DOI 10.52209/1609-1825_2024_4_204 UDC 624.131.55

Design Scenarios for The Foundation of 85 m Height 400 Tons 2MW Wind Power Plant Aqmola Region

[1]**TLEULENOVA Gulshat,** *PhD, Acting Associate Professor, gulshattlelenova23@mail.ru,*
[1]***RAKHYMBEKOV Altay,** *Master's Student, rakhymbekov_a@mail.ru,*
[1]**SHAKHMOV Zhanbolat,** *PhD, Associate Professor, zhanbolat8624@mail.ru,*
[1]**JUMABAYEV Atogali,** *Dr. of Tech. Sci., Professor, atagali@list.ru,*
[2]**KIKNADZE Rimma,** *Master's Degree, Senior Lecturer, KinadzeRimma@mail.ru,*
[1]*NPJSC «Abylkas Saginov Karaganda Technical University», N. Nazarbayev Avenue, 56, Karaganda, Kazakhstan,*
[2]*NPJSC «L.N. Gumilyov Eurasian National University», Satpayev Street, 2, Astana, Kazakhstan,*
**corresponding author.*

Abstract. *The problems in the design of foundations of wind power plants are presented. The purpose of the article is to develop experimental and theoretical recommendations for the calculation and design of foundations of wind power plants. A complex of theoretical, analytical, and numerical modeling of the foundations were used: analysis of natural-climatic and socio-economic zones of Aqmola region; collection of loads on the foundation of wind power plants using SCAD software and estimation of bearing capacity of foundation and soil-base. In total 3 design scenarios were adopted: slab, driven pile and bored pile foundations. The results revealed that the highest bearing capacity is in bored pile foundation with the value of 570 kN (960 kPa working load capacity), which is slab (580 kPa) and driven (470 kN, 770 kPa working load capacity) pile foundation. In terms of materials resources the most efficient appeared to be the scenario of driven pile foundation.*

Keywords: *wind plants, wind turbine, foundation, geotechnics, soil.*

Introduction

In the «Kazakhstan – 2050»: a new political course of an established state energy security was named one of the ten main problems of this century. The relevance of this problem is justified by the holding of the international exhibition in Astana, which is dedicated to green, renewable and safe energy. The regions of Northern, Central, Western and Southeastern Kazakhstan have a significant resource, especially the Dzungarian Gate and the Shelek Corridor, where the average annual wind speed is 7-9 m/s and 5-9 m/s, respectively, as well as Astana, Fort Shevchenko and Arkalyk. At the moment, 22 wind turbines have been put into operation, which are connected to the Ekibastuz power line and supply electricity to the city of Yerementau, the village of Yerkenshilik, as well as partially to Astana. Generation of electric energy in the amount of more than 172 million kW per hour per year without the consumption of hydrocarbon fuel will save more than 60 thousand tons of coal and increase the reliability of electricity supplies in the region. Analyzing the energy infrastructure of the Republic of Kazakhstan, a regional shortage of energy capacity is revealed. In this regard, the question arises: the construction of wind power plants that will provide the necessary energy to the population of the Republic of Kazakhstan.

Within the framework of this issue, there are tasks for calculating and analyzing the operation of the foundations of wind power structures, for ensuring the reliability and optimization of foundations. An analysis of the literature data on this topic allows us to conclude that the study of this topic has not been fully completed. As shown by numerous studies [1-7], the collection of loads and the analysis of the state of the soil state are the main criteria in the calculation of the structure. Some sources [7-8] offer a calculation method and a method for evaluating the safety for crack resistance using the double K crack propagation criterion, which differs from [9-13]. To ensure rigidity and stability, suggests using piles at an inclination of 90°/90°/60° (the innermost/middle/outer pile) and 90°/90°/45°. And the most standard refers to this problem, using standard design methods according to EN standards. The problem from here is the lack of an analogue in Kazakhstan. The research data can be used as recommendations in the design of foundations, as well as in the development of technical and regulatory documents. And also here are economic data of different types of foundations, which play an important role.

