ANNOTATION

of the dissertation work on the topic:

"MODELING OF GEODYNAMIC PROCESSES IN THE OIL AND GAS FIELD NORTH BUZACHI"

submitted for the degree of Doctor of Philosophy (PhD)
in the specialty 6D071100 - "Geodesy"

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The purpose of the study is to establish the patterns of subsidence of the earth's surface in a hydrocarbon field from the depth of the oil reservoir and changes in reservoir pressure to model geodynamic processes and predict future risks.

The main idea of the work is to consider the spatio-temporal trend of subsidence of the day surface, taking into account the Knote influence function.

Object and subject of research. The object of study is the Northern Buzachi oil and gas field in the Mangystau region. The subject of research is the process of subsidence of the earth's surface as a result of hydrocarbon production.

Research objectives. To achieve this goal, the following tasks were solved:

1. Determine the relationship between the depth of the oil reservoir and subsidence of the day surface.
2. Establish the regularity of subsidence of the day surface, depending on the physical and mechanical properties of rocks, the location of productive layers and changes in reservoir pressure.
3. Create a predictive geodynamic model in the development area of the Northern Buzachi oil and gas field.

Research methods. To solve the tasks set, a complex research method is used, including a systematic approach, comparative analysis, mathematical modeling, mathematical statistics, assessment of the accuracy of observation results and experimental calculations.

The relevance of the dissertation topic. As a result of the long and intensive development of oil and gas fields in Western Kazakhstan, the likelihood of man-made earthquakes is growing, which can lead to serious environmental, social and economic consequences.

A number of seismic events have already taken place in this region. For example, in 2008, an earthquake with a magnitude of 7 points occurred in the area of Lake Shalkar; An earthquake with a magnitude of 4.1 was registered on the territory of the Tengiz field. April 2000 there was a large-scale subsidence of the earth's surface, as a result of which huge sections of the Kalamkas and Karazhanbas fields, which are located close to the Northern Buzachi field, were flooded. In December 2018, the seismological services of Kazakhstan registered an earthquake with a magnitude of 3.3, 345 km from the city of Aktau.

It should also be noted that a number of nuclear explosions were carried out in the Caspian region to store gas condensate with the formation of large underground cavities, which also contributes to the occurrence of man-made earthquakes.

The general geodynamic situation of this region is also a consequence of the tectonic activity of the West Turan Plate, where most of the oil and gas fields are located.

In connection with the foregoing, the study of geodynamic processes in the territory of hydrocarbon deposits in Western Kazakhstan is a particularly urgent task. Since, the prevention and forecasting of dangerous geodynamic situations, based on the creation and application of predictive geodynamic models, calls for choosing a more environmentally friendly way to develop oil and gas fields and avoids negative environmental and economic consequences.

The creation of predictive geodynamic models that take into account the geology of the territory, the geometry of oil and gas reservoirs and the field characteristics of hydrocarbon deposits allows early warning of dangerous movements of the earth's surface and contributes to the safe development of deposits.

Scientific provisions submitted for defense:

1. Subsidence of the earth's surface in a hydrocarbon field varies from the depth of development according to a logarithmic dependence;
2. The variability of subsidence of the day surface, depending on the physical and mechanical properties of rocks, the location of productive layers and changes in reservoir pressure, is described by the Knote influence function, which differs in the mathematical description of the subsidence bowl.

Scientific novelty of the results of the work:

- establishing the relationship between the subsidence of the earth's surface and the depth of the formation;
- establishing regularities of subsidence of the day surface from the physical and mechanical properties of rocks, the location of productive layers and changes in reservoir pressure;
- building a predictive geodynamic model on the territory of the Northern Buzachi field.

The main results of the study:

1. The relationship between the subsidence of the earth's surface and the depth of the reservoir, in the form of a logarithmic function, has been established.
2. A geological model of the field has been built, which makes it possible to take into account the depth and thickness of oil reservoirs.
3. A calculation formula for the subsidence of the day surface is proposed, built on the basis of the adapted Knote influence function, which allows mathematical description of the existing trend of the day surface displacement in the territory of the oil and gas field.
4. A predictive simulation model has been built that takes into account the geological structure of the field, the physical and mechanical properties of reservoir rocks, the intensity of field development and geodetic observation data on the territory of the North Buzachi oil and gas field.
5. The results of the research are introduced into production (Geoservice-S LLP), included in lecture materials and practical exercises for undergraduates (International Educational Corporation), confirmed by the relevant Implementation Acts. The

monograph "Comprehensive monitoring of oil and gas fields in Kazakhstan" was published by the Lambert publishing house, Germany, in co-authorship with a scientific consultant.

The author's personal contribution consists in setting the goals and objectives of the research; in the study and analysis of geodynamic modeling methods on the territory of hydrocarbon deposits; in performing calculations using two methods of modeling and comparative analysis of the results; in creating a geological and geodynamic model of the field in Datamine and Matlab programs; establishing a correlation between the depth of the formation and subsidence of the day surface; establishing patterns of subsidence of the earth's surface; in the publication of articles based on research results.

The validity and reliability of scientific provisions and conclusions is confirmed by: high convergence of model values of subsidence of the earth's surface with the results of geodetic observations made in the field; the practice of using the results of research in production (TOO "Geoservice-S"); positive assessment and approbation of the results of the work at various conferences and in the press.

The scientific significance of the work lies in obtaining a new algorithm for calculating a predictive geodynamic model that contributes to the safe development of hydrocarbon deposits.

