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THE RESULTS OF MODELING AND FIELD STUDIES OF THE INTERACTION OF LARGE PILES WITH GROUND SUBSIDENCE

Abstract. The problems of modern geotechnical construction in the region of southern Kazakhstan are considered in this article. Engineering geological conditions in most of the territory are represented by ground subsidence. In conditions of tight urban and industrial buildings, as well as when it is necessary to transfer significant loads from high-rise buildings to the basement, the use of pile foundations is the only solution.

The aim of the work is to study the interaction of pile foundations with ground subsidence.

The article describes the principles of modelling the joint work of a long-bored pile with ground subsidence. The use of tensometry tools for studying the physical processes occurring on the contact surface between the pile and the soil is considered. The basis for obtaining information on the development of negative friction forces has been developed using model tests to pull piles out of the ground.

The results of tests of model piles and piles in full-scale conditions are presented. The tests were carried out on the action of a vertical pressing load, as well as on a pulling load. Experimental studies on models were carried out by the method of equivalent materials. The soil model was a mixture of sand, rubber chips and autoclave in a proportion by weight of 2: 0.1: 0.2. Strength and deformation properties of the soil model were determined by the degree of compaction. For comparison, the results of studying the work of field piles, obtained by the Association "Seismic Protection" are taken. Tests of piles were carried out during the construction of the METRO shopping complex in Shymkent. Due to the application of the modelling theory, the qualitative convergence of model and full-scale tests is achieved, including the receipt of "sediment-load" test schedules for models of piles and field piles.

The obtained experimental studies will make it possible to successfully use pile foundations in ground subsidence in the future. This will ensure the reliability of erected buildings and structures.

Modelling of joint work of long bored pile with ground subsidence allows us to make informed decisions on a wide range of tasks in production situations. Due to the observance of the postulates of the theory of modelling, the qualitative convergence of model and corresponding full-scale tests has been achieved in the studies carried out. Sufficient qualitative convergence of the "load-sediment" schedules of model and full-scale tests of piles has been achieved. The use of tensometry tools made it possible to detail the study of physical processes occurring on the contact surface between the pile and the ground.

Keywords: pile, pile model, tensometry pile, ground subsidence, "load-sediment" schedule, negative friction force.

Introduction. Summing up the experience of many years of base preparation and foundation construction in south region of Kazakhstan and analysing the current modern geotechnical situation it should be noted that the local geological conditions are very complex and specific. They are characterized by the proliferation of sharp inhomogeneous soils, in most of the territory - subsidence, the properties of which are heavily influenced by underground water, the level of which is constantly changing upwards and the seismicity of the region. In addition, current construction conditions characterized by crowded urban and industrial developments need a huge stress on the base of high-rise construction and need to use areas with problematic soil conditions [1-3]. The underestimation of even one of these factors or a flippant attitude to base preparation and foundation construction can lead to unacceptable deformation of buildings and structures, elimination of it at the stage of construction of the object, or after the completion is almost impossible. If it is necessary to restore the deformed emergency buildings or structures, the cost is very high.

With the implementation of mega projects in major cities around the world, through the use of advanced high-precision technology, it was possible to solve many problems of geotechnical construction, similar to the above. One of these methods is an arrangement of deep-laid foundations. As noted by leading domestic and foreign scientists, only the use of pile foundations make possible the perception of carrying loads of soil layer of about 4,000 - 25,000 kH of high-rise buildings. This dramatically reduces the volume of work "zero" cycle, for example, compared with the device of artificial bases that during the construction of a number of objects in the region associated with the necessity of excavation volume from passages 100,000 cubic meters of soil and delivery and seal of gravel-sand mixture of approximately equal to half of this amount.

