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Satbayev University

ХАБАРЛАРЫ

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

NEWS

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НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

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SATELLITE OBSERVATIONS OF EARTH CRUST AT ALMATY GEODYNAMIC POLYGON

Abstract. Problem of modern geodynamics is considered. Information on the modern movements of earthcrust in Central Asia, including Alataufoothills, which is seismic active geodynamic regionis presented. Geodetic observation methods play an important role in the study of the current movements of the earth's surface. For this reason, geodynamic polygons are created.

Almaty geodynamic polygon (GDP) wascreatedintheyearsbetween 1970 and 1971. The area is located in the zone of 5 deep faults andit refers to Almaty seismic areas with magnitude of 9.Since 1971 in Almaty geodynamic polygon have been hold about 52 cycles of high-precision leveling classesI and II. Leveling network consists of 5 sections that laid in the area of 200 .

Demand for geodynamics is also connected with the large-scale construction in the city, underground tunneling, etc. Data ongeological and geophysical conditions of Almaty has been collected.Particular attention is paid to modern determining methods of vertical movements of earthsurface by high-precision digital leveling and horizontal movements using GPS-measurements.Information on the organization of geodynamic processes monitoring in Almaty geodynamic polygon (GDP) is provided by the Institute of Seismology of the Republic of Kazakhstan and Satbayev University.

The paper analyzes the results of high-precision leveling and GPS observations.The graphs of changes in the nature of vertical movements were built. According to the results of GPS measurements, the tables, graphs and analysis on the comparative results are shown, and the values of horizontal displacements on the GDP were evaluated. The following parameters of deformations were calculated: shift, dilation, rotation, maximum and minimum tension, compression and azimuth.

Information on the organization of geodynamic processes monitoring in Almaty geodynamic polygon (GDP) is provided. Work results can be applied in any urbanized areas available for GPS.

They can also be taken as a basis for control of especially critical areas of long-distance objects, mineral deposits development.

Key words: geodynamics, Almaty geodynamic polygon, monitoring, geodetic methods, GPS-measurements, interpretation of results.

Introduction. The Central Asia region (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan) has complex contrasting relief and is very interesting for study of inland geodynamics. Active modern geodynamic processes are associated with the ongoing mountain forming in significant part of Asia, determine the high seismicity of this region.It is of significant practical interest. High seismicity of the Prialmatinsky region is proved by the 4 largest earthquakes known to us (Belovodskoe with a force of 9.5 points in 1885, Vernenskoe with a force of 7.3 points in 1887, Chilikskoe with a force of 8 points in 1899, Keminskoe with a force of 10 points in 1911) that happened before.

Geodynamic activity consequences are expressed in the frequent occurrence of natural phenomena in Central Asia, such as earthquakes, floods, landslides, outburst of glacier lakes, mudflows, droughts, etc. Occurring natural and technological disastersentail the death of people, material and economic losses, create environmental problems, and have strong negative impact on the sustainable development and well-being of society in Central Asia.

Almaty is located at the northern foot of Tien Shancrust, one of the most earthquake-prone in all of Central Asia. Almaty is located in specific engineering and geological conditionsin the impact zone the strongest earthquakes in the Northern Tien Shan. Geodynamic processes are also influenced by anthropogenic factors: engineering activities, mining, underground tunneling, etc. [1,2].

Among the potentially dangerous natural disasters for Kazakhstan, according to the Agency for Emergency Situations of the Republic of Kazakhstan, earthquakes rank first. About 18 million Kazakhstanis and about 450 thousand square kilometers of Kazakhstan are exposed to this danger. There are 27 cities and more than 400 settlements in the seismic zone. This territory contains about 40% of industrial potential of the country.

Intensive development of Almaty leadsto planning change, new large objects and structures, boundaries expansion should affect the size and load of upper parts of geological section with some changes in somegeodynamic parameters of upper section. In this regard, geodynamic state study of cities and urbanized territories using traditional methods is laborious, therefore high-precision GPS observations are extremely necessary for such areas and have significant practical interest.

