UDC 624.153.524

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CONSTRUCTION SOLUTION OF FOLDED-PLATE SHELL FOUNDATION FOR POWER TRANSMISSION TOWERS

The article presents the practice of applying different types of shell foundations. The peculiarities of foundation design for power transmission towers under complex engineering and geological conditions are considered. It is defined that under uneven deformations of the base when applying folded-plate shell foundations on weak or water-saturated soils load from the foundation must be uniformly redistributed to the ground base. It is proposed to use an alternative construction solution of the folded-plate foundation for power transmission towers with a hinged system for fastening folds comprising supporting beams. The improved design of the folded-plate shell foundation for power transmission towers can be used on water-saturated, marshy, weak soils and under uneven deformations of the base.

***Keywords:** shell foundation, hinge system, power transmission towers, folded-plate foundation.*

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КОНСТРУКТИВНЕ РІШЕННЯ БАГАТОХВИЛЬОВОГО СКЛАДЧАСТОГО ФУНДАМЕНТУ ПІД ОПОРИ ЛЕП

Наведено досвід використання фундаментів-оболонок різного типу. Розглянуто особливості проектування фундаментів для опор ліній електропередач у складних інженерно-геологічних умовах. Установлено, що при нерівномірних деформаціях основи та використанні багатохвильових складчастих фундаментів на слабких або водонасичених ґрунтах важливим є рівномірне перерозподілення навантаження від фундаментної конструкції на ґрунт основи. Запропоновано альтернативне конструктивне рішення багатохвильового складчастого фундаменту під опори ЛЕП із використанням шарнірної системи закріплення складок з опорними балками. З'ясовано, що вдосконалену конструкцію багатохвильового складчастого фундаменту під опори ЛЕП можна використовувати на водонасичених, болотистих, слабких ґрунтах та при нерівномірних деформаціях основи.

***Ключові слова:** фундамент-оболонка, шарнірна система, опори ЛЕП, багатохвильові фундаменти.*

Introduction. While engineering power transmission towers particular attention should be paid to the choice and design of an optimal type of foundation considering a number of factors, such as soil and climatic conditions, dimensional parameters of the tower and cost efficiency. These foundations are exposed to significant weight and wind loads, wire tension and lightning protection cables loads transferring them to the ground. Power transmission towers located in specific ground conditions (weak water-saturated soils case study) require a more meticulous choice of the foundation type when the use of traditional umbrella or pile foundations is not always suitable and cost-effective. As an alternative, it is possible to use folded-plate shell foundations that can be diverse in shape, working conditions and application areas.

One of the factors slowing down the process of these foundations active use is the insufficient amount of experimental and theoretical studies on the compatible operation of folded shells with a base. However, a series of new construction solutions for such foundations has been developed recently expanding the scope of their effective use from weak soils and peats to permafrost soils.

Analysis of latest sources of research publications. Interaction between folded-plate foundation and a base and the character of their work in weak, water-saturated soils are studied by many scientists [1 – 3]. Vanyushkin S.G. investigated features of the interaction between folded-plate shell foundation and a base [1]. For the research the following types of foundations are chosen: slab and beam raft, multibarrel shell, folded-plate structure, folded-plate structure with voids filled with other than gravel and earth. The results obtained indicate that the depth of voltage attenuation is the same for all models regardless of the foundation design, and is determined by its dimension and the general level of stress and strain module of a base [1].

Using shells of different types as foundations arose considerable interest all over the world [4, 5]. Their higher load bearing capacity and smaller subsidence compared to solid slab foundation are proved. Various researches showed that shell foundations were more effective when it was necessary to transfer significant loads to weak ground bases with uneven deformations of the base, and for structures exposed to a large wind load, such as smoke pipes, silos, and power transmission towers. Operational analysis of different shell foundations, introduction of the newest construction solutions, and development of calculation methods of such foundations are carried out by foreign scientists of the industry [4 – 6].

Today there is a practice of using folded-plate shell foundations in different countries of the world – in the USA, China, Mexico, France, etc. Such foundations were used in the construction of both ordinary 4 – 5 storey residential buildings and high-rise civil buildings.

The shell foundation was developed in the Tyumen State Architectural and Construction Academy. It represents a reinforced concrete thin-walled shell laid on a ground base. The shell is of zero or positive Gaussian curvature with a cross-beam system; the reinforcement of the shell can be made of single-layer steel or synthetics [2].

The usage of folded-plate shell foundations on water-saturated soils and marshes is of particular interest, especially when arranging foundations for power transmission towers. In some cases these foundations are used on weak soils, this indicates an improvement of foundation work. If the soils at the base are characterized by high water absorption and compressibility, this leads to permanent settling of the earth's surface. In this case it is appropriate to use a floating foundation as a folded-plate shell. An example of such use is the construction of the USA embassy in Mexico City [7, 8]. There are also alternatives floating foundation for power transmissions towers; it consists of 12 floats (metal cylinders with the capacity of 6 m^3 each) joined by small frames into three groups of four floats. A large metal girder rests on groups of floaters, the tower body is installed in the middle of the girder, and the brace is attached to each of the three ends of the girder [8]. Less time-consuming and simpler is the foundation which consists of overturned trough-shaped reinforced concrete slabs, connected on top by two metal girders. Additional grip of the foundation with peat is achieved by "suction" of the trough-like elements; therefore, this relatively light foundation can withstand a significant overthrow. During the installation such foundations gradually descend under load peat compacting, however, after reaching a certain value, further subsidence stops. As brief experience shows, the foundations of such design are the most economical having peat of 5 or more metres [9].

