13th Baltic Sea Region Geotechnical Conference

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HISTORICAL EXPERIENCE AND CHALLENGES OF GEOTECHNICAL PROBLEMS IN BALTIC SEA REGION

Edited by Jurgis Medzvieckas

LGD LIETUVOS GEOTECHNIKOS DRAUGIJA
LITHUANIAN GEOTECHNICAL SOCIETY

SIMSG ISSMGE
INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

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The 13th Baltic Sea Region Geotechnical Conference Historical Experience and Challenges of Geotechnical Problems in Baltic Sea Region. Volume contains selected papers of the 13th Baltic Sea Geotechnical Conference, held in Vilnius, Lithuania, on September 22–24, 2016. The conference was organized by the Lithuanian Geotechnical Society, the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE), Vilnius University, Vilnius Gediminas Technical University, Kaunas University of Technology and Klaipėda University. Edited by J. Medzvieckas. Vilnius: Technika, 2016. 296 p.

The volume contains the selected papers from these thematic areas: geotechnical art and historical experiences, soil and rock investigation, design experiences and theoretical solutions, geoenvironmental engineering, case studies, foundation construction and transport infrastructure.

All papers are reviewed by two appointed experts.

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Geoenvironmental engineering

Case studies

Transport infrastructure

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Design of Foundations for Wind Turbine with Analysis by Finite Element Method

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Abstract. Presents engineering solution of wind energy tower (WET) foundation and basement designing in hydrogeological conditions of the Ereymentau area. Calculations of forces perceived by the WET, and following bearing capacity, settlement and stability analysis are made by the Finite Element Method in the program complex SCAD and Plaxis 2D. The calculated results in paper had been presented in graphics and tabulars.

Keywords: alternative energy, wind turbines, slab foundation, Plaxis 2D.

Conference topic: Design experiences and theoretical solutions.

Introduction

The Project represents the wind farm with the capacity of 50 MW located in Akmola region to the south-east from Ereymentau city, about 130 km to the east from Astana. The project is the second wind farm of SGE company in Ereymentau from Pre-investing research (Government of Kazakhstan, United Nations Organization 2008) and represents the second phase of the project provided for increasing wind energy power in Ereymentau district up to 300 MW. The wind farm is located in the south-east of the Ereymentau city about 2 km from the city center; the nearest residential building is located at a distance of 500–600 m away from the wind turbine.

Ereymentau is located in a zone of high wind loads, and this makes it possible to use it for the production of electric power in a large scale. This article represents two sites near Ereymentau for setting of wind power plants according National program of wind energy development (2007).

Electric WPU with the capacity of 2 MW (WTU 2,0) represents 3 blade wind oriented turbine with variable rotating speed (Fig. 1). WPU meets the requirements of IEC 61400-1 Standard, it is projected according to European technical regulations 2006/42/EC. The main technical characteristics of WET are presented in Table 1.

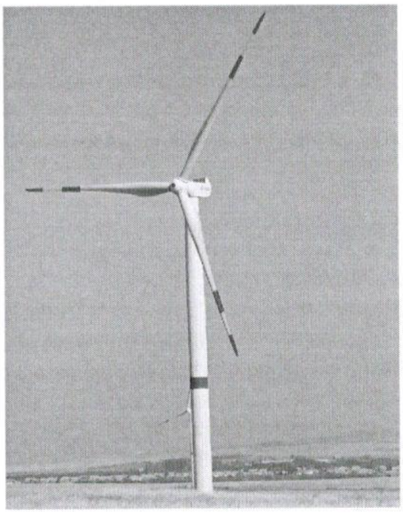


Fig. 1. WET in Ereymentau city

Table 1. Technical characteristics of WET

Index	Options
Rated power	2.050 MW
Project lifetime	20 years
The nacelle and rotor are certified according to	IEC 61400-1, class 2a
Working range of temperatures the environment	from –40 to +40 °C
Level platforms (height above sea level up to an axis of the rotor)	from 0 м to 1000 м over 1000 m (with power generation reduction)
Maximum level of a platform (height above sea level to a rotor axis)	2000 м

Hydrogeological and climatic conditions of the construction

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 north-east part of the city and covered with eluvia- diluvia quaternary deposits, presented by clay loams, sand loams and clays with land waste and breakstone, clay and clay loam saprolites, breakstone-land waste and land waste-breakstone soils with sandy and clay loam filler.

Ereymentau city is characterized by constant strong winds, mainly south-western and western directions, carrying masses of hot air in summer, which cause lingering cold storms. The average wind speed is 5–7 m/sec.

