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MONITORING DEFORMATION PROCESSES ON GROUND SURFACE AND AT CONSTRUCTION FACILITIES IN THE TERRITORY OF OIL FIELDS

The authors analyze deformation in the territory of oil production in the Caspian zone of the Republic of Kazakhstan. The deformation analysis includes integrated monitoring aimed at environmental protection and at safety of infrastructure, including construction of a search channel. The authors adhere to the integrated approach to the research, namely: generalization and analysis of the national and international experience of geodynamic studies; completion of repeated geodetic observation over deformation in the test areas using modern geodetic instrumentation; assessment of different influences on ground surface subsidence y means of theoretical calculation of reservoir roof subsidence; geodetic supervision of safe operation of such unique engineering structures as a sea channel.

For efficient and safe recovery of oil, the natural and manmade impacts on development of deformation processes at reservoirs ae analyzed. This can enable control of such impacts on ground surface and engineering facilities. The prediction procedure is developed for ground surface subsidence by calculated values of reservoir roof subsidence using experimental data.

Keywords: *hydrocarbon reservoirs, ground surface, roof subsidence, reservoir pressure, geodynamic testing ground, engineering structures, geodetic monitoring, GPS observations*
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Introduction

Western Kazakhstan holds rich hydrocarbon reserves. Large-scale development of oil and gas resources of the Caspian zone leads to intensive movements of ground surface, both within local areas and in individual structural elements of subsoil, which leads to borehole curving, oil/ gas / water pipelines breaking, railways and highways inactivation, failure of underground communications and engineering structures, which in turn results in significant economic damage [1–3].

The interest in this problem is constantly growing from year to year all over the world. This fact is confirmed by various reports and papers that are regularly published in international scientific and technical journals, and are discussed at annual scientific conferences dedicated to methods and principles of geodynamic monitoring in the territories of hydrocarbon deposits [4–6]. However, these works incompletely embrace the entire spectrum of geodynamic processes induced by development of oil and gas, which is convincingly proved by the experimental studies carried out in the framework of the Program of Comprehensive Geodynamic Monitoring of Natural and Induced Processes in Hydrocarbon Field in 2004–2007 and in 2015–2019 at the Satbayev University [7–9].

The article focuses on geodynamic processes during development of hydrocarbon deposits in the western region of Kazakhstan. The integrated monitoring results on deformation of ground surface and berthing facilities of the North Caspian Sea Canal, which is the Tengizchevroil LLP Project, are presented. The North Caspian Sea Canal is a promising construction, it can be called the Sea Gate of Kazakhstan. The facility will be used to deliver cargo to onshore fields with intensive oil production in the North Caspian. Safety of such unique and critical engineering structures is achieved with the help of geodetic monitoring.

Analysis of research and publications

Generalization of extensive experience gained in geodetic monitoring of deformation processes made it possible to identify the main factors of intense and extensive subsidence of ground surface over long-term mining fields. Moreover, the instrumental observations revealed the types and mechanisms of modern geodynamic movements of ground surface.

By now, large amount of experimental results on spatiotemporal manifestation of natural geodynamic processes of endogenous origin has been accumulated on geodynamic testing grounds, as well as along the lines of national geodetic and leveling networks. Such studies are described in the works of such scientists as Yu. D. Boulanger, A. N. Dmitrievsky, V. G. Kolmogorov, D. A. Lilienberg, V. K. Pankrushin, L. I. Serebryakova, Ya. S. Yatskiv and other foreign researchers [10–14]. The problems of rock mechanics are now widely solved using numerical methods. Substantial contribution to the methods of the stress–strain analysis of rock mass has been made by L. Mueller, G. Kratch, V. Wittke, A. S. Yagunov, S. V. Kuznetsov, M. V. Kurlenya, V. G. Zoteev, A. A. Baryakh, Yu. A. Kashnikov, S. G. Ashikhmin and others.

