

Most expedient mine surveying analysis and geodetic method for tracking the stability of the tailings dam position

Muhlisa Rahimova^{1,*}, Anvarjon Pardaboyev¹, Ibrohim Inogamov¹, Abdusamat Xudoyberdiyev¹, Nasiba Shamsieva¹, Ixtibar Tuychiyeva¹, Mehriniso Fathiddinova¹, Tohir Yakubov¹ and Nuriddin Mirjalolov¹

¹Tashkent State Technical University named after Islam Karimov, Tashkent, 100095, Uzbekistan

Abstract. This article examines the issues of mine surveying and geodetic observations of the stability of the position of the tailings dam of the Almalyk Mining and Metallurgical Combine (AMMC) in Uzbekistan. For these purposes, a geodetic network was created on the principle of geodetic serifs, including the course of polygonometry of the 1st category. To determine the stability of the position and condition of the dam of the combined tailing dump in order to improve the accuracy, observations were made using satellite technologies and classical methods. From the work performed, it was concluded that when determining the coordinates of points, it is convenient to use the method of geodetic serifs. It allows simultaneous measurements of both the main course and lateral points, which significantly reduces the time for making field measurements. In addition, in the case of short sides of triangles, the method of linear serifs is most appropriate, since it allows you to obtain more accurate values of the angles of triangles in comparison with angular measurements, which in the end result significantly increases the accuracy of determining the coordinates of points.

1 Introduction

Uzbekistan is rich in various minerals, the extraction of which is carried out both in closed (mines, etc.) and open (quarry) methods. One of such objects is the Kalmakyr quarry of the Almalyk Mining and Metallurgical Combine (AMMC). It produces non-ferrous metals. The quarry is the second largest in the territory of the Republic of Uzbekistan. Its length is about 3900 meters, width is 1900 meters and depth are more than 500 meters. After processing, a huge number of ore mined in it must be stored somewhere. For this purpose, tailing dumps are being created.

A tailing dump is a complex of special structures and equipment designed for storage or disposal of radioactive, toxic and other waste dumps of mineral processing (such waste is called tailings) [1, 2]. At mining and processing plants (MPP), concentrate is obtained from the mined ore, and the processing waste is transferred to the tailing dump. Typically, tailing

*Corresponding author: muxlisa.xasanovna@gmail.com

dumps are built a few kilometers from the mining and processing plant, in relief depressions: hollows, gorges, gullies. The tailing dump of the Kalmakyr open pit is shown in Figure 1.



Fig. 1. General overview of the tailing dump

At the present stage of development of the mining industry, one of the aspects of the problem is the task of organizing a comprehensive monitoring of alluvial enclosing structures for the entire period of their construction and operation [3]. The main directions of monitoring are:

- observation of deformations of dams, special hydraulic structures, the earth's surface;
- creation and reconstruction of a reference survey network;
- surveying control of geometric parameters;
- assessment of the state of structures, development of recommendations for observations, the formation of observation stations and the choice of the optimal observation methodology.

In general, the first place in terms of ensuring the safety of tailings is the solution to the issue of developing a methodology for monitoring and assessing their stability, including the interpretation of the results obtained and the forecast of the state of the enclosing structure. [4-6]

Analysis and generalization of the experience in the construction and operation of tailings dams of concentrating factories shows that at the present stage of development of the mining industry, one of the aspects of the problem is the task of organizing a comprehensive monitoring of alluvial enclosing structures for the entire period of their construction and operation [3].

The main directions of the comprehensive monitoring of alluvial enclosing structures are:

- monitoring the deformations of the sides of quarries and dumps, dams, special hydraulic structures, the earth's surface in the zones of influence of underground mining;
- creation and reconstruction of a reference survey network on the territory of mining allotments of enterprises;
- research of tailings water areas, determination of the degree of filling them with water and wastes from the ore dressing process (tailings);
- search and delineation of voids, control of the state of their ceilings during joint and repeated development of mineral deposits;
- mine surveying control of geometrical parameters of lifting complexes of mines and open pits;
- assessment of the state of structures, development of recommendations for observations, the formation of observation stations and the choice of the optimal observation methodology [7-12].

