

Technology of calculation of the number of sensors sufficient for accurate measurement of the ice load pressure on the walls of the oil platform

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Abstract. The article is devoted to problem of calculation the necessary number of sensors that used to determine the ice loads pressure acting on the flat wall (with known dimensions) of oil-production platform.

1 Introduction

The development of oil and gas resources in the sub-Arctic, and then in the Arctic shelf started in the US and Canada in the early 60s. Most of the work falls on the continental shelf of Alaska, the Arctic zone of Canada, the west coast of Greenland and the Antarctic waters. Cook Inlet (United States) is the most developed area among ice waters. Exploration work started here in 1959. In 1962, the first well was drilled, and in the summer of 1963 a temporary ice-resistant platform has been built at a depth of 19 m. Later more than 20 stationary ice-resistant structures were established in the bay area at a depth of 20 to 40 m. It should be noted that Cook Inlet is among the waters with seasonal ice cover, where industrial exploitation is realized.

The water area of the Western Arctic, including the regions of the Barents, Pechora and Kara Seas, is one of the most promising for the forecasted hydrocarbon reserves, and its role in the development of fuel and energy complex is very big. Large structures have been identified here in recent years and ten fields (two - oil, eight - gas and gas condensate) at different depths of both freezing and non-freezing waters have been opened. Among them we should highlight such fields as large Prirazlomnoye oil (shallow part of the Pechora Sea) and super-G - The Shtokman gas condensate (deep part of the Barents Sea).

In the light of the new data, the general approach to the development of the Eastern Arctic shelf (the Laptev Sea, the East Siberian and Chukchi Seas) requires clarification. It is also attractive as a reserve of giant and large oil fields.

Much attention continues to be paid to the development of the Caspian shelf.

Currently, a comprehensive environmental monitoring is one of the main instruments for controlling the environmental situation in the areas of offshore oil and gas deposits.

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Monitoring allows receiving regular reliable information on the state of ecosystems and taking effective and appropriate environmental protection measures. Under the environmental monitoring, we mean a comprehensive system of observations of the state of the environment, assess and forecast changes in the environment caused by natural and anthropogenic factors. Obligation for monitoring exploration and production at the offshore oil and gas fields is regulated by national laws. Nature manager is responsible for production control and local monitoring in the zone of the influence of the object.

An important aspect of monitoring in the zone of the influence of the object is to control its technical condition - with respect to the fixed offshore platforms operating in ice conditions, among other things, control of global ice loads on the platform [1].

It should be noted that a full-scale measurement of global ice loads is a very complicated task from a technical point of view, which requires significant financial and time resources in the preparation of both the measurement and the interpretation of the results. However, not all the possible ice-load estimation methods can be applied to real objects of offshore oil and gas fields. An insufficient regulatory framework should also be considered in this regard. The documents contain only general requirements for the safety of buildings in the design, construction, operation and disposal. These documents have no specific guidelines regarding the conduct of technical supervision, namely, the frequency of inspections, survey steps, subject-to-inspection structural elements, standards of permitted wear and damage to the hull structures, etc.

To sum up, there are two main topical tasks which deal with monitoring of the global ice loads on the offshore stationary platforms:

- supplementation of regulatory framework general requirements with explicit building safety criteria with consideration for individual peculiarities for each field-study project and all the peculiarities of the buildings being monitored.

- the choice and justification of the system monitoring elements reflecting the qualitative and quantitative characteristics of the safety criteria.

The works devoted to the questions of monitoring of global ice loads are written by [1-7] and other authors. Some questions of loads on offshore objects are considered by [1, 3, 8, 9].

In this article on the example of a real platform accommodation module like PZM-1 in the field V. Filanovsky be justified criteria for determining ice loads, and determine the required number of pressure sensors on a flat wall of the platform, the linear dimensions of which are known.

2 Problem formulation

As an example, we will consider an oil-production platform PZM-1 (see figure 1) - residential unit for the year-round personnel serving platform in the field V. Filanovsky. General view PZM-1 is shown in fig.1.

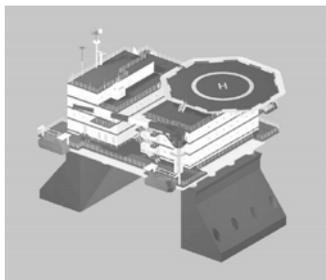


Fig. 1. General view PZM-1.

