Rational methods of geodetic control of technogenic consequences of the development of oil and gas fields

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Abstract. The methods of controlling the consequences of the influence of manmade geomechanical processes caused by the extraction of hydrocarbons from the subsurface in the fields under development are considered. The possibilities of methods from the standpoint of separate determination of spatial and temporal quantitative parameters characterizing the deformed state of the skeletons of reservoirs and host rocks, the entire thickness of the rock mass above the deposit in an uneven field of compressive stresses and deformations of the earth's surface are shown. The inconsistency of methods of classical repeated leveling, geodetic positioning and traditional radar interferometry in connection with the low level of representativeness of their results is noted. scientific novelty lies in the development of ways to improve the effectiveness of the method of radar satellite interferometry. As a result, the conditions for the effective use of radar satellite interferometry on the basis of a network of stationary points which coincide with the points of the leveling network method of spot geodetic sounding of deformation processes in the oil and gas fields under development have been determined and characterized.

1 Introduction

Oil and gas fields in the Russian Federation are mostly located in the territories of the Arctic Zone of the Russian Federation. Special attention is paid to the study of natural and manmade deformation processes developed in the near-surface layers of the earth crust in connection with the extraction of hydrocarbons from the subsurface. This study is implemented in the form of monitoring deformations of the skeletons of reservoirs, their host rocks and the entire thickness of the rock mass, lying over the fields and manifested in deformations (shifts) of the earth's surface and activation of tectonic disturbances. These deformations may lead to the disruption of technological processes of hydrocarbons extraction from the subsurface and destruction of elements of field development. The priority in organizing monitoring is to obtain results that separately characterize the spatial and temporal parameters of natural and manmade deformation processes that have developed in the developed near-surface layers of the earth crust, which, together with exogenous natural deformations, manifest themselves in deformations of the physical (daytime) earth's surface. An important component of the vertical displacements of the physical earth's surface recorded during monitoring in the natural conditions of the Russian Arctic, is numerous and diverse deformations of the near-surface layers of the earth's crust generated by natural exogenous geomechanical processes [1, 2]. Such processes are noise in the monitoring of technogenic deformation processes.

Currently, several methods of studying deformations of the physical earth's surface and the near-surface layers of the earth crust have been proposed for monitoring technogenic deformation processes [2, 3, 4, 5]. At the same time, the design of geodetic observations, does not consider the issue of achieving the goals of monitoring and the possibility of practical implementation of the recommended methods in the prevailing natural and man-made conditions. The purpose of the article is to establish the factors determining the possibility of effective application in the conditions of the Russian Arctic of common and little-known methods for studying the deformations of the earth crust, its near-surface layers and the Earth's surface for monitoring man-made deformations of reservoir skeletons, their host rocks, displacements of the Earth's surface and activation of man-made disturbances in the territories of oil and gas fields being under development

2 Methods

At the present stage, the main method of monitoring of technogenic consequences of the development of oil and gas fields located in the Russian Arctic is the geodetic

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method of re-leveling the control leveling points of profile lines. At the same time, in the territories of the developed oil and gas fields located in the Russian Arctic, traditionally the structural solution of observation systems is reduced to the construction of mutually intersecting re-leveling lines with a length from several tens to hundreds of kilometers. leveling lines (profile lines) are fixed standard ground and rock (in the presence of rocks) leveling points without assessing their resistance to repeated leveling of profile lines is carried out by the Class II program without scientific substantiation of the accuracy of leveling, their periodicity and requirements for the stability of leveling points [2, 4, 5, 6].

Using the example of the Bovanenkovskoye field, it looks as follows: at the predicted values of rates of technogenic subsidence of the earth's surface vpredicted = 9.2 mm/year and length of leveling lines L ≈ 130 km, the standard error in determining rates of vertical displacements of the earth's surface by results of repeated leveling of class II ($\eta = 2\sqrt{2}$ mm/km) is $m_{v\,(predicted)} = \frac{\eta}{T}\sqrt{2L} \geq 32$ mm/year

(η, mm/km is the mean square error of leveling for 1 km of travel; T, year – frequency of leveling) with the unaccounted forecast instability of ground leveling indicates the influence of exogenous processes [5, 6]. in the unaccounted forecast instability of ground leveling indicates the influence of exogenous processes

3 Discussion

Exogenous natural factors and the geomechanical processes generated by them influence the results of repeated leveling and the physical earth's surface through exogenous near-surface movements of the Earth's crust. The dynamics of natural exogenous geomechanical processes and the displacements of leveling points and the physical surface generated by them is complicated by the diversity and variability in space and time of moisture and temperature fields in the near-surface layers of the Earth's crust, which are heterogeneous in composition and depositional conditions. Natural exogenous deformations are superimposed on the studied technogenic deformations of reservoirs and rock massifs and manifest themselves in complexly differentiated displacements of leveling points and the physical earth's surface, which are mistakenly attributed to the parameters of the studied deformation processes, namely:

