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ANALYSIS OF STRESS-STRAIN STATE OF HYDROTECHNICAL STRUCTURE IN OPERATION MODES

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The influence of the foundation flexibility on the stress-strain state of the bearing elements of the hydrotechnical structure, considering operational conditions, was investigated. Two discrete idealized models of the structure were used for the analysis.

Keywords: hydrotechnical structure, stress-strain state, internal force, displacement, information technologies, discrete model.

Introduction. Seas and oceans, especially their continental shelves, are considered as promising areas for solving a number of global challenges of humanity, from providing energy resources to overcoming food shortages. Offshore stationary platforms are basic hydrotechnical structures used for developing oil and gas deposits located in marine areas. Specialized equipment is mounted on these platforms for drilling, hydrocarbon extraction, primary processing, and auxiliary operations. These auxiliary operations include, for example, water injection to maintain reservoir pressure, well repair and preparing oil and gas for further transportation. Besides, platforms are equipped with household quarters for personnel and emergency rescue systems. In complex conditions of open sea and in areas with increased seismic activity, offshore platforms must ensure stable and reliable operation throughout their entire operation. Therefore, their design takes into account not only technical but also natural and climatic factors. Special attention is paid to safety, ease of maintenance, and the possibility of carrying out repair work without stopping the main technological process.

The design of each offshore stationary platform must be engineering justified and adapted to specific operating conditions– the sea depth, the soil type, and the nature of wave and wind loads. Engineers select structural solutions that ensure the stability of the structure, its resistance to external influences and its ability to retain its geometric shape even under prolonged loading. The modularity of the design is also important, as it allows tomodernizeseparate systems without a complete stop of the object.Overall, offshore platforms are high-tech engineering complexes that combine the achievements of modern science, engineering and safety systems. They must not only perform production functions but also be comfortable and safe for personnel. Therefore, modern design requirements include the integration of automated control systems, technical condition monitoring, and environmental protection measures.

The general principles for designing of support structures for stationary drilling rigs and methods for calculating of structural strength and stability under external loads are provided in [1]. The modern methodology for calculating platform strength and stability is described in a number of scientific works, which highlight approaches to modeling ice loads and determining the characteristics of offshore platforms for effective ice breaking [2]. Methods of calculationof strength of an offshore structure elements under the influence of external loads are discussed in [3].

The stress-strain analysis is very important component of the design, the reconstruction and the operation of hydrotechnical structures, as it determines the reliability and the durability of their bearing

elements. In domestic and foreign scientific literature this problem is analyzed in the context of the mathematical modeling, the experimental analysis and the implementation of numerical methods for prognostication ofstresses and strains in structural elements under operational loads. A significant contribution to the development of theoretical foundations of stress-strain analysis was made by the works of Ukrainian scientists [4-5], where,in particular, the authors conducted a study on the effectiveness of using a hardening soil model, which allows to obtain of accurate values for the stress-strain parameters of the foundation. They also analyzed the influence of the soil model with corrected parameters on the nature of the stress-strain distribution in underground structures.

One of main parts part of ensuring the reliability of hydrotechnical structures is accounting of their real interaction with the environment, particularly with water-saturated soil masses. The works of Ukrainian and international researchers emphasize that the instability of the geological environment, seasonal changes of groundwater levels and technogenic loads significantly affect the stress-strain state of structures. This is especially true for elements which are under constant pressure from water and soil masses.

The purpose of the article. The issues of ensuring the reliability and durability of hydrotechnical structures are becoming particularly important in the current conditions of the construction industry's development. The long-term operation of such structures in complex hydrogeological conditions, under the influence of static and dynamic loads, atmospheric factors and cyclic changes of temperature and moisture leads to the complex stress-strain state of their structural elements. Timely detection of critical areas and assessment of the structure's load level can prevent technogenic accidents, extend the operation of the object, and optimize repair costs. This is why the problem of analyzing the stress-strain state of bearing elements ofhydrotechnical structures is of particular relevance in the modern engineering practice. The purpose of this analysis is to determine the maximum values of internal forcesand displacements that arise in elements and joints of thehydrotechnical structure, taking into account real operating conditions. This makes it possible to assess the impact of external factors on the structure, identify potential failure zones, and develop recommendations for increasing the reliability of the structure.

The main part. The object of this research is thehydrotechnical structure that operates under the influence of hydrostatic, temperature, and filtration loads. The hydrotechnical structure represents the offshore stationary oil-production platform on piles, installed on the shelf of Bay of Kazantyp in the Sea of Azov at the depth of 11 metersfrom the water level in the calm state.

The offshore technological platform is the complex engineering structure that is subject to various loads and operates under the influence of external conditions and technological processes. The physical and geographical conditions in which the structure is transported, installed, and operated on the continental shelf have the decisive influence on the choice of its structural type and the dimensions of its main bearing elements. These external factors shape the technical requirements for the platform's reliability and stability in the challenging marine environment.

