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Reviewing modern solutions for the foundations of engineered structures

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ABSTRACT:
The foundations of various types of engineered structures are a key element of any facility as it is the only point of contact with the subsoil and ensures stability and safety during operation. During the design of a structure, a suitable foundation solution should be selected that will ensure adequate stability in encountered ground conditions. This article presents contemporary solutions for the foundations of engineered structures that have been subjected to analysis and research over the last few years.

KEYWORDS:
modern constructions; bearing capacity; substructures; foundation solutions

1. Introduction

The foundations of any engineered structure is its lowest part, which is in direct contact with the ground. Its role is to safely transfer all loads from buildings. The foundations must be designed so that the subsoil, as a result of pressure, does not show any deformations that could affect the uneven or excessive subsidence of the structure or parts thereof [1]. The soil base is the outer part of the Earth's crust, thanks to which, transfers loads from the foundations. As a result of loading, changes in stress and deformation occur in relation to the existing state before the construction of the structure. It is assumed that the building foundations consist of such layers of soil up to the depth in which the additional stress resulting from the foundations' pressure decreases to 30% of the primary stress. The design of all substructures consists in the selection of an appropriate method of transferring loads to the ground, depending on the prevailing conditions in each place and what requirements the structure must meet during operation. An important factor in choosing the type of foundation is, of course, the economic aspect and the implementation possibilities under existing conditions [2]. A basic division of foundation types in engineered structures was made based on the method of transferring loads to the subsoil. Accordingly, the foundations are divided into direct and indirect. A direct foundation is one in which the loads are not significant and are transferred directly to the subsoil. These include all kinds of foundation feet, benches, plates, grates and boxes placed directly on the ground [3]. While, intermediate foundations transfer loads to layers of load-bearing soils over a greater depth. Loads are transferred by means of elements such as: lowered wells, caisson, piles, columns and diaphragm walls [4]. The next part of the article presents the latest structural solutions for building foundations that have been tested and provide greater load-bearing capacity than standard foundation solutions.

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2. A new and reusable foundation solution

In the case of structures subject to high wind loads, the footings must carry a large overturning moment. Traditional solutions use the weight of the foundation and the weight of the soil above the foundation to prevent the roll-over of the structure. In this case, a huge amount of concrete is needed to ensure adequate weight of the footing, which is associated with higher construction costs. To this end, a new footing solution with an active stabilization system was presented, using heavy natural materials as a moving load to improve the stability of the entire structure. An important advantage of this solution is the possibility of making adjustments to increase the load bearing capacity. This solution uses the weight of the foundation and the moving load, shifting to increase the load capacity [5]. In this case, there is no soil loading above the foundation, and the details of this solution are presented in Figure 1.

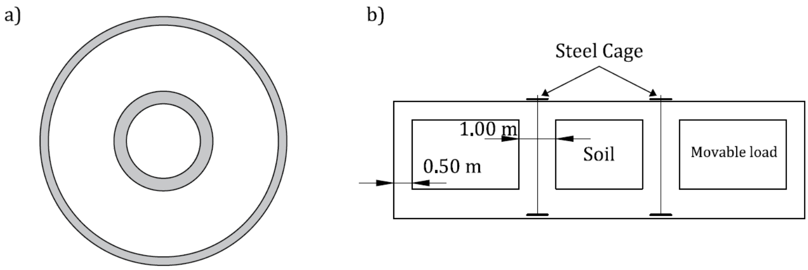

Fig. 1. Foundation footing with active stabilization system: a) plan view; b) cross section [5]

In the footing, the active stabilization system uses four wagons filled with natural material as a moving load. Various types of materials can be used, while the study used compacted soil and solid rocks, i.e. displaced soil excavated for the foundation. The number of bearings and electric motors (Fig. 2) used to move the wagons along a circular path depends on the maximum weight of the moving load, while the number of wagons should be an even number, because in the absence of wind, to keep the weight balanced, half the load will be shifted to one side and the other half to the other side. Ultimately, the position of the wagons will be adjusted by means of wind direction sensors [5].

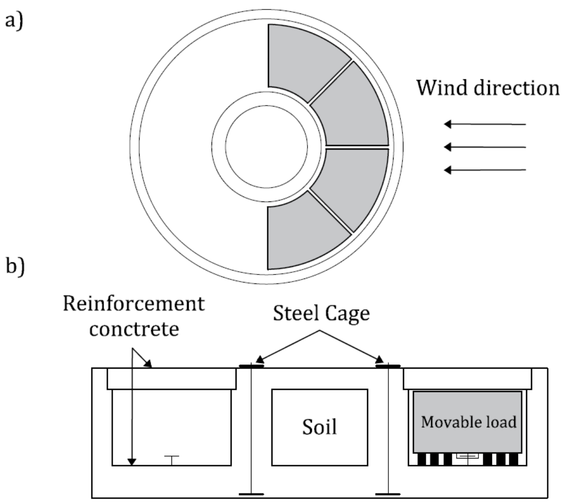

Fig. 2. Cell raft with an active stabilization system using movable wagons with natural material as a stabilizing charge: a) view from above; b) cross section [5]

The author of this solution has shown that the load bearing capacity of a cell raft with an active stabilization system, using automatically movable wagons controlled by means of appropriate sensors, is greater than that of a traditional round foot. In addition, the results showed that using this solution speeds up construction time and reduces significant amounts of CO_2 produced into the atmosphere during concrete production [5].