Control over the state of the tailing dump is carried out in several directions: visual observations; mine surveying control over the deformations of structures; monitoring the filtration regime; control of the design parameters of the structure, control over the observance of the reclamation technology; geotechnical control over the quality of tailings

injected into dams and thrust prisms; control over the filling of the storage capacity; control over the quality of clarified water [11, 13].

To ensure the safe operation of tailing dumps, constant awareness of the stress-strain state of rocks in the massif, physical and mechanical properties of rocks, stability of the structure, bearing capacity of the foundation is required [14-16].

2 Materials and methods

In order to monitor the stability of the position and condition of the dam of the combined tailing dump (CTD), a project of mine surveying and geodetic works was developed. This project included two parts:

- Draft planning justification.
- Project of high-rise justification.

To determine the stability of the position and state of the dam of the combined tailing dump, it was decided to increase the accuracy of determining the coordinates of the points to make observations using both satellite technologies and classical methods.

These works were carried out by employees of the Department of Mine Surveying and Geodesy of the Tashkent State Technical University together with the Mine Surveying Department of the Almalyk Mining and Metallurgical Combine (AMMC), independently of each other. Satellite observations were carried out by employees of the mine surveying department of the AMMC [17-20]. The measurements were carried out by a static method, the mathematical processing of the results of satellite measurements was carried out using the Leica SKI software. Observations by classical methods were carried out by employees of the Department of Mine Surveying and Geodesy (Tashkent State Technical University). The principle of performing satellite measurements is shown in Figure 2.

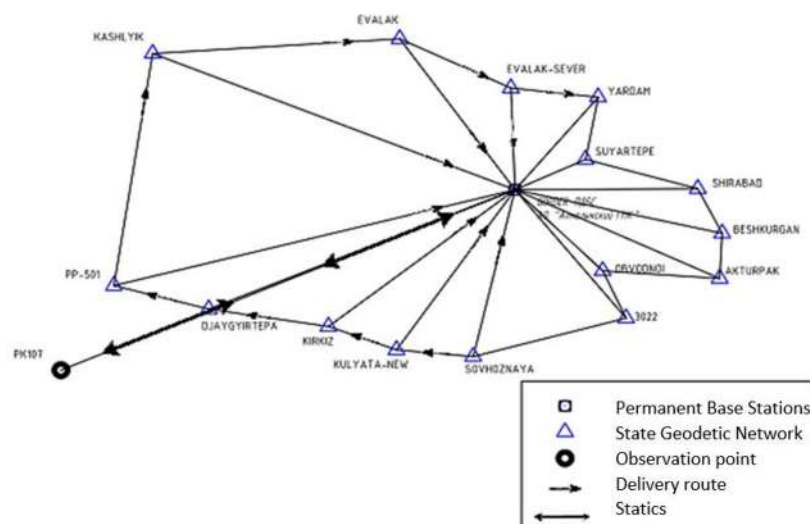


Fig. 2. The principle of satellite observations

In order to determine the coordinates of the points located on the dam, a network was designed in the form of geodetic marks, which includes the course of polygonometry of the 1st category, located on the dam and consisting of 13 points, at its beginning and end based on control points, the coordinates of which were obtained from satellite observations and 8

points located outside the dam, on solid ground free from the influence of the action of possible deformations. The principle of building a network is shown in Figure 3. The coordinates of these points were determined using both GNSS and classical methods [21-23].



Fig. 3. Layout of geodetic points

To conduct mine surveying observations of the deformations of the slopes of the enclosing dams, special observation stations are laid, at which instrumental observations are periodically carried out. The reference benchmarks of the geodynamic polygon should be located outside the influence of the work carried out and expected to be carried out in the future and, if possible, far from the boundaries of tectonic faults. Working and reference marks should be a network of connected triangles, in which all observation sites are inside the outer vectors of the network. Each point was fixed on the ground with the help of reference marks. The design of the reference marks, the way of their laying should provide: [22]

- convenience and normal conditions for the production of instrumental observations on the slopes and berms of dams;
- a strong connection with the ground, which allows the benchmarks of the profile line to move along with this process in the event of displacements and deformations of the rock mass;
- immobility to the influence of seasonal freezing and thawing of the soil;
- reliable safety for the entire service life of the observation station (guarantee against external damage);
- simplicity of design and low cost of manufacturing.