For the objects of oilfield construction named for Filanovskiy there can be distinguished three methods of global ice-load assessment, based on the various responses of the object:

- changes in the stress-strain state of the most loaded constructions of the object (pile joints)
- the movement of the object;
- changes in the stress-strain state of the object structures located directly in the zone of the ice influence

When determining the global ice load on the lines of the first two methods, the following factors that have an additional impact on the response object should be considered: variable loads, object mode, the state and properties of the soil around mounting piles, bottom friction on the ground, water level fluctuations. The latter method most reliably reflects the real value of the ice load, as the stress is recorded in the structures which are located directly in the zone of ice influence, extraneous factors do not affect the response of the structures.

Proceeding from the above, a method based on controlling stress-strain state of the structures of the ice belt constructions is chosen for determination of local and global ice loads on the oil-field facilities.

3 Problem solution

Let us consider a problem of detecting pressure on a flat wall of oil-production platform. Linear size of the wall is x and y . It's necessary to determine the number of pressure sensors which will be installed on the wall and then rely that the measured value is correct at all area.

As an example, let us consider an oil platform PZM-1, the external view of which is shown in fig. 2.

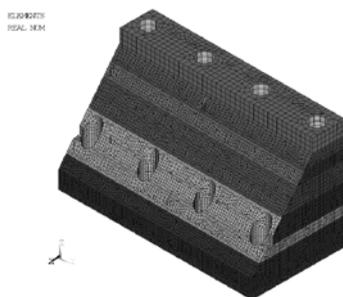


Fig. 2. External view of oil-production platform PZM-1 (axonometric).

Problem definition: the wall area is general totality volume. One sensor measures pressure at 1 m^2 . We know the maximum allowable pressure at each point of the wall. We want to know the number of pressure sensors (or general totality volume) that is necessary to get accurate results of acting pressure.

We use the formula where calculation of quantitative attribute is produced randomly without repeats:

$$n = \frac{t^2}{K^2 + \frac{t^2}{N}}, \quad (1)$$

where n – sample size at planning experiment; t – critical points of t-distribution; $K = \frac{\Delta}{S}$ – allowable inaccuracy in this experiment expressed in sigmas; $\Delta = X_B - X_T$ – allowable inaccuracy in determination of universal mean with its sampled mean (allowable difference distinguishing sampled mean from general value); N – general totality volume. Given the data of max and min values of the considered feature, the value of sigma can be obtained by dividing the range by 5 (or 6, 7 depending on the range).
 For preliminary study $K \approx 0,3-0,5$, for medium accuracy experiments - $K \approx 0,1-0,3$, for high accuracy experiments- $K \approx 0,1$.

3.1 Vertical, big (long) wall

According to initial data max pressure on the wall is 5,74 MPa, and min is 0 MPa. If we calculate the set of volume "n" using this formula the difference $X_B - X_T$ can be taking like 0,123 MPa (hereinafter), so $S = \frac{P_{max} - P_{min}}{7} = \frac{5,74}{7} = 0,82$.

Lets calculate allowable inaccuracy in sigmas $K = \frac{\Delta}{S} = \frac{0,123}{0,82} = 0,15$.

This result is corresponds to high accuracy calculations. Linear dimension of the wall is $x = 24,7$ (m) and $y = 2,5$ (m), so the area of the wall is 61,75 m². So the general set of volume is $N = 61,75$. We use standard critical points of t-distribution and collect them into the Table 1.

Table 1. t-distribution critical points

accuracy%	50,00	60,00	70,00	80,00	90,00	95,00	99,00	99,90
t	0,68	0,84	1,05	1,28	1,64	1,96	2,58	3,3

Results of calculation (number of sensors) using (1) and their round number at Table 2

Table 2. The number of sensors depending on the accuracy (vertical wall)

accuracy%	50.00	60.00	70.00	80.00	90.00	95.00	99.00	99.90
n(using formula)	15.38	20.71	27.06	33.4	40.75	45.39	51.11	54.72
n (round)	15	21	27	33	41	45	51	55

The accuracy depending on number of sensors (vertical wall) on figure 3.