3. A new type of bucket foundation

To adapt to difficult hydrogeological and geological conditions, a new form of a bucket foundation was proposed [6]. As shown in Figure 3 the new type of foundation is a rounded rectangular bucket consisting of two side semicircular shunts and a central cuboid. The foundation has two smaller buckets that form a wave wall. The entire structure is embedded by pressure and suction forces. Compared to a round shaped foundation [7], this new construction increases the load-bearing capacity on the soil, thus providing greater resistance in the longitudinal direction. In article [6], load capacity was examined and the mechanism of vertical load transfer of a new type of bucket foundation was discussed through a series of large-scale model tests. The study showed that the basic resistance was much greater than the friction of the outer shell, and the foundation base provided greater load-bearing capacity [7].

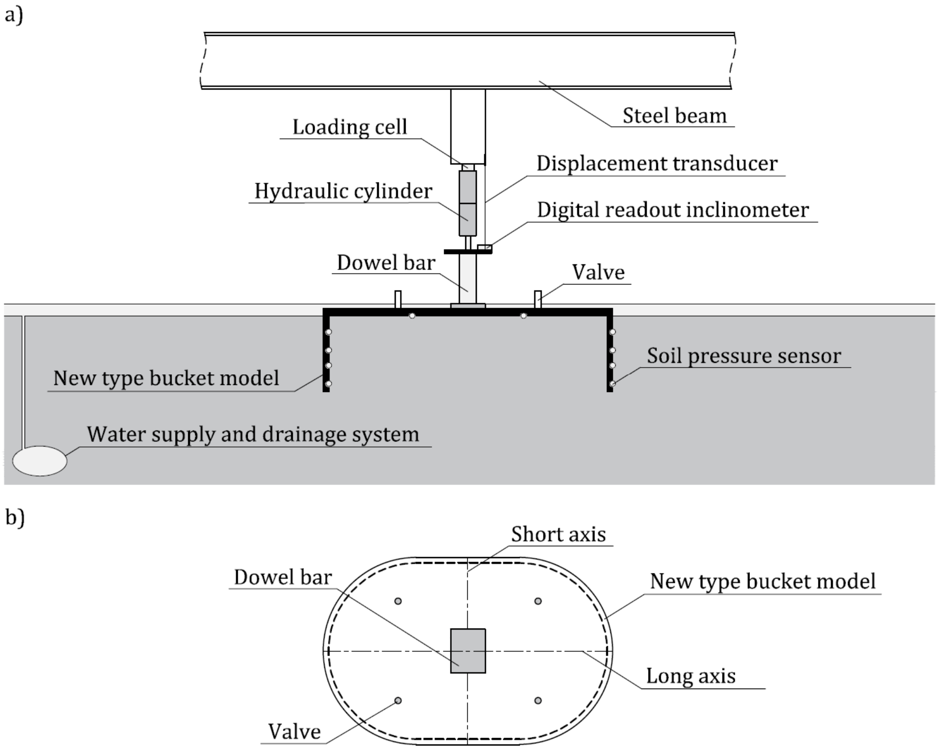

Fig. 3. Scheme of a new bucket foundation type: a) elevation view of test package; b) view from above. The drawing was made on the basis of the article [4]

The authors of this solution also proposed a plinth foundation with a similar principle of operation, while load capacity tests were conducted in a sand. The new type of caisson was used to build a breakwater in the Chinese port of Xuyu [8].

4. Innovative pile foundation with restriction plate

Pile foundations are one of the most commonly used foundations of marine and coastal structures. To this end, an innovative solution of pile foundation has been proposed, which adds the limiting plates inside the pile pipe, shown in Figure 4. Limiting plates of different shapes, one- and four-hole, is added inside the pile pipe. Comparative tests were carried out on pipes of different diameters, both without any limiting plates and with limiting plates. The study was performed using tests of centrifuge modelling. Pile models were tested at various centrifugal accelerations. As a result of tests, it was found that due to the use of limiting plates, the maximum load capacity increased significantly compared to open pipes.