Materials and methods

A complex of theoretical, analytical studies, numerical modeling of the object of study are used.Calculation and analysis consist of the following steps:

- Collection of loads on the foundations of wind turbines;
- Calculations of foundations and bases of wind power plants (limit states);
- Digital modeling based on the results of the study;
- Identify cost-effective options.

Windy weather is a characteristic feature of the local climate. The greatest number of days with strong winds falls on the winter and spring months. All climate data were taken from SP RK. The average monthly and annual wind speed (m/s) is given in Table 1. As an existing wind power device, the 2MW Vindkraftverk of the Swedish company is used, the geometric dimensions of which are shown in Figure 1.

The highest wind speeds (m/s) of various probabilities are given according to observational data in Table 2.

A characteristic feature of the local climate is its sharp continentality and dryness. Absolute minimum air temperature is −52.0°C, the absolute maximum is 41.3°C.

To facilitate the marking of soil models, EGE is used. EGE – engineering and geological element. Base consists of the following geological section of the soil:

Figure 1 – Wind power plant

EGE-1 is a soil-vegetation layer – loam with plant roots.

EGE-2 is a loam of light brown color, solid consistency, with the inclusion of a dredge.

EGE-3 is a clay of brownish-brown, yellow-gray color, solid and semi-solid consistency, with layers of multi-grained sands, including soils up to 5-10%.

EGE-4 is a sandy soil with a loamy filler up to 30%.

EGE-5 – crushed quartzite soil with loamy aggregate up to 30% and the inclusion of blocks.

EGE-6 is an eluvial loam of light gray, pink and ochre yellow color, solid consistency, with the inclusion of gravel and crushed stone up to 20-30%.

EGE-7 – rocky soil-quartzites, red-brown, light brown and dark gray, weathered, strong-

Table 1 – Average monthly and annual wind speed (m/s)

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	year
6.6	6.2	6.1	5.1	4.7	3.8	3.5	3.6	4.1	5.4	6.8	7.1	5.3

Table 2 – The highest wind speeds (m/s)

Period	Wind speed (m/s) possible 1 time per			
	year	5 years	10 years	20 years
Aqmola	26-27	30-32	33-35	36

ly fractured, medium strength, with pockets of weathering (crushed stone soil).

EGE-8 – rocky soil-mudstones, light gray, weathered, strongly cracked, weak with pockets of weathering (crushed stone ground).

Figure 2 shows the static calculation of the structure for permanent and temporary loads is performed.

Then, using these data, pre-calculations of several types of foundations were carried out using the FE method and layer-by-layer summation. 3 variants of the foundation are considered, as well as their effectiveness and economic feasibility.

The first foundation of the wind power plant (wind turbine) adopted a slab monolithic reinforced concrete round shape in plan. The diameter of the foundation plate is 22.0 m. The thickness of the plate is from 0.92 to 2.40 m. The height of the pedestal is 0.50 m, the diameter is 6.50 m. The total height of the foundation is 2.90 m.

The design soil resistance of the base is R = 5,76 kg/cm^2. Ground load P = 70 kPa. P = 70 kPa < R = 580 kPa.

The calculation and scheme of the pile foundation for wind turbines (driven piles) are given. When analyzing the engineering and geological conditions of the construction site, we select a layer of soil for supporting the driven piles. Such a layer is clay of a solid and semi-solid consistency of EGE-3. The calculation scheme is shown in Figure 3.

Bearing capacity of the pile is N = 470 kN. Working bearing capacity of the foundation is P_{II} = 72 kPa < R = 770 kPa.

The calculation and scheme of pile foundations for wind turbines are also given (bored piles). The calculation of bored piles differs from driven piles. The main problem is the manufacturing technology, since the reliability and strength coefficients of this foundation depend on it. The building structures of the foundation of the wind turbine are represented by a monolithic grillage (foundation plate) in the form of a circle with a diameter of 11 m in plan, as well as 12 drill piles with a diameter of 600 mm, with a depth of immersion of 12 m instead of C-8-30 on driven piles. The diameter of the circumference of the upper face of the grillage (the support base of the carrier tower) is 6.5 m.