Climatological characteristics are given on the basis of long-term observations at the meteorological station of Ereymentau.

According to Technical Norms and Regulations (2.01.07-85* 1987), the standard value of wind pressure is 0.38 kPa (wind region III), 2a and 3a wind classes. Rated wind velocity repeated once every 25 years, and determined by the regional map, is 40 m/sec. Values of physical and mechanical properties of soil shown in Table 2.

Table 2. Values of physical and mechanical properties of soil

Soil	Strength of layer	E MPa	C kPa	φ
Land waste soil	4.4	28	–	–
Breakstone soil	5.1	40	–	–
Clay loams eluvia	11	22	69	27 °

Calculation of the wind turbine foundation

Design scheme of the wind turbine shown in Figure 2.

The tower of a wind turbine is an auxiliary bar with a mass uniformly distributed along its length (Q2–Q4, Fig. 2), takes wind load (w_m, w_p), which has effect on the wind wheel and the tower, as well as the efforts created by wind wheel (Q1, M*x*, M*y*, M*z*).

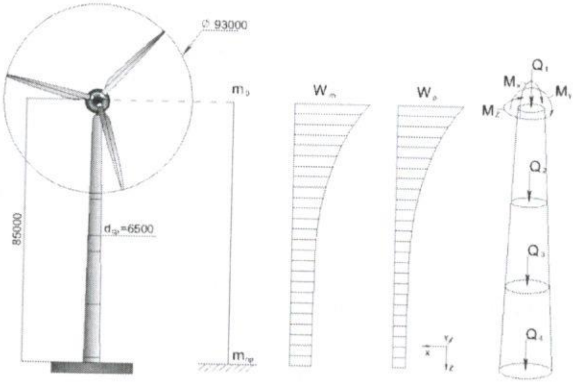


Fig. 2. Design scheme of WET

A standard calculation to determine the wind load includes: determination of an average component of wind load w_m, a pulsating component of wind load w_p, and the total standard load (Tables 3 and 4).

Calculations of the dead weight of a wind turbine are shown in Table 5. The tower is a vertical pipe made of special steel. The following parameters of the pipe are admitted: the average wall thickness is t = 2.5 cm; the average diameter throughout the height $d_{average}$ is 650 cm; the length of the stack l_{pipe} with the nacelle (1) and a wind wheel (2) on the upper end is 85 m (Fig. 1).

The shaft of the wind wheel, its bearing construction, gear, generator and other equipment of wind turbines are located inside the nacelle. Total weight of the nacelle (with wind wheel) is given: m_g = 45.000 kg.

Table 3. Wind loads on the of wind energy tower

Height, m	Characteristic			Design
	w_m t/m (kN/m)	w_p t/m (kN/m)	$w^c = w_p + w_m$ t/m (kN/m)	$w^d = w^c * F_s$ t/m (kN/m)
5	0.342 (3.35)	0.192 (1.88)	0.534 (5.23)	0.748 (7.33)
10	0.456 (4.47)	0.256 (2.51)	0.712 (6.98)	0.997 (9.77)
20	0.57 (5.59)	0.320 (3.13)	0.890 (8.73)	1.246 (12.22)
40	0.684 (6.71)	0.384 (3.76)	1.068 (10.47)	1.49 (14.66)
60	0.775 (7.60)	0.435 (4.26)	1.210 (11.87)	1.694 (16.62)
85	0.861 (8.44)	0.483 (4.73)	1.344 (13.18)	1.88 (18.46)

Note:

w_m – static (average) component of wind loading;
w_p – dynamic (pulsation) component of wind loading;
w^c, w^d – frontal resistance of the wind wheel;
F_s – factor of safety = 1.4.

Table 4. Wind loads on the wind wheel of wind energy tower

The characteristic values of drag the wind wheel (kN/m) $w^{n}_{general}$	The calculated values of drag the wind wheel (kN/m) $w^{p}_{general}$	Estimated wind speed V_p m/s (by KZ Code)	High-speed wind pressure the wind wheel q Pa	The area of the wind wheel S (m^2) (from manufacture)	Static component of the force P_h^s (kN)
0.78	1.09	5.3	17..5	6789	142.5

Table 5. The load of its own weight of wind energy tower

$\mu_б$ (t/m)	Density of steel ρ (t/m^3)	The cross-sectional area of the tower A_t (m^2)	Uniformly distribu ted mass of the tower $m_{reduced}$ (t)	Mass of gon-dolas (t)	The reduced mass (t)	The total vertical concentrated load (kN)
4	7.85	0.51	340	45	340	3850

Determination of efforts on a personal computer using the SCAD

Analysis of forces is made in the software package SCAD. Calculation scheme of wind turbines is presented in the form the system with one degree of freedom (Fig. 2). The plots are M = 7129 kNm, Q = 138 kN, N = 385 kN.

