Assessment of the Errors in the Transmission of the Orientation and Cartographic System from the Surface to an Underground Mine

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Abstract. A proper transmission of the orientation between surface and underground workings, by means of vertical shafts, is an important challenge in the mining industry, especially when the mine exceeds 200 meters deep. In fact, this study is developed in a mine located to 700 meters deep. Likewise, this paper assesses the accuracy of this operation, in a case study, using the two shafts plumbing and gyroscope methods in order to compare and analyse the planimetric displacement of the base line due to different source of errors in each one. Upsides and downsides of both methods are analysed in the paper. Some disadvantages in each method have been reduced thanks to the technological progress, especially in the two shaft plumbing method. The different sources of error that affect the measures are thoroughly analysed in the study with the aim to compensate them and achieve the required precision for an underground infrastructure. Mine ventilation has been found as one of the most important sources of error in the plumbing method due to intake and return airflow. In this direction, the paper unfolds some measures to reduce the ventilation influence and details a compensation method to reduce ventilation errors.

Keywords: Shaft plumbing, Ventilation, Plumb oscillation, Gravity force and earth rotation.

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1. Introduction

The mine assessed is located around 700 meters below the surface and its connection is done by means of two vertical shafts with a diameter of 4 meters each one. The first shaft, called Shaft2, is used for staff access and the airflow intake, while the second one, Shaft3, is used to extract the ore and airflow return. There is a separation of around 100 meters between them and they have a depth of 680 meters.

Currently, the company is planning to connect the underground workings to the surface by a ramp. Several surveys have been done with the idea to transmit the orientation and the cartographic system from the surface to the beginning of the tunnel from the underground side. This point is going to be 3500 meters far from the shafts. For this reason, it is necessary to ensure that the error in the axis of the tunnel, either horizontal or vertical, is acceptable. In fact, the accuracy is the main problem in tunnel measurement [1]. On the other hand, nowadays, optimization of the measurements is an important theme of the geodesy and especially engineering surveying [2]. Two methods have been used and compared for such purpose:

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1. Two plumbs, each one connected to wire, from the top of the shaft to the bottom. This system allows obtaining reliable results in deep shafts. Other options, like the laser beam, are not as precise owing to different pressures and temperatures between the top and the bottom, which can involve a deviation in the vertically of the laser. However, it is perfectly feasible in small depths such as the case of the underground coal mine in Digwadih [3].
2. A gyroscope survey. Nowadays, this method is a widely used system in the transmission of orientations [4].

2. Materials and Methods

2.1 Two shafts plumbing method

It is the best option when two shafts are available [5,6] and the company does not have a gyroscope. A plumb has been descended in each shaft and connected by means of an underground traverse. Henceforth, they will be referred as plumb P1 for Shaft3 and plumb P2 for Shaft2.

Two different sets of measures were done after eight hours without artificial ventilation in Shaft2. One with the entrance of the shaft uncovered and another with the entrance almost completely covered with a canvas to minimize the natural ventilation effect to the plumb and then quantify its influence to the plumb verticality. Results showed that the difference in the vertically of the plumb between the shaft covered and uncovered was of 1 cm at the bottom of the Shaft2. Hence, the set of measures with the shaft covered was taken as correct.

In the other case, Shaft3 could not be covered at the exit of the ventilation circuit, because turbulences were generated and the plumb stability worsens. Hence, the ventilation effect was compensated by several sets of measures at the bottom of the shaft.

Plumbs used had a weight of 64.4 kg and were attached to an anti-rotation steel wire rope of 3 mm of diameter. Besides, they were introduced in a viscous oil tank of 1 m^3. The necessary weight for the plumb was deduced from the equation 10+0.08L [7], where L is the depth of the shaft.

2.2 Gyroscope method

It allows monitoring and measuring with high accuracy. A gyroscope can define absolute directions at any measurement point and eliminate systematic errors [4]. A gyroscope GYROMAX AK-2M on a total station Leica TCRP 1201 of 1'' (3^s) was used in the survey. The system is able to calculate the true north with an accuracy of 20'' (60^s) in a single measure according to the supplier. However, after 10 tests with series of 5 measures, the standard deviation is around 40^s. Therefore, it has taken into account 40^s as the maximum precision of the gyroscope used in this case. In fact the gyroscope method is commonly used to correct the error accumulation of the traverses, and this is an effective method for improving the precision of the traverse control network and ensuring breakthrough of the long tunnels [8]. Two sets of 5 measures were done in the surface base called C4-C3, for the calibration and the underground base called INT3-INT2, used for the underground traverse between the plumbs.