Practical significance of the work: the obtained algorithm for calculating the construction of a geodynamic model serves to perform a predictive assessment of deformation processes, which contributes to the safe development of the field. The method of calculating the geodynamic model is used at the Department of "Engineering Geodesy" of the International Educational Corporation and at the Department of "Mine Surveying and Geodesy" KazNRTU named after. K. Satpaev.

Approbation of work. The main provisions and results of the dissertation work were reported and discussed at the following scientific-practical and international conferences: International scientific-practical conference "Satbaev Readings" (Almaty, KazNITU, 2018, 2019); International mine surveying forum "Digital technologies in geodesy, mine surveying and geomechanics" (Karaganda, KSTU, 2019), International scientific school of young scientists and specialists "Problems of subsoil development in the 21st century through the eyes of young people" (Moscow, 2019), International scientific and practical conference, dedicated to the 115th anniversary of Corresponding Member. Academy of Sciences of the Kazakh SSR A.Zh.Mashanov and the 100th anniversary of the Academician of the Academy of Sciences of the Kazakh SSR Zh.S. Erzhanov (Almaty, KazNITU, 2022).

Publication of work. 17 scientific papers were published on the topic of the dissertation, of which: 2 articles in journals included in the Scopus database (percentile - 40) and Web of Science (pre-base), 5 articles in journals of the Ministry of Education and Science of the Republic of Kazakhstan recommended by the Committee for Control in in the field of education and science of the Ministry of Education and Science of the Republic of Kazakhstan, 6 articles in the materials of international scientific and practical conferences, forums and congresses, 1 co-authored monograph.

Scope and structure of work. The dissertation work consists of an introduction, four chapters, a conclusion and a list of references. The work is presented on 89 pages of computer text, contains 13 tables, 49 figures, a bibliography of 80 titles.

The main content of the work

In the first chapter of the dissertation, the relevance of the problem of environmentally friendly development of hydrocarbon deposits is considered. Examples of geodynamic consequences of field development are given. The review of the reported and foreign literature on the topic of the dissertation is carried out.

An analysis was made of the method of monitoring on geodynamic polygons, including the method of high-precision leveling, satellite geodetic observations, gravimetric observations and seismic monitoring. Information about the study object of the Northern Buzachi oil and gas field is also presented, including the location, geological, tectonic and seismic characteristics of the object. The main factors of geodynamic risk as a result of long-term development of the field are highlighted. The analysis of geodynamic monitoring methods is carried out.

In the second chapter, methods for determining the magnitude of vertical movements of the earth's surface, a method for theoretical calculation of technogenic subsidence of the roof of the reservoir and the earth's surface are considered. The formulas for calculating the vertical compression of the reservoir are given, taking into account the hypothesis of the hydrostatic stress state of the rock mass.

This chapter also discusses methods for constructing a predictive geodynamic model, in particular, in the form of a stochastic model of soil subsidence, which allows statistical processing of soil movements. The application of this type of model assumes that the earth will reach its most probable state of geomechanical equilibrium when the field is completed. As a result, the normal distribution function (Gaussian distribution function) is taken to be a function that transforms the cause of deformation - pressure compaction in the form of a trough of subsidence.

Another method, considered in the second chapter of the scientific work, combines elements of the analytical and numerical approaches, combining a number of analytical functions that satisfy the elasticity equations, in such a way that the boundary conditions are approximated. This approach makes the method more widely applicable than analytical approaches, and the calculation time is much less than for numerical (for example, finite element) simulators.

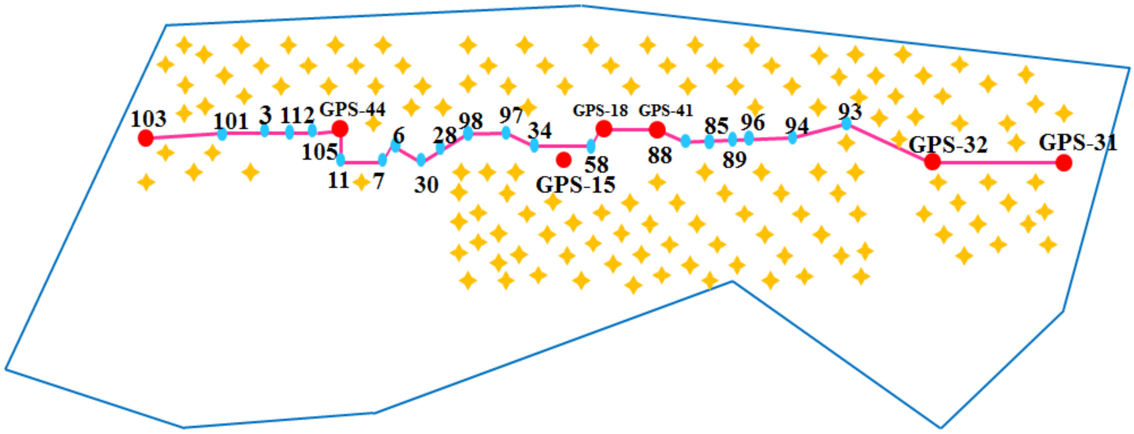
The third chapter is devoted to the implementation of geodynamic monitoring at the Northern Buzachi field. The geodetic security of the deposit area, the creation of a geodynamic polygon in the territory under consideration, as well as the basic system for monitoring the geodynamic state of the subsoil in the territory of the Northern Buzachi deposit are given. The results of repeated high-precision leveling and data processing are given. The subsidence troughs found on the territory of the deposit are described.

