ANALYSIS OF GEODETIC NETWORK DATA FOR INFRASTRUCTURE PROJECTS AND THEIR APPLICATION IN CONSTRUCTION PLANNING

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ABSTRACT:

This paper presents a detailed analysis of geodetic network data for infrastructure projects and their application in construction planning. The focus of the work is on the importance of geodetic data in the precise planning and design of roadways, as well as the methods of data collection and processing using modern technologies such as GNSS measurements and leveling. The paper examines the case study of the "National Stadium" traffic interchange, analyzing the impact of geodetic data on the efficiency, accuracy, and stability of constructions. It is concluded that modern technologies and continuous monitoring significantly contribute to the quality and dynamics of large infrastructure project construction.

KEYWORDS:

geodetic network, infrastructure projects, construction planning, GNSS measurements, levelling, construction stability, roadways

1 INTRODUCTION

Infrastructure projects form the foundation for the development and maintenance of modern society. Their successful implementation depends on precise planning, design, and execution, which requires reliable and accurate data. The geodetic network is a key element in this process, as it provides the necessary precision in measurement and positioning, enabling the exact determination of the location of all infrastructure elements. In the context of planning and constructing infrastructure projects, such as traffic interchanges, bridges, and road networks, the geodetic network plays a crucial role in ensuring the quality and efficiency of the project.

The aim of this paper is to analyze geodetic network data for infrastructure projects and their application in construction planning. Specifically, the paper will focus on a case study of the interchange in the Expo construction site zone, with the goal of exploring how geodetic data can contribute to better planning, design, and execution of such projects. Methods of data collection and processing, as well as the application of modern technologies in the analysis and interpretation of this data, will also be considered.

2 THEORETICAL FOUNDATIONS OF SPATIAL PLANNING

Urbanization is a global process that is accelerating, with more than half of the world's population living in urban areas since 2007. It is estimated that 60% of the world's population will reside in cities by 2030 [1]. This rapid expansion poses significant environmental, economic, and social challenges, with over 70% of growth occurring outside formal planning. In slum areas, where up to 90% of new residents in parts of the world like Sub-Saharan Africa reside, the problems become even more pronounced.

Cities are also key in the fight against climate change, as urban areas consume 80% of the world's energy and generate 80% of global greenhouse gas emissions [17]. The administrations of large cities face problems such as population density, traffic congestion, unplanned development, and a lack of essential services, which affect effective population growth management.

Informal settlements are a major challenge for many cities, as many citizens lack access to adequate land and housing [1]. Social exclusion and poverty will continue unless appropriate interventions are implemented within the broader context of economic growth policies and poverty reduction.

Natural disasters, such as floods and fires, further threaten urban areas, particularly slums [2]. Risk management and disaster preparedness have become critical in urban planning.

2.1 INTEGRATED SPATIAL PLANNING AND INFRASTRUCTURE DEVELOPMENT FOR SUSTAINABLE CITIES

Modern technologies, such as GNSS measurements and satellite positioning, have revolutionized the collection of data on urban areas [2]. These data enable detailed planning and integration of information into Geographic Information Systems (GIS). Precise land management has become the foundation for efficient resource use and sustainable urban development

2.2 DATA COLLECTION TECHNOLOGIES

Spatial data are collected using different methods: photogrammetry, field measurements, and cartographic digitization. Advanced methods, such as LiDAR and radar systems, contribute to the accuracy and speed of data collection [2].

2.3 DOCUMENTS FOR SPATIAL AND URBAN PLANNING

Spatial and urban planning in the Republic of Serbia aims to ensure conditions for quality management and improvement of living standards. Urban planning focuses on:

- Spatial organization of settlements.
- Preservation of architectural heritage.
- Creation of new urban values.
- Restoration of historical areas.
- Preservation of land and natural values.
- Alignment of infrastructure construction [3].

Spatial Plans in Serbia:

1. Spatial Plan of the Republic of Serbia.
2. Regional Spatial Plan.
3. Spatial Plan of Local Government.
4. Special Purpose Area Spatial Plan.

Urban Plans:

1. General Urban Plan.
2. General Regulation Plan.
3. Detailed Regulation Plan [4].

Geodetic foundations serve as the basis for planning and include:

- Topographic plan.
- Orthophoto.
- Digital terrain model.
- Cadastral plan [5].

