Traversing spiral decline - error propagation and surveying strategies

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Abstract: Use of "wall stations" become prominent in Australian underground coal and metalliferous mines. Authors analyse how the "wall station" arrangements and setup geometry may impact on the accuracy of direction and position transfer alone a small radius spiral decline. The theoretical error analysis and the results of practical trial surveys are presented.

1. Introduction

Traversing was and still is the conventional method of providing survey control in underground mines. Underground survey stations are usually stabilized in backs (in the roof) of underground drives to protect them from damage. Although, the backs position provides a secure location for control points it does however present a number of drawbacks for mine surveyor. The most obvious of which is the difficulty of installing and accessing such points. To access the backs in modern high-volume underground mines usually requires lifting apparatus to reach heights of over 5 meters. Additionally ventilation ducts, mining equipment and other components of mining infrastructure (power cables, water and compressed air pipes, etc.) may obstruct the control points located in backs and prevent their access. By locating survey points in walls, the installation and access of control points is easier, safer and faster.

B. McCormack (McCormack 2001) proposed the surveying technique named "Wall Station Traversing" at the Regional Mine Surveying Seminar in Kalgoorlie, Western Australia, in 2001. He proposed to stabilize control points in the form of aluminium sleeves inserted and fixed into holes drilled in mine drive's rock walls underground (**Figure 1**). The method requires specially designed target prisms that retain central position whatever their rotation. A Leica standard prism (GPR1) (with zero constant) and prism holder (GPH1) mounted on a stem is inserted into the aluminium sleeve (**Figure 2**) to form a virtual control point (located in the prism's centre).

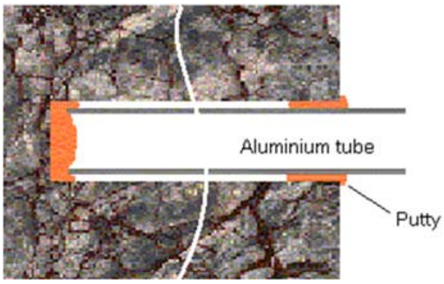

Figure 1. Wall Station – Sleeve installed into a 10mm diameter hole (McCormack 2001)

Figure 2. Leica prism and holder mounted on a wall station stem (McCormack 2001)

However, such realisation of control points does require a change of surveying technique from classical traversing, as the theodolite (total station) can no longer be set under a survey point. It also requires use of a coaxial total station with high accuracy of distance and angular measurements. “Wall Station Traversing” utilizes observations to wall-mounted prisms from a temporary instrument station that is located at a convenient position in the drive. The resection technique (free stationing), with all available distances and horizontal angles measured, is used to determine the position of the instrument (**Figure 3**). The instrument must be equipped with a processor and software able to determine instrument position from the resection observations (utilizing the least-square best- fit calculation method). The positions of forward wall stations are then surveyed and determined.

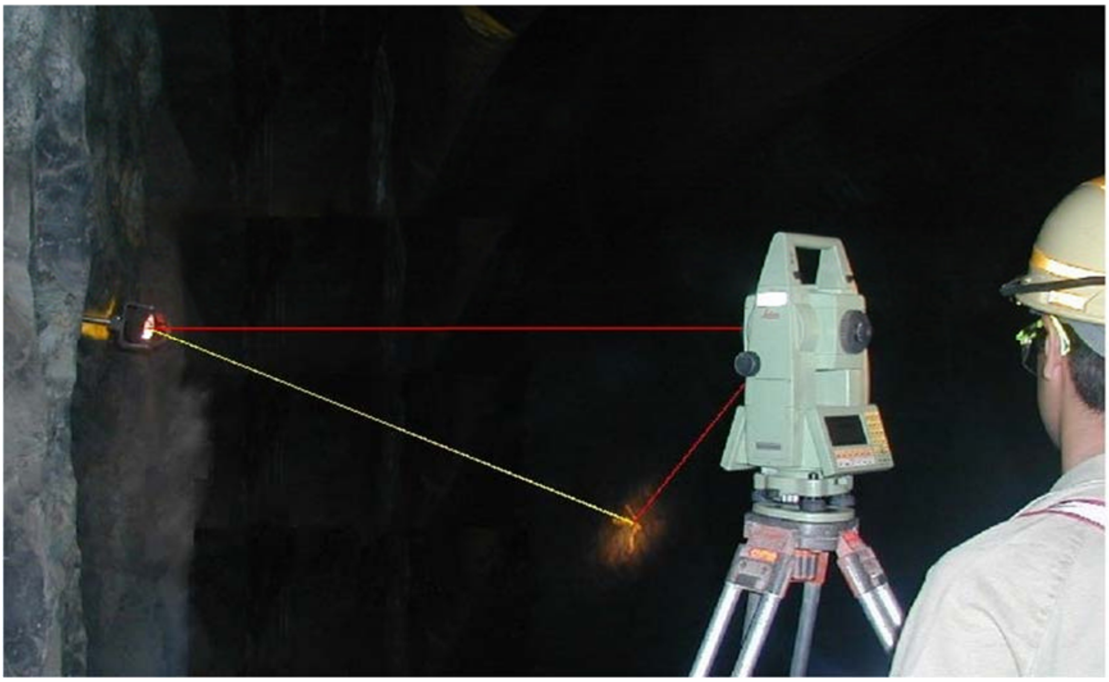

Figure 3. Resection based on wall stations (McCormack 2001)

This technique has become popular in underground mining operations in Australia. However, with this growing popularity it is important that surveying professionals have an in-depth understanding of methodology, accuracy and limitations of this technique.

The theoretical accuracy analysis (Jarosz and Shepherd 2004) of wall station traverses suggests that to achieve optimal directional accuracy, a configuration that has acute triangle geometry is necessary. Temporary instrument stations located normal or near normal to wall stations should impact negatively on the accuracy of bearing transfer.

The above analysis were never rigorously tested and confirmed by the practical test surveys. In this paper authors present the results of such tests.

The test were performed to:

test propagation of errors (direction and position) along a spiral decline

test different survey strategies and their impact on error propagation

develop the best surveying strategy to minimise error propagation

2. Test Survey Setup

It was decided that the test survey would be conducted on the surface along a simulated spiral (circular) decline with the radius of an inner wall of 30m and the width of 6m. The test decline was stabilised by 12 control points around a circle representing its outer wall with the radius of 36m. The

test points were positioned as the hours at clock face with the distance between them about 18m (Figure 4). The field implementation of test network is presented in Figure 5.
Wall station (control points) were stabilised with help of aluminium tubes (sleeves) attached to star pickets by U-bolts and driven into the ground (Figure 6).

