UDK 539.3

THE DYNAMIC ANALYSIS OF FIXED DEEP-WATER PLATFORM

R.M. Ostapenko,
Assistant

I.D. Kara,
PhD

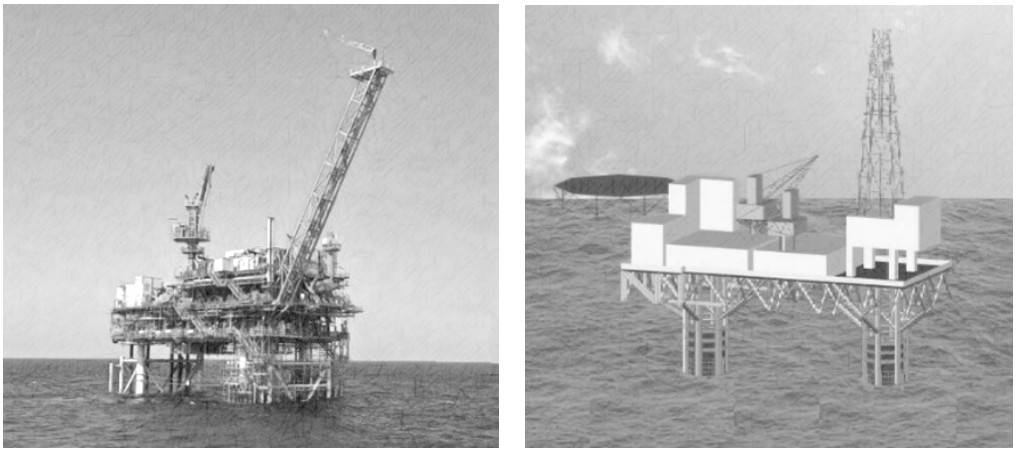
Kyiv National University of Construction and Architecture,
Povitroflotsky Ave., 31, Kyiv, 03037

DOI: 10.32347/2410-2547.2023.111.245-250

The impact of such factors as: the flexibility of the pile foundation, the connected mass of water media, the ice field on the value of the period of natural oscillations of the offshore fixed deep-water ice-resistant platform was researched. Two discrete idealized models of the platform were used for the dynamic analysis.
Keywords: period of oscillations; deep-water platform; discrete model; connected mass; ice field.

Introduction. The industrial progress is closely related with active using of hydrocarbonsin the modern world. The progress of the oil and natural gas industry is very important for the world and Ukraine in particular. The gradual growth of reserves of deposits on land led to reclaim and the gradual increase of the extraction of raw materials on the sea shelf. Specialists say that about 70% of hydrocarbon reserves lie in rock formations beneath seabed or ocean floor and more than half of them are located in shelf areas [1].

The development of sea oil deposits usually occurs using oil production platforms today [2]. For oil production at the depth of immersion more than 80 meters offshore fixed platforms are used most often (Fig. 1). A structure of this type consists of collected on land metal parts: the supporting part and the upper part that have a form of a spatial truss. Platforms rest on driven piles that have a tubular section and perceive vertical load from upper part and horizontal load from supporting part [3].



(a) (b)

Fig. 1. Examples of fixed oil production platforms

Platforms can be used in different climatic zones and also, they have wide exploitation opportunities such as: they are the placement of the equipment for well drilling and extraction of hydrocarbons, preparation of raw materials for transportation, water injection into layer, performing

repair works etc. But using of such technological structures is not limited only to interest of oil and natural gas industry whereas they are important for navigation and military purposes.

A type of structures with the supporting part in a form of a spatial truss are ice-resistant structures. The upper part of such platforms rests on several columns, and diagonal and vertical links are deleted in a zone of the water horizon because they can be fractured by floating ice [3].

