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CONDUCTING AND ANALYZING THE RESULTS OF THE EXPERIMENTAL BOX TEST OF RETAINING WALL MODELS WITHOUT PILES AND ON THE PILE FOUNDATION

Purpose. Taking into consideration that the bearing capacity of the foundation may be insufficient, in the study it is assumed that pile foundation can be used to reduce the impact of the construction of new retaining structures on roads and railways near the existing buildings or in areas of dense urban development and ensure the stability of the foundation. To reduce the volume of excavation it is necessary to choose the economic structure of the retaining wall. To do this, one should explore stress-strain state (SSS) of the retaining walls, to develop methods to improve their strength and stability, as well as to choose the most appropriate method of their analysis. **Methodology**. In the design of retaining walls foundation mat and piles are considered as independent elements. Since the combined effect of the retaining wall, piles and foundation mat as well as the effect of soil or rock foundation on the structure are considered not fully, so there are some limitations in the existing design techniques. To achieve the purpose the box tests of retaining walls models without piles and with piles for studying their interaction with the surrounding soil massif were conducted. **Findings.** Laboratory simulation of complex systems «surrounding soil – retaining wall – pile» was carried out and on the basis of the box test results were analyzed strains and its main parameters of the stress-strain state. Analysis of the results showed that the structure of a retaining wall with piles is steady and stable. **Originality.** So far, in Ukraine has not been carried out similar experimental box tests with models of retaining walls in such combinations. In the article has been presented unique photos and test results, as well as their analysis. **Practical value.** Using the methodology of experimental tests of the retaining wall models with piles and without them gives a wider opportunity to study stress-strain state of such structures.

Keywords: retaining wall; pile foundation; box tests; soil massif; stability and strength of structure; comparative analysis of options

Introduction

Modern construction requires maximum space use in the city. Engineering defenses and technologies of their application play a significant role in these conditions. They should provide minimal changes of strain-stain state (SSS) both of retaining wall and surrounding massif of soil [11].

Retaining walls throughout the service life must ensure safety and continuity of normal traffic, and also the simplicity and the lowest complexity of their service in the operation process.

In the thin retaining walls stability is provided by its own weight and the weight of soil, which is involved in to operation by the wall's construction [2].

Retaining walls have to be calculated taking into account the horizontal and vertical external loads, located on the wedge of failure, including vehicle loads, technological equipment, stocked material, etc. [1].

Load of wheels in the form (LW-100) (NK-100) was taken as notmative live vertical load from traffic when calculating the retaining wall, which consists of one wheeled machine.

Calculations of retaining walls should be performed taking into account the characteristics of the nonlinear behavior of soil. Moreover, some existing construction technologies, such as piles engineering without soil excavation, are new and have not been reflected in the standards [4].

Solving transportation problems in Ukraine is connected with the complex challenges in the construction of bridge crossings of combined type. Today one of these objects is a bridge across the Dnieper River in Kiev city at the Kyiv-

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Moskovskyi-Darnytsia railway section, which is provided with road exits on the right and left banks. One of these structures on the bridge approaches is a motorway junction with the over Dnieper highway on the right bank of the Dnieper river. This junction in a form of road exit is designed using retaining walls of complex structure, as shown in Fig. 1. [3, 10].