However, despite some novel research results available, the geomechanical patterns are yet generally determined using traditional methods. Complexity of studying geodynamic and geomechanical processes in the condition of oil and gas development consists in joint deformation of rock masses and ground surface, which makes traditional monitoring incapable to provide reliable information on displacements.

The oil industry specialists clearly understand that solution of such issues as reservoir pressure and ground surface subsidence is unthinkable without stability monitoring of rock mass and engineering structures using modern geodetic methods. The described situation is typical of the giant Tengiz oil field and the North Caspian Sea Canal under the Tengizchevroil LLP Project. Therefore, practical application of new generation devices can be assumed as the most significant technological innovation in the 21st century in mine surveying, geodesy and some other related industries.

Goal setting

Potential forms of occurrence of natural and natural–manmade events determine the choice of adequate basic set of methods for monitoring these processes. The use of such methods should be planned already in the early phase of monitoring, with subsequent adjustment depending on the results obtained. The analysis of available geological–geophysical and field-geology information, as well as data on the seismotectonic environment of the region make it possible to substantiate application of three basic monitoring methods (deformation, GPS and gravimetry).

Ground surface movement monitoring in the area of oil and gas production is imposed with a number of specific requirements: higher operativeness and larger information content of the results; enhanced economic efficiency of the research. In view of these requirements, the goal, concept and objectives of the Tengiz field research have been formulated at the Department of Surveying and Geodesy of the Satbayev University.

Research scope and results

Geodetic observations. At Tengiz geodynamic testing ground (GTG), class II leveling was carried out with digital laser gradienter of LEICA WILD NA 3003 with invar bars using double leveling method in forward and reverse directions. The accuracy tolerance of 0.4 mm was set for the gradienter, which corresponds to class I leveling tolerances.

Figure 1 shows the actual layout of improved accuracy class II re-leveling line and the leveling points located along this line.

Profile 1-1 runs along the strike of the deposit. In 2015, 15 leveling points were laid along the profile. Furthermore, GPS point No. 3 was included in the leveling. In total, profile 1–1 consisted 16 leveling points in the 1st cycle.

As a result, it is possible to control continuously changing geodynamic situation in accordance with continuously field-geology situation during hydrocarbon production process. Combination of above basic methods with available data will provide sufficient amount of information to study properties and spatio-temporal patterns of deformation processes in the field [15].

Enhanced accuracy class II re-leveling. In accordance with the Work Program for geodynamic monitoring in the field, another high-precision class II leveling cycle was accomplished in August 2019, and high-precision GPS measurements were continued in the field. Before the start of the measurements, reconnaissance of the network of GPS points was carried out, as a result of which it was established that all points were sufficiently well preserved and suitable for measurements. Measurements were carried out at 4 GPS points (including 1 GPS-5 control point and 3 row points) within the deposit outline. GPS measurements used 4 sets of GPS equipment: two-frequency receivers Leica 1200.

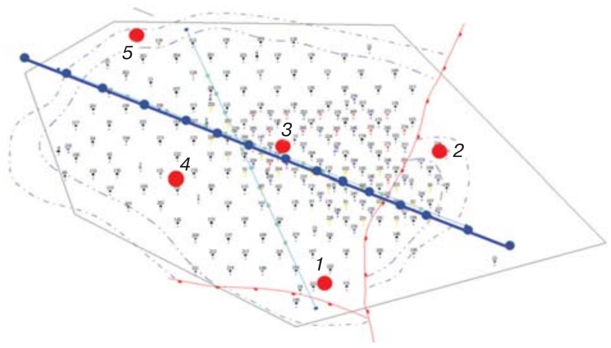


Fig. 1. Project layout of leveling points combined with gravity survey points and GPS points in the deposit area:
blue circles — leveling points combined with gravity survey points;
red circles — leveling points combined with GPS points

Field measurements were processed using specialized software Leica Geo Office from the GPS-5 base station. Coordinates of base 5 were fixed over the entire monitoring period.