Among the existing methods pile foundation construction device is fundamentally different in the nature of the load transfer on the ground [4, 5]. Therefore, in some cases, for example, for the rapid construction of foundations in the ground subsiding, they are regarded as the only possible option. However, even if the pile "cut" filler primer, cannot be guaranteed their full operational reliability [6, 7]. This is due to the fact that the side surface impact strength piles "negative" or biasing the friction [8-10], that can be so large that the load capacity decreases drastically and piles can be minimized. This complex, ambiguous process is poorly understood and requires both experimental research and analytical studies.

In this paper an attempt is made on the basis of pilot studies to identify the actual physical processes occurring in the soil, to make comparisons test piles on models and in natural conditions. This will later be successfully used in pile foundations subsiding soils, ensuring the reliability of constructed ground building constructions.

Methods of research. At the first stage the experimental studies carried out on models by equivalent materials [11-16]. Fundamentals of the method of equivalent materials were developed by G.N. Kuznetsov and et al. [13], and modelling systems "pile foundation-ground" with this method was developed in [14] and is as follows:

- from some artificially selected materials in compliance with the geometric similarity model and the nature of the soil and made a model of the pile;
- materials of which must be made the model chosen with such physical and mechanical properties, which would be in certain ratios with mechanical and physical constants of nature;
- these relations are based on the general law of dynamic similarity considering the simultaneous action of the forces of gravity and internal pressure;
- material that meets the above requirements, given the properties of the simulated soil and given a linear scale model, gets the name of the equivalent to this ground material;
- model of the foundation must also satisfy the requirements of the equivalent mechanical similarity of nature;
- in compliance with the requirements described, as well as the necessary initial and boundary conditions, the processes occurring in the model should be developed in a form close to nature. Just as in nature, the development of these processes will take place taking into account the influence of gravity of the model itself without any external additional loading. "

The general law of Newton's dynamic similarity is the basis of the method [15]

$$\frac{N_M}{\gamma_M i} = \frac{N_H}{\gamma_H J} = K = in\upsilon, \tag{1}$$

where K is "determining criterion of similarity" processes of deformation and destruction of the soil under the action of gravity and the stresses in the ground; $\gamma_M ; \gamma_H$ are specific gravity of modelling and full-scale soil; $i; J$ are linear dimensions of model piles and full-scale piles; $N_M ; N_H$ are value corresponding to different power characteristics of the model and nature state, dimension of which is force/area.

Equation (1) reduces to the form (2), in which selects mechanical properties of equivalent materials

$$N_M = \frac{i}{J} \cdot \frac{\gamma_M}{\gamma_H} \cdot N_H . \tag{2}$$

To do this, knowing the characteristics of the simulated rock expressed by some numerical parameters N_H, set the scale simulation $\frac{i}{j}$ and attitude $\frac{\gamma_M}{\gamma_H}$, with the equivalent materials in the elastic stage, the following dependencies must be followed

$$E_M = \frac{i}{j} \cdot \frac{\gamma_M}{\gamma_H} \cdot E_H ; \tag{3}$$

$$C_M = \frac{i}{J} \cdot \frac{\gamma_M}{\gamma_H} \cdot C_H ; \tag{4}$$

$$\mu_M = \mu_H ; \tag{5}$$

$$\varphi_M = \varphi_H . \tag{6}$$

To carry out comprehensive studies of the interaction of piles and soil of the array, the selected scale simulation of 1/40, using the formulas 3-6, the calculated values of deformation and strength characteristics of the model piles and soil were obtained. Model soil was a mixture of sand, rubber crumb and avtol in a proportion by weight of 2:0.1:0.2, strength and deformation properties of which are determined by the degree of compaction. Table 1 summarizes the characteristics of the equivalent mixture with a density adopted in the experiments placing it in the tray, and the appropriate nature of soil.

