of its screwed joints for longevity prediction in curvilinear cased well bore.

Methodology. The deformation of oilwell tubings and the normal stresses of the bend, which arise, were determined using integration of differential equation of elastic line with boundary conditions, which depend on well bore survey. A model of longitudinal-transverse bend of beam in plane was chosen as a calculation scheme. In particular, radial and axial components of weight were taken into consideration; force of tension caused by oilwell tubings that are placed below the drill interval under consideration; additional force of tension caused by the column of pumped fluid. Laboratory research of fatigue straight of oilwell tubings screwed joints was conducted too. The experiment was carried out under the regular loading of bend with symmetrical cycle of stresses.

Findings. Basic causes, types and allocation of failures of oilwell tubings elements were distinguished as a result of processing of statistical information about oilwell tubings operation. The method of analysis of oilwell tubings intense-deformed state was developed. This method allows assessing bending stress values and time behavior depending on external loading and geometrical parameters of curvilinear borehole. Two-parameter stress-cycle diagram for oilwell tubings with external diameter 89 mm was drawn.

Originality. The research showed that the oilwell tubings column in curvilinear borehole is affected by statical and dynamical bending moments in addition to the variable axial force. These moments appear due to the additional tension force caused by weight of fluid column, which influences working barrel valve during downward motion of rod hanger. We found out that bending moments could cause fatigue breakdown of oilwell tubings.

Practical value. The developed method can be used for calculation of normal stresses and prediction of oilwell tubings fatigue strength during operation in curvilinear borehole.

Keywords: *oilwell tubing, intense-deformed state, fatigue strength, curvilinear borehole*

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INTERACTION BETWEEN LARGE CROSS-SECTION BORED PILES WITH "HARD CORE" UNDER DYNAMIC LOADS AND SHELF SOILS

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ВЗАЄМОДІЇ БУРОНАБИВНИХ ПАЛЬ ВЕЛИКОГО ПЕРЕРІЗУ З „ЖОРСТКИМ СЕРДЕЧНИКОМ“ ЗА ДИНАМІЧНИХ НАВАНТАЖЕНЬ З ШЕЛЬФОВИМИ ГРУНТАМИ

Purpose. To apply the large cross-section bored piles (diameter from 620 to 1500 mm and over) with "hard core" for the construction of offshore structures so that they interact with shelf soils and perceive dynamic loads.

Methodology. In the laboratory study, the properties of shelf soils were investigated, and bored piles with a diameter of up to 30 to 600 mm were implemented into them. The behavior of piles in shelf soils with impulsive dynamic loads on the vibrators was theoretically generalized.

Findings. The interaction of large cross-section bored piles with "hard core" under dynamic loads with shelf soils was examined. In this case, the dynamic loads were taken from the process equipment and machinery, as well as from sea waves to offshore structures, with large section bored piles with "hard core" that convey dynamic loads to shelf soils. The calculation procedure on dynamic loads action through the piles on the soil and the graphs as for the compression phase and release/rarefaction phase are given. The effective time of the compression wave, the change of pressure in the compression phase, reflection, and depression in soil massif were determined.

Originality. For the first time, large cross-section bored piles with "hard core" were proposed for the construction of offshore structures which enable significant armature cost savings compared to conventional bored piles of the same cross-section. The estimation methods as for interaction of the large cross-section bored piles with "hard core" at static and dynamic loads and the shelf soil foundation were developed.

Practical value. The employment of the developed methods helps evaluate the properties of shelf soils, select the rational structure of pile foundations and their joint work, or the interaction of large cross-section bored piles with "hard core" and shelf soil, that will ensure the sustainability and durability of offshore structures.

Keywords: *wave processes, bored piles with "hard core", compression wave, rarefaction wave, elastic waves, elasto-plastic waves, shelf soils, pressure*

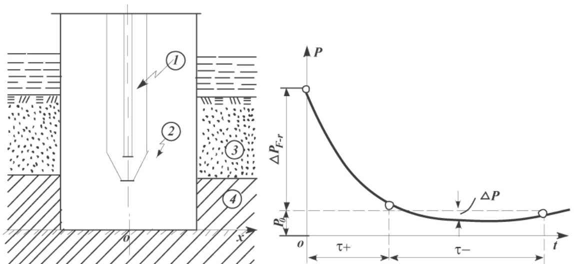
Introduction. The technologies and constructions of pile foundations were described in [1–8], but their application to offshore structures, and moreover, the influence of wave shocks on these constructions and the interaction between a pile and shelf soils are studied insufficiently.