On the territory of the field, in order to provide geodetic support for exploration and development work, topographic survey of the territory, and under the program for building state geodetic networks, work was carried out to create high-rise and planned networks of various classes.

In particular, the following geodetic works were previously performed:

- ✓ Polygonometry of the 1st category at the site "Northern Buzachi" were carried out by Predpr. No. 11 of the GUGK, 1998-1991;
- ✓ Class IV leveling at the "Northern Buzachi" site (Project No. 18 of the GUGK, 1987-1988);
- ✓ Triangulation of class 4 and polygonometry of classes 3, 4 at the facility (Enterprise No. 18 of GUGK, 1986-1988);
- ✓ Leveling of work at the facility by the Ukrainian "GiproNIIneft" together with the 105th expedition of the GUK of Kazakhstan, 1990-1991.
- ✓ The leveling of the first category performed at that time included 48 geodetic signs. The measurements were carried out along separate profiles crossing the anticlinal zones.

On fig. 1 shows the design scheme for the location of leveling points on the territory of the deposit. Profile 1-1 runs along the strike of the field. Along the profile in 2016, 12 main and 7 additional leveling points were laid. In addition, there were 4 GPS points in the leveling.



– are leveling points combined with gravimetric points.

- GPS points

Fig. 1. Scheme of the design location of points on the territory of the North Buzachi field

The fourth chapter presents the results of a comparative analysis of two methods of geodynamic modeling, as well as a geological model of the field built in the Datamine program. A simulation-predictive model of the territory of the Northern Buzachi field in the Matlab program is presented, and a forecast of the geodynamic situation for the next 8-9 years is made.

As a result of a set of stratigraphic data base in the Excel program for all available wells (approximately 450), the location of productive formations was determined and the location of the wells was adopted in the Datamine software product (Fig. 2).

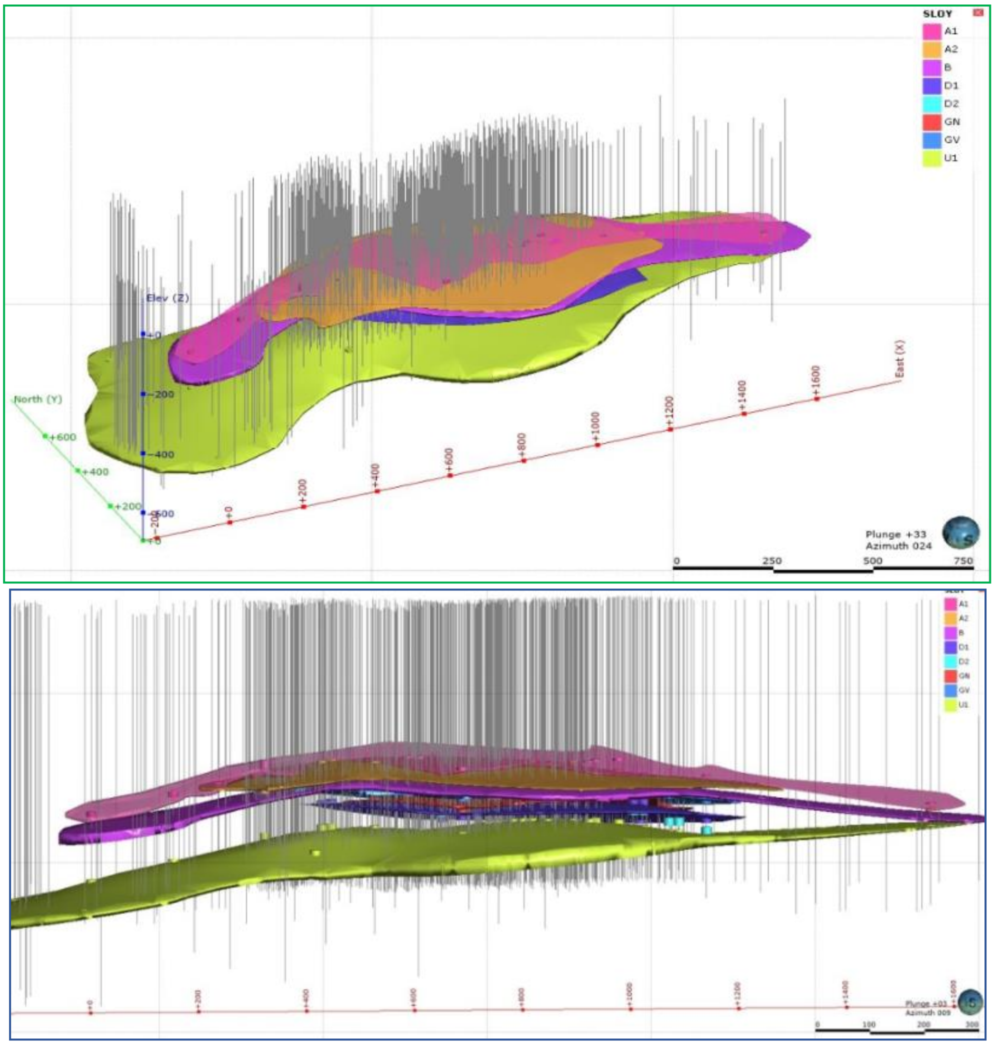
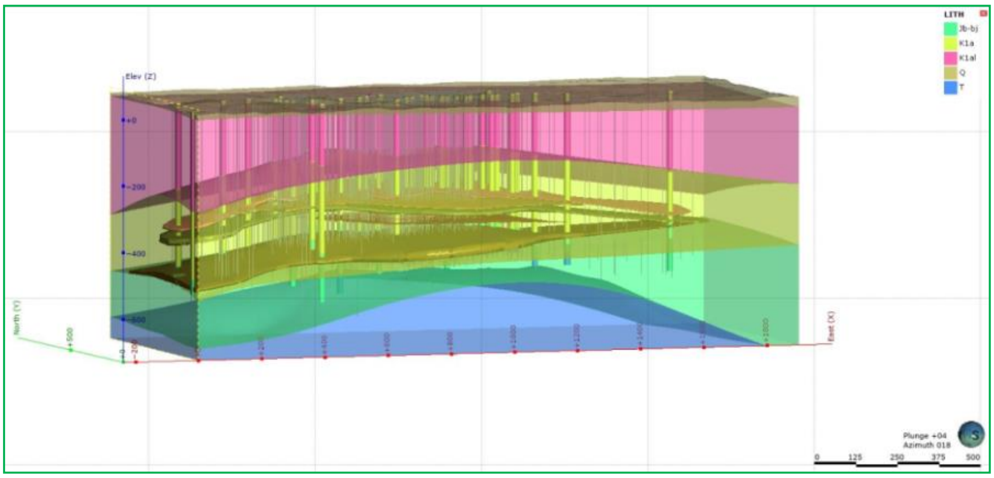