3. Results

3.1 Errors in the measures taken in two shafts plumbing method

This method requires some operations to perform the connection survey that generates errors [9,6] as well as the overall error exposed in next equation:

$$m = \sqrt{m_s^2 + m_b^2 + m_p^2} \quad (1)$$

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where m_α is the global error, m_s is the error produced in the surface works to determine the orientation and coordinates of the plumb in the surface, m_b is the error from the underground topographic survey to connect both plumbs or between the plumb and m_p is the vertical error of the plumb.

The surface traverse (Figure 1) done between base C1-C2 and plumbs P1 and P2 was a closed traverse, which allowed knowing the total error due to the angular and linear errors in the polygonal axis. The polygonal had the following characteristics:

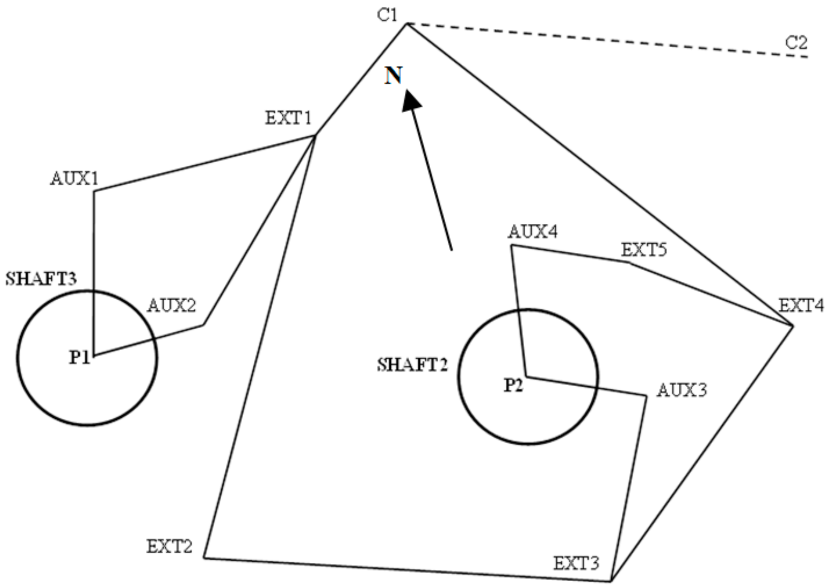

Figure 1. Exterior traverse.

Length: 436.374 m
Number of legs: 5
Error in X: -0.0015 m
Error in Y: -0.0007 m

The accumulation of angular and linear error in the axis, when the traverse was done, produced a displacement of the final station (C1):

$$E_{tr} = \sqrt{e_X^2 + e_Y^2} = \sqrt{0.0015^2 + 0.0007^2} \quad (2)$$

Coordinates of the plumbs (P1 and P2) were calculated through two different branches. In addition, Table 1 shows the error between measurements in each plumb.

Table 1. Error in the coordinates of plumbs P1 and P2 at the shaft top.

Plumb	Error X (m)	Error Y (m)
P1	0,000	0,003
P2	0,000	0,000

The real squared error of the base P1-P2 was:

$$Error\ in\ P1 = \sqrt{0.000^2 + 0.003^2} = 0.003\ m \quad (3)$$

$$Error\ in\ P2 = \sqrt{0.000^2 + 0.000^2} = 0.000\ m \quad (4)$$

$$Error\ in\ P1 - P2 = \sqrt{0.003^2 + 0.000^2} = 0.003\ m \quad (5)$$

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The small differences in the plumbs coordinates, as well as the angular and lineal errors in the exterior closed traverse indicate the goodness of these measures. However, the theoretical error in bases P1 and P2 regarding the external survey was calculated taking into account the topographic instruments and the leg characteristics. Its value will be the quadratic sum of the error ellipses in the semi axis per leg. These error ellipses were calculated according the studies carried out for several authors [10,11,12].

3.1.1 Errors calculation

3.1.1.1 Error m_s

Table 2 displays the error ellipses characteristics at the end of the external survey, plumb P1 and plumb P2, which have been obtained by means of the topographical software TCP-MDT version 7.

Table 2. Error ellipses characteristics at the final point of the exterior traverse.

