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Pregledni znanstveni članak

Evaluating the Usage of RTK GPS Technique in the Control of Highway Geometry

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ABSTRACT. Real Time Kinematic GPS technique displays really an efficient and fast improvement within today's technological developments. The most important reason of that is one can obtain coordinates instantaneously and in the cm level accuracy by using this technique. This technique is widespread used in construction and survey areas because of its mentioned properties. In this study, the usage opportunity of RTK GPS technique in land application of highway geometry and its consequences will be observed. Therefore, the determination of highway geometry (superelevation design) and its control are very important from the view point of optic and safety conditions. For this purpose, a finished highway project will be checked by using RTK GPS technique then the certainty degree in transition of geometric standards of highway from project to land and effects on it will be examined. The obtained results by using RTK GPS are compared with the project (terrestrial survey) results and are gained centimetre level accuracy.

Keywords: RTK GPS, superelevation, accuracy, highway design.

1. Introduction

Real Time Kinematic (RTK) surveying is an advanced form of relative GPS carrier phase surveying in which the base station transmits its raw measurement data to rovers, which then compute a vector baseline from the base station to the rover. This computation is done nearly instantaneously, with minimal delays between the time of the base station measurements and the time these are used for baseline processing at the rover (ideally a few seconds). The precision of RTK baselines can be almost as good as the precision of static-carrier phase baselines. If the base station coordinates are accurately known, this will usually result in accurate rover positions. The combination of fast and precise positioning, one-man operation, and wide work areas has resulted in RTK becoming an impressively power-

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ful tool for some survey applications. Like other survey techniques, RTK does not solve every survey problem. RTK is only suitable for environments with reasonably good GPS tracking conditions (limited obstructions, multipath, and radio frequency noise), and with continuously reliable communication from the base to the rover. Real Time Kinematic (RTK)-GPS is one of the measuring modes offering centimetre accuracy with real-time coordinates display. A set of RTK-GPS equipment includes one reference receiver, one or multiple rover receiver and a pair of radio or GSM-based modems. The working principle is that firstly a reference receiver is set up on a survey control point and the rover receivers are placed on an unknown point. Secondly, the GPS data collected by the reference receivers together with the control point data will be continuously transmitted to the rover receiver for processing. Thirdly, the data collected by the receivers will be processed to give the coordinates of the unknown points being occupied at real-time. Then, the rover receiver will move to the next unknown point to take other measurements. RTK GPS has the strengths that no survey control points are required in the vicinity of the highway, Ǐ1-2 cm accuracy can be achieved, and it allows setting out work to be carried out at any locations on the highway. Blocking of satellite signals by sky obstruction is the only constraint in using RTK-GPS. Good accuracy can normally be achieved with baselines (line between base and rover) in the order of 10-15 km, without networking at least three reference stations. When classical terrestrial surveying methods are used in surveying and staking out of highway construction projects, one can meet some difficulties such as lack of sight between two control points, inaccessible angle points and loss of time. Moreover, surveying and stakeout projects carried out using classical terrestrial surveying methods employ much more people. RTK GPS surveying method has some advantages over classical surveying methods in that RTK GPS does not need sight between control points. Furthermore, RTK GPS can be managed by only one person and whole staking out and surveying process can be carried out by using only one reference point, depending on the quality of the radio transmitter and the distance between the points and reference station. Another advantage of RTK GPS is that the coordinates of the points can be determined in national coordinate reference frame in real-time by entering previously the transformation parameters between WGS 84, ITRF and national coordinate system to the handheld computer so that there is no need of transformation process after field measurements. That the RTK GPS requires at least 5 satellites for the initialization but for the RTK measuring at least 4 satellites simultaneously and the system necessitates open sky view is the only handicap of the system. Today, staking out and surveying of points with centimetre level of accuracy is possible by using RTK GPS. The RTK GPS technology has been integrated into everyday surveying activities such as construction stake out, topography, as-built surveys (El-Rabbany 2006), (Hoffmann-Wellenhof et al. 2000), (El-Mowafy 2000), (Pirti 2007), (WIDOT 1996). This paper focuses on assessing the availability of RTK GPS for highway project. The objectives of this paper were to evaluate RTK GPS in terms of accuracy, precision, performance and repeatability in the highway projects (especially for highway geometry).