Such structures as offshore fixed platforms are exposed to effects of a high seismicity, wind, waves, strong undercurrents and an impulse impact during the movement of ice fields especially when exploitation in northern seas. Analyzes of offshore fixed hydrotechnical structures under the impact of different combinations of exploitative and external loads are based on the equilibrium condition of a structure under the impact of maximum possible loads. It's important during the analysis and the designing of offshore fixed platforms to choose the most rational constructive form and technical solution that should provide the strength, the reliability and the geometric stability of the entire platform and its individual members. Also, it's important to consider the dependence of the stress-strain state of platforms bearing structures on the technology of the transportation of its individual parts, the montage of a structure, the impact of hydrological, geological and meteorological factors, seismic loads.

The purpose of the article. The purpose isthe research of the impact of different factors on the value of the period of natural oscillations of offshore fixed deep-water ice-resistant platforms.The analysis and the designing of offshore platforms of various purposes is y relatively new field of an engineering art. First design and technological solutions of offshore fixed oil platforms were developed and patented in the second half of the twentieth century. General principles of the designing and methods of the strength and stability analysis of bearing structures of fixed platforms are given in [3]. In [4] the theory of description of sea waves and a reaction of production platforms to the action of external impact was developed. Also, analyzes of the action of wave loads on thin structures of a large diameter was performed on the basis of the diffraction theory. Recommendations for the designing of a pile foundation of fixed platform discrete models providing the practical accuracy are given in [5]. The modelling of the ice load using the polarization-optical method and the determination of offshore platforms properties for the ice destruction efficiency using the random balance method were performed in [6]. Analyzes of the strength of members of offshore structures were performed in [7]. Analyzes of the fixed platforms on the action of seismic loads were performed in [8, 9]. Considering the gradual transition to the extraction of hydrocarbons at the great depth, the research of the impact of various factors on the analysis of fixed deep-water platforms is actual.

The main part. The offshore fixed deep-water ice-resistant platform with the depth of immersion 120 m(Fig. 1b) was accepted as the object of the research. The structure is presented in a form of the spatial disc-bar system that rests on the pile foundation with the depth of immersion 100 meters. Driven piles consist of metal pipes of cylindrical section with the thickness of 20 mm and the diameter of 1820 mm that are filled with concrete mortal.

Discrete idealized models of the platform were used for the analysis. Standard spatial bar elements and also rectangle and triangle finite elements of shell were used for structure members modelling [5]. The first model was implemented without taking into account the flexibility of the pile foundation. Piles and ground foundation were rejected and the supporting part was attached to the absolutely immovable rigid body in this model. The flexibility of the pile foundation and the action of ground foundation were taking into account by the addition of elastic links in the second model. The interaction of foundation and piles was implemented by using of finite elements that simulate the elastic connection between joints in this model. The reaction of elastic ground foundation under external loads was replaced by the system of non-dimensional concentrated elastic-flexible links that modeled the resistance of foundation to linear displacements of a pile and its twisting around the longitudinal axis discretely. Links formed special non-dimensional elastic-flexible supporting elements that connected joints of the bar finite-elements model of a pile with immovable absolutely rigid body [5]. As a result of the

dynamic analysis values of periods of first ten forms of natural oscillations of both models were obtained (Tab. 1).

Besides the consideration of the impact of the pile foundation flexibility on the dynamic analysis of the fixed platform the impact of the connected mass of water mediathat was modeled in the form of additional distributed joints mass was also investigated. The consideration of this factor is important when analyzing of the platform on the action of dynamic loads that cause compatible oscillations of the structure with water media. In this case some primary assumptions were accepted: 1) oscillations of the system «the structure – water media» were expected to be small therefore the equation of oscillations of the structure and water mechanics could be linearized; 2) fluid of water media was considered ideal scilicet such that did not compress; 3) surface waves were not taking into account when determination the connected mass of water media; 4) the consideration of the foundation flexibility was allowed when analyzing of the system «the structure – water media». The determination of the connected mass of water were performed by the adding the connected mass of fluid that is included in the mass that was displaced by the immersed part of the structure to the structure mass [10]. Results of analyzes are given in Table 2.

