DOI 10.52209/1609-1825_2022_4_245 UDC 624.151.5

Designing the Foundation of a Wind Power Plant in the Hydrogeological Conditions of the City of Ereymentau

[1]***ORAZOVA Dinara,** *PhD, Associate Professor, dinarzhan_84@mail.ru,*
[2]**LUKPANOV Rauan,** *PhD, Professor, Director, rauan_82@mail.ru,*
[2]**TLEULENOVA Gulshat,** *PhD, Acting Associate Professor, gulshattleulenova23@mail.ru,*
[1]**OMAROV Zhumabek,** *Cand. of Tech. Sci., Associate Professor, zhumabek-omarov@mail.ru,*
[1]**AKIMBEKOVA Samal,** *Master, Senior Lecturer, sammi_ok@mail.ru,*
[1]NCJSC «Toraighyrov University», Kazakhstan, Pavlodar, Lomov Street, 64,
[2]NPJSC «L.N. Gumilyov Eurasian National University», Kazakhstan, Astana, Satpayev Street, 2,
**corresponding author.*

Abstract. *The issues of designing a wind power plant (wind turbine) in the hydrogeological conditions of the Ereymentau district, in particular, calculations of the foundation and foundation considered. The characteristics of a wind power plant that meets European technical requirements are given. The construction site described by the geological structure of the territory is shown. The calculation for determining the wind load is shown. The calculation of foundations and foundations is carried out in the Plaxis 2D software package. Modeling of the foundation in a flat problem is performed. The results of calculations are presented: vertical, horizontal and total displacements, relative deformation and normal, tangential and total stress. A slab foundation is considered, which is designed according to regulatory standards. The calculation results are presented in graphical and tabular display. The geometry of the foundation is selected from the condition of satisfying the limiting conditions: bearing capacity, draft and overall stability.*

Keywords: *alternative energy, wind turbines, slab foundation, wind load, Plaxis 2D software package, stress, displacement, bearing capacity, settlement, stability.*

Introduction

Ereymentau is located in a zone of high wind loads, which makes it possible to use it for electricity generation on a large scale. Within the framework of this article, two sites near the city of Ereymentau for the placement of wind farms are considered [1].

The 2MW power generating wind power plant (WTU 2.0) is a three-bladed, wind-oriented wind turbine with a variable rotor rotation speed (Figure 1). The wind turbine meets the requirements of the IEC61400-1 standard, designed according to the European Technical Standards 2006/42/EG. The main technical characteristics of the wind turbine are presented in Table 1 [2].

Research methods

The construction site is located on a slightly undulating foothill plain with a general slope to the north.

The geological structure of the described territory involves sedimentary and metamorphic rocks of the Proterozoic and Paleozoic, broken through in the northeastern part of the city by intrusions, and overlain by a cover of eluvial-deluvial quaternary deposits, represented by loams, sandy loam and clays with gravel and crushed stone, saprolites clay and loamy, crushed-gravel and crushed-gravel soils with sandy loamy placeholder. Figure 2 shows an engineering and geological section of the wind turbine sites.

Ereymentau is characterized by constantly operating strong winds, mainly from the south-west and west directions, carrying masses of hot air in summer, and causing prolonged cold blizzards in winter. The average wind speed is 5-7 m/sec.

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

According to [3], the normative value of wind pressure is 0.38 kPa (wind region III), wind class 2a, 3a. The normative high-speed wind pressure repeated 1 time in 25 years, determined by the regional map, is 40 m/sec.

Scientific results

The wind turbine perceives the wind load acting on the wind wheel and the tower, as well as the own weight of the structures. The wind load is calculated

