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## Choice substantiation of a folded foundation model via laboratory experiment

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The examples of recent developments of foundation thin-walled structures and their applications are presented. It is noted that the purpose is to develop a method for conducting experimental studies of contact interaction between a folded shell foundation and a deformed base. The purpose of the laboratory tray research is to determine the optimal characteristics of the suggested foundation design. The article suggested a method for conducting a laboratory tray experiment to compare the operation of two models of folded shell foundations. The main stages of conducting the scientific experiment have been described and the basic principles of selecting materials, devices and equipment for carrying out the experiment have been considered. The conduct of the experiment including data recording for each foundation model has been described. As a result, subsidence data for each foundation model have been obtained. The findings have been analyzed; subsidence graphs for each foundation design have been built. It is concluded that better distribution of external load to the foundation system elements is achieved due to the application of a hinged joint of prismatic folds with supporting beams. It has been found that the chosen parameters of the second foundation model complied with the optimized results of the experiment planning and enabled to demonstrate the properties of the foundation system load redistribution better.

**Keywords:** folded shell foundation, method of conducting an experiment, soil

## Обґрунтування вибору моделі складчастого фундаменту із застосуванням методики проведення лабораторного експерименту

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В статті проаналізовано дослідження вітчизняних та закордонних вчених, що займалися вивченням роботи фундаментів-оболонки при різних ґрунтових умовах, та їх контактної взаємодії з основою. Наведено приклади останніх розробок фундаментних тонкостінних конструкцій та сфери їх використання. Зазначено, що метою є розробка методики проведення експериментальних досліджень контактної взаємодії складчастого фундаменту-оболонки і деформованої основи. Метою лабораторних лоткових досліджень було визначення оптимальних характеристик запропонованої конструкції фундаменту. В статті було запропоновано методику проведення лабораторного лоткового експерименту для порівняння роботи двох моделей складчастих фундаментів-оболонки. Було описано основні етапи проведення наукового експерименту і розглянуто основні принципи при виборі матеріалів для виконання експерименту, приладів та устаткування. Було описано безпосередньо проведення експерименту із фіксацією даних по кожній із моделей фундаментів. В результаті було отримано дані осідань по кожній із моделей фундаментів, проаналізовано результати та побудовано графіки осідань для кожної фундаментної конструкції. Зроблено висновок, що завдяки застосуванню шарнірного з'єднання призматичних складок з опорними балками досягається більш рівномірне розподілення зовнішнього навантаження на елементи фундаментної системи. Встановлено, що обрані параметри другої моделі фундаменту у відповідності до результатів оптимізації планування експерименту дозволили більш повноцінно проявити властивості перерозподілу навантаження фундаментної системи.

**Ключові слова:** складчастий фундамент-оболонка, методика проведення експерименту, ґрунт



## Introduction

Shallow foundations such as shell foundations are studied and used to improve capacity of a foundation structure under conditions of weak and water-soaked soils. The practice of designing and constructing buildings and structures using plate-shell foundations, pier shell foundations, folded shell foundations, and others, is rather common.

One of the main stages of research is to conduct an experiment in laboratory or on-site conditions. The results of such studies enable to investigate nature and character of a foundation structure operation. The development of a full-fledged methodology for conducting an experiment is the basis for further analytical and practical research.

## Review of research sources and publications

Applications of shell foundations, diverse in form, operating conditions and materials, are found in many countries of the world. Modern investigations in the field of foundation engineering, in particular application of shell foundations, have common features aimed at constructing such foundations in different soil conditions and expanding the scope of their application. The development of fundamentally new constructive solutions is one of the main goals of research in this field.

Such domestic and foreign scholars of the industry as Pronozin Y.O., Vannyshkin SG, Tetior O.N., Mahmoud Samir El-kadya, Essam Farouk Badrawi, Kurian N.P. have studied the operation of shell foundations of various types when interacting with a soil in detail [1-9].