Folded-plate shell foundations were used for the construction of 220 kV power transmission towers in the Middle Urals and Tyumen region [7, 8]. The foundations were built on marshes of 5 – 6 meters depth. Reinforced concrete folded foundations were constructed as separate thin-walled folds connected on top by steel or concrete beam or girder. Power transmission towers of about 40 meters height were put on foundations. A great economic effect was obtained during the construction. The construction cost was reduced by 37% compared with the traditional arrangement of foundations. Inadequate work of folds at uneven deformations of base under foundation can be considered as a shortcoming of this foundation structure.

Parts of general problem unsolved before. One of the main unsolved issues in the design of folded-plate foundations for the power transmission towers is foundation structure and towers project stability during their operation. With uneven deformations of the base, using folded-plate foundations on weak or water-saturated soils it is important to evenly redistribute the load from the foundation to the ground base.

Problem statement. The aim of the research is to expand the scope of folded-plate foundation in difficult geotechnical conditions and also to improve the operation of folded-plate foundation for transmission towers by using a hinged system of folds fastening with supporting beams, which enables the load and emerging forces to be redistributed evenly in every fold of the foundation. Thus, it ensures high efficiency of each element of folded-plate foundation and the system of folds in general.

Main part and results. The study was conducted and it was proposed an alternative design solution of the foundation for the power transmission towers [10, 11]. However, while studying work of the foundation and interaction with the base, the disadvantages of its structural parts were revealed. Therefore, considering all the disadvantages of the previous design, we have developed a new improved construction solution of the folded-plate foundation for power transmission towers.

Folded-plate foundation for transmission towers consists of thin-walled reinforced folds which are interconnected on top by steel or reinforced concrete beams. The first two folds are connected with two separate beams, while the third one is connected with them with the same beam on the hinged joints forming a system of bearing beams with fixed hinges. A system of folded-plate foundation consists of six prismatic folds, that is why other three folds are interconnected symmetrically and in a similar manner to the first three folds (Fig. 1).

An element of the fold has three horizontal plates and two sloping planes in cross-section. The upper horizontal fold is used to support steel or reinforced concrete beam. Two lower plates are required for fold installation during assembly and for load distribution, and also as bearing elements for the folds. Width of the upper plate is determined based on the calculation of concrete bending and on design reasons [10].

For the structural elements of folded-plate foundation to work jointly, all six folds are interconnected due to the combination of three separate folds through a system of fixed joints and bearing beams similar to other three folds.

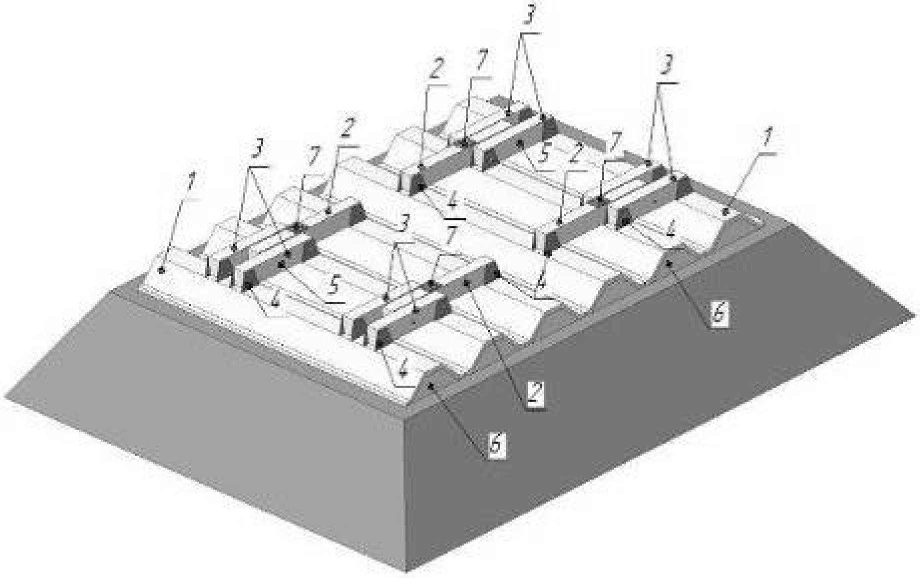

Figure 1 – Foundations for power transmission towers:
1 – thin prismatic reinforced concrete fold; 2 – bearing reinforced concrete beam;
3 – auxiliary reinforced concrete beam; 4 – metal hinge joints;
5 – bolt connection of the bearing beam and auxiliary beams;
6 – vertical reinforced concrete diaphragms;
7 – embedded plate with anchor bolts for fixing the base of the power transmission towers