2.4 LAW ON PLANNING AND CONSTRUCTION

The Law on Planning and Construction regulates the conditions for space management, land use, and building construction in Serbia. Key aspects of the law include:

1. Urban plans.
2. Building permits.
3. Geodetic data.
4. Inspection oversight.
5. Environmental protection [5].

2.5 ROAD PLANNING MANUAL

The manual provides guidelines for road planning and construction, including:

1. Planning procedures.
2. Technical requirements.
3. Investment documentation.
4. Safety and environmental protection measures.
5. Control and supervision [6].

2.6 REGIONAL DEVELOPMENT

Regional development represents a key aspect of improving the economic, social, and infrastructural status of various regions within the Republic of Serbia. The primary goal of stimulating regional development is to reduce disparities between different parts of the country, ensure sustainable development, and strengthen local economies. These development efforts contribute to improving the quality of life for citizens and promote more balanced national growth.

According to the Law on Regional Development, Serbia is divided into several regions, each with its own specific development potential and challenges. The Belgrade region holds a special position as the economic and administrative center of the country, playing a significant role in national development. Development projects focused on the Belgrade region aim not only to improve the infrastructure and business environment in this area but also to strengthen its influence on the development of other parts of Serbia through various mechanisms of regional cooperation and integration.

The city of Belgrade plays multiple roles in the Republic of Serbia. Primarily, it serves as the strongest functional area, contributing 41% of businesses and 40,2% of employees nationwide. Compared to other regions in Serbia, and according to the Law on Regional Development, Belgrade has the smallest territory (3.222,7 km^2), but the highest population density (around 538 people per km^2) and the highest density of businesses with more than 10 employees (1,42 per km^2). Additionally, Belgrade has the highest concentration of scientific, professional, intellectual, cultural, and service capacities, with developed infrastructure and potential in the fields of information technology, communications, high-yield creative industries, services, and public services. It also benefits from a strategically important location along the Danube River, Corridor 7, and Corridor 10. Although the Belgrade Fair is the largest exhibition institution in Serbia, its limited space, capacity, accessibility issues, and the condition of its buildings and infrastructure do not meet the necessary standards for organizing major events. Moreover, new programs, standards, technologies, and the need for a high level of flexibility—which characterizes these types of institutions—require a modern and innovative approach to the development of exhibition space [7].

To accommodate the “EXPO 2027” complex, the relocation of the Belgrade Fair is planned. However, it is important to note that Hall 1 of the Belgrade Fair (Figure 2) was declared a protected cultural monument in 2009. Despite this status, the space is still used for significant events [8].

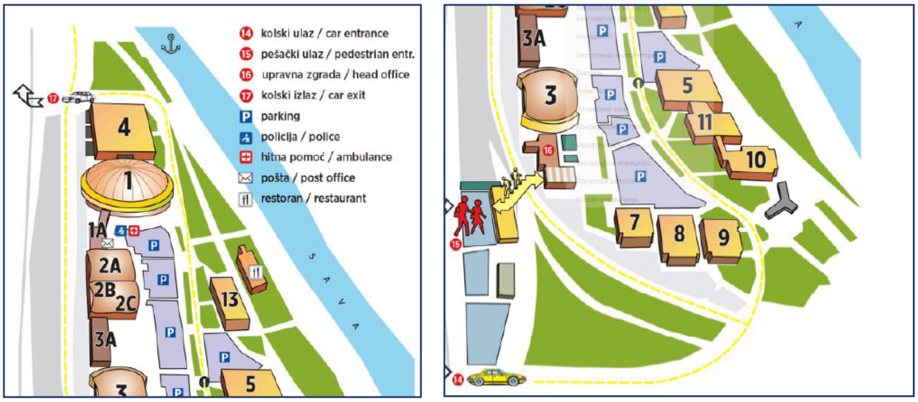

Figure 3: Layout of Belgrade Fair Halls

The regional aspect of developing the special-purpose area is viewed through the potential for the "EXPO 2027" complex (Figure 2), along with the National Football Stadium, to become a generator of future changes in the surrounding area. These expected changes may include:

- Expanding and enhancing Belgrade's existing tourism offer with a new modern complex for MICE (Meetings, Incentives, Conferences, Exhibitions) tourism.
- Promoting Belgrade as a host for major international trade fairs, congresses, economic, and cultural events.
- Showcasing cultural values and presenting a new, modern image of the Republic of Serbia [7][9].