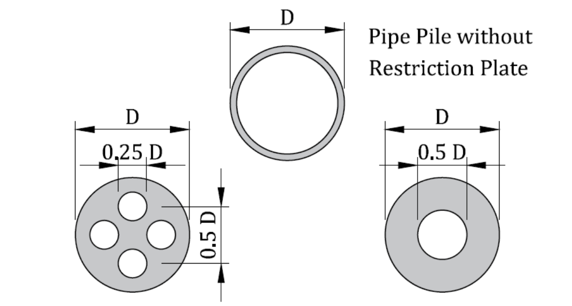

Fig. 4. Restriction plates of various shapes that are mounted inside the pile foundation [9]

Test results indicate that the use of limiting plates significantly increases the axial load bearing capacity of large diameter pile foundations. At different pile diameters, the limiting plates with four smaller holes gave a better result than those with one hole with the same pile diameters. Detailed results and a thoroughly described research methodology can be found in the article [9].

5. Innovative monopile-friction wheel-bucket hybrid foundation

The concept of the hybrid foundation [10] is to connect a monopile with a friction wheel and a bucket foundation. The solution diagram is shown in Figure 5. The bucket and friction wheel are integrated with one pile, while the friction wheel is filled with material to provide additional load, while increasing ground pressure. A series of geotechnical tests of centrifuge were carried out under monotonic and cyclic loading to test the load capacity of the innovative solution.

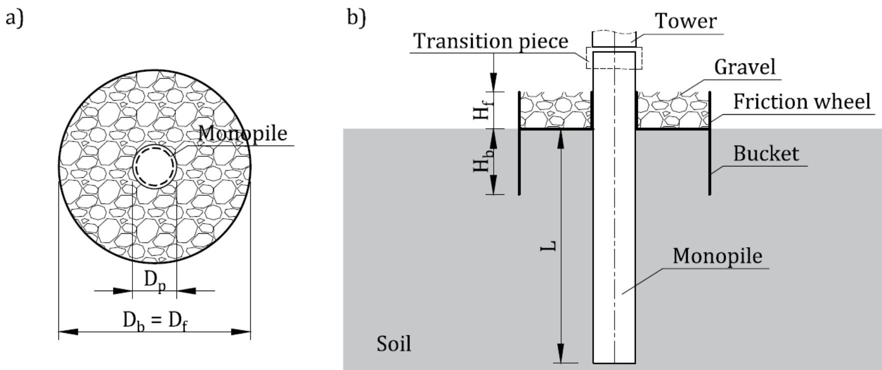

Fig. 5. Diagram of a monopile-friction wheel-bucket hybrid foundation: a) view from above; b) cross section. The drawing was made on the basis of the article [10]

The centrifuge test results showed that the load capacity of such a hybrid solution can be 4 times greater than the load capacity of the monopile foundation. As a result of cyclic loading, the final displacement is much smaller than for a standard monopile foundation. The friction wheel design size increases the foundation's load capacity. To sum up the MFB base, greater load capacity improvement in saturated loose sand, and a detailed analysis is provided in the article [10].

6. Monopile-friction wheel foundations under lateral loading

Wind energy is considered one of the main renewable energy resources. The offshore wind industry is gaining momentum because the wind is much stronger off the coast [11]. A reliable and efficient foundation is crucial for wind turbines. A new type of foundation consisting of a monopile and a friction wheel, for marine structures subjected to heavy loads. In this solution, two friction wheels, a solid and a gravel one, are integrated with the pile [12]. Hybrid foundations were tested using a centrifuge test and three-dimensional finite element analysis. With the help of such tests, it was possible to map the loads acting on wind turbines located off the coast [13]. The view of the model is shown in Figure 6.

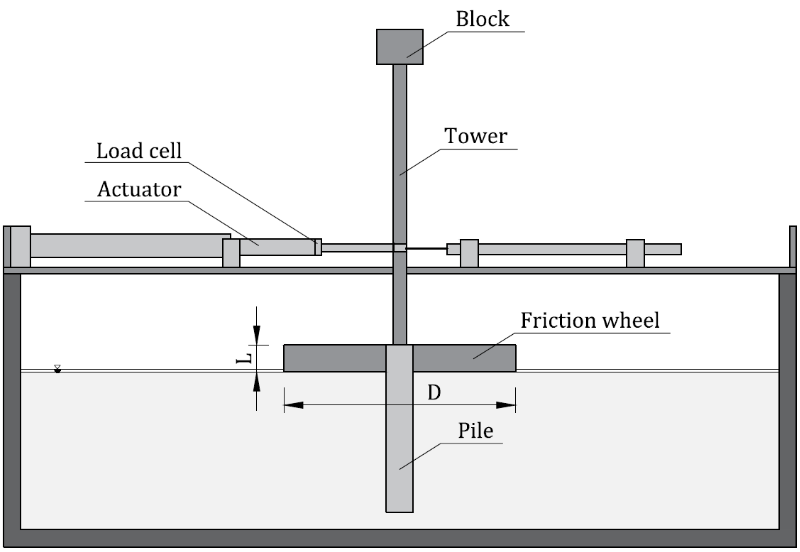

Fig. 6. Cross-sectional view of the analyzed hybrid pile model. The drawing was made on the basis of the article [13]

The results of the tests showed that the friction wheel significantly improved lateral load capacity and overall pile rigidity [13].

