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ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ
«ХАЛЫҚ» ЖҚ

ХАБАРЛАРЫ

ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ
АКАДЕМИИ НАУК РЕСПУБЛИКИ
КАЗАХСТАН»
ЧФ «Халық»

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NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

ЧФ «ХАЛЫҚ»

В 2016 году для развития и улучшения качества жизни казахстанцев был создан частный Благотворительный фонд «Халык». За годы своей деятельности на реализацию благотворительных проектов в областях образования и науки, социальной защиты, культуры, здравоохранения и спорта, Фонд выделил более 45 миллиардов тенге.

Особое внимание Благотворительный фонд «Халык» уделяет образовательным программам, считая это направление одним из ключевых в своей деятельности. Оказывая поддержку отечественному образованию, Фонд вносит свой посильный вклад в развитие качественного образования в Казахстане. Тем самым способствуя росту числа людей, способных менять жизнь в стране к лучшему – профессионалов в различных сферах, потенциальных лидеров и «великих умов». Одной из значимых инициатив фонда «Халык» в образовательной сфере стал проект Ozgeris powered by Halyk Fund – первый в стране бизнес-инкубатор для учащихся 9-11 классов, который помогает развивать необходимые в современном мире предпринимательские навыки. Так, на содействие малому бизнесу школьников было выделено более 200 грантов. Для поддержки талантливых и мотивированных детей Фонд неоднократно выделял гранты на обучение в Международной школе «Мирас» и в Astana IT University, а также помог казахстанским школьникам принять участие в престижном конкурсе «USTEM Robotics» в США. Авторские работы в рамках проекта «Тәлімгер», которому Фонд оказал поддержку, легли в основу учебной программы, учебников и учебно-методических книг по предмету «Основы предпринимательства и бизнеса», преподаваемого в 10-11 классах казахстанских школ и колледжей.

Помимо помощи школьникам, учащимся колледжей и студентам Фонд считает важным внести свой вклад в повышение квалификации педагогов, совершенствование их знаний и навыков, поскольку именно они являются проводниками знаний будущих поколений казахстанцев. При поддержке Фонда «Халык» в южной столице был организован ежегодный городской конкурс педагогов «Almaty Digital Ustaz.

Важной инициативой стал реализуемый проект по обучению основам финансовой грамотности преподавателей из восьми областей Казахстана, что должно оказать существенное влияние на воспитание финансовой грамотности и предпринимательского мышления у нового поколения граждан страны.

Необходимую помощь Фонд «Халык» оказывает и тем, кто особенно остро в ней нуждается. В рамках социальной защиты населения активно проводится работа по поддержке детей, оставшихся без родителей, детей и взрослых из социально уязвимых слоев населения, людей с ограниченными возможностями, а также обеспечению нуждающихся социальным жильем, строительству социально важных объектов, таких как детские сады, детские площадки и физкультурно-оздоровительные комплексы.

В копилку добрых дел Фонда «Халык» можно добавить оказание помощи детскому спорту, куда относится поддержка в развитии детского футбола и карате в нашей стране. Жизненно важную помощь Благотворительный фонд «Халык» оказал нашим соотечественникам во время недавней пандемии COVID-19. Тогда, в разгар тяжелой борьбы с коронавирусной инфекцией Фонд выделил свыше 11 миллиардов тенге на приобретение необходимого медицинского оборудования и дорогостоящих медицинских препаратов, автомобилей скорой медицинской помощи и средств защиты, адресную материальную помощь социально уязвимым слоям населения и денежные выплаты медицинским работникам.

В 2023 году наряду с другими проектами, нацеленными на повышение благосостояния казахстанских граждан Фонд решил уделить особое внимание науке, поскольку она является частью общественной культуры, а уровень ее развития определяет уровень развития государства.

Поддержка Фондом выпуска журналов Национальной Академии наук Республики Казахстан, которые входят в международные фонды Scopus и Wos и в которых публикуются статьи отечественных ученых, докторантов и магистрантов, а также научных сотрудников высших учебных заведений и научно-исследовательских институтов нашей страны является не менее значимым вкладом Фонда в развитие казахстанского общества.