Materials and methods. GPS observations will significantly simplify the technology of field work, reducing it to simple observation procedures at individual points. Observation data are subjected to primary processing using high-precision technology using well-known software packages such as BERNESE or GAMIT / GLOBK in a specialized processing center. Further, results of primary processing are used for interpretation and multifaceted analysis, which makes it possible to reveal detailed movement features and territorydeformation.

Reliable information about rock mass deformations can be obtained by direct geodetic observations at geodynamic polygons. Geodetic observations for predicting earthquakes in Kazakhstan began in the second half of the 70s of the XX century by the creation of experimental base of Almaty GDP, geographically coinciding with Almaty [3,4]. In modern works on earthquake prediction, methods of high-precision leveling of I and II classes, high-precision global positioning systems GPS and GLONASS, as well as satellite radar interferometry (InSAR - Interferometric Synthetic Aperture Radar), which appeared little laterare widely used.

High-precision geodetic measurements make it possible to reveal mobility of blocks of near the fault, which is essential for geodynamic situation assessment ofareaunder study. But geodetic measurements are discrete, they do not allow obtaining complete picture of deformation processes in time. This can be done only using complex method of geomonitoring (geodetic, seismological and gravimetric) [5,6].

Results. Main goal of geodynamic monitoring is to createsystem of rapid response and early warning in any type of hazard, such as earthquakes, landslides, hydrometeorological hazards, or caused by anthropogenic impact on the environment. Important point in carrying out these works will be the use of modern instruments for monitoring andmethods development for mathematical modeling of geodynamic processes for predicting natural and man-made disasters [7,8].

Construction of the Central Asian GPS network began in 1992. At present, it unites 639 points, of which in the territory of Kyrgyzstan -319, Kazakhstan-169, Tajikistan -42, Uzbekistan-35 and China -74 points. These stations are monitored, data of GPS measurements are stored in the database of the NS RAS (Fig. 1).

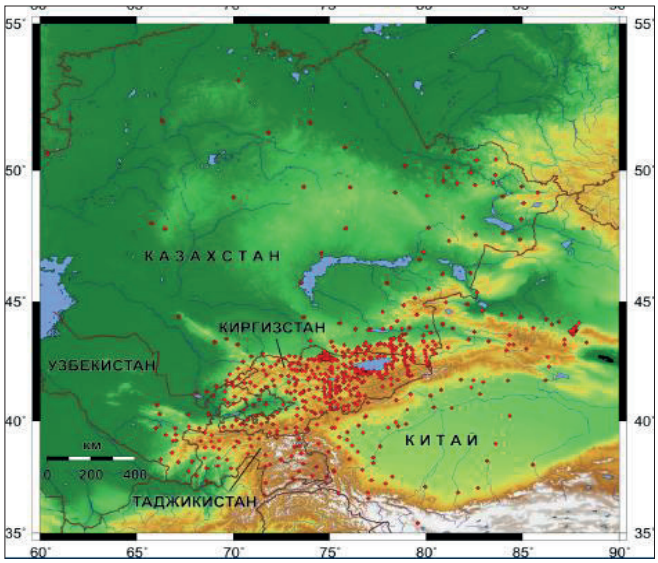

Fig. 1 - Central Asian GPS network.

Deformation's probability of earth surface is quite high for large megalopolises, such as Almaty. Mountainous area surrounding Almaty is the most densely populated region in Kazakhstan, prone to numerous risks of natural disasters (earthquakes, landslides, floods and mudflows). Landslide processes on Almaty territory and neighboring Central Asian countries are widespread due to the predominance of mountainous relief.