Calculation of the area of the foundation base is made according to Construction Codes and Regulations of Republic of Kazakhstan (5.01-01-2002. 2002). Foundation slab was finally adopted, and its geometry is shown in Figure 3.

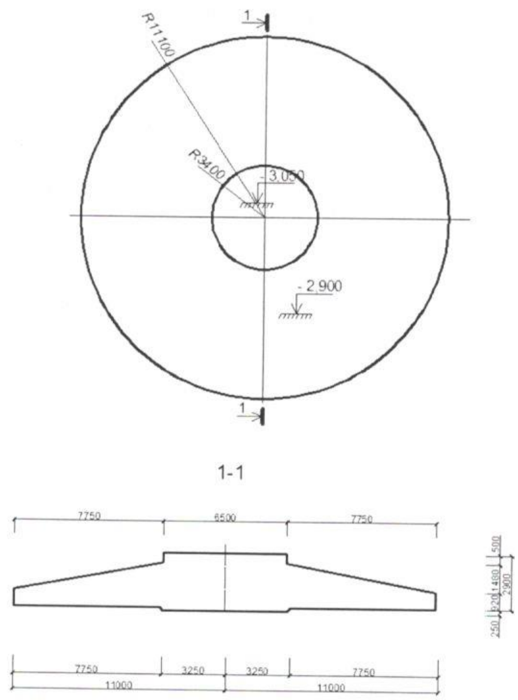


Fig. 3. The design of slab foundation

Numerical modeling of the wind turbine foundation

Two-dimensional modeling of wind turbine foundation is made in Plaxis software package. The boundary conditions of the panels of the model were given in the form of joint-movable bearing parts with free movement along the axis y, movement along the axis $x = 0$. The base of the model is given as an entire stuffing, movement along the axes x, $y = 0$.

Before calculating there had been defined initial conditions, which include initial geometric structure of the groundwater and initial state of effective stresses.

The first calculation stage included modeling of natural stresses caused by gravity. The second stage included the following loads applying to the model:

- The moment M_{max} in Plaxis software package will be presented by a pair of forces with respect to the center of the foundation.
- Longitudinal force will be presented by uniformly distributed load which acts along the cross sectional area of the lower part adjoining to the foundation.
- Horizontal load.

As the moment is represented by a pair of forces, the modeling of wind turbine foundation is made not in an axisymmetric formulation of the problem, but in a plane one. In this case, the correction of the cross section of the round foundation. Based on this condition, the width of the foundation for the plane problem is: $d = \sqrt{\pi \cdot r^2} = 19.4\ m$.

Calculation scheme and mesh of Finite Elements are shown in Figure 4. Figure 5 shows the results of calculations: vertical, horizontal and total displacements, relative deformation and normal, tangent and relative shear stress. Figure 6 shows the movement of the boundary points A and B presented in the calculation scheme (Fig. 4).