Measurements quality was assessed by discrepancies at the points of sessions overlap. Total control measurements were performed at 3 points. The standard error of single measurement was ± 0.8 mm for the coordinates and ± 1.3 mm for the heights. The results proved high accuracy of the work performed during GPS-measurement in the 3rd cycle, which made it possible to use these results for comparison with the previous cycle measurements [16].

Coordinates of GPS points obtained in 2019 made it possible to calculate vectors of horizontal and vertical displacements of GPS points at the deposit. In turn, this enabled plotting the areal distribution of vertical and horizontal movements of GPS points within a year (**Fig. 2**).

The analysis of the patterns in Fig. 2 allows some preliminary conclusions to be drawn:

- Almost the whole territory of deposit is characterized by negative values of vertical displacements of GPS points. The average value of the vertical displacement of GPS points in the field is –2.0 mm. This value is within the measurement errors. The maximum negative values of the vertical movements over a year reach –4.3 mm (Fig. 2a) and exceed the measurement errors.

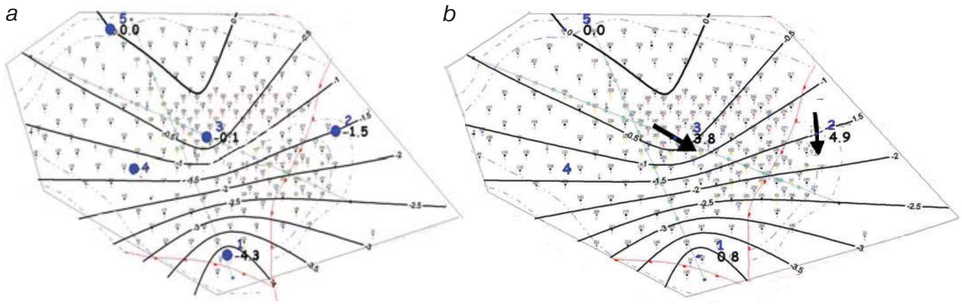


Fig. 2. (*a*) Scheme of areal distribution of vertical components of GPS point's movements (contours); (*b*) Scheme of comparison of areal distribution of vertical and horizontal component of the of GPS point's movements in the territory of deposit by GPS re-measurement data (2012–2019)

- The comparison results of the first and second cycles of GPS measurements indicate ground surface subsidence in the central and southeastern parts of the field. In this regard, the results of GPS re-measurements qualitatively coincide with the re-leveling data, which also imply subsidence of ground surface of the field.
- The areal pattern of horizontal movements of GPS points is characterized by their main direction toward the southeast of deposit (Fig. 2b). The average value of the horizontal displacement is 3.2 mm. The maximum horizontal movements of GPS points reach 4.9 mm (GPS-2). This figure exceeds the measurement errors and should be assumed as significant.
- Attention should be paid to the relationship between the vertical and horizontal displacement patterns of GPS points, from which it follows that the vectors of the horizontal movements tend to towards the increased subsidence of ground surface. If this is so, which can be disclosed in the subsequent measurement cycles, then a natural trend of horizontal displacements towards the subsidence trough can be expected. This trend has been reliably established at the number of deposits in the Republic of Kazakhstan.

Theoretical research

Simultaneously, theoretical calculations of ground surface subsidence were carried out. To correctly predict the 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 exactly the manmade component in the total vertical SES, otherwise subsidence prevention activities can lead to unnecessary material costs and can be ineffective.

The theoretical calculation of manmade SES gives less accurate results than the actual repeated geodetic measurements. However, it seems promising to use them both at the stage of designing testing grounds (places of possible maximum SES) and for comparing the calculated values of manmade SES with the instrumental observation data [17].

During development of oil deposits, rock pressure is changeable. As reservoir pressure decreases, the compressional stress grows in the skeleton of rock, an vice versa. In view of this, i.e. by the types of reservoirs, by the change in their elastic properties and by the vertical compression of the skeleton of oil reservoir, the reservoirs are divided into two groups: *granular* and *fissured-cavernous* reservoirs.