Fig.2 Location of productive formations in the field

Layers of geological periods were built: Quaternary, Upper Cretaceous, Lower Cretaceous, Triassic and Jurassic.

The resulting geological model (Fig. 3) of the field makes it possible to take into account the depth of productive formations and their thickness in different parts of the field.



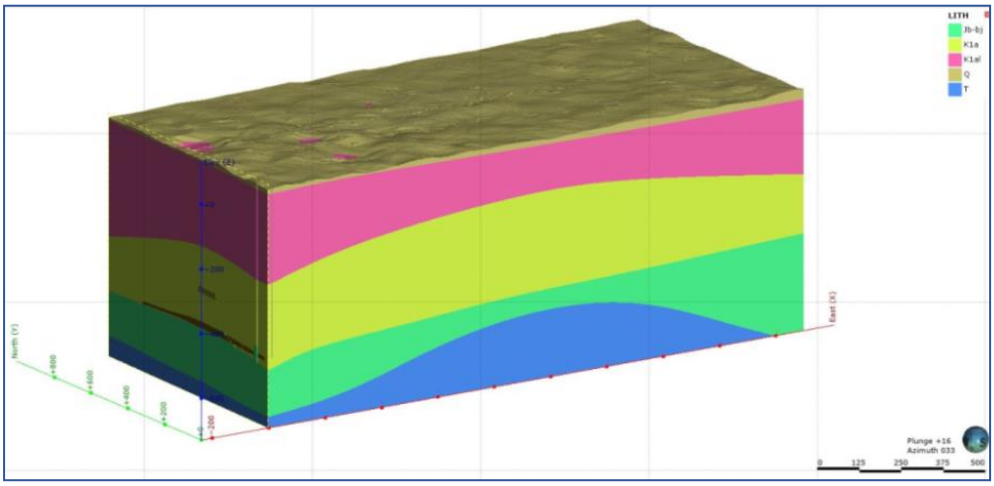


Fig .3 Geological model of the deposit

At the next stage of research, it is necessary to take into account the correlation between the change in reservoir pressure **Δp** and subsidence of the day surface **S**, since now we will build a model based on the Knote influence function k_z and taking into account the depth of the reservoirs **h**, changes in reservoir pressure and compaction of the reservoir rock **C** according to the formula (1):

$$S = -a\int_A Ck_z dA \qquad (1)$$

Here, the value of C will be found from the expression:

$$C=C_m \Delta ph, \qquad (2)$$

where Cm - Cm(z) is the coefficient of uniaxial compaction in (kPa–1) and is found by the formula:

$$C_m = C_b \frac{1+\nu}{3(1-\nu)}, \qquad (3)$$

where **ν** is the Poisson's ratio and C_b is the volumetric compressibility in (kPa–1), which is found from the expression:

$$C_b = \frac{0{,}001}{P_e} \qquad (4)$$

Where P_e- is the effective pressure, defined as the difference between the overburden pressure *Pr* and the average fluid pressure in the reservoir P_0 (Fig. 4):

$$P_e = P_r - P_0, \;\; P_r = \rho_r gH \qquad (5)$$

where ρ_r – overburden rocks, g – acceleration of gravity, H – formation depth.

