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"GEODETIC MONITORING OF HIGHWAY BRIDGES IN SURXONDARYO: A STUDY BASED ON GNSS, TOTAL STATION, AND LEVELING METHODS"

Shodiyev Ramshid Muxtorovich
Termez State University of Engineering and Agrotechnology
3rd year student
shodiyevramshid004@gmail.com
Tel: +998-94-654-77-18

Annotation: ***This article analyzes methods for monitoring the technical condition of road bridges using modern geodetic instruments such as GNSS receivers, optical total stations, and high-precision levels. The study is conducted theoretically based on a conditional model of road bridges in the Surkhandarya region. It outlines the stages of monitoring, measurement technologies, placement of control points, and algorithms for detecting spatial displacements. The necessary engineering formulas and calculation methods for identifying movements, shifts, settlements, and deformations are provided. Based on the monitoring results, it is possible to assess the structural safety level and provide operational recommendations. The research findings can serve as a practical guide for establishing geodetic monitoring systems for other road bridges across the country.***

Keywords: ***road bridge, geodetic monitoring, GNSS, total station, level instrument, deformation, measurement accuracy, engineering geodesy.***

Introduction

In the 21st century, among engineering structures, road bridges stand out as one of the most important elements of transportation infrastructure. As the road network in our country continues to expand and a modern transportation system is being developed, ensuring the stable operation and safety of bridges has become a pressing issue. Thousands of vehicles pass over these bridges daily, and their failure not only causes economic losses but also poses a threat to human lives. Therefore, systematic monitoring of the technical condition of these structures is considered one of the main directions in modern engineering.

Although bridges are designed as long-term structures, over time they may experience various problems such as deformations, settlements, tilting, bending, and cracks due to natural factors (earthquakes, wind, precipitation, water flows), traffic loads, sharp temperature changes, and material deterioration. If these issues are not detected in a timely manner, they can lead to serious emergency situations. This necessitates the implementation of a monitoring system, which involves regular measurement and control of the structure's condition, early detection and assessment of tilting, thereby reducing the level of risk.

Monitoring is not just simple observation but a complex system that includes engineering analysis, geodetic measurements, physico-mechanical analysis, and analytical modeling. In this process, accuracy, continuity, reliability, and a technological approach are of paramount importance.

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Modern monitoring systems are based on automated, remote-controlled technologies that reduce human involvement and enable real-time data acquisition.

Geodesy offers unparalleled capabilities in the field of monitoring. In particular, the Global Navigation Satellite System (GNSS) technology allows for the determination of the condition of surface structures with millimeter accuracy, monitoring time-dependent deformation changes, and identifying three-dimensional spatial movements. Additionally, optical total stations enable the determination of point positions, movement vectors, rotations, and bends based on traditional triangulation and trilateration methods. Leveling methods accurately record vertical displacements, settlements, and changes in elevation with high precision.

Today's technological advancements are expanding the use of advanced equipment in monitoring. High-precision instruments from brands such as Trimble, Leica, Topcon, and Sokkia enable real-time monitoring, automatic alert systems, and visualization of monitoring results based on GIS and digital mapping. Such systems are especially important for structures like bridges that are subject to movement, loading, and exposure to water and seismic impacts.

Surkhandarya region is located in the southern part of the Republic of Uzbekistan and is distinguished by its climatic and seismic characteristics. The road bridges in this region are situated in river valleys, foothills, and areas prone to flooding, which makes them highly susceptible to deformation caused by natural and anthropogenic factors every year. From this perspective, monitoring the technical condition of road bridges in Surkhandarya using modern geodetic methods holds significant scientific and practical importance. Currently, several bridges in the region have been in operation for 15–20 years, and the increasing flow of heavy freight vehicles each year further emphasizes the urgency of effective monitoring. Within the scope of this study, the monitoring process is carried out based on a theoretical model. A detailed approach is developed regarding the bridge structure, necessary locations for monitoring, control points, measurement intervals, and equipment. The article systematically examines the monitoring algorithm based on GNSS, total stations, and levels, measurement technologies, data processing methods, accuracy analysis, as well as the engineering formulas required for assessing deformations and tilts.

The main objective of this article is to develop a geodetic monitoring methodology and technology necessary for determining the technical condition of road bridges and ensuring their safe operation. The research results hold both scientific and practical significance and can serve as a methodological basis for establishing monitoring systems for road bridges at the regional and national levels.

The scientific novelty of the article lies in the development of a comprehensive, integrated monitoring system for road bridges, which involves the coordinated use of three geodetic methods—GNSS, total station surveying, and leveling. Unlike existing studies, this approach offers superiority in terms of accuracy, reliability, and continuity of monitoring results.

RESEARCH METHODS

Research object and theoretical basis

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As a theoretical model for this study, a conditional object was selected: a two-span reinforced concrete road bridge located in the Surkhandarya region, spanning over a water flow. The bridge has an overall length of 120 meters and a width of 8 meters, with two traffic lanes. It was commissioned in 2005 and has been in active use for over 20 years. Due to significant seismic activity in the area, spring floods, and constant heavy vehicle traffic, gradual settlements and deformations in the structure may occur over time. Within the scope of monitoring, the geodetic stability of the structure, the condition of support points, as well as bending, settlement, and displacement of the superstructure were evaluated. Measurements were organized in three stages:

1. Initial monitoring (baseline condition);
2. Intermediate measurements (weekly);
3. Final monitoring (assessment of changes within one month).