Features of equivalent mixture

Feature name	Symbol	Measure	Model grounds	Nature grounds
Deformation module	E	МПа	1.628-2.035	40.7
Specific adhesion	c	МПа	0.000575	0.0115
Angle of internal friction	φ	°	29	29

For a system of "pile foundation-soil" according to the formula (7) was calculated modulus of elasticity of the pile material model $E_{M.CB.} = 1500 МПа$. The tubes used for simulation of reinforced concrete piles were made of vinyl plastic with the elasticity module of $E_B = 1450 МПа$.

$$E_{M.CB.} = E_{M.ГР.} \frac{E_{H.CB.}}{E_{H.ГР.}}, \tag{7}$$

Results of the study. In this procedure, the work of piles was studied on the action of a vertical load pressed and the dependence of "sediment-load". Piles model was loaded increasingly pressed load steps ΔP = 20 H. At each step, after stabilization, rainfall was measured. General view of the test tray is shown in Figure 1.

Figure 3 shows a similar dependence obtained by 'Seism protection' Association [16] during the test piles great lengths to ground subsidence during the construction of the shopping centre "Metro" in Shymkent. Comparing the graphics test piles *S=f(P)* model piles (Figure 2), made with all the parameters as geometric dimensions, soil conditions, the nature of the load and etc. real-pile foundation, with these static tests on the construction site (Figure 3), we can say that they have the same character. Both comparable graphics have smooth character, without any fracture points expressions (breakdown). In the initial stages of loading the model and the actual pile had not any movement. The model received the first movement with a load of 20 H, a full-scale pile at P=1705 kH. This is primarily due to the significant dimensions of the full-scale pile: a length of 23 m and 1 m in diameter that allows the perception of large loads. Then, as the loading steps, the model and full-scale pile gently pressed into the soil, reaching move of 1 mm at 100 H and 2.94 mm at 3751 kH respectively.

Figure 1 – General view of the static tests of model pile vertical load pressure.

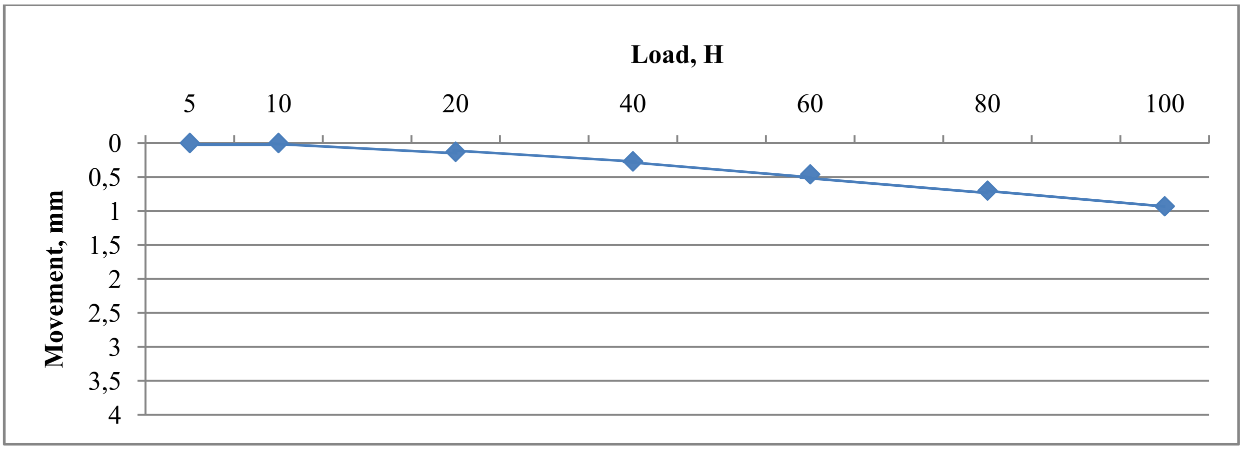

Figure 2 – Graph of S = f (P) relation in the test of model pile vertical load pressure