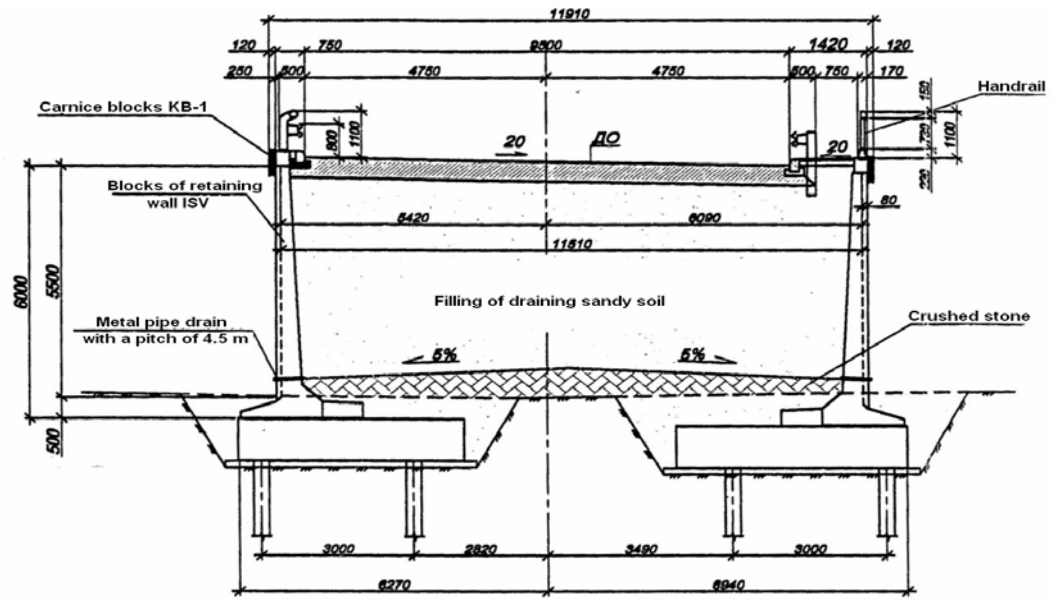

Fig. 1. Structure of a retaining wall

Purpose

The principal purpose of the research is conducting and comparison of experimental box tests results of retaining walls models without piles and with pile foundation with the surrounding soil, and analysis of obtained results.

In order to achieve this purpose it was necessary to solve the following tasks:

− Experimental study the stress-straine state of structures in the laboratory;

− Creation of computational model that without any changes could be used in the calculation of retaining walls;

− Creation of soil models, which would describe closely work of soil base;

− Development the model of pile calculation, flexible retaining walls;

− Development methodology of experimental research of interaction between the surrounding soil massif with different models of retaining walls at different loads and movements;

− Implementation the results of the experimental box tests at design, reconstruction or strengthening of mentioned structures;

− Results comparison of calculation accordingly to the method, which is offered with the experimental data of the author and other researchers, as well as with the results of calculation accordingly to regulatory documents;

− Recommendations development concerning the use of research results.

Methodology

For laboratory research a road section with the retaining wall «construction number 7P» at the interchange leg from the over Dnieper highway on the right bank of the Dnieper river was examined.

The total length of right-hand wall is 84 m. The retaining wall was designed using unified concrete structures of an angular bar from blocks.

Thus at the length of 42 m blocks of the retaining wall are installed together with sole blocks on the crushed-stone bed, thickness of 0.2 m. All dimensions correspond to the drawing (see Figure 1).

The area of 42 m length houses 50 pieces of piles with rectangular cross section 35x35 cm, therefrom 12 piles, 12 m long each, were ramed at 12 m long part of the area, and 38 piles, 14 m long, were installed at the other 30 m long part. The

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highest and the most complicated construction of the wall, with length of 30 m and maximum height of 6.5 m and 14 m long piles is considered in the paper.

For the purposes of this work several series of experimental box tests were conducted. Assembled device together with the installed box is shown in Fig. 2.

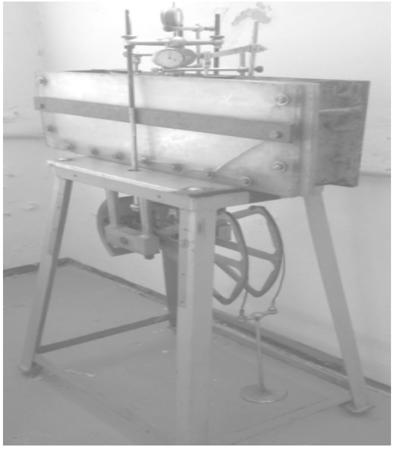

Fig. 2. General view of
a device with installed box

Testing flat box (see Fig. 2) has a width of 5.12 m, so for the test was taken a part of an angular wall, the length of 12.5 m along passage. Dimensions for production of models were taken from the drawing (see. Fig. 1). They were made on scale 1: 100, respectively sizes of models are: height 6.5 cm, width 4.5 cm on the sole and the length of the walls part in the direction of passage is 12.5 cm (Fig. 3) [6, 7, 8].