2. Highway geometry

Highway geometry is an important factor in road accidents, particularly in rural areas where speeds are high, injuries tend to be severe, and numbers of sites requiring investigation are large. Many of the traffic accidents on roads are a result of alignment defects in the roads. Therefore, it is very important to determine alignments, and correct the elements of the alignments that do not meet design requirements. This will insure that cars run on the roads safely. In order to determine the correct alignment of roads, a three-dimensional trajectory of the centre line shall be acquired as data. In this study the precision based on traditional design drawings was compared with the data acquired with RTK GPS. Surveying and staking out of horizontal and vertical alignments constitute an important part of highway construction projects. Horizontal and vertical alignments are the primary controlling elements for highway design. It is important to coordinate these two elements with design speed, drainage, intersection design, and aesthetic principles in the early stages of design. In general, superelevation rates are based upon the degree of curvature of the road and the speed design of the road. The smaller the radius of the curve, the higher the superelevation rate that is used by the road designer. Roads with a high-speed design will require a higher rate of superelevation. Inversely, roads with a low speed design will require a lower rate of superelevation. Curves with a large radius or low speed design may not require any superelevation. Most often, residential roads that have a low speed design will not be superelevated.

Superelevation is the rotation or banking of the roadway cross section to overcome part of the centrifugal force that acts on a vehicle traversing a curve. Superelevation is the amount of cross slope needed in a roadway that will allow the vehicle to safely traverse around a curve without slipping at a given design speed. Properly superelevated curves ensure smooth and safe riding with less wear on equipment. It may be abbreviated as (d) according to some reference manuals. Superelevation is expressed in a percent or a vertical distance drop per foot (or meter). An 8% (d) would represent a rate of slope equivalent to 0.08 (meter) drop per (meter) travelled. Notations such as 8% are common and both are considered acceptable by many organizations.

The sloping of the road provides a smoother rider for the motorist and allows the driver to enter the curve at a higher rate of speed. An example of (d) that is easy to see is the banking used in auto racing. These curves will most often have a high bank in the curve where the outside portion of the curve is higher than the inside portion of the curve. These 'high banks' are a form of (d) that allows the driver to enter the curve at a higher rate of speed and keeps the driver from slipping sideways as the curve is travelled.

Superelevation reduces the amount of centripetal acceleration that is placed upon the driver at the apex of the curve. Without superelevation in highways, the driver would tend to be thrown to one side of the vehicle as the curve is traversed. The driver would also need to slow down to take the same radius of curve without superelevation (d).

For highway design, superelevation rates range from flat to upwards of 12% or more. Superelevation rates of 4% are common in urban areas while rural high speed highway use 8%. Local governments will most often dictate maximum rates based upon the classification of the road. In climates where snow and ice is common, lower superelevation rates are chosen because of the tendency of the vehicle to slide across the pavement during frozen precipitation (Schofield 2001), (Wolf and Ghilani 2002).

3. Data capture

3.1. GPS observations and site condition

To evaluate performance of the RTK method in the highway project six tests were carried out. The objective of all tests was to assess the RTK achievable accuracy in highway project, and check the repeatability of the results under different satellite configurations. In these tests, accuracy and repeatability assessment of the RTK was carried out by comparing the coordinates of a group of points, determined separately from a number of RTK tests to their coordinates. For this purpose two reference points (R2 and R3) were located in the project area (Ortada### region of Istanbul, see Fig.1). The static GPS survey for determining the coordinates of the two reference points was carried out in the project area. The measurements on the primary network were performed in the static mode with at least 4^h

