

Development stages of the geodetic network in Tashkent city

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Abstract. The purpose of this study is to analyze the stage of development of the geodetic network in Tashkent city, conduct satellite observations, and preprocess measurements to establish a urban frame network. The stages of development of the geodetic network in Tashkent were analyzed and evaluated. A preliminary reconnaissance was conducted at the work site to verify the suitability of selected points for satellite observations. Suitable days for field measurements were scheduled using software. Observations were carried out at 9 points of the designed frame network using 6 Chcnv i90 GNSS receivers in 2 sessions employing the Static method. The sessions were linked by 3 points, and each session lasted four hours. Measurement data from the Chcnv i90 GNSS receivers were obtained in 'RINEX' format for processing. Joint measurements from the two sessions were processed using Trimble Business Center software version 5.52. Initial adjustments were made to the measurements of the lengths between points, and their accuracy was verified. The maximum root mean square error of side measurements was found to be less than the specified value for the frame network. A figure closure program was utilized to accurately determine baseline length errors.

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1 Introduction

1.1 Analysis of the development stage of Tashkent city's geodetic network

The first steps towards creating a geodetic network in the city of Tashkent began in 1914 under the auspices of the City Land Management. By order of this Directorate, military topographers constructed an urban triangulation network comprising 58 points during 1914-1915. It is connected to the 'Observatory-Nikolsky Village' side through the extension of a directional angle from the established state geodetic network. However, from 1916 to 1930, no further efforts were undertaken to expand the geodetic network.

In 1931, the Central Asian Geodetic Department continued developing a geodetic network for conducting topographic surveys in Tashkent. During 1931-1932, they established a network of 46 triangulation points covering an area of approximately 230 sq. km within the city. This included 10 points of class I, 8 points of class II, 9 points of class III, and 19 points of class IV.

Due to the rapid development of industrial and civil construction in the capital city of Tashkent, by 1936, the task of establishing a plan-altitude geodetic basis for large-scale topographic surveys at scales ranging from 1:2000 to 1:500 was assigned to the Geobureau under the Architectural Department of the Tashkent City Executive Committee. Considering the city's expanding territory, a new urban geodetic network project was devised. According to the project, during 1936-1937, a triangulation network consisting of 49 points was constructed in the city, including 14 points of class I and 35 points of class II.

In 1939, the Geobureau was assigned the task of systematizing the outcomes of earlier urban triangulation efforts and constructing a new urban geodetic network aligned with contemporary requirements. Upon reviewing materials from previous years, it was discovered that the triangulation points established in 1914 had been entirely lost. Furthermore, the class II triangulation network completed during 1936-1937 was deemed invalid due to measurement errors surpassing acceptable limits. Considering these findings, a project was created for the reconstruction of Tashkent's geodetic network.

According to the reconstruction project of the geodetic network, it comprised 11 points of Class I, 26 points of Class II, and 22 points of Class III. Therefore, a triangulation network of 59 points was constructed over an area of approximately 280-300 sq. km of the city at that time, in accordance with the requirements of the regulatory document [6].

In 1947-1950, in the newly annexed part of Tashkent city, 7 additional points of Class III were constructed among the existing triangulation points. From 1950 to 1951, 10 points of Classes II and III were concentrated between the triangulation points of Classes I and II that were built in the eastern and northeastern parts of Tashkent city during 1939-1941.

Summarizing the results of the work conducted in Tashkent city, it can be concluded that by 1960, the city possessed a high-quality geodetic base. However, the points of this geodetic base lacked sufficient density and were unevenly distributed throughout the city. In 1960, the Tashgiprogor Institute (Tashkent State Institute of City Design) was tasked with restoring and expanding the existing geodetic network. The Institute conducted geodetic work from 1960 to 1963, followed by the Tashkent city branch of the UzGIITI Institute (Uzbek Head Institute of Engineering and Technical Surveys) from 1963 to 1965.

After the Tashkent earthquake on April 26, 1966, polygonation points were served as the geodetic basis for construction work during the city's reconstruction from 1966 to 1968. From 1968 to 1970, the State Institute of Engineering and Technical Research of Uzbekistan carried out the restoration and development of Tashkent's triangulation and polygonation. The development of triangulation points of Classes III and IV in the city, along with connecting the tunnel triangulation along the metro route to Class II triangulation points, was carried out in full compliance with the relevant regulatory documents [8, 9].