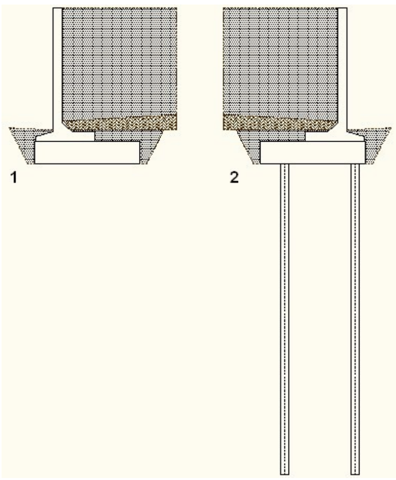

Fig. 3. Options of retaining wall:
1 – without piles;
2 − with 14 m long piles

Models of retaining walls, which are shown in Fig. 4, were produced in specially built form. Reinforcement cage was in the form of steel wire. Concrete was prepared of cement, additives for strength, graded sand and crushed stone of appropriate size [13].

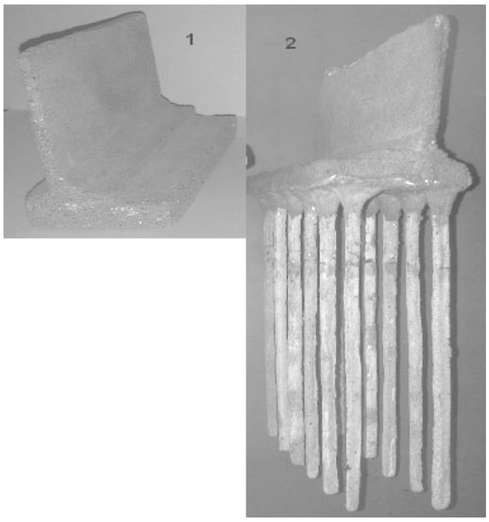

Fig. 4. Models of retaining wall:
1 – without piles;
2 – with piles, length of 14 m

In order to simulate the surrounding soil massif of a wall, the basic soil model, which is shown in Fig. 5, created from loam by soil layers compaction with tamping was applied. Density, humidity and deformation characteristics of models in different series of tests were identical, it gives the possibility to compare the stress-strain state (SSS) of models at different options.

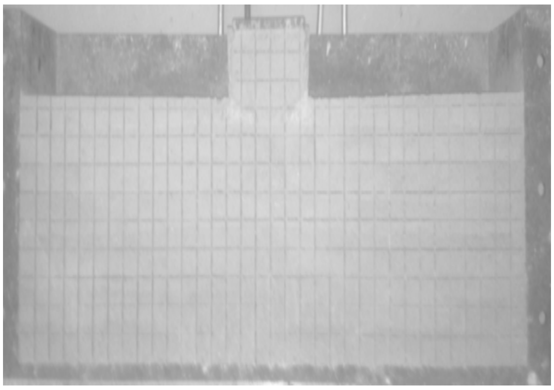

Fig. 5. The model of soil

Tamping is a horizontal metal disk and a rod, connected rigidly with it. A striker has the cylindrical shape with a hole in the center, by which it places on the rod and can move freely along it.

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Weight of the striker is 25 H. Shocks were hited on the horizontal disk of temping, which was on a wooden board on soil in the test box.

In order that power of strokes would be the same, the striker is released with free fall from a height of 30 cm, which is fixed by a limiter. For convenience the striker is lifted using a cable. Number of tamping strokes were experimentally established so that soil characteristics of each layer were similar.

On the side of soil massif a grid was divided (see. Fig. 5), which was drawn with a pencil into squares measuring 2 by 2 cm for a better view and test results processing.

Features of soil massif from loam were determined by laboratory tests (Fig. 6a) from selected samples and soil rings (Fig. 6b). An average, they were: moisture of soil was equal to 11.5%, soil density – 1.5 g / cm^3, the density of soil parts – 2.7 g / cm^3, initial ratio of porosity – 1 module of strain – 3.4 MPa. There were also found some other characteristics.

