Sustainable Civil Infrastructures

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Dynamic Soil-Structure Interaction for Sustainable Infrastructures

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Geotechnical Research and Design of Wind Power Plant

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Abstract. The paper refers to one of the sought-after directions – sustainable development and renewable energy. According to the world practice, the wind power industry has received a powerful impetus for development and has reached the leading positions in the economies of developed countries. AQ1

The paper presents the results of the research of the wind power plant foundations. The studies included in-situ observations (monitoring) of wind speed and vibration of the base plate (slab) of the wind power plant. Comparison of the results of the intensity of the wind pressure and the vibration parameters of the foundation helped to assess the vibration effect on the foundation in the windiest period (according to the standard for construction climatology).

After assessing the reliability of the operated wind power plant based on the results of in-situ observations, the output data of the maximum values of the parameters were obtained. These parameters had used for numerical analysis in the software Plaxis 2D to compare the data of the dynamic impact on the foundation from the tower of the power plant. Numerical simulation of the foundation of the wind power plant was carried out with the aim of analyzing the stress-strain state of the soil massif and evaluation of the stability of the basement. AQ2

1 Introduction

A lot of studies have been done to analyze the dynamic behavior of soils (Awwad and Donia 2016; Awwad et al. 2017; Alkayyal and Awwad 2015). However, there are not a lot of publication about the wind power plant foundations, especially for the geotechnical conditions of Kazakhstan. Wind power is the most dynamically developing type of renewable energy sources. Having studied the energy potential of wind in Kazakhstan, the Government of the Republic of Kazakhstan together with the UN development Program “Kazakhstan is the initiative of the development of wind power market” has resolved that the Ereymentau district of Akmola region is the most prospective area for the construction of wind power plants (National program 2007).

The research project represents the Wind Power Plant (WPP hereinafter) with the capacity of 50 MW located near Ereymentau city (Kazakhstan). The WPP is under construction and provided for increasing wind energy power in Ereymentau up to 300 MW. WPP located in a high wind zone, and this makes it useful for large-scale production of electric power.

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The construction site is located on the undulating foothill plain, which has the general slope to the north. The geological structure of this territory has the sedimentary and metamorphic rocks of the Proterozoic and Paleozoic era, which are broken by intrusions in the north-east part of the city and covered with eluvia-diluvia quaternary deposits. The geological cross section is presented in Fig. 1.

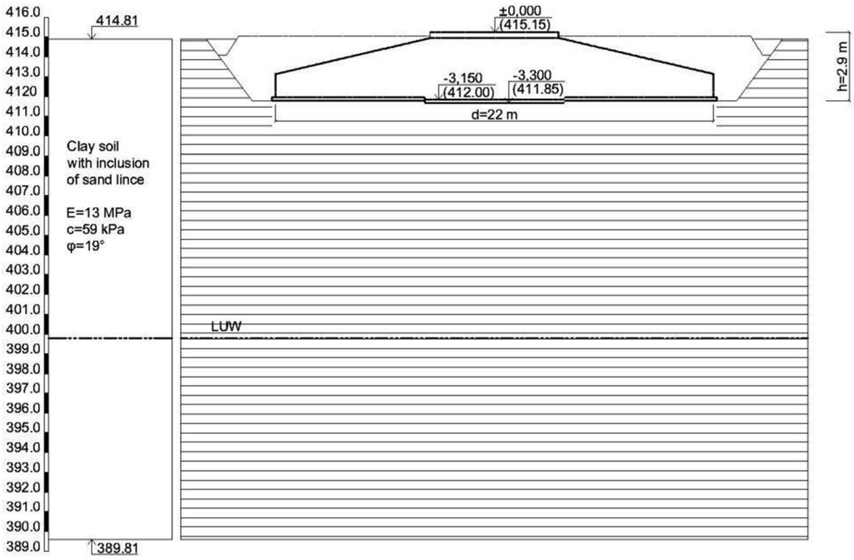


Fig. 1. Geological section of the site

Annual measurements of speed and direction of wind were made at the site within the context of the UNDP project on wind power. Measurements were performed in accordance with international standards in the field of measuring wind speed in order to estimate wind potential (IEA/IEC) [2].