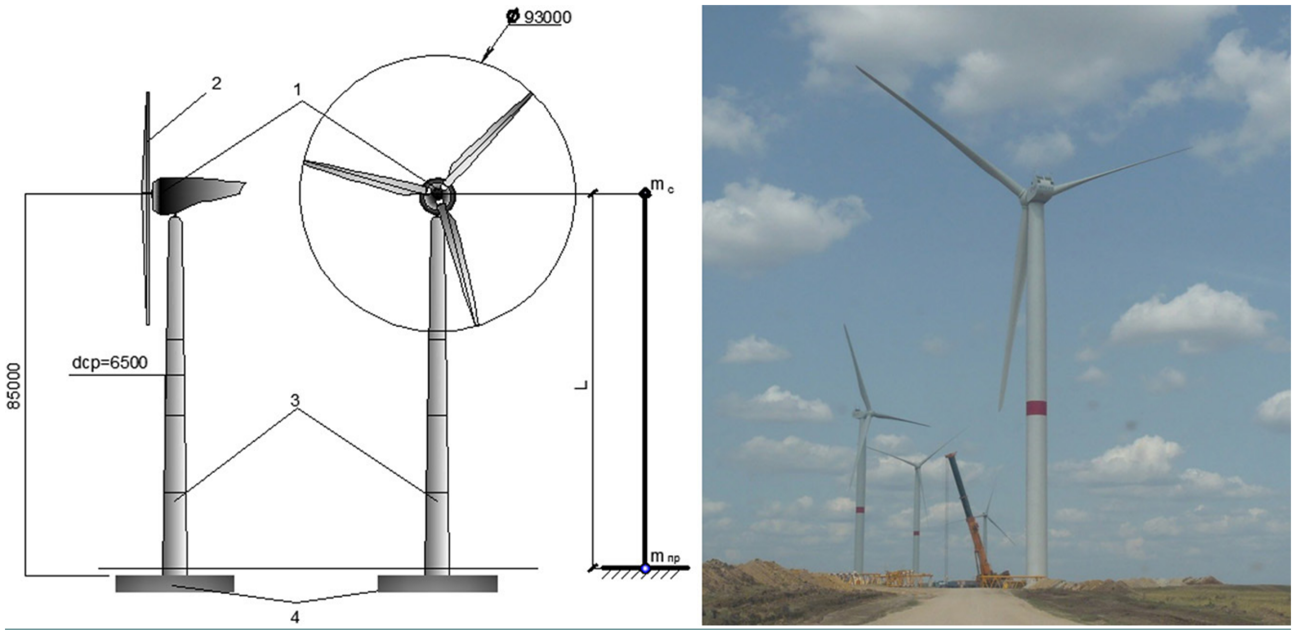


Figure 1 – Wind turbine in Erementau: 1 – gondola, 2 – blade, 3 – tower, 4 – foundation

Table 1 – Technical characteristics of wind turbines

Indicator	Parameters
Rated power	2,050 MW
Design service life	20 years
The gondola and rotor are certified according to	IEC 61400-1, Class 2a
Operating ambient temperature range Platform level (height above sea level to the rotor axis) The maximum level of the platform (height above sea level to the axis of the rotor)	from – 40 to + 40°C from 0 m to 1000 m over 1000 m (with reduced power generation) 2000 m

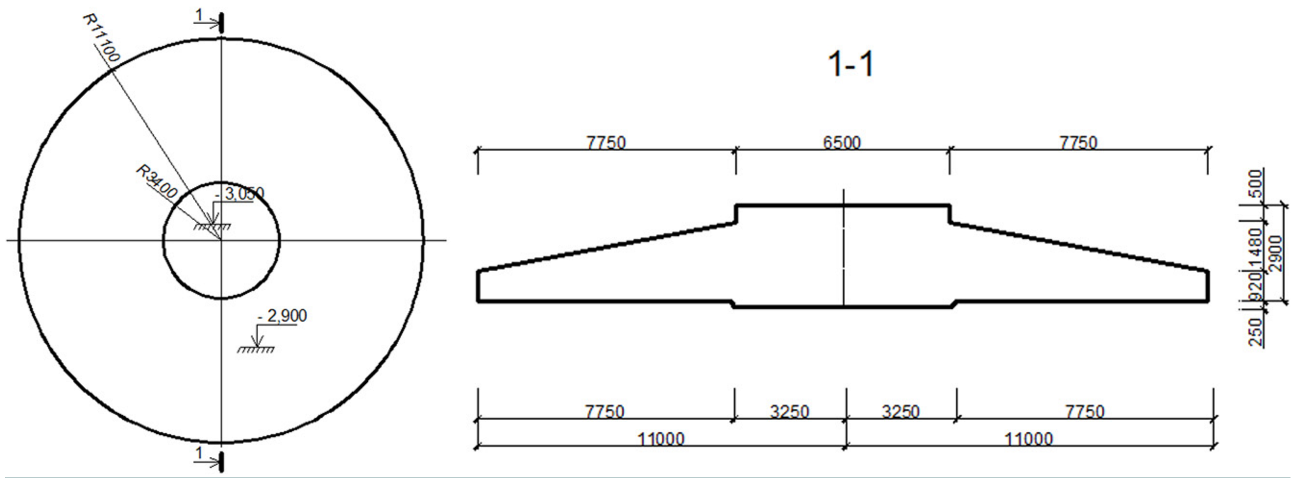


Figure 2 – Construction of the slab foundation

as the sum of the static (average) and dynamic (pulsation) components [4].