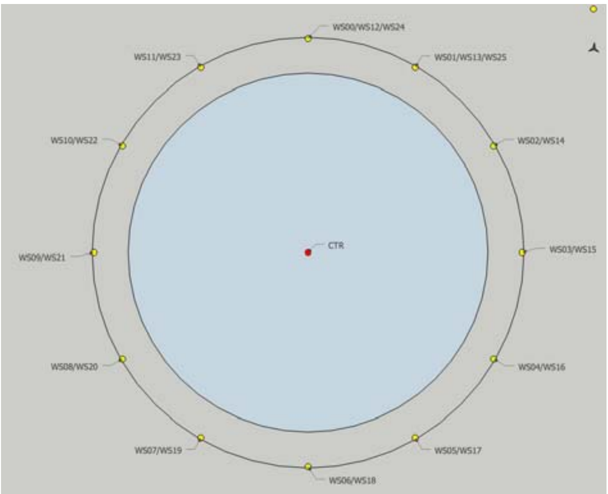

Figure 4: Configuration of Test Survey


Figure 5: Field implementation of Test Survey

Figure 6: Stabilisation of control points (Wall Stations)

The exact positions (reference positions) of all control points (WS00 – WS11) were determined from the centre (CTR) using a local coordinate system. To series of surveys using face left (FL) and face right (FR) were carried to achieve the high accuracy of results (positional accuracy less then 1mm).
These, as well as, all the following surveys were performed using the Leica TCRA 1105plus total station. This total station is characterised by the following specs: angle accuracy (Hz & V) of ±5”, distance accuracy of ±(2mm+2ppm) and auto target recognition (ATR) of ±3”.

3. Survey Scenarios Tested

Seven survey scenarios were tested. Five of them have used different configurations of the resection method and two the force centred traversing.

The details of all case study surveys are listed below:

Case#1: Simple resections (2 back sights (BS), face left only (FL), one series of angles, acute resection triangle, instrument station at temporary point (TP) close to one of the wall stations (WS) forming resection base, 2 foresight wall stations (WS))

Case#2: Simple resections (2BS, FL, one series of angles, right angle resection triangle, TP close to one of the WS forming resection base, 2 foresight wall stations (WS))

Case#3: Simple resections (2BS, FL, one series of angles, acute triangle, TP at mid position between WS, 2 foresight wall stations (WS))

Case#4: Free stationing (3BS+TP, FL, one series of angles, acute triangles, TP close to one of the WS forming resection base, 2 foresight wall stations (WS))

Case#5: Simple resections (2BS, FL+FR, one series of angles, acute triangle, TP close to one of the WS forming resection base, 2 foresight wall stations (WS))

Case#6: Free Stationing (3BS) at the start and then Forced Centred Traverse (FL only, one series of angles, 4WS as sideshots – 2 backsights and 2 foresights)

Case#7: Free Stationing (4BS) at the start and then Forced Centred Traverse (FL + FR, two series of angles, 4WS as sideshots – 2 backsights and 2 foresights)

The detailed presentation of all case surveys follows.

Case#1

The survey configuration is presented in Figure 7.

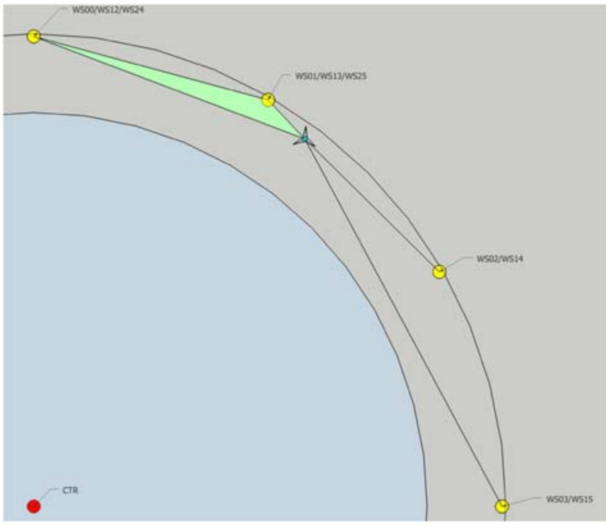

Figure 7: Survey configuration for the Case#1

The survey procedure was as follows:

Survey started from the base WS00-WS01 (stations with known positions - coords).

Instrument (TP) was located close (~4m) to one of the wall stations (WS01) and formed an acute shaped resection triangle.

The following measurements were taken:

One series on angles, only in one face (FL),

2 directions & 2 distances to backsight stations (WS00 & WS01),

2 directions & 2 distances to foresight stations (WS02 & WS03).

Then, the instrument was transferred to the new position (after WS03) and survey was continued until two full rounds were achieved (the station WS25 was reached).

The survey results (the locations and directions between WSs) were compared with the reference locations and directions, then, positional and directional errors were calculated. The comparative results are presented in Figure 8.