Deformations can be caused by both technogenic and completely natural factors: pressure on the ground of buildings and structures, large-scale multi-storey construction, intensive development of underground space, traffic flows increase, etc. These problems and difficulties are eliminated using geodynamic monitoring, main purpose of which is to obtain operational information about geomechanical processes occurring in the strata of rocks and earth surface and consequences they cause, necessary for the timely adoption of preventive measures.

Specialists of the Institute of Seismology and staff of Seismological Experimental and Methodological Expedition (SOME) created local networks of continuously operating GPS stations of Almaty GDP, Kazakhstan (Fig. 2), where constant observations and interpretation of GPS measurements are carried out. Observations are based on data of local network of continuously operating GPS stations of Almaty geodynamic polygon.

Fig. 2 - Local and permanent networks SOMEand Institute of Seismology.

On the local network, primary processing was carried out on «NOTEBOOK» LGO version 7.0, taking into account GPS measurements accuracy, including number of observed satellites, geometry of their location, observation duration, ephemeris accuracy, ionospheric and multipath effects and correspond to closed software package. At the output of these programs, adjusted coordinates, adjusted values errors and their correlation matrices are given. Pofiles of coordinatesshift of some points of local network for different observation cycles are shown in Fig. 3. For comparison of coordinates,measurements results of 2018 were taken, processed with reference to permanent station «Selezashchita» (Table 1) [9,10].

Table 1- Comparison list of triangulation points coordinates of measured by GPS receiver

№	Name points	2016		2017		2018	
		Latitude, φ ° ' "	Longitude, λ ° ' "	Latitude, φ ° ' "	Longitude, λ ° ' "	Latitude φ ° ' "	Longitude λ ° ' "
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	Boroldai	431848,10904	764833,20962	43 18 48,10891	76 48 33,21000	431848,10893	764833,20999
2	Chanalysay	430832,10475	764656,16778	43 08 32,10452	76 46 56,16780	430832,10432	764656,16858
3	Pionersky	431257,13447	764720,85517	431257,13445	764720,85502	431257,13403	764720,85459
4	Port- Arthur	431545,22201	770011,68804	431545,22289	770011,68926	431545,22385	770011,68881
5	Karatumsuk	431232,03233	765618,13709	43 12 32,03251	76 56 18,13718	431232,03243	765618,13718
6	Uzbek	431136,28083	764326,82908	43 11 36,28062	76 43 26,82932	431136,28051	764326,82923
7	Kursai	430933,09853	764936,08408	43 09 33,09855	76 49 36,08442	430933,09838	764936,08485
8	Gorniy Giant	431153,48289	770031,34657	43 11 53,48309	77 00 31,34673	431153,48319	770031,34671
9	Beregovoy	431852,05575	764415,33208	43 18 52,05559	76 44 15,33231	431852,05545	764415,33222
10	Ata-Kurgan	432013,23150	765207,08733	43 20 13,23145	76 52 07,08729	432013,23086	765207,08765
11	GES	430941,88212	765538,50146	43 09 41, 88229	76 55 38,50160	430941,88230	765538,50161
12	Kurtugul	431257,37240	770318,64999	43 12 57,37271	77 03 18,64952	431257,37269	770318,65021
13	Karauldy nov.	431518,77374	764331,53942	43 15 18,77340	76 43 31,53997	431518,77318	764331,53965
14	Prigorodniy	431912,80371	770124,30216	43 19 12,80302	77 01 24,30414	431912,80348	770124,30283
15	Basin	431624,86958	764626,77922	43 16 24,86940	76 46 26,77935	431624,86939	764626,77942
16	Koturbulak	431615,03219	770516,50689	43 16 15,03227	77 05 16,50705	431615,03226	770516,50704
17	Tastybulak	430636,16876	764945,50482	43 06 36,16811	76 49 45,50499	430636,16895	764945,50528
18	**SELE**	431043,43590	770100,83783	43 10 43,43590	77 01 00,83783	43 10 43,43590	77 01 00,83783

Table 1.