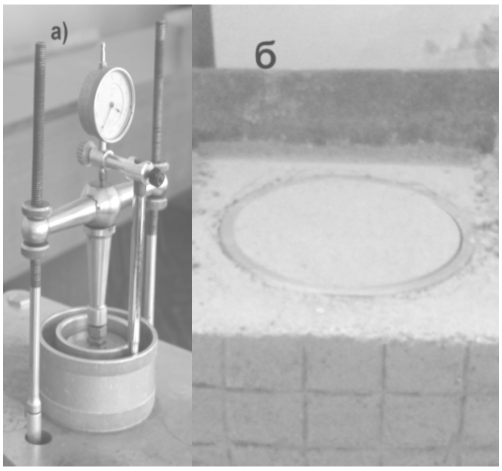

Fig. 6. Labotatory tests:
а) a type of device for compression tests;
б) soil rings

After preparing the soil by tamping for bedding, models of retaining wall were set in the center of the box (Fig. 7), soil was tamped by tamping between them and on either side of them. Then, on soil that was modeling the permanent way and locating between retaining walls at the maximum height, there was installed a metal die, width of 10 cm, length of 12.5 cm and height of 1 cm (Fig. 7.2).

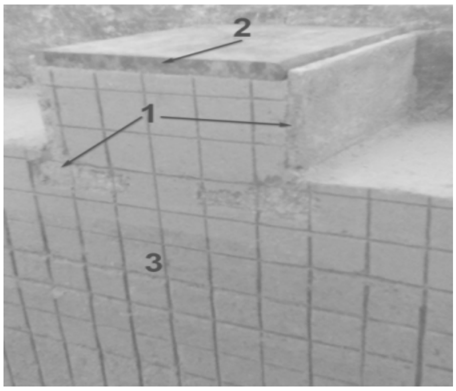

Fig. 7. Superstructure of a model:
1 – retaining walls; *2* – a metal die;
3 – massif of soil

Final box with soil massif in the box was mounted on compression device (see Fig. 2). Further lever system was set with lever arm 1:10. Through it the load on the die, area of 116 cm^2 was supplied. Load was applied by steps of 20N to achieve pressure under die, which corresponded to the existing load of wheels LW-100 (НК-100) in regulations.

On the die and lever five indicators of clock controlled type were installed (Fig. 8). During the loading of models, level was controlled both as the absolute displacements, with dial gage, an accuracy of 0.01 mm, and relative strains, which were calculated by dividing the displacements at the starting height of soil massif. At appropriate intervals of time readings were taken and recorded in the log for further processing.

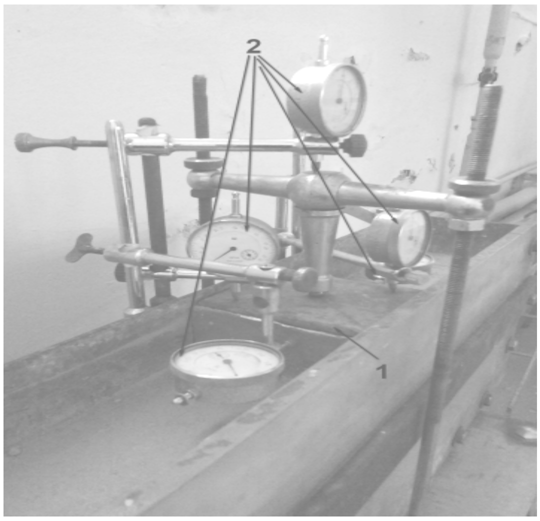

Fig. 8. Installing the lever system and indicators:
1 – a metal die; *2* –indicators of time type

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After reaching 100% or more of the (LW-100) NK-100 load, device and box were disassembled for examination of soil massif, the plotted grid, and also for photographing the results (Fig. 9).

Fig. 9. Analysis of test results

Findings

When conducting research, was investigated the general nature of the work, strain and fracture of the soil massif with retaining walls. These studies were conducted on two models:

− models of soil with an anglular retaining wall without pile;

− models of soil with an angular retaining wall on pile foundation.

In course of experiments, connected with the nature study of soil massif fracture, at all stages of the model load it was monitoring over deformation of soil massif using the deformation grid and absolute moving of vertical roadway surface by indicators of clock type, placed in 5 points [9].

During the experiments the values of vertical and horizontal displacements of the first model in soil massif were obtained.

