ENG4111/4112 – UNDERGRADUATE DISSERTATION

PROJECT REPORT

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RESEARCH TOPIC:

UNDERGROUND CHECK SURVEY

A DISSERTATION SUBMITTED BY:

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ABSTRACT

The wellbeing of the mine and underground workers directly rely on the accuracy of wall stations that controls the workings on the mine. Some of the daily responsibilities of a mine surveyor comprise of staking out construction lines to control the direction and gradient of development drives. When there is deviation in the direction and gradient of construction lines in relation to the design it can lead to damage to infrastructure within the mine that causes problems such as re-development or altering designs which are expensive. This is why it is significant high order check surveys are undertaken to follow up advancing capital development as a means to verify the quality of existing wall stations and provide accurate control to further advance into the mine.

The objective of the proposed research is to perform a high order control survey and adjust the observations of the traverse using a least squares adjustment incompliance with ICSM Class “D”. Variables of the network will be statistically assessed and important considerations in the check survey will be identified to educate and render the importance of check surveying.

Slope distance, direction and vertical angles were analysed to assess the quality of the check survey. It was observed that the greatest standardised residuals were located at the start and end of the survey. The assumption is that the traverse is closing onto another fixed control point which will lead to variation. Integrity of the original fixed control points was questioned as the fixed stations were verified in a check survey three years ago. Over three years wall stations are expected to move due to the nature of the mine.

The absolute and relative error ellipses were analyse at a 95% confidence interval. It was observed that there was an azimuth deficiency in the Eastern direction which was caused by the orientation of the fixed control. The relative ellipses semi-major axis did not exceed the limitation of 50mm with the greatest semi-major axis being 27mm.

The dissertation is to help mine surveyors understand the process of check surveys and show the importance of regularly performing high order controls surveys. While rendering the possible issues that can affect accuracy and quality when completing an underground check survey.

University of Southern Queensland
Faculty of Health, Engineering and Sciences
ENG4111/ENG4112 Research Project

LIMITATIONS OF USE

Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own efforts, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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13th October 2016

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ABBREVIATIONS & NOMENCLATURE

B&D	–	Bearing and distance
CI	–	Confidence Interval
SF	–	Scale Factor
TS	–	Total station
USQ	–	University of Southern Queensland
ICSM	–	Intergovernmental Committee on Surveying and Mapping
EDM	–	Electronic Distance Measurement
FL/FR	–	Face Left/Face Right
CMS	–	Cavity Monitor Scan
CALS	–	Cavity Auto scanning Laser System
SP1	–	Special Publication 1 (Standard for the Australian Survey Control Network)
SBQ	–	Surveyor's Board of Queensland
MPV	–	Most Probable Value
ENT	–	Enterprise
PPM	–	Parts Per Million
PU	–	Positional Uncertainty
RU	–	Relative Uncertainty
SU	–	Survey Uncertainty

1. CHAPTER 1: INTRODUCTION

1.1 OVERVIEW

Mount Isa Mines is controlled by Glecore Xstrata Copper which is a section of its North Queensland Operations. Some of the tasks involve mining, processing and smelting processes in Mount Isa and just mining and processing at Cloncurry and then Townsville control refining and port operations. The method of mining used at Mount Isa involves the ore broken down underground and then transported to the surface. Once the ore has been brought to the surface it is then grounded finely and then goes to the flotation operation, in this stage the copper- bearing sulphide minerals are separated and concentrated from the waste. Once the ore has completed these processes, the concentrated ore is sent to the smelter.

At Mount Isa Copper Operations (MICO) there are two underground mines which are called X41 and Enterprise (ENT). The survey department at Mount Isa performs surveys in both X41 and Enterprise to meet the demands of production and development of the mine. In order for the surveying department to remain confident in their everyday work, checks need to be implemented which is why check surveys are completed. Check survey traverses are an integral part of underground mine surveying. A check survey involves using high precision surveying techniques to transfer survey control from an area of established checked control to one with either no control, or survey control of low order. High order check surveys will follow up advancing capital development as a means to verify the quality of existing wall stations and provide accurate control to further advance into the mine.

1.2 BACKGROUND

"In underground mines the mine surveyor will determine and control the location and direction of tunnels as well as the mapping of all underground tunnels" (Surveyors Board of Queensland, 2016). Some of the work that an underground metalliferous surveyor can perform includes:

- Survey heading (as mined) pick ups
- Survey for development headings
- Lasers for development headings
- Survey for production mark ups
- Survey for service hole mark ups

- Survey for raisebore set outs
- Survey for diamond drill hole set outs
- Survey for Cavity Monitor Scan (CMS) and Cavity Auto scanning Laser System (CALS)

In order to relay mining instructions to underground mining staff, a survey memorandum is created detailing the control that survey have provided, how it relates to the design that is to be mined and any pertinent safety information that the miner should be aware of.

With the constant demand of the mine, the survey department is required to communicate instructions to mining staff as to what needs to be done. The mine surveyor must be able to ensure that all the survey work is in the correct position in relation to the mine's baselines to prevent mishaps such as; drilling operations drilled in the wrong position and not hitting the target which impacts on the production of the mine and raise bore drilling machine not hitting their targets. It is essential that mine surveyors prevent mishaps like these from happening as problems can potentially cost jobs, money and lives.

As a general operating procedure, high order "check" surveys will follow up advancing capital development as a means to verify the quality of existing wall stations and provide accurate control to further advance into the mine.

1.3 Project Aims & Objectives

Check surveys is a procedure which all mine surveyors should understand the importance and processes of. As no literature was found that discussed the process of the check survey method the dissertation aims to outline the need for check surveying and the important considerations of the practice.

The aims and objectives of the proposed research is to:

- Perform a high order control survey and adjust the observations of the traverse using a least squares adjustment.
- The observations in the check survey to the wall stations will be will be in compliance with the ICSM standards of a Class "D" primary survey control network.
- The least squares adjustment will be broken down to analyse the results of slope distances, directions and vertical angles and analyse the behaviour and reasoning of the survey data.
- Absolute and relative error ellipses at 95% confidence will be analysed and a summary of the size, shape and orientation will be outlined.

- The wall station resection method will be theoretically analysed to portray the importance of the number of wall station in a resection and the geometrical relationship of the instrument to the wall stations.
- The main objective is to help mine surveyors understand the process of check surveys and show the importance of regularly performing high order controls surveys. While rendering the possible issues that can affect accuracy and quality when completing an underground check survey.

1.4 JUSTIFICATION

Mine surveying has been well-defined by the International Society of Mine Surveyors as “the art of making such field observations and measurements as are necessary to determine the positions, areas or volumes of natural and man-made features on the earth's surface” (International Society for Mine Surveying, 2011).

The environment of an underground mine in which the mine surveyor performs everyday tasks is regulated by accuracy requirements imposed by the country. The wellbeing of the mine and workers directly rely on the accuracy of survey network wall stations that controls the workings on the mine. A mine surveyor has daily responsibilities that need to be implemented to exacting limits of error. Some of the daily responsibilities of a mine surveyor comprise of staking out construction lines to control the direction and gradient of development drives. When there is deviation in the direction and gradient of construction lines in relation to the design it can lead to damage to infrastructure within the mine that causes problems such as re-development or altering designs which are expensive.

Permanent damage to the infrastructure of the mine can be caused by grading and directions having deviation from what was planned and designed. These deviations can potentially lead to altering the design of the mine that was originally intended or making amendments to the development which are both expensive outcomes. Consequently, it’s vital that the quality of the accuracy of primary survey network is in compliance with the standards of accuracy and the wall stations used to stake out information are in agreement to the mine’s design.

Correlation between surface and underground mine workings are only confirmed and verified when there is a breakthrough between levels or a check survey is completed. Where the check survey is completed to verify the original survey and strengthen the quality of the survey network used to set out mining operations.

1.5 CONCLUSION

The unforgiving environment of an underground mine make the performance of relatively simple tasks for a mine surveyor difficult. Underground surveying requires a high level of accuracy and care in everyday tasks. The difference between other branches of surveying and mine surveying is the mitigation of risks and the significances related to making mistakes prove to be fatal in a mine. As the wall stations are used every day for resections to determine the instruments position to stake out information, the primary control network must be verified. Errors in the wall stations means that there is errors in setting out information for production and development needs which can be fatal.

The check survey is an essential duty for a mine surveyor to maintain the integrity of the primary survey control of the mine. In conclusion, the objective of this dissertation is to complete a high order control survey and assess the least squared adjustment. The adjustment will be analysed and variables will be assessed to portray the effects on the accuracy of the adjustment.

2. Chapter 2: Literature Review

2.1 Introduction

The objective of this chapter is to provide information in relation to control networks and demonstrate relationships with literature. This will be achieved by identifying methods and data with their limitations and making comments on the relevance to this research project. The literature review will provide a reliable and traceable base and will show relationships links with other literature.

2.2 Standards and Practices for Control Surveys (SP1) v2.1; ICSM

The Mine Surveyor have "in recent times been forced to adapt to a role that sees them ensuring that the core business drivers of their employers are met, while at the same time ensuring that all work is performed in compliance with all the relevant Safety and Health and company Standards and Procedures" (Cawood & Richards, 2007).

To completely understand the significance of the standards in place a summary of the important factors will be discussed. Bannister stated that "understanding the minimum standards of accuracy that limit the accuracy of the measurement techniques is but one step to ensuring specifications are achieved".

SP1 explains and analyses a broad variety of surveying operations and is deliberated as an inclusive guide to the procedures and practices for spatial science. SP1 was established by the Intergovernmental Committee on Surveying and Mapping (ICSM) and is continually referenced by surveyors to follow the correct guidelines and standards. A few topics the SP1 covers involves: survey and reduction practical guides, suggested marking practices, accuracy standards and expectations and suggested practices for the documentation process.

The key concept taken out of the SP1 is that the quality of all underground surveys must comply with Class D of the survey standards. This also agrees with Guidance Note QGN19 - Mine surveying and drafting published in 2011 as it states each control network underground when feasible should have a close which is in compliance with the standards of accuracy as stated in ICSM, SP1 Class D. Adjustment by the method of least squares is demanded by these standards; producing the necessary statistics to carry out the evaluation also requires the use of this technique (Grocock, 2014). The document is critically imperative as it states the class needed to be achieved in the traverse and it provides a basis of professional practice.

The first chapter that is relevant to this dissertation is Part A – Standards of Accuracy SP1 v2.1. The success of the underground traverse relies on agreeance with the SP1 in regards to class and order. Part A uses the standard confidence interval as the standard for statistical analysis which is used to determine the class and order. Class has a purpose of intended and achieved precision of a survey network. The SP1 defines class as:

> *"CLASS is a function of the precision of a survey network, reflecting the precision of observations as well as suitability of network design, survey methods, instruments and reduction techniques used in that survey. Preferably the CLASS is verified by an analysis of the minimally constrained least squares adjustment of the network."*
>
> (Inter-governmental Committee on Surveying and Mapping (SP1) v1.7, 2007)

As SP1 has verified, class is dependent on: the design of the survey network, the survey equipment and the reduction methods which are adopted. Class is generally "proven by the results of a successful, minimally constrained least squares network adjustment computed on the ellipsoid associated with the datum on which the observations were acquired" (Inter-governmental Committee on Surveying and Mapping (SP1) v1.7, 2007). This is generally attained by evaluating the semi-major axis of each standard error ellipse.

The semi-major ellipse is to be less than or equal to (<=) the maximum allowable semi-major axis length using the equation explained in SP1:

$$r = c\ (\ d + 0.2\ )$$

Where:

r = length of maximum allowable semi-major axis in mm.

c = an empirically derived factor represented by historically accepted precision for a particular standard of survey.

d = distance to any station in km.

(Inter-governmental Committee on Surveying and Mapping (SP1) v1.7, 2007)

The values of c assigned to various CLASSES of survey are shown in Table 2-1 below from SP1.

Table 2-1 Classification of Horizontal Control Survey (Inter-governmental Committee on Surveying and Mapping (SP1) v1.7, 2007)

CLASS	**C** (for one sigma)	**Typical applications**
3A	1	Special high precision surveys
2A	3	High precision National geodetic surveys
A	7.5	National and State geodetic surveys
B	15	Densification of geodetic survey
C	30	Survey coordination projects
D	50	Lower CLASS projects
E	100	Lower CLASS projects

It is noted that for a Class D survey which is relevant to any underground survey, the c value used is 50. By using the equation r = c (d + 0.2) for a class "D" survey for a comparative distance of 100 metres the length of allowable semi-major axis is determined as 0.015 metres.

Part B of the SP1 standards are a guide on how to correctly perform surveys to a minimally acceptable practice required to meet the requirements of a certain class and order. This chapter of the standards considers calibration of Electronic Distance Meter (EDM). "All ancillary equipment should be regularly calibrated, carry unique identifiers, and (where relevant) be regularly compared against each other" (Inter-governmental Committee on Surveying and Mapping (SP1) v1.7, 2007). The "frequency standard should be traceable to the national standard, and calibrated once per year (Inter-governmental Committee on Surveying and Mapping (SP1) v1.7, 2007).

When performing an underground control network survey it is expected to comply with class "D" standards. The table below outlines the requirements for horizontal angular measurement. Class "D" observation requirements state 1 set, 4 rounds of angles. This research project will utilise 1 set, 6 rounds to warrant that the suitable level of precision is attained. By adding more rounds into the research project it will ensure the survey complies within the standards and increase the redundancy of the survey network.

Table 2-2 Horizontal Angle Observation Requirements (Inter-governmental Committee on Surveying and Mapping (SP1) v1.7, 2007)

Any time except 1200-1500hrs (LMT)	Yes					
Any time, subject to checks	Yes	N/A	N/A			
2.Instrument Least Count Category Highest	0.2”	0.2”				
High	1”	1”	1”	1”		
Medium	6”	6”				
3.Horizontal Zero Settings Wild T3 (type)	Yes	Yes				
Wild T2 (type)	Yes	Yes	Yes	N/A	N/A	
Examples of Horizontal Circle Settings for six Zero Wild T3 (type) 00 00 05 30 02 15 60 00 25 90 02 35 120 00 45 150 02 55	Wild T2 (type) 00 00 10 30 11 50 60 03 30 90 15 10 120 05 50 150 18 30					
4.Sets A. Minimum number of sets	6*	*6	2	1	1	1
B. Number of rounds per set	6	6	6	6	4	2

“The following table should be used as a guide to achieve results commensurate with the CLASS of survey required” (Inter-governmental Committee on Surveying and Mapping (SP1) v1.7, 2007). It is noted that for class C and lower it is expected that the equipment (theodolite) will be 1” least count.

Table 2-3 Astronomical Azimuth Observation Requirement (Inter-governmental Committee on Surveying and Mapping (SP1) v1.7, 2007)

CLASS	**A**	**B**	**C (and lower)**
Std. Dev. (single arc)	0.4”	1.5”	Range 20”
Theodolite least count	0.1”	0.2”	1”
Method	σ Octantis	Hour Angle (E&W) Ex meridian altitude of a star (E&W)	Ex meridian altitude of Sun (E&W)
Timing	1.0 sec	1.0 sec	1.0 sec
Sets	4	2	1
Arcs	6 (2 nights)	6 (2 nights)	4
Striding Level	Yes	No	No
La Place Correction	Yes	No	No
Met. Corrections	Yes	Yes	No
Pointing Interval (time)	<2 minutes	<2 minutes	<2 minutes
Altitude Range	* ± 10°	± 10°	± 10°
Azimuth Range	* Meridian ± 20°	Meridian ± 20°	Meridian ± 20°
Close Circumpolar	Yes	Optional	Optional
Elongation	Yes	Optional	Optional
Hour Angle	--	Yes	Optional
Hour Angle (sun)	--	--	Yes
Extra Meridian Altitude (Star)	--	Yes	Yes
Extra Meridian Altitude (Sun)	--	--	Yes
Vertical Bubble Calibration	Wisconsin		Optional
Simultaneous Observations at both ends	Yes	Optional	Optional

For this research project, the check survey will have to meet the standards of a Class "D" primary survey network which is identified in SP1. In order for the check survey to be accepted and a means to verify the quality of original control it is essential that the survey standards are met.

2.3 WALL STATIONS IN METALLIFEROUS MINING

In an underground metalliferous mine, wall stations are strategically placed approximately 1.3-1.6 metres high from the floor along the side walls of the drive. A wall station is generally a standard circular prism which is attached to a specifically designed spigot which is inserted into a drilled hole which is approximately 12mm in diameter. The wall station is illustrated in Figure 2-1.