The standard calculation for determining the wind load includes: determination of the average component of the wind load w_m, the pulsation component of the wind load w_p, as well as the total regulatory load (Table 2 and 3) [5].

The tower is a vertical pipe made of special steel. The following pipe parameters are accepted: the average wall thickness t = 2,5 cm; the average diameter over the entire height dsr = 650 cm; the length lb of the pipe, at the upper end of which there is a gondola (1) with a wind wheel (2), is 85 m (Figure 1) [6].

Inside the gondola is the WW shaft, its supporting structure, gearbox, generator and other wind turbine equipment. The total mass of the gondola (together with the wind wheel) is set: mg = 45000 kg. The wind turbine tower is a rod with a uniformly distributed mass (linear density) along its length. Calculations of the wind turbine's own weight are presented in Table 4.

The calculation of the area of the sole of the foundation was made according to the SNIP RK 5.01-01-2002 – Foundations of buildings and structures. Finally, a slab foundation was adopted, the geometry of which is shown in Figure 2.

Two-dimensional modeling of the wind turbine foundation is performed in the Plaxis software package. The boundary conditions of the walls of the model were set in the form of pivotally movable supports with free movement along the y axis, movement along the x axis = 0. The base of the model is set as a solid seal, moving along the axes x, y = 0.

Prior to the calculation, the initial conditions were determined, which include the initial geometric structure of groundwater and the initial state of effective stresses [7].

The first calculation stage included modeling of natural stresses caused by the forces of gravity. In the second stage, the following loads were applied to the model:

- the M_{max} moment in the Plaxis software package will be represented by a pair of forces relative to the center of the foundation;
- the longitudinal force will be represented by a uniformly distributed load acting on the cross-sectional area of the lower one adjacent to the foundation [8];
- horizontal load.

Since the moment is represented by a pair of forces, the modeling of the wind turbine foundation is performed not in an axisymmetric formulation of the problem, but in a flat one. In this case, it is necessary to correct the cross-section of the circular foundation. Based on this condition, the width of the foundation for a flat problem is equal to: $d = \sqrt{\pi \cdot r^2} = 19{,}4$ м [9].

The calculation scheme and the grid of finite

Table 2 – Wind loads on the wind turbine tower

Height, m	Estimated			Regulatory
	w_m t/m (kN/m)	w_p t/m (kN/m)	w_{gen} t/m (kN/m)	w_{gen} 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 load;
w_p – dynamic (pulsation) component of wind load;
w_{gen} – frontal resistance of WW (windwheel).

Table 3 – Wind loads on WW wind turbines

Standard values of frontal resistance of WW $w^{н}_{общ}$	Estimated values of frontal resistance of WW $w^{р}_{общ}$	Estimated wind speed $V_р$	High-speed wind pressure of WW q	Square of WW S (м²)	Static component increasing strength P^{c}_{x} (kN)
0,78	1,09	5,3 м/с	17,5 Па	6789	142,5

Table 4 – Loads from the wind turbine's own weight

$\mu_б$ (t/m)	Steel density ρ (t/m³)	The cross-sectional area of the tower $A_б$ (m²)	Evenly distributed mass of the tower $m_{пр}$ (t)	Weight of the gondola (t)	Reduced weight (t)	Total vertical concentrated load (kN)
4,0	7,85	0,51	340	45	395	3870

elements are shown in Figure 3. Figure 4 shows the results of calculations: vertical, horizontal and total displacements, relative deformation and normal, tangential and total stress. Figure 5 shows the movements of the edge points A and B presented in the calculation scheme.

Conclusions

In conclusion, I would like to note the importance of wind power installations on the territory of Kazakhstan, in particular in the city of Ereymentau.

The article presents some aspects of the design of a wind power plant (wind turbine) in the hydrogeological conditions of the Ereymentau district. The calculation of foundations and foundations is carried out in the Plaxis 2D complex.