№	Name points	2019	2019	№ points according to figure 3.9	Latitude Δφ, "	Longitude Δλ, "
		Latitude φ ° ' "	Longitude λ ° ' "			
1	**2**	**9**	**10**	**11**	**12**	**13**
1	Boroldai	431848,10901	764833,21009	2	-0,00003	0,00047
2	Chanalysay	430832,10434	764656,16847	10	-0,00041	0,00069
3	Pionersky	431257,1332	764720,85787	15	-0,00132	0,00270
4	Port- Arthur	431545,22440	770011,68856	14	0,00239	0,00052
5	Karatumsuk	431232,03245	765618,13721	16	0,00012	0,00012
6	Uzbek	431136,28046	764326,82926	11	-0,00037	0,00018
7	Kursai	430933,09858	764936,08406	17	0,00005	-0,00002
8	Gorniy Giant	431153,48309	770031,34672	7	0,00020	0,00015
9	Beregovoy	431852,05546	764415,33273	1	-0,00029	0,00065
10	Ata-Kurgan	432013,23110	765207,08806	3	-0,00040	0,00073
11	GES	430941,88227	765538,50167	8	0,00015	0,00021
12	Kurtugul	431257,37239	770318,65014	6	-0,00001	0,00015
13	Karauldy nov.	431518,77349	764331,54008	12	-0,00025	0,00066
14	Prigorodniy	431912,80360	770124,30305	4	-0,00011	0,00089
15	Basin	431624,86927	764626,77897	13	-0,00031	-0,00025
16	Koturbulak	431615,03218	770516,50697	5	-0,00001	0,00008
17	Tastybulak	430636,16896	764945,50512	9	0,00020	0,00030
18	SELE	43 10 3,43590	77 0100,83783	SELE	0,00000	0,00000

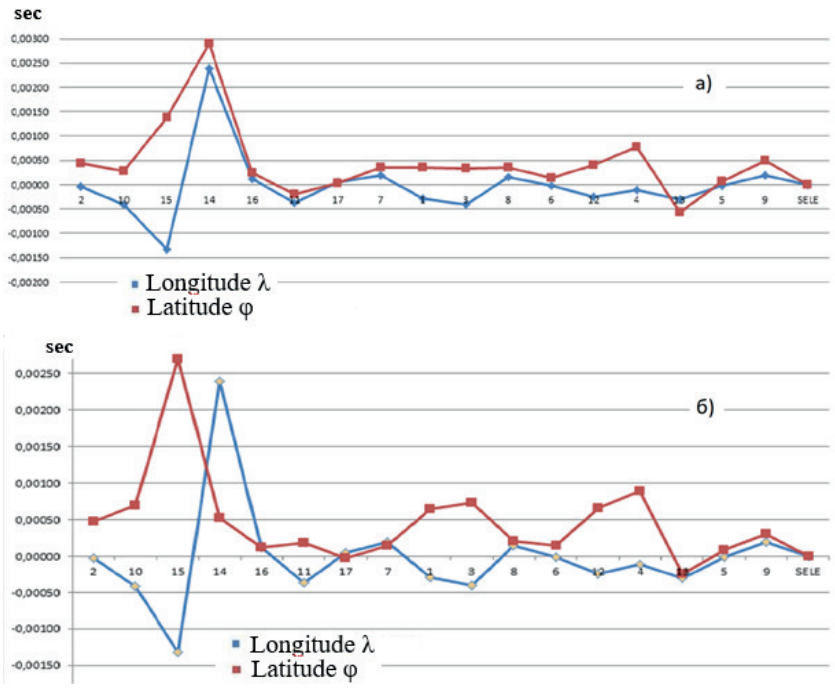

Fig. 3 - profile of coordinates shift of Pionersky 15 point and b) Port Arthur - 14 point.