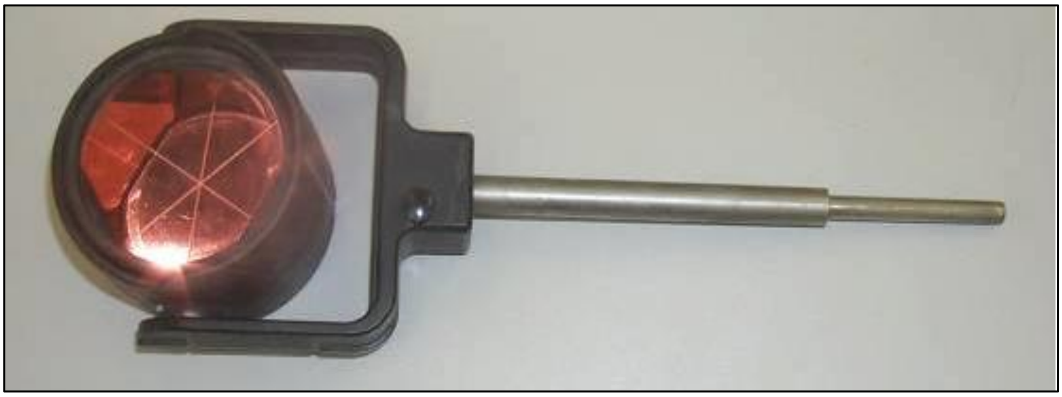

Figure 2-1 Wall Station Leica Circular Prism (McCormack, 2002)

A metal sleeve is inserted into the drilled hole which is secured by grout. Figure 2.12 illustrates how the aluminium tube should be placed into the side wall. With the grout setting correctly and securing the metal sleeve the spigot which is attached to the prism, can tightly slide into the sleeve. "The wall station sleeve is the physical "survey station" that is found underground" (McCormack, 2002).

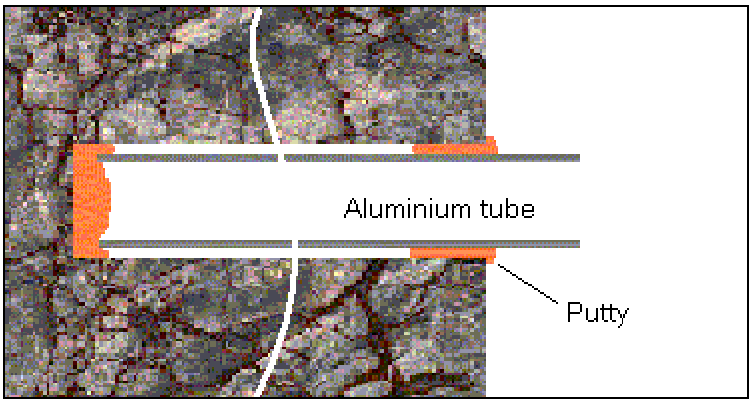

Figure 2-2 Aluminium Sleeve (McCormack, 2002)

Similar to conventional stations, the location and placement of wall stations directly impacts the accuracy of the wall station. According to Accuracy of Wall Stations Surveys by Smith and successively reinforced by McCormack in Wall Stations (Reference Points), the "accuracy of wall station surveys is dictated in part by the geometric relationship of the instrument station to the wall stations used for fixation" (Grocock, 2014). Smith compares the differences in error when performing a two and three wall station resection. The resection for both two point and three point had an arbitrary baseline of 25 metres and "six resection stations were established in varying relationships to the wall stations, each observing a forward station some 80 metres distant from the closer wall station." (Grocock, 2014).

TP	semi-major	semi-minor	Bearing sd"	Distance sd
1	2.2	0.9	20	2.4
2	1.7	1.2	13	2.4
3	1.6	1.5	12	2.4
4	2.2	0.9	20	2.4
5	1.6	0.7	13	2.4
6	3.4	1.6	33	2.3

Figure 2-3 Two Point Resection (Grocock, 2014)

TP	semi-major	semi-minor	Bearing sd"	Distance sd
1	1.0	0.7	7	2.4
2	1.4	0.6	8	2.4
3	1.4	0.7	8	2.4
4	0.9	0.7	7	2.4
5	1.2	0.7	7	2.4
6	1.3	0.7	8	2.4

Figure 2-4 Three Point Resection (Grocock, 2014)

When comparing the two tables it is evident that there is a significant progression in both semi-minor and semi-major axes of absolute error, this is the both station precision. There is also an improvement in the forward bearing precision when incorporating three points into the resection instead of two. With Smith's paper, an important relationship outlined is the accuracy of the forward bearing with the amount of prisms used in a resection. This dissertation will fill the gap of their papers and examine the propagation in errors over a larger network. By examining a larger network of wall stations the errors can be magnified and this will portray the importance of performing a check survey. No literature has been found that examines the check survey method only papers which examine impacts of the wall station resection.

The geometry of the existing wall station control relative to the station setup position of the total station is very important when carrying wall station control. The total station must be set up inside existing wall stations using two faced observations to coordinate the instrument position. The aim of this method is to generate a positional solution that is effectively "braced" within the existing control, hence balancing the errors associated with the total station measurements.

Importantly, this research will examine the check survey method for underground surveying which has yet to be reviewed. By reviewing the accuracy of the original wall stations to the "checked" wall stations this dissertation will show the importance and need for the check survey method.

2.4 Recent Changes in Underground Traversing Techniques in Western Australia – A.Jarosz & L.Shepherd

This paper covers a variety of aspects regarded to underground traversing and creating a control network which is pertinent to the data collection and analysis that will be conducted in the dissertation. Importantly, Jarosz and Shepherd's research is concerned with comparable themes as this research project therefore it should contribute a lot of valuable material.

The first section of this study refers to the two different types of underground traversing. The first method is classical surveying which means points are located in the roof and wall station traversing with points in the drive walls. This dissertation is more interested in the analysis of the wall station traversing method. The paragraph describing wall station traversing briefly describes the purpose and general methodology which is better described in Smith's literature.

This paper has common similarities and relationships with Smith's research with both papers analysing the changes in axes of the error ellipse of the forward azimuth. The paper has a baseline which is 0-1 and determines the points of 2, 3, 4 and 5. The instrument locations is calculated by observations to adjacent targets with known positions. Then, the subsequent wall station is calculated by distance and angle observations. This method is then repetitive to calculate the wall station's position. The first analysis was achieved for a configuration where the instrument was positioned 3 metres from the second wall station which was normal to the direction of the traverse. As expected, the parameters of the error ellipses semi-minor, semi-major and azimuth of major axis increased at the consecutive station which is a similar result proven by Smith.

Secondly, this paper by Jarosz and Shepherd acknowledges that the shape of the triangle used for the resection does effect the accuracy of the bearing transfer. The figure below illustrates the shape of the resected triangle.

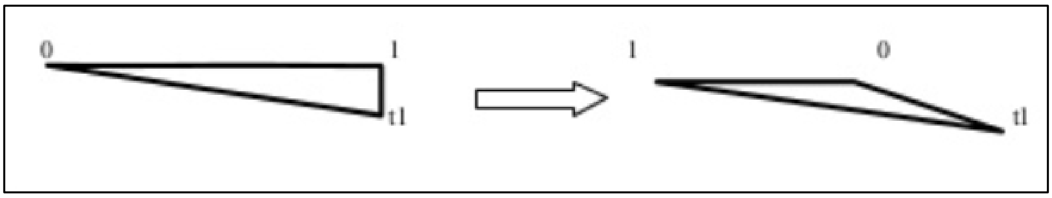

Figure 2-5 Replacement of Right Angled Triangles with Narrow Triangles (Shepherd & Jarosz, 2006)

Jarosz and Shepherd's review of wall stations method provides a good argument about the resected triangle shape. Proving that the parameters of the error ellipse increases when the triangle is narrowed. Meaning the geometry of the points in the survey has a paramount influence on the transferred direction and position accuracy. "Wall station traversing where acute geometry of resection angles cannot be maintained requires forced centring and additional observations between temporary instrument stations" (Shepherd & Jarosz, 2006).

Again, Jaroz and Shepherd's paper is concerned about the geometry of resection in wall station surveying. Even though the importance of the geometrical relationship between the wall stations and instrument is essential to maintain accuracy, this dissertation focuses on how errors in wall stations can propagate through wall station traversing. By analysing the check survey method it will show the importance of verifying the quality of the wall stations. When poor geometry and the number of points used in a resection are not adequate the errors in forwarding control and setting out information for the mine will not be correct. By resecting off wall stations that have not been verified mine surveyors can be magnifying errors throughout the mine. The greater the wall stations are from check survey control the greater the error will be propagated and can potentially cause fatal errors in production and development staking out.

2.5 LEAST SQUARES ADJUSTMENT

All adjustment methods are based on the assumption that all systematic errors and all mistakes have been removed from the observations. Thus they are designed to adjust Random Errors only that is those errors that remain after the correct equipment, methods and techniques have been used. An adjustment seeks to render a series of observed quantities consistent within themselves. Thus the same results, whether they are co-ordinates, heights, etc. are obtained no matter which adjusted observations are used.

Least squares adjustment is a processing methodology for the adjustment of surveys and an analysis. “This is particularly relevant to wall station control since poor geometry and other factors mean relatively small (less than 5mm) errors to control stations may cause major forward azimuth errors” (Grocock, 2014). The method incorporates all observations which increases the redundancy of the network and develops the quality creating positional precision in both horizontal and vertical axes which is in relation to the baseline.

Smith has elaborated on the meanings of positional and local uncertainties and shown the formulas for calculating positional and local uncertainty values. “Positional Uncertainty can be calculated using the Leenhouts formula and the semi major and semi minor axes of error ellipses which are given as a result of a least squares adjustment program based on the network input data provided.” (Roberts, Ozdemir, & McElroy, 2009). The formula below is Leenhouts formula to calculate uncertainty circle’s radius with a 95% confidence level using error ellipses:

$$C = b/a$$
$$K = q_0 + q_1 C + q_2 C^2 + q_3 C^3$$
$$\text{Radius} = aK$$

Where:

a = semi-major axis of the standard error ellipse
b = semi-minor axis of the standard error ellipse.
$q_0 = 1.960790$
$q_1 = 0.004071$
$q_2 = 0.114276$
$q_3 = 0.371625$

(Roberts, Ozdemir, & McElroy, 2009)

“Once the error ellipse in terms of the national geodetic datum is available, the radius of the 95% circle of uncertainty (Positional Uncertainty) can be easily calculated as shown in the formula” (Leenhouts, 1985).

Harvey's paper has elaborated on the methods to calculate a least squares solution for a survey network. Least squares adjusts random errors, however, doesn't correct systematic errors. Literature by Harvey (1993) and Roberts, Ozdemir, & McElroy (2009) may both thoroughly investigate least squares however do not consider potential systematic errors that can occur. In this dissertation the gaps from previous literature will be filled by emphasising the importance to calibrate instruments and check that prism constants are correct to ensure a reliable adjustment.

The instrument used will be in current calibration (less than 12 months since the previous EDM calibration) and will be in a clean state, free of dirt and grime. The prisms used will be specifically only used for control surveying and not used for normal operating surveying to ensure the prism constants are correct. The total station's atmospheric corrections will be set to zero and a Kestrel that has been calibrated against the Beaureau of Meteorologys instruments for temperature and pressure information will be used to obtain accurate pressure and temperature readings.

2.6 Conclusion

This chapter has described and substantiated the theories put forward by previous literature. The literature found in regards to wall station surveying focused on the resection method. Investigating the effect of the number of wall stations in the resection and the geometry of the resection. The literature concludes that major forward bearing azimuth issues can occur when poor resections are used as the norm. A theoretically analysis will be completed in this dissertation to depict the importance of redundancy in resections.

The papers do not analyse the effects of error propagation over a larger extent. As no literature was sourced that related to underground check surveys this research project will assess the check survey method and render the importance of the method in underground surveying.

The standards for control networks have been examined to outline the requirements that need to be met for the check survey.

3. CHAPTER 3: METHODOLOGY

3.1 INTRODUCTION

This chapter of the research project will outline and identify the planning and processes undertaken for methodology of the research project. By doing so, this chapter will provide a better comprehension of how the results were created and qualify an analysis to be directed on the results achieved in the underground control survey.

3.2 STUDY AREA

Mount Isa Mines is controlled by Glecore Xstrata Copper which is a section of its North Queensland Operations. Some of the tasks involve mining, processing and smelting processes in Mount Isa and just mining and processing at Cloncurry and then Townsville control refining and port operations.

Figure 3-1 Mount Isa, Queensland Map (Mount Isa Mines Rotary Rodeo, 2016)

At Mount Isa Copper Operations (MICO) there are two underground mines which are called X41 and Enterprise (ENT). The survey department at Mount Isa performs surveys in both X41 and Enterprise to meet the demands of production and development of the mine. In order for the surveying department to remain confident in their everyday work, checks need to be implemented which is why check surveys are completed.

3.3 IMPORTANCE

Traverse is a method in the field of surveying to determine a network of new points (Veres, 1999). Presently, the surveyors at Mount Isa are carrying control using the on board Leica "Free Station" program during underground surveying activities and a function on Surpac (processing software) for the post processing of data. This system enables the surveyor to survey in at least two existing wall stations and coordinate the total station "real time" for underground work. The post processing involves downloading the digital Leica file onto Surpac where a string file is created and a report written that details what control was used, any forward stations that were surveyed in and any points that were recorded during the survey. This system generally works well however relies on wall stations to be advanced correctly. With wall stations being used daily in resections it is expected that these wall stations are in the correct position. To verify the position of wall stations the underground check survey method will be completed.

3.4 WALL STATION SURVEYING

Wall stations need to be surveyed using a technique that ensures the best possible coordinated solution for the station setup is determined, and errors associated with the survey traverse are minimised as the survey is carried. As headings can extend a significant distance from the origin of the survey, any small deviation in the bearing or weakness in the calculated station position that is used to carry control will have a significant influence on the accuracy of the location of the mining at the end of the heading.

Figure 3-2 Wall Station Prism placed into Sleeve

Predominantly, underground survey works involve either establishing orientation off existing stations to enable the surveyor to set out required information for mining, or alternatively carrying wall station control to conduct a survey further into the development. Due to the nature of the ground conditions underground, movement of wall stations is common and it is essential that this is checked prior to carrying control further into the development.

The following techniques will be followed to allow the wall station control to remain reliable and accurate whilst mining headings.

- All wall stations are to be sleeved and grouted. A standard wall station sleeve is approximately 0.080m in length and has an internal tube diameter of 0.008m.
- All survey control stations must be carried “outwards” of the existing control. This means to carry control outwards from its origin rather than from “inwards” overlapping the area previously traversed when the control was extended. Error propagation is statistically more significant when control is traversed back on itself before being extended outwards.
- The geometry of the existing wall station control relative to the station setup position of the total station is very important when carrying wall station control. The total station must be set up inside a minimum of three existing wall stations using two faced observations to coordinate the instrument position. The aim of this method is to generate a positional solution that is effectively “braced” within the existing control, hence balancing the errors associated with the total station measurements. If the quality of the free station solution is not deemed acceptable, more wall stations need to be surveyed and analysis of the network solution investigated.

With a quality network solution established, forward wall stations can be carried with confidence. Forward stations are surveyed in two faces and should be staggered along both sides of the drive (subject to ground/wall conditions). Some examples of where wall stations should not be installed include:

- Within 5m of the corner of pillars/drive turnouts (where ground stress is likely to be great)
- On known slabby ground
- On walls that are directly exposed to the firing of the next face

3.5 FIXED STATIONS

As a general operating procedure, high order "check" surveys will follow up advancing capital development as a means to verify the quality of existing wall stations and provide accurate control to further advance into the mine. All surveyors will be responsible for the check surveys in their areas and these should be organised during a day when mining operations using large machinery are not being conducted in the survey area. As a rule, the working control should not advance more than ten "line of sight" setups from the existing high order survey network. The method of conducting check surveys differs from that of working control as all of the information recorded and documented, from the raw GSI file data to the final traverse report need to explain how the instrument was set up and the traverse was conducted during the survey.

For the check survey, the network is constrained by twelve fixed stations. A fixed station must be a wall station that has been verified by the check survey method previously. The (X, Y, Z) coordinates of the fixed wall station are known and are noted as check survey points in the mine's database. If the check survey was fixing on wall stations that have not been checked it would defeat the purpose of the check survey method.

3.6 CHECK SURVEY METHOD

As a general operating procedure, high order "check" surveys will follow up advancing capital development as a means to verify the quality of existing wall stations and provide accurate control to further advance into the mine. As a rule, the working control should not advance more than ten "line of sight" setups from the existing high order survey network.

Figure 3-3 Check Survey traversing up the Incline

The 'Sets of Angles' program on the Leica total station was used to conduct the survey traverse. The first instrument setup of a new section of traverse was a free station two setups back from the end of the existing network. The first set up was coordinated to verify that the existing control was correct and that the wall stations have not moved since they were last surveyed. The atmospheric corrections applied to EDM measurements must be set to 0ppm for the survey (corrections are applied during post processing).

Six sets of observations were taken to survey all visible survey stations, and any existing setups that are occupied during the survey. The connecting observations between the instrument station setups are critically important to maintaining the high order of the survey.

Check survey station naming conventions– the naming conventions for stations surveyed is to be as follows:

- Station setups are labelled as the date followed by A, B, C…. etc (for example 110716A for the first station setup done on July 11, 2016). This is to uniquely identify each free station setup as it is merged into the master check survey document and makes sorting of wall / back stations from free set up stations easier.

3.7 CHECK SURVEY PROCESSING

Post processing in CompNet – After setting up CompNet with the configuration with the correct path, the Instrument ID number, a new project is created for the processing of the check survey observations.

- Import the GSI file data, using individual observations and entering the instrument PPM and Constant corrections as calculated in the EDM calibration. Investigate and fix any errors that CompNet reports and then continue with adjustment.
- CompNet will automatically process the project if sufficient fixed stations are referenced to allow a solution to be calculated.
- All duplicate point numbers must be addressed.
- Re-import the GSI file and rerun the adjustment. Check the F-Test and Variance Number and whether the project passes or fails adjustment.
- When the project is optimized as best as can be determined, move the weighted coordinates to the fixed file.