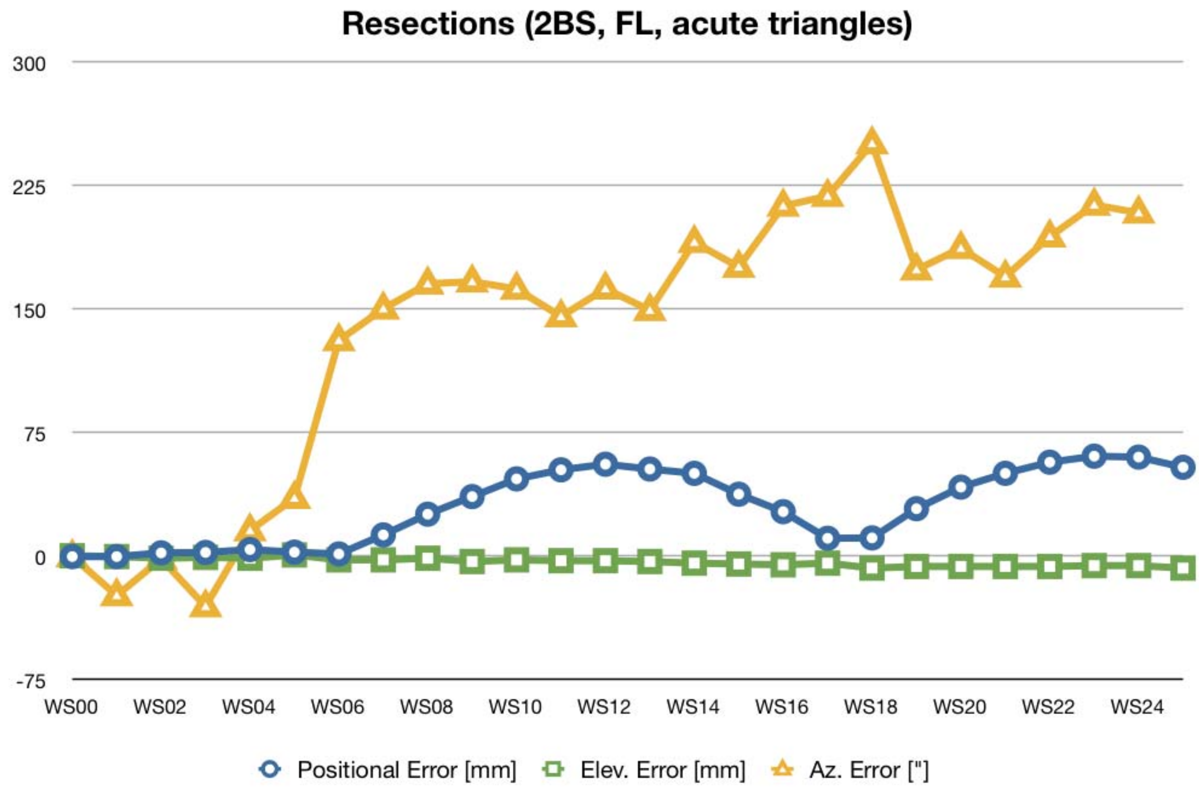

Figure 8: Survey errors for Case#1

Case#2

The survey configuration is presented in Figure 9.

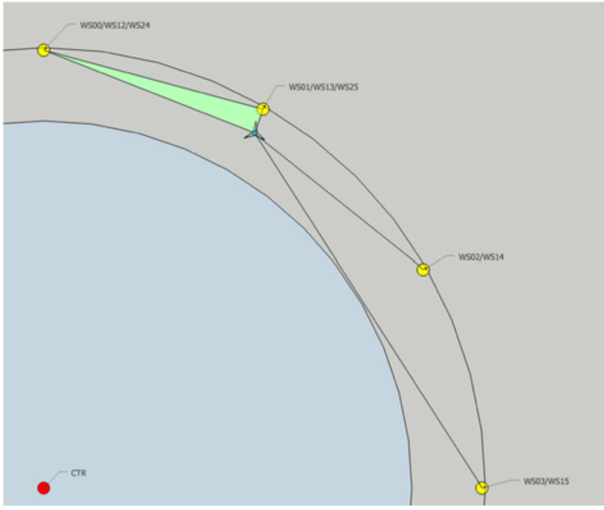

Figure 9: Survey configuration for Case#2

Survey started from the base WS00-WS01 (stations with known positions - coords).
Instrument (TP) was located close (~2.5m) to one of the wall stations (WS01) and formed a right angle (~90º) shaped resection triangle.
The following measurements were taken:
One series on angles, only in one face (FL),
2 directions & 2 distances to backsight stations (WS00 & WS01),
2 directions & 2 distances to foresight stations (WS02 & WS03).
The instrument was then transferred to the new position (after WS03) and survey was continued until two full rounds were achieved (station WS25 was reached).
The survey results (the locations and directions between WSs) were compared with the reference locations and directions, then, positional and directional errors were calculated. The comparative results are presented in Figure 10.

The survey procedure was as follows:

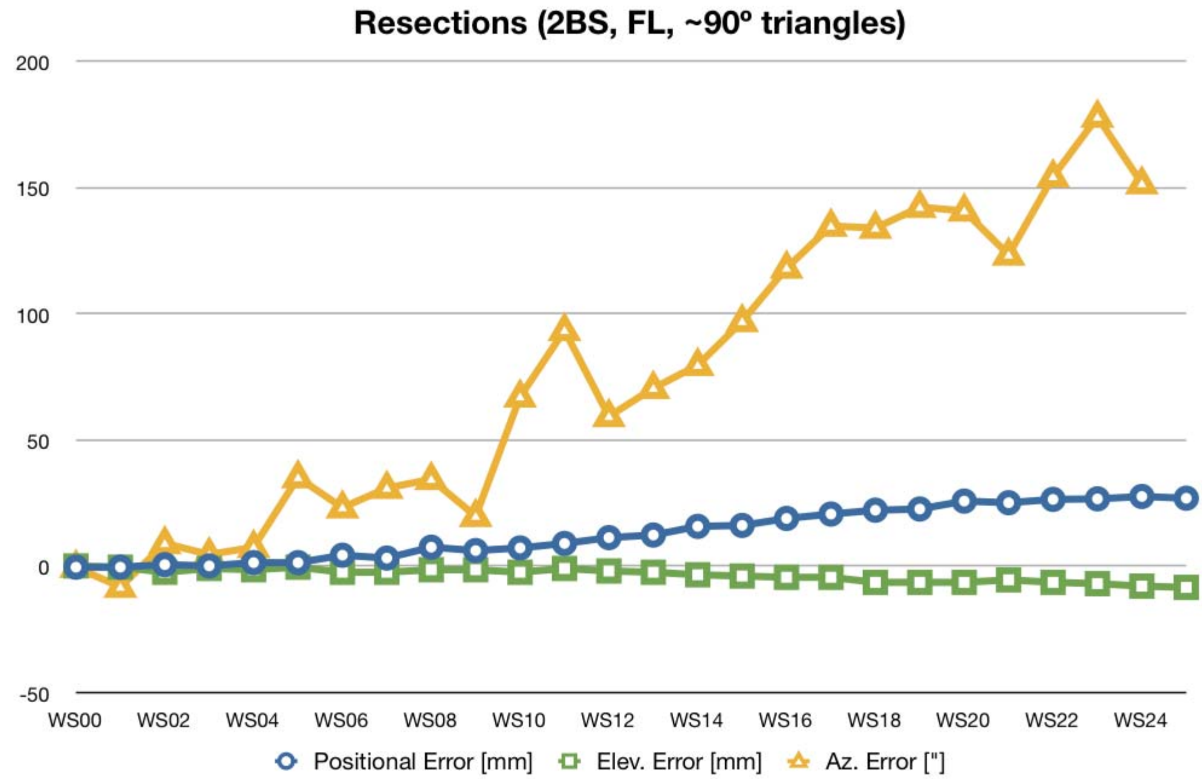

Figure 10: Survey errors for Case#2

Case#3

The survey configuration is presented in Figure 11.