The graph shows that the maximum displacement of point A = 9,92 m, point B = 1,18 mm. The resulting movements are within acceptable values. There is no need to use a pile foundation. A circular slab foundation (alternating wind loads) with a radius of 11 m is finally accepted as the foundation of the wind turbine. According to the results obtained, the overall stability of the wind turbine design is ensured [10].

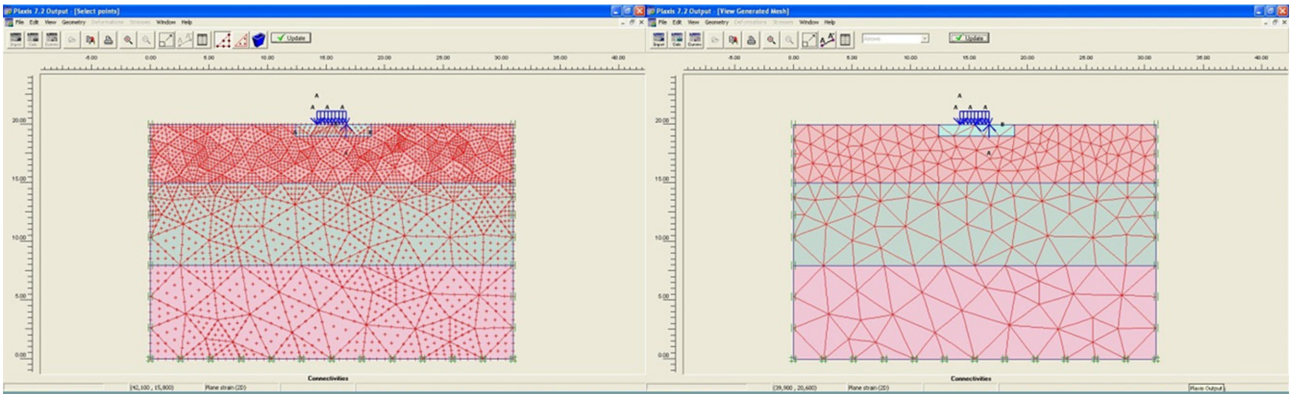
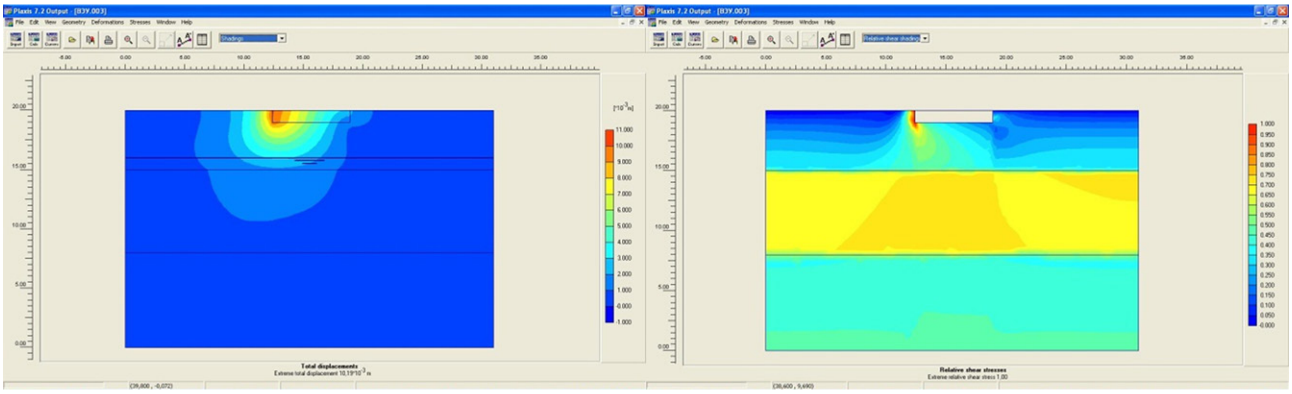
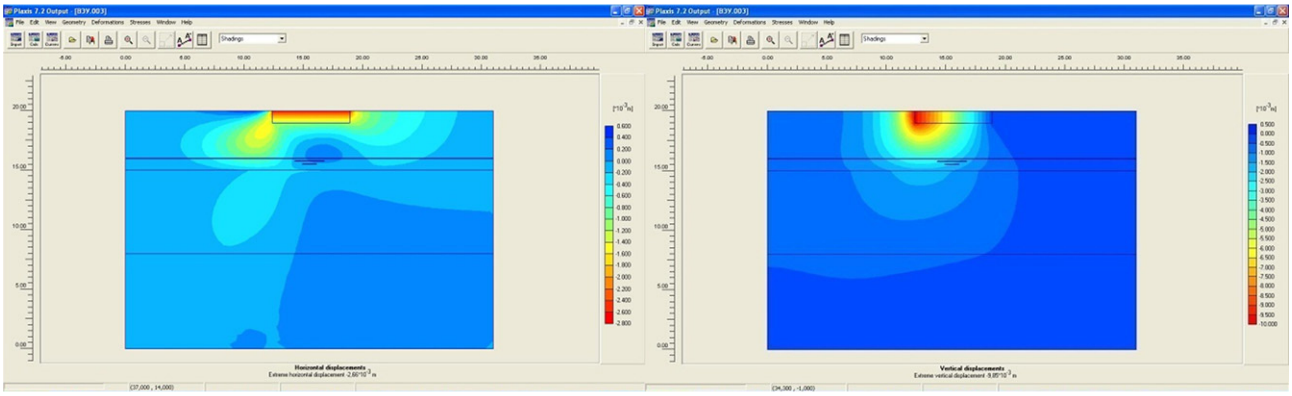