From 1960 to 1985, polygonation were conducted almost annually, separately in each building area of the city of Tashkent. By 1982, the composition and number of urban polygonation points were as follows: 4th class - 199, 1st class - 2860, and 2nd class - 1784. The construction of the polygonation network was carried out according to the instructions [9].

The triangulation and polygonometry networks of the city, established between 1939 and 1984, resystematized and adjusted. Network adjustment was carried out in two coordinate systems (1942 and Local (1967)). Following the network adjustment, catalogs containing coordinates of triangulation and polygonometry points were compiled.

Over the past few decades, no cumulative information has been found regarding systematic efforts in the reconstruction and development of the geodetic network of the city of Tashkent. Since no relevant efforts in the reconstruction and development of the geodetic network of the city of Tashkent is known, in this manuscript the authors are validating the applicability for establishing a geodetic network of the most commonly used geodetic technology, the GNSS.

2 Materials and methods

2.1 Performing Satellite Observations at Frame Network Points

The emergence of global satellite technologies in the United States in the early 1980s necessitated a significant reassessment of traditional approaches to constructing and reconstructing urban geodetic networks. With this technology, it became possible to obtain coordinates and heights of points on the Earth's surface across large areas with high accuracy, requiring minimal effort and time [9].

2.2 Reconnaissance of points

Based on the research objectives, a preliminary reconnaissance was conducted at the work site to assess the suitability of selected points for satellite observations, as outlined in [4, 5]. Objects that obstruct the transmission of radio signals from satellites near network points can impair measurement accuracy and create significant difficulties during the data processing phase [7, 4, 5].

Before heading out for field observations, the visibility of satellites during measurements, their minimum number, and DOP indicators were determined using the 'Planning' section of the Trimble Business Center software. Convenient days for field measurements were selected (November 5, 2023, and November 19, 2023)

2.3 Measurements

The observations at 9 points of the designed network were conducted in 'static' mode across 2 sessions, using 6 dual-frequency Chcnav i90 GNSS receivers developed in the People's Republic of China [12]. The points Toshkent, Taxtako'prik, and Taukat were selected as common points for linking the sessions (see Figure 1) [8]. Each session involved four hours of observation.

The duration of the sessions was determined based on the length of the measured lines, the number of points simultaneously monitored, the type of receivers used, and the required measurement accuracy.

The work at the stations begins with the installation of antennas. Initially, a tripod was positioned at the center of the point and secured with an optical centerer, ensuring centering

with an accuracy of ± 1 mm. Subsequently, the receiver is mounted on the tripod. To ensure that the height of the antenna did not change during the measurement, care was taken to ensure that the tripod on which the antenna was mounted was firmly fixed to the ground. Measurement errors in antenna height can impact the accuracy of point coordinate determination. Antenna height was measured twice before and after observations using a tape measure.