According to the hypothesis of the hydrostatic stress state by A. Heim, the stress state of the crust at any points is function of the occurrence depth of rocks. Heim believed that stresses in the crust should be distributed according to the hydrostatic law, i.e.

$$\sigma_x = \sigma_y = \sigma_z = \rho H, \tag{1}$$

where σ_x, σ_y are the normal horizontal stresses; σ_z is the vertical normal stress; ρ is the bulk density of rocks; *H* is the depth from ground surface.

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

$$\partial\eta = \frac{1}{3}h\left[\beta_{com} d(\sigma - P) + \beta_S dP\right], \tag{2}$$

where *h* is the height of the reservoir, m; β_{com} is the volumetric compression factor of the reservoir skeleton; σ is the average normal stress, MPa; *P* is the reservoir pressure, MPa; β_S is the solid phase compressibility factor; *dP* is the reservoir pressure drop, MPa.

As can be seen from formula (2), the main parameters characterizing the volumetric compression of reservoirs are the volumetric strains of pores and solid phase.

For calculation of ground surface subsidence, different formulas are available. S. Avershin [18] derived an equation for SES calculation:

$$\partial\eta/\partial z = a(z)\partial^2\eta/\partial x^2. \tag{3}$$

The equation of R. Myuller [19]:

$$\partial\eta/\partial z = a(z)[\partial^2\eta/\partial x^2 + \partial^2\eta/\partial y^2], \tag{4}$$

In all equations η is the SES value; a(z) is the coefficient of change in the properties of rocks along the vertical line; x, y, z are the rectangular coordinates.

The best description of the reservoir conditions is assumed to be provided by equation (4), but here it is necessary to determine three values (x, y, z).

For the SES calculation at oil and gas deposits, we introduce a cylindrical coordinate system (**Fig. 3**). The center of the reservoir roof is assumed as the coordinate origin. The reservoir occurs at the depth H and has the radius r. the reservoir roof subsidence (RRS) never expands beyond the circle of the radius r.

In this coordinate system, equation (4) acquires a parabolic shape:

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

After solution of equation (5), we obtained the computational formula:

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

where $\theta_{i,K}$ is the approximated value of subsidence; *i* is the step number (pitch) horizontally; K is the vertical step number.

Calculations were carried out both in fissured-cavernous and granular reservoirs over a period of time starting from 2010 per the fields of Kazakhstan. At the granular reservoirs, the shear roof subsidence rates were equal to zero. The maximum roof subsidence of the fissured-cavernous (pore) reservoirs was observed at the deposit Makat (64 mm) in 1974 to 1976. The cause of such high rate of the roof subsidence at this deposit was the essential reservoir pressure drop and the large thickness of the reservoir.

If we compare the fields by RRS values over the operation period, we should single out the Tengiz field where maximum RRS is q = 58 mm or V = 12 mm / year for 5 years. Despite the fact that the depth of the Tengiz field is huge (m = 1500 m), the

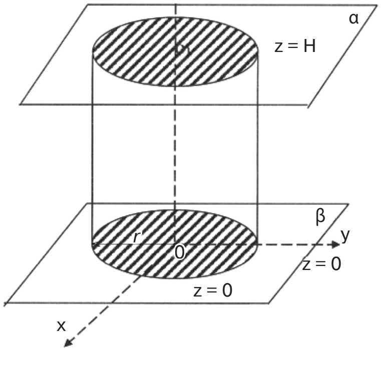


Fig. 3. Cylindrical coordinate system:
α – ground surface plane;
β – reservoir roof plane;
H – reservoir depth;
r – reservoir radius