Figure 3 – Wind turbine foundation model



Absolute displacements and stresses



Absolute horizontal and vertical movements

Figure 4 – Calculation results

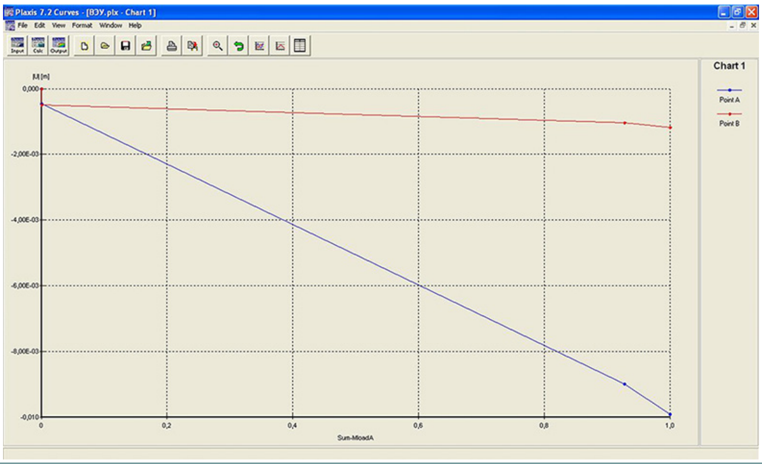


Figure 5 – Moving edge points

REFERENCES

1. Orazova D.K., Sapenova J.K., Tleubaeva A.K. Qazaqstandağy jel elektr stansialarynyñ qūrylysyna saraptama, Respublikalyq studenttık ğylymi konferensiasy. – Qarağandy: Qarağandy memlekettık tehnikalyq universitet, 2016. – Ch. 3. – pp. 33-34.
2. Design of Foundations for Wind Turbines: master's Dissertation by Henrik Svensson. – Sweden, 2010. – pp. 7-10.
3. Nacional`naya Programma razvitiya vetroe`nergetiki v Respublike Kazaxstan do 2015g. s perspektivoj do 2024 g. Proekt Programmy` razvitiya OON i Pravitel`stva Kazaxstana «Kazaxstan – iniciativa razvitiya ry`nka vetroe`nergetiki». – Almaty`; Astana, 2007.
4. Elistratov, V.V., Konstantinov, I.A., Panfilov, A.A. Nagruzki na e`lementy` vetroe`nergeticheskoj ustanovki, na ee fundament i osnovanie: uchebnoe posobie. – Saint Petersburg: Publ. SPbGTU, 2011. – 38 p.
5. Elistratov V.V., Konstantinov I.A., Panfilov A.A. Raschet fundamentov vetroe`nergeticheskix ustanovok. Monolitny`e zhelezobetonny`e fundamenty` melkogo zalozheniya: uchebnoe posobie. – Saint Petersburg: Publ. SPbGTU, 2001. – Ch. 1. – p. 9.
6. Sapenova Zh.K. Qazaqstandağy gidrogeologialyq jağdaidağy jel elektrlı qondyrğyly ırgetastardy jobalaudyñ geotehnikalyq aspektısı: magistrlık disertasia – Astana: ENU im. L.N. Gumileva, 2017. – 67 p.
7. Orazova D.K. Prognoz raboty` osnovanij i fundamentov vetrovy`x e`nergeticheskix sooruzhenij: dic. … dok. fil. Ph.D. – Astana: ENU im. L.N. Gumileva, 2016. – 174 p.
8. Lukpanov R.E., Orazova D.K. Raschet fundamenta VE`U v programmnom komplekse SCAD i Plaxis 2D v usloviyax g. Ereymentau // Nauchny`j zhurnal «Vestnik» ENU im. L.N. Gumileva. – 2014. – T. 1, no. 6 (103). – pp. 117-122.
9. Status of Land – Based Wind Energy Development in Germany. – Germany: Deutsche WindGuard, 2014.
10. Concrete Structures for Wind Turbines. Jurgen Grunberg, Joachim Gohlmann. Germany. – 2011.