Poroshin O.S. in his study [2] solved the issue of introducing in building practice the flat thin-walled cylindrical binary shell foundations inverted to soil, providing tensile strength within a slab foundation. The purpose of such foundations introduction was to reduce the time and cost of construction, improve the reliability of structures erected on weak soils, solve a number of geotechnical problems which have complex engineering and geological conditions. As a result, a new foundation design was developed and its interaction with a base was studied.

Govorov D.V., under the supervision of Goncharov Yu.M., developed and investigated the operation of shell foundations in the form of spatial folded slabs applicable for permafrost soils [6]. The suggested foundation model was used for constructing a four-story panel administrative building in industrial area "Oganer" and a warm long-stay car park.

Mahmoud Samir El-kady and Essam Farouk Badrawi conducted experimental and numerical studies using five square foundations; one of them was a flat foundation as a reference sample and four foundations of a composite form of shell type [7]. The method for conducting laboratory experiments for studying shell foundations operation in order to determine their bearing capacity and stress-strain state of a base was suggested.

## Definition of unsolved aspects of the problem

The complexity of a laboratory experiment is due to the lack of information on the correct algorithm of conducting such experiments for a folded foundation. Calculation and design of shell foundations require careful study of behavior and nature of the foundation model operation in laboratory conditions.

## Problem statement

The aim of the research is to develop a method for conducting experimental studies of contact interaction between a folded shell foundation and a deformed base.

## Basic material and results

One of the main engineering tasks is developing optimal constructive solutions considering specific operational conditions. Laboratory experiments are carried out using typical devices, special simulators, stands, equipment, etc. These experiments enable to conduct thorough and repetitive studying of some characteristics impact under alteration of others, and also provide relevant scientific information at minimum costs if the experiment is well-grounded scientifically.

Two types of foundations are considered: the first is a folded foundation in the form of separate thin-walled reinforced concrete folds that are joined together by a steel or reinforced concrete beam [3]; and the second - a folded foundation with an improved system of support beams and joints [10].

The basis for the experimental research is a laboratory tray experiment aimed at determining optimal characteristics of the suggested foundation design and identifying the qualitative patterns of interaction between a folded foundation and a base.

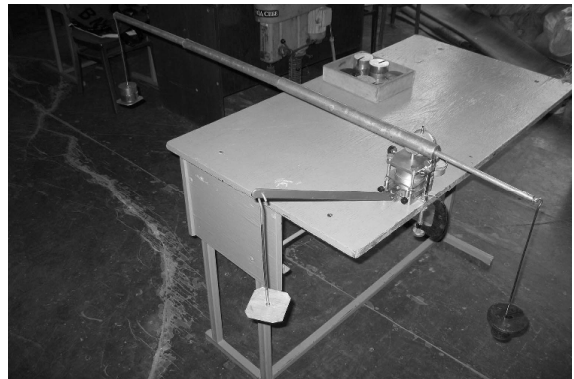
The set goal was achieved in two stages. At the first stage, the bearing capacity of foundation models depending on structural features of the foundations, their geometric parameters, and characteristics of the soil were investigated. At the second stage, it was necessary to compare contact interaction between the first and the second models of foundations.

The tray study was performed in a metal tray sized 600×650×680 mm. The metal frame was made of 80×80 mm angles and 50 mm wide steel stripes. The front edge was made of plexiglass with horizontal lines applied at 15 mm intervals. All other edges were made of 16 mm chipboard. The dimensions of the tray and the foundation models were specified in such a way as to exclude the compression by the tray walls (Fig. 1).