Results of points displacements at ten degrees of load of retaining walls models without piles are presented in Table 1.

A typical strain of a retaining wall model without piles is the case of soil massif compression between retaining walls and beneath them, which is visible upon bend of grid 2 x 2 cm, marked on the front side of the model (Fig. 10). Also, analyzing the results and calculating the relative strain of the model (Table 2) was constructed dependence graph of the relative strains from tension in the model with the retaining wall without piles, as it is shown in Fig. 11.

Table 1

Absolute strain of retaining walls models without piles, mm

Pressure on die of a model	Test number					
МПа	№1	№2	№3	№4	№5	№6
0	0	0	0	0	0	0
0.0172	0.08	0.09	0.14	0.07	0.09	0.11
0.0345	0.29	0.31	0.37	0.27	0.3	0.33
0.0517	0.44	0.46	0.52	0.48	0.5	0.47
0.069	0.67	0.74	0.81	0.74	0.81	0.71
0.0862	1.03	1.08	1.14	1.02	1.06	1.09
0.1035	1.91	2.05	1.81	1.83	1.91	2.01
0.1207	3.66	3.72	3.39	3.45	3.59	3.55
0.1379	5.34	5.71	5.45	5.83	5.95	5.85
0.1552	7.45	7.98	7.84	7.53	7.78	7.64
0.1724	9.05	9.08	9.23	8.93	9.05	9.13

Table 2

Relative strain of retaining walls models without piles, mm

Pressure on die of a model	Test number					
МПа	№1	№2	№3	№4	№5	№6
0	0	0	0	0	0	0
0.017	0.003	0.004	0.006	0.003	0.004	0.005
0.035	0.012	0.013	0.015	0.011	0.013	0.014
0.052	0.018	0.019	0.022	0.02	0.021	0.02
0.069	0.027	0.031	0.034	0.031	0.034	0.03
0.086	0.042	0.045	0.048	0.043	0.044	0.045
0.104	0.08	0.085	0.075	0.076	0.08	0.084
0.121	0.152	0.155	0.141	0.144	0.15	0.148
0.138	0.223	0.238	0.227	0.243	0.248	0.244
0.155	0.31	0.333	0.327	0.314	0.324	0.318
0.172	0.377	0.378	0.385	0.372	0.377	0.38

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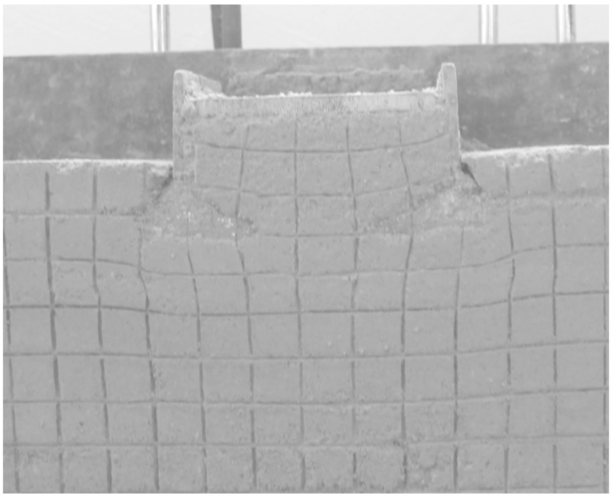

Fig. 10. Strain of the retaining wall model without piles after load application

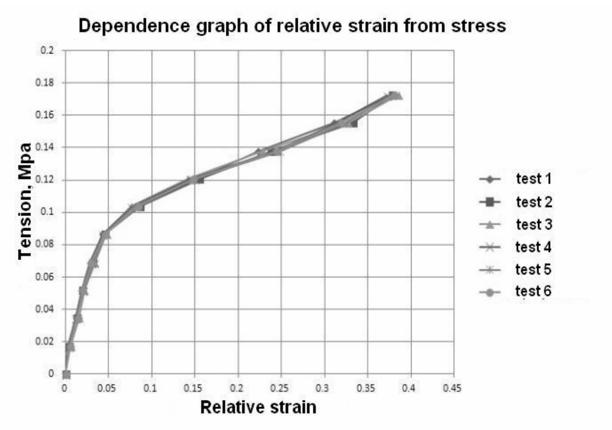

Fig. 11. Relative strain of the retaining wall model without piles

In the course of the study and results prossessing of experimental box testing of retaining walls models on pile foundation, values of vertical and horizontal displacements of models at different levels of load were obtained (Table 3).