Ерейментау қ. гидрогеологиялық жағдайында жел электр қондырғының іргетасын жобалау

[1]***ОРАЗОВА Динара Казбековна,*** *PhD, қауымдастырылған профессор, dinarzhan_84@mail.ru,*
[2]***ЛУКПАНОВ Рауан Ермагамбетович,*** *PhD, профессор, директор, rauan_82@mail.ru,*
[2]***ТЛЕУЛЕНОВА Гульшат Толеуовна,*** *PhD, доцент м.а., gulshattleulenova23@mail.ru,*
[1]***ОМАРОВ Жумабек Мухтарович,*** *т.ғ.к., қауымдастырылған профессор, zhumabek-omarov@mail.ru,*
[1]***АКИМБЕКОВА Самал Тотайкызы,*** *магистр, аға оқытушы, sammi_ok@mail.ru,*
[1]*«Торайғыров университеті» КеАҚ, Қазақстан, Павлодар, Ломов көшесі, 64,*
[2]*«Л.Н. Гумилев атындағы Еуразия ұлттық университеті» КеАҚ, Қазақстан, Астана, Сәтпаев көшесі, 2,*
**автор-корреспондент.*

Аңдатпа. *Ерейментау ауданының гидрогеологиялық жағдайында жел энергетикалық қондырғының (ЖЭҚ) жобалау сұрақтары, оның ішінде іргетас пен негіздің есебі қарастырылған. Еуропалық техникалық талаптарға сәйкес келетін жел энергетикалық қондырғының сипаттамасы келтірілген. Мекеннің геологиялық құрылымы сипатталатын құрылыс аумағы көрсетілген. Жел жүктемесін анықтау бойынша есептер көрсетілген. Іргетас пен негіздің есебі Plaxis 2D бағдарламалық кешенде орындалған. Іргетасты моделдеу жазық есептеуде орындалған. Есептеудің нәтижелері: вертикалды, горизонталды және толық орын ауыстыру, салыстырмалы деформация, қалыпты, жанама кернеу ретінде келтірілген. Нормативтік стандарттарға сәйкес келетін тақталық іргетас қарастырылған. Есептеу нәтижелері графикалық және кестелік түрде келтірілген. Іргетас геометриясы шекті жағдайларға сәйкес келетін: көтеруші қабілетке, шөгуге және жалпы тұрақтылық жағдайларынан алынған.*

Кілт сөздер: *баламалы энергетика, ЖЭҚ, тақталық іргетас, жел жүктемесі, Plaxis 2D бағдарламалық кешені, кернеу, орын ауыстыру, көтеруші қабілет, шөгу, тұрақтылық.*

Проектирование фундамента ветроэлектроустановки в гидрогеологических условиях г. Ерейментау