3.8 EQUIPMENT CHECKS

Prior to commencing the field work at Mount Isa underground mine, survey equipment should be checked to ensure that it is functioning as it is designed to, and that it is in good operating condition. This may contain but not be restricted to the following equipment.

3.8.1 TOTAL STATION

The instrument used to complete the check survey needed to have adequate instrument settings to ensure the accuracy of the network. The settings of the instrument directly affect the EDM observations in the check survey. The 'Check and adjust' calibration should be conducted prior to the check survey. Section 5 of the Leica MS50 User Manual explains the method used to complete the "Check and Adjust" on the Leica Instrument. Prior to conducting the calibration, the log file should be switched on and a minimum of three sets of observations is carried out to identify the c, a, l, t, i and ATR Collimation errors. If any of the numbers have changed by greater than 15 seconds from the instruments last check and adjust, this should be brought to the attention.

An EDM Calibration should be completed within a year of completing the check survey to ensure the accuracy of the instrument. In Appendix B, a reference to the latest EDM Calibration is made.

The total station should be in a clean state, free of dirt and grime, be in calibration and be set to run atmospheric corrections of zero parts per million. A Leica user manual states: "Distance measurement is influenced directly by the atmospheric conditions of the air in which the measurements are taken. In order to take these influences into consideration distance measurements are corrected using atmospheric correction parameters" (Leica Heerbrugg, 2009).

The atmospheric corrections applied to EDM measurements must be set to 0ppm for the survey (corrections are applied during post processing). The instrument was checked to be sure the correct adjustments for the work site were correct especially EDM calibration, Scale Factor, PPM settings.

3.8.2 WALL STATION PRISMS

The Wall Stations used underground are a Leica Circular Prism with a specially designed spigot attached. Before the survey, these should be checked to ensure that the prism will rotate firmly but freely about the spigot and prism holder.

The wall station prisms used for the check survey were checked to ensure the prism constants were the same as the instruments specifications. The prism itself must be locked securely inside the prism holder. This was tested by gently pressing the prism to see if it moves inside the prism holder. The spigot was also examined to check to make sure it was straight. When sliding prisms into the sidewall it is essential to check and verify that the spigot of the wall station prism is hard up against the sidewall rock. A drill was used on a number of occasions to clean the interior of the metal sleeve so the spigot is hard up against the wall.

When working in an underground mine there is variation in temperatures and pressures compared to above ground surveys. Due to the impact the instrument settings can have on observations raw measurements were taken underground and all corrections were changed in the processing stage. By recording pressure and temperature readings at every set up errors were eliminated.

3.8.3 TRIPOD

Before use, tripods were checked to ensure that all hinges, joints and locking mechanisms were functioning as designed. The tripod was checked for stability once set up by applying a downwards pressure to the tribrach plate.

3.8.4 KESTREL

Kestrel that has been calibrated against the Bureau of Meteorology's instruments for temperature and pressure information. Calibration must be completed within a year of check survey. In the below figure it portrays the calibrations differences. In Appendix C, it shows the latest calibration of the Kestrel.

3.8.4.1 BAROMETRIC PRESSURE

At MICO the air pressure is controlled by ventilation fans and managed by barricades and doors. Variations in the air pressure are not considered in daily survey procedures. With the check survey pressure readings were recorded at every station set up to ensure accuracy and quality. It is important to let the Kestrel climatise to the underground environment meaning readings were recorded half way through the sets of angles. The Kestrel used was calibrated within a year of the survey to verify the accuracy of readings.

3.8.4.2 TEMPERATURE

Fluctuations in the temperature within in underground mine is expected. When performing the check survey Kestrel readings were taken at the start, middle and end of each station set up. An average temperature was determined for each different set up to eliminate atmospheric errors.

3.9 SCOPE & LIMITATIONS

Data will be collected at MICO underground mine to verify the control stations in X41 around 15 level. The site map of the information needed for the check survey is attached as Appendix D.

Field work will be completed using Leica "Sets of Angles" on a Leica MS50 1" total station. The underground traverse will be in compliance with the requirements of ICSM SP1 v1.7 (Class D).

A 3D linear misclose assessment will be carried out which will examine consideration of any rotational issues. This adjustment will be completed with CompNet v2.9 which has the advantage of comparing parameters against the requirements of Class D of ICSM SP1.

A Kestrel 4000 Pocket Weather Tracker was used to collect atmospheric temperatures and pressures at each station set up to accurately edit the raw data collected.

3.10 CONCLUSION

In conclusion, the above sections outline in detail the methodology for the check survey within this project. In a larger mine, it is important to plan and understand the processes of the check survey prior to the field work. Problems are encountered that alter original plans while underground. Problems encountered must be overcome or minimise to optimise the check survey procedure. The methodology was followed closely in the field work to ensure eliminate any potential errors. By not following the correct procedures in the field it can lead to major problems in the processing phase. In an underground mine, mine surveyors should remain cautious due to the factors of heat stress that can potentially influence the decision making process of the surveyor.

The chapter provides a description of the procedures taken to ensure that the survey was completed correctly and in compliance with class "D" standards.

4. Chapter 4 – Results

4.1 Introduction

This chapter discusses the results produced from the least squares adjustment. Least squares is a common processing procedure for analysis and adjustment of survey data. The check survey has combined fixed stations at the start of the survey which aim to brace the survey network.

The software incorporated the sets of angles traversing data to generate least squares solutions of the rigorous network adjustment. The adjustment software CompNet was used to create output files which provide statistical information of the check survey. For the least squares adjustment to pass the adjustment it is evaluated statistically to assess the adjustments quality.

4.2 Summary of Survey

The field work for the check survey was completed over three full days to collect the desired data for adjustment. The check survey traverse consisted of:

- 62 wall stations
- 12 fixed stations (outlined in red at the start of the survey)
- 39 set ups (to the end and back to the start)
- 900 metres to the end and 900 metres back to start.
    - The check survey traverse is a closed traverse but it is not closing back onto itself it is closing back onto a different fixed control station.

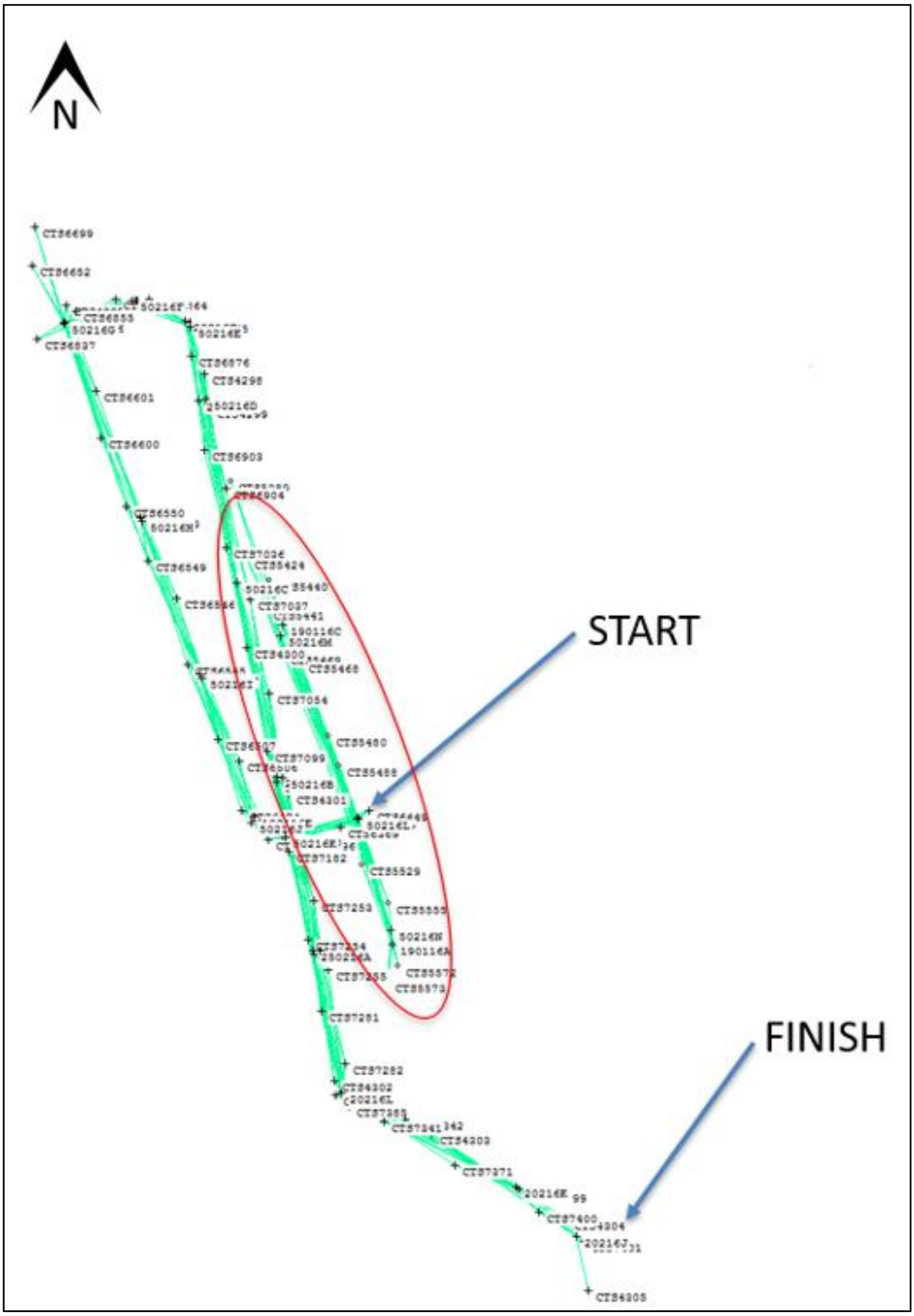

Figure 4-1 Survey Network in CompNet

The objective of a least squares survey adjustment is eliminate mistakes from the collected data and compute the best fit of the adjustment. After performing the least squares adjustment the solution of the survey stations need to be evaluated and assessed. CompNet software has the ability to summarise the adjustment and provide the user with the most important information.

NUMBER OF TAGGED RESIDUALS: 174

Maximum offset at vertical angle 148, offset 0.0082

MAXIMUM STANDARDISED RESIDUALS

Direction line 125: 2.70

Vertical angle line 148: 7.86

Slope distance line 2270: 2.95

ESTIMATE OF VARIANCE FACTOR: 1.01

F TEST AT 95% CONFIDENCE LEVEL, 1.17, 6706 DEGREES OF FREEDOM

ADJUSTMENT PASSES

Figure 4-2 CompNet Adjustment Measures

In comparison with the new checked survey wall stations and the original wall stations there was little deviation. The difference in the X, Y, Z coordinates were observed and all axis had small difference. The greatest difference was in the Z axis which was a difference of 30mm. The area of the mine that was checked had limited mining activity over the years which is assumed to have limited movement in the wall stations. Mount Isa mine surveyor’s ensure to incorporate an adequate positional fix for their resection when forwarding new control which will be discussed further.

4.3 Reliability of Measurements

The reliability of surveying observations is commonly categorised into three terms:

- Precision
- Accuracy
- Uncertainty

4.3.1 Precision

Precision is the degree of closeness and consistency of a set of observations in surveying terms. When analysing the observations the variance and standard deviation expresses the precision if the statistical information is reliable and unbiased.

When the variance of the observations is small it means the measurements are clustered and confined to the mean which produces a tall and thin normal curve. However, when the variance of the observations is large it means the set of observations has low precision and are spread about the mean which produces a flat and low normal curve.

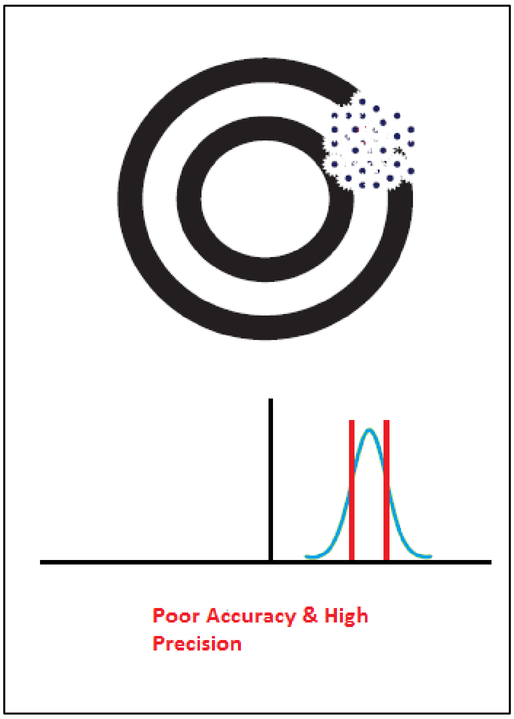

Figure 4-3 High Precision & Low Accuracy

If several measurements are taken repeatedly to represent the same quantity, precision is used to refer to the degree of closeness or conformity of those measurements to each other" (Inter-governmental Committee on Surveying and Mapping (SP1) v2.1, 2014). In the figure above, the observations represent high precision and low accuracy. High precision makes a narrow normal distribution curve as seen in the above figure.

4.3.2 Accuracy

Accuracy is the amount of closeness of a measurement to the true value. The true value is theoretically never known. The accuracy not only contains the influence of random errors, but also any bias due to systematic errors which have not been corrected.

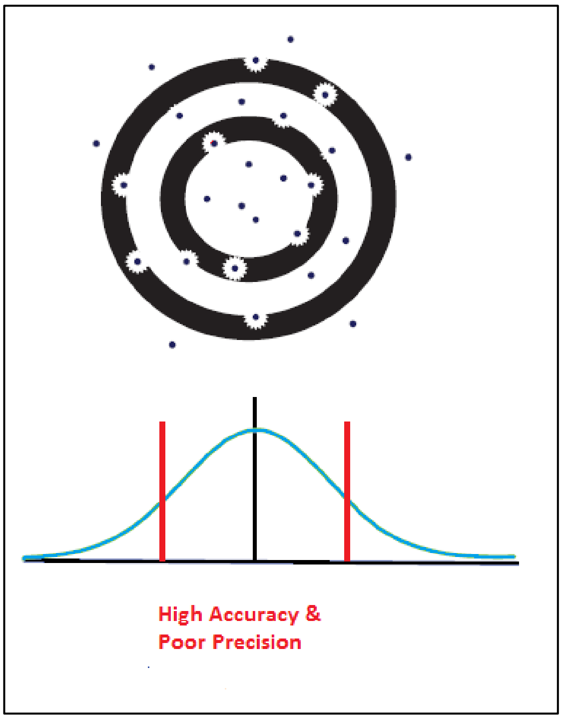

Figure 4-4 High Accuracy & Low Precision

In the figure above, it portrays high accuracy and low precision which gives a flattened normal distribution curve.

4.3.3 Uncertainty

Uncertainty is the extent within which it is projected the error of an observation will lie. A specific level of probability is commonly related to the uncertainty of observations. In this research project 95% uncertainty is the range within which it is 95% likelihood that the error of measurement will lie. According to ICSM SP1 v2.1 uncertainty is "an indication of how wrong a value may be and is used in this Standard to quantify the level of survey quality." The ICSM Standards categorise three types of uncertainty which include:

- Positional Uncertainty (PU)
- Relative Uncertainty (RU)
- Survey Uncertainty (SU)

4.3.3.1 POSITIONAL UNCERTAINTY (PU)

Positional uncertainty is defined by ICSM SP1 v2.1 as "the uncertainty of the horizontal and/or vertical coordinates of a survey control mark with respect to datum."

4.3.3.2 RELATIVE UNCERTAINTY (RU)

Relative uncertainty is defined by ICSM SP1 v2.1 as "the uncertainty between the horizontal and/or vertical coordinates of any two survey control marks. For this dissertation relative uncertainty of ellipses will be assessed at 95% confidence interval.

4.3.3.3 SURVEY UNCERTAINTY (SU)

Survey uncertainty is "the uncertainty of the horizontal and/or vertical coordinates of a survey control mark independent of datum. That is, the uncertainty of a coordinate relative to the survey in which it was observed, without the contribution of the uncertainty in the underlying datum realisation" (Inter-governmental Committee on Surveying and Mapping (SP1) v2.1, 2014).

4.4 TRAVERSING

Traversing is a surveying procedure performed to establish a control network. There is two main types of surveying, an open traverse and a closed traverse.

4.4.1 OPEN TRAVERSE

Open traversing is generally the more common used method of surveying when it comes to underground mining. "Traverses that do not close back on their starting point or on other known points are said to be "open," meaning that there is no automatic check on the validity of the work."(Bernard, Solomon & Britton, 1992).

An open traverse geometric close in the survey and there needs to be verification on the field work. Open traverses are used on a daily basis at MICO and the check survey process is a method of verifying the traverses.

4.4.2 Closed Traverse

A closed traverse is a traverse that is commenced on one point and finishes on one point which forms a polygon. This method of traversing is preferred as it gives a means of check because the start at end point of the traverse is fixed. For the purpose of this research project the survey network was closed by traversing to the end of drive and then traversing all the way back to the starting point. The check survey traverse is a closed traverse but it is not closing back onto itself it is closing back onto a different fixed control station. Errors in traversing can be somewhat balanced by methods of adjustment such as the Least Squares method.