Figure 2: Planned Project for "EXPO BELGRADE 2027"

2.7 SPATIAL PLAN FOR THE SPECIAL-PURPOSE AREA OF THE NATIONAL FOOTBALL STADIUM

The spatial plan outlines the foundations for organizing, using, developing, and protecting the special-purpose area of the National Football Stadium, in accordance with the construction project for the “EXPO Belgrade 2027” International Specialized Exhibition and its accompanying content. This area is designated as a special-purpose zone of national importance, compatible with the National Football Stadium.

The spatial plan allows for phased implementation of roadways. Areas planned for the construction of roads and utility infrastructure can be further subdivided through parceling/re-parceling projects to form multiple construction parcels within the defined public road regulation. Each construction parcel is part of a functional whole in accordance with the plan's defined purpose and regulation [10].

2.8 CURRENT STATE OF ROAD INFRASTRUCTURE

Within the boundaries of the Spatial Plan are the existing Zoran Đinđić Square Street and part of the State Road IA Class A1, E75, Belgrade Bypass. Zoran Đinđić Square Street is currently classified as a second-class street in the section from Vojvođanska Street to the Galovica Canal, and southwards towards the Sava River, it is a lower-class local road primarily serving agricultural areas and facilities. Within the boundaries of the Spatial Plan, Zoran Đinđić Square extends for approximately 3.6 km, and from the center of Surčin to the Galovica Canal, it has a two-lane roadway, greenery on both sides, and sidewalks. The street regulation in this area varies and reaches up to 50 meters in the central part of Surčin. South of the Galovica Canal towards the Sava River, the street runs through agricultural land and has a roadway width of approximately 6 meters, carrying two-way traffic.

The State Road IA Class A1, E75, Belgrade Bypass, in the section between the Surčin South interchange and the Ostružnica interchange (according to the Reference System of JP Putevi Srbije), partially falls within the boundaries of the plan, spanning approximately 1075 meters. This road is planned within the Spatial Plan for the Infrastructure Corridor of the E-75 Highway, Belgrade-Niš section ("Official Gazette of RS" No. 69/03 and 121/14) and the Regulation Plan for the E75 and E70 Highway Section Dobanovci – Bubanj Potok ("Official Gazette of Belgrade" No. 13/99) (Figure 3).

A large portion of the planned area is not directly served by the public transport system. Only the central part of Surčin, which falls within this plan, is served by the bus subsystem of public urban transport. Parking for users of the facilities within the planned area is provided either on the parcels where the buildings are located or on public parking spaces within the existing street regulation of Zoran Đinđić Square in the central zone of Surčin [11].

Sectoral development goals in the field of transport and transport infrastructure include:

- Connecting the planned area with the existing road infrastructure – State Road IA Class A1, E75, Belgrade Bypass.
- Connecting the planned area with the New Belgrade – Surčin section as part of the E-763 Highway (New Vinogradska);
- Connecting the planned area with Nikola Tesla Airport.
- Planning necessary parking areas for spectators and visitors.
- Serving the planned area with a public urban transport network.

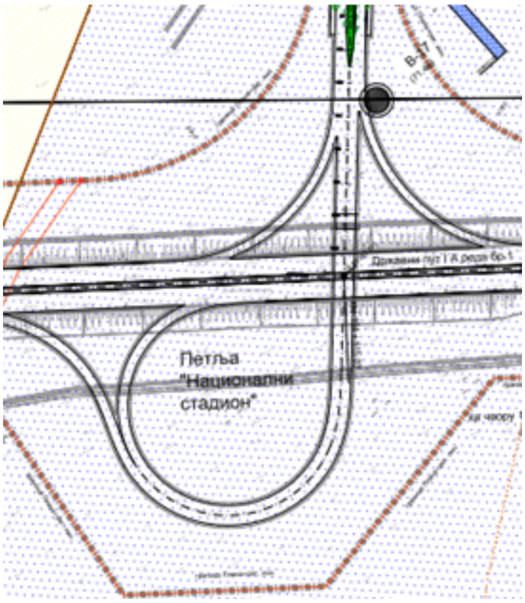

Figure 3: Excerpt from the Spatial Plan – Regulatory Map

3 GEODETIC WORKS DURING THE CONSTRUCTION OF THE STRUCTURE

Geodetic works are essential for ensuring the precision and stability of structures during construction. These activities ensure accuracy in all project phases, from the preparation of groundwork to the final control of the structure's geometry.