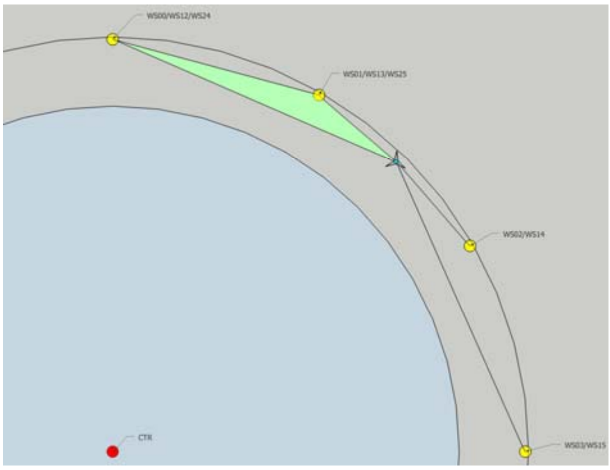

Figure 11: Survey configuration for Case#3

The survey procedure was as follows:
As in Case#1 and Case#2, the survey started from the base WS00-WS01 (stations with known positions – known coords), however, the instrument was positioned at a mid position (TP) between wall stations (WS01 & WS02) forming an acute shaped resection triangle.
The following measurements were taken:
One series on angles, only in one face (FL),
2 directions & 2 distances to backsight stations (WS00 & WS01),
2 directions & 2 distances to foresight stations (WS02 & WS03).
The instrument was then transferred to the new position (in the middle between points WS03 & WS04) and survey was continued until two full rounds were achieved (station WS25 was reached).
The survey results (the locations and directions between WSs) were compared with the reference locations and directions, then, positional and directional errors were calculated. The comparative results are presented in Figure 12.

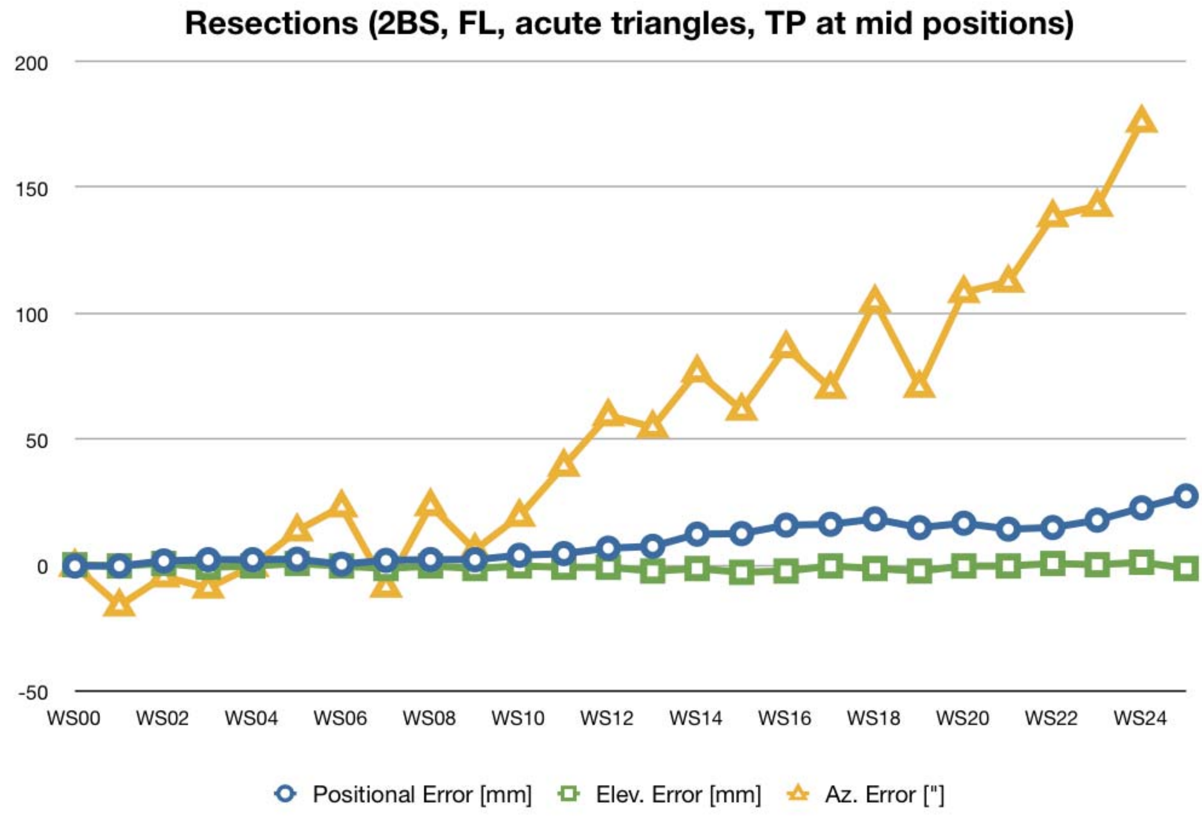

Figure 12: Survey errors for Case#3

Case#4

The survey configuration is presented in Figure 13.

Figure 13: Survey configuration for Case#4

In Case#4 the positions of instrument were determined using the free stationing. Survey started from the base WS11-WS00-WS01 (3 stations with known positions – known coords). Instrument (TP1) was set close to the last station (WS01) forming acute shaped resection triangles.

The following measurements (one series on angles with one face (FL) only) have been taken:

3 directions & 3 distances to backsight stations (WS11, WS00 & WS01),

2 directions & 2 distances to foresight stations (WS02 & WS03) and additionally direction and distance to the next instrument station (TP2).

Then, the instrument was transferred to the new position (TP2) and the following measurements were taken:
4 directions & 4 distances to backsight stations (WS01, TP1, WS02 & WS03),
3 directions & 3 distances to foresight stations (WS04 & WS05 and TP3).
Then the instrument was transferred to the new position (TP3).
The survey was continued until 2 full rounds were achieved.
The comparative results of this survey are presented in Figure 14.