4.5 Least Squares Adjustment (CompNet)

All types of adjustments are based on the assumption that all systematic and gross errors in the survey have been removed. Adjustments are designed to only adjust random errors which is errors that persist after the correct procedure, technique and equipment have been implemented.

The Least Squares method produces the best adjustment by altering the observations by the least possible quantity. All observations will be adjusted simultaneously when using the Least Squares. Essentially the aim of the adjustment is to minimise the sum of the squares of the residuals.

4.5.1 Iteration

Non-linear least squares is known as an iteration. Each iteration new values for the coordinates are incorporated for each iteration, where each set of values are the Most

Probable Values (MPV) resultant from the preceding calculation. Commonly when the input data has no gross errors the solution will converge in a few iterations.

4.5.2 Adjustment Redundancies

The adjustment redundancies is also known as the degrees of freedom (f) of the survey network. The entire number of observations in the survey network define the amount of equations that need to be solved by the least squares adjustment. This means that the data of directions, vertical angles and slope distances all alter the equations for the adjustment.

In a model there is (m) unknown variables which means there will have to be (m) independent observations to adequately determine these parameters. If (r_i) observations were made to estimate (m) variables and $(n > m)$ then the redundancies or degrees of freedom (f) is $(n - m)$. The redundancy of the network is equal to the amount of observations subtract the amount of unknowns. The process of the least squares adjustment allows the estimation of the (m) variables when there is (f) redundant observations obtainable. Repeated observations which are measured to estimate an unknown variable the additional observations are redundant. By increasing the redundancy in the survey network the confidence of the adjustment is increased.

4.5.3 Most Probable Value

The Most Probable Value (MPV) is the value with the highest occurrence determined from a set of observations. Theoretically, the true value cannot be determined therefore the most probable value is used. The MPV can be defined as:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

The MPV is the mean if the observations have the same precision.

4.5.4 RESIDUALS

Simply, the residual is the difference between what was observed and the value that best fits into the adjustment. The residual is determined from the Most Probable Value (MPV) where:

$$r_i = \bar{x} - x_i$$

It is important to understand that in theory there is a difference between error and residual. An error can be represented as:

$$\Delta_i = x_i - \hat{x}$$

4.5.5 STANDARD DEVIATIONS

The standard deviation (σ) of a population is a measure of closeness of individual measurements. The sample standard deviation of a sample is defined by (s) and is the square root of the sample variance.

The standard deviation in theory is represented with true errors:

$$\sigma = \pm\sqrt{\frac{\sum (x_i - \hat{x})^2}{n}}$$

When $\hat{x}$ in theory is the 'true value' and $x_i - \hat{x}$ represents the 'true error'.

The sample variance is defined as:

$$s^2 = \frac{\sum (x - x_i)^2}{n-1}$$

Where the standard deviation used for a set of sample is:

$$s = \pm\sqrt{s^2} \qquad = \pm\sqrt{\frac{\sum \bar{x} - x_i)^2}{n-1}}$$

There is a difference between a standard deviation of an observation to a mean of a set.

$$\sigma = \pm\sqrt{\frac{\sum(x_i - \widehat{x})^2}{n}}$$ Where $x_i - \widehat{x}$ is the error.

$$s = \pm\sqrt{\frac{\sum(\bar{x} - x_i)^2}{n-1}}$$ Where $\bar{x} - x_i$ is the residual.

Essentially, a smaller standard deviation will portrays a more accurate position whereas a larger standard deviation will indicate a less accurate position.

The research project considers a derived Root Mean Square (RMS) deviation which is a weighted deviation that takes into account the estimated predicted errors in the survey. The predicted errors entered into CompNet were obtained from instrument specifications and calibrations.

4.5.6 STANDARDISED RESIDUALS

The residuals are standardised so that it is clear to detect errors in the survey network. The standardised residual is determined by dividing the residual by its standard error value (the input standard deviation for the appropriate observation). It portrays how much the point has differed from the mean value. The standardised residuals are a superior way to identify poor observations, for this research project 3 σ was the limitation used.

Ideally, the standardised residual should be close to one and in this research project will examine standardised residuals (>3 σ) for mistakes. This is based on the assumption that if an observation is greater than $\pm 3\sigma$ from the mean it may be an error. The 3 σ rule of thumb is that it is a 99.7% probability of fallen in the range of 3 σ.

4.6 INTEGRITY TESTS

Chi-square and Fisher distribution are implemented to assess the confidence level of the variance. By applying these tests we can analyse the accuracy of the network and the adjustment. If the tests do not fall within this range then it fails the test which specifies that the adjustment is not satisfactory.

4.6.1 CHI-SQUARE TEST

The Chi-square test is intended to accept or reject the hypothesis that the predicted errors have been accurately estimated. A probability percentage is calculated which is the level of significance for the adjusted network and if this is less than 95%, the reference factor will not pass the test.

The Chi-square test is made by comparing a χ^2 value calculated from the observations, with that obtained from tables for the desired confidence level.

The statistical value χ^2 (chi-square) is defined as:

$$\chi^2 = \frac{\sum r^2}{\sigma^2}$$

Where,

$\sum r^2$ = the sum of the squares of the residuals resultant from an adjustment,

σ^2 = the variance, or square of the standard deviation of the population.

Now as, $s = \sqrt{\frac{\sum r^2}{n-1}}$

Rearranged to, $\sum r^2 = (n-1)s^2$

Where,

s is the standard deviation of the observations and n is the number of observations.

Then we can say, $(n-1) = f$ which the degree of freedom is

Therefore,

$$\chi^2 = \frac{fs^2}{\sigma^2}$$

A two-sided Chi-Square test at 5% significance level is performed on the adjustment to determine if the residuals are potentially due to random errors.

The chi square range is calculated to test if the variance factor s_0^2 lies within the allowable range.

$$\frac{fs^2}{\chi^2_{\frac{\alpha}{2},f}} < s_0^2 < \frac{fs^2}{\chi^2_{1-\frac{\alpha}{2},f}}$$

Where,

α is the significance level.

If s_0^2 is out of the range the test will fail.

This research project has incorporated a significance level of 5% meaning that the two sided Chi-Squared test will determine if a particular α^2 value is within the 95% area of all α^2 values. If it does the test will pass if does not and falls into the remaining lower and upper 2.5% areas then the test will fail. When this test fails it is assumed that it is caused by non-random errors. This statistic test in essence considers the quality of fit that the adjustment has made. It is important to realise that the Chi-Squared test is not an absolute test of the accuracy of the observations in the survey.

4.6.2 FISHER TEST

The Fisher test for surveying applications is defined as:

$$\frac{s^2}{\sigma^2} < F_{0.05,f,\infty}$$

Where, (f) represents the number of redundancies of observations which the sample variance (s^2) is calculated. The infinity symbol represents the degrees of freedom of the normal distribution population with variance (σ^2). It is important to understand the population that is sampled from is infinite.

4.7 CONCLUSION

The traverse and adjustment of the survey network were discussed in detail. Least squares is a common processing procedure for analysis and adjustment of survey data. The results outputted by CompNet have been explained and basic statistics were described to give meaning to the results attained.

The least squares adjustment process consists of complex mathematical formulae and are difficult for the profession of surveying to assess their results. However, statistical information can clearly depict the results of the quality of the network and adjustment. Analysis of the results obtained in the least squares adjustment will be assessed in the next chapter.

5. CHAPTER 5 – DISCUSSION

5.1 INTRODUCTION

In this chapter, the results obtained in the previous chapter will be analytically discussed. The theory of errors, effects of external factors in relation to underground mining, global precisions, instrument settings, and the results will be outlined and discussed in detail. Statistical behaviour will be analysed to thoroughly understand the check survey.

5.2 THEORY OF ERRORS

Reliable observations is a significant importance of the profession of surveying. There is no such thing as an observation with no error all observations will have errors.

Errors in observations can inherent from many different causes and should be reduced or overcome. There are generally three types of errors that surveyors are concerned with:

- Systematic
- Random
- Gross/ Mistakes

Least squares adjustment does not eliminate bad observations which means quality observations are important.

5.2.1 SYSTEMATIC ERRORS

A systematic error is an observed value follows some degree of physical law which can be portrayed in a mathematical formula. Systematic errors should be considered and removed as the adjustment require the complete absence of these errors. When these errors have a substantial magnitude, it will distort the adjustment producing incorrect and biased adjusted coordinates.

Systematic errors can include:

- Natural errors

    - Temperature, refraction, slope, sag, tension
- Instrumental errors
    - Adjustments comparative to the total station
    - Systematic positioning of an automatic compensator in an automatic level
- Periodic errors
    - Diurnal Refraction
    - Electronic Distance Measurement (EDM) cyclic errors

Systematic errors are more commonly caused by field procedures and the instrument used. It is important to realise the least squares adjustment will adjust random errors but will not adjust systematic errors.

To reduce the systematic errors observation procedures were consistently followed. Calibrations of the Leica MS 50 (1” instrument) and Kestrel 4000 Pocket Weather Tracker were completed within a year of the survey to ensure reliability of observations. By recording raw observations and applying atmospheric corrections of EDM such as temperatures and pressures at each station set up helped to eliminate systematic errors. Wall stations used for the check survey are only used for check surveys to ensure that prism constant used are reliable.

Statistical testing of the observations in the survey can aid in representing the presence of systematic errors in the survey. The adjustment passed statistical based tests meaning the survey achieved its desired accuracy.

5.2.2 RANDOM ERRORS

Surveyors aim to ascertain the best possible and most accurate observations in the field. However, inconsistencies in observations may occur in sets of observations. Random errors do not follow any degree of physical laws which means they must be handle by incorporating mathematical laws of probability. The least squares adjustments eliminates random errors by estimating predicted errors which are expected to be measured.

Depending on the circumstances random errors can be controlled but in other circumstances a set of observations may inherent these random errors.

5.2.3 Gross Errors

Gross errors is any blunders caused from the field techniques in the survey. The survey has sufficient checks throughout and no gross errors should be present.

5.3 Effects of External Factors

In an underground mine surveyors are confronted with extreme environmental conditions of heat, noise, poor visibility and risk. It is important that the check survey be performed with speed and accuracy, meaning the surveyor is expected to plan ahead and foresee problems before they transpire. "Underground measurements always take place under tough conditions,…, permanent time pressure, unfavourable conditions (visibility, light, noise, temperature, humidity, ventilation, traffic...and safety-related constraints…" (Haag & Stengele, 1997).

5.3.1 Illumination

When working in an underground mine artificial lighting is incorporated to be able to view and observe survey wall stations. "Artificial light is necessary in order to illuminate the point of sight and the cross hairs. Such light is generally very poor, and this fact greatly hampers work with the instrument." (Young, 2012). Problems with lack of natural light can effect the accuracy of sighting and recognizing wall stations. Problems with illumionation and wall station sighting can lead to gross errors through the survey.

5.3.2 Refraction

Refraction of light rays out of the vertical plane is due to presence of layers and currents of air at different temperatures and pressures along the line of sight. "Lateral refraction is the biggest source of systematic error that can be encountered in underground surveys. Every effort should be made to avoid its effect. …" (Fowler, 2006).

In underground surveying refraction is produced when the temperature is changing from the air and the temperature of the surrounding rocks. Refractions relates to the density of air and when the density is not constant line of sight to a wall station will not be straight.

Refraction is not the same as shimmer in observations. When there is errors caused by shimmering the error is commonly cancelled out by increasing observations. When six sets of angles is more than sufficient to eliminate the error of shimmer.

5.3.3 GROUND CONDITIONS

Poor conditions of the floor of the drive can lead to problems with the setup of the total stations and fore and back sights. Tripods were set up correctly following standard procedures to minimise the potential movement of the tripod. When blasting and firing of the ore occurs it can directly impact the wall station’s stability and stations can be destroyed or damaged. When the surrounding rock is damaged and unstable it can result in movement of the survey wall stations.

5.3.4 MECHANICAL

When setting up the total stations and fore and back sights ideally the centre of the drive is desired. At the start and end of the check survey “Surveyor’s at Work” signs were displayed along the drives to warn ongoing traffic. Heavy machinery did pass by the vicinity of the survey on a few occasions. Using cap lamps signals, hand signals and radios to slow the machinery’s speed down was a way to minimise the effect on the set ups.

5.3.5 VENTILATION

The flows of ventilation in the mine’s drives can impact the centring of the total station and fore sight and back sight set ups. The survey was over a large distance and variations in the ventilations occurred when the survey got nearer to air ventilators. To minimise any centring errors ventilation was turned off in some scenarios.

5.4 GLOBAL PRECISIONS (PREDICTED ERRORS)

Predicted errors are expected observational errors that may be achieved based on the field procedures followed and the quality of the instrument and equipment used. It is an approximation of the standard deviation of observations. By increasing the predicted errors it specifies that the observations taken aren’t as accurate.

5.4.1 PREDICTED ERROR CONSTANTS

Horizontal and vertical pointing is an angular error which is in seconds. It is an estimate of the error attached to the total station pointing to the target. This error is influenced by the atmospheric errors, the optics of the instrument and if the instrument has been taken care of. In humid environments such as an underground mine the pointing error is increased to account for heat waves. As the Leica total station used had Automatic Target Recognition (ATR) turned on for the pointing error shall be increased as greater accuracy is achieved by manual sighting techniques.

Horizontal and vertical reading constant errors in the angular reading errors which is related to the theodolites reading precision. For the survey the Leica MS 50 one second instrument was used.

The distance constant and distance Parts per Million (PPM) is obtained from the EDM variables determined when the calibration was completed on the total station.

Instrument plumbing standard error relates to the centring of the instrument. The amount of error will be increased as centring of the instrument is expected to have some error when setting up in an underground environment.

5.5 STATISTICAL ANALYSIS

Statistical analysis will examine the behavioural characteristics of the observations. The least squares adjustment process consists of complex mathematical formulae and are difficult for the profession of surveying to assess their results. However, statistical information can clearly depict the results of the quality of the network and adjustment.

5.5.1 SLOPE DISTANCES

To form the normal equations directions, vertical angles and slope distances were used. The slope distances had the lowest maximum standardised residuals. Using a Lecia MS50 total station the results obtained from the EDM was expected to be under standardised residual of 3 σ.

By observing the graph below it is evident that none of the standardised residuals exceeded the limitation of 3 σ. When a standardised residual exceeds 3 σ it is expected to be an error. The 3 σ rule of thumb is that it is a 99.7% probability of fallen in the range of 3 σ.

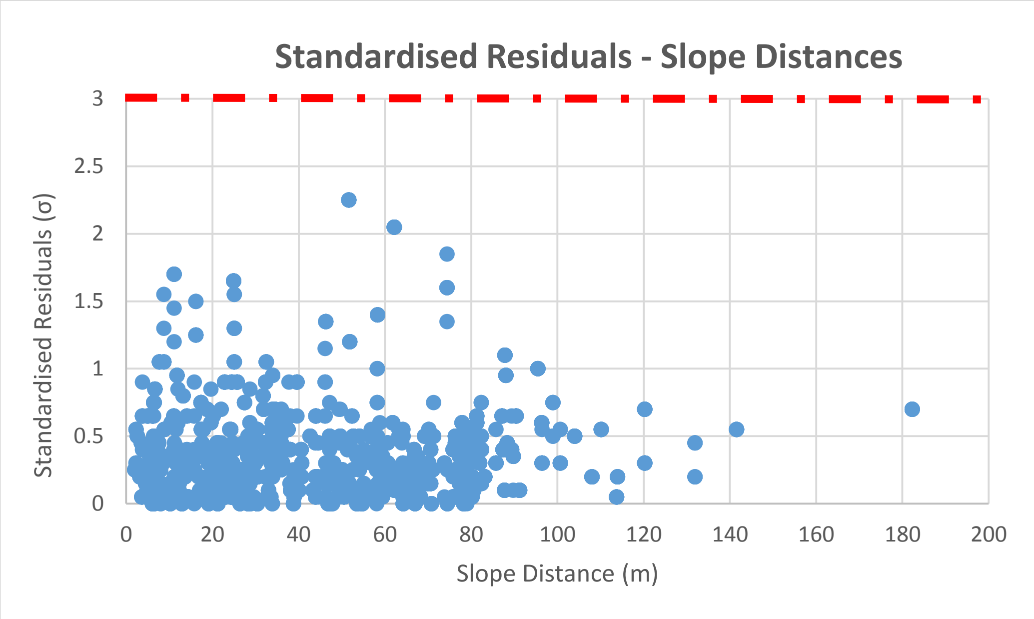

Figure 5-1 Standardised Residuals – Slope Distances

Shorter and longer observations were included in the check survey for purposes of the research project. The predicted errors that are applied to the adjustment will have greater influence on a shorter distance in comparison to a longer distance. For example a 1" predicted pointing error will influence a 2 metre observation greater than a 100m observation.

The standardised residuals are used to easily interpret the data. When the standard deviation of the slope distances is analysed it is seen there is little to no deviation from the mean with all measurements being the same. When plotted on a normal distribution curve the measurements specify that the slope distance measurements are precise and depict no or very little deviation from the mean.

The linking observations between the instrument station set up and the forward and back sights on tripods are critically important to retaining the high order of the survey. For example it was observed that a combination of a short backsight and a long foresight is a combination that produces higher angular uncertainty.