- Seasonal thawing and freezing of dispersed soils in the conditions of the Russian Arctic is accompanied by their frost heave, generating vertical irreversible displacements of standard leveling points at a rate of up to 250 mm/year and fluctuations of the Earth's surface ± (4÷300 mm/year) [2, 7, 8].
- Thermal and moisture exchange in the near-surface layers of the earth's crust, composed of dispersed rocks, generates in them volume deformations (swelling and shrinkage), jointly manifested in poorly studied oscillatory and short-period vertical displacements of leveling points and heterogeneous in space and time hydrothermal movements of the physical earth's surface with an amplitude of several millimeters to meters [1, 2, 4].
- Periodic changes in the geothermal field of rocks and their temperature deformations cause inhomogeneous in space and time vertical displacements of ground and rock leveling points and the physical earth's surface with amplitudes from 0.2 mm to 39 mm [1, 2]. Consequently, the lack of consideration of significant effects of exogenous factors on the results of traditionally performed re-leveling, as well as other known disadvantages [2, 4, 5, 8], inherent in repeated leveling, exclude the possibility of its use for monitoring of man-made deformations at oil and gas fields developed in the Russian Arctic.

3.1. Method of spot geodetic sounding of deformation processes in oil and gas fields. Developed by the authors of the article and tested at the Yamburgskoye oil and gas condensate field [4], method of point geodetic observation of deformation processes in oil and gas fields allows us to separately monito the deformations of the reservoir skeleton, its host rocks and rock masses lying above the reservoir, as well as their joint manifestation in the movements of the Earth's surface.

At the same time, a geodetic network of observation stations is being created on the territory of oil and gas fields, consisting of reference (initial) and control (deformation) leveling points (LPs). Within the boundaries of the predicted manifestation of dangerous technogenic processes outside the integral contour of hydrocarbon production vertically or laterally, reference LP are equipped on the basis of mothballed exploration and observation wells. To control the development of deformations of reservoirs, rocks and the earth's surface at the lateral distance

$$S_{km} \leq \frac{3 \cdot 10^{-2} v_{predicted}^{2} T^{2}}{M^{2}}$$

($v_{predicted}$, mm/year – the predicted values of deformation rates; M, mm/km - the design accuracy of leveling) from the reference LPs on the basis of preserved exploration or observation wells, control deep LPs are equipped in pairs with control ground LPs. The base of the reference LPs is located above the developed deposit , and the bearing pipe of the reference soil LPs is embedded outside the zone of seasonal thawing (freezing) of soils in permafrost rocks to the depth $z \geq f\left(1 + 1,4\frac{P_{Spec\ Heaving}}{P_{Spec\ Freezing}}\right)$

at the thickness f of seasonal thawing and freezing of soils with specific values of soil heaving ($P_{Spec\ Heaving}$) and freezing of the bearing pipe with soil ($P_{Spec\ Freezing}$), in which the laying is carried out. Control LPs (based on wells) record reservoir deformations, while surface ones record total deformations of both collectors and rock massifs overlying the deposit, manifested in displacements of the earth's surface. The permissible influence of exogenous factors (interference of repeated leveling) on t LPs is set by an inequality $m_{interf} \leq 3 \cdot 10^{-2} v_{predicted} \cdot T$, and the distance of the reference LPs from the reference LPs of observation stations is designed as S < 1 km. This design of measurements makes it possible to register the deformations of reservoirs, rock massifs located above them, as well as the earth's surface throughout the year with an average square error of less than 1 mm.

Approbation of this method [4] confirmed the high accuracy, significance, and representativeness of the results of repeated leveling pf points performed as part of monitoring of technogenic deformations of the skeleton of reservoirs, rock massifs overlying them, and activation of tectonic disturbances in the territories of oil and gas fields located in the Russian Arctic. At the same time, it should be noted that the detail control of technogenic deformation processes on the territory of oil and gas fields by this method depends on the presence of preserved wells used as reference and control leveling points and the density of their location within the mining allotment.

3.2. Method for monitoring deformations of the Earth's surface based on global positioning stations.

The comparatively low accuracy of the results of determining the vertical component of the deformations of the Earth's surface 4-10 mm [3] and the level of their representativeness at high cost of staging and complexity of organizing satellite observations in the far North do not allow using this method when monitoring deformation processes in oil and gas fields located in the territories of the Russian Arctic.

3.3. Method for monitoring deformations of the Earth's surface based on the traditional radar interferometry techniques.

At the same time, the rates of such vertical displacements, as shown by studies [1], change in the natural conditions of the Russian Arctic during a day, month and year in the range from millimeter to 250 mm/year, with man-made shifts of the Earth's surface characterized by rates of 5-10 mm/year. Vertical displacements of the physical surface generated by exogenous geomechanical processes are difficult to differentiate in space and time due to the heterogeneity of the composition of the soils of the surface layers of the Earth's crust, their physical properties and natural and man-made conditions of occurrence [2, 4]. At the same time, the rates of such vertical displacements change in the natural conditions of the Russian Arctic during the day, month and year in the range from a millimeter to 250 mm/year, and manmade shifts of the Earth's surface are characterized by speeds of 5-10 mm/ year.