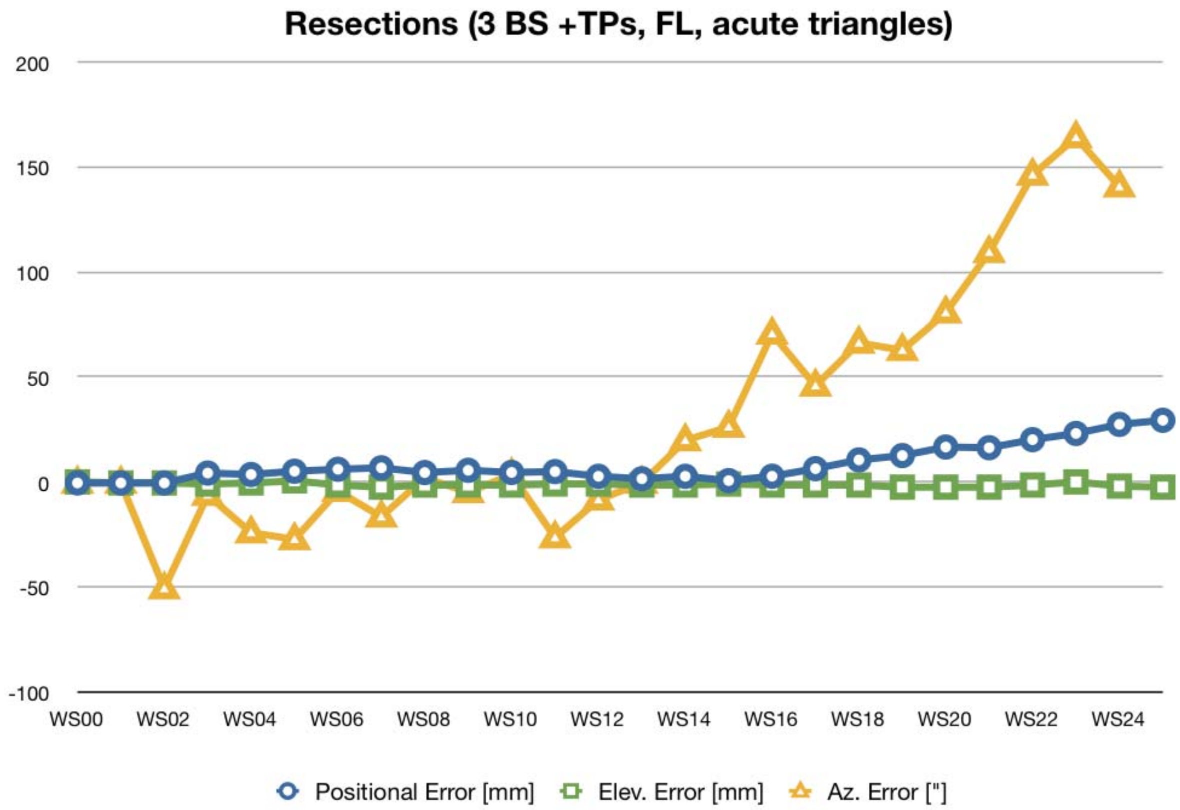

Figure 14: Survey results for Case#4

Case#5

The survey configuration for this case was identical as for the Case#1 (Figure 7), however all angles were measured using face left (FL) and face right (FR), as well as, all distances were measured in two repetitions.

The comparative results of this survey are presented in Figure 15. It can be seen that by doubling the number of measurements the errors were significantly reduced (approximately by half).

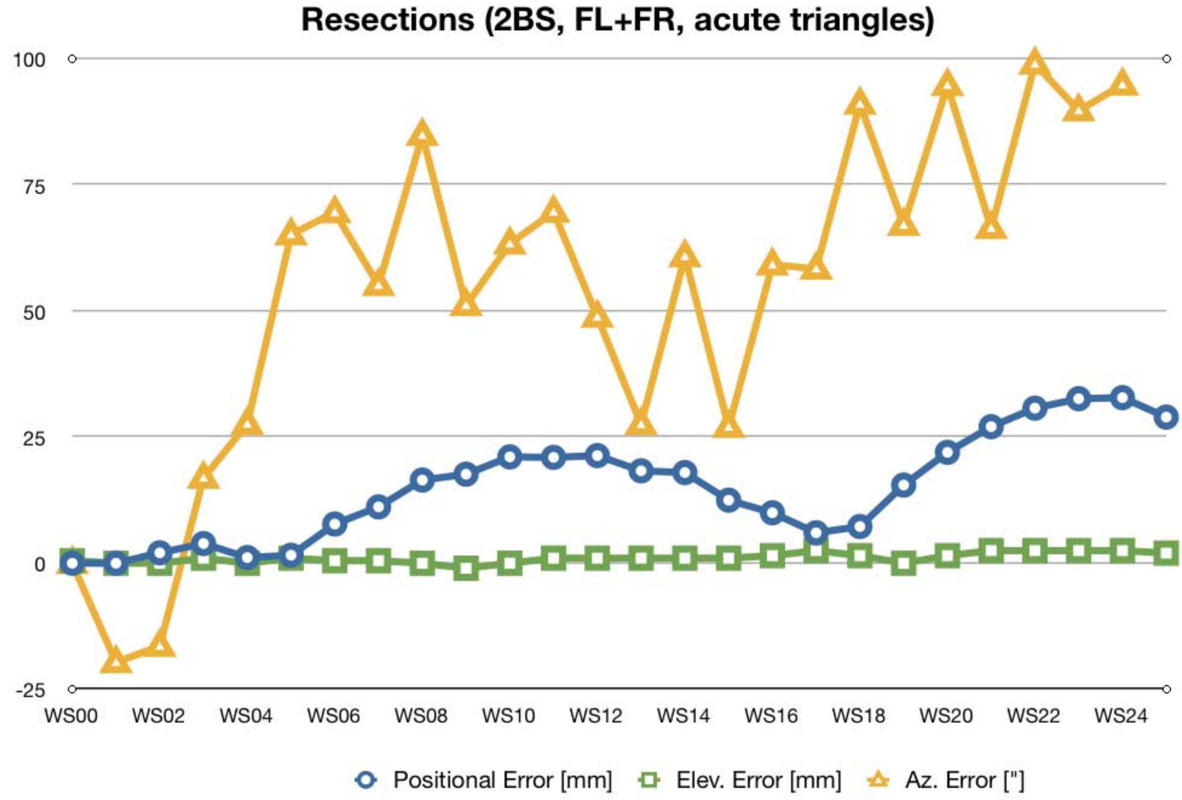

Figure 15: Survey results for Case#5

Case#6

In this case, the surveying technique was significantly changed. The forced centred traverse over temporary points was used and the positions of wall stations were determined as side shots from the traverse stations. The initial station of traverse (STN1) was determined using the free stationing to tree reference wall stations (WS00-WS01-WS02). Directions and distances were measured only in one face (FL). The following traverse stations (STN2, STN3, …) were determined using the forced centring technique. Positions of wall stations were determined twice, from the previous, as well as, from the following traverse stations. The configuration of this survey is presented in Figure 16, and comparative results to the reference survey in Figure 17.