Precision is the degree of closeness and consistency of a set of observations in surveying terms. The observations for distance represents high precision. To assess the accuracy of the results for slope distances standard deviations were derived from a combination of Root Mean Square (RMS). The derived RMS deviation takes into account global precisions for the instrument used in the check survey. The global precisions include: pointing, plumbing, constants and parts per million (PPM) which are obtained from the instruments specifications. The derivation of RMS deviation measures the difference between the best fit of the adjustment and what was observed. The combination of the RMS deviation aims to total the extents of the errors in predictions for the set of measurements into a single measure of prediction power for each measurement.

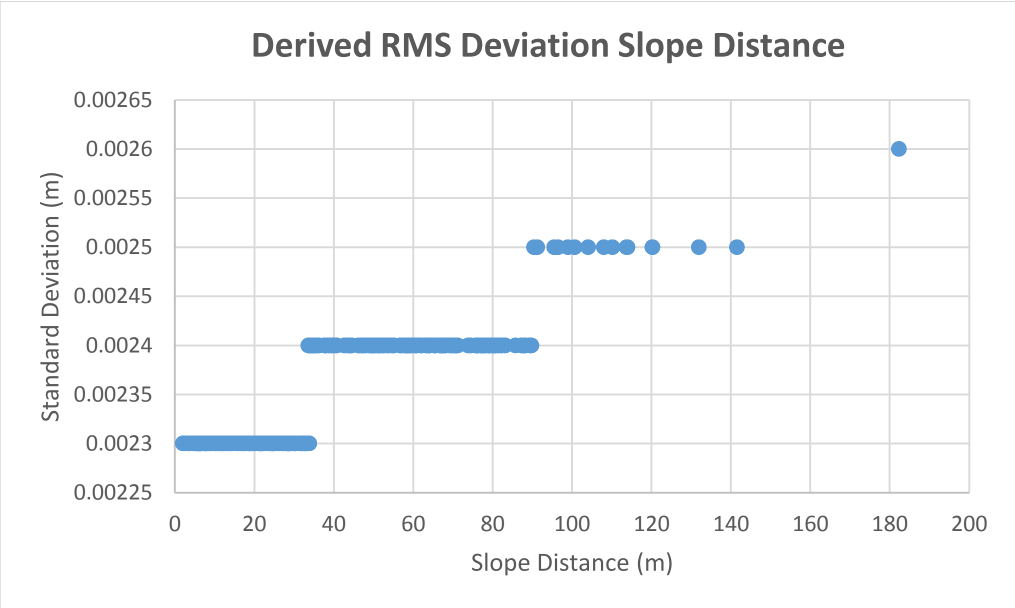

Figure 5-2 Derived RMS Deviation Slope Distances

The derived RMS deviations for the slope distances increase slightly as the slope distance is lengthened. The variations are extremely small and was expected that the difference in predicted and observed over the single measures will increase slightly as distance lengthens. When analysing the derived RMS deviations of direction and vertical angles there statistical behaviour is similar to each other.

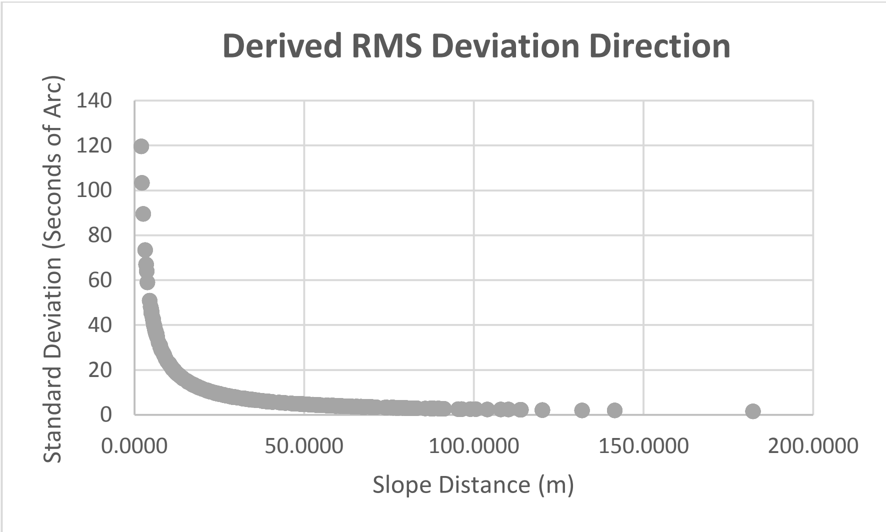

Figure 5-3 Derived RMS Deviation Direction

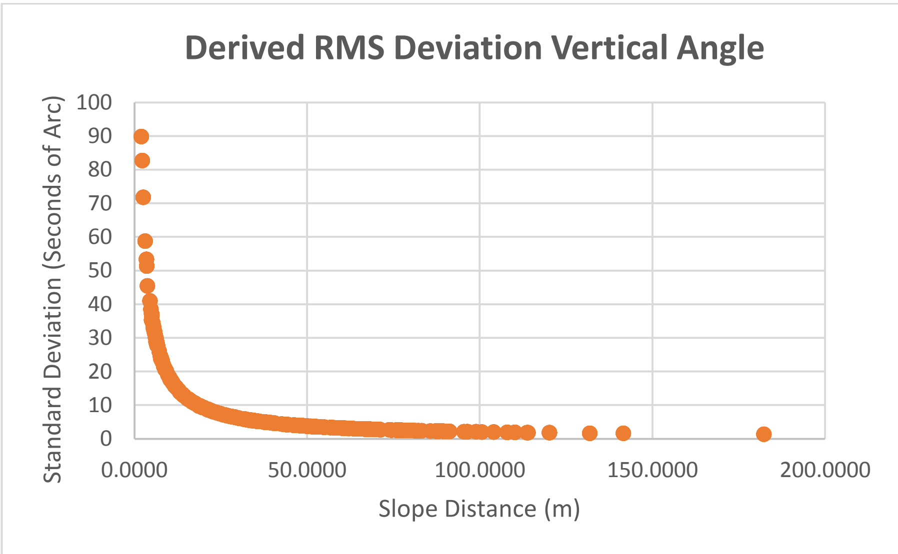

Figure 5-4 Derived RMS Deviation Vertical Angle

Both of the direction and vertical angle derived RMS deviation graphs follow a similar pattern. The difference between an observed and the best fit on a single measurement will have a higher seconds of arc difference on a shorter observation length.

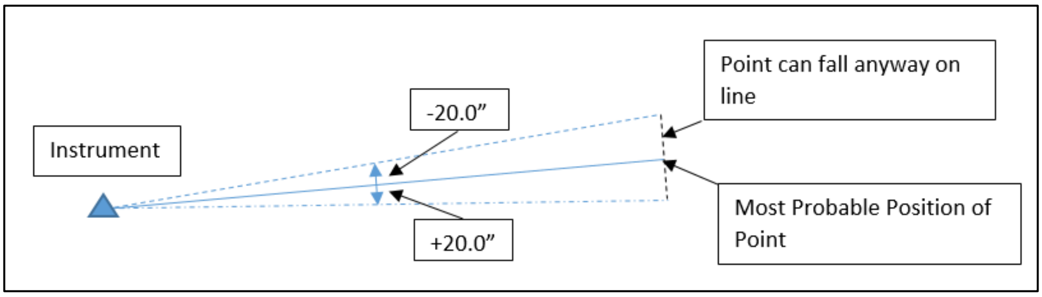

Figure 5-5 Effect of Derived RMS Deviation

When the slope distance from the instrument to the point increases the +/- 20 seconds of arc is going to be a greater error over a longer distance. The global precisions which are the estimation of standard deviation of errors will have greater impact on shorter observational lengths. However, when the offsets are determined the high seconds of a short distance will calculate a similar offset compared to a smaller seconds of arc over a longer distance. The RMS deviations of vertical angles and direction is predicted as the seconds of arc is proportional to the slope distance.

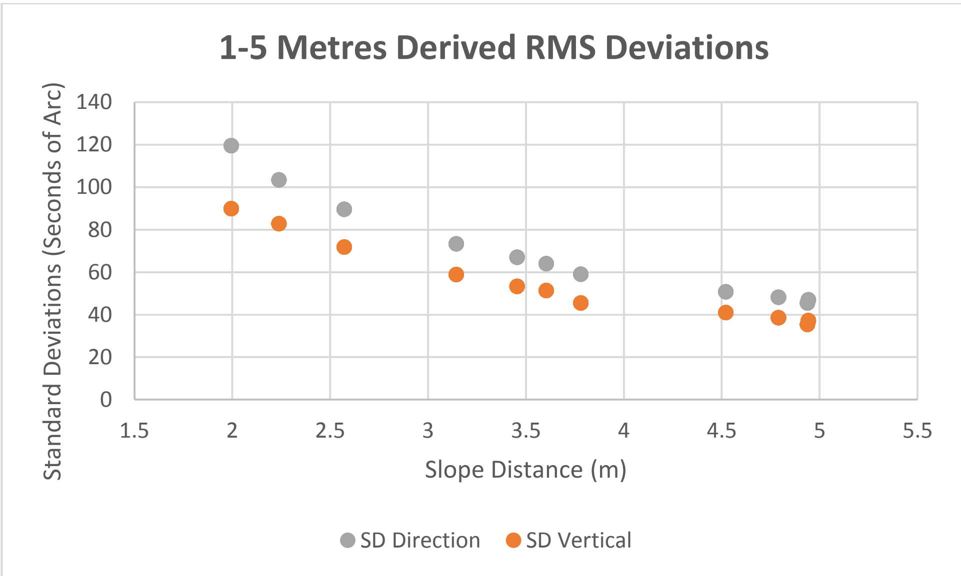

Figure 5-6 Metres Derived RMS Deviations

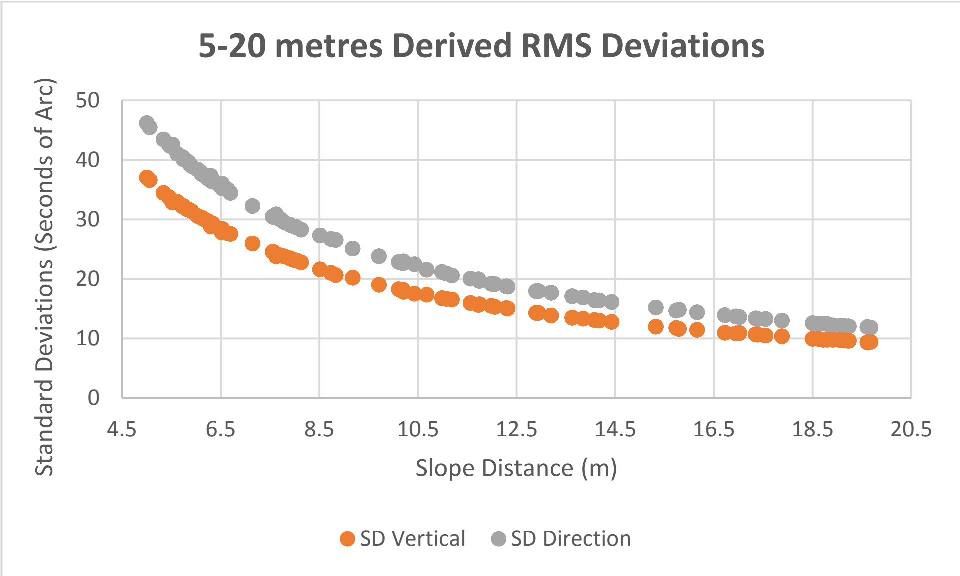

Figure 5-7 5-20 Metres Derived RMS Deviations

The graphs indicate that the difference between the adjusted and observed readings for the single measure. It is clear that the direction has larger derived RMS deviation than vertical angles over shorter distances. By observing the graph above, at approximately the 20 metre observation length the seconds of arcs stabilise and seem to be a similar value from 20 metres to 100 metres.

5.5.2 Directions and Vertical Angles

The vertical angles had numerous observations where the standardised residual exceeded 3 σ. In the graph below the standardised residuals were plotted for direction and vertical angles. The x-axis represents the traversing and where the traverse has close onto itself is at the beginning and end of the x-axis.

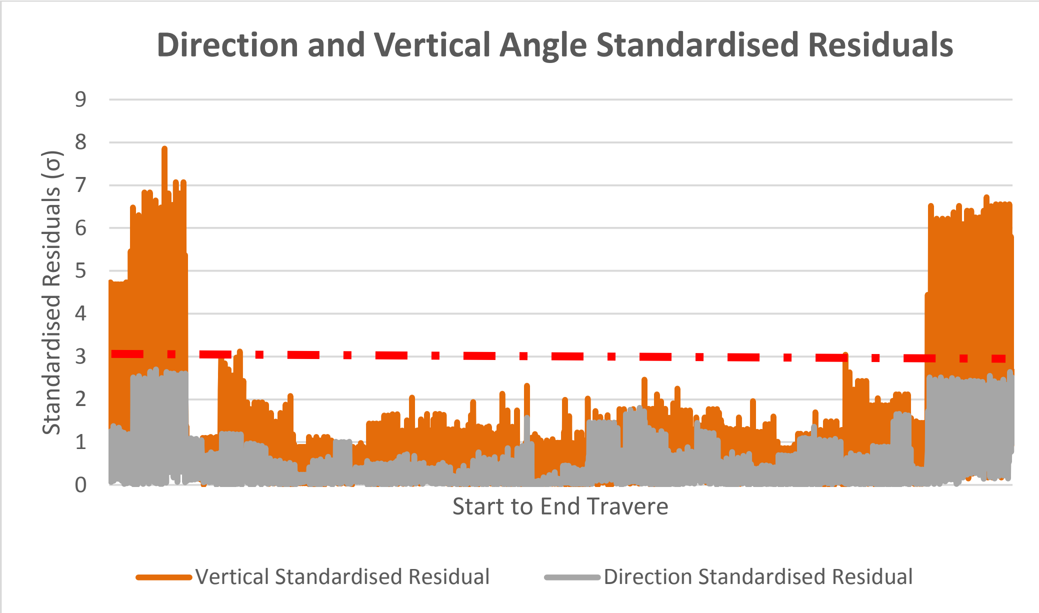

Figure 5-8 Direction and Vertical Angle Standardised Residuals

It is seen that the standardised residuals for slope distances and direction are all under the limit of 3 σ apart from one or two measurements. However, the vertical angles seem to have numerous measurements which exceed the 3 σ limitation. Both the direction and vertical angle standardised residuals are greatest at the start and end of the traverse. The observations where the standardised residuals were greatest were then investigated. The conclusion as to why the standardised residuals are high at the closure of the traverse is because of the fixed stations used in the adjustment.

The survey has greatest differences between observed and adjusted at the start and end of the traverse. The traverse is a closed traverse but it is not closing back onto itself it is closing back onto a different fixed control station. As the traverse is not closing back onto the same point we are seeing deviation between observed and adjusted at the start and end of the traverse.

The reasoning behind this behaviour has come down to the fixed stations at the start of the network are forcing the entire adjustment to produce a best fit based on the fixed stations. The twelve fixed stations at the start of the network may have moved over time. The integrity and reliability of the stations which are fixed is in doubt. With the fixed stations of the network being on an incline which is subject to high traffic and machinery passing through the wall stations are prone to movement.

The vertical angle standardised residuals seemed to be high in comparison to slope distance and direction standardised residuals. As many of the standardised residuals for vertical angle exceeded the 3 σ limit the standardised residuals greater than 3 σ were investigated. The vertical angle offsets between observed and adjusted for standardised residuals greater than 3 σ were interrogated.

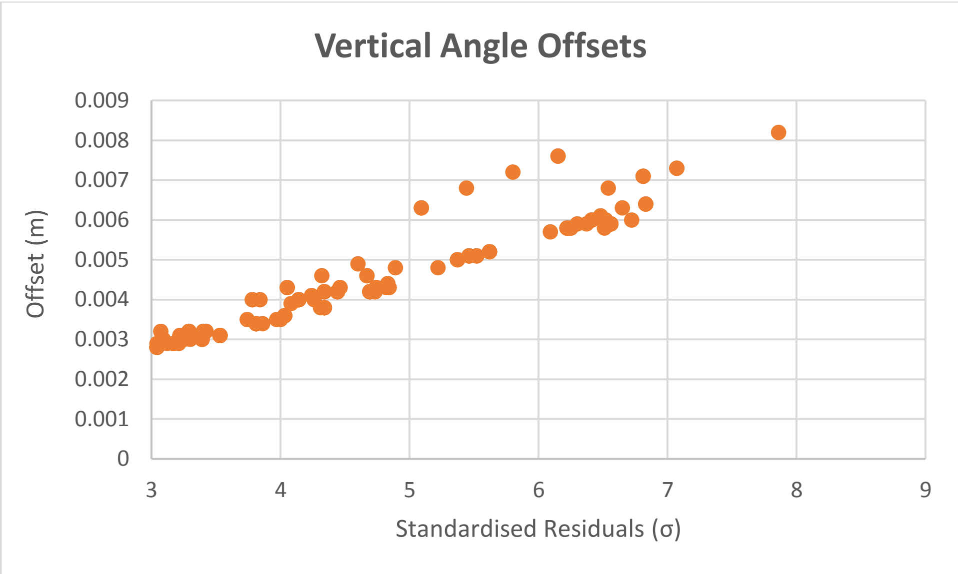

Figure 5-9 Vertical Angle Offsets

The vertical angle standardised residuals greater than 3 σ have been compared to their offset between the observed and adjusted. The greatest vertical angle standardised residual is 7.9 σ and its offset is 8mm between the observed and adjusted. As the check survey was performed in an underground environment an 8mm offset for such a high standardised residual is not overly concerning.