The determination of the deformations of the Earth's surface using the results of interferometric radar surveys carried out from spacecrafts is based on comparing the phase of radar signals reflected at points on the physical surface at certain time intervals. The choice of intervals between observations is not scientifically justified. In this case, the distances Di (i is the number of repeated interferometric radar survey) traveled by the radar signals in the direction from the spacecraft to j = 1, ... , m point of the physical surface and back are determined. By the sign ("+" and "-") and the magnitude of changes in the distances, the character (rise and fall) and the scale of deformations of the Earth's surface are judged. The development of deformations is caused by extraction of hydrocarbons from the subsurface, whereas the change in distances is the result of the combined impact on the physical surface of the Earth of natural exogenous geomechanical processes and deformations of mountain massifs and reservoirs caused by extraction of hydrocarbons [9, 10, 11].

It is obvious that exogenous geomechanical deformations of the physical surface of the Earth are a significant hindrance in determining the deformations of the Earth's surface, making it difficult or impossible to interpret the results of repeated radar surveys. The impossibility of interpreting the results of repeated radar surveys is also explained by the presence of snow cover on the reflecting surface during the autumn and winter periods and herbaceous vegetation in the summer period.

Consequently, the use of the interferometric radar survey method to monitoring the technogenic consequences of of hydrocarbon deposit development in the territories of the Russian Arctic is impractical because there is no possibility of obtaining reliable and representative data on the deformations of the Earth's surface. The obtained values of deformations indicate the stress-strain state of reservoirs and the overlying rock massifs.

3.4. Method for monitoring deformations of the Earth's surface using interferometric radar based on stationary points (InSAR).

The InSAR (Interferometric synthetic aperture radar) method is similar in principle to the method of monitoring the physical surface of the earth based on interferometric radar imagery from spacecraft. The difference can be attributed to the use of stationary reflectors, which are triangular prisms with a right reflecting inner angle. The levels of reflected signals from such reflectors are significantly higher than the levels of signals reflected from the physical surface of the Earth. The reflectors installed on the bases form a network of stationary InSAR points, which also includes roofs of buildings, large metal and other natural and man-made objects, which have reflectivity in relation to radar signals and do not experience vertical displacements due to deformations of their bases and foundations.

Studies of this method show that the accuracy, representativeness of its results and the effectiveness of their use in controlling the technogenic consequences of the development of hydrocarbon deposits in the Russian Arctic depends on the implementation of a number of conditions [9, 10, 11, 12, 13], namely:

- Combination of radar interferometric survey sessions with geotechnical monitoring cycles, which makes it possible to exclude from the survey results vertical displacements of real estate objects caused by deformations of their foundations and settlements (or elevations) of foundations.
- The size of the edges of the reflective prisms should provide a sufficient level of reflected radar signal and should be 1 meter or more.
- The design of the bases of reflective prisms should ensure their resistance to the effects of natural exogenous geomechanical processes within $\Delta_{destabilization} \leq 0,18 \cdot v_{predicted} \cdot T$ ($v_{predicted}$ - forecast rates of controlled deformations mm/year, T - frequency of repeated radar interferometric survey) [2].
- The use for the analysis of radar images obtained from the maximum possible number of spacecraft with various geometric groupings of spacecraft.
- The frequency and number of radar survey sessions should exclude the influence of the inhomogeneous ionosphere and atmosphere, that is, the requirements for the minimum number of freely distributed radar images (at least 12 pieces) must be met [9, 10].
- The value of the controlled vertical displacements based on the results of two radar surveys should be no more than 25% of the wavelength of the radar signal [10, 11].
- Inclusion in the network of stationary InSAR points, equipped on the basis of moth exploration and observation wells, located outside the integral contour of hydrocarbon production (reference points), as well as on wells, the bases (bottoms) of which are located above the developed deposit and on stable tubular ground leveling points [2, 4, 5].
- Mandatory verification of the results obtained by the InSAR method, based on their comparison with the results of repeated deformation processes obtained by the geodesic method of point probing.
- The use of radar images obtained from spacecraft in order to significantly reduce the influence of tropospheric noise (interference) [12, 13].
- Radar survey should be carried out in the absence of snow cover on the reflective elements of the terrain and prisms.

4 Conclusion

1. In the practice of monitoring to control the technogenic consequences of the development of oil and gas fields located in the territories of the Russian Arctic, over the last century and currently, there is essentially no even a formulation of research problems, as a consequence, there are no necessary solutions to the problems related to the choice of method for monitoring technogenic deformation processes, design of repeated instrumental and remote repeated observations, their implementation, as well as the description, analysis and interpretation of their results.
2. At the present stage [14, 15], the control of technogenic consequences of the development of oil and gas fields is possible with the joint application of methods of point re-leveling and interferometric radar survey as part of monitoring observations, given that the results of radar interoferometry allow minimizing the interpolation errors of the deformation characteristics point-set by repeated leveling over all areas of mining allotment.

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