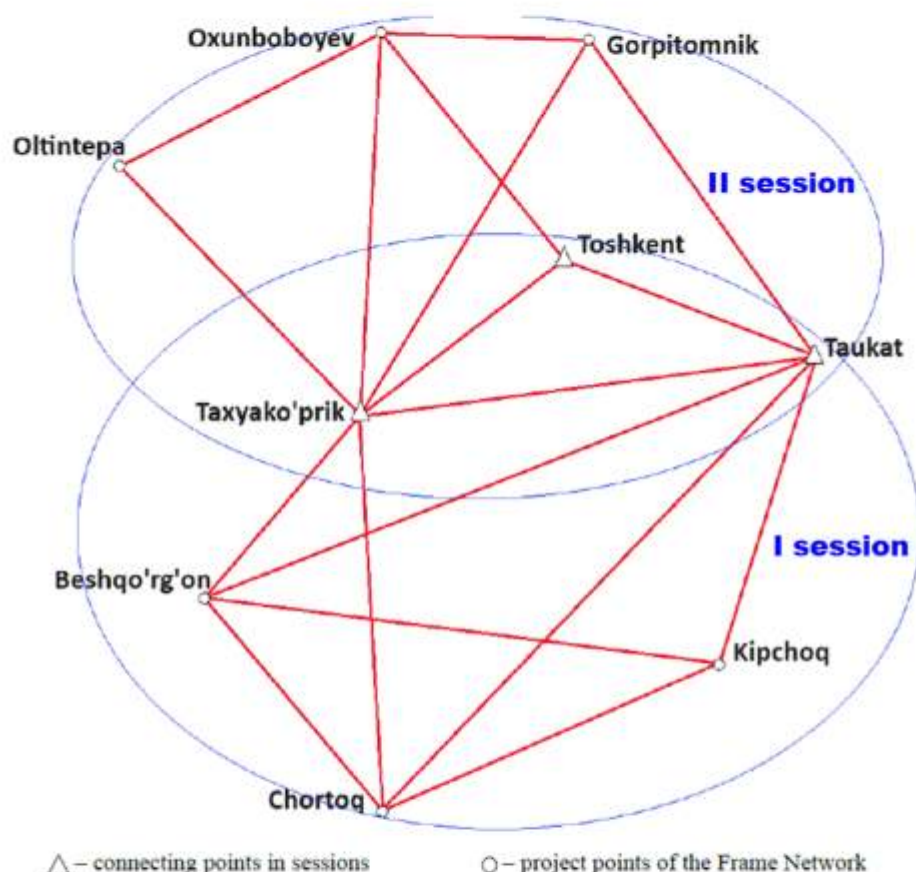


Fig. 1. Project for Reconstruction of the Urban Geodetic Network of Tashkent

The receiver was powered on, satellite measurements were taken, and the receiver was powered off by a specialist. Measurements commenced based on the agreed and approved 'Map of Satellite Observations at the Point' (Table 1). The receiver was allowed to be powered on after proper centering. All receivers at the points were powered on simultaneously at the agreed time.

Table 1. Map of Satellite observations at the Point

The name of the point on the controller is KIPCHAK, $t^{\circ}-22^{\circ}\text{C}$. P-1010 mmHg

Indicators	Session No. 1		Session No. 2	
	Start	End	Start	End
Date	19.11.23	19.11.23	19.11.23	19.11.23
Time	10:20	14:20	11:10	15:10
Antenna height	2,200	2,200	2,200	2,200

Tripod height	1,350	1,350	1,420	1,420
Satellite receiver antenna number			№ 3420105	
Control unit number			№ 611230192	
Memory type			Internal memory	
Number and type of power supply			Standard battery	

Before the measurements, the operational status of the receiver was also verified, focusing on aspects such as the data recording interval, storage of measurements in memory, and available memory space, among others. It was ensured that the data recording interval was consistent across all receivers.

At each network station, the Chcnv i90 GNSS receiver antenna and the control unit (controller) were connected via Bluetooth. The project was created using the 'Projects' menu on the controller, where information such as the time interval for recording coordinates, number of sessions, point name, receiver antenna height, and other details were entered into the 'Statics' section.

Figure 2 shows several photographs depicting the setup of instruments and the observation process at points of the Frame Network.



Fig. 2. Field measurement work at points of the Frame Network (FN).

3 Results and discussion

3.1 Pre-processing of satellite observations

The office processing of measurement results in geodetic networks involves two stages: pre-processing and network adjustment. During pre-processing, baselines (vectors) between network observation points are calculated.

When obtaining measurement data from the Chcnv i90 GNSS receiver, attention was given to the accuracy of point names and the installation position of the antenna – whether mounted on a tripod or a forced center. The primary focus was on the operational uptime of the GPS receivers. If all procedures meet the required standards, the data will be exported in .RINEX format and transferred to the next stage. Otherwise, measurements may need to be repeated [11, 14].

The results of satellite observations can be processed using various programs. For each point in the frame network, preliminary processing of combined measurements from two

separate sessions was conducted in the WGS-84 spatial rectangular coordinate system and the 1942 coordinate system using Trimble Business Center software.

Table 2 presents the preliminary equations and the accuracy of the results for measuring the distances between points in the frame network.

Table 2. Results of measuring side lengths and their accuracy.