Exterior Traverse	**Point**	**Sx (m)**	**Sy (m)**	**Major axis (m)**	**Minor axis (m)**	**Max. Error**
C1-EXT1-AUX1-P1	P1	0.0001	0.0001	0.00028	0.00018	0.0003
C1-EXT1-AUX2-P1	P1	0.0001	0.0001	0.00029	0.00017	0.0003
C1-EXT1-EXT2-EXT3-AUX3-P2	P2	0.0002	0.0002	0.00064	0.00053	0.0008
C1-EXT1-EXT2-EXT3-EXT4-EXT5-AUX4-P2	P2	0.0017	0.0015	0.00465	0.00410	0.0062

Hence, the maximum theoretical error in P1 and P2 coordinates due to the exterior measurements was:

P1= 0.0003 m (Average error between two legs)
P2= 0.0035 m (Average error between two legs)

Consequently, the total theoretical error of the base P1-P2 because of the surface topographic survey was:

$$m_s = \sqrt{0.0003^2 + 0.0035^2} = 0.00353\ m \qquad (6)$$

As it can be seen from previous sections, the theoretical error is higher than real error. The most unfavourable, theoretical one, will be taken into account for the underground survey.

3.1.1.2 Error m_b

Figure 2 details the closed traverse (INT1-INT2-INT3-INT4-INT1), in the underground survey, used to transmit the coordinates of P1 and P2, which has the subsequent characteristics and total errors:

Length: 187.270 m
Nº of legs= 4
Total error in X= 0.0030 m
Total error in Y= -0.0015 m

The angular and linear error accumulation in the different axis produced the next final station displacement:

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$$E_{tr} = \sqrt{e_X^2 + e_Y^2} = \sqrt{0.0030^2 + 0.0015^2} = 0.0034\ m \quad (7)$$

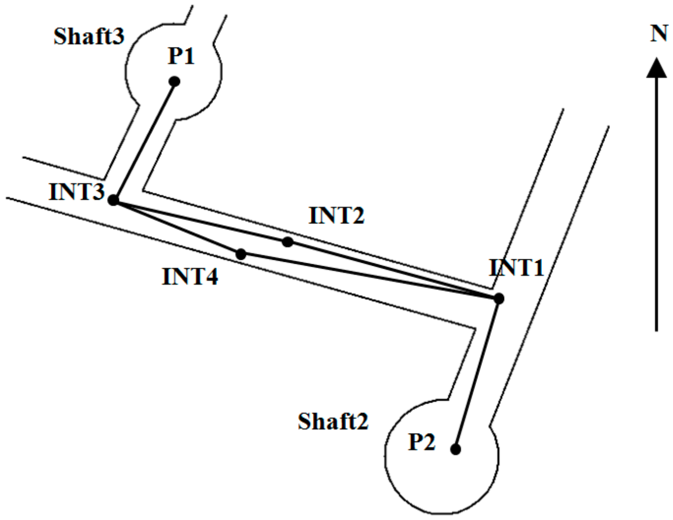

Figure 2. Interior traverse connecting plumb P2 and plumb P1.

Table 3 exposes the adequacy of the angular and lineal errors in the closed underground traverse. The error determination was done following the same procedure in the exterior measures.

Table 3. Error ellipses characteristics at the final point of the underground traverse.

Underground Traverse	Point	Sx (m)	Sy (m)	Major Axis (m)	Minor Axis (m)	Max. Error
P2-INT1-INT2-INT3-P1	P1	0.0012	0.0016	0.00456	0.00346	0.0057

In this case, the maximum theoretical error in the base P1-P2 was, directly, the average error in the two legs of underground traverse between P2 and P1, m_b=0.0057 m, which is larger than the real error obtained in the measures of the closed traverse (INT1-INT2-INT3-INT4-INT1). Once more, it is considered the most adverse case.

3.1.1.3 Error m_p

The sources of error, m_p, that could affect the verticality of the plumbs are quite complex and have to be thoroughly studied. These errors are especially important in the orientation transmission (α) because it is an angular measurement and the final lineal error increases with the length of the traverse. Therefore, the plumb has to be as separated as possible in order to reduce the potential error. It is very difficult to do it with only one shaft, but in the case both shafts are separated 100.618 meters, being able to reduce the angular error significantly. The next paragraphs detail the factors that cause this error and the ways to calculate and compensate it. The paper has been based on previous studies [13,9]. It was also demonstrated that the verticality of a plumb in a shaft is affected by: ventilation, oscillation and vibration of the plumb, shape of the cable and the effect of the gravity force.