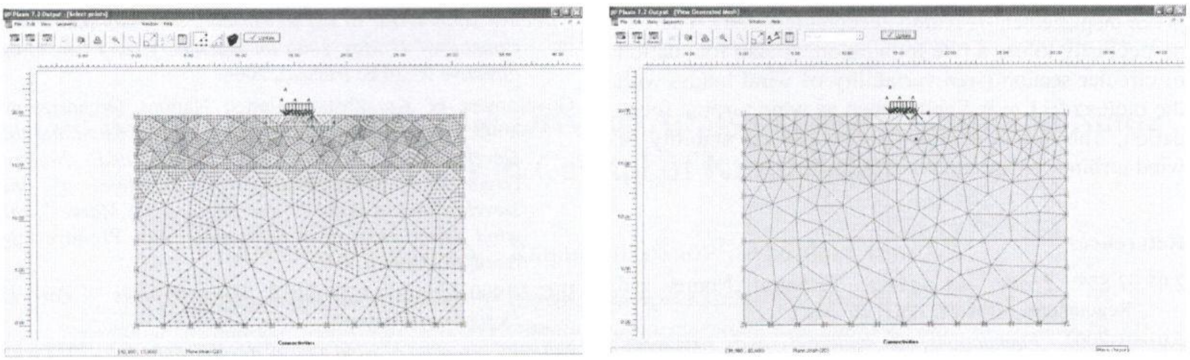
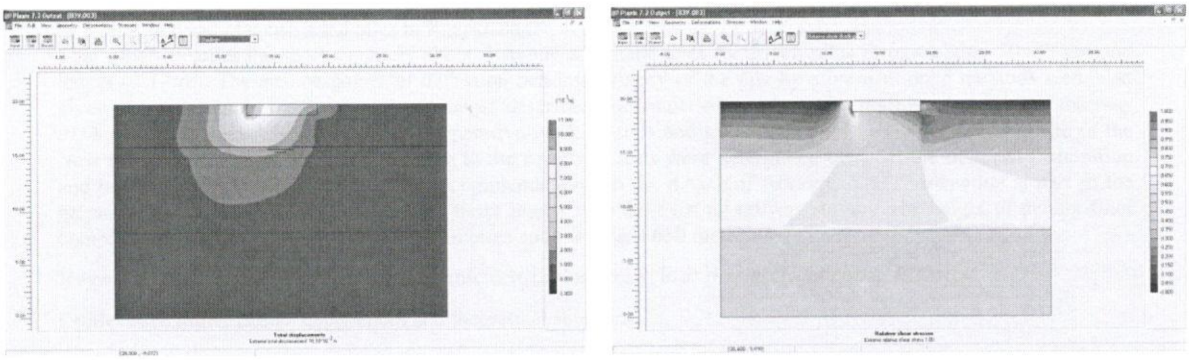
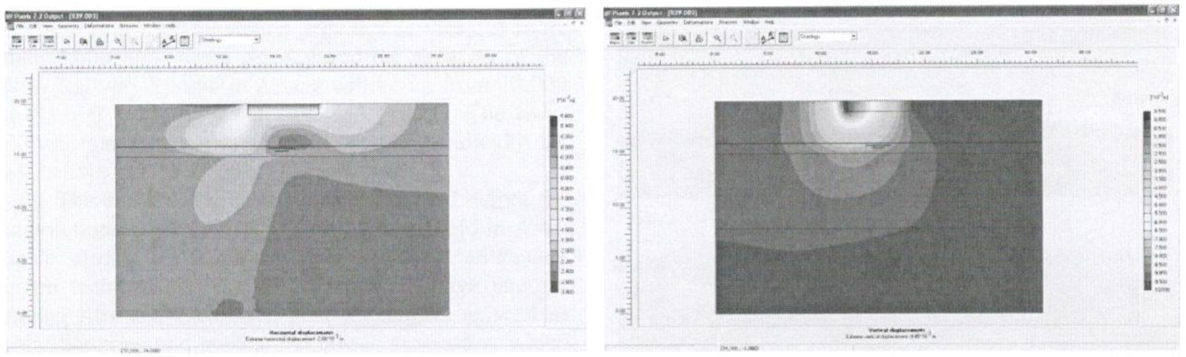


Fig. 4. Model of the foundation WET



Absolute displacements and stresses



Absolute horizontal and vertical displacements

Fig. 5. Results of the calculation

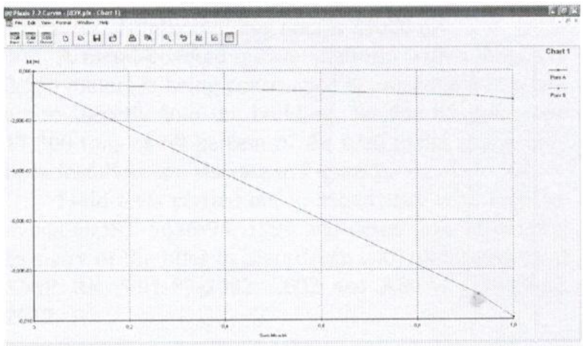


Fig. 6. Displacement the regional points

Conclusions

In conclusion, we would like to note the importance of wind turbines on the territory of Kazakhstan, particularly in Ereymentau city. It is connected with the provision of facilities of EXPO-2017 with electric energy.

The article revealed some aspects of the wind turbine projecting in the hydrogeological conditions of Ereymentau region. Calculations of forces perceived by wind turbine tower were performed in the software package SCAD, the calculation of bases and foundations was performed in the complex Plaxis 2D.

The diagram shows that the maximum displacement of point A = 9.92 mm, point B = 1.18 mm. The given displacement is within acceptable values. There is no necessity to use a pile foundation. A slab foundation of circular section (sign-variability of wind loads) with the radius of 11 m is finally taken as wind turbine foundation. The results obtained show that the stability of wind turbine construction is provided.

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