzing the data, the dependence between the wind pressure and the vibration effects on the WPP foundation from the tower was obtained.

After assessing the reliability of the operated wind turbine based on the results of in-situ observations, the output data of the maximum values of the parameters were obtained. These parameters were entered into the software package Plaxis 2D to compare the data of the dynamic impact on the foundation from the tower of the wind turbine.

By extrapolation method, the impact on the foundation is taken at the maximum wind speed of 25 m/s.

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