1- Ventilation influence

The airflow generated in an underground mine can produce a significant displacement on the verticality of the plumbs. Hence, it is absolutely necessary to stop the artificial ventilation system so that the verticality error of the plumb wire decreases. The air speed dropped to 1.90 m/s at the bottom of Shaft2 after 8 hours since the fans were switch off. Afterwards, the shaft was covered about 95% of its section and consequently the air speed at the bottom was reduced from 1.90 m/s to 0.79 m/s. Two sets of 20 measures were carried out, the first one with the shaft uncovered and the second one with the shaft covered, two hours later on. Regarding the Shaft3, air speed was reduced to 1.2 m/s at the

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bottom of the shaft after 31 hours since fans were stopped. Hence, the four sets of 20 measures were done under similar conditions of airspeed. Figure 3 details the relative position of both shafts and the flow direction of the ventilation circuit. Moreover, taking account a study in a potash mine [14], where it is indicated that the air volume in winter is higher than that in summer at the same ventilation point, the whole of the measures of this work were performed in summer.

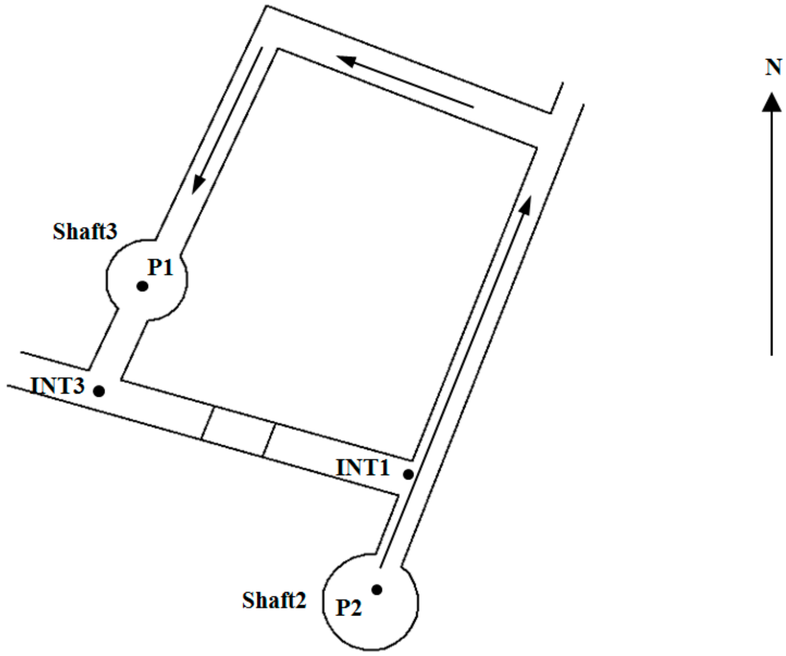

Figure 3. Direction and sense of the ventilation.

Mine ventilation is one of the main sources of error using the plumbing method, having different procedures to compensate this potential error. According to Chrzanowski, the calculation of plumb displacement caused by ventilation has to take into account: air speed during the measurements in each shaft, depth of the shafts, plumb weight and section of the shaft and tunnel, among other factors. Figure 4 and Figure 5 display how the ventilation varies the position of the plumb.

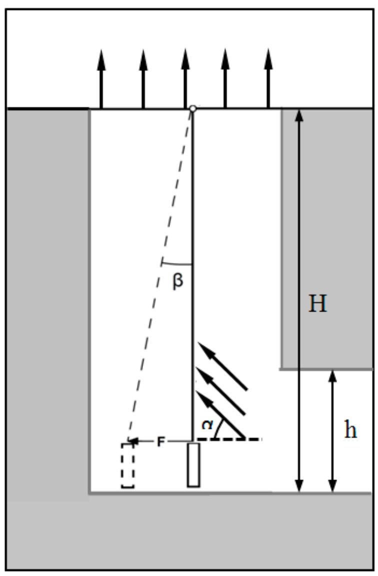

Figure 4. Diagram showing the ventilation effect on plumb P1 (shaft3).