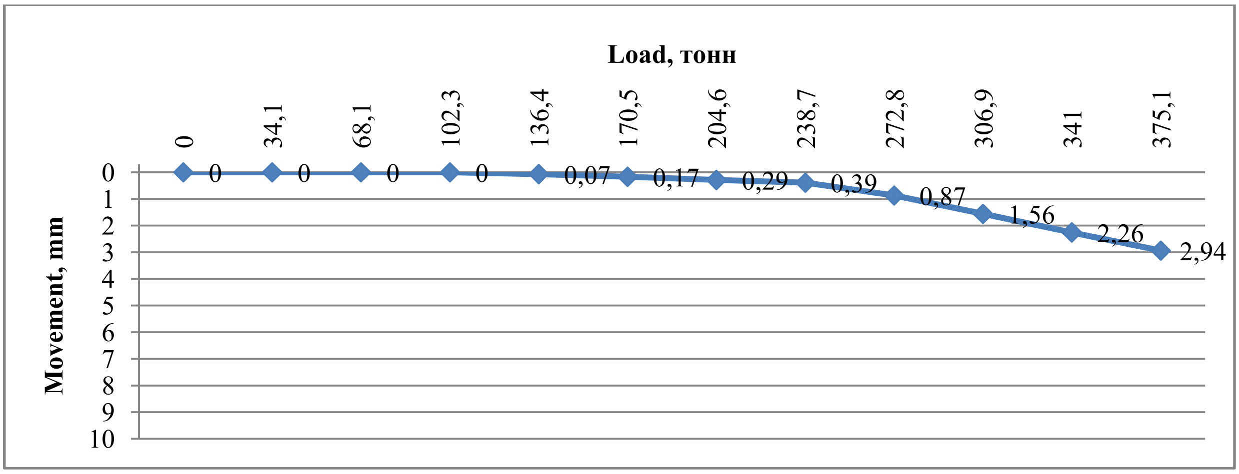

Figure 3 – Graph of S = f (P) relation in the test of full-scale pile vertical load pressure

As 'Seism protection' Association [16] indicates, further loading of full-scale pile pressed load was discontinued from the condition of the bearing capacity of the anchor installation. This achieved, when tested in a load-bearing capacity of as 'Seism protection' Association [16] indicates, further loading of full-scale pile pressed load was discontinued from the condition of the bearing capacity of the anchor installation. This achieved, when tested in a load-bearing capacity of 3751 kH, exceeds the force provided by the project (2727 kH). The model tests were also achieved the vertical force, comparable to a force at which stopped the test in real conditions.

Given the fact that the base in the case of construction are subsiding loess soils in the study paid attention to studying the possible development of the forces of "negative" friction. To this end, in accordance with applicable regulations of [17 - 20], in the second phase were carried out tests on the pile pulling (Figure 4).

Figure 4 – General view of the model strain gauge static test pile pull out

Similarly to full-scale tests carried out modelling studies in compliance with the relevant parameters of real foundation structures. The results of model experiments are shown in Figure 5, full-scale in Figure 6. The comparison of the graphs show that the curves as in the case of the test on the pinch load is