Statement of the research purpose. In many cases, the dynamical loads caused by the action of uncontrollable wave processes result in a breakdown for any offshore structures, and they considerably exceed operational statical loads. Therefore, one can make demands to offshore structures as for their resistance to damage/collapse caused by dynamic loads. In this case, it is possible to assume the development of plastic deformations, to take into account the increase of materials strength characteristics at high-speed deformations, and as a result, the construction by calculation is supposed to provide protection against intensive dynamic impacts.

Therefore, it is necessary to take into account the principle of impact waves and different dynamical loads interaction from production equipment to the construction of pile foundations in shelf soils.

Research results. As it is known, due to wave phenomenon, the shock waves that form compression waves in the constructions of a great cross-section pile with a "hard core" are propagated in the environment. Within the shock wave front, there occurs a step change in pressure, density, velocity of particles' motion in the medium that are transmitted to shelf soil. For the compression waves, the gradual buildup of these parameters is typical. Under the pressure of the compression waves, we understand excessive pressure arising in the medium in passage of a wave, i.e. the pressure that differs from normal atmospheric pressure and everyday pressure of specific weight of the soil at propagation of a wave in soil. The wave parameters depend on the energy source of a disturbing force, the period of a wave process, its form, amplitude and frequency.

The waves act on the constructions of offshore structures, on pile foundations as short-time dynamical loads. The shock waves consist of compressive phase that has more atmospheric and hydrostatic and rarefaction phase (fig. 1).



a b

Fig. 1. Bored pile with a "hard core" (a) and change of compression and rarefaction pressure (b): 1 – a "hard core"; 2 – the body of the bored pile; 3 – the medium size and medium density sand; 4 – the firm clay; $\Delta p_{k,r}$ – the excessive pressure of wave; Δp – maximum rarefaction pressure; p_k – the initial pressure; τ_+, τ_- – the period of phase compression and rarefaction

The degree of fault in offshore structures caused by the action of wave shock depends on the pressure in compression phase since it usually exceeds the pressure in rarefaction phase. To determine the values of loads arising at the action of wave shock on pile foundations, it is necessary to take into account the conditions of its interaction with pile foundations (reflection, flow, streak and so on).

The basic parameters of the wave shock propagated in soils essentially depend on the distance to the center of the wave shock source. If the wave shock source is strong and the distance on the pile foundation surface is small, then there happens structure fracture, particles displacement and soil crushing with formation of cavity or funnel and the shock waves propagate in the form of compression waves. The parameters of these compression waves in the soil are determined by the parameters of water shock wave generating them and by the characteristics of the soil.

At plane wave front in the soil, the characteristics of the soil determining the type of the propagating wave and its intensity is the compression diagram: dependence of stress σ on strain ε, where the dynamical load differs from the statistical one (fig. 2).

If the pressure at the wave front corresponds to the initial area of the dynamic diagram σ~ε on which $d^2\sigma/d\varepsilon^2<0$, then due to growth of pressures, the instant modulus of deformation $E_{0,d}= d\sigma/d\varepsilon$ and consequently, the wave propagation velocity $\alpha_0 = \sqrt{\frac{E_{0,d}}{\rho}}$, (where ρ is the density of the shelf soil) decrease. In consequence of this, the pressure rise time in wave increases and it results in formation of compression wave in the soil. At great pressures caused by the wave shock and corresponding to the diagram area, on which $d^2\sigma/d\varepsilon^2>0$, with growth of pressure the velocity α increases and shock waves propagate in the soil. Stress decrease in the soil in passage of wave (unloading) happens in accordance with area 3 as shown in the diagram (fig. 2).

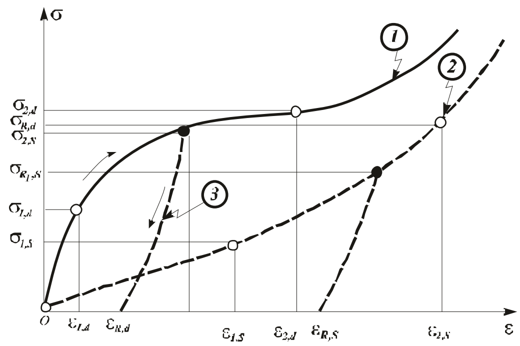


Fig. 2. Diagram of shelf soils deformations σ~ε: 1– dynamic; 2 – statical; 3 – at unloading; $\sigma_{1,d}$, $\sigma_{2,d}$, $\sigma_{R,d}$, – the stress at dynamical loadings; $\sigma_{1,s}$, $\sigma_{2,s}$, $\sigma_{R,s}$, – the stress at statical loads; $\varepsilon_{1,d}$, $\varepsilon_{2,d}$, $\varepsilon_{R,d}$, and $\varepsilon_{1,s}$, $\varepsilon_{2,s}$, $\varepsilon_{R,s}$, – are deformations; $\sigma_{R,s}$, $\sigma_{R,s}$, – at unloadings

To calculate the wave shock parameters in the soil, the ordinary diagram σ~ε suggested by Prandtle as a diagram of material strengthening (fig. 3).