The equation for calculating Fp1 is based on the physical principles and it allows calculating the

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plumb displacement owing to the ventilation. The result from the equation gave a horizontal displacement suffered in plumb P1 of 5.4 mm.

$$F_{P1} = \frac{\frac{1}{2} \cdot \rho_A \cdot v_{\text{int}}^2 \cdot C_f \cdot D \cdot h \cdot (\cos\alpha)^{2} \cdot \left(H - \frac{h}{2}\right)}{g \cdot \left(\frac{m_c}{2} + m_p\right)} \ (m) \quad (8)$$

Table 4. Variables description from Eq. (11) and the case study.

Parameter	Definition	Value
ρ_A (kg/m³)	Air density	1.16
v int (m/s)	Air velocity at the bottom of the shaft	1.2
C_f	Friction coefficient	1.3
D (m)	Rope diameter	0.003
H (m)	Length of rope exposed in the gallery	4
α (º)	Air angle incidence	45
H (m)	Length of the plumb rope	680
G (m/s²)	Gravity	9.8
m_c (kg)	Weight of the rope	37.7
m_p (kg)	Weight of the plumb	64.4
F_{P1} (m)	Horizontal displacement of the plumb in the Shaft3	0.0054

The fact of covering the shaft and its geometry affected the ventilation and as a consequence, the plumb was also affected. The equation for calculating Fp2 has been used in this case. The angles θ and α created by the air and the horizontal can be graphically determined depending on the way the ventilation system introduces the air to the shaft and the intersection between the bottom of the shaft and the underground tunnel. However, a standard value of 45º can be adopted in the majority of the cases, as it has been done in this survey. The deviation of plumb P2 was 2.4 mm.

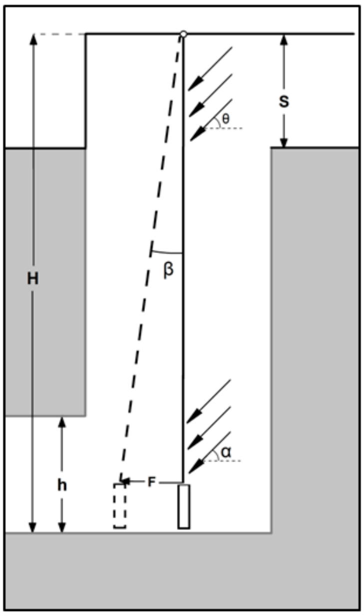

Figure 5. Ventilation effect on plumb P2 (shaft2).

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$$F_{P2} = \frac{\frac{1}{2}\cdot\rho_A\cdot C_f\cdot D\cdot\left[h\cdot v_{\text{int}}^2 ?\cos\alpha)^2\cdot\left(H-\frac{h}{2}\right)+\left(v_{ext}^2 ?\cos\theta)^2\cdot\frac{S^2}{2}\right)\right]}{g\cdot\left(\frac{m_c}{2}+m_p\right)} (m) \quad (9)$$

Table 5. Variables description from Eq. (12) and the case study.

Parameter	**Definition**	**Value**
ϱ_A (kg/m³)	Air density	1.16
v int (m/s)	Air velocity at the bottom of the shaft	0.79
v ext (m/s)	Air velocity at the head of the shaft	8
S (m)	Square opening entrance of the shaft	0.5
C_f	Friction coefficient	1.3
D (m)	Rope diameter	0.003
H (m)	Length of rope exposed in the gallery	4
α (º)	Air angle incidence at the bottom of the shaft	45
Θ (º)	Air angle incidence at the head of the shaft	45
H (m)	Length of the plumb rope	680
G (m/s²)	Gravity	9.8
m_c (kg)	Weight of the rope	37.7
m_p (kg)	Weight of the plumb	64.4
F_{P2} (m)	Horizontal displacement of the plumb in the Shaft2	0.0024

Fp1 and Fp2 values indicate the distance to compensate due to ventilation. However, it is necessary to know its direction and sense for the compensation. Previous studies indicated several methods that allowed the calculation of this direction, but they are laborious, complicated and dangerous for the employees, because they have to work around the bottom of the shaft. Fortunately, the current surveying stations allow to measure distances without prism and then apply the compensation. The movement direction of the plumb in the shaft Shaft2 was deduced from two points, 1º and 2º, obtained by the mean value of each set of measurements. There was an important airspeed reduction between the first set, 1.90 m/s, and the second one, 0.79 m/s, once the shaft was covered. This reduction produced a displacement of 1 cm between both points. Tables 6 and 7 display the standard deviation in each set according to several studies [15,16].