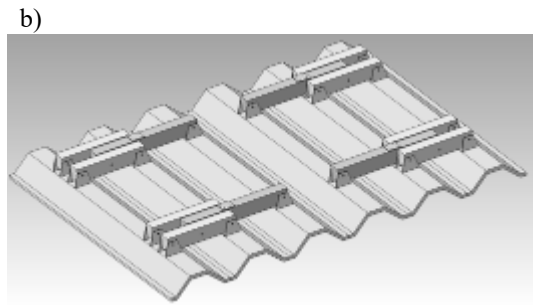
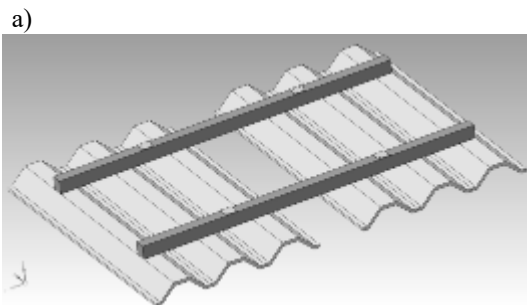
Sandy soil was taken as a base. The amount of fine sand necessary for the experiment was dried to a dry state. After that, the sand was sifted through a sieve with 0.5 mm axes diameter. The sand base model was arranged in 15 mm thick layers and tamped. This process was controlled with control horizontal lines on the front of plexiglas. Physical and mechanical characteristics of the soil were determined according to a conventional method [11] in laboratory conditions using a compression device of Litvinov system (Fig. 2). The soil surface in the tray was thoroughly planned.



**Figure 1 – Tray in a metal frame to conduct the experiment**



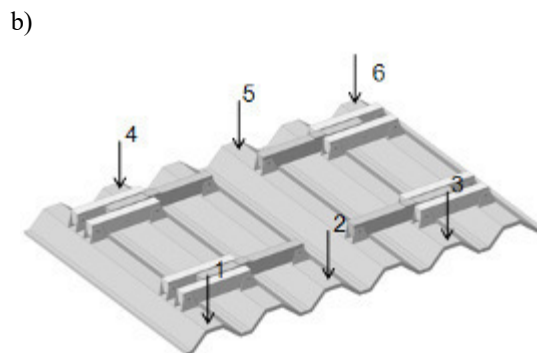
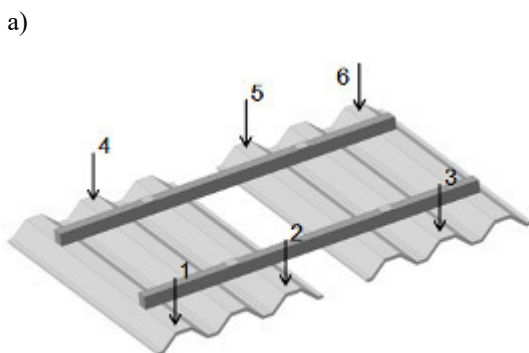
**Figure 2 – Determination of physical-mechanical characteristics of soil using PLL-9 device**



**Figure 3 – 3D modeling of the folded foundation structures:  
a) the first model; b) the second model**



**Figure 4 – Models of the folded foundation structures in assembled state:  
a) the first model; b) the second model**



**Figure 5 – Location of time-type indicators on elements of foundation models  
a) the first model; b) the second model**

Two series of tray experiments were conducted. The task of the first series was to study the impact of structural features of foundation models and ground characteristics of the base on the bearing capacity of the suggested foundation models.

The purpose of the second series of experiments was to compare subsidence and bearing capacity of the foundation models.

The foundation models were created using the technology of 3D modeling and 3D printing. The foundation elements were printed on a 3D printer XYZprinting da Vinci 1.0 Pro from plastics with typical characteristics (thread diameter – 1,75 mm; oval shape – +/- 0,03; density – 1250 kg/m<sup>3</sup>; melting viscosity – 2000Pa·s; melting point – 230 C°; bending resistance – 20 times; printing technology – FDM). Computer modeling of foundations was carried out via Kompas 3D V16 software application (Figure 3).

All elements of the foundation were glued with the special glue; the parts which required preservation of hinges were joined with metal rods of the required diameter.

The first set of parts was made to simulate the first type of foundation. Here the supporting beam is to be rigidly joined with all six folds of the foundation. The second set was made to simulate the second type of foundation (Figure 4).