С уважением,
Благотворительный Фонд «Халык»!

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NUMERICAL MODELLING MICRO PILES AND EVALUATION OF THE O-CELL TEST RESULTS

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Abstract. The paper describes the results of a numerical simulation of micro-pile tests using the PLAXIS 2D software. The application of the Osterberg method (O-Cell) in axial pile load testing nowadays found widespread use due to the increase of the construction of high-rise buildings. The O-cell method is a sacrificial hydraulic jack (O-Cell) typically installed within the lower or the middle part of an instrumented pile to measure skin friction and bearing resistance. These two cases are described in detail in terms of geological conditions, pile configuration, and the testing procedure. In this study, an asymmetric finite element numerical model (FEM) was used to simulate and analyze the pile-soil interaction problem of a bi-directional pile load test using PLAXIS 2D. The staged loading of the pile in the program was simulated by increasing the bi-directional load on the pile by 1450 kN, at a maximum load of 14500 kN. In this study, an asymmetric FEM model was used to simulate and analyze the pile-soil interaction problem of the O-cell method of a pile load test using PLAXIS 2D. This geotechnical investigation is important for understanding the soil-pile interaction on difficult and problematical soil ground conditions.

Keywords: Micro pile, O-Cell, Plaxis 2D, FEM, BDSLT

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МИКРО ҚАДАЛАРДЫ САНДЫҚ МОДЕЛЬДЕУ ЖӘНЕ O-CELL СЫНАҚ НӘТИЖЕЛЕРІН БАҒАЛАУ

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Аннотация. Мақалада PLAXIS 2D бағдарламалық құралын пайдалану арқылы микро қада сынақтарының сандық модельдеу нәтижелері сипатталған. Остерберг әдісін (O-Cell) осьтік қада жүктемесін сынауда қолдану қазіргі уақытта көпқабатты үйлердің құрылысының өсуіне байланысты кең тараған. O-cell әдісі - әдетте терінің үйкелісін және мойынтіректердің кедергісін өлшеу үшін аспаптық қаданың төменгі немесе ортаңғы бөлігінде орнатылатын гидравликалық домкрат (O-Cell). Бұл екі жағдаятта геологиялық жағдайы, қада конфигурациясы және сынау тәртібі тұрғысынан егжей-тегжейлі сипатталған. Бұл зерттеуде PLAXIS 2D көмегімен екі бағытты қада жүктемесі сынағының қада мен топырақтың өзара әрекеттесу мәселесін модельдеу және талдау үшін асимметриялық моделі шекті элементтердің әдісі (ШЭӘ) пайдаланылды. Бағдарламада қаданы кезең-кезеңмен жүктеу қададағы екі жақты жүктемені 1450 кН, максималды жүктеме 14500 кН арттыру арқылы модельденді. Бұл зерттеуде PLAXIS 2D көмегімен қада жүктемесін сынаудың О-ұяшық әдісінің қада мен топырақтың өзара әрекеттесу мәселесін имитациялау және талдау үшін асимметриялық ШЭӘ моделі пайдаланылды. Бұл

геотехникалық зерттеу күрделі және проблемалы жағдайындағы топырақ пен қаданың өзара әрекеттесуін түсіну үшін маңызды.

Түйін сөздер: Микроқада, O-Cell, Plaxis 2D, ШЭӘ, BDSLT

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ЧИСЛЕННОЕ МОДЕЛИРОВАНИЕ МИКРОСВАЙ И ОЦЕНКА РЕЗУЛЬТАТОВ МЕТОДОМ O-CELL

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Аннотация. В работе описаны результаты численного моделирования испытаний микросвай с помощью программы PLAXIS 2D. Применение метода Остерберга (O-Cell) при испытании осевой нагрузки сваи в настоящее время получило широкое распространение в связи с увеличением строительства высотных зданий. Метод O-cell представляет собой расходуемый гидравлический домкрат (O-Cell), обычно устанавливаемый в нижней или средней части установленной сваи для измерения поверхностного трения и несущей способности. Эти два случая подробно описаны с точки зрения геологических условий, конфигурации сваи и процедуры испытаний. В этом исследовании использовалась асимметричная численная модель методом конечных элементов (МКЭ) для моделирования и анализа проблемы взаимодействия сваи с грунтом при испытании двунаправленной нагрузки сваи с использованием PLAXIS 2D. Ступенчатое нагружение сваи в программе моделировалось увеличением двунаправленной нагрузки на сваю на 1450 кН, при максимальной нагрузке 14500 кН. В этом исследовании асимметричная модель FEM использовалась для моделирования и анализа проблемы взаимодействия сваи с грунтом методом