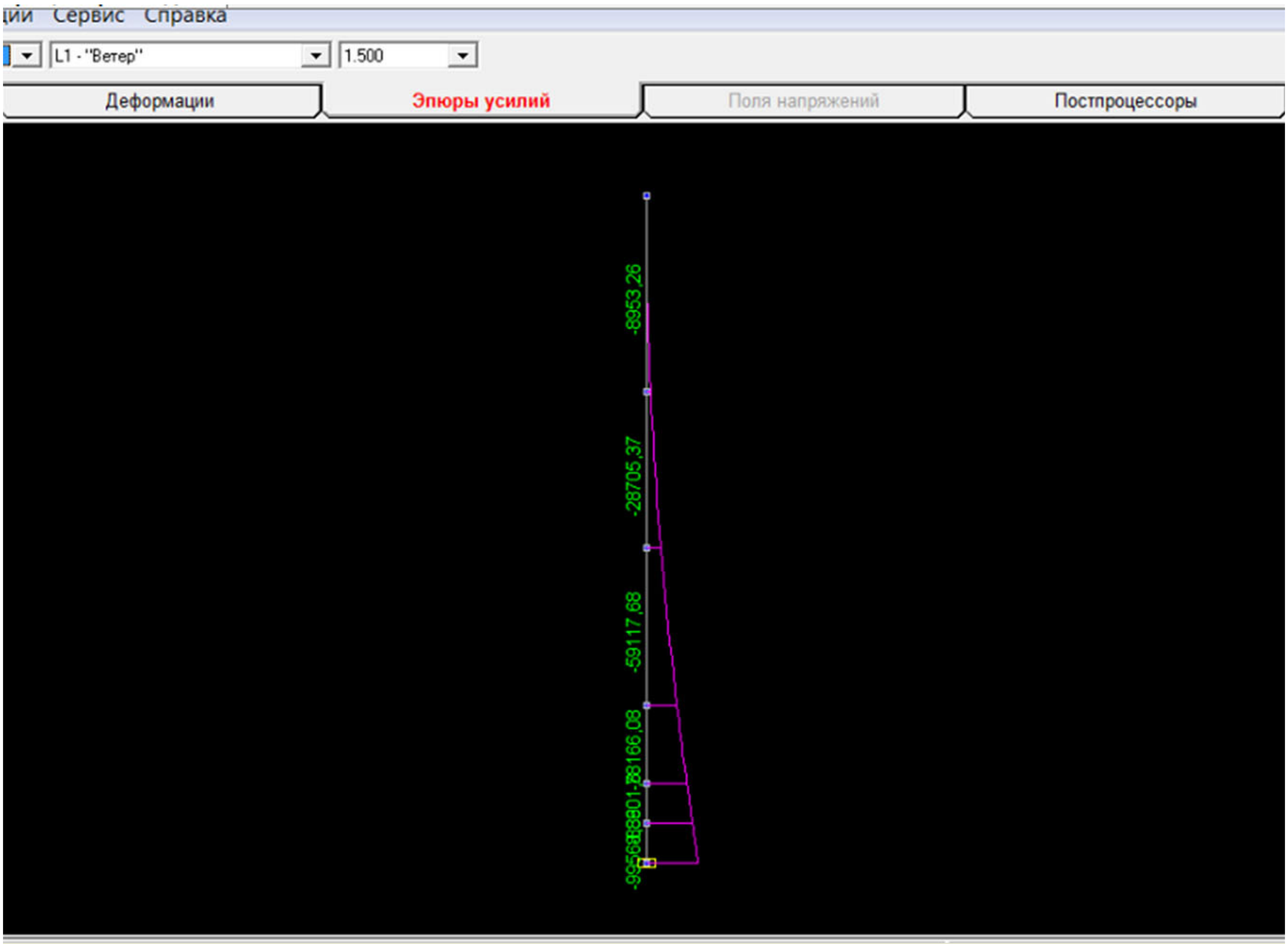

Figure 2 – Structure model

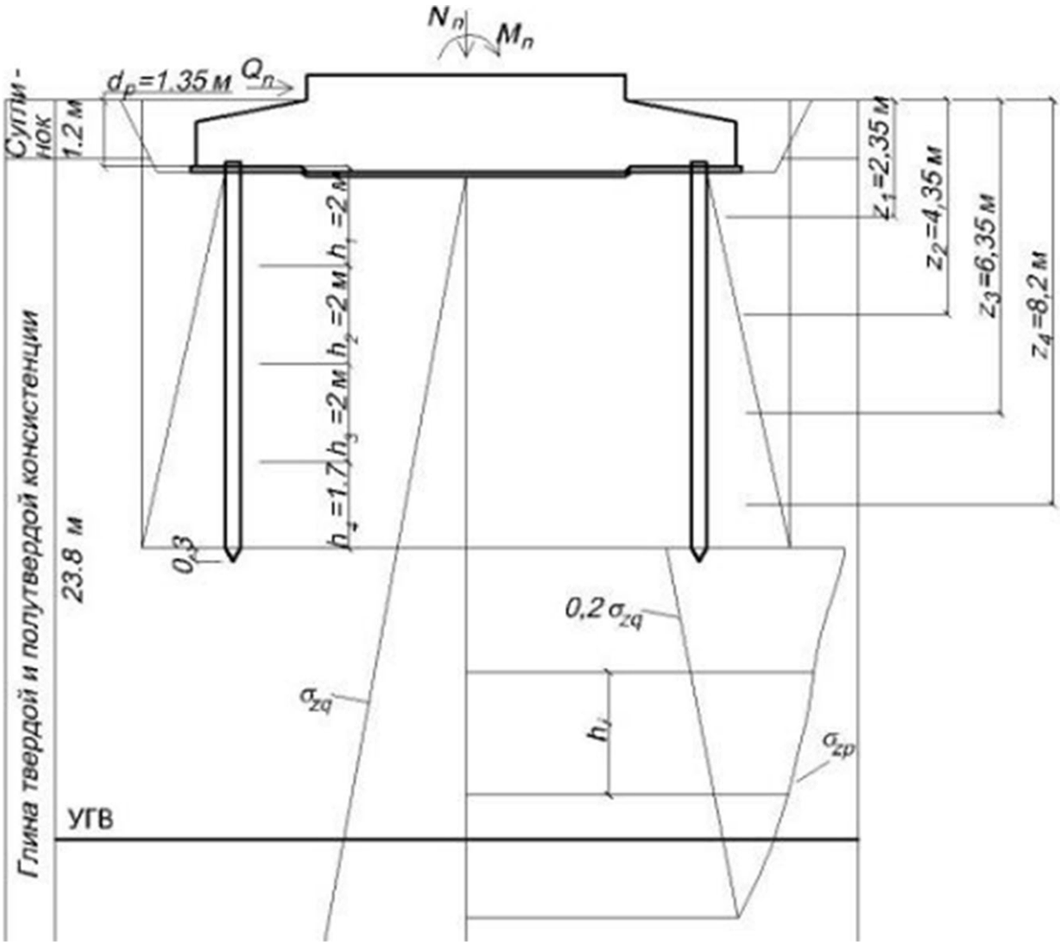

Figure 3 – The scheme of calculation of the pile foundation

Bearing capacity of the pile is N = 570 kN. Working bearing capacity of the foundation is P_{II} = 35 kPa < R = 960 kPa.

Results and discussion

The results data were presented in graphical form for more visual analysis. Figure 4 shows the indicators of the bearing capacity of piles. The bearing capacity of the bored pile exceeds by 28%.