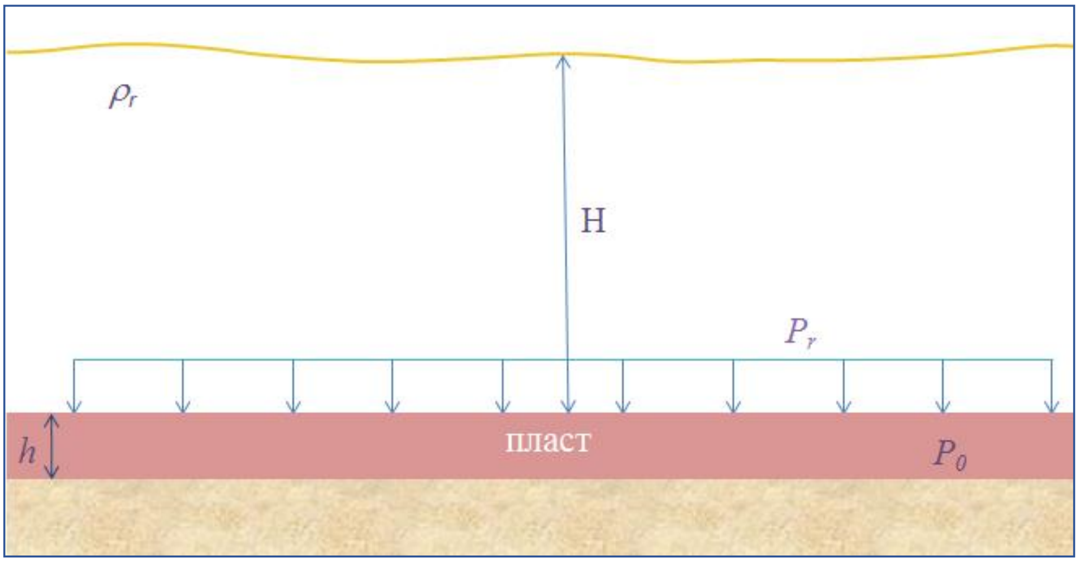


Fig.4. Rock compaction

If we take the average depth of the reservoir H=315m, g=9.8m/s^2, ρ_r = 1850kg/m^3 (taking into account the fact that the overburden is represented by sands, loams, sandy loams, silts and clays), we get:

$\sigma_г=\rho*g*H=1850*315*9.8=5.7$ MPa; $\sigma_0=3,6$Мпа; $\sigma_{эф}= 2.1$ MPa.

When creating a predictive geodynamic model, it is also necessary to take into account the depth of the reservoir location. In this case, the influence of the thickness of the overburden will be taken into account when calculating the coefficient a, which is the coefficient of formula (1) for calculating the amount of subsidence of the day surface.

Taking into account the different depths of location and the observed subsidence in different parts of the field, we performed a correlation-regression analysis and selection of an approximating function. At the same time, the reservoir depth - H (x) was taken as an argument, and the multiplier - a (y) as a function. The result of the regression analysis is shown in Table 1.

Table 1. Log Regression

i	x_i	y_i	$\hat{y}_i$	$y_i-\bar{y}$	$(y_i-\bar{y})^2$	ε_i	ε_i^2	A_i	$\Delta\varepsilon_i$	$(\Delta\varepsilon_i)^2$
1	50	0.69	0.6859	0.2962	0.0877	0.0041	0	0.0059	—	—
2	100	0.57	0.6091	0.1762	0.031	−0.0391	0.0015	0.0687	−0.0432	0.0019
3	150	0.55	0.5642	0.1562	0.0244	−0.0142	0.0002	0.0259	0.0249	0.0006
4	300	0.5	0.4874	0.1062	0.0113	0.0126	0.0002	0.0251	0.0268	0.0007
5	500	0.45	0.4308	0.0562	0.0032	0.0192	0.0004	0.0426	0.0066	0
6	700	0.42	0.3936	0.0262	0.0007	0.0264	0.0007	0.0629	0.0073	0.0001
7	1000	0.4	0.3541	0.0062	0	0.0459	0.0021	0.1149	0.0195	0.0004
8	1500	0.33	0.3091	−0.0638	0.0041	0.0209	0.0004	0.0632	−0.0251	0.0006
9	1800	0.3	0.2889	−0.0938	0.0088	0.0111	0.0001	0.0369	−0.0098	0.0001
10	2100	0.25	0.2719	−0.1438	0.0207	−0.0219	0.0005	0.0874	−0.0329	0.0011
11	2500	0.23	0.2525	−0.1638	0.0268	−0.0225	0.0005	0.098	−0.0007	0
12	2800	0.22	0.24	−0.1738	0.0302	−0.02	0.0004	0.0909	0.0026	0
13	3000	0.21	0.2323	−0.1838	0.0338	−0.0223	0.0005	0.1064	−0.0024	0
$\sum$	—	—	—	—	0.2827	—	0.0075	0.8288	—	0.0055

The result of approximation by a logarithmic function is shown in Figure 5.

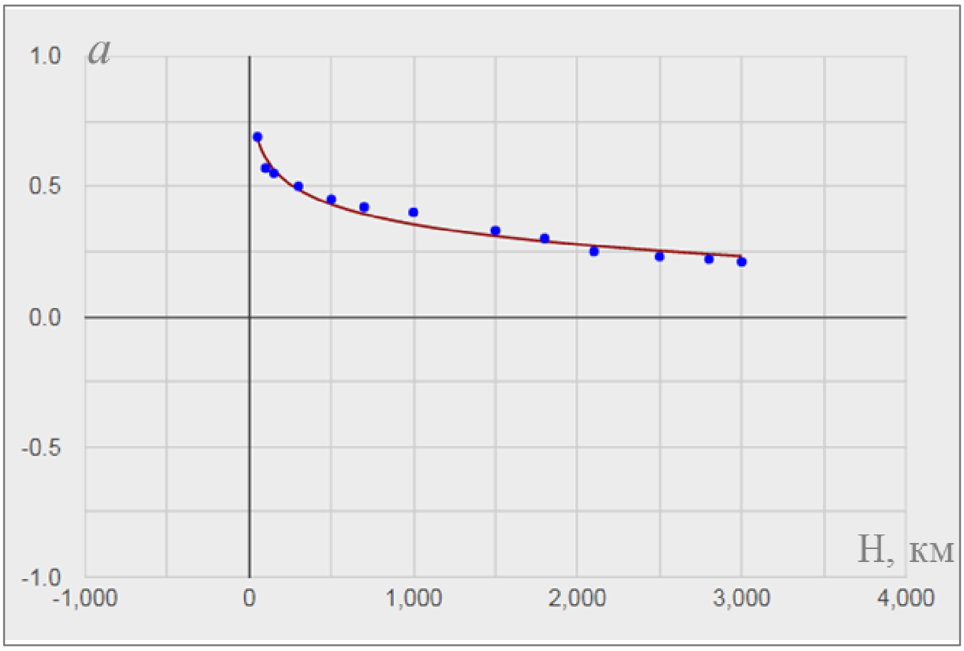


Fig.5 Approximation by a logarithmic function

The established logarithmic dependence between the considered parameters H and a is described by the expression:

$$a=1.1193 - 0.1108 \cdot lnH \tag{6}$$

.