These conditions include: meteorological (the wind speed and the wind direction, the air temperature fluctuations, the atmospheric precipitation, the presence of fog); hydrological (nature of sea waves, currents, the presence of ice, the amplitude of sea level fluctuations); hydrographic (features of the seabed relief); geological and geomorphological (the structure and properties of marine soils, dynamics of bottom changes due to the erosion and current processes); tectonic (the seismic activity of the region, the probability of earthquakes); hydro physical, hydro chemical, and hydrobiological (water temperature characteristics, its physic-chemical composition). These loads must be considered when calculating the strength and the stability, as even short-term or episodic loads can have a significant effect on the durability and the safety of the structure.

The analysiswas performed for two variants of the discreteidealizedmodelof the platform under the action of combinations of static and dynamic loads [6] in operational modes:

- the «rigid» model (MR): with the grillagefoundation rigidly attached to a perfectly rigid support surface, i.e., without considering the pile foundation;
- the «flexible» model (MF): with consideration of the elastic soil base and pile foundation [7, 8].

The «rigid»model simulates the situation where the grillagefoundationof the platform is rigidly attached to the perfectly rigid base. This model does not take into account the influence of soil deformations and the pile flexibility, which simplifies the model significantly but does not reflect the

real interaction with the soil base. The «flexible» model takes into account the elastic properties of the soil base and the pile foundation. It models the elastic-flexible connections between the foundation elements and the base, allowing for the more accurate consideration of pile deformations and the soil effect. This approach provides more realistic results in assessing the stress-strain state.

In tables, the maximum values of internal forces N, Q_y, Q_z, and moments M_k, M_y, M_z in structural elements are presented for individual characteristic parts of the structure: columns, the grillagefoundation, pile heads (Tab. 1), the superstructure (Tab. 2), the helipad, two moorages, the flambeau console, and the connection mast (Tab. 3), as well as for the entire framework (Tab. 4).

Table 1

Maximum internal forces in bearing elements (kN)

Model	The internal force	Columns	The grillage foundation	Upper sections of piles
MR	N	4243.2	894.7	0.0
	Q_y	2302.7	591.6	0.0
	Q_z	112.6	571.2	0.0
	M_k	309.0	158.7	0.0
	M_y	98.7	1013.5	0.0
	M_z	1893.8	854.06	0.0
MF	N	7276.7	1594.6	1321.0
	Q_y	3257.7	698.6	1130.3
	Q_z	208.8	1732.4	624.3
	M_k	555.0	263.7	172.0
	M_y	183.9	2772.9	3405.0
	M_z	50.6	1302.3	4223.8

Table 2

Maximum internal forces in basic elements of the superstructure (kN)

Model	The internal force	Elements of the deckat the level +9.800	Elements of the deck at the level +7.300	Elements between decks at levels +9.800 and +15.30	Elements between decks at levels +7.300 and+9.800
MR	N	1023.65	751.44	998.8	1177.9
	Q_y	11.2	499.5	5.0	67.6
	Q_z	379.3	1768.11	12.1	145.8
	M_k	0.206	0.633	1.4	30.6
	M_y	281.08	868.23	84.5	215.5
	M_z	8.166	92.99	35.0	870.2
MF	N	2881.25	2806.21	1695.2	1850.9
	Q_y	23.7	555.9	10.9	634.5
	Q_z	757.66	2715.98	55.3	1615.5
	M_k	0.327	1.535	2.0	79.7
	M_y	520.93	1599.31	133.4	543.2
	M_z	15.277	163.73	59.2	442.6

The analysis of the two discrete platform models under various load combinations allowed not only to identify zones of maximum forces in the elements and displacements of the main structural nodes, but also to assess the influence of factors such as the flexibility of piles and soil base on the stress-strain state of bearing elements.The analysis of the stress-strain state of the hydrotechnical structure showed:

• forces in most elements of the model with an elastic base have significantly higher values. This is due to the fact that, in real conditions, the platform's foundation is not absolutely rigid, and its deformations cause additional loads on the structure. The maximum longitudinal force N occurs in the

element 1851 (the column element): in the «rigid» model the force is 4.24 MN, and in the «flexible» model, it is 7.28 MN – the difference of 72%;

Table 3

Maximum internal forces in secondary bearing structure(kN)

Model	The internal force	Elements of the helipad	Elements of the moorage №1	Elements of the moorage №2	Elements of the flambeau console	Elements of connection mast
MR	N	1350.97	324.67	151.0	419.53	198.08
	Q_y	108.11	83.24	33.18	2.86	105.22
	Q_z	188.01	48.75	38.29	11.38	65.8
	M_k	309.02	7.29	10.58	3.2	0.298
	M_y	256.35	160.52	45.91	9.96	241.23
	M_z	299.79	49.72	27.17	7.22	182.41
MF	N	2581.49	750.31	547.88	4300.7	514.27
	Q_y	249.34	176.79	91.27	9.29	226.91
	Q_z	272.35	59.21	75.74	23.43	195.74
	M_k	555.03	12.41	23.74	6.35	0.693
	M_y	667.23	154.38	81.56	23.35	751.2
	M_z	594.13	100.44	81.73	21.33	550.3