The bearing capacity of piles affects the working bearing capacity. The working bearing capacity of each foundation is shown in Figure 5.

Three different foundations for a wind power plant were designed for one soil model. Economic benefit is the first requirement for this type of design. The payback time for the cost of the structure should not be longer than the expected service life of the structure. Cases when a cheap design option is technologically complex are very rare.

An important factor is their economic efficiency. Technical and economic indicators are given in Figure 6.

The total cost of the work was: for the slab foundation – 66.8 mln. KZT, the pile-slab foundation (driven piles) – 17.3 mln. KZT and the pile foundation (bored piles) – 28.8 mln. KZT.

Conclusion

Pre-calculations on load-bearing capacity, pre-calculations of precipitation and general stability for each type of wind turbine foundation were performed. The results of analytical calculations of the slab foundation of the wind turbine, the pile-slab foundation of the wind turbine with the use of driven piles, as well as the pile-slab foundation with the use of bored piles are obtained.

The comparison of technical and economic indicators for three types of foundations is carried out: slab, pile-slab foundation with the use of driven piles, as well as for pile-slab foundation with the use of bored piles. The calculation of the local estimate has been completed. All structural solutions of wind turbine foundations are taken from the same conditions of reliability in terms of load-bearing capacity, precipitation and overall stability. However, based on these conditions, for the slab foundation of the wind turbine, the cost indicators for ma-