The distribution of wind speed and Weibull parameters at the height of 51 m (the axis of the gondola) for the site of Ereymentau WPP are shown in Fig. 2.

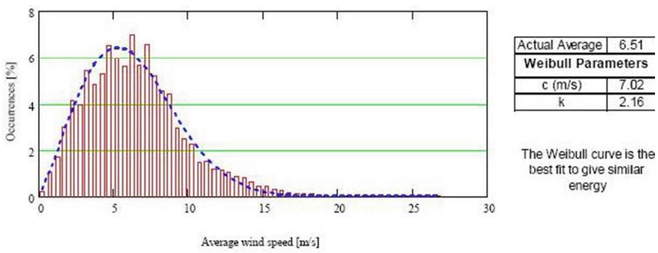


Fig. 2. Distribution of wind speed and Weibull parameters at the height of 51 m

According to the results of wind pressure measurements, the diagram of a seasonal distribution of wind speed was made. It demonstrates the changes in the wind flow speed by month in relation to average annual wind speed (Fig. 3).

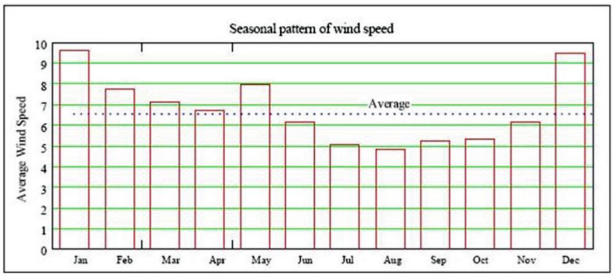


Fig. 3. Monthly average wind speed at the height of 50 m

2 In-Situ Monitoring

The field studies and measuring the vibrational effect on WPP foundation were made with the help of VIBRA Profound indicators. These instruments allow defining the speed, acceleration, vibration frequency and foundation displacement caused by wind pressure. The instrument system meets national and international standards SBR 2002, DIN 4150 and DIN 45669.

The source of vibration is the WPP tower located on a reinforced concrete foundation with a thickness of 2.9 m and a diameter of 22 m. Fluctuations caused by the tower, are passed to the ground base through the foundation Zhussupbekov et al. (2017). AQ3

Vibration loads from the tower to the foundation were measured by sensors with the help of VIBRA Profound device (Fig. 4). Movements are recorded on the WPP tower (Fig. 4). Intermediary measurements were counted every 10 s.

A measurement takes a month to make all the measurements. Control points data was obtained according to the diagrams of the device. The relationship between wind pressure and vibration impacts on the WPU foundation from the tower was obtained after data analyzing. The method of extrapolation can allow measuring the impact on the foundation at a maximum wind speed of 25 m/s.

The diagram in Fig. 5 shows a dependence of the foundation movement (due to of tower fluctuation) and time elapses. The diagram shows the maximum values of displacements for each position. The maximum values of displacements for the 1 position are 0,1 mm, the maximum values of displacements for the 2 and 3 positions are 0,2 mm, and 0,3 mm – for the 4 position, at the maximum wind pressure of 4,75 m/s.

The measurement results of vibration shown in the graphs of a dependence of displacements, accelerations, frequencies of vibration, a velocity of vibration from wind speed (Fig. 6).

According to the results, the measurement was made the prediction of vibration parameters of the wind turbine foundation from wind pressure.