Correlation coefficient R_{xy}= 0.98, and the average approximation error M=6.37%.

And in the case of approximation by a linear function (Fig. 6), the coefficient of linear pair correlation R_{xy}= 0.89, and the average approximation error M=9.81%.

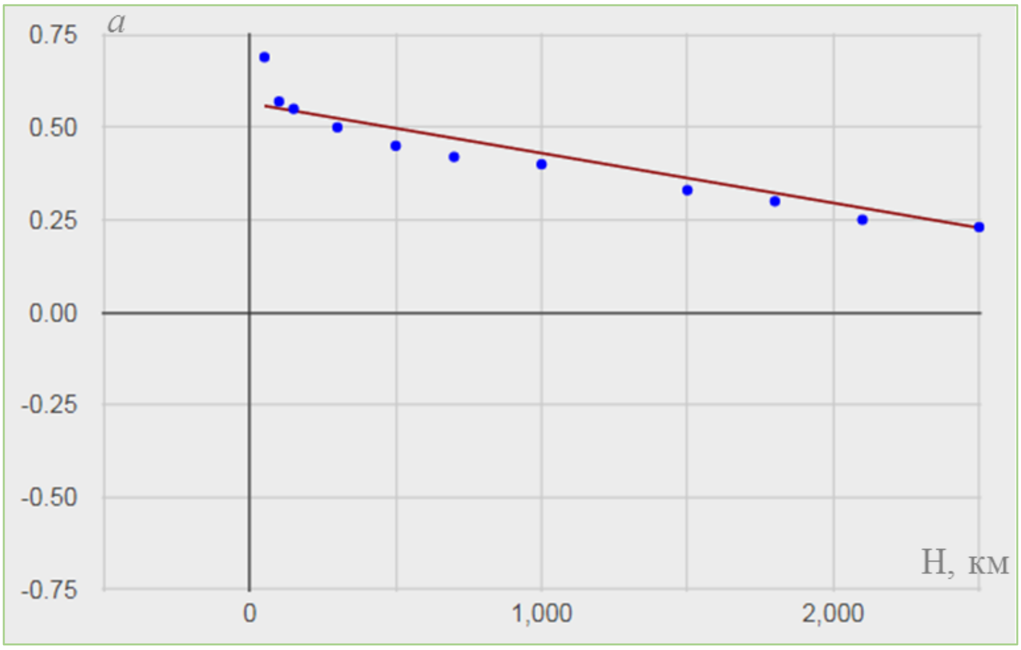


Fig.6 Linear function approximation

To calculate the subsidence of the day surface, we use formula (1) and, as a result of calculations, we obtain a model of the subsidence bowl (Fig. 7).

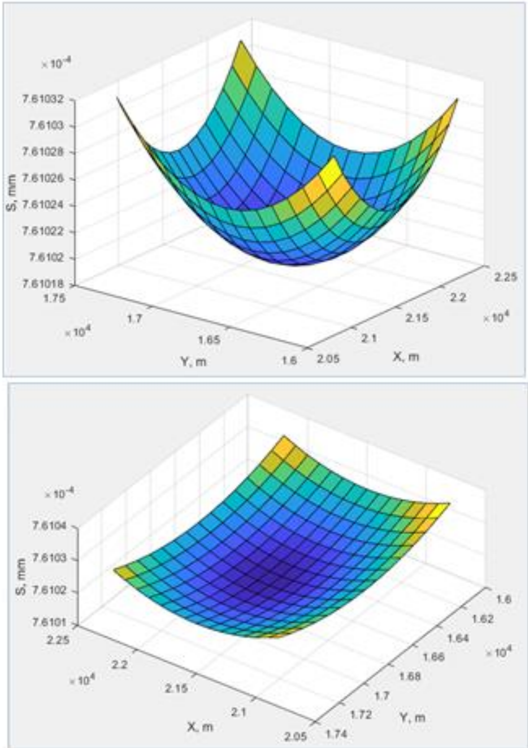
As can be seen, the calculated and actual values of subsidence are very far from each other, because the Knote influence function, determined from the following expression:

$$k_z = \frac{e^{\left(\frac{\pi r^2}{R^2}\right)}}{R^2}. \quad (7)$$

does not allow to obtain the desired shape and depth of the bowl of subsidence. In order to eliminate this shortcoming, we will somewhat change the form of the Knote function by removing - R^2 in the denominator, and also by removing π from the exponent. Such modifications will make it possible to obtain a more accurate simulation model of the subsidence of the day surface.

It should be noted that a new expression for the function describing the shape and dimensions of the bowl is also present in the space-time parametric model.