Using of pile foundation in the retaining wall model has improved the strain figure as it is shown in Fig. 12. This model has revealed no character strain of soil massif and forming the core of soil compression between retaining walls and beneath them in comparision with the version without pile.

Application of piles has reduced vertical displacement, absolute strains of retaining walls model on pile foundation and strain of soil massif around them compared with the option without piles at average from 9.15 mm up to 2.34 mm.

Table 3

Absolute strain of retaining walls models on pile foundation, mm

Pres-sure on die of a model	Test number					
МПа	№1	№2	№3	№4	№5	№6
0	0	0	0	0	0	0
0.0172	0.045	0.11	0.04	0.065	0.06	0.04
0.0345	0.205	0.275	0.21	0.2	0.2	0.22
0.0517	0.4	0.42	0.4	0.34	0.35	0.4
0.069	0.59	0.55	0.6	0.47	0.495	0.58
0.0862	0.76	0.69	0.77	0.61	0.65	0.765
0.1035	0.97	0.84	0.96	0.765	0.83	0.955
0.1207	1.19	1.03	1.18	0.94	1.03	1.175
0.1379	1.46	1.28	1.46	1.19	1.32	1.46
0.1552	1.85	1.68	1.85	1.55	1.72	1.85
0.1724	2.48	2.18	2.49	2.15	2.24	2.5

Fig. 12. Strain of the retaining wall model with piles after load application

According to relative strain reducing, models with pile foundation are quite significant (table 4).

Using calculations were constructed dependency graph of relative strains from tension in the model with the retaining wall on pile foundation (Fig. 13).

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Table 4

Relative strain of retaining walls models on pile foundation, mm

Pressure on die of a model	Test number					
МПа	№1	№2	№3	№4	№5	№6
0	0	0	0	0	0	0
0.017	0.003	0.004	0.006	0.003	0.004	0.005
0.035	0.012	0.013	0.015	0.011	0.013	0.014
0.052	0.018	0.019	0.022	0.02	0.021	0.02
0.069	0.027	0.031	0.034	0.031	0.034	0.03
0.086	0.042	0.045	0.048	0.043	0.044	0.045
0.104	0.08	0.085	0.075	0.076	0.08	0.084
0.121	0.152	0.155	0.141	0.144	0.15	0.148
0.138	0.223	0.238	0.227	0.243	0.248	0.244
0.155	0.31	0.333	0.327	0.314	0.324	0.318
0.172	0.377	0.378	0.385	0.372	0.377	0.38

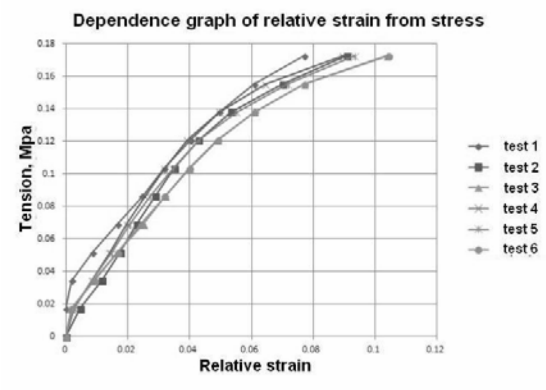

Fig. 13. Relative strain of the retaining wall model on pile foundation

In figure 14 the dependence joint graph of relative strain from tensions under a stamp of the first and second versions of retaining walls models with the surrounding soil massif is presented.

From this graph one can conclude that the use of piles has positive impact on the stability of retaining walls [14, 15].

The observations allowed studying models fracture pattern of fixed soil massif by piles of the retaining wall and unfixed soil massif (Fig. 10 and 12). As it can be seen in the figure, nature of their fracture is different [16, 17]. Loads are also different at which the destruction has occurred: soil massif, fixed by retaining walls on piles, did not ruin under load of 172.41 kPa, which is approximately 171% of the equivalent load (LW-100) (НК-100), and soil massif, fixed by the retaining wall without piles under this load destructed and lost stability.