To secure working benchmarks for a service life of up to 3-6 years, driven benchmarks can be recommended. The hammer-in benchmark is a metal pin with a diameter of 25-35 mm, completed and sharpened at one end, the other end is machined into a hemisphere, on which the center is applied. The length of the pin, depending on the plane of the ground, is from 0.7 m to 1.5 m. The minimum depth of the benchmark in soft rocks is not less than 1.5 m. The fixed benchmark must have a strong bond with the rock and have a distinct center on the bench head to ensure accuracy observing its movement in the horizontal plane [22].

When calculating the coordinates of points by classical methods, the traverse on the dam is processed as a classic traverse of polygonometry, the coordinates of points located outside the traverse are determined using angular and linear (trilateration) serifs.

The most expedient method for determining the coordinates of points located outside the dam turned out to be the trilateration method, since it allows to largely eliminate the errors of angular measurements due to the fact that the angles of the serif triangles calculated from the measured sides using the cosine theorem have much higher accuracy compared to with angles

measured by a total station, especially since the lengths of the sides of the triangles fluctuate within 300-750 meters, which affects the accuracy of angular measurements.

The coordinates of the points were determined using both satellite technologies and classical methods. For the production of angular and linear measurements, an electronic total stations Leica TS07 was used, which has a mean square error of measurement of horizontal angles of 5" and an accuracy of distance measurement: 1mm + 1.5ppm. Satellite measurements were carried out by a static method, using geodetic satellite GNSS receivers [1, 8, 13, 15].

The coordinates of the side points were determined using serifs, and in addition to measuring the angles from at least three points for each point, linear measurements were also made, as a result of which the coordinates of each point were determined using three methods: angular serifs, linear serifs and linear-angular serifs. When determining the final values of coordinates, in addition to this, the values of coordinates obtained from satellite measurements were also taken into processing.

3 Results

The scheme of the geodetic network with the names of the points in which the geodetic observations were made is shown in Figure 4.

It should be noted that the values of the angles of triangles obtained through calculations from the measured horizontal distances have a much higher accuracy compared to the angles measured by an electronic total station. The discrepancies in the coordinates of the lateral points obtained from linear serifs ranged from 10 to 30 mm, while when calculating coordinates from angular serifs these values often exceeded 100 mm or more, which is unacceptable for such works [13].

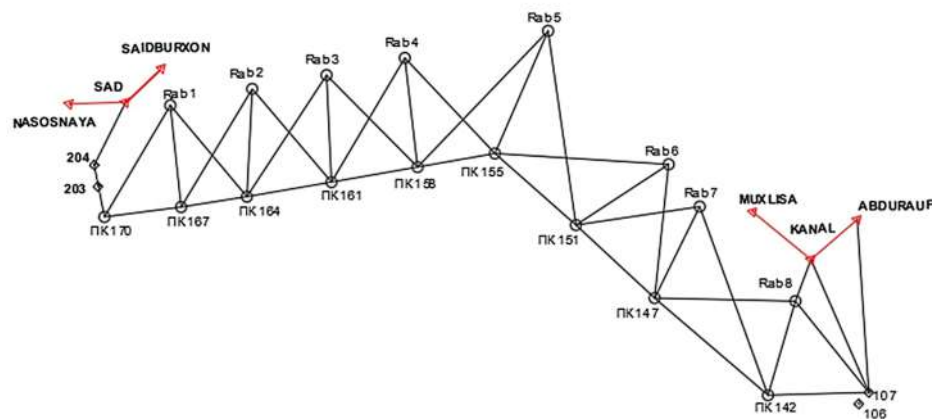


Fig. 4. Scheme of a geodetic observation network with the names of points

The accuracy of the angles of the triangles obtained from calculations on the measured sides can be determined from the expression:

$$m_A^2 = \frac{\rho^2}{h_A^2} (m_a^2 + m_b^2 \cos^2 C + m_c^2 \cos^2 B). \quad (1)$$

This formula establishes the dependence of the error m_A of the calculated angle A on the errors in measuring the sides of the triangle m_a, m_b, m_c and on the shape of the triangle (the values of the angles A, B and C).