О- Cell испытания сваи под нагрузкой с использованием PLAXIS 2D. Это геотехническое исследование важно для понимания взаимодействия грунта и сваи в сложных и проблематичных грунтовых условиях.

Ключевые слова: Микросвай, O-Cell, Plaxis 2D, МКЭ, BDSLT

Introduction

Around three decades ago, a new technology was introduced to solve the problem of testing bored piles at the site, where a hydraulic jack built into the piles was installed to test the piles with a load. This new testing method is called bidirectional pile load testing (Fawad et al., 2013: 1284; Omarov, 2016).

The test continues until the base or pile body reaches the ultimate resistance. This is a disadvantage for the O-cell test because only the lower limit of the total bearing capacity can be determined (Fawad et al., 2013: 6169; Omarov, 2016), the full value is only approximated when both resistances have nearly the same value. Introducing more than one O-cell at different depths alleviates this limitation, allowing the engineer to obtain both final edge support and final shear values in cases where the final edge support is less than lateral shear (Fawad et al., 2013: 1284; Omarov, 2016). Single-level and multi-level O-cell piles are shown in Figure 1.

Since the introduction of bidirectional load testing of piles, there are two types of jacks:

1) The Tomer method was patented in 1978 in Europe (Omarov, 2016; Yu et al., 2013: 2). However, this method is not very popular worldwide.

2) The Osterberg method, the O-Cell method (Osterberg, 1989) was patented in 1989 in the United States (Osterberg, 1989; Osterberg, 1989; ASTM, 2018). Since then it has become popular all over the world.

The Professional O-Cell method adopts jack sealing technology. That gives a more reasonable product value which avoids too wasteful long life of normally sacrificed test jacks. Meanwhile, it offers lower height, a larger loading area, lower oil pressure, and safer loading results.

Technically, O-cell method is conceptually different in design compared to Tomer method with more advantages (Yu et al., 2013). Functionally, both methods are the same, i.e. to conduct Bi-Directional pile test. The Bi-Directional Static Load Test (BDSLT) method is described in ASTM D8169/D8169M-18 (ASTM, 2018).

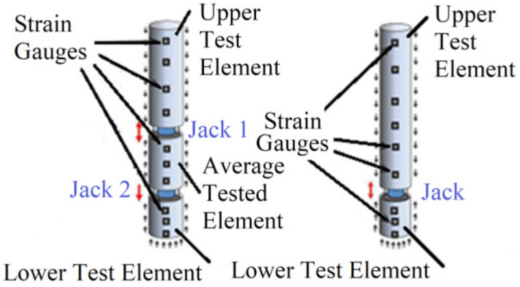

Fig.1. Testing one level of jacks on the right and two levels of jacks on the left

Based on the results (Zhussupbekov et al., 2016: 35; Zhussupbekov et al., 2016: 251) of the evaluation of the bearing capacity of the soils, the dimensions of the tested pile segments must be determined (Zhussupbekov et al., 2016: 88; Zhussupbekov et al., 2016: 27). It must be taken into account that the segments, depending on the test pattern (each individually or several segments together), must work as both a tested and an anchored structure on the top. In this regard, it is particularly important to involve expert organizations with the appropriate experience to design such pile tests. The material of the pile segments as well as the capacity and number of hydraulic jacks must be selected with regard to the ground load capacity (Yu et al., 2013). While designing the tests, it must be taken into account that the design load capacity of the pile segment material must be higher than the maximum expected load capacity of the pile segment in the ground for the test to be successful.