The quantitative values of foundations subsidence were recorded using IT-10 time type indicators. Location of the indicators on the shelves of foundation folds is shown in figure 5. They were installed on a specially made metal frame which was rigidly secured with the experimental tray (Figure 6). The indicators fixed folds vertical movements. The data on the indicators were entered in a journal and based on the aver-

age indicators; the graphs of subsidence were drawn.

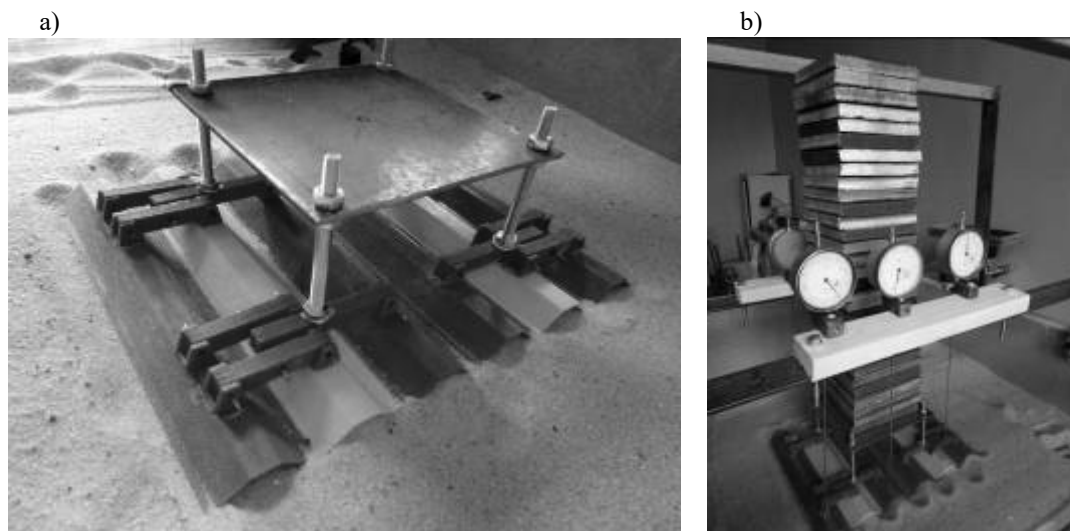
A special device was created for simulating a real load transfer of a power transmission line to the foundation. It consists of a metal plate which joins four metal rods through which the transfer of external load to the supporting beams and, accordingly, to the folds of the foundation (Figure 6) takes place.

The loads were applied in levels of 1 kPa, each pressure level was kept until conditional stabilization of soil deformation. The speed of foundation models subsidence (not more than 0.1 mm per 30 minutes) was taken as a criterion of deformation conditional stabilization [12]. Each subsequent level of pressure also lasted during the time of conditional stabilization.

As a result of a series of tray experiments, subsidence graphs for two foundation models were drawn. In order to facilitate further analysis, the subsidence graphs were separately drawn for the three front and three rear indicators (Figure 7, 8).

Additionally, the trend lines (linear type) were constructed on the subsidence graphs as a geometric representation of the mean values of the analyzed parameters obtained via any mathematical function. This is a graph of the approximating function. The R2 value shows the accuracy of the approximation. When this value approaches a unit, the approximation error is equal to zero [13].

Thus, it is possible to predict future behavior of the subsidence graphs. This type of the trend line (linear) was chosen as the alteration of the indicators that occurs almost linearly (increases at constant speed). According to the approximation values (within 0.95-0.99), chosen linear approximation provided high accuracy and a well-predicted result.