We determine the velocity of elastic wave propagation $\alpha_0 = \sqrt{\frac{E_{0,d}}{\rho}}$ and elasticoplastic wave propagation $\alpha_0 = \sqrt{\frac{E_{0,d}}{\rho}}$ by experiments, in the case of no experimental data of the values α_0 and α_1 for different shelf soils, in calculations we can use the values given in table.

Table

Values of Elastic and Elasticoplastic Velocities of Wave Propagation

Soils	Velocity of Wave Propagation, m/s	
	elastic a_0	elastico-plastic a_1
Loose sand	200	100
Undisturbed structure sand	200	250
Disturbed structure sandy loam, loam	250	150
Undisturbed structure sandy loam, loam	700	350
Loose clay	300	150
Dense clay	1500	500

We calculate the parameters t_V and ΔP_i of the compression wave in the shelf soil arising under the action of the shock wave on the soil surface, i.e. $z=0$ (fig. 4), by the formulas:

a) effective time of shock wave

$$t_V = z\left(\frac{1}{\alpha_1} - \frac{1}{\alpha_0}\right);$$

b) wave pressure rise at infinite dynamical modulus of deformation $E_{i,d}=\infty$, according to fig. 2, will be

$$\Delta p_i = \Delta p_{F,r}\left(1 - \frac{0,5z}{\alpha_1 t_V}\right);$$

c) if $E_{i,d}=E_{0,d}$, then

$$\Delta p_i = \Delta p_{F,r}\left[1 - \frac{0,5z}{\alpha_1 t_V}\left(1 - \frac{\alpha_1^2}{\alpha_0^2}\right)\right],$$

where $E_{i,d}$ – the modulus of deformation of the shelf soil at dynamical load within any interval of time; $E_{0,d}$ – the modulus of soil deformation at initial (instant time, i.e $t=0$).

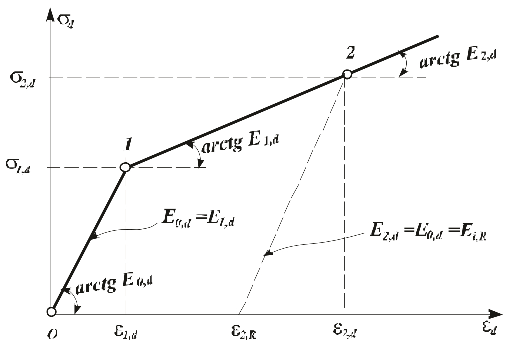


Fig. 3. Calculation diagram of shelf soil deformations at dynamical loading: $E_{0,d}$, $E_{1,d}$, $E_{2,d}$ – are deformation modulus of the soil at dynamical loadings; $\sigma_{1,d}$ – the dynamical limit of stresses in elastic stage; $\sigma_{2,d}$, – the same beyond the elasticity; $\varepsilon_{1,d}$, $\varepsilon_{2,d}$ – are dynamical limits of deformations in elastic stage and beyond the elasticity; $\varepsilon_{2,R}$ – are deformations at unloading

When calculating offshore structures for the action of shock wave at time t, one can use excess pressure on the shockwave front by the formula

$$\Delta p(t) = \Delta p_{F,r}\left(1 - \frac{t}{t_V}\right).$$

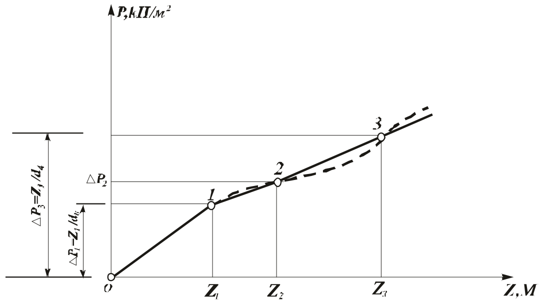


Fig 4. Compression wave in shelf soil at the depth z, м

The effective time of shock wave t_V depends on the period of compression phase τ_+ and on the rarefaction phase τ_-. Then the effective time of shock wave is as follows

$$t_V = \frac{2\tau_+}{k_{pov} + 1}.$$

If we assume the period of the compression phase as $\tau_+=30c$, and change of wave pressure at dynamical loading $\Delta p_{F,r}$, at time τ_+, and we get $\Delta p_{F,r}= 0,4MPa$, then the number of wave repetition k_{pov} is

$$k_{pov} = \frac{\Delta p_{F,r} 2\tau_+}{q_V}, \quad (1)$$

where $q_V = 2MPa{\cdot}s/м^2$ is the pressure acting on $1\ m^2$ area assumed at normal sea waves in time (without storm phenomena).

