COMPARATIVE ANALYSIS OF GEOMETRIC LEVELLING AND STATIC GNSS SURVEYING METHODS FOR THE DEVELOPMENT OF ONE-DIMENSIONAL MICRO-NETWORK

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Summary: *The paper analyzes two geodetic methods for data collection - geometric levelling and static GNSS (Global Navigation Satellite System). For the purpose of monitoring the occurrence of landslide and deformations - the subsidence of the terrain and object (St. Nicholas Church in Stari Slankamen), the localization and stabilization of one-dimensional micro-network in the area surrounding the church was performed. The network was developed on a stable terrain as a reference basis for observing the church's subsidence by means of geodetic benchmarks built into the very foundations of the church. Height differences between the points of the network were determined by using geometric levelling and static GNSS method and the obtained values were compared. The height differences obtained with these two methods vary several millimeters. Based on the conducted research, the paper considers advantages and disadvantages of both methods, analysis the accuracy of the obtained results and possible application of these two methods.*

Keywords: *GNSS, geometric levelling, accuracy, height difference*

1. INTRODUCTION

At each point on the Earth's surface, there are constant changes due to various effects, such as tectonic disturbances, groundwater, landslide, earthquake, etc. Consequently, the

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built objects are subjected to subsidence and deformations due to internal and external forces, such as the influence of the wind, changes in temperature and groundwater, tectonic and seismic influences, dynamic and static load. If any deformations are ignored during design of building or are not noticed on time, they can damage the building, lead to its demolition, and in the worst case, human casualties. In order to prevent such consequences and assess the reliability, health of the structure, the ability to carry loads and update the model of the facility itself, it is necessary to perform regular inspection and surveillance of objects by geodetic methods [1], [2].

Today we witness the era where there are exceptional inventions and discoveries. Geodesy combines the greatest achievements of mathematics, physics, astronomy, informatics, electronics, and so on. Of great importance for its advancement is the improvement of measuring devices, such as total stations, digital levels, GNSS receivers. These systems enable automated and semi-automated procedures of collecting data of significantly improved accuracy, in a shorter time interval. Also, in this way, the range of geodetic instruments that can be used to measure deformations increases [3].

In accordance with the trends of progress, increasing efficiency in work and minimal time consumption, two methods for collecting 1D data are presented in the paper, geometric levelling as a more traditional method and GNSS method, as a modern and efficient method of spatial data collection. Observations were made in the 1D micro-network by both methods, height differences between points were obtained and compared. Based on this, conclusion about the advantages and disadvantages of both methods and their possible applications was made.

Similar research was carried out in other works. In the paper [4], the testing of the accuracy of the geometric and trigonometric levelling method was performed, as well as the GNSS method on a closed levelling traverse with 12 points. The height differences between the points obtained by the geometric levelling are adopted as reference values and the analysis of the internal and external measurement accuracy is given. In the paper [5], a study of use of the GNSS method for determining height differences in case of steep terrain was presented. In comparison with the results of the geometric and trigonometric levelling, the GNSS method has shown satisfactory accuracy. In addition, it has been found that using the GNSS method in field work can save 1h of work on a steep terrain 100 m long, compared to levelling methods.

2. METHOD OF GEOMETRIC LEVELLING AND GNSS METHOD

The geometric levelling method is a slow but highly reliable and accurate method for determining height differences. Digital levels are used for the realization of highly precise measurements using the geometric levelling method. These levels are automatic levels with a system of digital image processing that allows automatic reading from a special bar code staff and electronic recording. This way all the errors caused by man reading and by manual recording are eliminated and also the speed of levelling increases. In the realization of precision levelling, invar staffs are used. The recommended and generally accepted method for determining the height difference between two points in the realization of high precision measurements is the method of reading the levelling staff from two different instrument heights in two directions of levelling. In this way, the height difference between the two points is determined on the basis of the arithmetic mean of two measurements of the height difference in the forward direction of levelling and two measurements in the back direction [6].

The most significant errors that occur in the realization of the measurement by the method of geometric levelling are the result of [6]:

- non horizontal line of sights (vertical collimation error - angle *i*),
- errors in reading the staff and the error of the level micrometer,
- errors in manual reading of the staff,
- setting up a tripod on unstable terrain such as sandy or humid terrain,
- the temperature effects of the sun's rays on the level,
- temperature adaptation of the level,
- the influence of the magnetic field on the automatic levels,
- non-vertical staff,
- temperature,
- refraction.

