Geodynamic Processes Modeling On Oil-Gas Deposits

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Abstract- The article is devoted to the study of geodynamic processes occurring during the development of hydrocarbon deposits in the western region of Kazakhstan. The results of the complex monitoring of the deformation of the earth's surface are presented on the example of areas of intensive and large-scale exploration of mineral resources in seismically active areas.
To perform the work following integrated research methods were used: analysis and synthesis of domestic and foreign experience in geodynamic studies; conducting repeated geodetic observations of the deformations of the undermined areas using modern geodetic instruments; assessment of various factors affection on the process of subsidence of the earth's surface by theoretical calculation of the subsidence of the roof of the stratum; affection of deposits development intensity on the earth surface displacement; conclusions on the nature of geodynamic processes in the territory under consideration.
Innovative methods of conducting geodynamic monitoring using modern geodetic instruments have been substantiated and proposed, which makes it possible to increase the reliability and efficiency of parameters determining of the earth's subsidence in order to ensure maximum safety and economic efficiency of oil and gas deposits development.
***Keywords**:* hydrocarbon deposits, earth surface, subsidence, roof of the seam, formation pressure, geodynamic polygon, geodesic monitoring, GPS observation, modeling of geodynamic processes.

1. Introduction

Subsoil of the western region of the Republic of Kazakhstan is rich in hydrocarbon deposits. Large-scale development of oil and gas resources leads to intensive movements of the earth's surface, both within local areas and in individual structural elements, resulting in borehole curvature, rupture of oil and gas and water pipelines, disruption of railways and highways, underground utilities and engineering structures, which in turn leads to significant economic damage.
Strong and even catastrophic geodynamic phenomena associated with oil and gas production have been recorded during hydrocarbon deposits development in many oil and gas basins of the world. These phenomena are realized in the form of earthquakes, faults activation, intensive subsidence of the earth's surface. Examples would be strong earthquakes in gas fields: Gazley (Uzbekistan), Lac (France), Strachan v Snipe Lake (Canada), Fashing (USA) and several others. These examples are direct consequence of changes in the geodynamic regime of the geological environment under the influence of large-scale exploration of the subsoil, which is convincingly confirmed by the results of experimental studies of earth surface movement conducted by KazNRTU named after K.I.Satpayev in the framework the "Program for conducting of comprehensive geodynamic monitoring of natural and technogenic processes in hydrocarbon field from 2012 till 2017" [1-3].
Interest to this problem all over the world is constantly growing from year to year. This is confirmed by various reports regularly published in international scientific and technical journals and discussed at annual scientific conferences devoted to methods development and principles for conducting geodynamic monitoring in hydrocarbon deposits territories. [4-6]
In accordance with [7] of the State Monitoring of the Subsoil of the Republic of Kazakhstan, function of the geodetic service are following: subsoil monitoring including the rocks displacement and earth's surface, geomechanical and geodynamic processes in subsoil use, as well as objects of the earth's surface and natural environment.
In order to monitor the current geodynamic state of the subsoil at oil and gas deposits, it is necessary to organize systematic (repeated) geodesic observations at specially created geodynamic polygons.
Forecasting these negative phenomena and reducing the scale of their consequences is an actual problem, as far as their occurrence can have disastrous consequences for enterprises and natural environment. In this regard, modeling of geodynamic processes based on geodesic observations on specially created geodynamic polygons is an actual scientific and practical task.

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The aim of the workto simulate geodynamic processes in hydrocarbon deposits in order to predict and reduce the consequences of dangerous geomechanical and geodynamic phenomena.
The main idea of the work to develop and use the various mechanical models to forecast the stress-strain state of rocks that fully reflect the specifics of the geological conditions of hydrocarbon deposits, as well as the results of instrumental observations of the deformation of the earth's surface and theoretical studies of the properties of productive objects.

2. The Object And Methods Of Research

Comprehensive geodynamic monitoring was performed on the territory of the North Buzachi oil - gas deposit located in Mangystau region of Kazakhstan.

3. Main Project Scope

Analysis of available geological, geophysical and field geological data, as well as data on the seismotectonic situation in the region allow justifying the need to use three basic methods (geodetic monitoring based on re-leveling, GPS monitoring and theoretical calculations) to solve the above problems at the first stage of monitoring. Further, the end result of comprehensive studies of the deformation of the earth's surface should be predictive geodynamic models that serve to prevent and ensure maximum safety in the development of oil and gas deposits.