Key elements of geodetic works include:

1. Ensuring groundwork for design.
2. Resolving property and legal relations (expropriation).
3. Designing the primary geodetic network.
4. Implementing and placing the network on-site.
5. Connecting the structure to the geodetic network.
6. Marking project points.
7. Marking and controlling the geometry.
8. Deformation analysis of the structure [12].

3.1 GEODETIC NETWORK PROJECT FOR THE "NATIONAL STADIUM" INTERCHANGE

The geodetic network project for the "National Stadium" interchange has the following requirements:

1. Continuity with the existing network.
2. Configuration and accuracy within allowable deviations: Δ=20 mm horizontally and Δ=10 mm vertically.
3. Homogeneity and isotropy of the network.

4. Compatibility with geodetic equipment.
5. Stability and durability of network points [12].

3.2 STRUCTURE DESCRIPTION

The "National Stadium" interchange is the junction of the Nova 3 road and the state road E75. The interchange is designed in a "trumpet" configuration, with two lanes in each direction and pedestrian walkways [12].

Table 1: Dimensions of the "National Stadium" Interchange

Element	Dimensions
Elevated connector	
Roadway width	6,0 m
Central reservation	3,0 m
Road shoulder	2 x 1,5 m

3.3 STRUCTURE LOCATION

The interchange is located within the EXPO2027 complex, in the Surčin municipality, between the Surčin-South interchange and the Ostružnica interchange (Figure 4). The location of the interchange is on the Belgrade bypass [12].

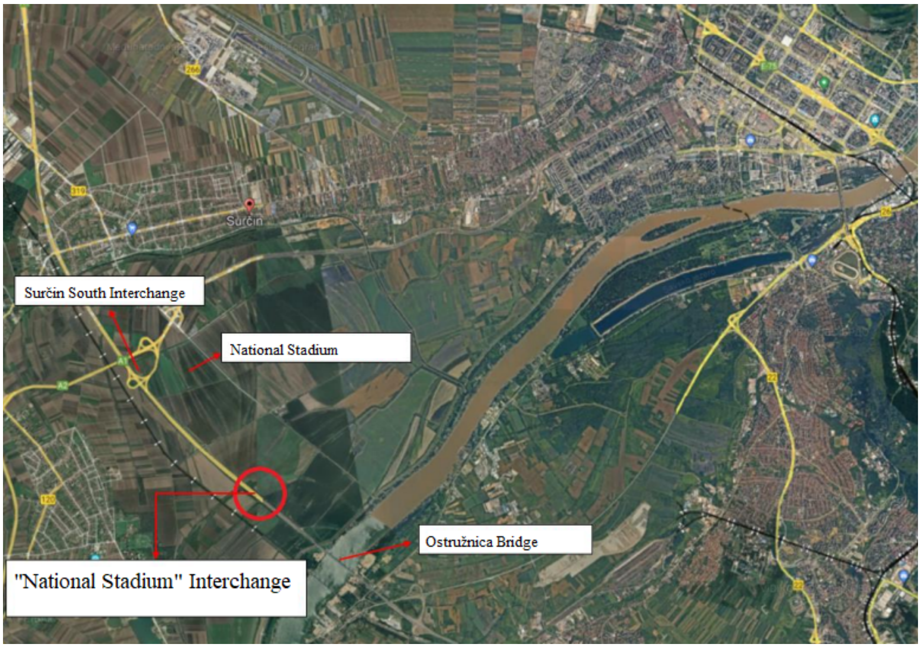

Figure 4: Location of the "National Stadium" Interchange

3.4 PROJECT COORDINATE SYSTEM

The project's coordinate system is based on the SREF (WGS84) system and transformed into the national coordinate system (NCS). The project used 12 trigonometric points to define the network (Figure 5) [12].