Positioning and navigation are revolutionized with the development of a GNSS system. This system is an alternative to geometric levelling, providing fast and reliable information. Today, the GNSS system plays an important role in geodesy, field surveying, earth science and cadastre [7]. Static GNSS method provides data of higher accuracy. For its operation, two receivers are needed - one located at a control station with previously defined coordinates with high precision, and another receiver at a point whose coordinates should be determined. Observation data is stored on the device memory. The differences between the observed coordinates and fixed, determined by the control station, provide corrections of the points whose position should be determined [8].

The advantages of GNSS sensors in relation to conventional geodetic methods are [9]:

- there is no need for visual observation between points,
- large number of automatic measurements,
- work in all weather conditions,
- obtaining 3D position data.

The main challenges that arise when implementing GNSS technology are [10], [11]:

- errors of bad satellite geometry,
- clock errors,
- ephemeris errors,
- ionospheric and tropospheric errors,
- multipath errors.

3. FORMING OF ONE-DIMENSIONAL MICRO-NETWORK AND NETWORK MEASUREMENT ANALYSIS

The research presented in the paper was conducted in the area of the church of St. Nicholas (Figure 1), located in Stari Slankamen, in the municipality of Indjija. It is counted in the oldest churches built in the medieval style, and as such is a culture monument of exceptional significance, under the protection of the Institute for the Protection of Cultural Monuments in Sremska Mitrovica. It was designed as an elongated building with a triangle-shaped base, probably modeled based on the Ravanica monastery church.

Figure 1. Church of St. Nicholas in Stari Slankamen

The need for the development of a one-dimensional micro-network in the area of the mentioned church appeared because cracks were seen on the church wall. The deformation is caused by the possible subsidence of the terrain and landslide. In order to conduct analysis of the state of the building and find the causes of the cracks with the certainty, as well as define the potential future risks of safe use of the facility, one-dimensional micro-network was developed. For these needs, in the network, measurements were made by geometric levelling. In addition, the measurements were performed by the static GNSS method in order to compare the obtained results and accuracy. Based on these data, conclusions are given regarding the advantages and disadvantages of both methods and the possibilities of their application.
Points R1, R2, R3, R4 and R5 (Figure 2) represent the points of the developed 1D geodetic network. They are stabilized by brass levelling benchmarks embedded in reinforced concrete structures placed outside the deformation zone of the church, properly funded and protected against physical damage. Points of the geodetic 1D network must be well-founded so as not to shift them due to local surface effects (frost, drying, humidification) in order to reflect the movement of the terrain, i.e. objects, and not its own moving. Therefore, for points of the 1D geodetic network, foundation depth of minimum 0.80 m is envisaged. The points are placed in the optimum position in the immediate vicinity of the church and on a stable ground (outside the zone of deformation affecting the church). In general, care must be taken to keep the points out of the roads and agricultural areas, overgrown fences or saffron, which makes them naturally protected from physical damage to agricultural machinery, cars and, in general, human factors.

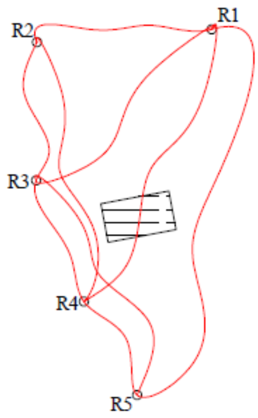

Figure 2. Location of points of 1D micro-network in the vicinity of St. Nicholas Church in Stari Slankamen

In order to check the state of the 1D network, its points are mutually observed. Then, the control points placed on the church are observed from points of 1D geodetic network. Control points are levelling benchmarks that are built into the construction of the church whose movement is being monitored. By processing the levelling data, 1D movement of each control point on the church can be calculated. As the topic of this paper is a comparative analysis of the accuracy of the height differences obtained by the geometric levelling and the static GNSS method, the results that are related to this topic will be presented in the future.
Measurements within the geometric levelling were realized by the digital levelling instrument *Leica DNA03*, whose precision is 0.3 mm / km, with two measurements of the height difference on the station using the invar bar code staff (the same manufacturer as the levelling instrument). The staffs have their stands and are positioned directly on the benchmark, and through the center bubble control of their verticality is carried out. The line of sight should not exceed 20 m. Levelling is done in one direction. After completion of the levelling, the measurements were processed and adjusted using the least squares method, according to the model of indirect adjustment. The network is adjusted as local. The obtained adjusted values of the benchmark heights are given in Table 1.