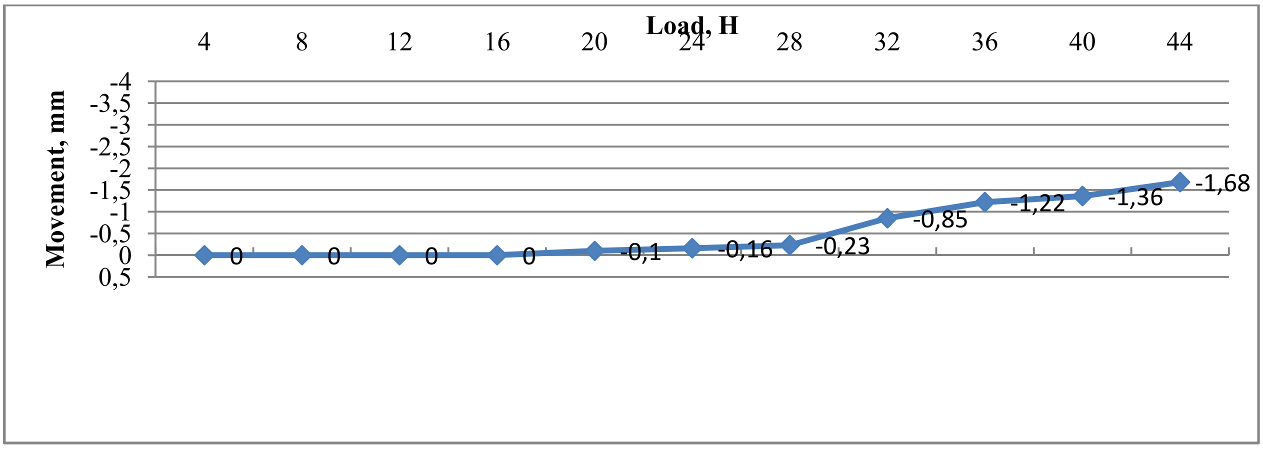

Figure 5 – Graph of S = f (P) relation in the test of model pile on pulling load pressure

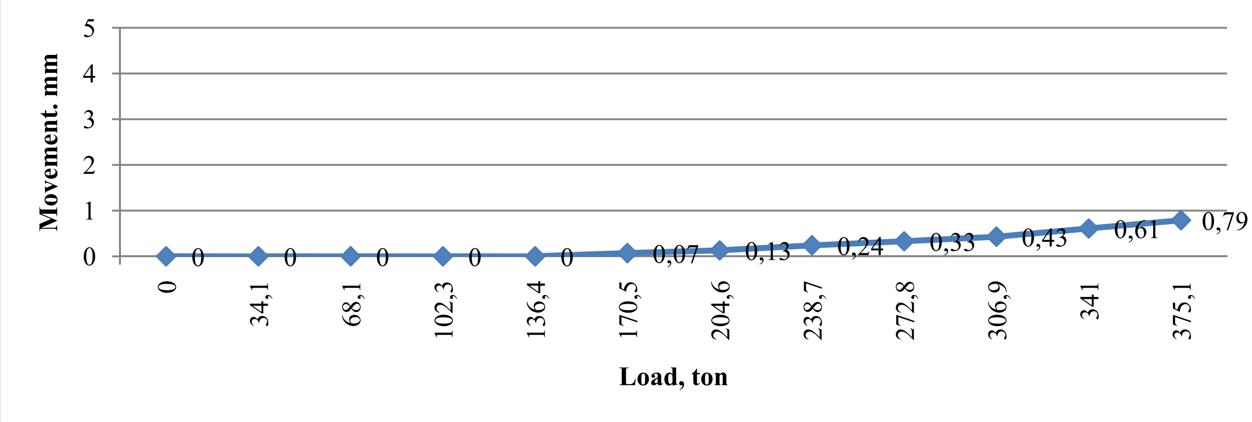

Figure 6 – Graph of S = f (P) relation in the test of full-scale pile on pulling load pressure

approximately the same. In Figures 5 and 6, there are areas with "zero" displacement values. That is the load pulls are applied and there is no movement. This section of graphs can be interpreted as a lack of effort to vertically pulling out of the pile. In other words, this section of the graph there is not enough force to overcome the friction forces between the side surface of the pile and the ground. For model pile vertical force of 20 H was sufficient to start pulling it.

Pulling an experimental full-scale pile as shown in Figure 6 started at 1705-1875.5 kH. Further, by increasing the pull out loads, there is capacity vertical upward movement

In the case of field tests these movements are smoother than in the case of model piles. Note that the graphic is visually distinguished in this range but the absolute value of the difference is less than 1 millimetre. This is due to the different scale of charting. In the experimental test piles in natural conditions found that the resulting pull out load in 1875 kH when it moved 0.79 mm, satisfies design requirements of 1620 kH.

For a detailed study of the interaction of the pile to the surrounding soil models were fitted with strain gauges. Indications of gages allow tracing the features of the contact with the ground in piles four levels along the length of the pile shaft (in places strain gauge installation).