Table 1

Values of oscillations forms periods (T, s)

The form number	The first model	The second model	The difference, %
1	2,659	2,893	8,8
2	2,351	2,808	19,44
3	2,025	2,194	8,35
4	0,682	0,931	36,51
5	0,638	0,801	25,55
6	0,582	0,757	30,07
7	0,547	0,652	19,2
8	0,460	0,555	20,65
9	0,450	0,540	20
10	0,436	0,506	16,06

Table 2

Values of oscillations forms periods taking into account the connected mass of water media (T, s)

The form number	The first model	The second model	The difference for the first model, %	The difference for the second model, %
1	2,907	3,768	9,33	30,25
2	2,792	3,274	18,76	16,6
3	2,203	2,646	8,79	20,6
4	1,267	1,793	85,78	92,59
5	1,114	1,550	74,61	93,51
6	1,076	1,427	84,88	88,51
7	0,950	1,324	73,67	103,07
8	0,945	1,303	105,43	134,77
9	0,885	1,135	96,67	110,19
10	0,838	1,021	92,2	101,78

According to the [11] the impact of the ice field in the winter period must be taken into account when analyzing of offshore fixed platforms on the action of dynamic loads. The impact of this factor was modeled by the addition of additional links that simulated the condition of the

contact of the structure and the ice field. Therefore, additional supporting links that restrain displacements of supporting part joints in both orthogonal directions of the horizontal plane were added at the level of ice along the perimeter of columns in both models. This factor caused the change of values of oscillations forms periods of models also (Tab. 3).

Table 3

Values of oscillations forms periods taking into account the connected mass of water media and the influence of the ice field(T, s)

The form number	The first model	The second model	The difference for the first model, %	The difference for the second model, %
1	1,160	1,453	-56,37	-49,78
2	0,985	1,425	-58,1	-49,25
3	0,928	1,258	-54,17	-42,66
4	0,916	1,252	34,31	34,48
5	0,915	1,240	43,42	54,81
6	0,896	1,160	53,95	53,24
7	0,868	1,109	58,68	70,09
8	0,813	0,943	76,74	69,91
9	0,793	0,917	76,22	69,81
10	0,779	0,866	78,67	71,15

Obtained values show that values of periods of natural oscillations form of the second model where the flexibility of the pile foundation was taken into account exceeded corresponding values of the first model on 8-20% depending on the form of oscillations. Taking into account such factor as the impact of water media in the form of the connected mass affected the dynamic analysis significantly: values of periods of natural oscillations of the first form increased by 9-100%; values of periods of natural oscillations of the second form increased by 16-100%. The impact of the ice field and water media caused the decrease of values of natural oscillations periods of both models of 50-70%.

Conclusion. Analyzes of models of deep-water platform show that taking into account the impact of connected mass of water and the impact of the ice field changes values of periods of natural oscillations significantly especially of the model where the flexibility of the pile foundation was taken into account. Whereas values of dynamic indicators affect on the stress-strain state of members of the structure therefore taking into account these factors is very important when analyzing of offshore fixed platforms.

REFERENCES

1. Bileckyy, V.S., Orlovskyy V.M.,Vitryk V.G. Osnovy naftogazovoyi ingeneriyi (Basics of oil-gas engineering). Poltava: TOV «ASMI», 2018.415 p. (ukr).
2. Orlovskyy V.M., Bileckyy, V.S., Vitryk V.G., Sirenko V.I. Tehnologiya vydobuvannya nafty (Technology of oil production). Lviv: «Novyysvit – 2000», 2022. 308 p. (ukr).
3. Douson, T.H. Proektirovaniye soorugeniy morskogo shelfa (Offshore structural engineering). L.: Sudostroeniye, 1986. 288 p. (rus).
4. Brebbia, C.A., Walker, S. Dinamika morskih soorugeniy (Dynamic Analysis of Offshore Structures). L.: Sudostroeniye, 1983. 238 p. (rus).
5. Sveshnikov, O.H. Pobudova modeley dlya rozvyazku statychnyh I dynamichnyh zadach morskyh platform na pulyah (Developing of models for solving of static and dynamic broblems of offshore platforms on piles). Strength of Materials and Theory of Structures: Scientific-and-technical collected articles. 2001. Issue 69. P.86-91 (ukr).
6. Khotnyanska, O.V., Oveckyy, S.O. Vyznachennya efektyvnosti aktyvnogo protylyodovogo zahystu naftogazovyh morskyh stacionarnyh platform (Determination of efficiency of active anti-icing protection of oil offshore fixed platforms). Scientific announcer of Ivano-Frankivsk national technical university of oil and gas. 2009. № 4. P.71-76 (ukr).
7. Kopey, B.V., Yarynovskyy, M.G. Rozrahunok micnosti morskkyh stoyakiv pry diyi zovnishnih navantagen', vnutrishnyogo tysku ta temperaturnogo rozshyrennya (Calculating the strength of marine risers by the action of