Table 1. Adjusted benchmark heights

Reper	*H [m]*
R1	100.00001
R2	109.99659
R3	115.84349
R4	121.60578
R5	125.63582

As noted above, measurements on the 1D micro-network benchmarks were performed by a static GNSS method. The measurements were made at the points R1, R2, R3 and R4 of the developed local 1D micro-network. At the point R5 of 1D network, measurements have not been made because the point is stabilized under dense overgrowth that interferes with the reception of signals from the GNSS satellite. Before the start of the measurements, at each point, the GNSS antenna was horizonted and force-centered (Figure 3). The height of the antenna was measured at an accuracy of 0.001 m, while the instrument centering error was 0.002 m. The measurements were made in two sessions. In the first session, measurements were made at points R4, R3 and R1, and so the vectors R3-R4, R3-R1 and R1-R4 were observed. After the first session was completed, another session was measured. In the second session, the instrument was transferred from point R4 to point R2, and so the vectors R3-R1, R3-R2 and R2-R1 were observed (Figure 4). In total, 5 vectors were measured. In addition, vectors between mentioned measured points and the station Novi Beograd of GentooARS permanent network were observed. The Novi Beograd station is equipped with a GNSS receiver, placed on a stable ground and protected from external influences. Distance between surveyed points and permanent station is around 35 km. The duration of the session is averagely 1h 30min, with an observation interval of 15 s. Measurements in both sessions were performed with three GNSS instruments: Trimble R4, Trimble R6 and Trimble R8s, with accuracy specification given in Table 2. After static GNSS measurement, the collected data were processed in the *Trimble Business Center* software and the coordinates and heights of the points on which measurements were made were obtained (Table 3). Point's locations and heights were derived not only based on five measured vectors, but also relative to permanent station in Novi Beograd. In the adjustment process precise ephemerides were used.

Figure 3. Force-centered GNSS antenna

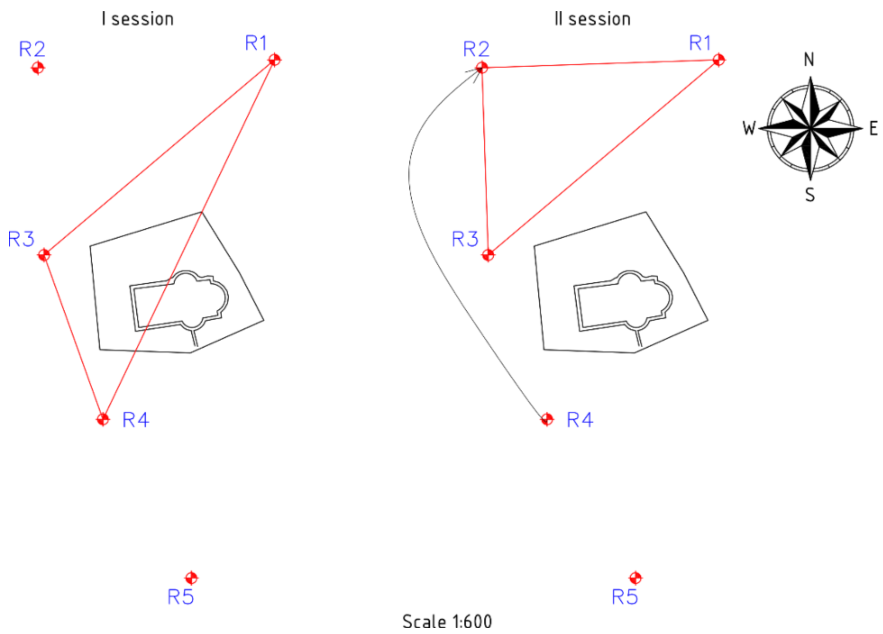

Figure 4. Static GNSS measurements – I and II session

Table 2. Specification of receiver Trimble R4, Trimble R6 and Trimble R8s [12], [13], [14]

Receiver / *Pos. mode*		*Trimble R4*	*Trimble R6*	*Trimble R8s*
Static and Fast Static	*Horizontal*	3mm+0.5ppm	3mm+0.5ppm	3mm+0.5ppm
	Vertical	5mm+0.5ppm	5mm+0.5ppm	5mm+0.5ppm

Table 3. Point coordinates determined by GNSS method

Benchmark	*Latitude*	*Longitude*	*Height [m]*
R1	45°08'28.76451"	20°15'30.11910"	127.096
R2	45°08'28.67204"	20°15'27.04669"	137.088
R3	45°08'26.95145"	20°15'27.14869"	142.936
R4	45°08'25.44691"	20°15'27.93335"	148.703

Measurements using the geometric levelling method achieve an accuracy smaller than 1 mm, while by using the GNSS static method the measurements achieve a height accuracy of 2 mm in the processing of the GNSS vectors, and after applying the adjustment, an accuracy of 1 mm was obtained. The achieved accuracy of the measurement is best seen through the values of the standard deviation of the benchmark height (Table 4).