The principle of the O-cell test is that one segment is jacked in, the other is an anchoring structure. No other anchoring structure is required, as in classical static pile testing. Figure 2 a, b and c shows a schematic of a single jack level test (O-cell method):

- The example uses one level of jacks to determine the resistance under the bottom end and the lateral surface friction for the top segment, i.e., the pile to be tested consists of two segments. If the bearing capacity under the bottom end of the pile is low, it is possible to select the length of the bottom segment so that it works together for the bearing capacity under the bottom end of the pile and for the lateral surface (ASTM, 2018; Zhussupbekov et al., 2016: 88; Zhussupbekov et al., 2016: 27). A differentiated determination of the components of the pile bearing capacity: the lateral surface friction and resistance under the bottom end of the pile is made by subsequent analysis of the results (Fawad et al., 2013: 1284; Omarov, 2016). With a certain ratio of lateral surface friction and bottom end bearing capacity, the upper segment can be approximately the length of the pile to be designed (Figure 3);

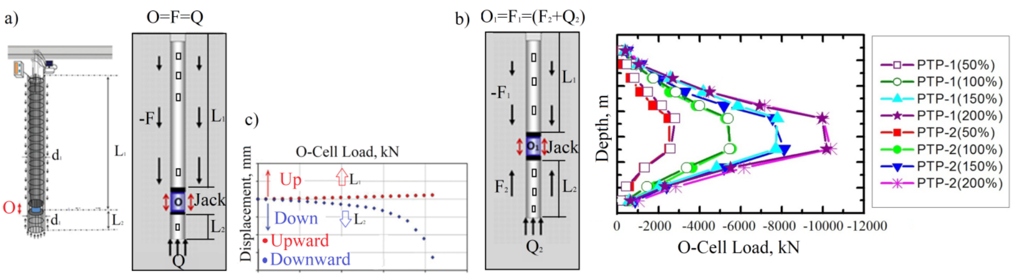

Fig. 2. Schematics of the O-cell method of pile load testing: a) typical gauge mechanisms and loads; b) typical load-transfer distributions (O-cell method); c) typical load-displacement (O-cell method)

- Strain gauges are installed in each of the pile segments along its entire length, which transmit the data to the surface (Zhussupbekov et al., 2016: 35; Zhussupbekov et al., 2016: 251; Zhussupbekov et al., 2016: 27). The computer processing of this data determines the deformation of the concrete, which is accordingly taken into account in the calculation of the bearing capacity of the soils. A strain gauge is installed to monitor the total deformation in the structure of the pile being tested. Displacement meters are also provided at the jacking levels. The data from these instruments are also transmitted to the surface and are subject to computer processing. In this way, it is possible to determine the strain along the entire length of the segment working in lateral surface friction, which provides a differentiated calculation of this parameter depending on the depth of the pile segment (Fawad et al., 2013: 1284; Omarov, 2016).

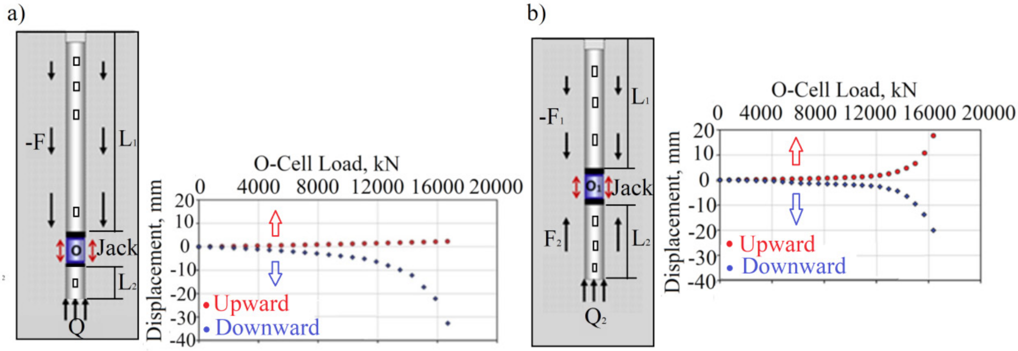

Fig. 3. Diagram of the jack location in the body of the piles: a) O-Cell jack is placed at the bottom; b) O-Cell jack is placed at mid-depth

In this study, an asymmetric FEM model was used to simulate and analyze the pile-soil interaction problem of the O-cell method of a pile load test using PLAXIS 2D. FEM made it possible to preview results as close as possible to those obtained in field tests, while saving time and resources when solving geotechnical problems.