Lowering the heights h_B and h_C from the vertices of angles B and C of triangle ABC (Figure 5) to the opposite sides B and C , we obtain similar formulas for the mean square errors of angles B and C :

$$m_B^2 = \frac{\rho^2}{h_B^2} (m_b^2 + m_a^2 \cos^2 C + m_c^2 \cos^2 A), \quad (2)$$

$$m_C^2 = \frac{\rho^2}{h_C^2} (m_c^2 + m_a^2 \cos^2 B + m_b^2 \cos^2 A) \quad (3)$$

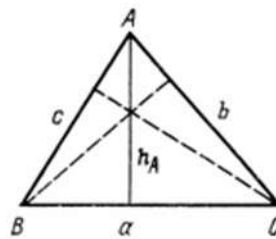


Fig. 5. Triangle with sides measured

In the case of an equilateral triangle, the root means square error of the angle calculated by formula (1) for our case when using a Leica TS07 electronic total station with a distance measurement accuracy of $1 \text{ mm} + 1.5 \text{ ppm}$ with an average triangle side length of 500 m will be equal to $m_\beta = 1.0''$. Since the triangles in the network have different angles and side lengths, then choosing the triangle with the most unsuccessful configuration, having the sharpest angle in comparison with other triangles and formed by the vertices of PK 147, Rab 7 and PK 142, having corresponding angles at PK 147, Rab 7 and PK 142, respectively, having angles at PK 147 = $104^\circ 10' 33.56''$, at PK 142 = $29^\circ 32' 27.67''$ and at Rab 7 = $46^\circ 16' 58.77''$ and horizontal distances, respectively $b = 750.3305 \text{ m}$ and $c = 381.5673 \text{ m}$, we get $m_B = 1.6''$ and $m_C = 0.6''$ (sides and corners are marked according to Figure 5).

The root-mean-square error of the position of the desired point P , determined from two starting points in the case of a linear intersection, is determined by the formula:

$$M_P = \sqrt{\frac{m_{d1}^2 + m_{d2}^2}{\sin \gamma}} \quad (4)$$

where m_{d1} and m_{d2} are the root mean square errors in measuring the lengths of the sides between the original and the determined points; γ is the angle at the determined the position of point P according to formula (4) will be equal to 3.1 mm .

In the case of a direct angular intersection, the root means square error of the position of the desired point P , determined from two initial points, can be determined by the formula:

$$M_P = \frac{m_\beta}{\rho''} \sin \gamma \sqrt{d_{1-P}^2 + d_{2-P}^2} \quad (5)$$

For our case, $M_P = 28 \text{ mm}$, which is much rougher than a linear intersection.

4 Discussion

These calculations are given without taking into account the errors of the initial data; therefore, they must be taken into account when designing the initial justification and the size of the network. In our case, the course of polygonometry of the 1st category with a length of 4232 m was laid along the dam. In the first cycle, the relative error of the stroke was $\frac{1}{282000}$, in the second cycle, $\frac{1}{14100}$, with a permissible relative error of $\frac{1}{10000}$.

According to the results of the work performed, both in the first and in the second cycles, it turned out that the differences in the values of the coordinates of the points determined using satellite observations and linear serifs have very insignificant discrepancies, within a few millimeters, only in some cases a few tens of millimeters. At the same time, the largest coordinate discrepancies were observed in triangles having the sharpest angles on one side, on the other side their values were within tolerances, provided by the relevant instructions. This accuracy in determining the coordinates is quite acceptable when creating a survey justification for large-scale surveys, but in no case is it unacceptable when determining horizontal displacements. Therefore, it was decided to accept the coordinates obtained from satellite observations and linear serifs as the final values, and the coordinates obtained from angular serifs and linear-angular serifs should not be accepted for processing, since they will only reduce the accuracy of the final results. To determine the coordinates by angular marks, a more high-precision goniometer is needed, the choice of which must be determined during further observations in the following cycles (Table 1).