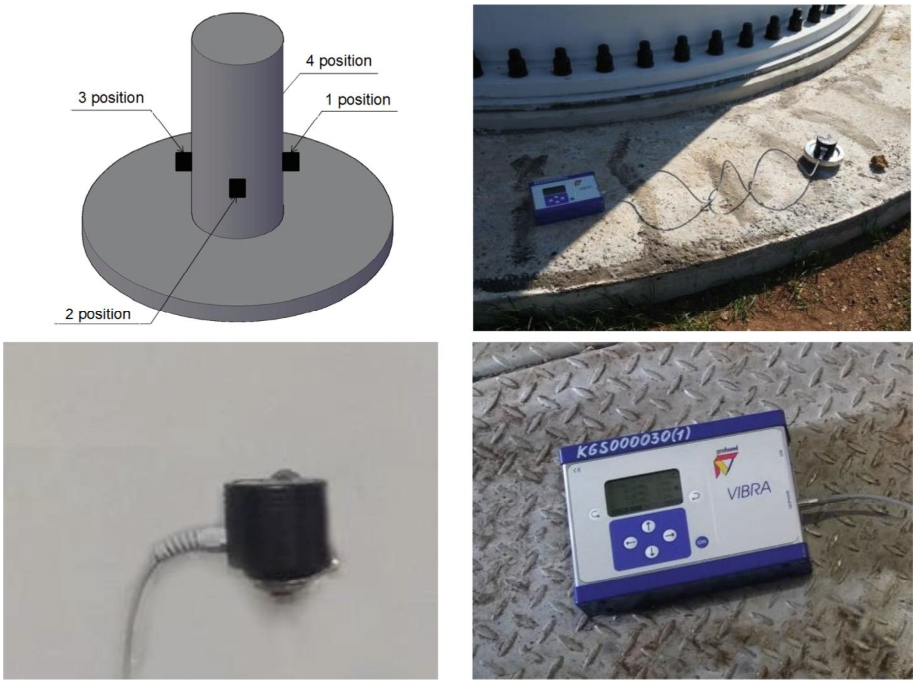


Fig. 4. In-situ monitoring of wind power

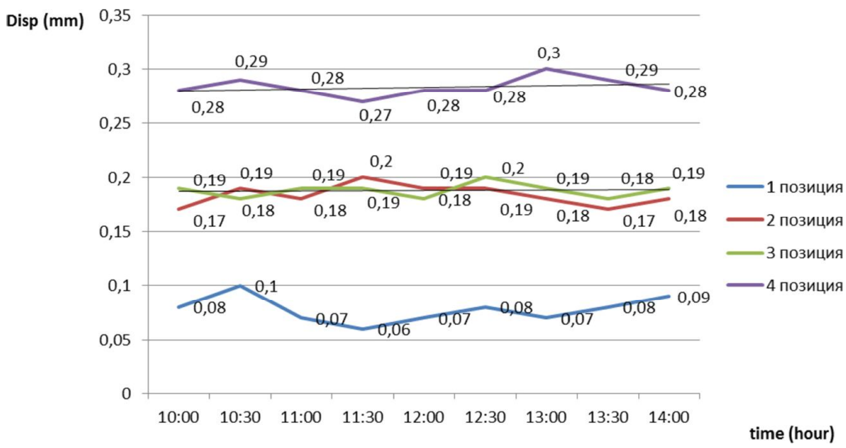
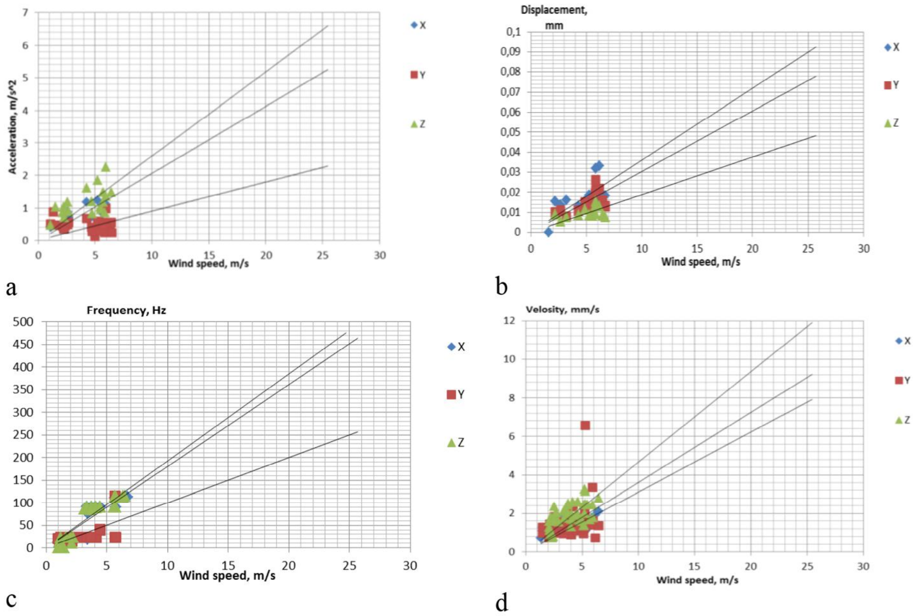