Materials and methods

Two-dimensional simulation of the bored pile is performed in the asymmetric presented view of the problem, in which the pile is located around the axis of symmetry, because in the asymmetric formulation the lateral pressure must be the same, Figure 4.

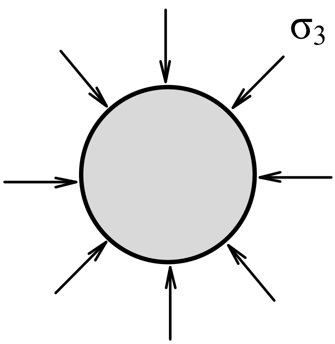

Fig. 4. Distribution of lateral ground pressure on the pile (Pile of circular cross section σ_3= const)

The 15-node finite element mesh was automatically generated by Plaxis 2D program. To obtain a qualitative picture in the areas near the pile, the finite element mesh was crushed. After the element mesh was generated, the initial stress state from the soil's own weight was modeled. All the displacements obtained during the initial stress state modeling phase were zeroed out before the probe plunge began. The calculation was performed using a variable mesh with the Update Mesh option, which implies the use of the so-called Updated Lagrange, when the finite element mesh is constantly updated during the calculation process.

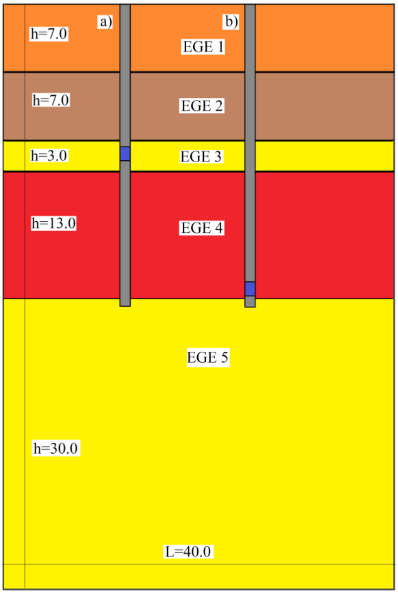

Fig. 5. Geometry and boundary conditions of the asymmetric model

The calculations were performed according to the finite element scheme shown in Figure. 5. Due to the symmetry of the pile foundation cross-section relative to the vertical axis, only half of the soil mass and the pile foundation area were considered in the computational scheme, which were automatically divided into triangular finite elements (Issakulov et al., 2023: 11; Zhussupbekov et al., 2021: 301; Wulandari et al., 2015: 363; Afsharhasani et al., 2020: 6169). The geotechnical characteristics of considered soils are presented in the form of engineering-geological elements (EGE) in Table 1. The sequence of soil layers is given according to Figure 5 which consists of 5 EGEs.

Table 1 - Material properties of soil layers and piles

Parameters	Desig-nation	Concrete Pile model	Clay sand (brown) (EGE-1)	Silted sand (EGE-2)	Clay sand (red) (EGE-3)	Clay sand (EGE-4)	Deep sand (EGE-5)
Material model	-	Linear-elastic	Coulomb-Mora	Coulomb-Mora	Coulomb-Mora	Coulomb-Mora	Coulomb-Mora
Ground behaviour	-	Non-porous	Drained	Drained	Drained	Drained	Drained
Weight in an unsaturated state	γ_{unsat}	24,0	17,00	18,8	19,8	16,7	17,6

Weight in water-saturated state	γ_{sat}	-	19,0	18,8	19,8	16,7	20,0
Young's module	E	30000000	20000	13000	13500	9150	19000
Poisson's ratio	v	0,3	0,33	0,3	0,3	0,3	0,3
Clutch	c	-	8	12	14	13	17
Angle of friction	φ	-	29	23	23	26	23

The geometric dimensions of the pile model with a width of 500 mm and a length of 31 m were used in the calculations (Omarov et al., 2022: 17).