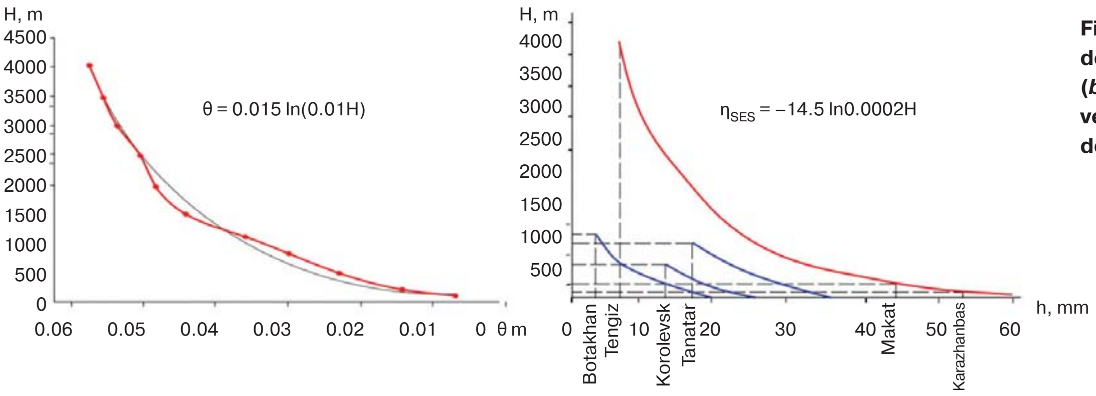


Fig. 4. (*a*) RRS–mining depth H curves; (*b*) SES prediction versus RRS and mining depth H

average RRS value in 5 years is only 12 mm. This small value is due to maintenance of the reservoir pressure at the initial level (at insignificant drop of 2.6 MPa), as well as by the elastic properties of the reservoir.

Now that theoretical values of RRS are known, it is necessary to determine which part of this subsidence is transferred to ground surface, which allows predicting SES at the deposits. Since fluids are produced at great depths while maximum RRS is only 60 mm in five years, it is first necessary to theoretically test whether there is any ground subsidence at all. For this purpose, minimum occurrence depth for the reservoirs is taken to be $H = 3500$ m and maximum RRS is ≈60 mm.

The problem reduces to determining subsidence of point 0_1 located at a distance of 3500 m from point 0 (**Fig. 4**). To solve this problem, it is necessary to calculate successively subsidences of points along the axis 00_1, which are a spaced from point 0 at distances of 500, 1000, 1500 and 3500 m. In the notation of formula (5), these values are: $q_{0.2}$ ($q_{1.1}$), $q_{0.3}$ ($q_{1.2}$), $q_{0.4}$ ($q_{1.3}$), $q_{0.5}$ ($q_{1.4}$), $q_{0.6}$ ($q_{1.5}$), $q_{0.7}$ ($q_{1.6}$), $q_{0.8}$ ($q_{1.7}$) and so on.

Calculations using formula (6) is a very complex and time-consuming task. Therefore, for the real-time prediction of RRS and SES, we created an express calculation. Based on the results of theoretical calculations, the graphic analytic dependence of RRS on the reservoir depth is obtained (See fig. 4):

$$\theta_{exp} = 0.015\ln(0.01H). \qquad (7)$$

Figure 4a shows that with increasing depth of fluid production, the reservoir pressure increases, accordingly, the value of RRS is higher than at shallow depths. Regarding the impact of mining on SES, ground surface deformations diminish with increasing depth of mining [20]. On this basis, the graphic analytic dependence is obtained for SES prediction as well (Fig. 4b).

Thus, to predict SES depending on the RRS and mining depth, we recommend the graphic analytic dependences of two types: logarithmic with error of 6.8% :

$$\eta_{SES\ log} = -14.5\ \ln(0.0002H), \qquad (8)$$

and liner with error of 29.8%:

$$\eta_{SES\ lin} = 45.5 - 0.0127H. \qquad (9)$$

Obviously, the logarithmic dependence more accurately predicts subsidence of the earth's surface.