Table 6. *Standard deviation in each set of the measures from shaft2.*

Plumb P2 of the shaft Shaft2	**First set of measures (1º) (20 measures)**			**Second set of measures (2º) (20 measures)**		
	X(m)	**Y(m)**	**Total(m)**	**X(m)**	**Y(m)**	**Total(m)**
P2 standard deviation	0,0016	0,0008	0,0018	0,0006	0,0006	0,0008

Table 7. Standard deviation in each set of the measures from shaft3.

Plumb P1 of the shaft Shaft3	**All series of measures (80 measures)**		
	X(m)	**Y(m)**	**Total(m)**
Standard Deviation in P1	0,0008	0,0019	0,0021

Once the displacement of P2 is calculated, its coordinates without the ventilation effect can be

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obtained. This point is called P2N and it was determined by means of the second set mean value, orientation and horizontal displacement, F_{P2} from Table 5. Finally, it was possible to calculate the new horizontal angle and distance towards P2 from the traverse station INT1.

Plumb P1 was determined by the same procedure previously detailed, getting the average point P1N. Based on the coordinates from point P1N, it was calculated the new horizontal angle and distance towards P1 from station INT3 of the underground traverse.

Table 8 shows the linear error of the underground traverse with and without the ventilation compensation. It reflects an over 20% reduction of the linear error, from 14.8 to 11.8 cm.

Table 8. Linear error of the connecting interior traverse between plumbs P2 and P1.

	Real measures	Compensated measures
Error X	-8.3 mm	-6.6 mm
Error Y	12.3 mm	9.7 mm
Linear error	14.8 mm	11.8 mm

Hence, it is very important to take into account the compensation due to the ventilation effect in this kind of surveys. Particularly, when it is not possible to cover the shaft or the natural ventilation is considerable. Besides, the angular and distance measures have to be taken at the same time from the total station to the plumbs, and many times (two set of twenty measures to plumb P2 in Shaft2, and four sets of twenty measures to plumb P1 in Shaft3). For that purpose, it was necessary a laser capable of measuring the distance aiming a cable with a diameter of 3 mm from, at least, 10 meters.

Apart from the method described, there are other options available such as applying a vertical load to the plumbs for reducing the ventilation effect [17].

2- Plumb oscillation influence

Plumb was equipped with special wings to achieve more stability. P2 measures began five hours after it was immersed inside a tank full of oil. On the other hand, P1 measures started after one hour immersion. The centre point of the pendulum movement was found in both cases because of the important amount of measures carried out.

3- Influence of vibrations and shape of the cable

Errors of vibration and shape of the cable were considered negligible because of several actions done to reduce it: the wings, the tank of oil and an anti-rotation cable.

4- Effect due to gravity force and earth rotation

The distance between two plumbs, when they are being descended, varies because they do not go down in parallel and if they were prolonged until the center of the earth they would converge due to the influence of the gravity force. However, the existence of a centrifugal force changes the direction of the plumbs and they finally do not converge to the center of the earth but in another intermediate point as it is exposed in Figure 6 [18,19].

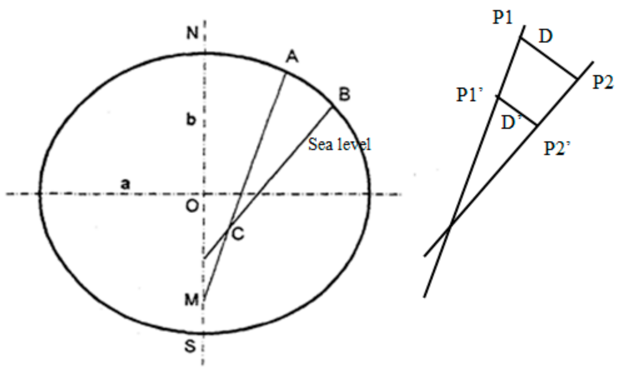

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Figure 6. Scheme of the distance reduction because of the gravity and centrifugal force.

The distance in an alignment projection for a certain depth is deduced from the next equation

$$D = D' + \left[D'\frac{H}{R_o} + D'\frac{H^2}{R_o^2} \right] \text{(m)} \qquad (10)$$

where D is the distance of the alignment in the surface (m), D′ is the distance of the alignment in a certain depth (m), H is the depth of the projection of the surface alignment (m) and Ro is the average earth radius (6375000 m in this study).