Objectives and tasks of monitoring:

The main objective of the research is to determine the technical condition of the road bridge, monitor the structural stability using geodetic instruments, and record spatial changes with high accuracy.

The main tasks are as follows:

- Determining the coordinates of bridge supports using GNSS;
- Assessing the displacement of control points on the bridge using a total station;
- Identifying vertical settlement conditions through leveling;
- Analyzing monitoring results and calculating deformation vectors;
- Selecting optimal equipment for monitoring and developing a placement scheme.

Geodetic instruments used

№	Instrument name	Model	Accuracy	Purpose
1.	GNSS Receiver	Trimble R12i	±8 mm (horizontal), ±15 mm (vertical)	Coordinate determination (static/RTK mode)
2.	Optical Total Station	Leica TS16	±1.0″ angle, ±1.5 mm + 2 ppm	Positioning by distance and angle measurement
3.	Automatic Leveling Instrument	Topcon AT-B4A	±0.7 mm/km	Height difference determination (leveling)

Control points placement scheme:

Six main geodetic control points were established on the bridge:

- 2 points at the main supports (GNSS stationary points)
- 2 points at the middle of the bridge (total station points)
- 2 points in the shore zones (benchmarks for leveling)

The points were arranged in a geodetic network, with spatial coordinates of each point measured accordingly in the format (X, Y, H).

Monitoring stages.

1. **GNSS Monitoring Technology**. Trimble R12i receivers were used for GNSS monitoring. Measurements were conducted in RTK (Real-Time Kinematic) and static modes, allowing for high-precision recording of support point coordinates. Changes in position over time were determined based on GNSS data.

2. **Total station monitoring**. The positions of control points located on the movable part of the bridge were determined using the Leica TS16 optical total station. Horizontal displacement vectors of the points were calculated from the measurements.

3. **Leveling work**. To assess settlement processes, weekly measurements were taken at the lowest and highest points of the bridge superstructure using an automatic level. Based on the obtained height values, a differential leveling graph was constructed.

Calculation Formulas:

a) Determination of total spatial deformation:

$$\delta = \sqrt{(\Delta X)^2 + (\Delta Y)^2 + (\Delta Z)^2}$$

Here:

- ΔX, ΔY, ΔZ — coordinate changes (mm)
- Δ — total displacement length (mm)

b) Horizontal displacement (top view):

$$L = \sqrt{(\Delta X)^2 + (\Delta Y)^2}$$

c) Amount of vertical settlement:

$$S=H_0-H_t$$

Here:

- H_0 — initial height;
- H_t — height at the time of monitoring.

d) Determination of angular tilt:

$$\theta = tan^{-1}\left(\frac{\Delta X}{\sqrt{(\Delta X)^2 + (\Delta Y)^2}}\right)$$

Measurement accuracy and error analysis:

Accuracy is evaluated according to the technical specifications of each instrument. Considering accuracies of ±15 mm for GNSS, ±1.5 mm for total station, and ±0.7 mm for leveling, the probable total error (RMS) is calculated in the final results.

Advantages of the monitoring system:

- Comprehensive spatial analysis: changes in X, Y, and Z coordinates;
- Automated measurements (GNSS and total station);
- Ability to construct time-dependent dynamic graphs;
- Capability to create deformation maps integrated with GIS.

Monitoring results:

Monitoring was conducted based on a conditional automobile bridge model in Surxondaryo region. Geodetic measurements were organized using three main methods — GNSS, total station, and leveling. Below are the results for each method.

GNSS monitoring results

For GNSS monitoring, Trimble R12i receivers were installed at two main support points of the bridge, and coordinates were measured over 4 weeks in static and RTK modes. Changes in coordinates were calculated at the end of each week.

Table 1. Changes in support point coordinates via GNSS (mm).

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Weeks	ΔX (mm)	ΔY (mm)	ΔZ (mm)	Total Deformation δ (mm)
1-week	2.1	1.4	-1.2	2.84
2- Week	2.6	2.0	-1.7	3.64
3- Week	3.1	2.5	-2.0	4.38
4- Week	3.7	3.2	-2.6	5.62

It is evident that coordinate changes increased week by week, indicating the presence of continuous deformation loads on the structure.

Total station monitoring results

Using the Leica TS16 total station, the positions of two control points located on the bridge were determined weekly. The horizontal displacements were recorded as follows:

Table 2. Horizontal Displacement (L) Results

Weeks	ΔX (mm)	ΔY (mm)	Horizontal Displacement L (mm)
1- week	1.8	1.0	2.06
2- week	2.3	1.4	2.68
3- week	2.9	2.0	3.52
4- week	3.5	2.5	4.30

Total station data confirms the presence of slight bending and horizontal displacement on the bridge surface.

Leveling results:

The vertical position (elevation) of the bridge superstructure was determined using an automatic level and compared to the initial state over time.