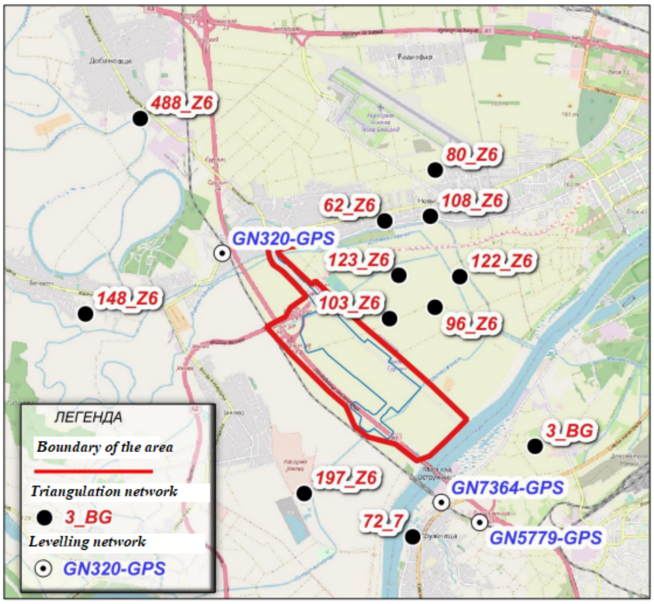

Figure 5: Layout of Points Used to Define the Project Coordinate System

3.5 EXISTING GEODETIC NETWORK

The "Main Frame" geodetic network consists of 17 points determined through GNSS measurements and leveling. This network provides precise monitoring and control of the structure's geometry [12].

3.6 GEODETIC NETWORK FOR LINEAR INFRASTRUCTURE

The network includes 60 stabilized points distributed along the planned roads of the EXPO2027 complex. These points will be integrated into the new interchange network [12].

3.7 CONCEPT OF THE GEODETIC NETWORK

In line with project requirements and the structure's configuration, the concept of the geodetic network includes:

- A three-dimensional coordinate system materialized by the "mainframe" network (17 points).
- The development of separate 2D and 1D geodetic networks with points located outside the construction zone to ensure stability.
- The 2D network is realized by measuring GNSS vectors, while the 1D network is based on leveling measurements of height differences.
- "Mainframe" and linear infrastructure points (LI1, LI2, LI3, LI4, LI52, LI56) are used to align the new network with the coordinate system (Figure 7).
- Stability of datum points is controlled through measurements and available data [14].

3.8 GEODETIC NETWORK CONFIGURATION

The geodetic network of the "National Stadium" interchange consists of 16 points: 7 new points (S1, S2, S3, S4, S5, K1, K2), 6 existing points from the linear infrastructure network

(LI1, LI2, LI3, LI4, LI52, LI56), and points from the "Mainframe" network (T002, T004, T009) [12].

3.9 STABILIZATION OF POINTS

The points are stabilized based on the characteristics of the ground. New points S1, S2, S3, S4, and S5 are stabilized with deeply embedded columns, while points K1 and K2 are stabilized with anchored benchmarks in concrete [12].

3.10 MEASUREMENTS IN THE 2D AND 1D NETWORKS

The measurement plan includes GNSS measurements for the 2D network (Figure 6) and levelling measurements for the 1D network (Figure 7). The GNSS network includes 16 points, while the 1D network involves the measurement of 22 height differences [12].

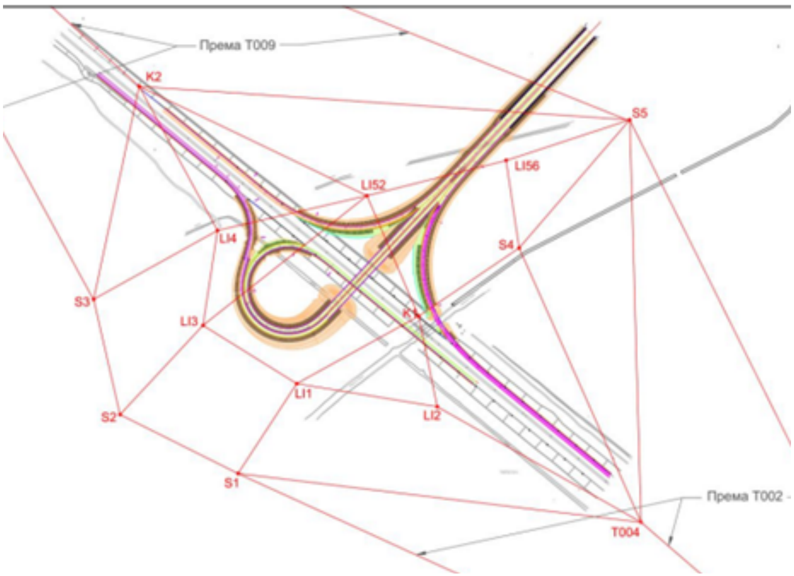

Figure 6: Measurement Plan for the "National Stadium" Interchange Geodetic Network

Field measurements were conducted using high-precision GNSS receivers with an accuracy of 3 mm + 0,1 ppm horizontally and 4 mm + 0,1 ppm vertically. Digital levels with an accuracy of 0,3 mm/√km and invar barcode leveling rods were used for height measurements. Instrument centering was achieved using optical plummets and tripods, maintaining a centering error below 1 mm.