4. Geodetic Observations

In accordance with the Program on conducting geodynamic monitoring on the territory of the Buzachi deposit the 3rd cycle of II class of enhanced accuracy was conducted in June 2016.
Basic requirements for construction of leveling points and technology for their backfill were taken from the Instructions for Leveling I, II, III and IV Classes, which were valid for that period of time. Table 1 shows main characteristics of the existing knowledge of re-leveling of II class of increased accuracy on the territory of deposit according to work results of 2012.
Fig. 1 shows design layout of leveling points in deposit and Fig. 2 shows diagram of actual position of II class re-leveling line increased accuracy and leveling points located along this line.

Profile number	Profile length (km)	Points amount	Cycles leveling amount	Average distance between points, m.
1-1	11,1	16	1	690

Blue circles - leveling points, combined with gravimetric points.
Red Circles - GPS Points

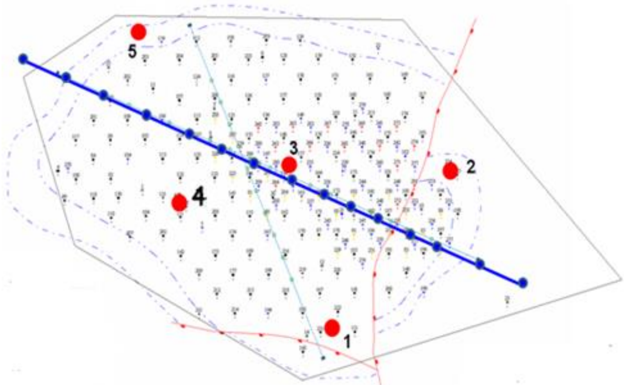

Fig. 1. Project location scheme of leveling points combined with gravity points and GPS points in deposit

Profile 1-1 runs along the strike of deposit. 15 leveling points were laid along profile in 2009. In addition, GPS point number 3 was included in the leveling. In total, 16 points were included along the profile 1-1 in the leveling of the 1st cycle [8].
As a result, control system is created for continuously changing geodynamic situation in accordance with continuously changing field geological situation in the process of hydrocarbon production. Combination of above basic methods along with available information will allow obtaining sufficient amount of information to study the properties and spatial-temporal manifestation patterns of deformation processes in deposit.
II class re-leveling of increased accuracy. In accordance with Program on conducting geodynamic monitoring on the territory of deposit regular cycle of II class leveling of increased accuracy was performed in August, 2016 and regular field reconnaissance was conducted on the territory.

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High-precision GPS measurements were continued on the deposit territory in 2016. Before the measurements reconnaissance network of GPS points was carried out, as result of which it was established that all the points are reasonably well preserved and suitable for measuring [9].
Measurements were carried out at 4 GPS points (including 1 main base of GPS-5 and 3 regular points). 4 sets of GPS equipment were used to perform GPS measurements: two-frequency receivers of the Leica 1200 type.
Positioning of 4 long-term GPS - points on deposit was determined in static mode in groups of 4 receivers with reference observations to the base GPS-5 reference point. Only two observation sessions were performed on polygon, the second session was control one. Observations were made in static mode with synchronous session duration of at least 24 hours with a recording interval of 30 seconds.
Field processing was carried out directly at the work site to assess measurements quality and need for additional control measurements. Processing was performed using the Leica Geo Office specialized software from the GPS-5 base station. Coordinates of base 5 are fixed at all time of monitoring.
Measurements quality was assessed by discrepancies at the points of sessions overlap. Total control measurements were performed on 3 points. The standard error of single determination of coordinates was ± 0.8 mm, heights - ± 1.3 mm. These results showed high accuracy of the work performed during GPS-measurement of 3rd cycle, which made it possible to use these results for comparison with the results of the previous measurement cycle.
Coordinates of GPS points obtained in 2016 made it possible to calculate vectors of the horizontal and vertical components of GPS point's movements on deposit. In turn, this made it possible to draw up diagrams of the areal distribution of the vertical and horizontal components of GPS point's movements for annual time interval scheme of which is shown in Fig. 2.