Using the data from the case study, where D is 100.618 m, H is 680.591 m, D′ will be 100.607 m, with an error of 0.011 m. This error has been compensated increasing each distance of the underground traverse between P1 and P2 a value calculated applying the indicated equation according previous studies of Chrzanowski and other authors. In this case, this error has been the most important. However, it is very easy its compensation, mainly if it is compared with the compensation of the error due to the ventilation system.

5- Other errors affecting the plumb verticality

Some authors consider the possibility that the plumbs could be affected in their displacement by masses, but [20] stated that the attraction among the masses and the plumb is insignificant when the shaft has a depth of less than 1000 meters. It is also said that the attraction of two plumbs is different if they are separated more than 1500 meters [20]. As the plumbs in the case study are separated only 100 meters with a depth of 680 meters, their deviation due to the attraction between the plumbs and the ground do not influence the verticality, transmission of the orientation and cartographic system.

3.1.1.4 Quality control

The closing error of the underground traverse, between P2 and P1, has been used as a quality control of the survey. This linear traverse closing error in the traverse P2-INT1-INT2-INT3-P1 is an indicator of the work global precision, because it accumulates the errors committed on the surface and the plumb verticality. Table 9 exposes the linear error of the underground traverse between the plumbs after and before applying the compensations.

Table 9. Error analysis of the underground traverse.

	Without compensation	Ventilation compensation	Ventilation and earth gravity compensation
Error X	-8.3 mm	-6.6 mm	-0.5 mm
Error Y	12.3 mm	9.7 mm	0.7 mm
Linear error	14.8 mm	11.8 mm	0.9 mm

3.1.2 Error m_α

All the errors that compose the plumb vertical deviation m_p could be compensated with the equations of Fp1 and Fp2, achieving an error m_p practically nullified. Therefore, the total error m_α affecting the orientation from the base P1-P2 to the underground tunnel would be detailed in the next equation:

$$m_\alpha = \sqrt{m_s^2 + m_b^2 + m_p^2} = \sqrt{3.5^2 + 5.7^2 + 0.9^2} = 6.75\ mm \qquad (11)$$

From this lineal error m_α was possible to find the angular error with the length of the base, and this error was:

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$$Error = \frac{0.00675m}{100.618m} = 6.670762.10^{-5} \cdot \frac{636620^s}{1rad} = 43^s \quad (12)$$

3.2 Errors in the measures taken in Gyroscope method

Errors generated by the gyroscope in the orientation depend on its precision. In this case, it has an accuracy of 60^s in a single measure according to the specifications of the supplier. However, a set of measures can have a standard deviation about 40^s as indicated in section 2.2.

Measures done with the gyroscope consisted in two sets measures of the underground base INT3-INT2 in different days. Each set consisted in five measures: three measures with the gyroscope located in the point INT3 measuring INT3-INT2 and two measures with the gyroscope located in INT2 measuring INT2-INT3.

Table 10 shows the results and accuracy of the measures. The standard deviation has been calculated according to several studies [15,16].

Table 10. Gyroscope measures.

	Underground axis INT3-INT2	**Underground axis INT3-INT2**
Number of measures	5	5
Average of the true north orientation	128.0780^g	128.0844^g
Standard deviation	37^s	45^s
Final Meridian convergence	0.9217^g west	0.9171^g west
Projected north orientation system UTM	128.9997^g	129.0015^g

The mean value of base INT3-INT2, using gyroscope, was 129.0003^g. The final meridian convergence is calculated from the theoretical meridian corrected by the data obtained from the calibration baseline (C4-C3).The theoretical meridian convergence in point of known coordinates is obtained by a software application from the Cartographic and Geological Institute of Catalonia website and some equations exposed by Estruch [18]. The convergence has been taken into account in final orientation determination.

If only the method of gyroscope was applied, the coordinates of a known point would have to be projected to the underground tunnel from the surface using a conventional method, one plumb in a shaft for transmitting the cartographic system. Hence, there will be two sources of errors: the true north orientation to the underground base and the transmission of the cartographic system from the surface.

The error generated by the gyroscope affects the orientation of the base measured, while the errors of the cartographic system transmission have been described in section 3.1, but regarding only one plumb. The global error m_α is also determined by the first equation.

Considering that the cartographic system is transmitted by the plumb P1, the error in the surveying works in the surface according to section 3.1.1.1 is 0.0003 meters. Therefore, m_s is 0.0003 m.