external loads, internal pressure and thermal expansion). Scientific announcer of IFNUOG. 2013. № 1(34). P.105-110 (ukr).
8. Korniyenko, M.V., Permyakov, V.O.,Sveshnikov, O.H., Klyuchka, I.O. Osoblyvosti vplyvu seismichnogo navantagennya na kryhostiyki morski stacionarni platformy (Peculiarities of impact of seismic load on ice-resistant offshore fixed platforms). Collection of scientific articles (industrial ingineering, construction). 2005. Issue 15. P.109-114 (ukr).
9. Myitsuk, S.V., Ostapenko, R.M., Kuzmin, B.V. Osoblyvosti rozrahunku paluovyh opor morskyh stacionarnyh platform na seismichni vplyvy (Peculiarities of the calculation of the pile supports of sea stationary platforms on seismic influences). Strength of Materials and Theory of Structures: Scientific-and-technical collected articles. 2016. Issue 97. P.214-224 (ukr).
10. Birbraer, A.N. Raschyot konstrukcyy na seismostoykost (Seismic analysis of structures). StPt.: Nauka, 1988. 256 p. (rus).
11. DBN V.2.4-3:2010. Hidrotehnichni sporudy (Hydrotechnical structures). [Valid since 2011-01-01]. Edit. offic. Kyiv: Minregionbud, 2020. 37 p. (ukr).

Стаття надійшла 20.11.2023

Остапенко Р.М., Кара І.Д.

ДИНАМІЧНИЙ РОЗРАХУНОК СТАЦІОНАРНОЇ ГЛИБОКОВОДНОЇ ПЛАТФОРМИ

Індустріальний розвиток тісно пов’язаний із активним використанням вуглеводнів, більшість запасів якихрозташовані в покладах морського та океанського ден.При видобутку нафти на великій глибині занурення найчастіше використовують нафтовидобувні платформи стаціонарного типу. Проте використання таких технологічних споруд не обмежується лише інтересом нафтогазової промисловості, оскільки важливе значення вони мають також для військових та навігаційних цілей. Стаціонарні платформипіддаються впливам високої сейсмічності, вітрових хвиль, сильних підводних течій та імпульсному впливу при русі льодових полів, особливо при експлуатації в північних морях.Досліджувався вплив різних факторів на значення періоду власних коливань морської стаціонарної глибоководноїкригостійкої платформи з глибиною занурення 120 м, яка опирається на пальовий фундамент. Для проведення аналізу використовувались дві ідеалізовані дискретні моделі платформи: перша модель, яка була реалізована без врахування піддатливості фундаменту та друга модель, в якій враховувались піддатливість фундаменту і дія ґрунтової основишляхом додавання пружних в’язей, що моделюють пружний зв’язок між вузлами.Також досліджувались впливи приєднаної маси водного середовища, яка моделювалась у вигляді додаткових розподілених вузлових мас, та крижаного поля в зимовий період, яке моделювалось додаванням додаткових в’язей в місцях контакту споруди з крижаним полем.Розрахунки показали, що при врахуванні такого фактору як піддатливість пальового фундаменту значення періодів власних коливань збільшуються на 8-20%; при врахуванні впливу приєднаної маси водного середовища збільшуються на 9-100%;при врахуванні дії крижаного поля зменшується на 50-70% залежно від форми коливань, що є суттєвимпри визначенні напружено-деформованого стану елементів споруди.