7. Conclusions

The article presents 5 different structural solutions for the foundation of engineering facilities. The most important stage in the design of each structure is the appropriate selection of the solution that would be optimal due to soil and water conditions and the purpose of the facility during operation. The structure after construction must provide adequate stability. Designing the foundations is difficult due to the fact that the most important factor in the selection of the solution are the conditions of the soil base on which there is a need to erect the structure, and before proceeding with designing, the area should be thoroughly examined to find out its specificity and bearing capacity. In the era of modern engineering achievements, economic and environmental impact are an important aspect, as is the reduction of carbon dioxide emissions into the atmosphere.

References

[1] Kysiak A., Koniecko M., Awaria budynku wielorodzinnego w wyniku naruszenia stanu równowagi wilgotnościowej w podłożu ilastym wskutek oddziaływania roślinności, Zeszyty Naukowe Politechniki Częstochowskiej 2018, seria Budownictwo 24, 203-208.

[2] Cios I., Garwacka-Piórkowska S., Projektowanie fundamentów, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2003.

[3] Hulboj R., Major M., Wybrane aspekty dotyczące posadowień budynków, Zeszyty Naukowe Politechniki Częstochowskiej 2014, seria Budownictwo 20, 81-88.

[4] Puła O., Projektowanie fundamentów bezpośrednich według Eurokodu 7, Wyd. II, Dolnośląskie Wydawnictwo Edukacyjne, Wrocław 2012.

[5] Wael Mohamed, Per-Erik Austrll, Ola Dahlblom, A new and reusable foundation solution for onshore windmills, Computers and Geotechnics 2018, 99, 14-30.

[6] Yan Z., Fu D.F., Zhang B.H., Zhang H.Q., Large-scale laboratory tests of a new type of bucket foundation in sand subjected to vertical loading, Applied Ocean Research 2020, 97, 102072.

[7] Lian J.J., Chen F., Wang H.J., Laboratory tests on soil–skirt interaction and penetration resistance of suction caissons during installation in sand. Ocean Eng. 2014, 84, 1-13.

[8] Lian J.J., Chen F., Wang H.J., Model tests on jacking installation and lateral loading performance of a new skirted foundation in sand, Ocean Eng. 2020, 197, 106914.

[9] Jiale Li, Xuefei Wang, Yuan Guo, Xiong (Bill) Yu, Vertical bearing capacity of the pile foundation with restriction plate via centrifuge modelling, Ocean Eng. 2019, 181, 109-120.

[10] Xinyao Li, Xiangwu Zeng, Xuefei Wang, Feasibility study of monopile-friction wheel-bucket hybrid foundation for offshore wind turbine, Ocean Eng. 2020, 204, 107276.

[11] Xuefei Wang, Xiangwu Zeng, Jiale Li, Xu Yang, Haijun Wang, A review on recent advancements of substructures for offshore wind turbines, Energy Conversion and Management 2018, 158, 103-119.

[12] Xu Yang, Xiangwu Zeng, Xuefei Wang, Hao Yu, Performance of monopile-friction wheel foundations under lateral loading for offshore wind turbines, Applied Ocean Research 2018, 78, 14-24.

[13] Xu Yang, Xiangwu Zeng, Xuefei Wang, Hao Yu, Performance and bearing behavior of monopile-friction wheel foundations under lateral-moment loading for offshore wind turbines, Ocean Eng. 2019, 184, 159-172.

Przegląd współczesnych rozwiązań posadowień konstrukcji inżynierskich

STRESZCZENIE:
Posadowienie różnego rodzaju konstrukcji inżynierskich jest kluczowym elementem każdego obiektu inżynierskiego, gdyż stanowi jedyne połączenie z podłożem gruntowym oraz zapewnia stabilność i bezpieczeństwo w trakcie eksploatacji budowli. Projektując daną konstrukcję, należy dobrać takie rozwiązanie posadowienia, które zapewni odpowiednią stabilność w napotkanych warunkach gruntowych. W artykule przedstawiono najnowsze rozwiązania posadowień konstrukcji inżynierskich, które zostały poddane analizie i badaniom na przestrzeni kilku ostatnich lat.

SŁOWA KLUCZOWE:
nowoczesne konstrukcje; nośność; podkonstrukcje; rozwiązania posadowienia