Table 1. Analysis of differences in coordinates of points in cycles between satellite and classical measurements

Names points	Differences in coordinate values between satellite and classical measurements			
	1st cycle		2nd cycle	
	X, mm	Y, mm	X, mm	Y, mm
204	-31	-2	-46	+16
PK170	+8	-11	-35	+21
PK 167	+2	-12	-37	+22
PK 164	-2	-15	-36	-11
PK 161	+11	-27	-28	-16
PK 158	+10	-10	-4	-14
PK 155	+14	+7	-32	-46
PK 151	+14	+1	-12	-39
PK 147	-22	0	-5	-10
PK 142	-23	+5	-27	-16
107	-24	-2	-31	-31
Rab1	-28	-20	-32	-26
Rab2	-21	-32	+11	+37
Rab3	-13	-28	-22	+11
Rab4	-27	-14	+33	-22
Rab5	-20	-17	-40	+31
Rab6	-18	+16	+22	+22
Rab7	-14	+8	+22	+26
Rab8	-32	-15	+11	+22

In addition to the serifs, the coordinates of the network points were determined from satellite measurements. The differences in the coordinate values determined by the serifs and satellite measurements are insignificant and are presented in Table 1. The differences in the values of

the coordinates obtained from the joint processing of satellite and classical measurements are presented in Table 2.

Table 2. Analysis of horizontal displacements between 1 and 2 cycles, according to the values of coordinates obtained from satellite and classical measurements

Names points	Differences (1 - 2 cycles)	
	X, mm	Y, mm
204	+23	+23
PK170	-1	+38
PK 167	-10	+24
PK 164	+9	+40
PK 161	+45	+27
PK 158	+32	+4
PK 155	-15	-24
PK 151	+13	+14
PK 147	+47	-6
PK 142	+13	+11
107	+8	+23
Rab1	-2	-3
Rab2	-6	+2
Rab3	-16	+7
Rab4	-3	-16
Rab5	-20	+33
Rab6	+6	+13
Rab7	+4	+9
Rab8	+21	+7

The marks of the benchmarks were determined using a closed course of leveling of the III class, two measurement cycles were also carried out, while their differences did not exceed the values presented in the Leveling Instructions for I, II, III and IV classes [6,7,8,19, 22].

5 Conclusions

From all of the above, we can conclude that when monitoring tailings dam benches, it is whenever possible convenient to use the geodetic survey method. It allows simultaneous measurements of both the main course and side points, which significantly reduces the time for making field measurements. In addition, in the case of short sides of triangles, the linear serif method is the most appropriate, since it allows one to obtain more accurate values of the angles of triangles compared to angular measurements, which ultimately significantly increases the accuracy of determining the coordinates of points. Also, linear measurements require much less time to produce compared to angular measurements, which further reduces field measurement time. In addition, when producing linear notches, instruments are needed that only have significant linear measurement accuracy. When making angular measurements, only high-precision angular measuring instruments are needed, the characteristics of which can be judged after further work is performed, when processing observations from subsequent cycles. This requires very high accuracy in obtaining coordinates when determining horizontal displacements.

In addition, to date, only two observation cycles have been completed. Therefore, final conclusions can be made after a whole series of observation cycles have been carried out, especially with regard to the accuracy of goniometric instruments, which must be

substantiated not only by theoretical research, but also by the results of field geodetic measurements.