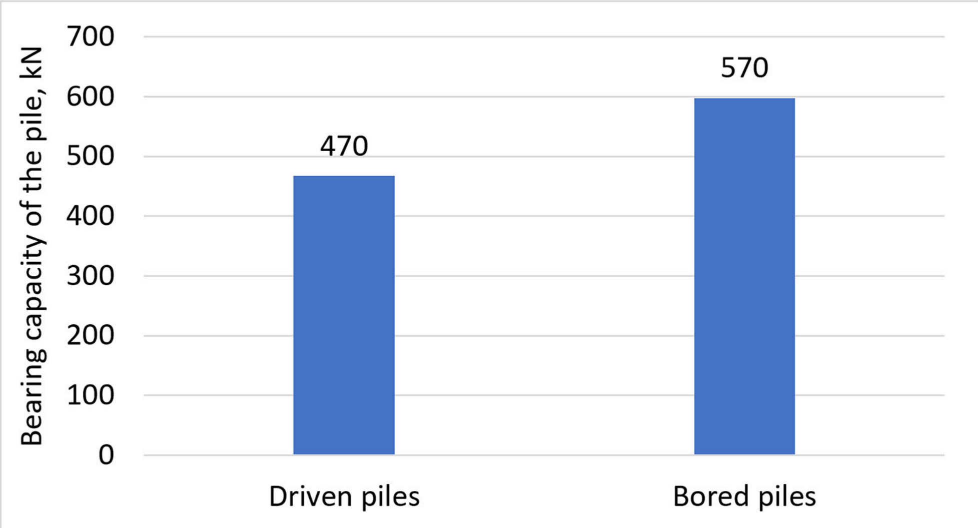

Figure 4 – Comparison diagram of bearing capacities of piles

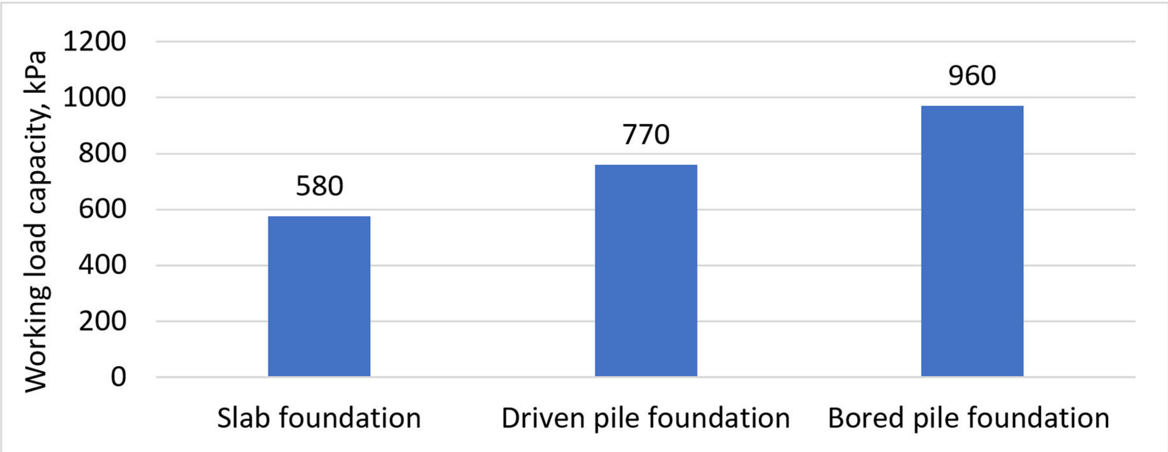

Figure 5 – Comparison diagram of working bearing capacity

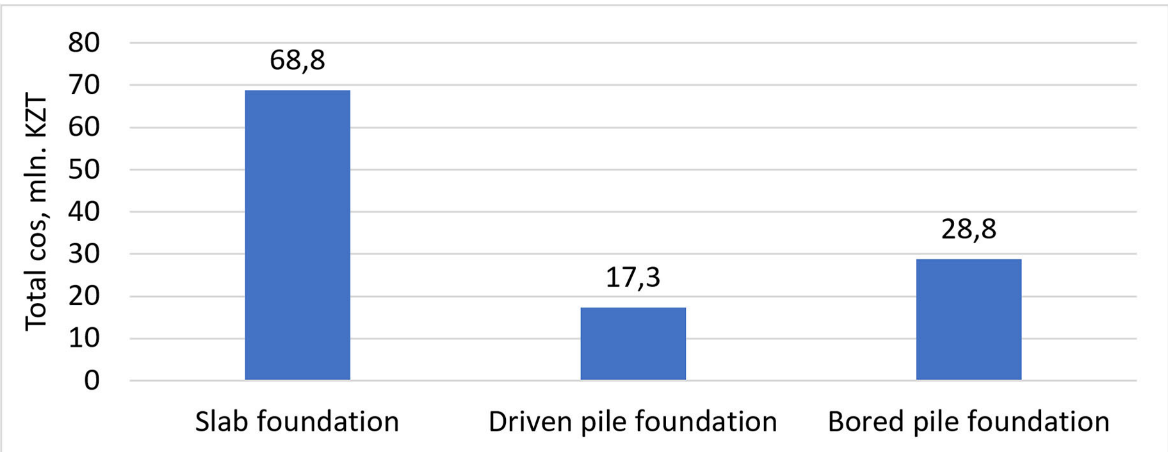

Figure 6 – Total cost of foundation types

terial intensity and labor intensity 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 the future development of this project.

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Ақмола облысында 85 м биіктіктегі 400 тонна салмағымен 2 МВТ қуатымен жел электр станциясының іргетасын жобалау

[1]***ТЛЕУЛЕНОВА Гульшат Толеувна,*** *PhD, доцент м.а., gulshattleulenova23@mail.ru,*

[1]***РАХЫМБЕКОВ Алтай Медетұлы,** *магистрант, rakhymbekov_a@mail.ru,*
[1]**ШАХМОВ Жанболат Ануарбекович,** *PhD, қауымдастырылған профессор, zhanbolat8624@mail.ru,*
[1]**ДЖУМАБАЕВ Атагали,** *т.ғ.д., профессор, atagali@list.ru,*
[2]**КИКНАДЗЕ Римма Кенесовна,** *магистр, аға оқытушы, KinadzeRimma@mail.ru,*
[1]«Әбілқас Сағынов атындағы Қарағанды техникалық университеті» КеАҚ, Н. Назарбаев даңғылы, 56, Қарағанды, Қазақстан,
[2]«Л.Н. Гумилев атындағы Еуразия ұлттық университеті» КеАҚ, Сәтбаев көшесі, 2, Астана, Қазақстан,
**автор-корреспондент.*