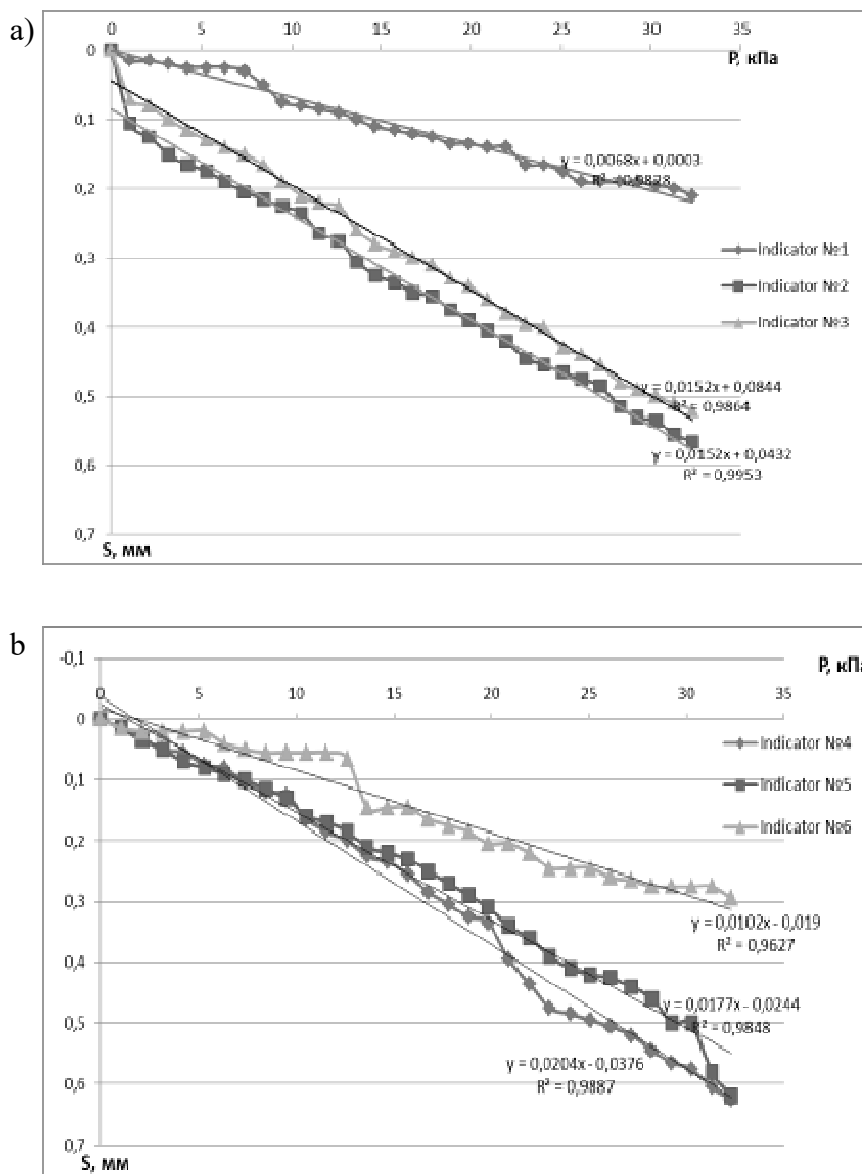
**Figure 6 – Preparation of the laboratory equipment and conducting the experiment:**

a – metal device for transferring external load to foundation structure;