Fig. 5. Diagram of a dependence of displacement and time

In accordance of field measurement maximum values of the parameters at the maximum wind pressure in this region are follows:

(1) Maximum displacement on X = 0,038 mm, Y = 0,031 mm, Z = 0,08 mm;



a) graphs of a dependence of displacements from wind speed
b) graphs of dependence frequencies of vibration from wind speed
c) graphs of a dependence of accelerations from wind speed
d) graphs of a dependence of velocity of vibration from wind speed

Fig. 6. Monitoring data

(2) Maximum acceleration on X = 2,8 m/s^2, Y = 2,1 m/s^2, Z = 0,7 m/s^2;
(3) Maximum frequencies of vibration on X = 122 Hz, Y = 120 Hz, Z = 65 Hz;
(4) Maximum velocity of vibration on X = 4,2 mm/s, Y = 3,6 mm/s, Z = 2,8 mm/s.

3 Numerical Modeling of WPP

PLAXIS 2D allows modelling the interaction between soil and construction. The influence of vibration work on the soil on which it is installed was considered.

The dimensions of the soil mass are determined based on the computation of compressible stratum, represented by a clay layer of 60 m. The soil surface is set at the point y = 0. The foundation is represented by clay, which is considered here as an elastic-plastic material. A dataset is formed by selecting the soil type and interface, according to the information given in Table 1. Dynamic stiffness of soil is significantly higher than its static stiffness, as dynamic loading is usually rapid and it results in ultra-small deformations.

Table 1. Material properties of soil

Parameter	Name	Value	Unit
General			
Material model	Model	Mohr-Coulomb	–
Type of material behaviour	Type	Drained	
Soil unit weight above the phreatic level	γ_{unsat}	16	kN/m^3
Soil unit weight below the phreatic level	γ_{sat}	18	kN/m^3
Parameters			
Young's modulus (constant)	E′	13*10^4	kN/m^2
Poisson's ratio	ν'	0,38	
Initial			–
K_o determination	–	Automatic	–
Lateral earth pressure coefficient	$K_{o,x}$	0,674	–

The material dataset for footing according to the information given in Table 2.

Table 2. Material properties of the footing

Parameter	Name	Value	Unit
General			
Material model	Model	Linear elastic	–
Type of material behaviour	Type	Non–porous	–
Soil unit weight above the phreatic level	γ_{unsat}	24	кН/м^3
Parameters			
Young's modulus (constant)	E′	30*10^6	кН/м^2
Poisson's ratio	ν'	0,2	
Initial			–
K_o determination	–	Automatic	–
Lateral earth pressure coefficient	$K_{o,x}$	1	–

A distributed load is applied to the foundation, as well as a horizontal force and a concentrated moment for modelling the wind turbine weight, and fluctuations that it causes Lukpanov et al. (2016). The geometric model is shown in Fig. 7.