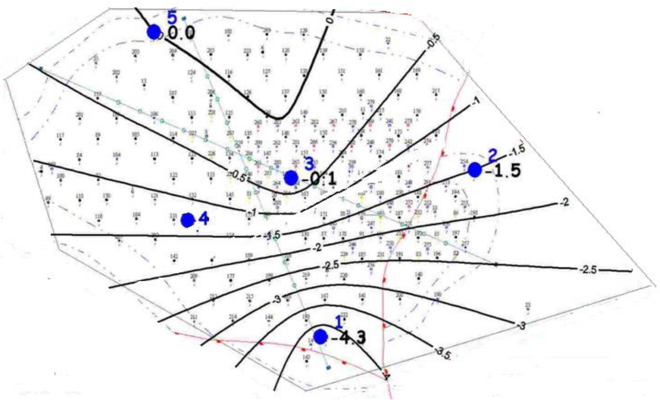

Fig. 2. Scheme of areal distribution of vertical componentsof GPS point's movements (contours) on the territory of deposit byGPS re-measurement data (2009-2016)

After consideration of these schemes we can conclude following:
1. Almost all territory of deposit is characterized by negative values of vertical component of GPS-point' s movement. The average value of the values of the vertical component of the movement of GPS points for the field is -2.0 mm. This value is in the area of measurement errors. The maximum negative values of the vertical component of the movements over a period of one year reach -4.3 mm (Fig. 2) and exceed measurement errors [10, 11].
2. The obtained comparison results of the first and second cycles of GPS measurements indicate the subsidence of the earth's surface in the central and south-eastern part of deposit. In this regard, results of repeated GPS measurements qualitatively coincide with the results of re-leveling, which also indicate the process of subsidence of the earth's surface of deposit.
At subsequent stages of GPS measurements results obtained in 2010 should be concretized taking into account the possible influence on these results of real man-made factors.
3. Area distribution of horizontal component of GPS point's movements is characterized mainly by their directional movement to the southeastern part of deposit (Fig. 3). The average value of horizontal component is 3.2 mm. The maximum values of horizontal component of GPS point's movements reach 4.9 mm (GPS-2). This amount of movement exceeds measurement errors and should be considered significantly.

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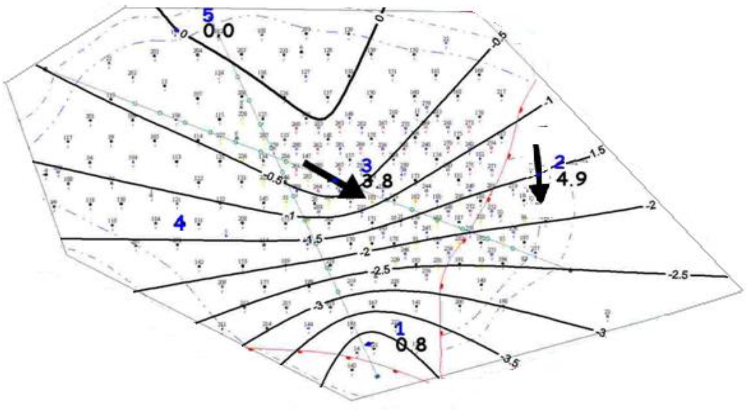

Fig. 3. Scheme of comparison of areal distribution of vertical andhorizontal component of the of GPS point's movements in the territory of deposit.

4. Attention should be paid to balance between areal distribution of vertical horizontal component of GPS point's movements, from which it follows that vectors of horizontal components of the movements tend to move towards the increased subsidence of the earth's surface. If this is so, then it can show that in subsequent measurement cycles, manifestation of natural tendencies is planned - horizontal displacements of rock massifs towards the subsidence trough. This trend has been reliably established for number of deposits in the Republic of Kazakhstan.

5. Theoretical Researches

Simultaneously, theoretical calculations of subsidence of the earth's surface were carried out. To correctly predict subsidence of the earth's surface (SES) and take appropriate measures to prevent harmful effects from oil and gas production, it is necessary to know technogenic component of total vertical SES, otherwise measures to prevent these subsidence will lead to unnecessary material costs and will be ineffective. In this connection, it is important to provide reliable and operational forecast of technogenic SES, which are scientifically based judgments about possible object's states in space and time.

Theoretical calculation results of man-made SES are less accurate than the actual repeated geodetic measurements. However, it seems promising to use them both at the design stage of man-made polygons (determining the locations of possible maximum SES) and to compare the calculated values of technogenic SES with similar values obtained by instrumental observations results [12].