As seen from Fig. 4, ground surface is given 6 mm from RRS of 60 mm at the depth H = 4 km. At the Kenkiyak, Kulsary, Oryskazgan and other deposits, where the mining depth is more than 1000 m, and RRS fails to reach ground surface, SES is zero. Oppositely, at the Makat, Tanatar, Korolevsk, Tengiz and Botakhan deposits, manmade SES are 43, 18, 12, 6 and 4 mm, respectively.

Deformation monitoring at engineering structures

Currently, according to special project of Tengizchevroil LLP, the North Caspian Sea Canal with berthing facilities for the transportation of goods is being built in Kazakhstan. Concurrently, geodetic monitoring is carried out for this hydraulic structure [21]. The project includes (**Fig. 5**): sea channel; turning basin; areas of sea dump of soil; berthing facilities for discharging cargo (FDC); dump site for soil and sedimentation basin; an access road, etc. The North Caspian Sea Canal will be used to transport cargo in support of construction operations and to help oil fields and industries in West. In 2021, it is expected to ship all general cargo of 272 000 tons / year.

The nearest oil fields under development are: one of the world's richest Tengiz field, Western Prorva, Prorva, Kozhan, Morskoe, Aktobe, etc. All these fields are located in the Caspian lowland, on the coastal regions of the Western Caspian Sea. The average elevation at the aforementioned fields is −25.00 m above the level of the Baltic Sea, which, with an average level of the Caspian Sea of −28.30 m, makes these fields flooding susceptible. Solution to this problem is protective dams with the crests arranged at an elevation of −23.50 m.

Construction of large technical structures such as dams, canals and high buildings is a challenging problem. Safe operation of the unique and critical engineering structures, as well as the equipment is achieved through periodic monitoring, which also includes geodetic monitoring. Deformation monitoring of such structures is one of the application areas

Fig. 5. Construction scheme of sea channel and turning basin

1 – sea channel; *2* – unloading point; *3* – temporal storage; *4* – shift camp; *5* – access motor road; *6* – public road

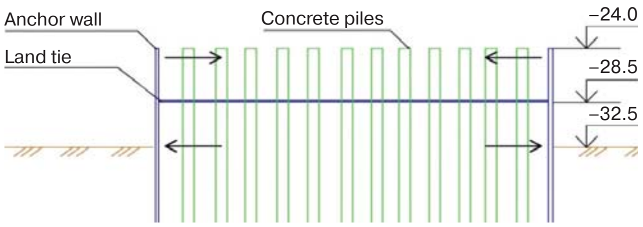


Fig. 6. Test sheet pile wall

of high-precision geodetic methods and measuring instrumentation [22].

One of the most critical stages of construction is sheet pile walls forming berths. The inner side of quays consists of a 9 m high sheet pile wall. The sheet piles themselves are driven to a depth of 15 m from ground surface. After driving sheet piles to the depth of 15 m, the inner side of the berths is covered with sand with subsequent by tamping, and then two opposite berths are reinforced with anchor rods at –28.50 m to prevent swelling due to the impact of compacted soil. Later on, by the same procedure, sand backfilling is carried out, in layers 30 cm thick, followed by tamping to a mark of –24.00 m (**Fig. 6**).

Further, inn the prepared tamped bottom, for the construction of a more rigid foundation, concrete piles with a cross section of 0.4´0.4 m, two-piece and 17 m long are driven by a grid of 2 by 3 meters. Such foundation will provide a more rigid floor for the port to receive and send goods with a weight more than several hundred tons.,

Driving of piles is accompanied by compression of tamped soil, which subsequently affects outer walls of berths. As a result, walls deform. **Figure 7** shows the approximate behavior of deformation. In order to determine and analyze this deformation behavior, some groups of sheet piles were selected, and measurements were taken on them during driving. For deformation analysis, *Autodesk AutoCAD* and *MS Excel* were used [23].