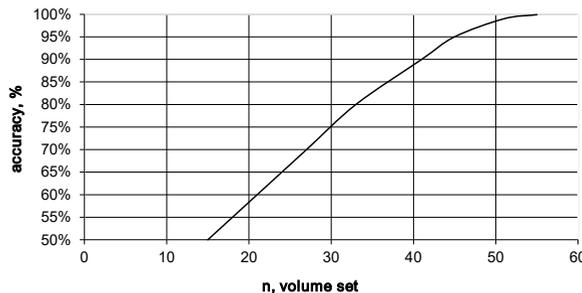


Fig. 3. Sampling accuracy against the sample number (vertical wall)

3.2 Oblique, big (long) wall

According to initial data max pressure on the wall is 4,92 MPa, and min is 0 MPa. If we calculate the set of volume "n" using this formula the difference $X_B - X_T$ can be taking

$$\text{like } 0,123 \text{ MPa (hereinafter), so } S = \frac{P_{max} - P_{min}}{7} = \frac{4,92}{7} = 0,702 .$$

$$\text{Lets calculate allowable inaccuracy in sigmas } K = \frac{\Delta}{S} = \frac{0,123}{0,702} = 0,175 .$$

This result is corresponds to high accuracy calculations.

Linear dimension of the wall is $x = 24,7(\text{m})$ and $y = 2,5(\text{m})$, so the area of the wall is 61,75 m². So the general totality of volume is $N = 61,75$.

The results of sensors number calculation (sample number) from formula (1) and their round number are presented in Table 3.

Table 3. The results of sensors number calculation depending on the accuracy (oblique wall)

accuracy%	50,00	60,00	70,00	80,00	90,00	95,00	99,00	99,90
n(using formula)	12,1	16,7	22,5	28,64	36,3	41,42	48,11	52,57
n (round)	12	17	23	29	36	41	48	53

The graph of sampling accuracy against the sample number (oblique wall) is presented in figure 4.

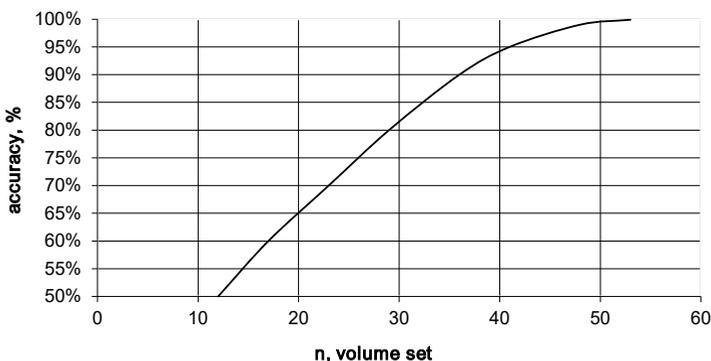


Fig. 4. Sampling accuracy against the sample number (oblique wall)

3.3 Vertical, small (short or side) wall

According to initial data max pressure on the vertical wall is 5,74 MPa, and allowable inaccuracy is $K = 0,15$.

A. Waterline.

Wall linear dimensions (trapezoidal) are $x_{bottom} = 7,2$ (m), $x_{top} = 9$ (m) and $y = 2,5$ (m), so

$$\text{wall area is } \frac{x_{bottom} + x_{top}}{2} \cdot y = \frac{7,2 + 9}{2} \cdot 2,5 = 20,25 \text{ m}^2 .$$

This is a volume of general set: $N = 20,25$.

The results of sensors number calculation (sample number) from formula (1) and their round number are presented in table 4.

Table 4. The results of sensors number calculation (side wall, waterline)

accuracy%	50,00	60,00	70,00	80,00	90,00	95,00	99,00	99,90
n(using formula)	10,17	12,28	14,24	15,84	17,32	18,1	18,95	19,43
n (round)	10	12	14	16	17	18	19	19

The graph of sampling accuracy against the sample number (side wall, waterline) is presented in figure 5

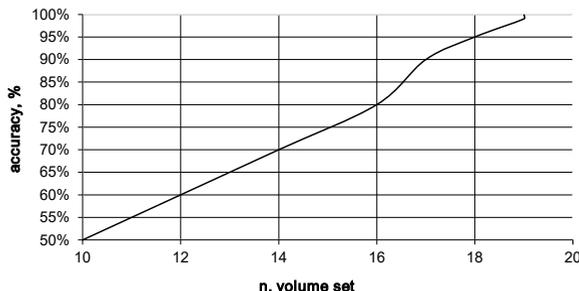


Fig. 5. Sampling accuracy against the sample number (side wall, waterline)

B. Under waterline.

Linear dimensions of the wall (trapezoidal) are $x_{bottom} = 8,1$ (m), $x_{top} = 9,9$ (m) and $y = 2,5$ (m), so wall area is $\frac{x_{bottom} + x_{top}}{2} \cdot y = \frac{8,1+9,9}{2} \cdot 2,5 = 22,4$ m². This is a volume of general set: $N = 22,4$.

The results of sensors number calculation (sample number) from formula (1) and their round number are presented in table 5.