But, in that model, there is no consideration of the physical and mechanical properties of the reservoir rock, the depth of the reservoir and the change in reservoir pressure, which seems to be very important in geodynamic modeling of hydrocarbon deposit areas.



$$S= -a\int_A C k_z dA\,,\ -a=S/C,\quad k_z=\frac{e^{\left(\frac{\pi r^2}{R^2}\right)}}{R^2}$$

Sрасч.	Sнабл.
0.000761032	-20
0.000761028	-47
0.000761026	-78
0.000761023	-125
0.000761022	-220
0.00076102	-280
0.00076102	-305
0.000761019	-330
0.00076102	-320
0.00076102	-270
0.000761022	-230
0.000761023	-170
0.000761026	-120
0.000761028	-80
0.000761032	-60

Fig.7 Analysis of the model by the Knote influence function

Thus, we obtain a new calculation formula for constructing a simulation-predictive model of geodynamics:

$$S = -a\int_A C k_z dA;\ k_z = e^{-\frac{1}{2}r_i^2}. \quad (8)$$

And after performing calculations on the new adapted version of the model, we see that the subsidence bowl becomes closer to the actual subsidence trough (Fig. 8).

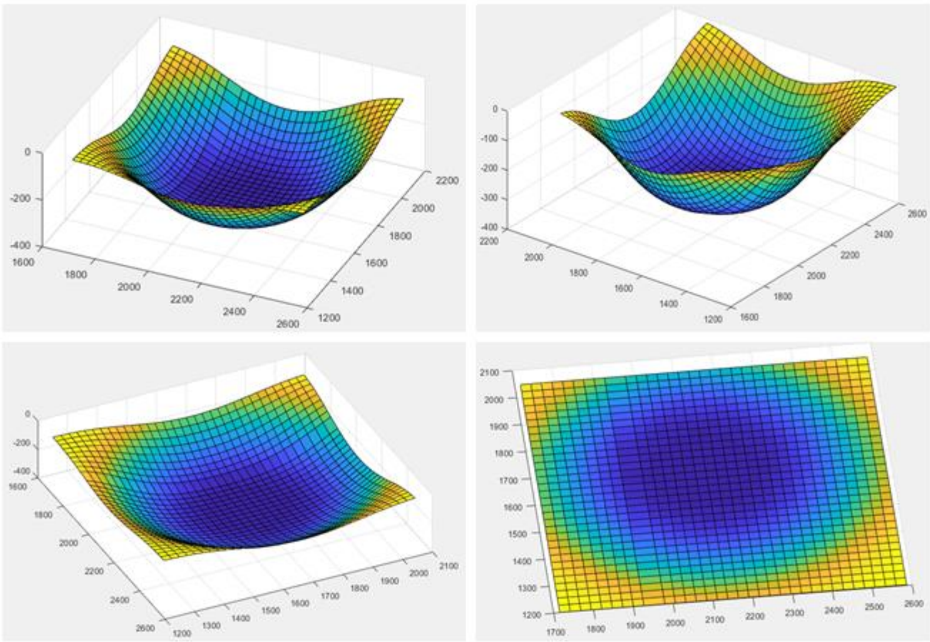
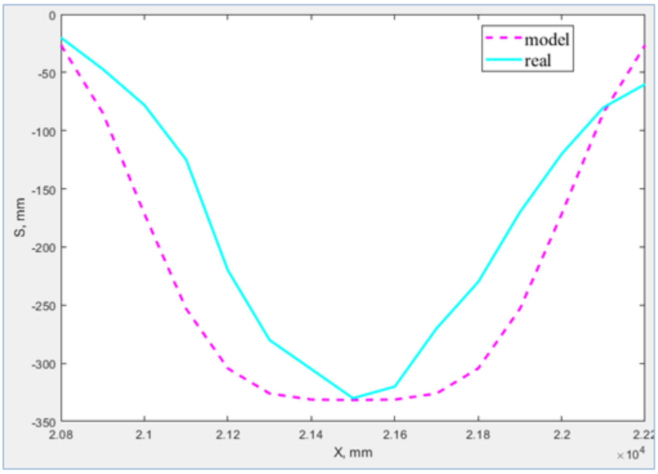


Fig.8 Settling bowl according to the new calculation formula

A comparative analysis of model estimates of the earth's surface displacement using the new calculation formula and actually observed subsidence is shown in Figure 9. In this approach, we obtain a calculated curve that is closer to the actual observed one. The root-mean-square error in determining subsidence decreased by 1.1 mm compared to the spatial-parametric method and became 6.34 mm. Although the difference in accuracy is not large, the preference for the new calculation formula is given due to the fact that it takes into account the geological structure of the field and the change in reservoir pressure.



X, м	S, мм	S1, мм	ΔS, мм
20800	-20	-26.39	6.39
20900	-47	-84.57	37.57
21000	-78	-171.55	93.55
21100	-125	-253.10	128.10
21200	-220	-304.37	84.37
21300	-280	-325.96	45.96
21400	-305	-331.15	26.15
21500	-330	-331.50	1.50
21600	-320	-331.15	11.15
21700	-270	-325.96	55.96
21800	-230	-304.37	74.37
21900	-170	-253.10	83.10
22000	-120	-171.55	51.55
22100	-80	-84.57	4.57
22200	-60	-26.39	-33.61
22400	-30	-4.42	-25.58

ΔSmax=128.10 мм
ΔSmin=1.50мм

$$m = \sqrt{\frac{\Delta S^2}{n-1}} = 6{,}34 \text{ мм}$$

Fig.9 The results of assessing the accuracy of the simulation model

It is possible to demonstrate the mutual arrangement of two bowls of subsidence in the Matlab program environment (Fig. 10).