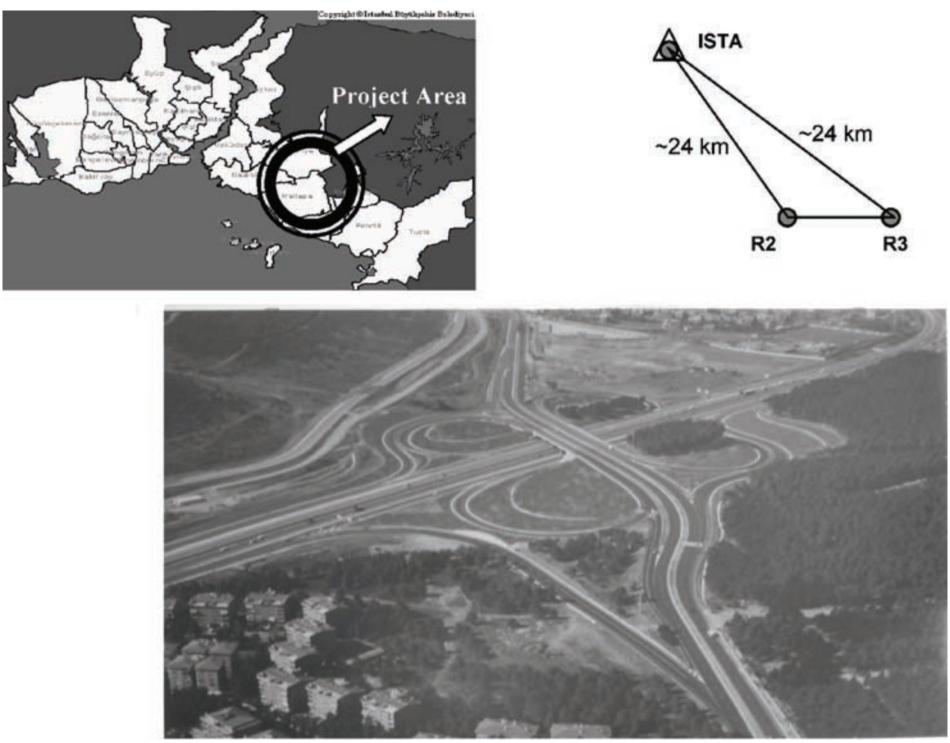

Figure 1. *Project area and GPS network.*

Table 1. *Coordinates and their standard deviations of the two reference points.*

Point	X_{ITRF} (m)	St.dev. (mm)	Y_{ITRF} (m)	St.dev. (mm)	Z_{ITRF} (m)	St.dev. (mm)
ISTA	4208830.275	fixed	2334850.326	fixed	4171267.254	fixed
R2	4210955.697	7	2355004.203	7	4158001.956	15
R3	4210900.942	7	2354909.304	8	4158102.392	16

of observation times. The minimum elevation cut-off angle and sample rate were 10° and 15 seconds. All the measurements were carried out by using Ashtech Z Max GPS receivers. Data processing and network adjustments were conducted using Ashtech Solution (Version 2.60). In the adjustment procedure, the ITRF 2000 coordinates of ISTA were taken fixed (Table 1).

The test included a group of 230 points, marked on the highway ground. Figure 2 illustrates the distribution of the tested points. The maximum distance between the reference stations and rover stations along the North-South direction was about 500 m, while in the East-West direction it was about 600 m, with the largest distance between any two points 700 m (Figure 2). In order to compute the coordinates of the 230 points, horizontal direction, zenith angle and slope distance were recorded with Topcon GTS-701 (angle accuracy: ±2", distance measurement accuracy: 2 mm+2 ppm) by using two reference points. To minimize the errors introduced by curvature and refraction, sight distances should be restricted to less than 300 metres In order to obtain reliable and accurate results for vertical components, the measurements for geometric levelling were carried out by using digital level (Topcon DL 102 (Accuracy, standard deviation for 1 km double-run levelling 1.0 mm/Fiberglass staff)).