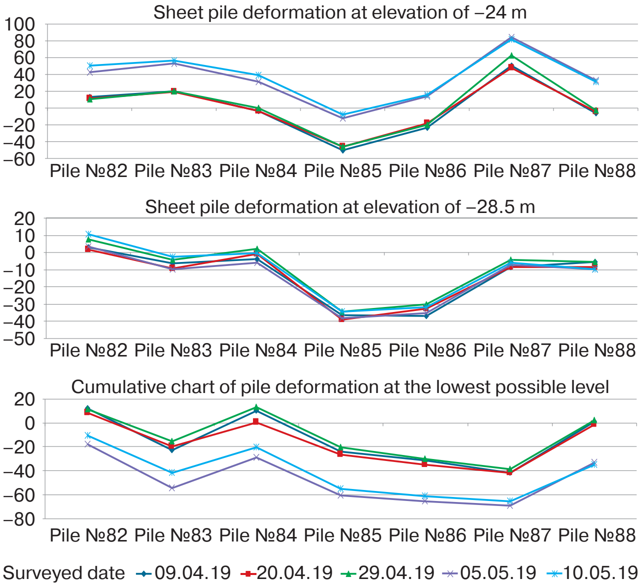
According to the observations results obtained between April and May 2019, it can be stated that the top of the berth at the elevation of –24.00 m is most susceptible to pressure from the inside during pile driving, as it shifts from the initial position by an average of 40 mm. It can be seen from graph, the measurement midpoint at the mark –28.50 m at the location of the anchor struts was free from significant deformation. And only the bottom of the pile wall at the elevation of –32.50 m was deformed inward by 20 mm from its initial position over the entire observation period.

During monitoring of hydraulic structures, such measurements are the main method for detecting deformation, which, with timely maintenance and due anti-deformation measures, will not pose a threat to the further operation of the facility.

Conclusions

1. The comprehensive review of domestic and foreign experience of geodynamic research with instrumental observation of deformations in undermined territories has been carried out, which makes it possible to develop methodology for integrated prediction and hazardous phenomena at geodynamic testing grounds.

2. The methodology of repeated observations at geodynamic testing ground points GDP points has been improved, including complex geodetic observations: high-precision digital leveling, use of electronic total stations and GPS technologies, which can enhance accuracy and efficiency of determining ground surface subsidence, as well as the monitoring effectiveness due to the computerization of the field and office geodetic works.



Comment: Negative deformation is directed inwards from the initial value

Fig. 7. Deformation diagram of sheet pile wall

3. The results of the second cycle of GPS measurements in the territory of the field and their comparison with the first cycle data reveal some trends in the areal patterns of the vertical and horizontal movements of rock mass towards the displacement trough.

4. The developed ground surface subsidence procedure is novel for the theoretical substantiation of interaction of the reservoir roof and ground surface deformations and technological parameters.

5. The proposed methodology for monitoring hydraulic structures using modern geodetic instrumentation can enable highly accurate control of the facilities, prompt anti-deformation activities and environmental protection.

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References

1. Sidorov V. A. Forecast and control of geodynamic situation in the regions of the Caspian Sea in connection with the development of oil and gas potential. Moscow : Nauchny mir, 2006. 13 p.
2. Kashnikov Yu. A., Ashikhmin S. G. Rock mechanics in hydrocarbon production. Moscow : Nedra-Biznestsentr, 2008. 467 p.
3. Panzhin A. A. Observations results of deformations of rock masses using satellite geodesy methods. *International Conference Proceedings Geodynamics and Stress State of the*

*Earth's Interio*r. Novosibirsk : IGD SO RAN, 2003. pp. 36–38.