The 31 m long piles were tested through a variety of simulations (Figure 5):

- a) Model 1- the jack installed inside at a depth of ½ of the pile (Figure 5a);

- b) Model 2- the jack is installed inside the pile at a depth of 29 meters (Figure 5b).

The pile bearing capacity was determined based on the results of a numerical simulation of the pile in the PLAXIS 2D software package (Karakouzian et al., 2020: p. 922, Xu et al., 2013: 2223; Jia et al., 2022: 838).

The stress-strain state of the foundation was calculated using the Moore-Coulomb elastic-plastic model. The calculations were performed in an asymmetric formulation.

The stepwise loading of the pile was simulated by increasing the applied load on the pile by 1450 kN, with a maximum load of 14500 kN. The main monitored parameters of the results are the magnitude of the applied load and the pile settlement (Omarov et al., 2022: 17; Sokolova et al., 2014: 10). As a result of the calculation, load-settlement plots of the pile are plotted. Figures 6 and 7 show the geometric models of a numerical simulation of a bored pile, including soil separation within a separately considered engineering geological element, a pile element, and a uniformly distributed load on the pile. The dimensions of the geometric model are taken from the condition that the stress distribution will be negligibly small within a given zone (Sokolova et al., 2014: 195; Lukpanov et al., 2022: 212).

The calculation consists of six phases and will be set in Staged construction mode. Figures 6 and 7 show isolines of total ground motions at static bi-directional for models 1, 2 (Omarov et al., 2022: 17).

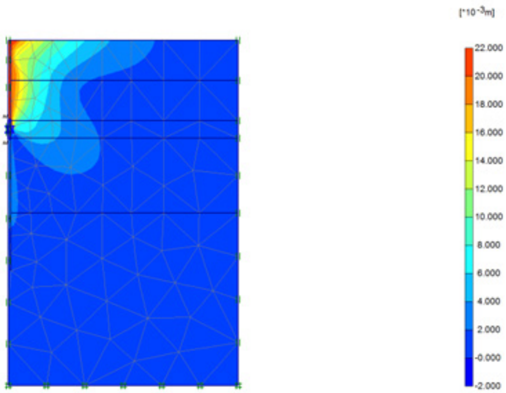

Fig. 6. Full settlement (model 1)

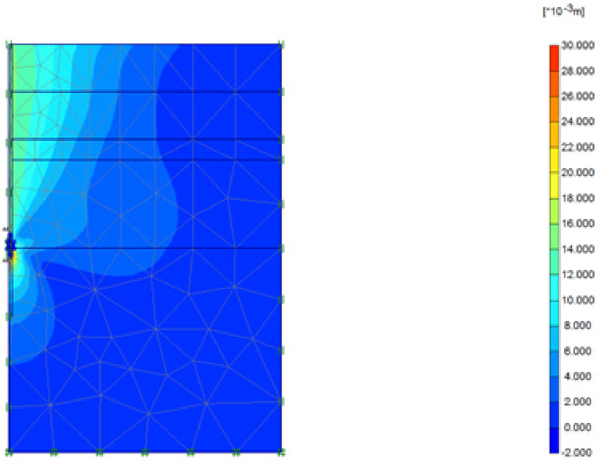

Fig. 7. Full settlement (model 2)

Results and discussions

The bi-directional load-settlement testing relationship of two-segmental composed pile is presented in Figure 8.

The stepwise loading of the pile was simulated by increasing the applied load on the pile by maximum load of 14500 kN.

On the basis of the results shown by numerical modeling the method of preliminary estimation of bearing capacity under the top and bottom end of the pile (Model-1, at vertical maximum load of maximal displacement upward of 22 mm and Model-2, at vertical maximum load of maximal displacement downward of 55 mm) for bearing layers of the ground, is realized by modeling the asymmetric problem in the elastoplastic statement by the method of finite elements was accepted (FEM).