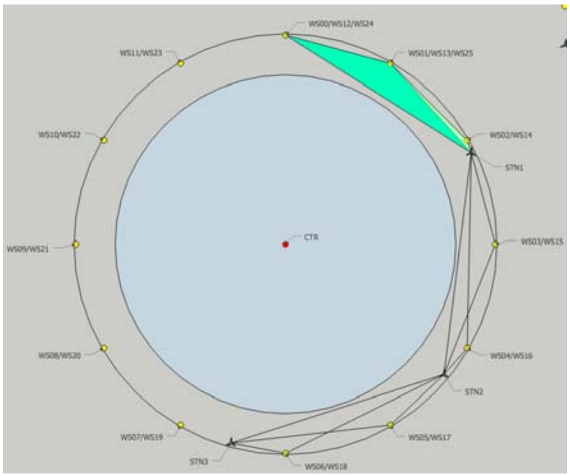

Figure 16: Survey configuration for Case#6

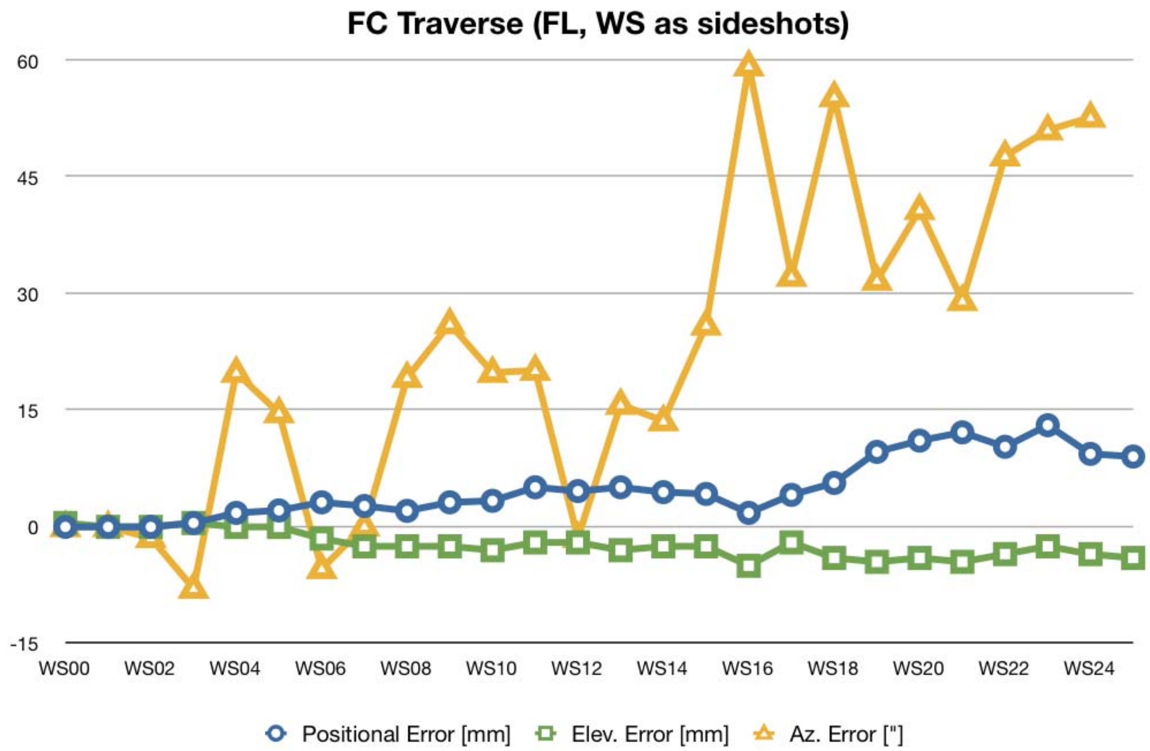

Figure 17: Survey results for Case#6

Case#7

As in the previous case the traversing technique was used, however, all measurements were performed in two series using face left (FL) and face right (FR) for all measured directions. Position and orientation of the initial traverse station (STN1) was determined by free stationing (double resection) to four consecutive wall stations with known positions (WS00-WS01-WS02-WS03). The survey configuration is presented in . The comparative results to the reference survey in . This case provided the results with lowest comparative errors.