4. *Proceedings of International Scientific Conference GEO-SIBERIA.* Geodesy, Geoinformatics, Cartography, Mine Surveying. Novosibirsk : SSGA, 2009, 2015–2018.
5. Zemtsova A., Omarov E. From geodesy and mapping to geospatial information. *Proceedings of the International Workshop on Innovative Technologies of Efficient Geospatial Management of Earth Resources*. Almaty : KazNTU, 2012. pp. 132–138.
6. Dagistanova K., Belanger D., Bateman P., Camerlo R., Fitzmorris R. et al. Integration of Dynamic Data into Characterization of the Tengiz Reservoir: Tengiz Slope. *AAPG European Region Annual Conference*, 17–19 October 2010, Kiev, 2011. 50399.
7. Henschel M. D., Shen L., Shipman T., Lehrbrass B., Aubé G. Monitoring of SAGD Operations With Satellite Based InSAR. *SPE Heavy Oil Conference, Canada, Calgary, June 2014*. SPE-170082-MS. DOI: 10.2118/170082-MS
8. Study of vertical movements of the earth's surface under the influence of the Tengiz field (research work No. I-14-01.05). Research report. Almaty : KazNTU, 2006. 125 p.
9. Polygon for monitoring geodynamic processes during operation of the Karachiganok oil and gas condensate field (research work No. 3.507). Research report. Almaty : KazNTU, 2009. 120 p.
10. Research on capacity development for pollution prevention and control in the oil industry in the Caspian Sea and its coastal regions in the Republic of Kazakhstan (Japan International Cooperation Agency). Research report. Ministry of Environmental Protection of the Republic of Kazakhstan, 2007. 55 p.
11. Nurpeisova M. B., Rysbekov K. B., Zhardaev M. K. Innovative methods of conducting complex monitoring at geodynamic test polygons. Almaty : KazNITU, 2015. 265 p.
12. Conducting geodynamic monitoring of natural and manmade processes at the hydrocarbon field. Research report. Almaty : KazNTU, 2017. 200 p.
13. Plischke B. Finite element analysis of compaction and subsidence–Experience gained from several chalk fields. *Eurock'2000*. Balkema, Rotterdam. 2000. pp. 795–801.
14. Kulibaba S., Esina E. A new approach to the problem of protection of undermined objects on the earth's surface. *3rd International Innovative Mining Symposium*. 2018. Vol. 41. DOI: 10.1051/e3sconf/20184101043
15. Grasso J. R, Volunt P., Fourmaitrauh D. Scaling of Seismic Response to Hydrocarbon Production: A Toll to Estimate Both Seismic Hazard and Reservoir Behavior Over Time. *Eurock 1994: Conf, Delft*. 2004.
16. Conducting geodynamic monitoring at the Karakuduk field. Report. Atyrau, 2010. 34 p.
17. Kashnikov Yu. A., Ashikhmin S. G., Bukin V. G., Shadrin D. M., Shustov D. V. Instrumental observations of displacement of the earth's surface in the oil fields of the Verkhnekamsk region. *Neftepromyslovoe delo.* 2010. No. 7. pp. 50–54.
18. Avershin S. G. Displacement of rocks during underground mining. Moscow : Ugletekhizdat, 1994. 245 p.
19. Muller R. A. The influence of mine workings on the deformation of the earth's surface. Leningrad : Ugletekhizdat, 1978. 150 p.
20. Nurpeisova M., Bekbassarov Z., Kenesbayeva A., Kartbayeva K. Complex evaluation of geodynamic safety in the development of hydrocarbon reserves deposit. *News of the National Academy of Sciences of the Republic of Kazakhstan-Series of Geology and Technical Sciences*. 2020. Vol. 1. pp. 90–98. DOI: 10.32014/2020.2518-170X.11
21. Route of goods transportation for objects of the north-eastern part of the Caspian Sea. North Caspian Maritime Canal with mooring facilities. The project. RSE Gosexpertiza No. 01-0561/15.
22. Nurpeisova M., Myngzhassarov B., Shultz R. Geodetic construction support of the North Caspian Sea channel with berthing facilities. *Mining Journal of Kazakhstan*. 2020. No. 1. pp. 6–10.
23. Myngzhassarov B., Shultz R. Geodetic construction support of the sea channel. *I International scientific and practical conference "Ways of science development in modern crisis conditions"*. May 28-29, Kiev, 2020.