The geodetic network was established following the 2D + 1D principle, where 2D coordinates were determined using relative-static GNSS positioning, and heights were obtained using geometric leveling. GNSS sessions lasted 45 minutes, ensuring linear independence of measured vectors. For leveling, measurements were conducted in forward and backward directions to control precision and minimize random errors.

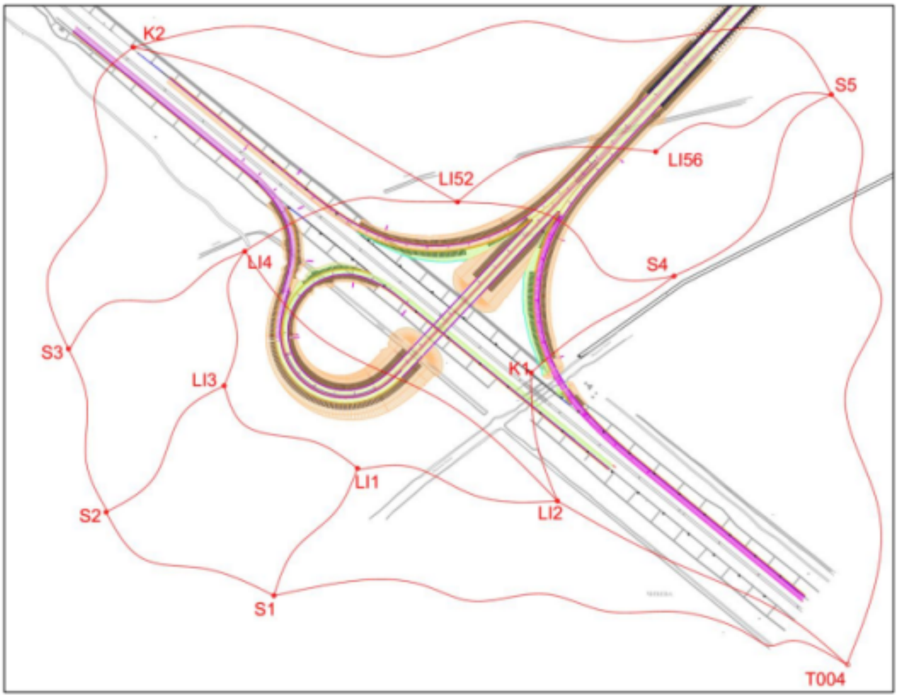

Figure 7: Measurement Plan for Height Differences

Data processing in the GNSS network involved loading and controlling measured data, processing GNSS vectors, and performing least-squares adjustments. Misaligned vectors were eliminated, and final coordinates were transformed into the local coordinate system using transformation parameters from known "Mainframe" and linear infrastructure network points. A stochastic model, including covariance matrices, was applied to describe measurement errors. The accuracy assessment confirmed compliance with project requirements.

For the 1D geodetic network, leveling data was adjusted using least-squares adjustment, ensuring accurate orthometric heights. The accuracy was calculated based on a stochastic model with a standard error of $\sigma_{\Delta h}$=0,5 mm/√km. The datum was defined with a minimal trace on all points to ensure stability and consistency in the network [12].

3.11 PROCESSING OF GNSS AND 1D MEASUREMENTS

The GNSS and 1D measurements were processed with special attention to accuracy. GNSS measurements were conducted in relative-static mode, while levelling measurements were processed with an accuracy of $\sigma_{\Delta h}$=0,5 mm/√km [12].

4 ANALYSIS OF GEODETIC NETWORK DATA

Geodetic networks are the foundation for all construction projects. This analysis examines both the existing and newly developed networks for the "National Stadium" interchange within the EXPO2027 complex.

Network Configuration: The geodetic network consists of 16 points, combining existing "Mainframe" points, linear infrastructure points, and new points, ensuring precision and reliability in measurements.