The results of the trough test can state that the strain gauges (installed in pairs on different sides of the pile) consistently responded to the emerging body of model piles in force. Gages indications on compressive strain had the "minus" sign and on stretching "plus".

With increasing load on the pile is pressed into the head, respectively, increased its sediment and body piles developed compressive stress, which is reflected in the readings of strain gauges. The appearance of the compressive stress occurred as a result of soil resistance on the tip and lateral surface of the pile. Thus, evidence of strain gauges is used to characterize the collaborative model tensor pile with the surrounding soil.

The load on the pile readings of strain gages, taking into account the reduction of negative values, increased at all levels investigated in depth. The exception to the general picture is the testimony to the first loading stage at P = 20 H, where contrary to the general logic with minimum load obtained the highest readings. It was not found any other explanation, as a failure in the testimony of strain gages themselves on the verge of the threshold sensitivity.

Evaluating work on levels of sensor location, it can be seen that the largest value in all stages of loading piles showing upper sensor and this is due to the proximity of load, which is attached to the head, the greater the stress concentration in the upper portion of the pile body. As the depth of the considered area, tension in the body of the pile is reduced and fixed the 2nd and 3rd sensor on top, whose evidence at different stages of loading were approximately equal. Reducing stress in the pile, the depth, probably due to the increasing entry into the work of the soil surrounding the pile, which is because of friction forces with the depth of the body relieves piles. Consequently, these can be indirectly sensor readings interpreted as an increase of friction forces on the lateral surface to the depth.

Lower probe testified less than the top but more than two medium-depth probes. This is due, in our view, again with increasing stress concentration at the lower portion of the pile but this time associated with the presence of dense soil, which was loaded in the lower part of the pile pattern, as in the case of real pile.

In general, assessing the overall picture of the work of the model piles, equipped with strain gauges, in cooperation with the base it can be stated that the transfer of the load on the pile, the work enters the side surface and the tip. Moreover, soil resistance force on the lateral surface, which can be described as the specific friction force, increases with depth.

The lower part of the pile, near the plane of the bearing, is affected by the supporting reaction dense soil layers that affect the lateral surface of the bottom of the pile. The sensor mounted on the 4d (where d - diameter piles) from the bottom of the pile has shown that the impact of the work keenly felt at this distance.

In accordance with the applicable rules, during the construction on loess soils type II subsidence, it is necessary to pull out of the pile load test. These tests were carried out in field conditions, and we are duplicated models. From the testimony of the strain gauges can be seen that when a load pulls the head of the pile they are not all at the same time entered into operation: the first stages of booting up from 4 H to 12 H gauges all showed zero. Then, with a load of 12 H to 24 H work involved in almost simultaneously sensors mounted on the lower three layers. And only in the last instance the upper sensor at 28 H. This character model pile of work when pulling can be explained by the degree of "pinching" piles in the ground that was more on the middle and lower levels. In these areas, piles of body experience more load, which is reflected in the testimony of strain gages. Upper sensor later others joined in the work, as in the upper layer "pinched" the pile of soil was minimal. Further, with increasing efforts pulls in the range 28 to 36-40 H sensor readings uniformly increased, reflecting the increase of friction forces on the lateral surface. Then, the moment reduction of strain gages readings in the range of 40-44 H in which began to pull out the slip model with respect to the surrounding soil.

As these studies have established with efforts 46-48 H come "breakdown" of the pile, that is, without a further increase in load, began to pile vertically extracted from the ground. It should be noted that throughout the period of the test, except for the last two stages of 40-44 H, the testimony of two medium-sensor installation depth is greatest. On the steps of 40-44 H, when the "slippage" of the pile started, set a definite pattern in the testimony. The largest observed reading at the top of the sensor and with increasing depth of the sensor installation its readings in this range of loadings are reduced. This, in our opinion, due to the entry into force of gravity itself piles. That is, at the moment when the pile start to slip, and then free to be pulled out of the ground to the sensors began to affect the weight of the pile. We can say that at the level of the top of the sensor affects the weight of the pile located below it. Consequently, each sensor located below the weight acting increasingly short pile portion, and hence the voltage in the lower sections was less.