The state of oil and gas reservoir in the process of its development depends on natural and technogenic factors. Natural factors include geological features of oil and gas reservoirs structure and rocks properties that make up the reservoir. Technogenic factors are following: ways of placing operational and injection wells, rate of extraction and injection of liquid and others. According to the hypothesis of the hydrostatic stressed state advanced by A.Geem, stress state of the earth's crust at any of its points is a function of the depth of occurrence of rocks. Heim believed that the stresses in the earth's crust should be distributed according to the hydrostatic law, i.e.

$$\sigma_x = \sigma_y = \sigma_z = \rho H \qquad (1)$$

Where **σ_x, σ_y**- normal horizontal stresses;
σ_z - vertical normal stress;
ρ - the volume weight of rocks;
H - the depth of the surface.

Taking the hypothesis of hydrostatic stress state, the magnitude of the vertical compression of the reservoir can be determined by the following formula

$$\partial \eta = \frac{1}{3} h\left[\beta_{ск} d(\sigma - P) + \beta_{TB} dP\right] \qquad (2)$$

where $\beta_{ск}$– index of volume compression of reservoir skeleton; σ- the average normal stress, MPa; h – the height of the reservoir, m; P - reservoir pressure, MPa; $\beta_{тв}$- compressibility factor collectors solid phase; dP - drop in reservoir pressure, MPa.

As can be seen from the formula (2) the basic parameters characterizing the volume compression of collectors are the value of volumetric strain and the magnitude of the reservoir pore volume strain of solid phase collectors.

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For the calculation of subsidence earth's surface features different formulas. S.Avershin derived equation for SES calculation [14]:

$$\frac{\partial \eta}{\partial z} = a(z)\frac{\partial^2 \eta}{\partial x^2}, \qquad (3)$$

In equation of R.Myuller [15] factor adopted by Z are linearly dependent:

$$\frac{\partial \eta}{\partial z} = a(z)\left[\frac{\partial^2 \eta}{\partial x^2} + \frac{\partial^2 \eta}{\partial y^2}\right], \qquad (4)$$

All equations η – JPG quantity; a (z) – coefficient characterizing the change in the properties of rocks in the vertical; x, y, z – rectangular coordinates.
Most accurately reflects the actual occurrence of reservoir conditions is considered to be the equation (4), but here it is necessary to determine three values (x, y, z).
For the SES calculation in terms of oil and gas deposits, we introduce a cylindrical coordinate system (Figure 4). Center field roof we accept as the origin of the system.

α - plane of the earth's surface; β - flat seam roof; H- the depth of the reservoir;
r- the radius of the formation.

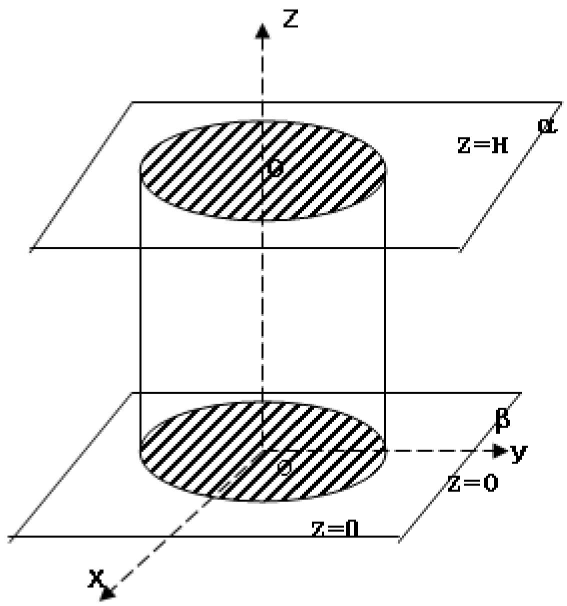

Fig. 4. Cylindrical coordinate system

Plats lies at a depth H and its radius is r. Subsidence of seam roof (SSR) does not extend beyond the circle of radius r c centered at the origin. In this coordinate system, the equation (4) becomes a parabolic form:

$$\frac{\partial \eta}{\partial z} = \left[\frac{\partial^2 \eta}{\partial r^2} + \frac{1}{r}\cdot\frac{\partial \eta}{\partial r}\right]\cdot a(z), \qquad (5)$$