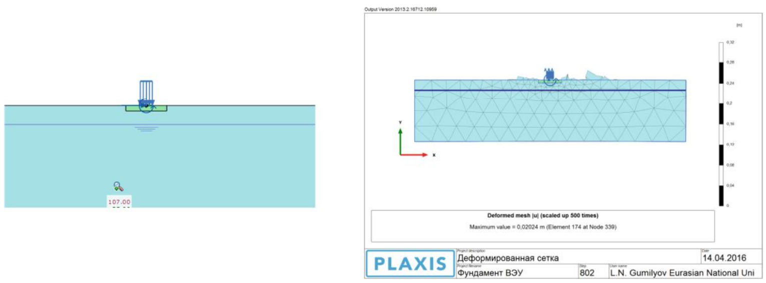


Fig. 7. Geometric model and mesh of the foundation

Figures 8, 9 and 10 show the results of the accelerations, the results velocity of vibration values and the diagram of the dependence of vertical displacement on time. AQ4

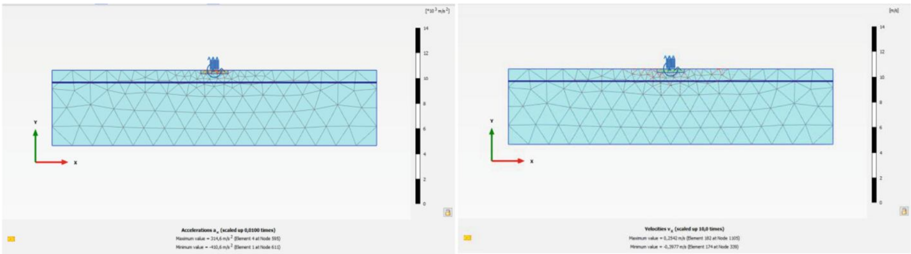


Fig. 8. The results of the acceleration and velocity

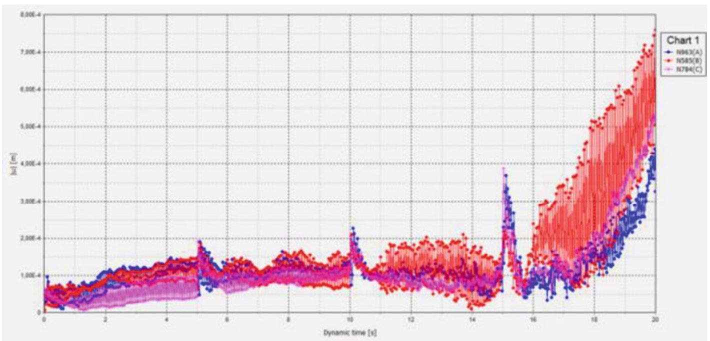


Fig. 9. The diagram of the dependence of vertical displacement on time

4 Conclusions

According to the results, the measurement was made the prediction of vibration parameters of the wind turbine foundation from wind pressure.

Maximum values of the parameters at the maximum wind pressure in this region are:

- Maximum displacement on X = 0,038 mm, Y = 0,031 mm, Z = 0,08 mm;
- Maximum acceleration on X = 2,8 m/s2, Y = 2,1 m/s2, Z = 0,7 m/s2;
- Maximum frequencies of vibration on X = 122 Hz, Y = 120 Hz, Z = 65 Hz;
- Maximum velocity of vibration on X = 4,2 mm/s, Y = 3,6 mm/s, Z = 2,8 mm/s.

This parameter of displacements for wind turbine does not exceed the maximum permissible value of 5 mm (DIN 45669-1 1995).

The obtained vibration impacts from the tower to the foundation under maximum wind pressure were integrated with the Plaxis 2D software program. Having applied static and dynamic loads in the program we got the displacement with a certain frequency and acceleration, and vibrations speed.

The diagram of the dependence of vertical displacement on time shows that these displacements do not exceed a limit value for WPU foundations.

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