Table 4. Standard deviation of the benchmark height obtained by measurements using the method of geometric levelling and static GNSS method

Benchmark	*σ_H [mm] (geom. levelling)*	*σ_H [mm] (GNSS static)*
R1	0.153	1
R2	0.136	1
R3	0.105	1
R4	0.108	1
R5	0.149	-
Max. value	0.153	1
Min. value	0.105	1
Average value	0.1302	1

Table 5 gives the obtained values of height differences by the method of geometric levelling and the static GNSS method. In addition, the differences in height differences obtained by these two methods are also determined. The largest value of the difference is 4.7 mm, while the smallest difference is 1.1 mm. The mean value of the obtained differences is 3.0 mm.

Table 5. Height differences obtained by measurements using the method of geometric levelling and GNSS static method and difference between them

from - to	*Δh [m] (geom. levelling)*	*Δh [m] (GNSS static)*	*Δh difference [m]*
R1-R2	9.99658	9.992	0.0046
R1-R3	15.84348	15.840	0.0035
R1-R4	21.60577	21.607	0.0012
R2-R3	5.84690	5.848	0.0011
R3-R4	5.76229	5.767	0.0047

4. CONCLUSION

The paper presents measurements in a one-dimensional geodetic micro-network developed for the purpose of observing the church of St. Nicholas in Stari Slankamen. Measurements were performed using the geometric levelling method and the static GNSS method. The difference values in point's height differences between the geometric levelling method and the static GNSS method differ by an average of 3 mm. Based on this, it can be said that the measurements collected by these two methods show the agreement of the values of height differences to a considerable extent. More accurate results using GNSS method could be achieved by processing the measurement in relation to a permanent station that is located closer to the place where the measurement is done, i.e. closer to the church in Stari Slankamen in this case. The method of geometric levelling is a more accurate method, but gathering data on the ground requires much more time, effort and expert's work than it is with the GNSS method. However, as shown in the paper, the GNSS method can not produce any measurement results on locations that are obstructed by trees, buildings, and the like. What should certainly be pointed out in this method is that one or two workers are enough for its work where, after setting the instrument, the worker remains only to keep the instrument and wait for a predetermined period of observation at the point. In conclusion, it can be said that both methods have advantages and disadvantages regarding the accuracy, time and effort that need to be spent, and the number of professionals required to work on the field. The static GNSS method is much simpler to operate and less demanding, but it is of a lower accuracy than the geometric leveling method, as shown in the paper. In addition, it should be noted that the method of the geometric leveling only provides height data of the points, while with the GNSS method, in addition to height data, the position data are simultaneously obtained. In cases where the required accuracy criteria do not go beyond the accuracy limit of the GNSS method and where the locations on which the surveying is done allow for undisturbed signal reception from satellites, it is advisable to use the GNSS method.

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КОМПАРАТИВНА АНАЛИЗА ГЕОМЕТРИЈСКОГ НИВЕЛМАНА И СТАТИЧКЕ ГНСС МЕТОДЕ ПРИ РАЗВОЈУ ЈЕДНОДИМЕНЗИОНАЛНЕ МИКРО МРЕЖЕ

Резиме: *У раду су анализиране две геодетске методе за прикупљање података – геометријски нивелман и статичка ГНСС (Глобални навигациони сателитски систем) метода. У циљу праћења појаве клизишта и деформација - слегање терена и објекта (црква св. Николе у Старом Сланкамену) извршена је локализација и стабилизација једнодимензионалне микро мреже у простору око цркве. Мрежа је развијена на стабилном терену као референтна основа за посматрање слегања цркве помоћу репера уграђених у саме темеље цркве. Разлике висина између тачака мреже одређене су геометријским нивеланом и статичком ГНСС методом и упоређене су добијене вредности. Разлике у висини добијене овим методама варирају неколико милиметара. На основу спроведеног истраживања у раду се разматрају предности и недостаци обе методе, анализира тачност добијених резултата и могуће примене ових метода.*

Кључне речи: *ГНСС, геометријски нивелман, тачност, висинска разлика*