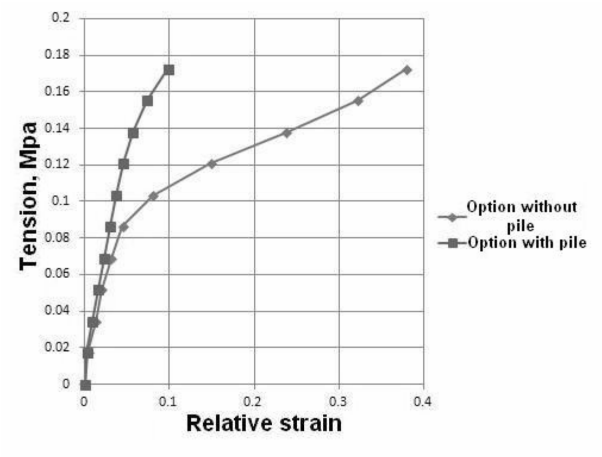

Fig. 14. Relative strain of the supporting wall model on pile foundation

The vertical strains of the second variant of the soil massif model with retaining walls on pile foundation are by 3.91 times smaller than the first version of soil massif of soil with retaining walls on a natural basis. It was also noted reduction of horizontal displacements (deviation from vertical ones) of retaining walls with piles by 2.5 … 3 times.

Originality and practical value

Originality of the research is the following:

− Firstly in practice of simulation with equivalent materials was developed the method of experimental studies of retaining walls on pile foundation and without it in large-scale models. It let reproduce their work in semi-stabled soil and identify the nature of the interaction between retaining walls and soil massif;

− Experimental research of the soil massif stability with two options of retaining walls were performed. As a result, new scientific results were obtained, that allow revealing and assessing the stability of the construction of retaining walls, depending on various factors;

− Conducted field studies in real construction projects allowed assessing not only

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assurance factor, technical feasibility, economic efficiency and a degree of this fastening security, but confirm theoretical and experimental research reliability on models;

− Design scheme and the proposed method of construction calculating of retaining walls that takes into account the actual loading pattern were substantiated.

Conclusions

The complexity of the mechanical processes when there is an interaction of angled retaining walls on the pile foundation and without them with soil massif, as well as the variety of factors affecting the nature of their interaction, cause difficulties both for the analytic solution of the problem at static work of supporting walls and for the direct research in the full-scale conditions. This circumstance has determined the choice of research line, mainly with experimental and laboratory methods on models.

Taking into account such specific features of challenge as engineering and geological conditions of construction, the need for experiments on models, variety parameters under research and others, it is worthwhile further investigation of the system operation «pile foundation– retaining wall –surrounding soil massif» to carry out by the method of equivalent materials.

To study the static work features of supporting walls on models using equivalent materials the author has developed a method of experimentations that includes recommendations concerning equivalent materials selection that simulate soil massif and functions of main criteria of similarity depending on the considered range of tasks.

Experimental research on two variant models, conducted with the purpose to study the stability of retaining walls construction on pile foundation and without it, showed that as a result of piles application in the foundation of retaining walls there is soil massif reinforcement and self-supporting soil massif is formed. It was found that the pile foundation in the retaining walls is a robust design, a feature of which is determined by its interaction with the surrounding soil massif.

The stability of the retaining wall, fixed with pile foundation, and performance of formed, self-supporting soil mass depends on applied load.

The results of the experimental studies let obtaine changes dependences of absolute and relative strains from load and stress under die.

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ПРОВЕДЕННЯ ТА АНАЛІЗ РЕЗУЛЬТАТІВ ЕКСПЕРИМЕНТАЛЬНОГО ЛОТКОВОГО ВИПРОБУВАННЯ МОДЕЛЕЙ ПІДПІРНОЇ СТІНИ БЕЗ ПАЛЬ І НА ПАЛЬОВОМУ ФУНДАМЕНТІ