Table 5. The number of sensors (side wall, under waterline)

accuracy%	50,00	60,00	70,00	80,00	90,00	95,00	99,00	99,90
n (using formula)	10,69	13,03	15,27	17,12	18,87	19,8	20,82	21,4
n (round)	11	13	15	17	19	20	21	21

The graph of sampling accuracy against the sample number (side wall, under waterline) is presented in figure 6.

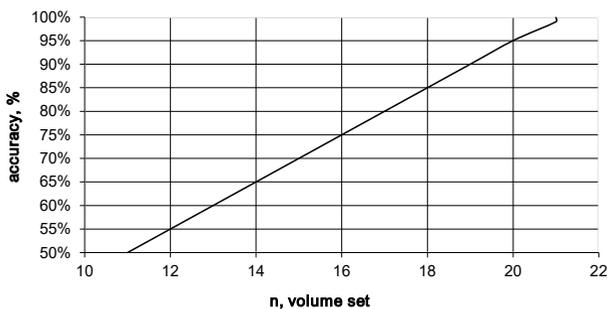


Fig. 6. Sampling accuracy against the sample number (side wall, under waterline)

C. Above waterline.

Wall linear dimensions (trapezoidal) are $x_{bottom} = 6$ (m), $x_{top} = 8,1$ (m) and $y = 2,5$ (m), so wall area is $\frac{x_{нижн} + x_{верх}}{2} \cdot y = \frac{6 + 8,1}{2} \cdot 2,5 = 17,62$ m². This is a volume of general set: $N = 17,62$.

The results of sensors number calculation (sample number) from formula (1) and their round number are presented in table 6.

Table 6. The results of sensors number calculation (side wall, above waterline)

accuracy%	50,00	60,00	70,00	80,00	90,00	95,00	99,00	99,90
n (using formula)	9,64	11,25	12,9	14,17	15,36	15,97	16,62	16,99
n (round)	10	11	13	14	15	16	17	17

The graph of sampling accuracy against the sample number (side wall, under waterline) is presented in figure 7

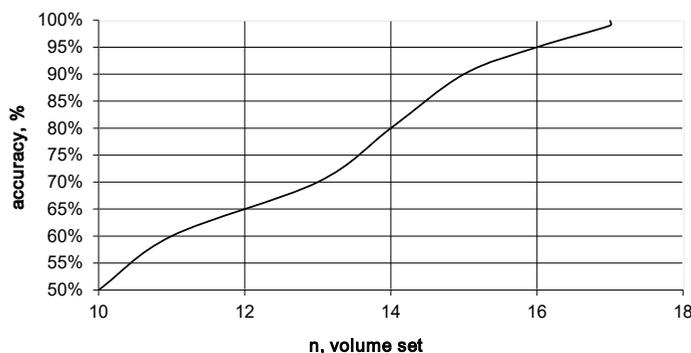


Fig. 7. Sampling accuracy against the sample number (side wall, above waterline)

4 Discussion and conclusion

Full-scale measurement of global ice loads is a very complicated task from a technical point of view, which requires significant financial and time resources in the preparation of both the measurement and the interpretation of the results. Different design and research studies institutes introduced various solutions to global ice-load estimation – ice field stress, moving and tilt operations of objects as well as object vibrations and stress in the hull structures were measured, special measuring panels were installed in the hull of the object etc. It should be noted, however, that not all the possible ways of ice-load estimation can be applied to the objects under consideration in the current project.

At determining the required number of sensors and developing their installation schemes it is important to determine the place of peak response of the stiffeners to the ice-load action. In order to determine the exact mounting locations of the sensors and get acceptable consistent results of stress-strain state calculations, a detailed finite element scheme of the object, reflecting all design features is created, using specialized software. The model is then loaded with the substitute ice load and using the finite element method, an analysis of the stress-strain state of the support unit is carried out. Thus, two problems can be solved:

- determination of strain gauge installation zones
- determination of the relation between the local pressure and effective voltage for each point.

We solved the problem of determination of the necessary number of pressure sensors that determine the pressure acting on the flat wall (with known dimensions) of the living quarter platform. Calculations were made for vertical and oblique walls. Interesting fact that for oblique wall we can use less sensors than for vertical wall with the same accuracy because max pressure for oblique wall is less than for vertical. The calculations for side wall were made. Three levels were used: waterline, under waterline, above waterline. Using the data from Table 2,3,4,5,6 it possible to select the required number of strain sensors to assure the required level of accuracy of the results of ice-load pressure determination on all the walls of oil platform.

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