After deciding the type of equation (5) was obtained by calculating formula:

$$\theta_{i,K+1} = \frac{1}{2}\theta_{i,K} + \frac{1}{4}\left(\theta_{i-1,K} - \theta_{i+1,K}\right) + \frac{1}{8i}\left(\theta_{i-1,K} - \theta_{i+1,K}\right), \qquad (6)$$

where $\theta_{i,K}$ – approximate value of subsidence; *i* – step number (range) horizontally; K – step number vertically.
Calculations were carried out both in fissured-cavernous and granular reservoir for a period of time beginning development to 2010 on the fields of Kazakhstan. Note that on the deposits of granular reservoirs shear roof subsidence rate were equal to zero. Maximum roof subsidence on fissured-cavernous (pore) collectors was

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observed by the deposit Makat (64 mm) from 1974 to 1976. Reason for high rate of roof subsidence on this deposit is a significant reservoir pressure decline and large capacity of developed reservoir.
If we compare the fields by the roof subsidence indicators for the period of operation, we should single out the Tengiz field, where the maximum value of SSR is q = 58 mm or V = 12 mm / year for 5 years. Despite the fact that the depth the reservoir of the Tengiz field is huge (m = 1500 m) compared to other deposits, the value of the average subsidence of the roof subsidence in 5 years is only 12 mm. This small value is due to the maintenance of reservoir pressure at the initial level (insignificant drop of 2.6 MPa), as well as by the elastic properties of the reservoir.
Now that theoretical values of SSR are known, it is necessary to determine what part of this subsidence is transferred to the daytime surface, i.e. predict the SES deposits.
Since the extraction of fluids is carried out from great depths, and the maximum roof subsidence is only 60 mm in five years, it is first necessary to theoretically test whether there is any place of land subsidence at all. For this purpose, the minimum depth of occurrence of the deposit of the considered deposits is taken to be H=3500 m and the maximum value of SSR is $\approx$60 mm.
The problem reduces to determining the subsidence of the point 0_1, located at a distance of 3500 m from the point 0 (Figure 7). To solve such a problem it is necessary to calculate successively the subsidence of points along the 00_1 axis, which are from point 0 at distances of 500.0; 100.0; 1500.0 and 3500.0 m. In the notation of formula (5), these will be the values: $\theta_{0.2}$ ($\theta_{1.1}$), $\theta_{0.3}$ ($\theta_{1.2}$), $\theta_{0.4}$ ($\theta_{1.3}$), $\theta_{0.5}$ ($\theta_{1.4}$), $\theta_{0.6}$ ($\theta_{1.5}$), $\theta_{0.7}$ ($\theta_{1.6}$), $\theta_{0.8}$ ($\theta_{1.7}$) and so on.
Carrying out calculations using formula (6) is a very complex and time-consuming task. Therefore, express calculation methodology of has been created with the aim of operational forecasting of the SSR and SES. Based on the results of theoretical calculations, the graph-analytical dependence of the SSR on the depth of the developed reservoir is obtained (Fig. 5).

$$\theta_{exp} = 0{,}015\, ln(0{,}01 \cdot H) \qquad (7)$$

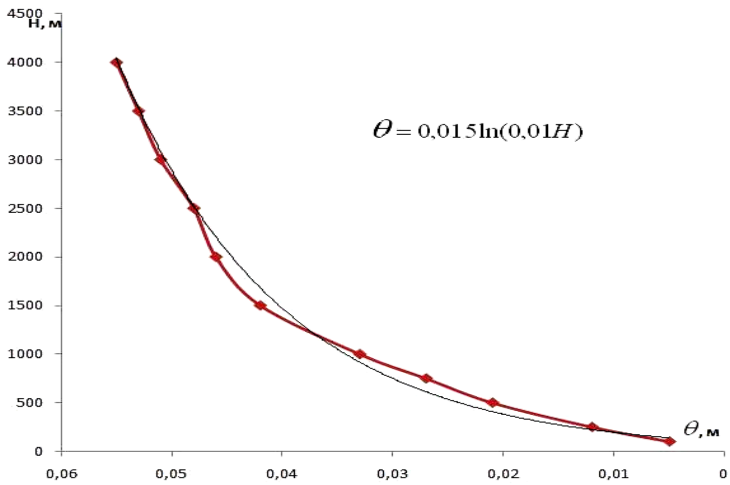

Fig. 5. Dependency graph of SSR on the depth H

Figure 5 shows that with increasing depth of fluids production reservoir pressure increases, hence, the value of SSR are greater than in shallowness. When impact of mining development on SES is considered with increasing depth of development the magnitude of the deformations alternately decreases [16].
According to this truth for SES prediction based SSR and depth of development and received graphoanalitical dependence (Figure 6), where the horizontal axis represents SES.