The direction standardised residuals has one result that exceeds the 3 σ limitation. Its standardised residual is 3σ and its direction offset between observed and adjusted is 3mm. When analysing the results obtained from the least squares adjustment it is evident that slope and bearing measurements have a higher degree of accuracy than the vertical angles.

5.6 PRECISION MEASURES

5.6.1 ERROR ELLIPSES

Error ellipses represents the confidence region of the calculated position of a certain point. The locations of the point itself is not in doubt because it is the established survey mark. However, the surveyed position of the point is in doubt because it is likely that there are errors in the measurements to establish the position. The error ellipses can be used to give a clear indication of the likely precision or quality of the coordinates of the points which will be fixed in the survey.

The standard deviation of the two coordinates for each point indicate the precision of the northing and easting coordinate values respectively. These values can be positive and negative which can be easily graphed and a rectangle can be drawn around the values to represent the area of error.

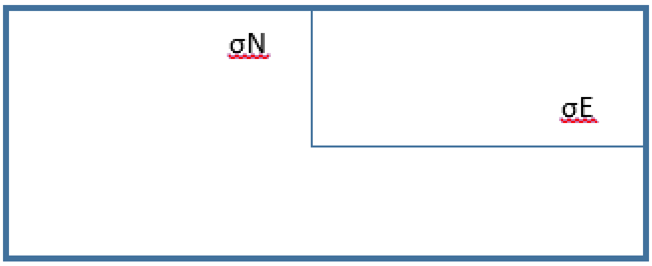

Figure 5-10 Error Rectangle

Graphing the values using a rectangle to portray the area of error is based on the geometry of the coordinate system. When using an error ellipse to show the area of error it represents the geometry of the survey network rather than the geometry of the coordinate system.

The maximum standard deviation is the semi- major axis (a) and the minimum is the semi-minor axis (b) of the ellipse which is at a right angle to the semi-major axis. The orientation of the semi-major axis is defined by the azimuth. The ellipse azimuth gives the orientation of the ellipse based from the coordinate system.

Essentially, the error ellipse is two normal distribution curves intersected on a three-dimensioned plane. The values used in the error ellipse are calculated from the observations but the design. This means that the error ellipse don't not portray actual errors made in the survey but instead portrays the probable errors.

In this research project, error ellipses will be examined with a confidence level of 95%. That means that there is a 95% confidence that the adjusted point is in the extents of the ellipse's dimensions used. The size of the ellipse represents the measurement of reliability of the adjusted point. These error ellipses are used to evaluate the strength of the survey network and the reliability of the adjusted points calculated.

5.6.1.1 Absolute Ellipses

Absolute ellipses are defined by the datum of the survey which is the fixed stations. The figure below shows the Absolute error ellipses for the survey network. The small black dots located on the Eastern side of the survey network represent the twelve fixed stations which is the start of the network. The absolute error ellipses are the red ellipses and portray the extent of uncertainty at 95% confidence interval.

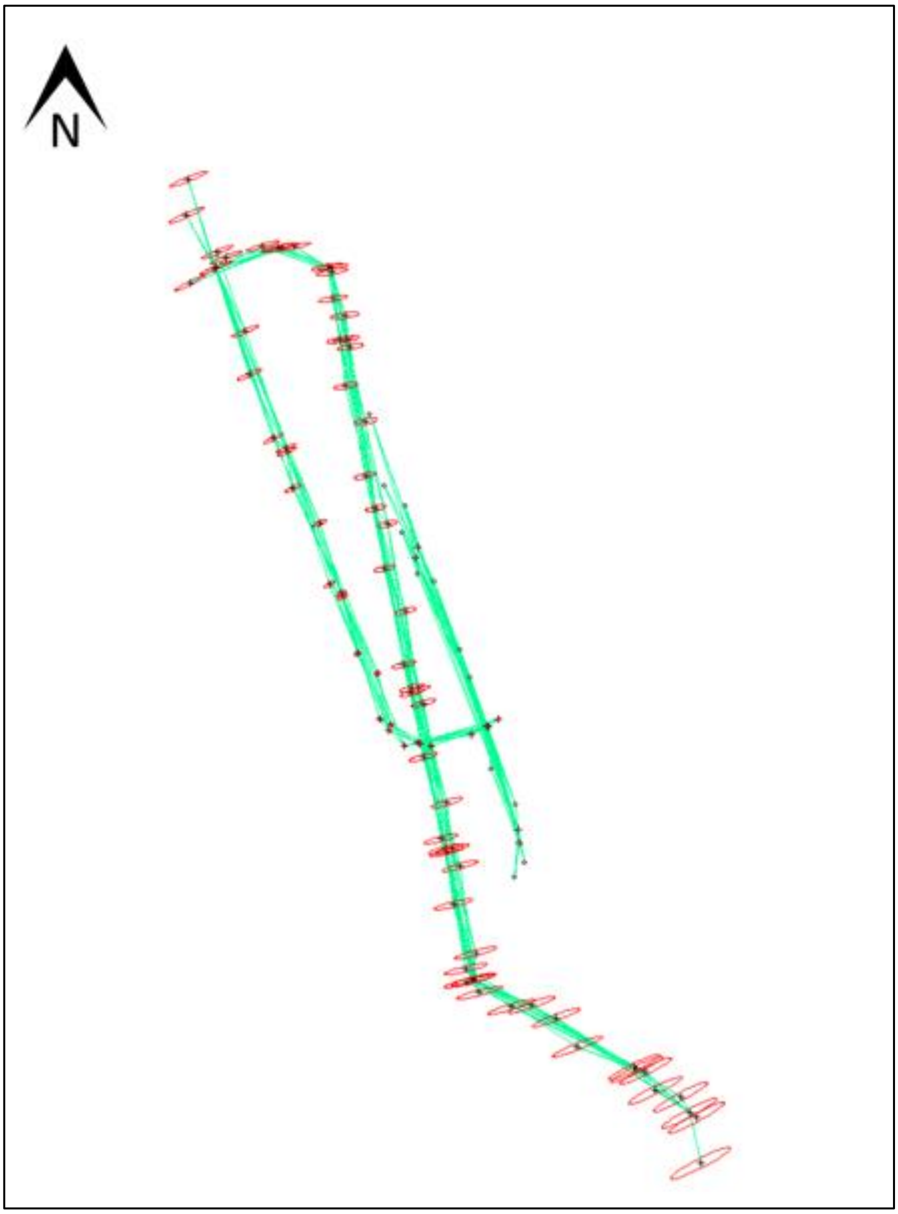

Figure 5-11 Absolute Error Ellipses

By observing the absolute error ellipses on CompNet visual comparisons can be made of the shape, size and orientation of the ellipses. There are twelve fixed stations in the network which are at the start of the network. When the distance between a fixed station and a free station increases the size of the absolute ellipse will increase. At the end of the network which is South of the network the absolute error ellipses are greatest as the further a traverse is away from the known control the less confidence you have in the position.

When observing the absolute error ellipses it is evident that most are orientated in the same direction. When many ellipses are in the same direction it means that the survey network is unbalanced in that direction. There is an azimuth deficiency and one side of the network has minimal resistance to rotation.

In the figure below it portrays the semi-minor and semi-major axis of the wall stations.

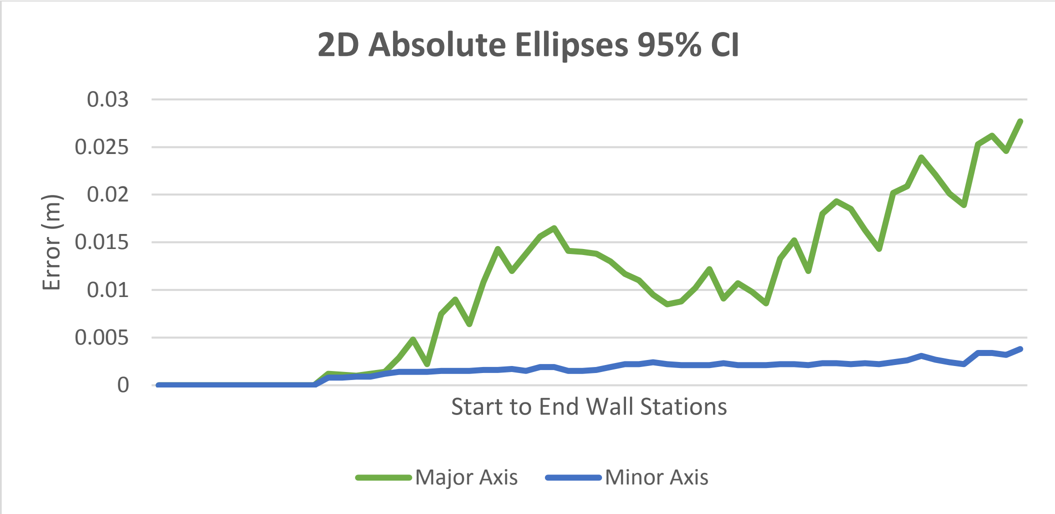

Figure 5-12 2D Absolute Ellipses 95% CI

At the beginning of the graph lines are flat which represents the twelve fixed stations incorporated in the adjustment. These twelve fixed stations will have no error in their axis as they are used as the reference control throughout the network. The maximum standard deviation is the semi- major axis (a) and the minimum is the semi-minor axis (b) of the ellipse which is at a right angle to the semi-major axis. When analysing the two axis on the line graph there is a particularly large difference between each other which indicates the absolute error ellipses will be elongated. This means that there is greater uncertainty in one of the coordinates. The graph below portrays the standard deviations in easting and northings for the adjusted coordinates in the network.

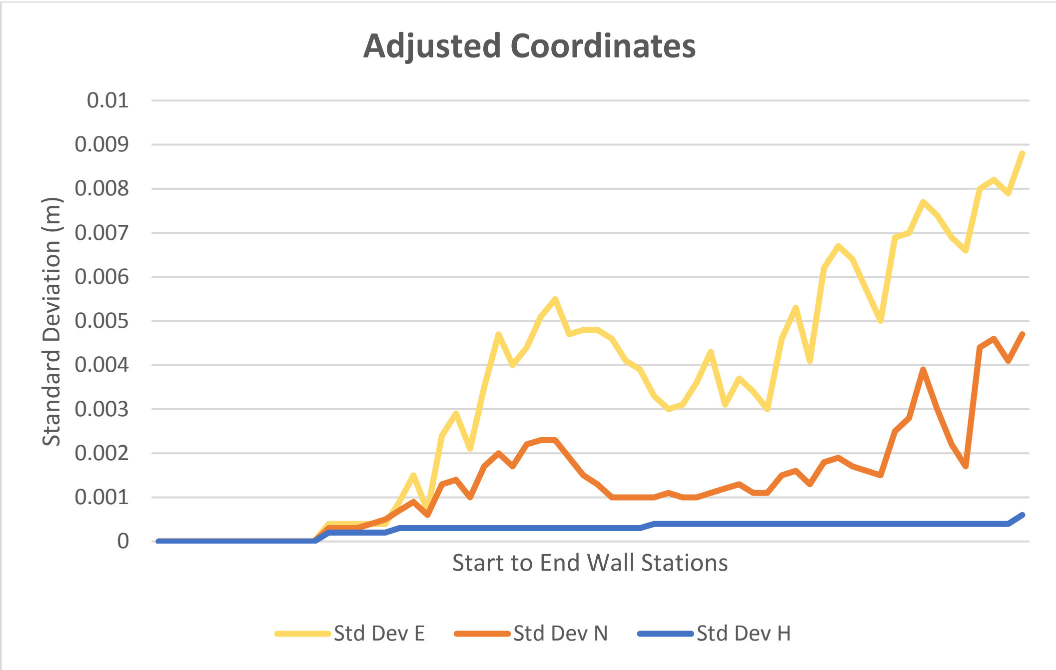

Figure 5-13 Adjusted Coordinates

The assumption as to why the standard deviation of the height component is low is the positioning of the wall station prism sits at the lowest point in the sleeve each time it is inserted. Whereas, horizontally the prism can move around and can sit at a different point each time the prism is inserted.

Observing the standard deviations of the adjusted coordinates it represents that there is a greater uncertainty in the Easting coordinates. This difference is quite significant and confirms why the error ellipses are elongated and have similar azimuths. Elongated ellipses represent an azimuth distortion in the survey adjustment.

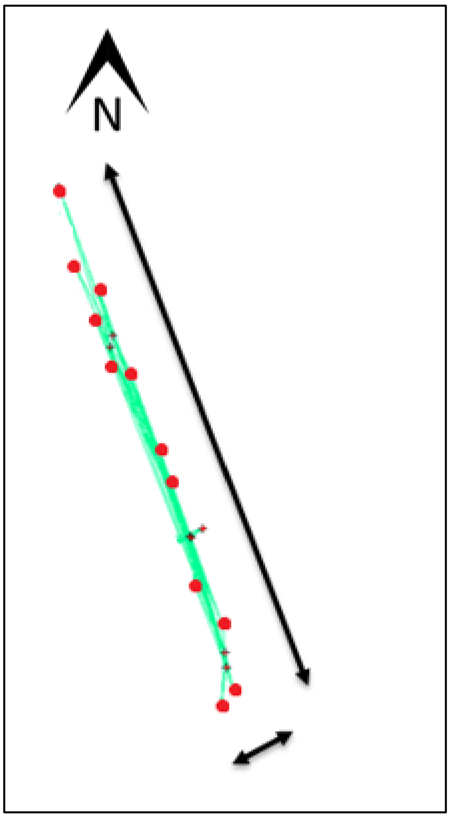

Figure 5-14 Orientation of Fixed Stations

In the above figure, the red circles represent the twelve fixed stations. It is evident that the strength of the network is constrained adequately along the Northern axis yet in Eastern direction the fixed stations are poorly braced. Along the Northern axis the fixed stations are stretched for 180 metres in comparison to the Eastern axis which is over 10 metres. The orientation of the fixed control has caused an azimuth distortion in the Eastern direction which has been confirmed by the standard deviations in the adjusted coordinates. The fixed stations of the network are all running along the same direction which is a straight line. The ideal geometry of a network should form closed figures which are braced.

The orientation of the fixed control in an underground mine with narrow tunnels is difficult to achieve the ideal geometry of fixed stations that is braced in all axis. Instead, using the sets of angles program was used to increase the redundancy in the network. By increasing the number of observations will reduce the size of the error ellipse since redundancy increases confidence.

5.6.1.2 RELATIVE ELLIPSES

Relative ellipses represent the precision of the relative position of the two different coordinates of the point. "The uncertainty between the horizontal and/or vertical coordinates of any two survey control marks" (Inter-governmental Committee on Surveying and Mapping (SP1) v2.1, 2014). Relative Uncertainty "can be expressed in SI units at the 95% confidence level, or in a proportional form such as a ratio of uncertainty per unit length or survey misclosure" (Inter-governmental Committee on Surveying and Mapping (SP1) v2.1, 2014).

The check survey network must comply with the requirements of a class "D" survey. An easy method to compare the uncertainty of the survey to the standards is by examining the relative error ellipses. The 95% confidence relative uncertainties for the network used an error ellipsoid factor of 2.796 where all ellipsoid semi-major axes and height precisions were within the relative uncertainty limit of 50mm. The greatest relative semi-major axes is 27mm which is well under the limitation required by the standards. The ICSM relative uncertainties at 95% confidence interval are attached in Appendix G.

5.7 NUMBER OF STATIONS IN RESECTION

A resection is expressed as "… a method of a point position determination which requires only the observation of directions from the point itself to a minimum of five well-spaced control points" (Watt, 1988).

The concept of a resection is to determine the position of the setup by observing known points. Theoretically the number of wall stations in the resection will be analysed and the redundant observations will be examined.

The amount of wall stations which are observed and the geometric association with the total station and the wall stations is dependent on the formation of the mine. By increasing the number of wall stations included in the resection the observations redundancy is increased. By increasing the redundancy of the resection the confidence of the observations is increased.

When examining a two point resection the two wall stations in the resection have known coordinates. This means that the bearing and distance between these two wall stations is known. When there is two wall stations there is two distance measurement from the total station to the wall stations. The total station can determine its location when a two-point resection is performed by triangulation.

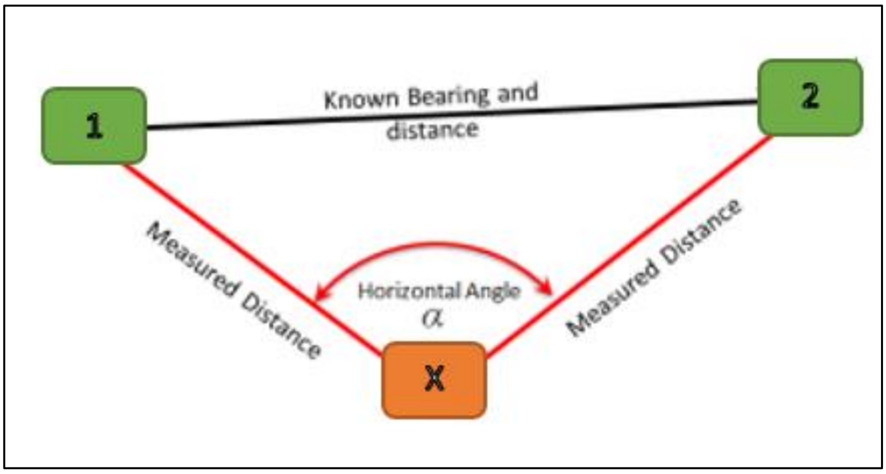

Figure 5-15 Two Point Resection

Table 5-1 Two Point Resection Options

Bearing	Angle (DMS)	Distance (metres)
1 to 2	1-X-2	X to 1
	2-X-1	X to 2

The unique solutions of a two point resection is displayed in the following table. This means that a two station resection has two unique solutions.