Мета. Беручи до уваги, що несуча здатність фундаменту може бути недостатньою, в науковій роботі передбачається, що пальовий фундамент може бути використаний для зниження впливу будівництва нових підпірних споруд на автомобільних і залізничних дорогах, біля вже існуючих будівель або в місцях щільної міської забудови, та гарантувати стабільність фундаменту. Для зниження обсягів земляних робіт потрібно обрати економічну конструкцію підпірної стінки. Для цього необхідно дослідити напружено-деформований стан (НДС) підпірних стін, розробити методи підвищення їх міцності та стійкості, а також обрати найбільш доцільний метод їх аналізу. **Методика.** При проектуванні підпірних стінок ростверк і палі вважаються незалежними елементами. Оскільки спільна дія підпірної стінки, паль, ростверку, а також вплив ґрунту або скельної основи на споруду враховуються не в повній мірі, тому є деякі обмеження в існуючих методах їх проектування. Для досягнення мети були проведені лоткові випробування моделей підпірних стін без паль і з палями з метою вивчення їх взаємодії із оточуючим масивом ґрунту. **Результати.** Вченими було виконано лабораторне моделювання складної системи «оточуючий грунт – підпірна стінка – паля». На основі результатів лоткових випробувань були проаналізовані деформації та основні параметри їх напружено-деформованого стану. Аналіз отриманих результатів показав, що конструкція підпірної стіни з палями є стійкою та міцною. **Наукова новизна.** До цього часу в Україні не було проведено аналогічних експериментальних лоткових випробувань із моделями підпірних стін у таких комбінаціях. В статті приведені унікальні фотографії та результати випробувань, а також їх аналіз. **Практична значимість.** Використання методики проведення експериментальних лоткових випробувань моделей підпірних стін із

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палями і без них дає більш широку можливість дослідження напружено-деформованого стану таких конструкцій.

Ключові слова: підпірна стінка; пальовий фундамент; лоткові випробування; грунтовий масив; стійкість та міцність конструкції; порівняльний аналіз варіантів

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ПРОВЕДЕНИЕ И АНАЛИЗ РЕЗУЛЬТАТОВ ЭКСПЕРИМЕНТАЛЬНОГО ЛОТКОВОГО ИСПЫТАНИЯ МОДЕЛЕЙ ПОДПОРНОЙ СТЕНЫ БЕЗ СВАЙ И НА СВАЙНОМ ФУНДАМЕНТЕ

Цель. Принимая во внимание, что несущая способность фундамента может быть недостаточной, в научной работе предполагается, что свайный фундамент может быть использован для снижения влияния строительства новых подпорных сооружений на автомобильных и железнодорожных дорогах, возле существующих строений или в местах плотной городской застройки, и гарантировать стабильность фундамента. Для снижения объемов земляных работ нужно выбрать экономичную конструкцию подпорной стенки. Для этого необходимо исследовать напряженно-деформированное состояние (НДС) подпорных стен, разработать методы повышения их прочности и устойчивости, а также выбрать наиболее целесообразный метод их анализа. **Методика.** При проектировании подпорных стенок ростверк и сваи считаются независимыми элементами. Поскольку совместное действие подпорной стенки, свай, ростверка, а также влияние почвы или скального основания на сооружение учитываются не в полной мере, то есть некоторые ограничения в существующих методах их проектирования. Для достижения цели были проведены лотковые испытания моделей подпорных стен без свай и со сваями с целью изучения их взаимодействия с окружающим массивом грунта. **Результаты.** Учеными было выполнено лабораторное моделирование сложной системы «окружающий грунт – подпорная стенка – свая». На основании результатов лотковых испытаний были проанализированы деформации и основные параметры их напряженно-деформированного состояния. Анализ полученных результатов показал, что конструкция подпорной стены со сваями является устойчивой и прочной. **Научная новизна.** До сих пор в Украине не было проведено аналогичных экспериментальных лотковых испытаний с моделями подпорных стен в таких комбинациях. В статье приведены уникальные фотографии и результаты испытаний, а также их анализ. **Практическая значимость.** Использование методики проведения экспериментальных лотковых испытаний моделей подпорных стен со сваями и без них дает более широкую возможность исследования напряженно-деформированного состояния таких конструкций.

Ключевые слова: подпорная стенка; свайный фундамент; лотковые испытания; грунтовый массив; устойчивость и прочность конструкции; сравнительный анализ вариантов

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