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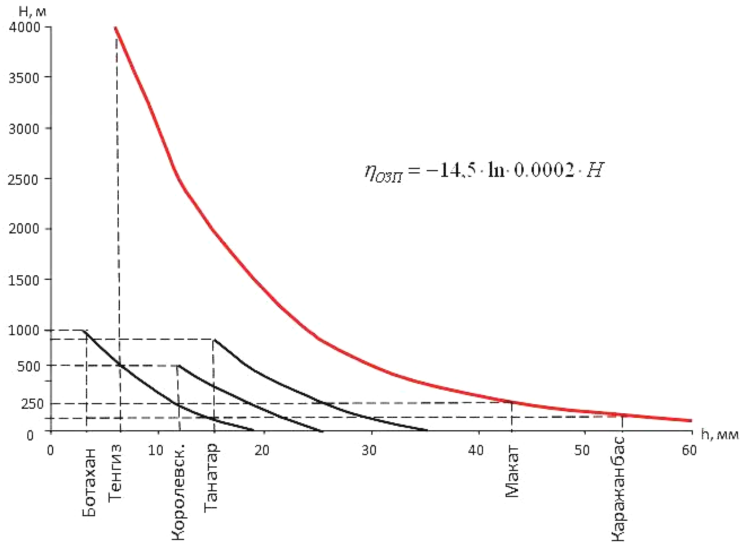

Fig.6. Graph predict of SES depending on SSR and the depth of the development of the H

Thus, to predict SES depending on SSR and depth of development, two types of grapho-analytical relationship are recommended: exponential (logarithmic) and linear.

$\eta_{\text{ОЗП}\ exp} = -14,5 * ln * (0,0002H)$ (8)

With an accuracy of 6,8% and linear.

$\eta_{\text{ОЗПлин}} = 45,5 - 0,0127H$ (9)

with an error of 29.8%, i.e. logarithmic dependence more accurately predicts the subsidence of the earth's surface and easier to make calculation.
As seen from the graph, on the earth's surface at a depth H = 4 km of 6 mm is passed magnitude roof subsidence is 60 mm.
On the Kenkiyak, Kulsary, Oryskazgan and other deposits, where the development depth is more than 1000 m, and SSR on the day surface is not transmitted at all, i.e. SES will be zero. In contrast to these, in the Makat, Tanatar, Korolevskoye, Tengiz and Botakhan deposits, the technogenic SES are 43, 18, 12, 6, 4 mm, respectively

5. Geodynamic Processes Modeling

The result of complex studies of earth's surface deformation should be predictive geodynamic models that serve to prevent dangerous displacements leading to man-made earthquakes and disruption of the integrity of the territory's ecosystem. Over the past decades, various methods have been undertaken for calculating the subsidence of the earth's surface based on theory of elasticity, theory of plasticity, on the theory of the ultimate equilibrium of friable medium using differential equations and models of random processes. Each of these approaches has its undoubted advantages and weaknesses. In our opinion, more modern and universal approach to modeling dynamic processes is method based on the use of cellular automata [17].
Cellular automata are universal computing environment for modeling the dynamics of complex systems. We made forecast of the strain – stress state of mountain massif. Data obtained made it possible to carry out reliable forecast of the stress-strain state of the mountain massif with further oil production. The reservoir lies at considerable depth and is represented by fairly strong limestone, deposit is characterized by abnormally high reservoir pressure. The complex salt-dome tectonics, as well as the asymmetrical nature of the area of lowering the initial reservoir pressure, necessitated the development of a volumetric finite element model (Fig. 7) Productive carbonate rocks were the main "base" layer.

Fig. 7. Volumetric model of oil deposit site

Results discussion of ground-based monitoring of earth surface displacements that occurred over Tengiz field and recorded during the interferometric processing of ENVISAT radar data showed the presence of land surface

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accelerations over the area of active hydrocarbon production from this field. As well as the results of interferometric monitoring fully confirm data obtained by geodetic observations in the period 2008-2016.
Technique of conducting repeated observations of the points of GDP has been improved, including complex geodesic observations: (high-precision digital leveling electronic tachometers and GPS-technology) which will improve the accuracy and efficiency of determining of earth's surface subsidence and the effectiveness of monitoring due to the computerization of field and office of surveying and geodetic works [18,19].
Currently, instrumental geodynamic studies conducted in a number of regions have shown that in many cases localized seismic manifestations and accidents are directly or indirectly associated with anomalous changes in the current strain - stress state of the earth's surface. The technogenic geodynamic phenomena are necessarily confined to the areas of the influence of technogenic loads created in the production areas.