Аңдатпа. *Жел электр станцияларының іргетасын жобалаудағы мәселелер көрсетілген. Мақаланың мақсаты – тәжірибені дамыту, жел электр станцияларының іргетасын есептеу және жобалау бойынша теориялық ұсыныстар беру. Негіздерді теориялық, аналитикалық және сандық модельдеу үшін келесі кешендер пайдаланылды: Ақмола облысының табиғи-климаттық және әлеуметтік-экономикалық аймақтарын талдау; SCAD бағдарламалық құралын пайдалана отырып жел электр станцияларының іргетасына жүктемелерді жинау және іргетас пен топырақты негіздің көтергіштігін бағалау. Барлығы 3 жобалық нұсқа қабылданды: плита, қағылмалы қада және бұрғыланған қадалы іргетас. Ең жоғары көтергіштік қабілеті 570 кН (960 кПа жұмыс жүктемесі) бұрғыланған қадалы іргетаста, одан кейін тақта-плиталы (580 кПа) және қағылмалы қадалы іргетаста болатыны анықталды (470 кН, 770 кПа жұмыс жүктемесі). Материалдық ресурстар, техника-экономикалық көрсеткіштер бойынша ең тиімдісі қағылмалы қадалы іргетас нұсқасы екені анықталды.*

Кілт сөздер: *жел энергетикалық қондырғылары, жел турбиналары, іргетас, геотехника, топырақ.*

Проектирование фундамента ветроэлектростанции высотой 85 м весом 400 тонн мощностью 2 МВт в Акмолинской области

[1]**ТЛЕУЛЕНОВА Гульшат Толеувна,** *PhD, и.о. доцента, gulshattleulenova23@mail.ru,*
[1]***РАХЫМБЕКОВ Алтай Медетұлы,** *магистрант, rakhymbekov_a@mail.ru,*
[1]**ШАХМОВ Жанболат Ануарбекович,** *PhD, ассоциированный профессор, zhanbolat8624@mail.ru,*
[1]**ДЖУМАБАЕВ Атагали,** *д.т.н., профессор, atagali@list.ru,*
[2]**КИКНАДЗЕ Римма Кенесовна,** *магистр, старший преподаватель, KinadzeRimma@mail.ru,*
[1]НАО «Карагандинский технический университет имени Абылкаса Сагинова», пр. Н. Назарбаева, 56, Караганда, Казахстан,
[2]НАО «Евразийский национальный университет имени Л.Н. Гумилева», ул. Сатпаева, 2, Астана, Казахстан,
**автор-корреспондент.*

Аннотация. *Представлены проблемы проектирования фундаментов ветроэнергетических установок. Целью статьи является разработка экспериментальных и теоретические рекомендаций по расчету и проектированию фундаментов ветроэнергетических установок. Использовался комплекс теоретического, аналитического и численного моделирования фундаментов: анализ природно-климатической и социально-экономической зон Акмолинской области; сбор нагрузок на фундамент ветроэлектростанции с помощью программы SCAD и оценка несущей способности фундамента и грунтового основания. Всего было принято 3 расчетных сценария: плитный, фундамент на забивных сваях и фундамент на буронабивных сваях. Результаты показали, что наибольшей несущей способностью обладает буронабивной свайный фундамент со значением 570 кН (рабочая несущая способность 960 кПа), за ним следуют плитный (580 кПа) и забивной (470 кН, рабочая несущая способность 770 кПа) свайные фундаменты. С точки зрения материальных ресурсов наиболее эффективным оказался сценарий с забивным свайным фундаментом.*

Ключевые слова: *ветроэнергетические установки, ветротурбина, фундамент, геотехника, грунт.*

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