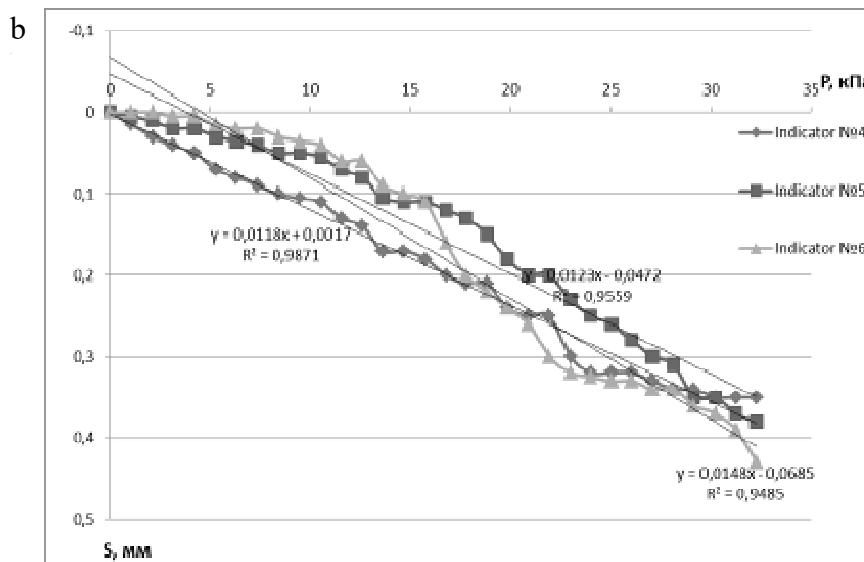
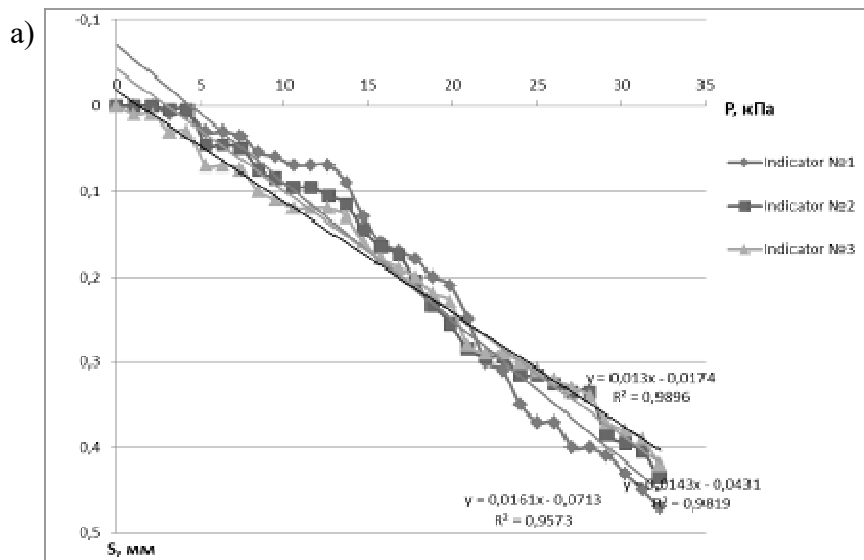
b – loading the foundation structure and fixing the indicators of subsidence using IT-10 time type indicators

Analyzing the subsidence graphs of the first foundation model (Figure 7), it is possible to see almost similar values of subsidence on indicators 2 and 3 (4 and 5 are similar) caused by external load. While the values of the indicators 3 and 6, following the same linear law, have considerably less values of subsidence. This indicates the uneven distribution of load in this system. The type of load transfer through a solid support beam does not ensure full and even operation of the entire soil under each fold at a time.

At the same time, in the graphs of subsidence on the second foundation model (Figure 8) it is evident that the curves of subsidence of the front indicators 1-3 are of the same nature and the value of the final subsidence is almost identical. The rear indicators 4-6 behave similarly. It shows that this foundation model is performed due to the peculiarities of co-operation of the structural elements of the folded foundation. More even distribution of external load to the elements of the foundation system is achieved through the use of the hinged joint prismatic folds with support beams.



**Figure 7 - Subsidence graphs based on indicators values of the first foundation model**  
a – for indicators № 1-3; b – for indicators № 4-6



**Figure 8 – Subsidence graphs based on indicators' values of the second foundation model**  
a – for indicators № 1-3; b – for indicators № 4-6

### Conclusion

The methodology was developed and the laboratory experiment was conducted to determine subsidence of the foundation structures; two models of folded shell foundations were compared. The advantage of the second foundation model in terms of the conditions of interaction with a base was shown. As a result, it was found that the chosen parameters of the second foundation model complied with the optimized results of the experiment planning and enabled to demonstrate the foundation system load redistribution properties better.

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