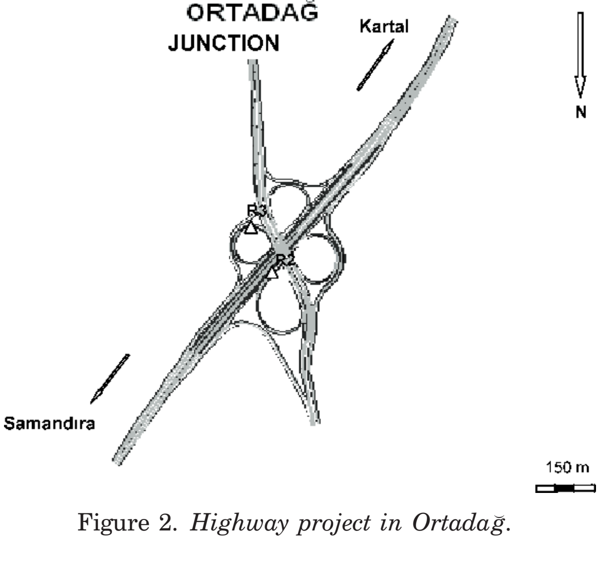

Figure 2. *Highway project in Ortadağ.*

In these six tests, the GPS equipment was used with the RTK test consisted of a pair of Ashtech Z Max GPS receivers (Horizontal accuracy 0.010 m+1.0 ppm, Vertical accuracy 0.020 m+1.0 ppm), with UHF radio modems of a power of 2 Watts, using Ashtech GPS Fast Survey Software and Ashtech SSRT modem. The data acquiring and processing rate was set to one second, with a cut-off elevation mask angle of 10 degrees. To evaluate the RTK repeatability, six independent RTK tests were carried out occupying all of the test points by using two reference points (R2 – R3). The six tests were conducted on different times of the three days (23, 25 and 28 April 2007), with substantial changes in satellite configuration to ensure the independence of the results. Table 2 lists the reference points and the dates and the times the observations. The satellite windows were good for six tests, where the number of satellites observed ranged between 6-9 satellites, and the recorded PDOP average values 2.8 and 1.6, for the first and second, third, fourth, fifth and sixth tests, respectively.

Table 2. *Time schedule of the RTK GPS measurements by using two reference points.*

Reference Point	Date	Time Interval (h)
R2	23, 25, 28th April 2007	(08:00-11:00), (11:30-14:45), (15:00-18:25)
R3	23, 25, 28th April 2007	(11:30-14:35), (15:05-18:15), (08:00-11:15)

3.2. Test results

When comparing the RTK results of these six tests (the survey points in the highway project by using R2 and R3 in the different times of the three days), the horizontal and vertical coordinates of the points as separately determined by these tests seems very consistent, with the changes from a few millimetres up to 5 cm. In the first phase of the test, the RTK derived the coordinates of the survey points by using R2 reference point on three days were compared with each other. Figure 3 shows; compare the measured coordinates by using R2 reference point in I. Day, II. Day and III. Day. It is find that there are about 0-5 cm differences in the horizontal and vertical coordinates. This is shown in Figure 3 which gives the average differences and standard deviations, for all 230 points, between their determined (measured) coordinates from the first and the second and third RTK GPS tests. In the second phase of the test, the RTK derived the coordinates of the survey points by using R3 reference point were compared with each other. Figure 4 shows coordinate differences between the measured coordinates by using R3 reference point in I. Day, II. Day, III. Day. Figure 4 shows; compare the measured coordinates by using R3 reference point in the different days. It is find that there are about 0-5 cm differences in the horizontal and vertical coordinates. This is shown in Figure 4 which gives the average differences and standard deviations, for all 230 points, between their determined (measured) coordinates from the first and the second and third RTK tests.

In the other phase of the tests, the RTK derived the coordinates of the survey points by using R2 and R3 references point on the three different days were compared with each other. Figure 5 shows comparison of the measured coordinates by