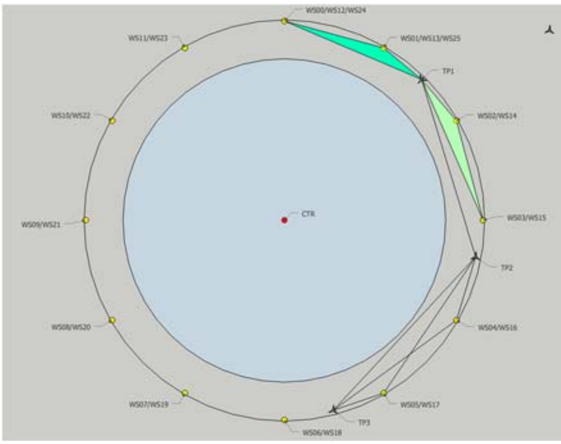

Figure 18: Survey configuration for Case#7

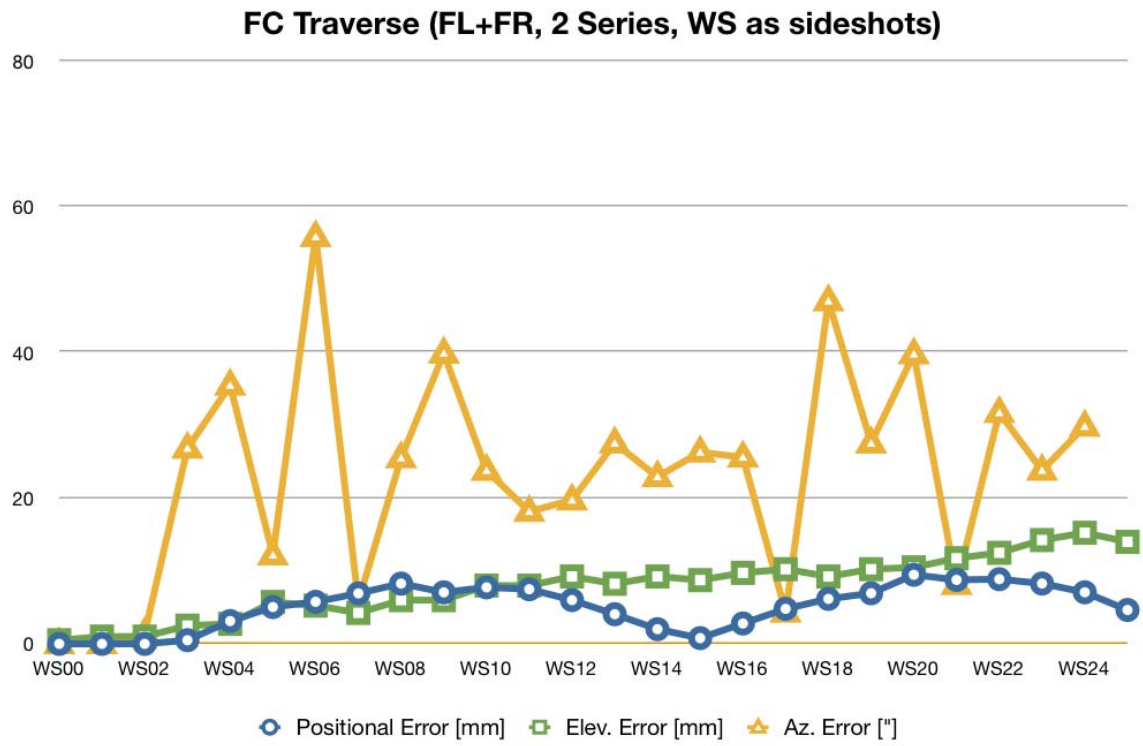

Figure 19: Survey results for Case#7

4. Comparison of Results

The comparison of results for all surveys is presented in Figure 20.

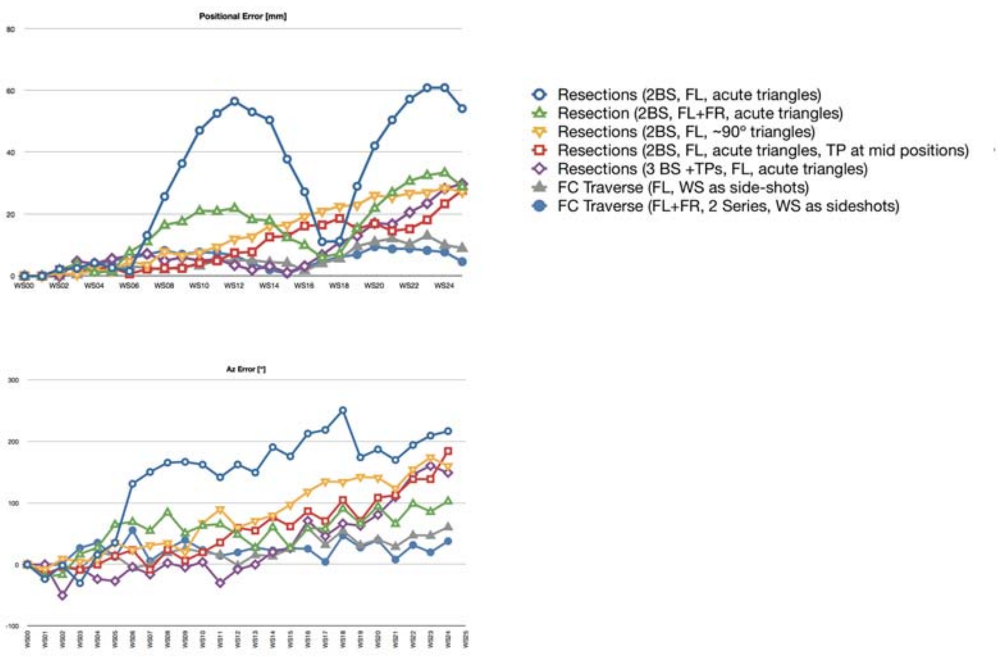

Figure 20: Comparison of positional and directional errors by case study.

It can be clearly seen that the best results were achieved by applying the forced centred traversing technique with wall stations determined as side shots. The positional error reached the value of 9.5mm (at WS20) and directional error of 38.1” at the end of the traverse. Also, the forced centred traverse was characterised by the smallest growth of positional and directional errors.
The surveying techniques based on simple resection (2 backsights) or free stationing (3 or more backsights) produced significantly worse results (larger positional and directional errors).
The large errors noticed in Case#1 were related to the significant direction error after the station WS05.

5. Error analysis

Close review of errors propagation along traverse (Case#7) suggests that there are two components impacting these errors (Figure 21). The first component is the initial orientation error, the result of linking the first traverse station (STN1) and the initial wall stations (WS00 … WS03). Resection or free stationing was used to achieve this. The initial directional error has value of 27” and makes profound impact on the positional errors of all following wall stations. The second component is the directional error, which is induced by traverse survey. The growth of this directional error is significantly smaller then the initial one (linking error).
The initial (linking error) has such profound impact on the position of following traverse points, that it creates specific pattern of positional errors as presented in Figure 21b. This pattern is consistent with a rotation of the whole traverse by the angle (E) around the last wall station used for traverse orientation (WS03). Such rotation results with maximum positional errors at wall stations located on the opposite side of circular decline (stations WS09/WS21).

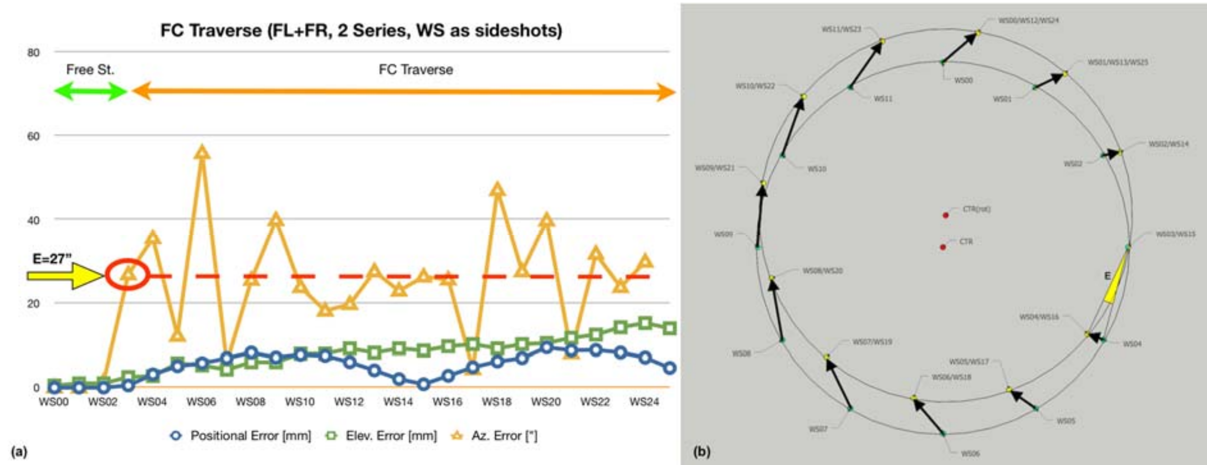

Figure 21: (a) Propagation of errors along traverse; (b) Impact of initial orientation error

Similar patterns of errors propagation are present in the Case#6. They are clearly visible, even that the angles were measured only in one series and one face. The Figure 22 presents propagation of errors along the surveyed traverse.