For calculating the error in the underground leg INT3-INT2 it is necessary to indicate that the necessary underground traverse to find the coordinates of points INT3 and INT2 was the traverse P1-INT3-INT2. In short, only two legs. In this way the error ellipse in INT2 was:

Table 11. Error ellipses on the final leg of underground traverse between P1 and INT2.

Underground Traverse	**Point**	**Sx (m)**	**Sy (m)**	**Major Axis (m)**	**Minor Axis (m)**	**Max. Error**
P1-INT3-INT2	INT2	0.0007	0.0008	0.00228	0.00191	0.0030

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Therefore, the maximum theoretical error of base INT2 in the underground topographic survey was, directly, the error in the leg of underground traverse between P1 and INT2:

$$m_b = 0.0030m$$

Overall, the nest equation includes the error generated to transmit the cartographic system through the plumb P1 to the base INT3-INT2 is:

$$m_\alpha = \sqrt{m_s^2 + m_b^2 + m_p^2} = \sqrt{0.3^2 + 3.0^2 + 0.9^2} = 3.1\ mm \quad (13)$$

It has to be pointed out that this error does not affect the orientation of the base line INT3-INT2, it only produces a coordinates displacement. The error in the orientation is the standard deviation, 41^s, of the measures done by gyroscope.

4. Discussion

Table 12 shows how the underground orientation of the base INT3-INT2 varies because of the ventilation compensation, but it is not affected by the gravity force compensation. It can also be observed that the difference between both methods is only 44^s after the compensations.

Table 12. Variation of the orientation in the underground base INT3-INT2.

	Orientation without compensation	Ventilation compensation	Ventilation and gravity compensation
Plumb method with 2 shafts	128.9932^g	128.9959^g	128.9959^g
Gyroscope	129.0003^g	129.0003^g	129.0003^g
Difference	71^s	44^s	44^s

Despite similar accuracy, both methods have upsides and downsides:

- The two shaft plumbing method is operationally more laborious than the gyroscope alternative. It needs to transmit the orientation and cartographic system from two shafts, whereas the gyroscope only needs one. This fact involves several hours working around the shafts, increasing the risk of the staff.

- The plumbing method also needs more surface and underground surveying. However, the closed traverse in the plumbing method allows checking the accuracy of the values, whereas the gyroscope can only verify the results doing an extra set of measures.

- The most dangerous measurements are those around the shaft, especially at its bottom due to falling rocks in this case, to calculate the central position of the plumb during its pendulum movement. The usage of a total station without prism allows avoiding this situation.

- Despite the plumbing method takes more time than the gyroscope option, the case study was 20 hours for the plumbing and 31 hours the gyroscope. This difference is because of verification measures done in the second case, while the two plumbing method does not need it to verify the measurements. This time is subdivided in the following operations:

1. Plumbing method: 20 hours.
    a) 11 hours in Shaft2.
    b) 9 hours in Shaft3.

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2. Gyroscope: 31 hours with verification measures and 19 hours without them.
    a) 7 hours in Shaft3 (works for transmitting cartographic system from exterior to underground in the case that two shaft method was not applied.)
    b) 2x5 hours calibration base C4-C3 and verification measures.
    c) 2x7 hours underground measurement INT3-INT2 and verification measures.

5. Conclusions

The study describes some adaptations of existing procedures, applied in studies quite a long time ago, by means of new technologies, improving the accuracy of the measures and safety levels during the survey because of less time working around the shafts. In addition, the two shaft plumbing and gyroscope method have been analysed, emphasising the characteristics of both options. Their comparison exposes similar accuracy, only a difference of 44^s between them. This confirms the goodness of the measurements made in this study and the suitability of both options.

The study suggests the most important source of error in the two shafts plumbing method is the ventilation factor. Therefore, it is important to stop the artificial ventilation, at least, 24 hours before taking the measures to reduce the airflow as much as possible. Unfortunately, it is very difficult to stop the operating fans for such a long time and covering the intake shaft is an alternative to reduce its effect. Hence, it is still necessary to compensate the deviation of the plumb due to the ventilation effect due to remaining flow.

It has also been confirmed the necessity to compensate the projected distances in a certain depth because of gravity and rotation forces, achieving a reduction in the linear error of the traverse between plumbs of both shafts in large part. Despite it is, proportionally, important in terms of error, its compensation is much easier than the ventilation effect.

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