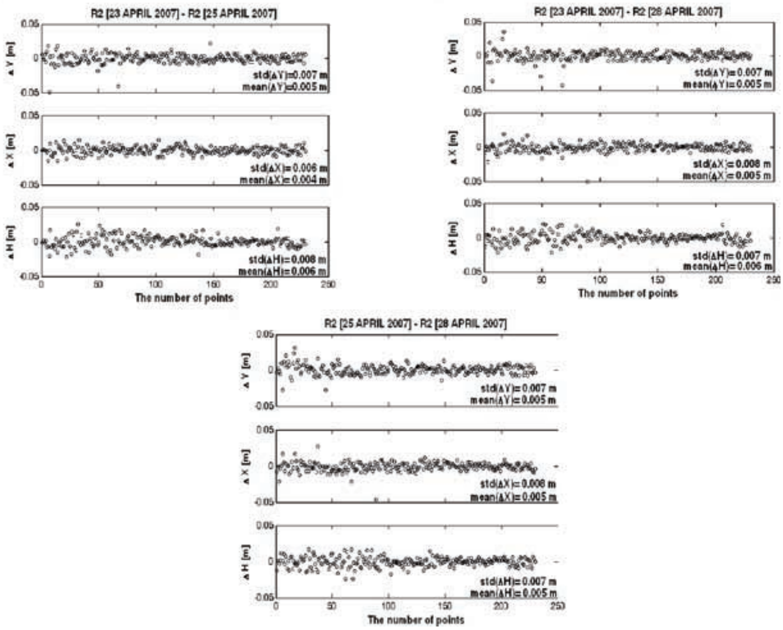

Figure 3. *Comparison of the coordinates of the surveying points in I. Day, II. Day, III. Day by using R2 reference point.*

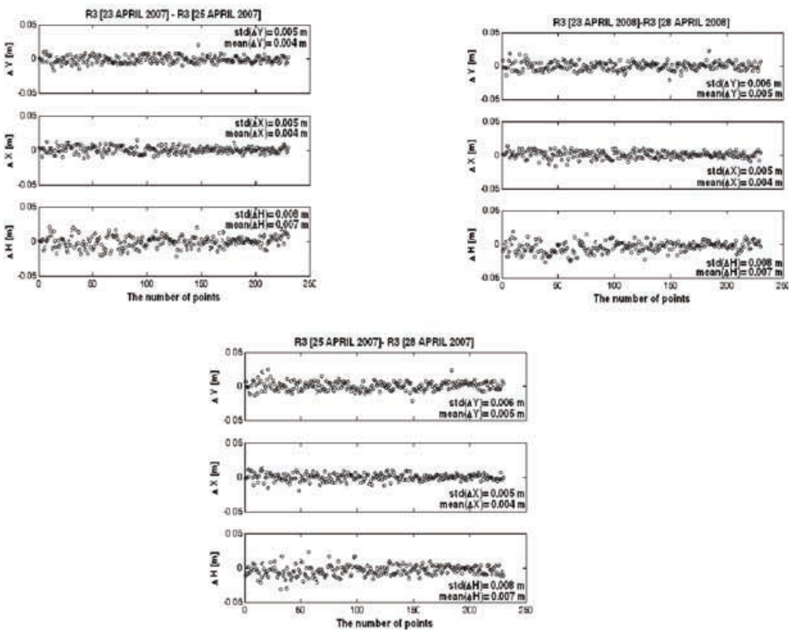

Figure 4. *Compare the coordinates of the surveying points in I. Day, II. Day, III. Day by using R3 reference point.*