Ключові слова: період коливань, глибоководна платформа, дискретна модель, приєднана маса, крижане поле.

Ostapenko R.M., Kara I.D.

THE DYNAMIC ANALYSIS OF FIXED DEEP-WATER PLATFORM

The industrial progress is closely related with active using of hydrocarbons more than half of reserves of which lie in rock formations beneath seabed or ocean floor.For oil production at the great depth of immersion oil production fixed platforms are used most often. But using of such technological structures is not limited only to interest of oil and natural gas industry whereas they are important for navigation and military purposes. Offshore fixed platforms are exposed to effects of a high seismicity, wind, waves, strong undercurrents and an impulse impact during the movement of ice fields especially when exploitation in northern seas.The impact of different factors on the value of the period of natural oscillations ofthe offshore fixed deep-water ice-resistant platform with the depth of immersion 120 m that rests on the pile foundation was researched. Two discrete idealized models of the platform were used for the analysis: the first model that was implemented without taking into account the flexibility of the foundation and the second model where the flexibility of the pile foundation and the action of ground foundation were taking into account by the addition of elastic links that simulate the elastic connection between joints.Also, impacts of the connected mass of water media that was modeled in the form of additional distributed joints mass and the impact of the ice field that was modeled by the addition of additional links were investigated.The analysis showsthat values of periods of natural oscillations form increase by 8-20% when the flexibility of the pile foundation was taken into account; increase by 9-100% when the impact of the connected mass of water media was taken into account; decrease by 9-100% when the impact of the ice field and water media were taken into accountthat is significant when analyzing of stress-strain state of members of the structure.

Keywords: period of oscillations, deep-water platform, discrete model, connected mass, ice field.

УДК 539.3
Остапенко Р.М., Кара І.Д. **Динамічний розрахунок стаціонарної глибоководної платформи**// Опір матеріалів і теорія споруд: наук.-тех. збірн. – К.: КНУБА, 2023. – Вип. 111. – С. 245-250.
Розглядається задача про дослідження впливу таких факторів як: піддатливість пальового фундаменту, приєднаної маси водного середовища, дії крижаного поля на значення періоду власних коливань стаціонарної глибоководної платформи.
Табл. 3. Іл. 1. Бібліогр. 11 назв.

UDK 539.3
Ostapenko R.M., Kara I.D. **The Dynamic Analysis of Fixed Deep-Water Platform** // Strength of Materials and Theory of Structures: Scientific-and-technical collected articles – Kyiv: KNUBA, 2023. – Issue 111. – P. 245-250.
The problem about the research the impact such factors as: the flexibility of the pile foundation, the connected mass of water media, the ice field on the value of the period of natural oscillations of the fixed deep-water platformis considered.
Tab. 3. Fig. 1. Ref. 11.

Автор (науковий ступінь, вчене звання, посада): асистент кафедри будівельної механіки ОСТАПЕНКО Роман Миколайович.
Адреса робоча: 03037 Україна, м. Київ, Повітрофлотський пр., 31, Київський національний університет будівництва і архітектури ОСТАПЕНКУ Роману Миколайовичу.
Роб. тел. + 38(044) 2415412
E-mail: ostapenko.rm@knuba.edu.ua
ORCIDID: https://orcid.org/0000-0003-3770-9913

Автор (науковий ступінь, вчене звання, посада): кандидат технічних наук, доцент, доцент кафедри будівельної механіки КАРА Ірина Дмитрівна.
Адреса робоча: 03037 Україна, м. Київ, Повітрофлотський пр., 31, Київський національний університет будівництва і архітектури КАРІ Ірині Дмитрівні.
Роб. тел.:+ 38(044) 2415412
E-mail: karaidknuba@tutanota.com
ORCIDID: https://orcid.org/0000-0003-4700-997X