Discussion. From Figure 3, (Pionersky) and (Port-Arthur) points have the greatest displacements, for example, over these years, Pionersky point has shifted in latitude to the north by 0,00132, in longitude to the east by 0,0027then the point Port -Arthur in latitude moved in the opposite direction by 0,00239, in longitude to the east by 0.00052 (Fig. 3, a).

Point 15 - Pionersky in 2008 - 2017 was almost stationary, and in 2018 its shift to the east in longitude was 0,00328, in latitude to the south - 0.0088. Point 14 - Port Arthur has minor latitude and longitude offsets(Fig. 3.b).

When determining reasons for displacements of above points in longitude and latitude, based on data of repeated leveling and GPS observations, studies results of the Institute of Geophysical Research of the National Nuclear Center of the Republic of Kazakhstan were taken into account and, together with thestaff of the Seimological Experimental and Methodological Expedition, geophysical research was carried out in 2019. According to SOME studies, from 2005 to 2018, 1347 earthquakes of 2–3 magnitude were registered in Almaty and its environs, and new scheme of tectonic faults in the territory of Almaty GDP was revealed (Fig. 4).

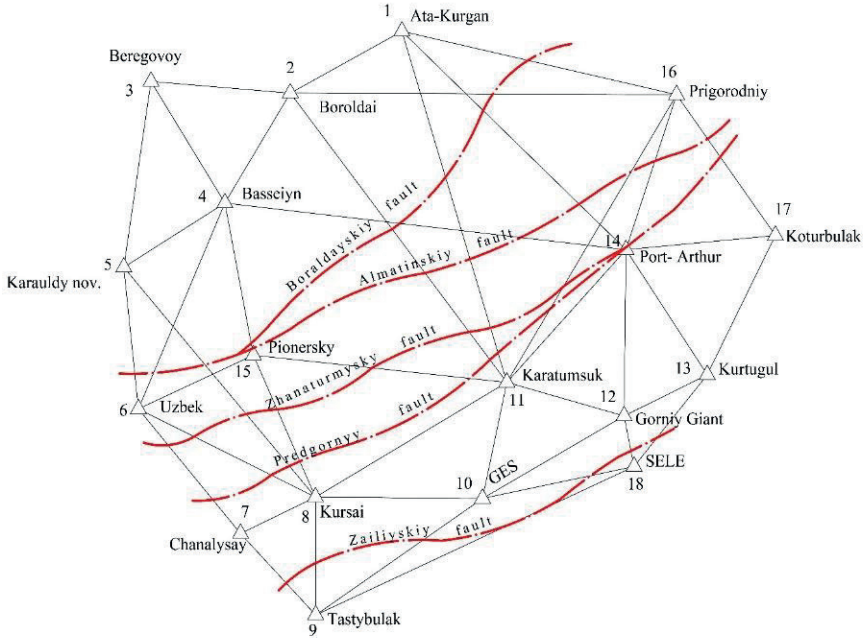

Fig. 4 - Scheme of tectonic faults combined by triangulation points.

Figure 4 shows that the Ile, Predgorny and Zhanaturmys tectonic faults pass between the Tastybulak-Kursai-Pioner points, and also corresponds to the maximum value at the junction of Almaty and Boraldai faults ofpoint 15 Pioner. There are no tectonic faults between the points of Gorny Gigant and Port-Arthur, and only the 14th Port-Arthur point is located at the confluence of the Foothill and Zhanaturmys faults [11].

And also, in local areas, leveling was carried out with digital laser level of Trimble DiNi company with barcode rail. System advantage is measurement simplicity, absence of reading and writing errors, automatic calculation of heights during measurement and data recording.

Based on the results of re-leveling data, stable regularities of time course of changes in the excess have been established. For example, for strong earthquakes with magnitude of more than 5, removed from the leveling profiles by no more than 200 km, several years before the earthquake, the surface tilts in the north direction; 1-2 years before the earthquake, slope ceases and reverses sign. Several years before the earthquake, changes patternsin the elevations along different profiles are consistent [12].