6. Conclusions

1.Comprehensive analysis of domestic and foreign experience in geodynamic studies on instrumental observations of deformations areas was carried out, which allowed developing methodology for integrated assessment and prediction of hazardous phenomena in GDP.
2. Results of the second cycle of GPS measurements on the territory of deposit and their comparison with the results of measurements in the first cycle allowed us to outline some trends in the areal distribution of vertical and horizontal component of movements. Once again, it should be emphasized that results obtained are the first experience of conducting repeated GPS measurements on the territory of deposit which should be specified and refined by subsequent measurements.
3. Method for calculating SSR to predict SES according to the data SSR has been developed, novelty of which lies in the theoretical support of the interaction of the deformations of roof of the sea and the earth’s surface with technological parameters.
4. A numerical model for estimating the intensity of anthropogenic seismic phenomena in oil and gas production has been developed and implemented, based on the use of special model of rocks, taking into account the full deformation diagram along sectional planes. In the future, all information about the patterns of displacement process of the system and the parameters of its critical state enters into an expert system, which based on database integration and knowledge assessment and the corresponding solutions are justified. Ultimate goal of these solutions - to ensure industrial safety of subsoil development.

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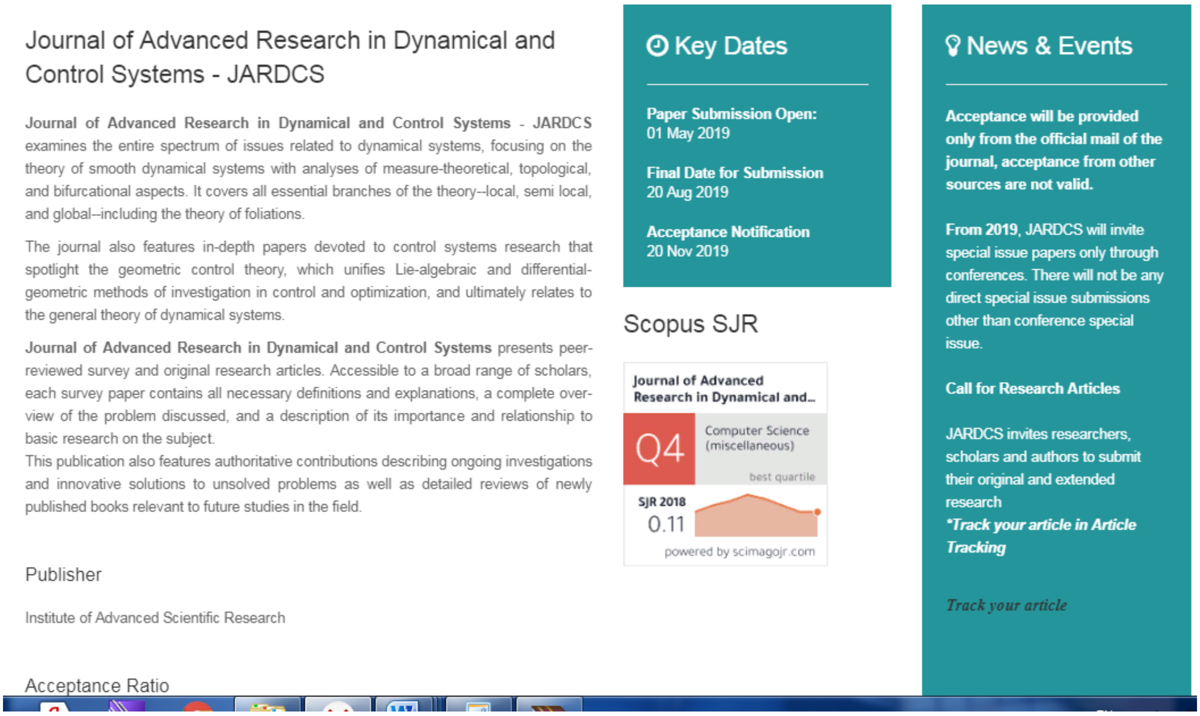

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