GNSS Measurements: GNSS measurements provide high accuracy for determining coordinates. The accuracy of the measurements was analyzed based on HDOP and VDOP factors and the precision of GNSS devices.

Levelling Measurements: Levelling measurements of height differences were carried out using the geometric levelling method, ensuring the accuracy of heights and the stability of benchmarks.

Accuracy Analysis (Figure 8**):** The accuracy of the measurements is illustrated through graphs showing the spatial distribution of points, height profiles, and measurement precision. The network has been shown to meet the project's requirements [1].

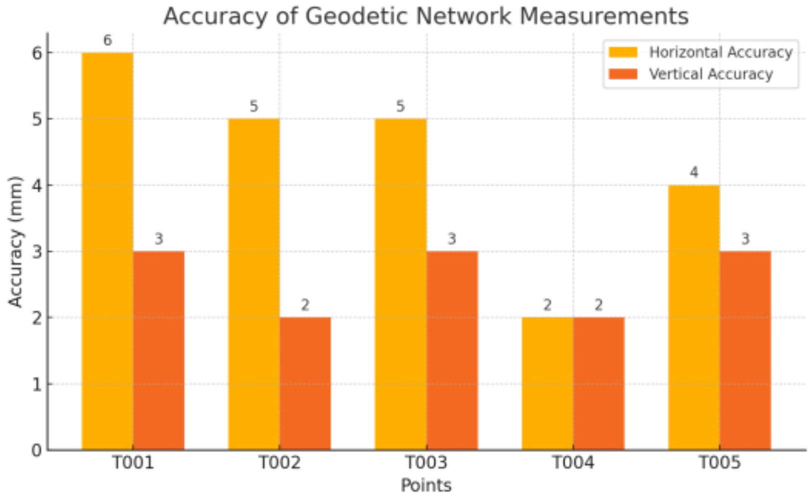

Figure 8: Measurement Accuracy of the Geodetic Network

Table 2 provides the coordinate values (*Y* [m] and *X* [m]) for points in a GNSS network. It also includes the corresponding standard deviations (σ_Y [m] and σ_X [m]) that indicate the precision of measurements in both directions. The data reflects accuracy achieved during GNSS measurements for various geodetic points.

Table 2: Precision Assessment of Coordinates in the GNSS Network

Point	*Y* [m]	*X* [m]	σ_Y [m]	σ_X [m]
T002	7444901,150	4956331,510	0,001	0,002
T004	7444705,420	4956428,800	0,001	0,002
T009	7444661,600	4956619,050	0,002	0,003
LI1	7443567,230	4956718,140	0,002	0,003
LI2	7443551,290	4956915,230	0,002	0,003
LI3	7443453,770	4957114,280	0,002	0,003
LI4	7444737,170	4956970,310	0,002	0,003
LI52	7446118,880	4956613,710	0,003	0,003
LI56	7445710,300	4956251,000	0,002	0,003
S1	7444206,670	4957449,570	0,003	0,003
S2	7444214,300	4957448,970	0,003	0,003
S3	7444258,920	4957438,820	0,003	0,003
S4	7444283,130	4957441,640	0,003	0,003
S5	7444513,940	4957144,570	0,002	0,003
K1	7445542,670	4956848,580	0,002	0,003
K2	7445542,670	4956848,580	0,002	0,003

Table 3 evaluates the precision of height measurements for points in the 1D geodetic network. It lists the point names and the standard deviations of their heights (σ_n), expressed in millimetres.

Table 3: Precision Assessment of Heights for 1D Geodetic Network Points

Point	σ_n [mm]
S1	0,18
S2	0,16
S3	0,17
S4	0,17
S5	0,19
K1	0,18
K2	0,21
T004	0,22
LI1	0,16
LI2	0,15
LI3	0,15
LI4	0,14
LI52	0,16
LI56	0,22

Spatial Distribution Diagram (Figure 9): A graph illustrating the spatial position of all points in the network in a 2D coordinate system. This allows for visualization of the relationships between the points and their positions relative to the future infrastructure.