Station name	Name of the observed point	Root mean square error		Azimuth	Adjusted distances between points S , m	Elevation vertical distance between points, h , m
		m_s plan, m	m_H height, m			
Toshkent	Oxunboboyev	0,015	0,043	321°16'38"	9092,722	-15,844
Toshkent	Taukat	0,007	0,037	111°02'03"	8435,958	3,748
Gorpotomnik	Karima Guk	0,008	0,023	245°30'29"	10876,587	-31,785
Beshqo'rg'on	Chortoq	0,007	0,022	140°14'57"	8626,552	-36,996
Beshqo'rg'on	kipchak	0,012	0,038	97°24'44"	16135,093	-1,795
Chortoq	kipchak	0,009	0,028	66°34'45"	11429,116	35,126
Taxtakoprik	Oltintepa	0,010	0,029	316°09'07"	10795,501	3,702
Taxtakoprik	Toshkent	0,009	0,035	53°00'50"	7996,702	27,313
Taxtakoprik	gorpt	0,011	0,031	31°39'47"	13681,527	34,170
Taxtakoprik	Karima Guk	0,010	0,027	339°10'01"	7624,638	2,370
Taxtakoprik	Beshqo'rg'on	0,014	0,043	220°26'02"	7437,703	-21,733
Taxtakoprik	Chortoq	0,013	0,049	176°47'53"	12316,527	-58,988
Oltintepa	Oxunboboyev	0,010	0,033	63°12'59"	9149,296	7,773
Taukat	kipchak	0,008	0,025	198°02'54"	10030,881	-54,673
Taukat	Chortoq	0,013	0,047	224°03'14"	19564,298	-89,786
Taukat	Chortoq	0,013	0,047	224°03'13"	19564,294	-89,864
Taukat	Beshqo'rg'on	0,013	0,049	248°47'19"	20490,743	-52,801
Taukat	gorpt	0,009	0,029	324°24'34"	12135,887	3,247
Taxtakoprik	Taukat	0,014	0,048	82°50'50"	14375,964	31,116
Oxunboboyev	Karima Guk	0,006	0,017	215°30'18"	5863,753	-8,858
Oxunboboyev	gorpt	0,010	0,028	92°15'20"	6493,373	22,941
Taxtakoprik	Oxunboboyev	0,014	0,049	3°20'05"	11920,109	11,597

As shown in the table, the maximum root-mean-square error in measuring distances between points in the network occurs between 'Toshkent' and 'Oxunboboyev', with an absolute error of 0,015 m or a relative error of 1:600000. This value is below the specified limit (1:500000) for frame networks [5, 6].

3.2 Assessing the accuracy of satellite observations

For geodetic networks, identifying problematic lines is best accomplished using figure closure programs, which aggregate vector components along a closed path to calculate residuals. Most software packages include such tools. In each figure, discrepancies (w_x, w_y, w_z) for each coordinate can be obtained as the sum of the corresponding increments,

which theoretically should equal zero [5, 7]:

$$w_x = \sum_k \Delta X; \quad w_y = \sum_k \Delta Y; \quad w_z = \sum_k \Delta Z, \quad (1)$$

where k is the number of sides of a closed figure.

Using coordinate residuals, you can obtain the overall residual

$$w_s = \sqrt{w_x^2 + w_y^2 + w_z^2}. \quad (2)$$

and compare it with the expected residual w_{check} :

$$w_{check} = \sqrt{\sum_k (\Delta_D^2 + \Delta_H^2)}. \quad (3)$$

Errors Δ_D and Δ_H are determined based on passport data or set according to the instructions for this type of work. The following condition must be met with a 95% probability:

$$w \leq 2w_{check}. \quad (4)$$

Figure 3 shows a diagram of the triangles of the frame network.