Horizontal deformationsstudy showed that they deformations are block nature and before earthquakes they reveal horizontal compression (even for distant earthquakes), and after - tension. Main compression axes are oriented across the faults (Fig. 5), where earthquakes with magnitudes from 6,1 to 7,3 occurred.

Vertical deformations are oscillatory nature, but at the same time, for several years before strong earthquakes, tilts of earthsurface in the meridional direction are observed, which can change sign within one or two years [13].

The complex of works from receiving and processing initial data of satellite monitoring of movements of the earth's surface to obtaining the final product in the form of maps of velocities of the earth's crust is the basic basis of the developed methodology for studying the geomechanical state of the crust of crisis areas using satellite technologies and mathematical modeling.

Presented results are certain stage of our research, later they will be supplemented with new data. Comprehensive monitoring made it possible to reveal blocks mobility of near the fault, which is essential for geodynamic situation assessmentof study area and will be used for analysis, which makes it possible to reveal movement features of the region's crust.

Conclusions. 1. The analysis of geological and geophysical characteristics of the territory and Almaty surroundings, as well as data on fracture tectonics, surface conditions was carried out. In general, data on the deformations of the earth surface at the Almaty geodynamic polygon obtained from geodetic measurements in recent years do not have strongly expressed anomalous character preceding strong earthquakes.

2. Comprehensive monitoring - observations, including high-precision re-leveling, GPS observations and geophysical research, made it possible to increase labor productivity, measurement accuracy and collect spatial data on the state of the earth crust in seismic zones. In Almaty GDP, it was revealed that tendency to slow deformation of earth crust in time is directly related to seismic indicators and tectonic disturbances of the Northern Tien Shan.

3. Vertical deformations are oscillatory, and horizontal deformations are of a block nature, where horizontal compressions are found, main axes of which are oriented across the faults. Currently, map of the speeds of modern vertical movements in the territory of the Republic of Kazakhstan is being compiled.

4. Performed complex of works from obtaining and processing the initial data of satellite monitoring of the earth's surface movements to obtaining the final product in the form of velocities maps of the earth's crust is the basis for developed methodology for geomechanical state studying of the earth's crust in crisis areas using satellite technologies and mathematical modeling.

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АЛМАТЫ ГЕОДИНАМИКАЛЫҚ ПОЛИГОНЫНДА ЖЕР ҚЫРТЫСЫНЫҢ ЖАҒДАЙЫН ЖЕРСЕРІКТІК БАҚЫЛАУ

Аннотация. Мақалада осы заманғы геодинамика мәселелері қаралған. Жер қыртысының Орталық Азиядағы, оның ішінде Алатау бөктеріндегі сейсмикалық белсенді геодинамикалық аймақ болып табылатын заманауи қозғалыстары туралы ақпарат келтірілген.

Жер қыртысының ағымдағы жылжуларын зерделеуде бақылаудың геодезиялық әдістеріүлкен роль атқарады. Сол себептен геодинамикалық порлигондар құрылады. Алматы геодинамикалық полигоны (ГДП) 1970-1971 жылдар аралығында құрылған. Полигон 5 терең жарылымдар және магнитудасы 9 балдық Алматылық сейсмикалық аймақта орналасқан. 1971 жылдан бастап Алматы геодинамикалық полигонында I және II кластық дәлдігі жоғары нивелирлеулердің 52 циклі жүргізілген. Нивелирлік торап 200 км^2 ауданды алып жатқан 5 участкеден тұрады.

Геодинамикалық мәлеслелердің сұранысы Алматы сияқты мегаполистегі ауқымды құрылыстармен метрополитен және т.б. жұмыстарға да байланысты. Алматы аймағының геологиялық-геофизикалық жағдайы туралы мәліметтер жинақталған.