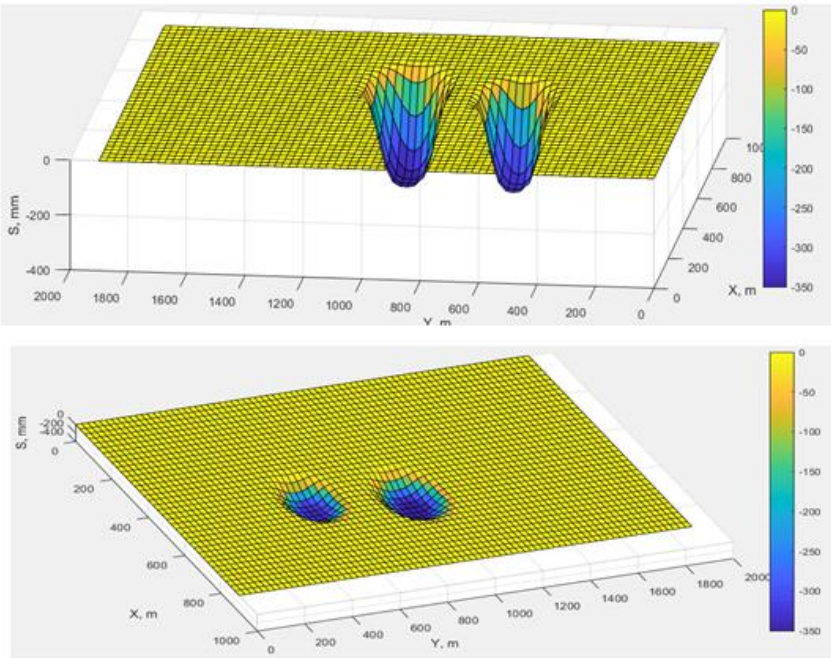


Fig.10 Two bowls of settling in the field

Since the bowls are located close to each other and, moreover, subsidence occurs intensively, with acceleration in time, it can be assumed that at the current rate of development of the field in 8-9 years, the two bowls will merge and form one large subsidence trough.

In general, intense geodynamic processes negatively affect the entire ecosystem of the region, including fauna and flora, disrupting the entire natural cycle of life. For this reason, it is recommended to take more environmentally friendly methods of field development, especially when deepening into the offshore area of the Caspian Sea, in search of new deep-sea hydrocarbon reserves..

Conclusion

In the dissertation work, a solution is given to the scientific and technical problem of modeling the subsidence of the earth's surface based on the data of integrated monitoring of geodynamic processes, which ensures an increase in the safety and efficiency of field development.

The main scientific and practical results of the research are as follows:

1. Based on the analysis of domestic and foreign scientific and technical literature, experience in the field of studying the movement of the earth's crust, methods and means of observing deformations, as well as studying the geology and tectonics of the object of study, a comprehensive methodology for studying natural and technogenic geodynamic processes is recommended.

2. On the basis of stratigraphic data, a geological model of the field was built in the Datamine software, which allows taking into account the depth and thickness of productive layers in geodynamic modeling.

3. The relationship between the subsidence of the day surface and the depth of the reservoir is established, which makes it possible to perform a more objective assessment of the geodynamic situation in the field.

4. A calculation formula for the subsidence of the day surface is proposed, built on the basis of the adapted Knote influence function, which allows mathematical description of the existing trend of the day surface displacement in the territory of the oil and gas field.

5. A predictive simulation model was built in the Matlab program, taking into account the geological structure of the field, the physical and mechanical properties of reservoir rocks, the intensity of field development and geodetic observation data on the territory of the North Buzachi oil and gas field.

6. A simulation model of the subsidence of the earth's surface on development areas of the Northern Buzachi oil and gas field in the Matlab program.

7. The results of the dissertation work are introduced into production and included in lecture materials and practical classes for undergraduates of the International Educational Corporation, which is confirmed by the relevant Implementation Acts.

The main provisions of the dissertation are published in the following works:

1. Kenesbaeva A., Zemtsova A.V. On geodynamic monitoring using GIS technologies. Bulletin of KazGASA No. 1 (67) -2018. pp.183-186.
2. Kenesbaeva A., Nurpeisova M.B. Forecasting of technogenic subsidence of the earth's surface. Mining journal of Kazakhstan. - No. 11,. -2018 - S. 24-27.
3. Kenesbaeva A., Orynbasarova E.O. Possibilities of using data from the new Sentinel-1 satellite. Bulletin of KazGASA No. 2 (68) -2018. - P.168-174.
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5. Kenesbaeva A., Orynbasarova E.O. Geodynamic model of an oil and gas field based on cellular automata. Bulletin of KazGASA. - No. 3 (73). - 2019. - S. 295-302.
6. A. Kenesbayeva, M. Nurpeisova, Zh. Bekbassarov, K. Kartbayeva, U. Gabitova. Complex evaluation of geodynamic safety in the development of hydrocarbon reserves deposits. News of the national academy of sciences of the Republic of Kazakhstan. Series of geology and technical sciences. ISSN 2224-5278. Volume 1, Number 439 (2020), p.90 – 98.
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8. Kenesbaeva A., Nurpeisova M.B. Monitoring of displacements of the earth's surface during the development of hydrocarbon deposits. Scientific-production and technical magazine "Mine surveying and subsoil use". Moscow, RF. 2019 pp.42-46.
9. Nurpeisova M., Kenesbaeva A., Levin E., Baltiyeva A., Nizamova M., Aitkazinova S. Geodynamic Processes Modeling On Oil-Gas Deposits. Journal of Advanced Research in Dynamical and Control Systems - JARDS. V11, Special issue 8, 2019. -2075-2083 p.
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