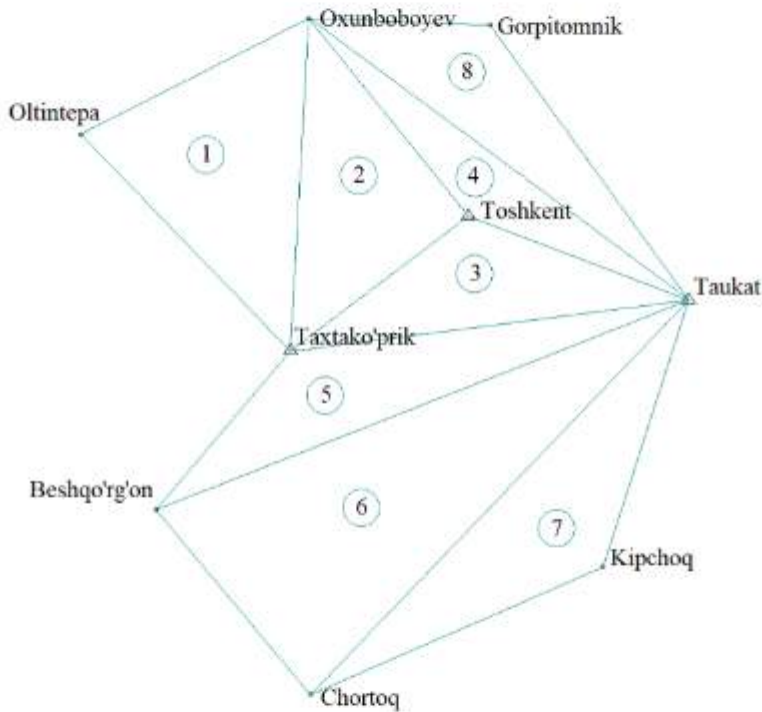


Fig. 3. Diagram of basis vectors in a closed-form Frame Network.

Three-dimensional vector residuals w_x, w_y, w_z , determined by closed forms in the network, are calculated using formula (1) and are given in Table 3.

Table 3. Residuals of triangle vectors within the network.

Triangle Network	Total Distance D , (m)	w_x , m	w_y , m	w_z , m	w_s , m	$w_{s_{check}}$, m
Session Number: 1 Station Number: 3						
Oltintepa-Oxunboboyev-Taxtak'o'prik-Oltintepa-Taxtak'o'prik-Oxunboboyev	31867,144	-0,004	-0,012	0,006	0,014	0,027
Taxtak'o'prik-Oxunboboyev-Toshkent	29011,661	0,005	0,008	0,005	0,011	0,026

Oxunboboyev-Toshkent-Taxtak'o'prik						
Toshkent-Taxtak'o'prik-Taxtak'o'prik-Taukat-Toshkent-Taukat	30810,922	0,002	0,010	-0,005	0,011	0,027
Toshkent-Taukat-Taukat-Oxunboboyev-Toshkent-Oxunboboyev	34451,304	0,007	-0,010	0,009	0,015	0,029
Taxtak'o'prik-Taukat-Taxtak'o'prik-Beshqo'rg'on-Taukat-Beshqo'rg'on	42307,494	-0,003	-0,006	-0,011	0,013	0,034
Taukat-Beshqo'rg'on-Beshqo'rg'on-Chortoq-Taukat-Chortoq	46660,113	-0,009	0,001	-0,013	0,016	0,037
Taukat-Chortoq-Chortoq-Kipchak-Taukat-Kipchak	41024,419	-0,009	-0,003	0,002	0,010	0,033
Taukat-Oxunboboyev-Oxunboboyev-Gorptomnik-Taukat-Gorptomnik	27722,023	0,010	-0,004	0,009	0,014	0,030

Using the maximum values of the discrepancies between the triangle vectors in Table 3, we calculate the absolute discrepancy in the triangle using formula (2):

$$w_{S_{max}} = \sqrt{(0.007)^2 + (0.010)^2 + (0.009)^2} = 0.015 \text{ m.}$$

From the analysis of the data presented in Table 3, we can conclude that the average side length obtained in each session is 35,6 km. Next, we calculate the relative error of the network:

$$\frac{w_{S_{max}}}{D_{ypr}} = \frac{1}{2370000}.$$

4 Conclusions

The maximum root-mean-square error in measuring the sides of the frame network occurred between points 'Toshkent' and 'Oxunboboev', resulting in an absolute value of 0,015 m or a relative error of 1:600000 (refer to Table 2). This value is less than the specified 1:500000 tolerance outlined in the frame network construction instructions. Furthermore, the maximum absolute value of the triangle vector was also determined to be 0,015 m (line 4, Table 3). The relative error for the triangle perimeter, spanning 35,6 km, was calculated at 1:2370000. Based on the above, the accuracy of GNSS observations obtained in the field meets the requirements for constructing satellite geodetic networks as established in [5]. Therefore, we can proceed to network adjustment.

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