Maximum rarefaction pressure Δp_{zar} and period of rarefaction phase τ is

$$\Delta p_{zar}=0,15MPa;\ \tau_-=10s.$$

The pressure change in compression phase in time $\Delta p(t)$ is accepted by the linear law in the form

$$\Delta p(t) = \Delta p_{F,r}\left(1 - \frac{1}{\tau_+}\right)^{k_{pov}},\quad 0 \le t \le \tau_+.$$

According to the formula (1)

$$k_{pov} = \frac{0,4 \cdot 30}{2} = 6.$$

Maximum reflection pressure Δp_{otr} acting at initial time on the surface of the large cross-section pile with a "hard core" is determined by the formula:

$$\Delta p_{otr}=3\Delta p_{F,r}.$$

When colliding with the surface of the pile, the compression wave is reflected, and this increases the pressure on the pile compared with the pressure of transmitted wave.

As shown in fig. 4, compression wave acts on the surface of the pile and is transferred through the piles to shelf soils to the depth z in accordance with the following formula

$$\Delta p(t,z)=\Delta p(t) \cdot n_g,$$

where $\Delta p(t,z)$ − pressure in compression wave on soil basis at the depth z (fig. 4); n_g − the coefficient dependent on the depth of the shelf soil basis that piles cut from the soil surface under water; to $z=1i$, of depth $n_g=0,7$; $z=2i$, $n_g=0,45$; $z=3i$, $n_g=0,2$; and so on.

Reflections of compression wave of shelf soil is expressed by the reflection coefficient $\alpha_{otr}=\alpha_0/\alpha_1\approx 2$. The reflection coefficient of soil α_{otr} depends on the kind of soil and is about $\alpha_{otr}=2,5$ for sand; $\alpha_{otr}=2,0$ for sand loam; $\alpha_{otr}=1,8$ for loam; $\alpha_{otr}=1,6$ for clays.

Thus, shock of wave force is transferred through the piles to shelf soil and is of a damped character.

Conclusions. For reasons given, we draw the conclusions:

1. Shock wave in constructions of pile foundations forms compression waves that the piles transfer to shelf soil, and this fact provokes the changes in density, velocity of soil particles motion, and deformation of soil. Compression wave on the pile surface may be of reflective, squeezing, flowing, absorbing and other interaction types and transferred to soil. Compression wave arises in soil when wave shock increases and is reflected during loading. The soil basis state may be determined by the graph σ~ε. Herewith it is necessary to determine the modulus of dynamic deformations of the instant elastic $E_{0,d}$ and modulus of deformation of elastico-plastic state $E_{i,d}$.
2. Using the values of elastic and elastic-plastic velocities of wave propagation in shelf soils, one can determine the values of pressure increase, effective time of wave compression, change of pressure in compression phase in time, maximum reflection pressure, and rarefaction pressure within the thickness of a soil layer.

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Мета. Застосовувати для будівництва морських споруд буронабивні палі великого перерізу (діаметром від 620 до 1500 мм і більше) з „жорстким сердечником“, аби вони взаємодіяли з шельфовими ґрунтами та сприймали динамічні навантаження.

Методика. У лабораторних умовах досліджені властивості шельфових ґрунтів і впроваджені в них буронабивні палі діаметром 30 мм й довжиною до 600 мм, теоретично узагальнена поведінка палі в шельфових ґрунтах при імпульсивно-динамічних навантаженнях від вібраторів.

Результати. Розглянуті взаємодії буронабивних паль великого перерізу з „жорстким сердечником“ за динамічних навантажень з шельфовими ґрунтами. При цьому динамічні навантаження були прийняті від технологічного устаткування, машин і механізмів, а також від морських хвиль до морських споруд, з буронабивними палями великого перерізу з „жорстким сердечником“, що передають динамічні навантаження шельфовим ґрунтам. Складені розрахункові схеми дії динамічних навантажень через палі на грунт, побудовані графіки σ~ε у фазі стискування та фазі розтиснення. Визначені ефективний час хвилі стискування, зміна тисків у фазі стискування, віддзеркалення й розрідження у грунтовому масиві.