Table 5-2 Two Point Resection Solutions

Resection Triangle	Angle (DMS)	Distance (metres)
1X2	1-X-2	X to 1
1X2	1-X-2	X to 2

When a three point resection is observed the coordinates of three wall stations is known which means there is three known bearing and distances between stations. Three measurements are observed to each wall station to determine a triangulation solution of the set up location.

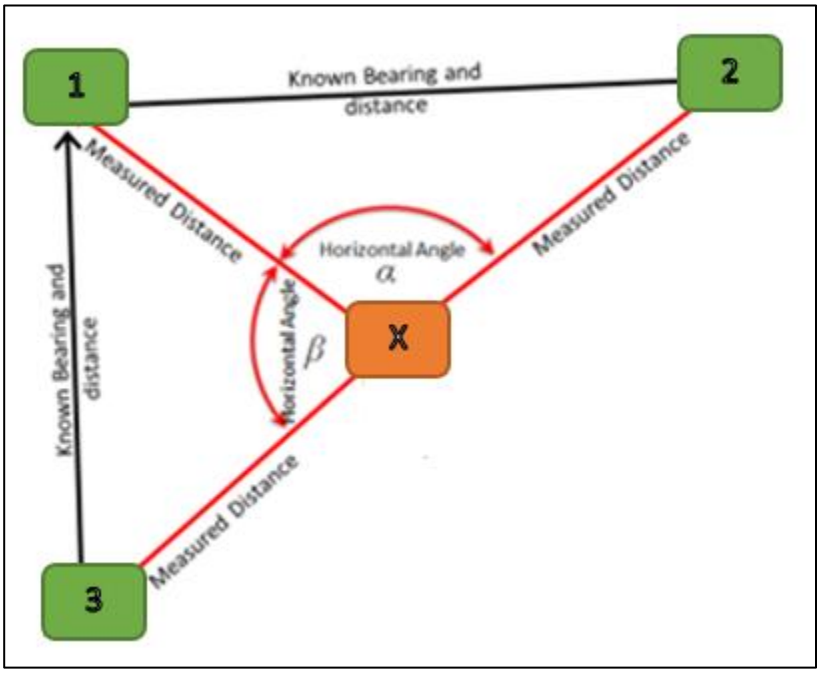

Figure 5-16 Three Point Resection

Table 5-3 Three Point Resection Options

Bearing	Angle (DMS)	Distance (metres)
Bearing 1 to 2	1-X-2	1 to 2
Bearing 1 to 3	1-X-3	1 to 3
	2-X-3	X to 1
		X to 2
		X to 3

When the position of three wall stations is known are observed in a resection, three measured distances and angles make up greater combinations which increases the redundancies. With a three wall station configuration seven unique (including one resection) solutions for the location of the total station set up are determined.

Table 5-4 Three Point Resection Solutions

Solution Resection	Solution Triangle	Angle (DMS)	Distance (metres)
Resection 1-2-3	Triangle 1-X-2	Angle 1-X-2	1 to X
	Triangle 1-X-2	Angle 1-X-2	2 to X
	Triangle 1-X-3	Angle 1-X-2	X to 1
	Triangle 1-X-3	Angle 1-X-2	X to 3
	Triangle 2-X-3	Angle 3-X-2	X to 3
	Triangle 2-X-3	Angle 3-X-2	X to 2

When a four station resection is conducted four coordinates of the wall stations is known. When using four wall stations it will provide the coordinates to determine six join and four distances measured to the known wall station and the location of the total station. Meaning, four angle measurements will be observed from the total station to the wall stations.

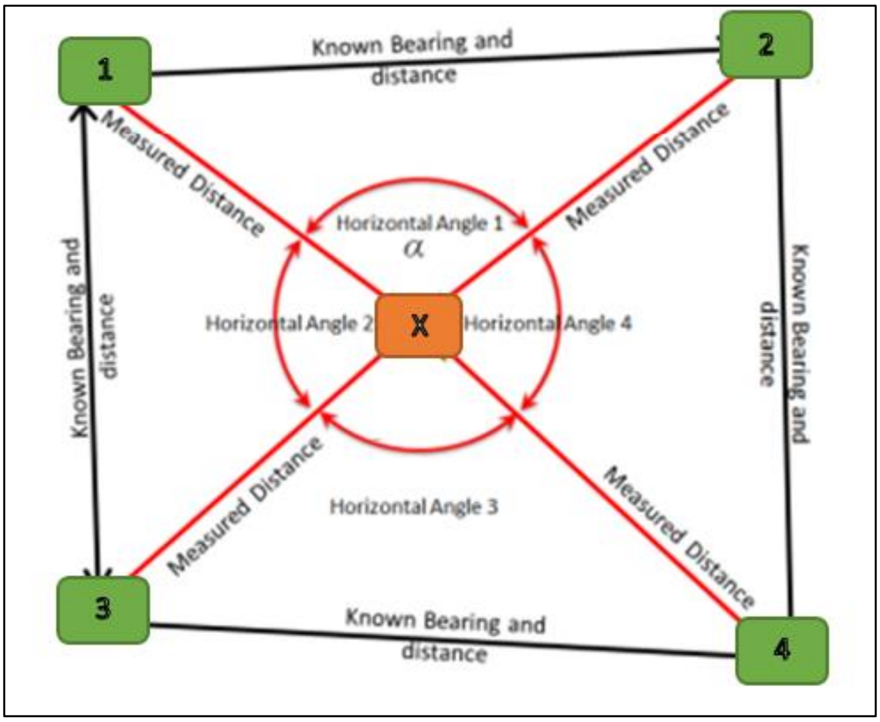

Figure 5-17 Four Point Resection

Table 5-5 Four Point Resection Options

Bearing	Angle (DMS)	Distance (metres)
Bearing 1 to 2	1-X-2	1 to 2
Bearing 1 to 3	1-X-3	1 to 3
Bearing 2 to 4	3-X-4	2 to 4
Bearing 4 to 3	4-X-2	3 to 4
Bearing 1 to 4		1 to 4
Bearing 3 to 2		2 to 3
		X to 1
		X to 2
Bearing	**Angle (DMS)**	**Distance (metres)**
		X to 3
		X to 4

When there is four wall stations in the resection the measurements will provide sixteen unique solutions of the location of the total station.

Table 5-6 Four Point Resection Solutions

Solution Resection	Solution Triangle	Angle (DMS)	Distance (metres)
Resection 1-2-3	Triangle 1-X-2	Angle 1-X-2	1 to X
Resection 1-2-4	Triangle 1-X-2	Angle 1-X-2	2 to X
Resection 1-3-4	Triangle 1-X-3	Angle 1-X-2	X to 1
Resection 4-2-1	Triangle 1-X-3	Angle 1-X-2	X to 3
	Triangle 2-X-3	Angle 3-X-2	X to 3
	Triangle 2-X-3	Angle 3-X-2	X to 2
	Triangle 3X4	Angle 3-X-4	X to 3
	Triangle 3X4	Angle 3-X-4	X to 4
	Triangle 2X4	Angle 2-X-4	X to 2
	Triangle 2X4	Angle 2-X-4	X to 4
	Triangle 1X4	Angle 1-X-4	X to 1
	Triangle 1X4	Angle 1-X-4	X to 4

It is evident that the theoretical analysis of the resection method to calculate the position of the set up shows the importance of the number of wall stations used. By increasing the number of unique solutions in the resection the degree of confidence increases. When forwarding new control from two and three point resections there can be significant problems with azimuth control. This theoretical analysis outlines the importance of the number of points used in resections. Ideally four points used in a resection is most suitable for underground surveying when using wall stations to increase confidence in the instruments position.

A two point resections has minor effect on the precision of the wall station and the distance to the foresight but heavily impacts the precision of the forward bearing which directly impacts azimuth control. Whereas, when using three stations in the resection distance strength is similar and there is an improvement in the precision of the stations and the forward bearing improves. It is vital when resections are implemented to forward control to incorporate more than two stations with adequate geometry to maintain azimuth integrity.

5.8 GEOMETRY OF STATIONS IN RESECTION

The geometric relationship between the wall stations and the total station is controlled by the layout of the mine and the surroundings in the work environment. It is not always possible to put in wall stations in a position which is optimal for observational geometry. When installing wall stations the placement relies on wall conditions, visibility, and likelihood of the wall station being damaged.

The ideal geometry of wall stations has been discussed in literature and differs from each paper. Assessing the ideal geometry for a resection is difficult to compare and analyse. However, the previous literature conclude that the accuracy of wall stations is not affected significantly by the geometry of wall stations or the distance of the forwarded control. However, "it is apparent that while the geometry of the resection has minor effect upon the station precision and a negligible effect upon that of the distance to the foresight, it has major impact upon the forward bearing precision and thus azimuth control" (Grocock, 2014).

The setup position of the instrument is very important when carrying wall station control. The instrument should be set up inside a minimum of three good wall stations using two faced observations. The purpose of being inside the existing wall stations means that the network solution generated will effectively be braced by the existing control. If a good free station solution is not calculated, more wall stations need to be surveyed in and analysis of the network solution investigated. Serious thought should be employed as to whether forward stations should be surveyed from what is likely to be a poor network of existing wall stations. If a station is found to have moved, or has been damaged, it should be remove from the primary control network and then destroyed.

The ideal geometry of a resection has varied through literature which makes it hard to assess. In regards to distances the first wall station to be surveyed in during setup is to be the furthest (up to 100m), line of sight station that can be used. This will help stabilise the carried bearing. The other stations should include a medium length shot (25-50m) and a short length shot (between 5 -10m). With a quality network solution established, forward wall stations can be carried with confidence. Forward stations are surveyed in two faces and should be staggered along both sides of the drive (subject to ground/wall conditions)

5.9 ERROR PROPAGATION

Errors can either accumulate, cancel or reduce and should be detected in the survey network. In this research project the check survey network will contain errors that have been propagated while advancing the traverse. By performing six sets of angles at each station set up the confidence of the positions of the wall stations will be increased.

Propagation of errors is disturbed with behaviour of small errors which are commonly random propagating through a traverse. The least squares adjustment eliminates the random errors in the survey which limits the propagation of random errors.

Error propagation can be predicted by incorporating statistical tests and models. Random variation in the fixed stations is transformed by the model into corresponding random variation in the resulting free stations. This uncertainty in the adjusted free stations can be scaled to a probability such as 95% and presented in error ellipses.

The primary control network of wall stations will have errors that have been propagated. Each time a mine surveyor visits a site they commonly resect off wall stations. Errors that are accumulated from each visit from a surveyor can lead to deviation in the true position. A major problem with the wall station resection method is errors can be propagated extensively in bearing. "Any error in measuring distance would be carried throughout the entire traverse, but that error would not compound. Errors in turning an angle would be magnified by the further traverse from that point." (McCormack, 2002).

The wall station furthest away from the fixed points that were checked by a previous check survey is approximately 900 metres. That means that 900 metres of traversing and forwarding control into the walls was required. As the distance from a checked wall station increases it will have an impact on shape and size of the angles observed. Numerous instrument set ups and resections would have been implemented to forward wall stations. Over that substantial distance of traversing and where number and geometry of the resections might not have been optimal we can expect distortion in azimuth. It is clear that bearing errors can be produced by uncertainty in resections.

5.10 CONCLUSION

The chapter has analysed the results of the least squares adjustment and discussed statistical behaviour. The important considerations analysed was the types of errors expected in an underground check survey and the external factors that can cause deviation in observations.

Slope distance, direction and vertical angles were analysed to assess the quality of the check survey. It was observed that the greatest standardised residuals were located at the start and end of the survey. The assumption is that the traverse is closing onto another fixed control point which will lead to variation. Integrity of the original fixed control points was questioned as the fixed stations were verified in a check survey three years ago. Over three years wall stations are expected to move due to the nature of the mine.

The absolute and relative error ellipses were analyse at a 95% confidence interval. It was observed that there was an azimuth deficiency in the Eastern direction which was caused by the orientation of the fixed control. The relative ellipses semi-major ellipses were in compliance with class "D" ICSM standards which was required.

The next chapter will consider important requirements that mine surveyors should consider when completing a check survey. These requirements were based from the field work completed and the behaviour of the results.

6. CHAPTER 6 – CONCLUSION

6.1 INTRODUCTION

Check survey control was required to be extended to replace unchecked wall stations within X41 mine at MICO. The high order check survey control was to be verified and compliant with ICSM SP1 Mines Class D Standard. As a surveyor it is a professional duty to comply with legislation and provide accurate and adequate data. The requirements of legislation such as ICSM SP1 v2.1, Survey and Mapping Infrastructure Act 2014 and the Surveyor Code of Practice, ensure a reliable and accurate survey control network is available. This legislation determines the standards of accuracy and consistency of survey work performed within Queensland, Australia.

This research project focused on assessing the statistical results obtained by the adjustment and particularly investigate slope distances, angular observations and error ellipses. The network was assessed in terms of accuracy and precision and its uncertainty was evaluated. By assessing the results obtained considerations for future surveyors have been outlined when completing a check survey.

6.2 IMPORTANT CONSIDERATIONS

Check surveys are an essential procedure in underground mine surveying and should be planned and performed on a regular basis. Some of the important considerations to consider when completing a check survey include:

- It is advised to use survey equipment that is in a clean and equipment that has not been disturbed. It is advised all survey equipment be calibrated and checked to reduce any potential errors in the check survey.
- By completing at least four rounds of sets of angles it will improve the confidence in the accuracy of network as redundancy will be increased.

- To check the accuracy of the survey when shorter distances are surveyed is to take longer observations which bypass intermediate survey stations to minimise the propagation of error by decreasing the number of stations observed.
- The geometry of the fixed stations is ideally balanced in the East and North direction to avoid azimuth distortions in certain directions. In a narrow tunnel environment it is difficult to get an even spread of fixed stations due to the layout of the mine.
- Wall stations are expected to have some movement in an underground mine so it is essential for the mine surveyor to install wall stations in areas that will have least amount of disturbance to the surveyor's best ability.
- When it is feasible it is recommended that the check survey should be closed on a base of origin.
- When closing the traverse is not feasible it is recommended to apply a check on different levels of the mine to verify the survey network.
- Wall stations when not occupied and are in an area of the mine with high activity should be covered with a plastic sleeve to protect the station from being removed or covered by shotcrete.
- The baseline of the check survey should ideally be at the start and end of the check survey as well as connections on each level of the mine and be in stable area of the mine when possible.
- The check survey should be in compliance with the SP1 standards.
- Mine surveyors should make conscious effort to use at least three wall stations in resections when forwarding new control. By having adequate geometry and number of wall stations in the resection where feasible the risk of error in the positional fix by poor observations will be avoided. The wall station method can have major error propagation problems in bearings when poor observations are obtained to get a positional fix of the instrument.
- As errors in bearings is propagated greater degree in comparison to distance measurements it is recommended to verify the azimuth of the baseline used by taking gyroscope observations to check the bearing.

6.3 Conclusion

Mine surveyors are using wall stations into their daily processes to orientate the position of their total station by resection. As wall stations are used so often and are critical to staking out information for the operations of the mine there needs to be a verification on the wall stations.

The main weakness of the wall station method has been recognized as the potential error in positional due to poor observations. The research indicated the likelihood of error propagation especially in the angle component. In saying this, it is vital to verify the integrity of the primary survey control which is used on a daily basis.

Over the length of the dissertation ideas for potential and further work were considered that relates to the check survey method. The next chapter, will outline further research that could be completed on this dissertation and propose recommendations that have not been analysed in the past.

7. Chapter 7 – Recommendations

7.1 Introduction

This chapter of the dissertation will aim to recommend further work that can lead from a basis of this research project. By completing the check survey and examining an analysis of the survey network further work that can be completed that would build on this dissertation were identified. No previous literature was found that specifically examined the check survey method so potential work in this study area should be further assessed. Some of the recommendations have been discussed in the following chapter.

7.2 Minimally Constrained (Free) Adjustment

A minimally constrained adjustment was incorporated in the check survey procedure to examine the measurement precisions. Each baseline was examined to determine whether the correction exceeds a 95% confidence value. The minimally constrained adjustment could be further statistically analysed and fixed stations could be altered.

By examining a free adjustment an analysis can be completed to examine the changes of the survey network when different fixed stations are used in a network. Further work and analysis can be completed in this area to assess the amount of fixed stations required and how different fixed stations can alter the survey network. The integrity of the survey network will only be as good as the wall stations that are used in the adjustment.

7.3 Tunnel Deformation Effect of Wall Stations

In an underground mine with deep levels such as MICO the rock and tunnels are expected to have some movement and deformation. Research could be completed on movement of the rock and what effect that will have on the primary control network of wall stations. Rock movement will cause a dislocation in the position and evaluation of the wall stations. The impacts of tunnel deformation needs to fully assess to examine the impacts it can have on the primary control network of wall stations.