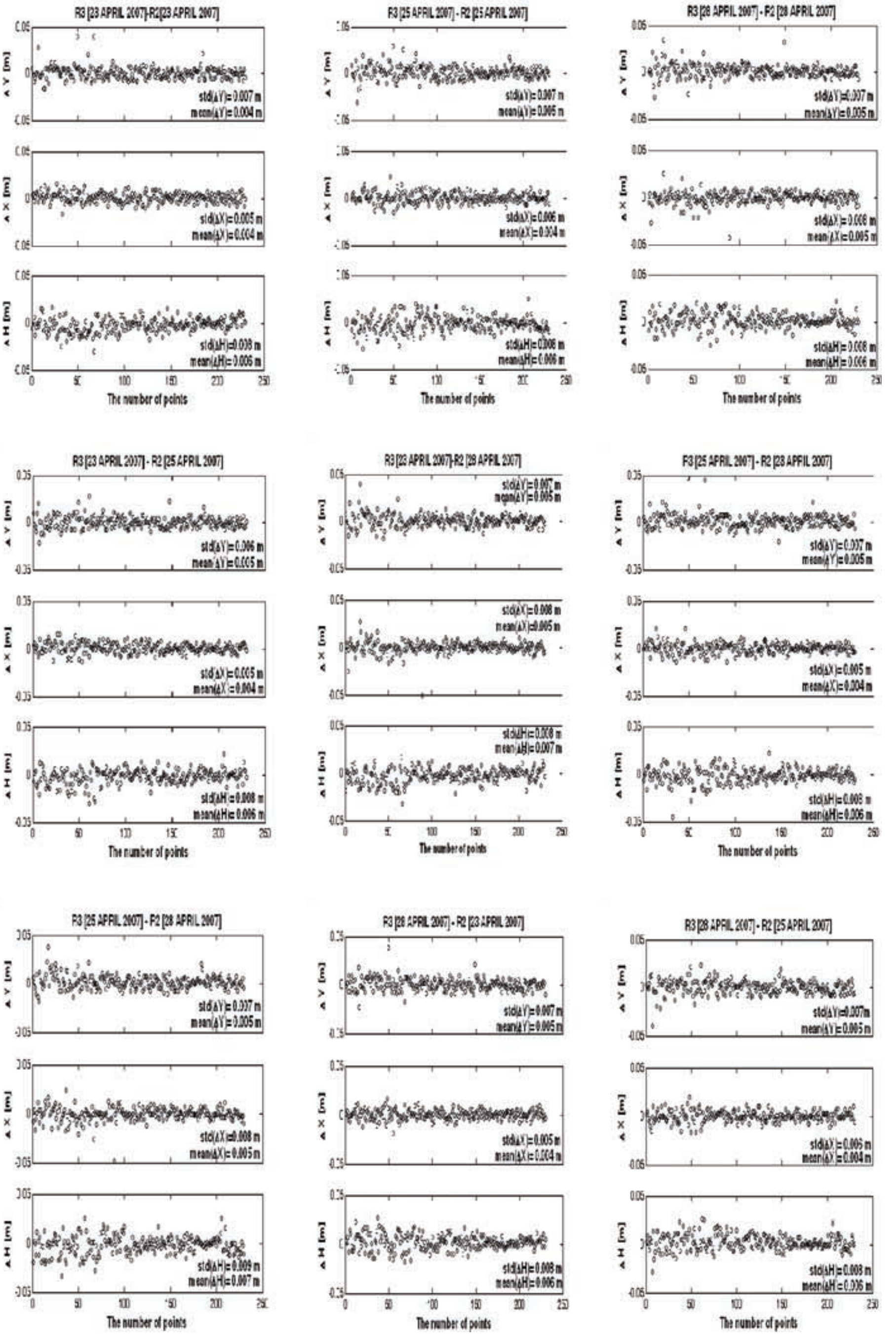

Figure 5. *Comparison of the coordinates of the surveying points in I. Day with II. Day and III. Day by using R2 and R3 reference points.*

using R2 and R3 reference points in the different days. It is find that there are about 0-5 cm differences in the horizontal and vertical coordinates. This is shown in Figure 5 which gives the average differences and standard deviations, for all 230 points, between their determined (measured) coordinates from the first and the second and third RTK tests.

Thus the accuracy of the RTK results is presented as derived from the estimation process. Figure 6 shows the average standard deviations for these six tests, in the Easting (Y), Northing (X), and Height (H) coordinate directions. The coordinates (Easting, Northing) of all the survey points were good in general with standard deviation was ±(6-7) mm. As expected, the height accuracy was less than that, as its average standard deviation reached ±8 mm. The horizontal and vertical components were consistent, and the mean values sometimes differed up to 1 cm (Figure 6) at the same point between the six RTK tests by using R2 and R3 reference points. Considering the dynamics involved in this test, and the changing geometry of satellites, the results clearly show that the RTK technique is a stable system, and the cm level of accuracy is generally obtainable under various operational conditions (Figure 6).

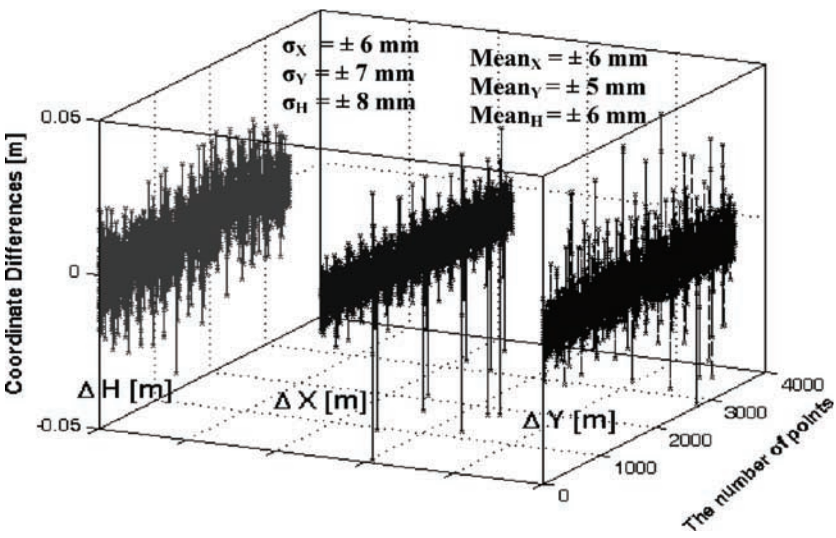

Figure 6. *Compare all of the coordinates of the points in all days by using R2 and R3 reference points on three days.*

In order to compare the RTK GPS measurement results with those obtained using an independent measurement method, were measured the between-point distances, with a total station and were measured the between-point height differences with a digital level. The obtained values of the superelevation both RTK GPS and terrestrial surveys were compared with each other. When comparing the superelevation values to that of the six RTK GPS tests by using R2 and R3 reference points in three days were in the 0%-0.8% range, where the maximum difference did not exceed % 0.8. This is shown in Figure 7 and Figure 8 which gives

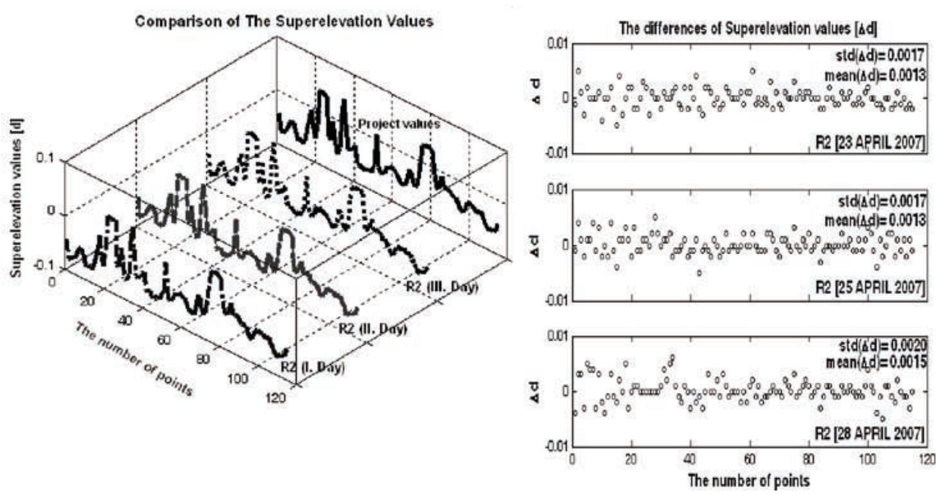

Figure 7. *Comparison of the obtained superelevation values by using R2 reference points on three days with the superelevation values in the project.*