Наукова новизна. Уперше запропоновані буронабивные палі великого перерізу з „жорстким сердечником“ використовувати для будівництва морських споруд, що дозволяють отримати значну економію арматури в порівнянні зі звичайними буронабивными палями такого ж перерізу. Розроблені методи визначення взаємодії буронабивних паль великого перерізу з „жорстким сердечником“ за статичних і динамічних навантажень з шельфовою ґрунтовою основою.

Практична значимість. Застосування розроблених методів дозволяє оцінити властивості шельфових ґрунтів, вибрати раціональну конструкцію свайних фундаментів і їх спільну роботу або взаємодію буронабивних паль великого перерізу з „жорстким сердечником“ з шельфовим грунтом, що забезпечить стійкість і довговічність морських споруд.

Ключові слова: *хвилеві процеси, буронабивні палі з „жорстким сердечником“, хвилі стискування, хвилі розрядки, пружні хвилі, упругопластичні хвилі, шельфові ґрунти, тиск*

Цель. Применять для строительства морских сооружений буронабивные сваи большого сечения (диаметром от 620 до 1500 мм и более) с „жестким сердечником", чтобы они взаимодействовали с шельфовыми грунтами и воспринимали динамические нагрузки.

Методика. В лабораторных условиях исследованы свойства шельфовых грунтов и внедрены в них буронабивные сваи диаметром 30 мм длиной до 600 мм, теоретически обобщено поведение сваи в шельфовых грунтах при импульсивно-динамических нагрузках от вибраторов.

Результаты. Рассмотрены взаимодействия буронабивных свай большого сечения с „жестким сердечником" при динамических нагрузках с шельфовыми грунтами. При этом динамические нагрузки были приняты от технологического оборудования, машин и механизмов, а также от морских волн к морским сооружениям, с буронабивными сваями большого сечения с „жестким сердечником", которые передают динамические нагрузки шельфовым грунтам. Составлены расчетные схемы действия динамических нагрузок через сваи на грунт, построены графики σ~ε в фазе сжатия и фазе разжатия. Определены эффективное время волны сжатия, изменение давлений в фазе сжатия, отражения и разрежения в грунтовом массиве.

Научная новизна. Впервые предложены буронабивные сваи большого сечения с „жестким сердечником" использовать для строительства морских сооружений, которые позволяют получить значительную экономию арматуры по сравнению с обычными буронабивными сваями такого же сечения. Разработаны методы определения взаимодействия буронабивных свай большого сечения с „жестким сердечником" при статических и динамических нагрузках с шельфовым грунтовым основанием.

Практическая значимость. Применение разработанных методов позволяет оценить свойства щельфовых грунтов, выбрать рациональную конструкцию свайных фундаментов и их совместную работу или взаимодействие буронабивных свай большого сечения с „жестким сердечником" с шельфовым грунтом, что обеспечит устойчивость и долговечность морских сооружений.

Ключевые слова: *волновые процессы, буронабивные сваи с „жестким сердечником", волны сжатия, волны разряжения, упругие волны, упругопластичные волны, шельфовые грунты, давление*

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CREATION AND IMPLEMENTATION OF GEOLOGICAL AND ANTHROPOGENIC MODELS OF MINING SYSTEMS

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СТВОРЕННЯ ТА ВТІЛЕННЯ ГЕОЛОГО-АНТРОПОГЕННИХ МОДЕЛЕЙ ГІРНИЧОПРОМИСЛОВИХ СИСТЕМ

Purpose. Development of methods of geoinformation modeling of anthropogenic systems for raising the efficiency of mining operations.

Methodology. Building of anthropogenic models of mining enterprises and selection of efficient solution options using simulation modeling and GIS-technologies.

Findings. It was found that developed anthropogenic models enable to describe processes of mining operations to the fullest extent possible.

Originality. The research used the methods of simulation modeling and GIS-technologies in the building of anthropogenic models of mining systems enabling to ensure adequate model representation of the main facilities and processes of a mining enterprise.

Practical value. The main types of anthropogenic models have been developed as well as methods for running of simulation studies. As tested at a number of coalmines of Kuznetsk Basin they proved the possibility of their practical application.

Keywords: *anthropogenic models, mining systems, geoinformation modeling*

Geoinformation systems (GIS) are used in many fields of human activity. At the same time, a number of such fields and lines of the use of GIS are steadily on the rise. These systems are of particular importance in mining. GIS are used at all stages of mining systems: