ISSN: 0975-833X

Available online at http://www.journalcra.com

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

International Journal of Current Research
Vol. 14, Issue, 02, pp.20592-20595, February, 2022

DOI: https://doi.org/10.24941/ijcr.42991.02.2022

RESEARCH ARTICLE

RAILWAY PRECISION SURVEY WORK: DETERMINATION OF THE EFFECT OF ATMOSPHERIC REFRACTION ON ALTIMETRY MEASUREMENTS

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ARTICLE INFO

Article History:

Received 14th November, 2021
Received in revised form
09th December, 2021
Accepted 10th January, 2022
Published online 25th February, 2022

Keywords:

Railway, Precision Geodetic Engineering Work, Atmospheric Refraction.

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ABSTRACT

The use of a tacheometer (total station) during precision surveying makes it possible to combine the altimetry and planimetric components for the rapid execution of the work. Tacheometers offer the advantage of defining with enough precision the position of the points in the plane. But for a comparison of the altimetry component to the results of a direct leveling it is desirable to take into account certain factors in order to improve the accuracy of the measurements. The evolution of technology gives the possibility not only to carry out certain works quickly but also with the necessary precision. The tacheometer makes it possible to make a tacheometric survey (detail survey) simultaneously in planimetry and altimetry. This avoids performing this task first with the theodolite for the planimetric component and then with the level for the altimeter component. The section of the railway adjaha crossroads "Commune of Cotonou" – Pahou crossroads "Commune of Ouidah" was chosen in order to be able to compare the results of the measurements on different ranges. The fieldwork was divided into two stages. The first is based on the use of theodolite for planimetric measurements and the level for altimetry. For the second phase the tacheometer was used for a combination of the two measurements (altimetry and planimetry). For ranges greater than 150m it is recommended to evaluate the joint influence of refraction and curvature of the earth in order to improve the altimetry component of the measurement.). The study focuses on the methodology and content of geodetic engineering work on railways (Carrefour Adjaha – Carrefour Pahou). It gives an analysis of existing methods and describes the characteristics of the work using electronic tacheometers.

Citation: Dr. KOSSOUGBETO Briac Kevin Patrick, Dr. YESSOUFOU Moukadamou Joslin et al. "Railway precision survey work: Determination of the effect of atmospheric refraction on altimetry measurements.", *2022. International Journal of Current Research, 14, (02), 20592-20595.*

INTRODUCTION

The development of our cities is linked to infrastructure. Transport infrastructure (road and rail) occupies an important place in the development of cities, as evidenced by the remarkable technological developments in the field as well as the appearance of new means of characterization and studies. The development of railways is an important issue because of the efficiency, reliability and safety that this means of transport represents. They ensure interconnection between several cities or countries but also in some cases between industrial production units. Rail transport remains one of the most reliable means of transport (1). Unfortunately in Africa this means of transport is obsolete and has not been very developed.

In the dynamic of reviving this means of transport, some African states including Benin have undertaken studies on existing infrastructure (2). To maintain the railway system and monitor the condition of the tracks, topographical work is undertaken; topographic surveys have been carried out and take into account the tracks at stations and lines dedicated to large industries that need locomotives for travel. The influx of trains at stations, yards or other areas makes topographic survey work a little difficult. But the technological advances of recent years that have facilitated the creation of new devices make it possible to carry out this work with less difficulty than traditional methods (3). For geodetic studies, it is necessary to identify and record all the constituent elements of the system. These elements include rails, suspended or underground lines or cables, buildings and warehouses, etc.

This study focuses on the methodology and content of geodetic work on railways (Carrefour Adjaha – Carrefour Pahou). In this study it will be a question of making an overview of the existing methods of reading and a valorization of the use of electronic tacheometers.

Traditional topographic survey methods

Topographic survey method: Taking into account the current context, three measurement methods can be chosen based on the type of device used. These are:

- Traditional method with combined use of theodolite and level;
- Method with the use of the electronic tacheometer,
- Method with GNSS receiver and level of accuracy.

The realization of topographic measurements using optical device is done in several stages. We can mention among others, the recognition of the places, the realization of the sketch, the picketing, the taking of the measurements, the processing of the data ... (1, 4, 5). When surveying by traditional methods one of the important factors to consider is picketing. The installation of the different points of support and polygonation makes it possible to obtain a better precision.

For this it would be desirable:

- to have practically equal spans between stakes;
- inter-visibility;
- possibility of raising each point of the base polygon from at least two other points;
- arrangement of the stakes so as to be able to observe the maximum detail.

In addition to the above, creating a closed polygonal especially during work in stations or areas with multiple track and equipment, also offers control advantages. The survey is done along the axis of the tracks at regular intervals chosen in accordance with the requirements of the project or and the relief. For connections it is customary to make measurements every 5, 10 or 20m, to determine the angle of deviation, the radius and the other elements necessary for the studies (1, 4). The altimetry survey of the railways is carried out following the requirements of second-order levelling. The determination of the differences in altitude is done every 50m at most. The measurements are made by placing the sights on the left rails (depending on the direction of travel) and in the connections on the internal rails? As for the planimetric survey it is necessary to measure all the characteristic changes of the profile, the entries in the sheds or warehouses, the switch and others. In addition, it is necessary to determine the height of the different lines of communication that cross the rails in heights, level crossings or bridges. Traditional survey methods based on the use of instruments and devices such as level, chain, theodolite require enough time in the field but also in the office for data processing. This is without forgetting the fact that all measurement results are recorded manually and can be sources of error. In the bus to exclude faults, it is advisable to redo the measurements in the opposite direction. However, surveys with the use of tacheometer and GNSS receiver require less time. In addition, the results of the measurements are recorded automatically. The processing time is also less.

In the case of the use of the GNSS receiver it is mandatory to make the altimetry studies after the readings with a level of precision. We contact then that the measurements with the tacheometer is the most adapted that combines altimetry and planimetric simultaneously saves more time. The problem with the use of the tacheometer is that it uses waves So at certain times of the day, the accuracy of measurements is strongly influenced by atmospheric refraction. To be reassured of a good precision of the work, it is then necessary to eliminate the influence of refraction on the measurements. Survey work requires the creation of a local network or at least the offset of a geodetic landmark in the area. This step is sometimes complex to carry out since the geodetic terminals are not near the stations, yard or even the rails in general. To overcome these situations in some countries, a special geodetic network is created along the railway. As with the planimetric survey for better accuracy, measurements are made at predefined regular intervals and especially more detailed in certain areas if necessary. The measurements shall be carried out without any change in the usual train traffic regime. This sometimes creates situations of insecurity and it is often necessary to move the sight or the device in order to free the track when a train passes. All these factors significantly increase the time it takes to complete the work (1).

Altimetry survey and consideration of vertical refraction: The creation in recent years of high-precision measuring instruments such as electronic tacheometers or GNSS receivers for simultaneous altimetry and planimetric surveys has significantly changed traditional survey methods. The accuracy of the realization of the profiles and plans has increased, the duration of the field work has been reduced and this makes it possible to work a little more securely. The use of electronic tacheometer offers the possibility of reducing the number of base points included in the polygonal and thus increasing the length of the sides by parking the device on points in height (building roof, level crossing, vagon ...). While increasing the accuracy of measurements, this method offers the possibility of enlarging the field of view from each station (6). The high accuracy in distance and vertical angle measurements thanks to electronic tacheometers gives the possibility of replacing geometric leveling with trigonometric leveling. The planimetric and altimetry survey is then done simultaneously with the same device. The difference in height and the mean quadratic error in determining the difference in height on one side of the path by trigonometric levelling are determined by the following formulas (1, 6, 7, 8):

$$h = d \tan v + h_t - h_v \;;$$

$$m_h = \sqrt{(\tan v * m_d)^2 + \left(\frac{d}{(\cos v)^2} * \frac{h_v}{\rho} m_v\right)^2} \;;$$

d –distance between the device and the reflector ;
$h_t\ et\ h_v$–height of the instrument and reflector determined with the smallest possible deviation;
v–angle of inclination of the line of sight;
$m_d\ et\ m_v$–error measuring distance and vertical angle;
ρ–number of seconds in a radian.

Total stations nowadays offer the possibility of making measurements with accuracies ranging from 1.5mm on distances and 1" on angles.

Table 1. Effect of refraction on result of altimetric measurements with tacheometer

Points	Distance D (m)	H_{Level} (m)	$H_{Tacheometer}$ (m)	Δh_{ref} (m)
P2	5,286	20,122	20,123	0,001
P3	5,740	20,121	20,122	0,001
P6	156,745	20,297	20,295	-0,0001
P7	156,750	20,314	20,315	0,003
P13	117,119	20,365	20,367	0,003
P14	117,100	20,337	20,334	-0,002
P18	207,314	20,495	20,496	0,004
P19	207,246	20,495	20,495	0,003

Studies have shown that the most influential factor on the results of trigonometric leveling is nature, characterized by the vertical refractive coefficient that is not constant. Its value is determined by the application of appropriate corrections when measuring vertical angles. Given the difficulty of taking into account constantly changing meteorological factors and which determines the value of refraction, the corrections applied only allow to characterize and tend towards its influences. This factor is one of the reasons why the difference in the determination of the difference in altitude by trigonometric leveling especially on long paths is greater than that obtained for geometric leveling. But it is always possible to reduce its effect by using appropriate methods and techniques (1, 6, 7, 8). This can be achieved by doing a double leveling or by placing the device in the middle of the range each time. Using the double leveling technique, the difference in altitude is determined on the outward and return journeys. Half of the difference between the go and the return represents the effect of the curvature of the earth and refraction. But this technique requires enough station and therefore more time to work in the field. By using the technique of equal distance between the device and the points most errors are eliminated.

When the points to be measured are at distances of 100 – 150m then the influence of refraction can be overlooked. But for greater distances, the approximate value of the refractive effect can be determined for a given place and time interval and introduced into the electronic tacheometer. For this it is proposed to compare, the difference in height between distant points, determined by double geometric or trigonometric leveling or even half carried to that obtained by the electronic tacheometer during measurements in given time intervals in order to obtain the characteristic value of the effect of refraction. Small tolerable deviations are not taken into account. But if the difference is significant then it is necessary to determine the correction coefficients of the effect of refraction in order to apply them to the results. The common effect of earth curvature and refraction on the accuracy of the determination of elevation is determined by the formula (1, 6, 7, 8):

$$f = \frac{d^2}{2R} \sim \frac{kd^2}{2R},$$

Where R –earth diameter;

k –coefficient of the refractive curve, taken equal to 0.16;

Given that $f = h_{niveau} - h_{tachéomètre}$ then the correction of the difference in altitude obtained by trigonometric leveling is determined by the formula:

$$\Delta h_{ref} = \frac{kd^2}{2R} = \frac{d^2}{2R} - f,$$

and the coefficient of refraction by the formula:

$$k = \frac{d^2 - 2Rf}{d^2} \; ou \; k = 1 - \frac{2Rf}{d^2}.$$

Railway Planimetric Survey: As with traditional methods, measurements begin at known points in coordinates. When there are geodetic markers of the national network it is desirable to attach the measurements and if possible at the beginning and at the end. But if the terminals are far from the work area, densification must be carried out using GNSS receivers. In principle, measurements can be made in any coordinate system and if necessary make the transformation to any system. In the case of this study, we had created a point canvas on a rail road axis. The measurements were carried out using a traditional method (theodolite + level) on the one hand and using a tacheometer on the other hand (4). We had calculated the influence of refraction in the data processing obtained with the tacheometer. The results obtained on a few points are presented in the table below.

Conclusion

The survey method analyzed here not only increases the accuracy of the measurements but also reduces the measurement time. The possibility of simultaneous surveying in planimetry and altimetry makes it possible to obtain a three-dimensional set of coordinates with the same device and thus avoid the combination of results obtained by different devices. The possibility of parking the device at height makes it possible to observe a large number of points and also to work with more safety.

Abbreviations

GNSS – Global Navigation Satellite Systems
d –distance between the device and the reflector;
h_t et h_v–height of the instrument and reflector determined with the smallest possible deviation;
v–angle of inclination of the line of sight;
m_d et m_v–error measuring distance and vertical angle;
ρ–number of seconds in a radian;
R –earth diameter;
k –coefficient of the refractive curve, taken equal to 0.16;

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