References

1. Ski Documentation (G2-545-Oen II-98) – Leica Geosystems Inc., GPS, CH 9435, Heerbrugg, Switzerland (1998)
2. Yakovlev V.N. Monitoring and assessment of the stability of the tailings dam slopes based on the results of mine surveying. / Dissertation for the degree of candidate of technical sciences. (Ekaterinburg, 2002)
3. Rakhimov V.R., Lebedkova A.A., Aflyatunov F.F. Some issues of geomechanics in the operation of tailings. (Tashkent, UzSSR, 1978)
4. Law of the Republic of Uzbekistan. On the safety of hydraulic structures. 08/20/1999, No. 826-I.
5. Instructions for observing deformations of sides, slopes, benches and dumps in open pits and the development of measures to ensure their stability. Registered by the Ministry of Justice of the Republic of Uzbekistan on February 26, 1999, Registration No. 649.
6. Instructions for leveling I, II, III and IV classes. (Nedra, Moscow, 1990)
7. Instructions for polygonometry and trilateration. (Nedra, Moscow, 1976)
8. Instructions for the production of mine surveying work. (Nedra, Moscow, 2004)
9. Besimbaeva O.G.. Forecasting the stability of ash dumps enclosing dams. / Dissertation for the degree of candidate of technical sciences. (Karaganda, Kazakhstan, 2010)
10. Report. 63-4082yur from 09/22/2020. Assessment of the state of the dam of the combined tailing dump (CTD) of the CPP and CPP-2 according to geological-geophysical and mine-surveying-geodetic observations (TSTU). (Tashkent, 2021)
11. Rules "On the safety of operations during the operation of tailings facilities." [Registered by the Ministry of Justice of the Republic of Uzbekistan on May 31, 2006.].
12. Recommendations for the design and construction of sludge collectors and tailings for the metallurgical industry. (Stroyizdat, Moscow, 1987)
13. RTM on the use of geodetic satellite receivers in the creation and reconstruction of thickening networks (GKKINP-01-014-98). (Uzgeodezcadastre, Tashkent, 1998)
14. SNiP 2.06.05-84 * Dams from soil materials. (Moscow, 1991).
15. Technical instruction manual for geodetic satellite receiver Leica System-300.
16. Sayyidkasimov S.S., Kazakov A.N., Rahimova M.Kh. Construction of dependencies of parameters of the maximum slope of dams tailing dumps CPP AMMC using software.(3rd International scientific and technical conference "Innovative development of resource-saving technologies and sustainable use of natural resources". 2020), p. 164-167
17. Sayidkasimov S.S., Inogamov I.I., Rahimova M.H., Yakubov T. Constructing dependencies of the maximum slope parameters of tailings dams at the Mining Plant of AMMC using software. (Scientific and technical and production journal "Mining Bulletin of Uzbekistan", Vol. 4, (83), 2020), p. 78-83
18. Instructions for small-scale topographic surveys at scales of 1:5000, 1:2000, 1:1000 and 1:500. (Tashkent, Uzgeodezcadastre, 2003)
19. Sayyidkoshimov S.S., Raimzhanov B.R., Umarov F.Ya., Rakhimova M.Kh. Predictive assessment of the stress-strain state of tailings dams based on a spatial finite element model (Mining Information and Analytical Bulletin. No. 9, Moscow, 2023) p. 38–55. DOI: 10.25018/0236_1493_2023_9_0_38.
20. Sayyidkasimov S.S., Kovalev N.V., Kazakov A.N., Rakhimova M.Kh., Xakberdiyev M.R., Hakimov A.M., Goziyev I.R., Abdukodirov A.A. Analysis of the most expedient mine surveying and geodetic method for tracking the stability of the tailings dam position.

- (Technical science and innovation, ISSN: 2181-0400, Volume 4, Tashkent, 2021.), p. 92-100.
21. Mirmakhmudov E.R., Kovalev N.V., Niyazov V.R., Rakhimova M.Kh. The optimal method of designing a geodetic network of condensation near a quarry. (ISSN : 2311-5122, DOI - 10.32743/UniTech.2021.87.6.11986. UNIVERSUM: TECHNICAL SCIENCES. Scientific journal. Issue: 6(87), June 2021, Part 1) p. 83-88, <http://7universum.com/ru/tech/archive/category/687>
 22. Altiyev A.S.; Pardaboyev A.P., Karamatov V.SH.; Fayzullayev Z.S., Xolboyev B.A. Stages of the formation of the land market, the main directions of its development and socio-economic importance. Annals of Forest Research Peer-reviewed, open access journal of forestry & environmental sciences ISSN: 18448135, 20652445. 65(1): 9151-9163, 2022. <https://www.e-afr.org/article/view/9151.html>