Мақалада жер бетінің вертикаль қозғалыстарын жоғары дәлдіктегі цифрлық нивелирлеу және горизонталь ығысуларын GPS өлшемдерін қолдану арқылы анықтаудың заманауи әдістеріне ерекше назар аударылған. Алматы геодинамикалық полигонындағы (ГДП) Қазақстан республикасының сейсмологиялық институты мен Сәтбаев университетініңгеодинамикалық процестердің мониторингін заманауи аспаптарды қолдану және нәтижелерін математикалық өңдеу арқылы ұйымдастыру туралы мәліметтеркелтірілген. Сонымен қатар дәлдігі жоғары нивселирлеу мен GPS бақылауларының нәтижелері талданған. Вертикаль ығысуларды сипаттайтын жылжу графиктері құрылған. GPS өлшеулердің нәтижелері бойынша кестелер, графиктер сызылған және оларға салыстырмалы талдаулар жасалған, сонымен қатар ГДП дағы горизонталь ығысуларға баға берілген. Деформациялардың ығысу, сығылу, макималь және минималь созылулар мен азимут сияқты параметрлері есептелген.

Жұмыс нәтижелерін GPS үшін қол жетімді кез-келген урбанизацияланған аймақтарда қолдануға болады. Олар сондай-ақ, алынған нәтижелер ерекше маңызды нысандарды, пайдалы қазбалар кен орындарын игерілетін аймақтарды бақылауға негіз бола алады.

Түйінді сөздер: геодинамика, Алматы геодинамикалық полигоны, мониторинг, геодезиялық әдістер, GPS бақылаулары, нәтижелерді талдау.

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СПУТНИКОВЫЕ НАБЛЮДЕНИЯ СОСТОЯНИЯ ЗЕМНОЙ КОРЫ НА АЛМАТИНСКОМ ГЕОДИНАМИЧЕСКОМ ПОЛИГОНЕ

Аннотация. Рассмотрена проблема современной геодинамики. Приведены сведения о современных движениях земной коры Центральной Азии, в том числе предгорья Алатау, которое является повышенным сейсмическим активным геодинамическим регионом. Геодезические методы наблюдений играют большую роль в изучении текущих движений земной поверхности. По этой причине создаются геодинамические полигоны. Алматинский геодинамический полигон (ГДП) был создан в период с 1970 по 1971 год. Район расположен в зоне 5 глубоких разломов и относится к

Алматинским сейсмическим зонам с магнитудой 9. С 1971 года в Алматинском геодинамическом полигоне проведено около 52 циклов высокоточного нивелирования I и II классов. Нивелирная сеть состоит из 5 участков, проложенных на площади 200 км^2.

Востребованность геодинамики связана и с ведением в городе крупномасштабного строительства, проходкой метрополитена и др**.** Собраны данные о геолого-геофизических условиях г.Алматы. Особое внимание уделено современным методам определения вертикальных движений земной поверхности высокоточным цифровым нивелированием и горизонтальных движений методами GPS- измерений. Приведены сведения организации мониторинга геодинамических процессов в Алматинском геодинамическом полигоне (ГДП) Институтом сейсмологии РК и Satbayev University с использованием современных приборов и математической обработки их результатов.

В статье проанализированы результаты высокоточных нивелирных и GPS наблюдений. Построены графики изменения характера вертикальных перемещений. По результатам измерений GPS показаны таблицы, графики и анализ сравнительных результатов, а также оценены значения горизонтальных смещений на ГДП. Были рассчитаны следующие параметры деформаций: смещение, растяжение, вращение, максимальное и минимальное растяжение, сжатие и азимут.

Результаты работ могут применяться на любых урбанизированных территориях, доступных для GPS.Они также могут быть приняты за основу при контроле особо ответственных участков объектов большой протяженности, разработках месторождений полезных ископаемых.

Ключевые слова: геодинамика, Алматинский геодинамический полигон, мониторинг, геодезические методы, GPS наблюдения, интерпретация результатов.

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