Conclusions. Analysis of the results experimentally obtained from models and their comparison with the data of full-scale tests brings to the following conclusions:

- collaboration modelling bored piles of great length with collapsible loess, carried out by the method of equivalent materials allows to make informed decisions on a range of tasks and production of geotechnical problematic situation;
- by adhering to the tenets of the theory of modelling in conducted studies the qualitative convergence of model and the relevant full-scale tests was achieved;
- sufficient convergence of high-quality produce for the most important geotechnical charts "load - sediment" model and full-scale tests of piles was achieved, which holds great promise for further research;
- use of tensometry means has allowed detail study of the physical processes occurring at the contact surface between the pile and the ground;
- model tests on the pull-out of the pile of soil laid the foundations of information about the development of the negative forces of friction, taking into account local characteristics of soil basements.

In accordance with the chosen methodology and research on the basis of these findings, this work continues and is aimed at testing the model tensor pile in soils of different density and resistance to structural changes on the lateral surface. In addition, the situation will be examined when the pile affects settling layer of soil, located on the top, and when the edge of the pile under the soil loses its bearing capacity as a result of soaking the bottom.

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ҮЛКЕН ҰЗЫНДЫҚТАҒЫ ҚАДАНЫҢ КӨП ШӨГЕТІН ГРУНТПЕН ӨЗАРА ӘРЕКЕТІН, ҮЛГІ ЖӘНЕ ДАЛАЛЫҚ ЖАҒДАЙДАҒЫ ЗЕРТТЕУЛЕРДІҢ НӘТИЖЕСІ

Аннотация. Мақалада Оңтүстік Қазақстан регионындағы қазіргі геотехникалық құрылыс мәселелері қарастырылған. Көп шөгетін сарғыш грунттар инженерлік-геологиялық тұрғыдан қарағанда үлкен аймақты қамтиды. Қысылған қалалық және өнеркәсіптік құрылыс жағдайларында негізгі едәуір салмақ беретін биік ғимараттар құрылысында қадалы іргетасты қолдану бірден-бір мәселе болып табылады. Жұмыстың мақсаты қадалы іргетастың көп шөгетін сарғыш грунттың өзара әрекетін үйрену. Мақалада үлкен ұзындықтағы бұрғылап тойтарылған қаданың көп шөгетін сарғыш грунтпен бірге жұмыс істеуін үлгілеу принциптері (көзқарастары) берілген. Мұнда тензометриялық жүйелердің қолдануында қаданың грунтпен жанасу нүктелеріндегі физикалық процестері қарастырылған. Бұл мақалада жағымсыз үйкелістің дамуы туралы мәліметтер үлгі қаданы жұлуға сынау арқылы қарастырылған. Мақалада қаданың далалық және зертханалық жағдайдағы сынақ нәтижелері келтірілген. Сынақ қадаға вертикал және жұлу жүктемелер берілу арқылы жүргізіледі. Эксперименталдық сынақтар эквивалентті үлгі материалдармен жүргізіледі. Грунт үлгісі ретінде құм майдаланған резинаны автолмен 2:0,1:0,2 қатынасында дайындалған қоспа пайдаланылады. Қоспаның деформативтік және беріктік қасиеттері тығыздалу дәрежесімен анықталады. Салыстыру күшін «Сейсмо-защита» ассоциациасы алған дала жағдайында сығылған қаданың нәтижесімен тексерілген. Қаданы сынау Шымкент қаласында «Метро» сауда комплексі құрылысында жүргізілді. Үлгілеу теориясын қолдану арқылы далалық және зертханалық жағдайда өткізілген сынақ нәтижелерінің бір-бірімен жақындығына қол жеткізілді. Алынған эксперименталды зерттеулер қадалы іргетастарды көп шөгетін сарғыш грунттарды ойдағыдай қолдануға болатынын көрсетеді. Құрылған ғимараттардың қауіпсіздігі сенімді. Үлкен ұзындықтағы бұрғылап тойтарылған қадамен көп шөгетін грунтпен біргеліктегі жұмысын үлгілеу құрылыстың көп мәселелерін негізделген шешімдер қабылдауға мүмкіндік береді. Үлгілеу теориясын қолдану арқылы далалық және зертханалық жағдайында сынақ нәтижелерінің бір-бірімен жақындығы негізделген. Экспериментте тензометриялық қолдану грунтпен қаданың жанасу жерлерінде болатын физикалық процесстерді үйлестіру мүмкіндігін көрсетеді.