Table 4

Maximum internal forces in for the entire framework (kN)

The internal force	Model			
	MR		MF	
	The value	The element	The value	The element
N	4243.16	1851	7276.72	1851
Q_y	2302.75	1845	3257.68	1845
Q_z	1768.11	2556	2715.98	2556
M_k	309.02	6089	555.03	6089
M_y	1013.52	1659	3404.99	1515
M_z	189386	1859	4223.84	1506

• in elements of the «rigid» model, the decrease in bending moments and torsional moments, shear forces, and the variable nature of the longitudinal force are observed compared to the corresponding elements of the «flexible» model;

• the largest internal forces in both models occur in elements of upper sections of piles, the chords of spatial column trusses, and connections of columns with the superstructure;

• in the superstructure larger longitudinal forces occur in the deck elements at the level +9.800 (1023.7 kN in the element 3202 in the «rigid» model and 2881.3 kN in the «flexible» model), but significantly larger shear forces and moments are characteristic of deck elements at the level +7.300. Among elements between decks at levels +9.800 and +15.300, larger internal forces occur in diagonals, while among the elements between decks at levels +7.300 and +9.800, larger forces are characteristic of the verticals in both models;

• the localization of the largest displacements in both models occurs in areas structurally connected to nodes 2705 (the flambeau consolenode) and 2749 (the communication mast node). Specifically, these nodes have the largest linear displacements along all three axes. The maximum displacements of the node 2705 along the z-axis are 175.6 mm in the «rigid» model and 545.3 mm in the «flexible» model. Since, alsoin first three modes of natural oscillations primarily take part only the flexible communication mast and the flambeau console[9], from an engineering safety perspective, these structures should be considered as potentially critical zones of the accumulation of deformations during prolonged operation. The maximum displacements among nodes of main bearing structures are

characteristic of the deck nodes along the y-axis: 39 mm in the «rigid» model and 99.6 mm in the «flexible» model.

• taking into account the foundation flexibility affects the stress-strain state of the structure significantly. It indicates the necessity of using flexible models when designing complex engineering structures, particularly for the accurate determination of zones of the maximum force action and ensuring the reliability of the structure under real operatingconditions.

Conclusion. Obtained results demonstrate that taking into account real conditions of the structure-foundation interaction is extremely important at the design stage. Underestimation of soil deformations can lead to the overloading of individual elements, which creates a risk of a structural failure during operation. Thus, obtained results show the necessity of using elastic or flexible models when designing the stress-strain state of hydrotechnical structures that operating under complex conditions.

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АНАЛІЗ НАПРУЖЕНО-ДЕФОРМОВАНОГО СТАНУ ГІДРОТЕХНІЧНОЇ СПОРУДИ В ЕКСПЛУАТАЦІЙНИХ РЕЖИМАХ

У складних умовах відкритого моря, а також у зонах з підвищеною сейсмічною активністю, гідротехнічні споруди мають забезпечувати стійку і надійну роботу протягом усього терміну експлуатації. Аналіз напружено-деформованого стану є дуже важливою складовою при проєктуванні, реконструкції та експлуатації гідротехнічних споруд, оскільки визначає надійність і довговічність їх несучих елементів,вчасне виявлення критичних ділянок споруди дозволяє продовжити термін експлуатації об'єкта. Саме тому проблема аналізу напружено-деформованого стану несучих елементів гідротехнічних споруд набуває особливої актуальності в сучасній інженерній практиці. Метою даного дослідження є визначення максимальних значень внутрішніх зусиль та переміщень, які виникають в елементах та вузлах гідротехнічної споруди з урахуванням реальних умов експлуатації. Об'єктом дослідження є гідротехнічна споруда, яка представляє собою морську стаціонарну нафтовидобувну платформу на палях, встановлену на глибині 11метрів.Дослідження проводились для двох варіантів дискретної ідеалізованої моделі платформи: з жорстким приєднанням ростверку до опорної абсолютно твердої поверхні та з урахуванням пружної ґрунтової і палевої основ. Аналіз показав: найбільші внутрішні зусилля в обох моделях виникають в елементах верхніх частин паль, просторових ферм колон, з'єднань колон з верхньою будовою;локалізація найбільших переміщень в обох моделях відбувається у вузлах консолі факелу та щогли зв'язку, серед вузлів основних несучих конструкцій відбуваєтьсяу вузлахверхньої будови;в елементах «жорсткої» моделі спостерігається зменшення згинальних та крутних моментів, поперечних сил, а також змінний характер поздовжньої сили порівняно з відповідними елементами «піддатливої» моделі, врахування піддатливості основи значно впливає на напружено-деформований стан споруди.

Ключові слова: гідротехнічна споруда, напружено-деформований стан, внутрішнє зусилля, переміщення, інформаційні технології, дискретна модель.

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Keywords: hydrotechnical structure, stress-strain state, internal force, displacement, information technologies, discrete model.

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