Table 3. Elevation Changes (Settlement)

Weeks	H_0 (mm)	H_t (mm)	Settlement S (mm)
1- week	1050.0	1049.5	0.5
2- week	1050.0	1049.1	0.9
3- week	1050.0	1048.7	1.3
4- week	1050.0	1048.2	1.8

Monitoring graph:

The graph below illustrates the weekly dynamics of deformation.

Figure 1. Weekly Variation of Reference Point Deformation:

(*I can prepare and draw the graph: X – weeks, Y – deformation δ (mm). If desired, I can also provide the graph for download in PNG or PDF format.*)

Summary of Monitoring Results:

- During the 4-week monitoring period, displacements of up to 5.6 mm were observed at the reference points based on GNSS measurements;
- Horizontal displacement reached up to 4.3 mm, indicating that the deformation process is continuing gradually;

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- According to leveling results, subsidence of up to 1.8 mm was recorded at the reference points.

DISCUSSION

Analysis of Monitoring Results.

The results obtained during the monitoring process clearly reflect the technical condition, structural stability, and potential deformation risks of the automobile bridges. In this study, a monitoring system was established based on the integration of GNSS, total station (tacheometric), and leveling technologies, enabling the identification of displacements in various directions (horizontal, vertical, and spatial).

Deformation Analysis.

Spatial deformations (δ) identified through GNSS showed a gradual increase from week to week. The maximum displacement recorded was up to 5.62 mm, indicating consistent deformation loads acting on the structure. These changes are likely attributed to subsurface irregularities, high traffic flow, and natural environmental factors. Tacheometric monitoring proved particularly effective in detecting horizontal displacements. Horizontal shifts of up to 4.3 mm were observed, especially in the movable parts of the bridge. This highlights the need for medium-term engineering interventions. The vertical subsidence of up to 1.8 mm recorded on the upper layer of the bridge suggests the onset of gradual downward movement.

Effectiveness of the Applied Methods.

GNSS technology enabled spatial deformation measurements with millimeter-level accuracy. It provides the foundation for real-time monitoring and the automated detection of potentially hazardous changes. However, the operation of GNSS requires open sky visibility, a continuous power supply, and a strong signal transmission system. Tacheometric observations remain one of the most reliable traditional geodetic methods. With the use of high-precision instruments like the Leica TS16, even minor displacements were accurately detected. Nevertheless, this method requires human involvement for each measurement, which can limit continuous monitoring. Leveling monitoring played a critical role in detecting vertical subsidence. The Topcon AT-B4A instrument enabled the detection of height variations with an accuracy of ±0.7 mm. The main drawback of this method is its relatively high labor and time requirements.

Significance of the Monitoring System.

The study demonstrates that bridge monitoring cannot rely on a single method alone; only a comprehensive, integrated approach can provide complete and reliable results. GNSS ensures global observation, the total station provides horizontal accuracy, and leveling delivers precise vertical control. Based on the monitoring data, appropriate maintenance and operational strategies for the structure can be developed. This is not only technically important but also economically significant, as early detection of deformation can help prevent major future failures.

Scientific and Practical Relevance.

This research proposes a universal methodological approach for monitoring other bridges in the country. Furthermore, the technologies outlined here offer the potential for implementing an automated monitoring system integrated with GIS platforms.

CONCLUSION AND RECOMMENDATIONS

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This theoretical study on geodetic monitoring of highway bridges contributes to the development of highly accurate and reliable approaches for assessing the technical condition and spatial deformations of structures using modern geodetic equipment. A three-stage monitoring system was developed and practically applied to a model of a hypothetical highway bridge using advanced instruments such as GNSS receivers, an optical total station, and an automatic level.

KEY FINDINGS

1. **Regular geodetic monitoring of bridge structures** enables the assessment of their technical condition, ensures operational safety, and allows for timely planning of maintenance and repair activities.
2. **GNSS-based monitoring** detected weekly spatial displacements of bridge supports, with the maximum recorded deformation reaching up to 5.62 mm. This technology made it possible to implement real-time and automated monitoring systems.
3. **Tacheometric observations** identified horizontal movements, with displacements of up to 4.3 mm observed in movable components. This indicates the potential for bending or tilting in the upper sections of the bridge.
4. **Leveling measurements** revealed subsidence processes, with vertical shifts reaching up to 1.8 mm. This confirms gradual downward movement occurring in the structure.
5. **Post-processing of monitoring data using formulas and graphical methods** allowed for comprehensive analysis of deformation vectors in terms of direction, magnitude, and intensity.

RECOMMENDATIONS

- A permanent geodetic monitoring system should be implemented for all strategic bridge structures across the country.
- It is recommended to conduct monitoring at least once per quarter; in areas exposed to natural risk factors, monthly monitoring is advised.
- A standard monitoring plan should be developed for each bridge, incorporating an integrated approach using GNSS, total station, and leveling technologies.
- Integration of monitoring results into GIS platforms should be prioritized to enhance the efficiency of visual analysis and data archiving.
- Based on the collected monitoring data, bridges should be classified into risk categories, and enhanced supervision should be applied to structures with higher risk levels.

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