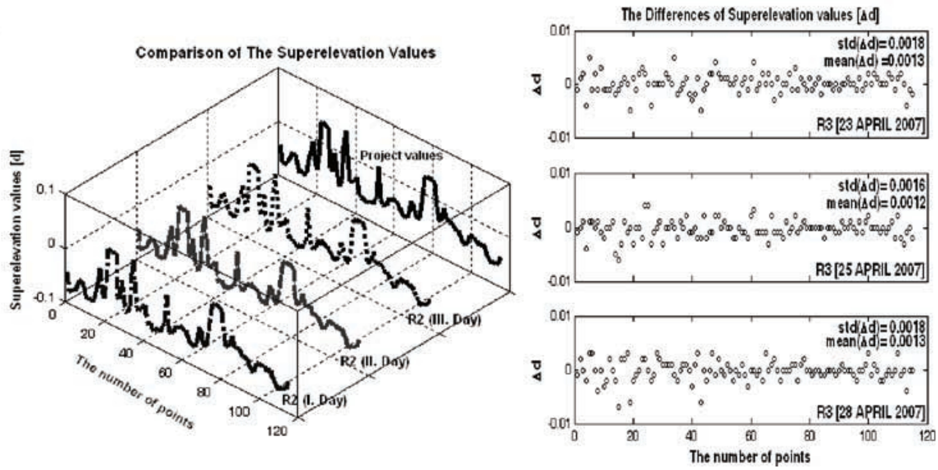

Figure 8. *Comparison of the obtained superelevation values by using R3 reference points on three days with the superelevation values in the project.*

the average differences and standard deviations of the superelevation differences for all 230 points.

4. Conclusion

As expected, vertical RTK GPS accuracies are generally lower than horizontal accuracies. This is caused by a number of factors including satellite geometry, atmosphere errors affecting the vertical solution, antenna phase centre differences, geoidal undulation uncertainties, instrument height errors, etc. Some projects may have horizontal accuracy targets that are suitable for RTK, however, the vertical project requirements may not be reliably achieved with RTK, and conventional levelling may have to be used instead. The conclusion is that the RTK GPS method does not give a vertical accuracy, which can be used for all sorts of levelling tasks, where the geometrical levelling is used. For this reason, if very precise elevations are required in the highway construction project, RTK GPS is unsatisfactory.

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References

El-Mowafy, A. (2000): Performance Analysis of the RTK Technique in an Urban Environment, The Australian Surveyor, 45 (1), June 2000, pp. 47–54.

El-Rabbany, A. (2006): Introduction to GPS: The Global Positioning System, Second Edition, Artech House, Boston, USA.

Hoffmann-Wellenhof, B., Lichtenegger, H., Collins, J. (2000): GPS Theory and Practice, Fifth Revised Edition, Wien-New York.

Pirti, A. (2007): Performance Analysis of the Real Time Kinematic GPS (RTK GPS) Technique in a Highway Project (Stake-out), Survey Review, Vol. 39, No. 303, January.

Schofield, W. (2001): Engineering Surveying: Theory and examination problems for students, 5th Edition, Butterworth-Heinemann, Oxford, Great Britain.

WIDOT (1994-2001): "State of Wisconsin Department of Transportation, Facilities Development Manual", Wisconsin Department of Transportation, Wisconsin, USA.

WIDOT (1996): "Wisconsin Department of Transportation Guidelines on Standarts and Specificationsfor Global Positioning System (GPS) Surveys in Support of Transportation Improvement projects-Draft", 23 October, Wisconsin, USA.

Wolf, P. R., Ghilani, C. D. (2002): Elementary Surveying, an Introduction to Geomatics, 10th Edition, Pearson Prentice Hall, New Jersey, USA.

Ocjena uporabe RTK-GPS tehnologije u kontroli geometrije autocesta

SAŽETAK. Kinematička metoda u stvarnom vremenu predstavlja efikasnu i vrlo naprednu tehnologiju. Najvažniji je razlog popularnosti ove metode mogućnost brzog pridobivanja koordinata centimetarske točnosti. Zahvaljujući navedenim prednostima metoda je vrlo raširena u građevinarstvu i geodetskoj izmjeri. U ovom su radu prikazane mogućnosti primjene RTK GPS-a u zemljanim radovima i mjerenjima geometrije autocesta (poprečni nagib), čija je kontrola vrlo značajna s gledišta uvjeta vidljivosti i sigurnosti. Za ovu je namjenu završeni projekt autoputa provjeren uz pomoć RTK GPS-a. Potom je izračunat stupanj sigurnosti pri primjeni prijenosa geometrijskih standard a autoputova iz projektne dokumentacije na teren. Rezultati dobiveni RTK GPS-om su uspoređeni s rezultatima terestričkih mjerenja pri čemu je dobivena centimetarska točnost.

Ključne riječi: RTK GPS, poprečni nagib, točnost, projektiranje autocesta.

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