The proposed foundation consists of six separate reinforced concrete thin-walled folds 1; three of them are arranged symmetrically to other three folds in respect to power transmission tower axis. Two folds on the edges are joined with two auxiliary reinforced concrete beams 3 on the top by metal hinge joint 4. The third prismatic fold is joined with the first two through the bearing reinforced concrete beam 2, on one side the bearing reinforced concrete beam 2 is connected to the fold 1 by the metal hinge joint 4, on the other side the bearing beam 2 is fixed directly to the auxiliary reinforced concrete beams 3 by the bolted connection. In the places of beams 2 and 3 bearing on the folds 1 vertical reinforced concrete diaphragms 6 are arranged. Vertical reinforced concrete diaphragms 6 are also installed in the center of the folds and at the edges. This type of connection is performed on both edges of folds 1 longitudinally. The other three folds 1 are joined similarly.

Presented foundation design is implemented through the joint work of structural elements of folded-plate foundation. More even distribution of external loads to the elements of the foundation system is achieved due to hinged joint of prismatic folds with bearing beams. Voids of the folds are of prismatic shape to provide the formation of a compact core of a certain value and to redistribute base pressure on the foundation.

According to the proposed design, prismatic folds 1 are joined with beams 2 and 3 on both edges longitudinally. Bearing beams 2 and 3 are installed in places designed for supporting the slabs of metal power transmission towers. In addition, folds 1 are designed with transverse diaphragms 6 located in spots of beams contacting 2 with 1 folded-plates, in the middle of the fold and across its edges. Diaphragms 6 are used for fixing fold 1 to the beam 2 with bolts installed in diaphragm. These diaphragms are supporting and designed considering shear forces in fold on a support.

Bolt connections 5, and bolts of the hinged element 4 are selected based on shear calculation to prevent from the action of all external loads.

The lower horizontal plates of prismatic fold 1, which are the end beams, reduce horizontal and vertical deformation of the fold’s edges [7].

The dimensions of each structural part of the foundation are selected individually for each power transmission tower; the main geometric parameter in selecting the geometry of the entire foundation is the base of the tower, while the geometry of prismatic folds, bearing and auxiliary beams should be constant. This relates to the dimensions ratio of the supporting parts of the fold, inclination angle of the sloping planes of the fold (it should be within 30 – 40 ^{o}), the ratio of height and width of the cross section of bearing and auxiliary beams.

Significant loss of foundation weight is reached due to application of shells which work as spatial structures having a curved shape and a large bearing capacity with minimal thickness. The shells are also characterized as having compressive and stretching tensions at relatively small bending moments [12].

The purpose of this construction is to limit (prevent) absolute and (or) relative foundation and superstructure displacements to the extent required for proper operation and durability of a structure [12].

Uneven vertical displacements under power transmission towers, under base, provoke load growth, but contact pressure cannot exceed its limit; as a result there is an intensive fold's voids filling 1 with subsoil in these areas [13]. Whereas the power load is redistributed again: it is reduced in areas with high values and increased displacements of the fold's voids; accordingly it increases in areas with lower values and insignificant displacements of the fold's voids. Thus, process of contact pressure self-regulation of fold's voids is realized. All this allows: smoothing out uneven deformation of soil base; smoothing the peaks of stress concentration in substructures and reducing the stress value in superstructures eliminating foundation tilt. Eventually when the effect of uneven vertical displacements stops, all components of folded-plate foundation gain new stable state of static equilibrium. At repeated uneven vertical displacements under power transmission towers character of fold's voids work 1 is repeated according to a new scheme of load redistribution. The process of self-regulation is possible as long as there is free capacity in fold's voids [14].

Foundation stiffness impacts the distribution of contact pressure significantly. Therefore, alteration of shell's stiffness may result in qualitative change in the shape of contact pressure diagrams. The research results state that for the reinforced concrete thin-walled shell foundations distribution of contact pressure can be taken as uniform in excess strength [12].

The improved design of foundation construction meets a number of requirements: the possibility to use weak structural capacity of the soil and water buoyancy force; minimum weight of prefabricated elements to be transported to remote zones; minimum materials consumption; uniformity of prefabricated elements; voids formation in the bottom to create osculum effect in case of foundation separation; creation of porous lower surface to increase foundation resistance to horizontal displacement.

According to the construction solution, under uneven base deformations the redistribution of contact pressures occurs and the system comes into equilibrium. The alternative construction design of folded prismatic foundation for transmission towers can evenly redistribute the loads to the structural elements of the foundation system.

Conclusions. The scientific novelty of the research is the folded-plate foundation new improved design solution development for the power transmission towers with the specific hinged system use of fastening bearing structural elements, and the formation of a special load calculation scheme. The further investigation presupposes the development of methods for calculating this type of foundation. Analysis of shell foundations showed that these foundations are in many cases more effective not only in terms of interaction conditions with the base, but also in economic aspects, as the material costs during the construction of such foundations are much lower compared to other foundations. The proposed folded-plate foundation can be used for transmission towers which are applied in water-saturated, marshy and weak soils and at uneven base deformation.

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Received 15.09.2017