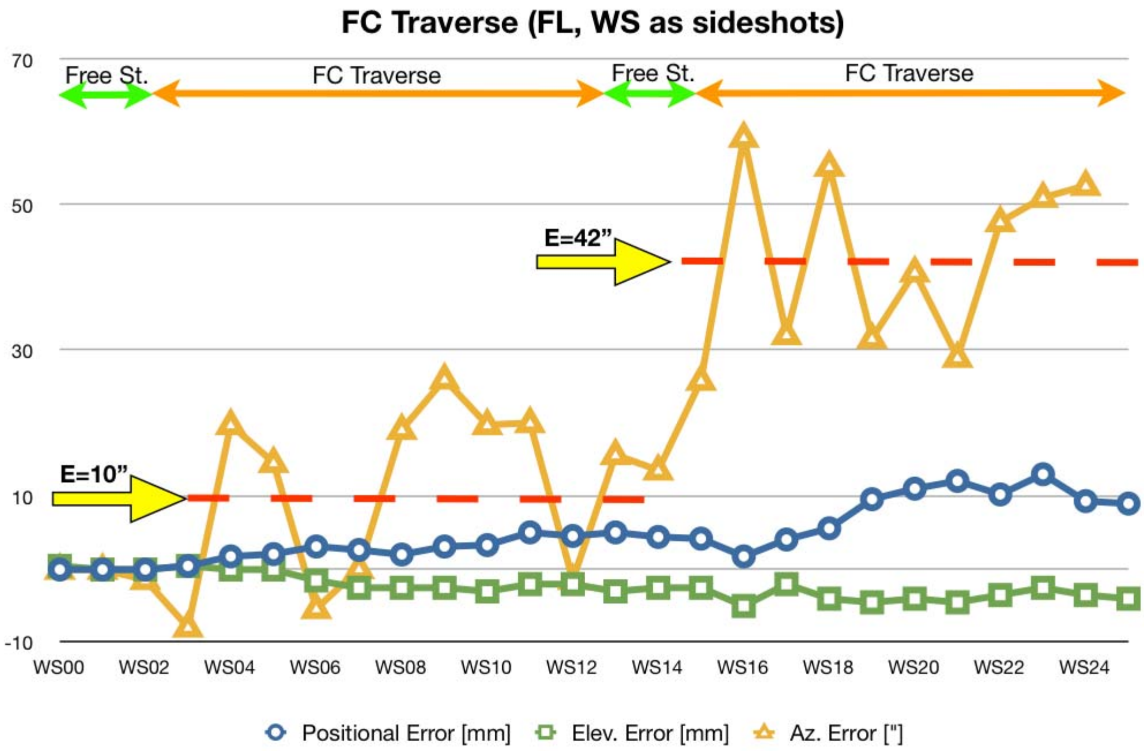

Figure 22: Propagation of errors along traverse - Case#6

In Case#6 the traverse was linked (by free stationing) to the wall stations WS00-WS01-WS02 and continued to the wall station WS15. This section of the traverse is characterised the initial orientation error of E=10". The second section of the traverse was continued by linking it to the wall stations WS13-WS14-WS15 and completed at the station WS25. This section is characterised by the initial orientation error of E=42". It can be clearly visible that the initial linking surveys (resection or free stationing) have major impact on the positional and directional errors of the following control points (wall stations).

To confirm the magnitude of errors registered in these case studies, especially in Case#7, authors performed theoretical calculations of directional errors induced by positional errors of traverse stations. It was assumed that traverse stations might have positional errors (e) of ±1mm and/or ±2mm.

Simple straight traverse with distances between stations of ~18m (as distances between wall stations) was analysed (Figure 23).

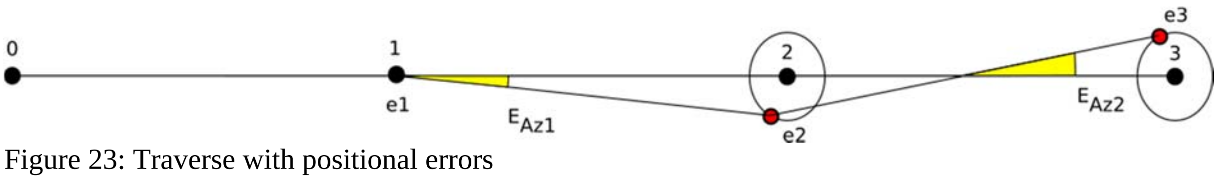

Figure 23: Traverse with positional errors

Using the formula:

$$E_{Az} = \frac{\rho"}{b}\sqrt{\frac{e_1^2 + e_2^2}{2}}$$

directional errors were calculated.

The results are in Table 1.

Table 1: Directional errors

Base (b) [mm]	**e1=0; e2=1**	**e1=0; e2=2**	**e2=1; e3=1**	**e2=2; e3=2**
18,000	8.1”	16.2”	11.5”	**22.9”**
35,000	4.2”	8.3”	5.9”	11.8”

Taking into account the technical specs of total station used for measurements, it can be assumed that positional accuracy of wall stations is ~±2mm, which translates into directional accuracy of wall station base of about ±23”. Such value is consistent with errors recorded in Case#6 and Case#7.

6. Conclusions

Positional and directional errors along a spiral decline are affected by two components:
1. The initial survey linking the following survey structure (along a decline) to the starting control points (Wall Stations),
2. A surveying technique applied for the transfer of position and direction along a decline.

The best results could be achieved using the following strategy:

- Free Stationing to 3 or more wall stations as the initial survey (linking survey).
- Angles should be measured minimum in two series using face left (FL) and face right (FR). Coordinates and orientation of instrument station (TP) should be calculated by use of the Least Squares Adjustment (LSA).
- Special care should be applied to the initial survey, as the initial error of direction (Az Error) will be transferred (and magnified) to all following control points.
- Forced Centring Traverse over temporary stations (TPs) is the best method to transfer position and direction along a decline to the next set of wall stations. Wall stations can be surveyed as side-shots from the traverse stations (TPs).
- Traverse surveys should be done using face left (FL) and face right (FR) with angles measured minimum in two series.

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