Түйін сөздер: қада, қада үлгісі, тензометриялық қада, көп шөгетін сарғыш грунт, шөгу мен жүктеме арасындағы тәуелділік, жағымсыз үйкеліс күші.

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РЕЗУЛЬТАТЫ МОДЕЛЬНЫХ И НАТУРНЫХ ИССЛЕДОВАНИЙ ВЗАИМОДЕЙСТВИЯ КРУПНОГАБАРИТНЫХ СВАЙ С ПРОСАДОЧНЫМ ОСНОВАНИЕМ

Аннотация. В статье рассмотрены проблемы современного геотехнического строительства в регионе южного Казахстана. Инженерно-геологические условия на большей части территории представлены просадочными лессовыми грунтами. В условиях стесненных городских и промышленных застроек, а также при необходимости передачи значительных нагрузок от высотных зданий на основание применение свайных фундаментов является единственным решением. Цель работы заключается в изучении взаимодействия свайных фундаментов с просадочным лессовым грунтом. В статье описаны принципы моделирования совместной работы буронабивной сваи большой длины с просадочным лессовым грунтом. Рассмотрено применение средств тензометрии для изучения физических процессов, происходящих на контактной поверхности между сваей и грунтом. Разработаны основы получения информации о развитии сил негативного трения с помощью модельных испытаний на выдергивание сваи из грунта. Приводятся результаты испытаний модельных свай и свай в натурных условиях. Испытания проводились на действие вертикальной вдавливающей нагрузки, а также на выдергивающую нагрузку. Экспериментальные исследования на моделях осуществлялись методом эквивалентных материалов. Моделью грунта служила смесь из песка, резиновой крошки и автола в пропорции по весу 2:0,1:0,2. Прочностные и деформационные свойства модели грунта определялись степенью уплотнения. Для сравнения взяты результаты изучения работы натурных свай, полученные Ассоциацией «Сейсмозащита». Испытания свай проводились при строительстве торгового комплекса «МЕТРО» в г. Шымкент. За счет применения теории моделирования достигнута качественная сходимость модельных и натурных испытаний, в том числе при получении графиков испытаний «осадка-нагрузка» для моделей свай и натурных свай. Полученные экспериментальные исследования позволят в дальнейшем успешно применять свайные фундаменты в просадочных грунтах. Это обеспечит надежность возводимых зданий и сооружений. Моделирование совместной работы буронабивной сваи большой длины с просадочным лессовым грунтом позволяет принимать обоснованные решения по широкому кругу задач в производственных ситуациях. За счет соблюдения постулатов теории моделирования в проведенных исследованиях достигнута качественная сходимость модельных и соответствующих натурных испытаний. Достигнута достаточная качественная сходимость графиков «нагрузка – осадка» модельных и натурных испытаний свай. Применение средств тензометрии позволило детализировать изучение физических процессов, происходящих на контактной поверхности между сваей и грунтом.

Ключевые слова: свая, модель сваи, тензометрическая свая, лессовый грунт, график «осадка-нагрузка», силы негативного трения.

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