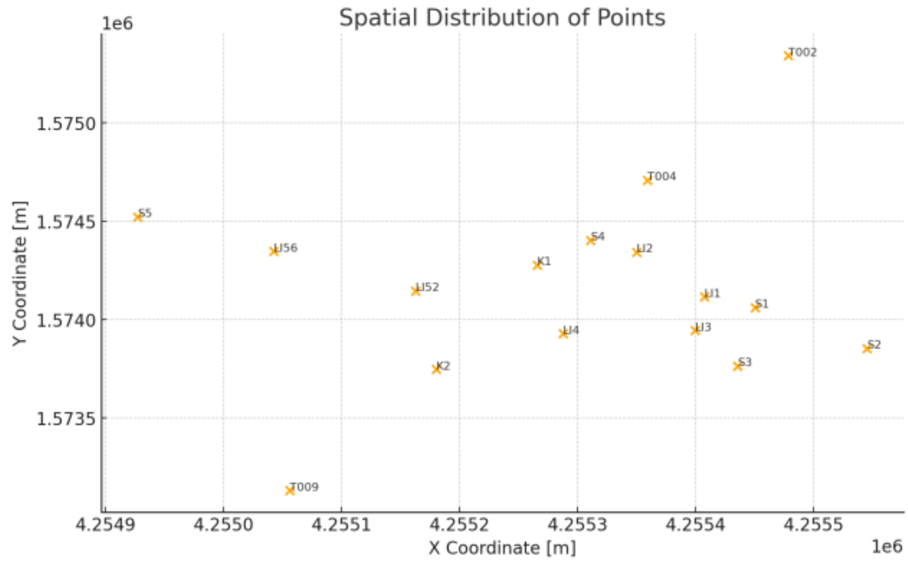

Figure 9: **Spatial Distribution of Points**

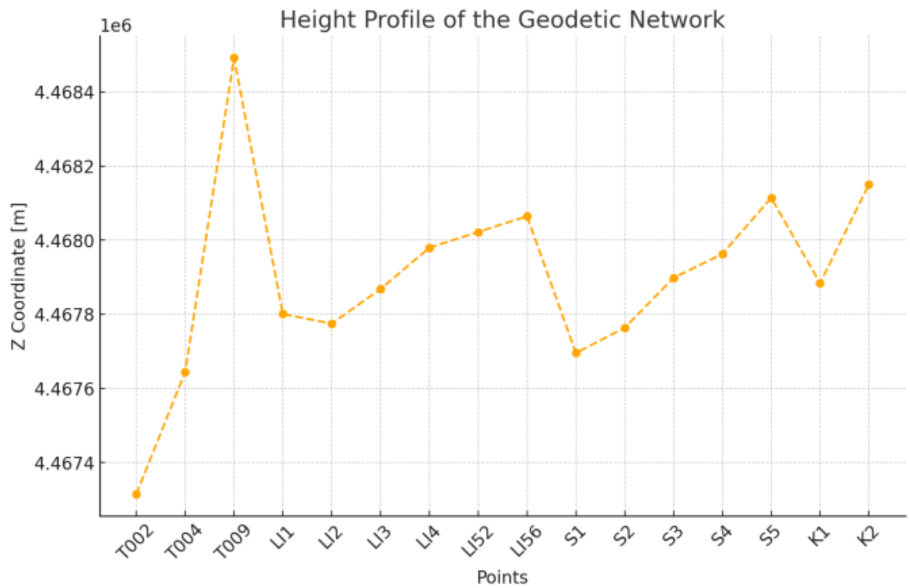

Figure 10: **Height Profile of the Geodetic Network**

Height Profile (Figure 10**)**: A graph showing the height profile of the network, with points arranged by elevation. This graph illustrates the height differences between various points in the network.

The geodetic network is designed to provide high precision and reliability, utilizing modern GNSS technologies and levelling methods. Continuous monitoring and collaboration with other experts ensure long-term stability of the network and the project's success.

5 CONCLUSION

This paper explored the role of geodetic data in infrastructure projects and its application in construction planning. The key conclusions are as follows:

- **Importance of Geodetic Data:** Precise and up-to-date data are crucial for all phases of infrastructure projects, enabling accurate positioning, resource optimization, and cost reduction.
- **Integration of Geodetic Networks:** Coordinating various geodetic systems and institutions, while using modern technologies, contributes to the creation of reliable databases.
- **Impact on Urbanization:** Geodetic data assists in making informed decisions for sustainable urban development, addressing issues such as overpopulation and informal settlements.
- **Challenges:** Data collection in difficult conditions, the need for regular updates, and the complexity of integrating different systems pose challenges that require advanced technologies and continuous professional development.

Future recommendations include the development of new methods for data collection, improving standards for data exchange, and investing in the education of geodetic professionals.

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