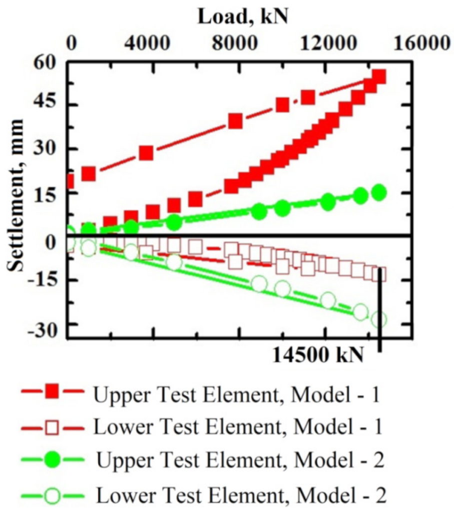

Fig. 8. The upward and downward load movement curves (model 1 and 2)

Figure 9 shows a comparison of the results of the numerical simulation tests: the equivalent "upward-facing load curve" obtained by model-1 and model-2 (Omarov et al., 2022: 17).

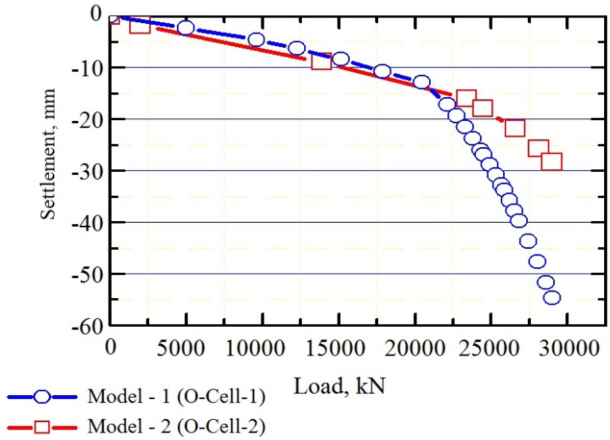

Fig. 9. Equivalent load-cell curve for model 1 and 2

In the O-cell pile tests, the maximum test load of 29,000 kN corresponds to a settlement of 29.00 mm (for the Model-1 pile) and – 55.00 mm (for the Model-2 pile). Both elastic and plastic deformation of the soil was observed in the pile tests (lower test element in Figure 9), due to the higher test load on the pile compared to the Model-2 method.

Overlapping of the curves showed that the convergence of the graphs is observed only at the initial stage of loading, further there is a change in the trajectory of the O-cell curve (model 2, settlement – 55mm), characteristic of the creeping stage of soil resistance.

Based on the results of model 1 testing, it was determined that for a given load it was necessary to increase the depth of the jack in the pile because the top test element had the lowest resistance on the side surface of the pile and as a consequence of the fact that the actual ground bearing capacity of the pile was not determined.

Based on the results of Model 2 testing, it was found that the specified load and jack-in-place depth of the pile meet the ground bearing capacity of the pile. In this model, it is possible to increase the jack load until the pile reaches its full ground bearing capacity.

After two decades of development, Bi-Directional pile tests obtained worldwide acceptance, especially in developed and rich countries such as the United States (USA), Europe (Germany, Netherland, and Spain and. etc), and Dubai and South-East Asian countries. These countries adopt Bi-Directional pile tests because many high-rise buildings and structures are using piles of large diameter and length designs.

Conclusions

The analysis of using of an asymmetrical problem in elastoplastic statement by the method of finite elements (FEM) for investigation of "pile-base" system behavior has shown expediency of using of FEM implemented by "Plaxis 2D" program for O-Cell Method.

On the basis of the results shown by numerical modeling the method of preliminary estimation of bearing capacity under the bottom end of the pile (see Figure 8) for bearing layers of the ground, is realized by modeling the asymmetric problem in the elastoplastic statement by the method of finite elements was accepted (FEM).

When testing a pile with hydraulic jacks and dividing it into segments, special attention should be paid to studying the engineering-geological structure of the soil mass at the investigated site.

In the process of surveys it is especially important to identify possible zones of heterogeneity in the geological structure of soils, such as zones of weathering, alternation of soil layers, etc. These data have to be considered when testing with hydraulic jacks and dividing the pile into segments in order to get an accurate design for the soil layer in question.

When testing soil with piles in order to assess as accurately as possible the lateral surface friction and bearing capacity under the bottom end of the pile, a sound program for studying the bearing layers by means of laboratory and field tests as well as an analysis of existing construction experience in these and similar soil conditions must be made.

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