[1]****ОРАЗОВА Динара Казбековна,** PhD, ассоциированный профессор, dinarzhan_84@mail.ru,*
[2]***ЛУКПАНОВ Рауан Ермагамбетович,** PhD, профессор, директор, rauan_82@mail.ru,*
[2]***ТЛЕУЛЕНОВА Гульшат Толеуовна,** PhD, и.о. доцента, gulshattleulenova23@mail.ru,*
[1]***ОМАРОВ Жумабек Мухтарович,** к.т.н., ассоциированный профессор, zhumabek-omarov@mail.ru,*
[1]***АКИМБЕКОВА Самал Тотайкызы,** магистр, старший преподаватель, sammi_ok@mail.ru,*
[1]*НАО «Торайгыров университет», Казахстан, Павлодар, ул. Ломова, 64,*
[2]*НАО «Евразийский национальный университет имени Л.Н. Гумилева», Казахстан, Астана, ул. Сатпаева, 2,*
**автор-корреспондент.*

***Аннотация.** Рассмотрены вопросы проектирования ветроэнергетической установки (ВЭУ) в гидрогеологических условиях Ерейментауского района, в частности, расчеты основания и фундамента. Приведена характеристика ветроэнергетической установки, которая соответствует Европейским техническим требованиям. Показана площадка строительства, описываемая геологическим строением территории. Показан расчет по определению ветровой нагрузки. Расчет оснований и фундаментов выполнен в программном комплексе Plaxis 2D. Выполнено моделирование фундамента в плоской задаче. Представлены результаты расчетов: вертикальные, горизонтальные и полные перемещения, относительная деформация и нормальное, касательное и полное напряжения. Рассмотрен плитный фундамент, который спроектирован по нормативным стандартам. Результаты расчета приведены в графическом и табличном отображении. Геометрия фундамента подобрана из условия удовлетворения предельным состояниям: на несущую способность, осадку и общую устойчивость.*

***Ключевые слова:** альтернативная энергетика, ВЭУ, плитный фундамент, ветровая нагрузка, программный комплекс Plaxis 2D, напряжение, перемещение, несущая способность, осадка, устойчивость.*

REFERENCES

1. Orazova D.K., Sapenova J.K., Tleubaeva A.K. Qazaqstandağy jel elektr stansialarynyñ qūrylysyna saraptama, Respublikalyq studenttık ğylymi konferensiasy. – Qarağandy: Qarağandy memlekettık tehnikalyq universitet, 2016. – Ch. 3. – pp. 33-34.
2. Design of Foundations for Wind Turbines: master's Dissertation by Henrik Svensson. – Sweden, 2010. – pp. 7-10.
3. Nacional`naya Programma razvitiya vetroe`nergetiki v Respublike Kazaxstan do 2015g. s perspektivoj do 2024 g. Proekt Programmy` razvitiya OON i Pravitel`stva Kazaxstana «Kazaxstan – iniciativa razvitiya ry`nka vetroe`nergetiki». – Almaty`; Astana, 2007.
4. Elistratov, V.V., Konstantinov, I.A., Panfilov, A.A. Nagruzki na e`lementy` vetroe`nergeticheskoj ustanovki, na ee fundament i osnovanie: uchebnoe posobie. – Saint Petersburg: Publ. SPbGTU, 2011. – 38 p.
5. Elistratov V.V., Konstantinov I.A., Panfilov A.A. Raschet fundamentov vetroe`nergeticheskix ustanovok. Monolitny`e zhelezobetonny`e fundamenty` melkogo zalozheniya: uchebnoe posobie. – Saint Petersburg: Publ. SPbGTU, 2001. – Ch. 1. – p. 9.
6. Sapenova Zh.K. Qazaqstandağy gidrogeologialyq jağdaidağy jel elektrlı qondyrğyly ırgetastardy jobalaudyñ geotehnikalyq aspektısı: magistrlık disertasia – Astana: ENU im. L.N. Gumileva, 2017. – 67 p.
7. Orazova D.K. Prognoz raboty` osnovanij i fundamentov vetrovy`x e`nergeticheskix sooruzhenij: dic. … dok. fil. Ph.D. – Astana: ENU im. L.N. Gumileva, 2016. – 174 p.
8. Lukpanov R.E., Orazova D.K. Raschet fundamenta VE`U v programmnom komplekse SCAD i Plaxis 2D v usloviyax g. Ereymentau // Nauchny`j zhurnal «Vestnik» ENU im. L.N. Gumileva. – 2014. – T. 1, no. 6 (103). – pp. 117-122.
9. Status of Land – Based Wind Energy Development in Germany. – Germany: Deutsche WindGuard, 2014.
10. Concrete Structures for Wind Turbines. Jurgen Grunberg, Joachim Gohlmann. Germany. – 2011.