7.4 Gyroscope Observation

The research has specified the possibility of error propagation in the bearing of the survey network. It is very important to verify the integrity of the survey network to different levels of the mine. In underground mines, accuracy of survey networks on independent levels cannot be verified unless there is a closure between two levels. Deviation of error which has been propagated by the survey network can be recognized when azimuth is checked by a gyroscope reading. When using a gyroscope the error in bearing transfer and error propagation of the survey network can be checked. The azimuth observed from the gyroscope is compared to the check survey over a baseline. The gyroscope observations should be repeated to increase the accuracy of the observations.

7.5 Misalignment of Optical Centre and Nodal Point of Prism

By completing the check survey and completing an analysis it has been observed that observations to wall station prisms can result in errors in the position of the wall station. The calculation of the wall station position is dependent on the connections and size of the prism. A potential line of research would be to examine the effects on misalignment of using wall station prisms which have not been intended to be a true 360 degree wall station prism. The optical centre of a wall station prism does not continue to be true when the prism is rotated.

7.6 Planning of Underground Survey Networks

Planning of underground survey networks in new and existing mines seems to not be given the specific attention and thought it desires. By planning and budgeting the survey networks in an underground mine it would optimise the establishment of survey networks within the mine. Distances between survey networks, when gyroscope observation checks need to be completed and the dates that they should be expected to be completed should be planned. By implementing network analysis within planning of development the survey networks can be optimised. The planning could overcome potential error in propagation and plan to prevent the magnification of the error.

7.7 Conclusion

This dissertation has achieved the aims and objectives by field testing and a thorough statistical analysis. The dissertation has aimed to outline the importance for check survey networks in underground mines and provide important requirements that should be considered when completing. Due to the limited literature on wall station surveying in mining, recommendations have been discussed for further work.

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9. APPENDICES

Appendix A: PROJECT SPECIFICATION

Project Specification

For: Brad Costello

Title: Underground 'Check Survey'

Major: Surveying

Supervisors: Zahra Gharineiat

Enrolment: ENG4111 – ONC S1 and ENG4112 – ONC S2, 2016

Project Aim: A high order check survey will be carried out to verify the quality of existing wall stations and provide accurate control to further advance into the mine. A least squared adjustment will be computed and an analytical study will be investigated on the variables.

Programme: Issue B, 12th October 2016

1. Research the background information relating to underground 'check surveys', accuracy of wall stations and mining methods incorporated at Mt Isa Copper Operations.
2. Design a plan of the check survey network by roughly determining the amount of setups and time it will take.
3. Collect field data with Leica MS50 with the Leica 'Sets of Angles' function radiating to the wall stations.
4. Process data collected using 'CompNet' to perform a full least square adjustment of the observations which includes atmospheric and scale correction.
5. Analyse and compare the network variables and explain the behaviour of the statistical analysis.

6. Recommend important considerations that should be considered when conducting a check survey based on the results obtained.

If times and resources permit:

7. Complete a theoretical analysis on the number of wall stations in a resection and explain how resections can influence accuracy and the need for the check survey method.

Appendix B: EDM CALIBRATION

MOUNT ISA MINES

Memorandum

To	MICO Survey
From	Noel Causerano
Date	04/09/2015
CC	
Subject	Leica MS50 #368307 EDM Calibration

The Leica MS50 total station, serial number 368307 underwent testing against the Mica Creek EDM Baseline (reference QLD.MICA1.130906) by Noel Causerano and Steve Andrews on September 4th, 2015.

The purpose of this exercise was to test the EDM in the instrument against a certified baseline in order to obtain values to calibrate the EDM. The calibration values are then used to correct the EDM observations used in high order survey work at Glencore Mount Isa Copper Operations.

A Minimum of five sets of observations were recorded (in both face left and face right) between all pillars at the baseline. During observations, an atmospheric correction of 0ppm was set in the Total Station. The temperature and pressure were recorded at each setup with the Kestrel Pocket Weather Tracker (S/N 642876). The Mean temperatures were calculated during post processing with the BOM Mount Isa webpage used to establish a variable humidity result for the time of the survey.

A GSI file was extracted from the total station displaying pillar names, bearings, slope distances, target heights, instrument heights and prism constants and formatted into a CSV file. The CSV file was corrected to include temperature, pressure and humidity and saved as a text file.

The Queensland government EDM calibration processing software V6.1.0.3 04-Sept-2015 was downloaded and used to adjust the slope distance readings with accordance to the Leica MS50 instrument specifications. The text file data was then processed to create an EDM Calibration Certificate and EDM Calibration Report. This data analysed and checked the EDM measurements against the QLD government certificate of verification.

The data was processed on September 4th, 2015 and the following particulars were noted:

EDM Constant: -0.00073m (SD of 0.50mm)
PPM Correction: 0.88ppm (SD of 1.0ppm)
Variance Factor: 0.442

The EDM Constant and PPM correction numbers show that the instrument is inside of the specified accuracy of the Leica MS50 which is 1mm ± 1.5ppm. The calibrated values are to be used in post processing when this total station is used for high precision work, while the total station is also still deemed fit for everyday use.

The Adjustment Variance Factors shows that the observations were done to a precise standard and that the baseline does not appear to show any movement of any particular pillar since the last time it was calibrated.

Noel Causerano
Mine Surveyor | MICO Co-Ordination
Mount Isa Mines
Copper Assets Australia

Steve Andrews
Senior Mine Surveyor, MICO Coordination
Mount Isa Mines
Copper Assets Australia

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Appendix C: KESTREL CALIBRATION

MOUNT ISA MINES

Memorandum

To	MICO Survey
From	Hamish Chrisp
Date	12/05/2015
CC	
Subject	Kestrel 4000 Pocket Weather Tracker – Check Survey

The Kestrel 4000 Pocket Weather Tracker (serial number 642876) was tested at the Mount Isa Bureau of Meteorology (BOM) on the morning of the 12th May 2015.

The instrument was tested against the B.O.M. atmospheric measuring equipment to compare their readings with the Kestrel reading. This was to verify that our means of measuring temperature and pressure for EDM corrections was correct.

The following observations were recorded:

Temperature:

Dry Bulb		Wet Bulb	
Kestrel	BOM	Kestrel	BOM
21.9°C	22.0°C	14.0°C	13.9°C
22.1°C	22.0°C	14.0°C	13.9°C
21.7°C	21.9°C	14.1°C	14.0°C
		14.0°C	13.9°C

Pressure

Kestrel	BOM
978.7hPa	980.6hPa

The average temperature difference shows the Kestrel is 0.1°C lower than the BOM.

The average pressure difference shows the Kestrel is 1.9hPa lower than BOM.

If we convert the differences in these readings to a PPM value, the difference is 0.7ppm.
Assuming the theory that an error of 1°C or 3hPa is the equivalent to 1 ppm

When conducting an EDM calibration apply the average differences in temperature and pressure to the observed Kestrel readings to bring them into line with the BOM "correct" readings.

1ppm is not significant given the distances observed in an underground environment. The observed Kestrel readings will be fine for correcting the EDM distances for underground high order surveys.

Hamish Chrisp
Mine Surveyor- Underground, MICO Coordination
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Appendix D: ATMOSPHERIC DATA

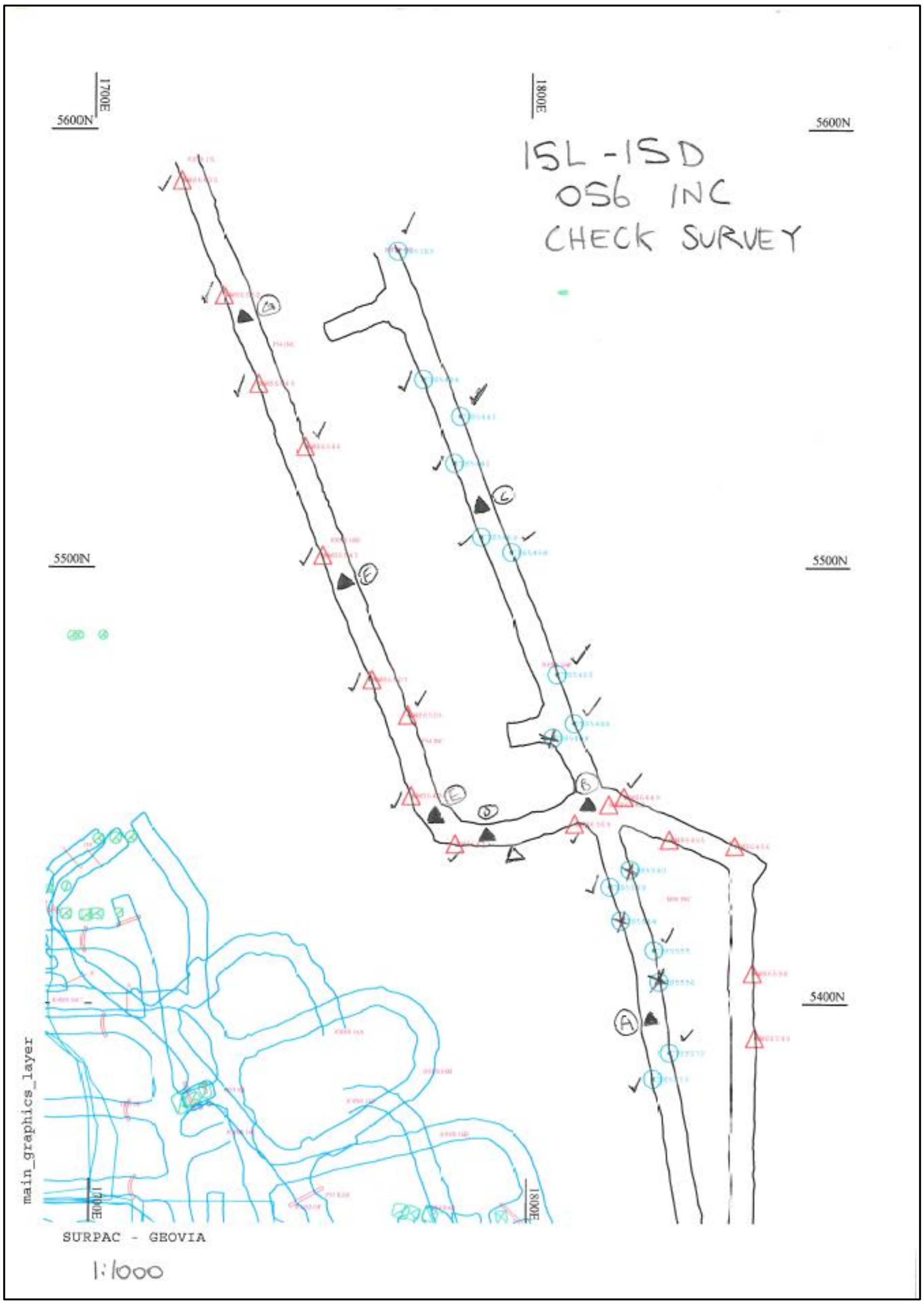
Day 1	Location: 15L/15D O56 INC	FileName: RS190116		
Station	**Type (Inst/BS)**	**Height**	**Temp(°C)**	**Press(hPa)**
RS190116A	INST	0	34.0	1049.5
RS190116B	INST	0	35.5	1049.0
RS190116C	INST	0	34.9	1049.4
RS190116D	INST	0	34.9	1047.3
RS190116E	INST	0	34.5	1046.7
RS190116F	INST	0	35.2	1045.5
RS190116G	INST	0	35.3	1043.9
RS190116H	INST	0	35.8	1042.3
RS190116I	INST	0	35.4	1041.3

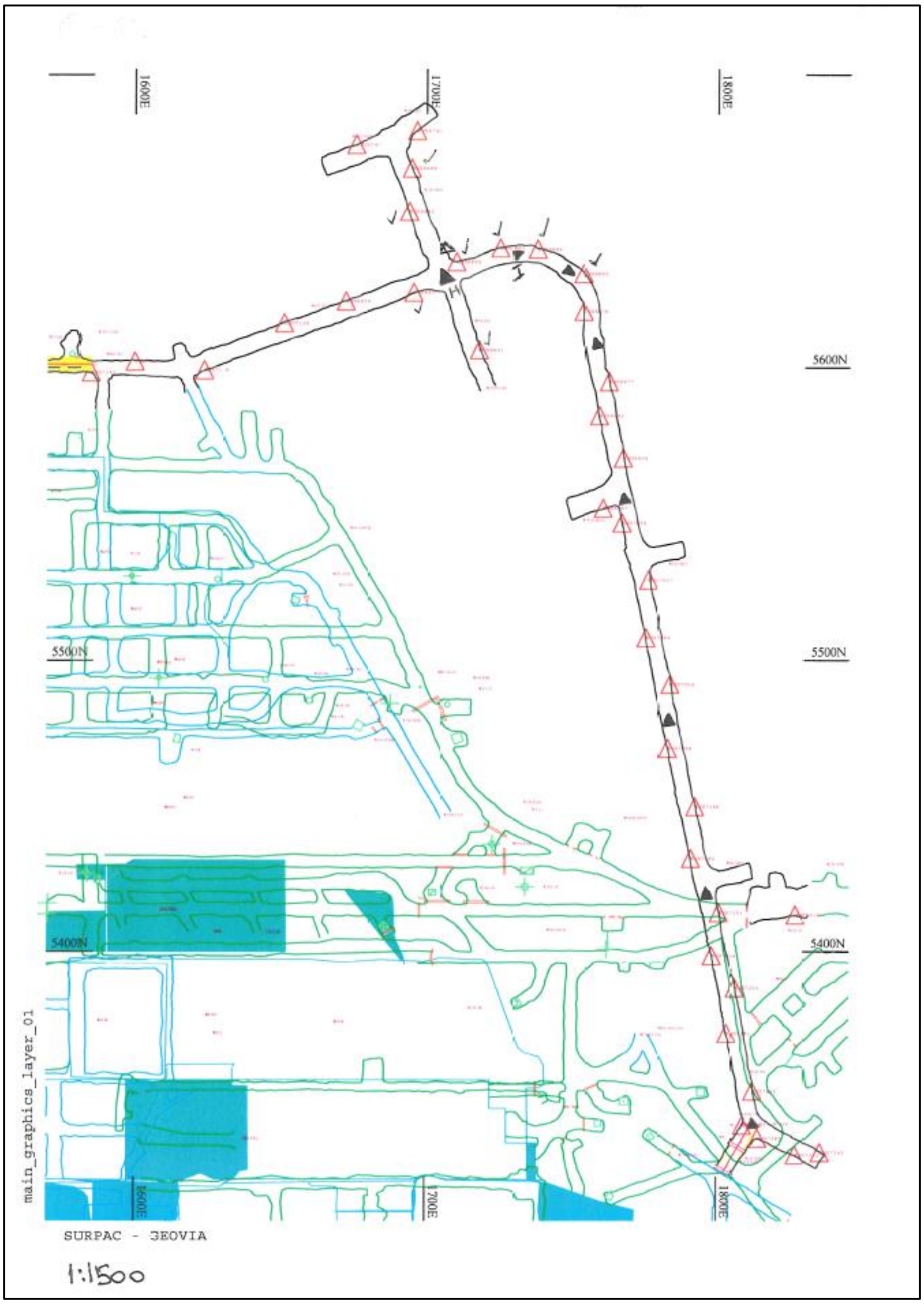
Day 2	Location: 15L/15D O56 INC	FileName: RS020216		
Station	**Type (Inst/BS)**	**Height**	**Temp(°C)**	**Press(hPa)**
RS020216A	INST	0	34.1	1041.0
RS020216B	INST	0	34.7	1040.6
RS020216C	INST	0	34.9	1040.5
RS020216D	INST	0	34.6	1040.2
RS020216E	INST	0	33.9	1038.9
RS020216F	INST	0	33.0	1037.7
RS020216G	INST	0	32.9	1037.8
RS020216H	INST	0	34.2	1035.7

RS020216I	INST	0	35.1	1033.9
***RS020216J**	INST	0	35.9	1032.7
***RS020216J**	INST	0	35.7	1032.7
RS020216K	INST	0	36.7	1032.8
RS020216L	INST	0	35.0	1033.6
RS020216M	INST	0	34.4	1033.5
RS020216N	INST	0	33.1	1034.1

Day 3	**Location: 15L/15D O56 INC**	**FileName: RS050216**		
Station	Type (Inst/BS)	Height	Temp(°C)	Press(hPa)
RS050216A	INST	0	31.0	1039.7
RS050216B	INST	0	32.1	1040.4
RS050216C	INST	0	32.9	1041.2
RS050216D	INST	0	33.5	1042.6
RS050216E	INST	0	34.6	1043.6
RS050216F	INST	0	34.0	1043.4
RS050216G	INST	0	35.0	1043.3
RS050216H	INST	0	33.6	1041.4
RS050216I	INST	0	33.5	1041.2
RS050216J	INST	0	33.5	1042.0
RS050216K	INST	0	32.5	1041.8
RS050216L	INST	0	33.0	1041.7
RS050216M	INST	0	32.7	1042.6
RS050216N	INST	0	33.3	1040.3

Appendix E: FIELD SHEETS OF SITE




1600E
1700E
1800E
5600N
5500N
5400N
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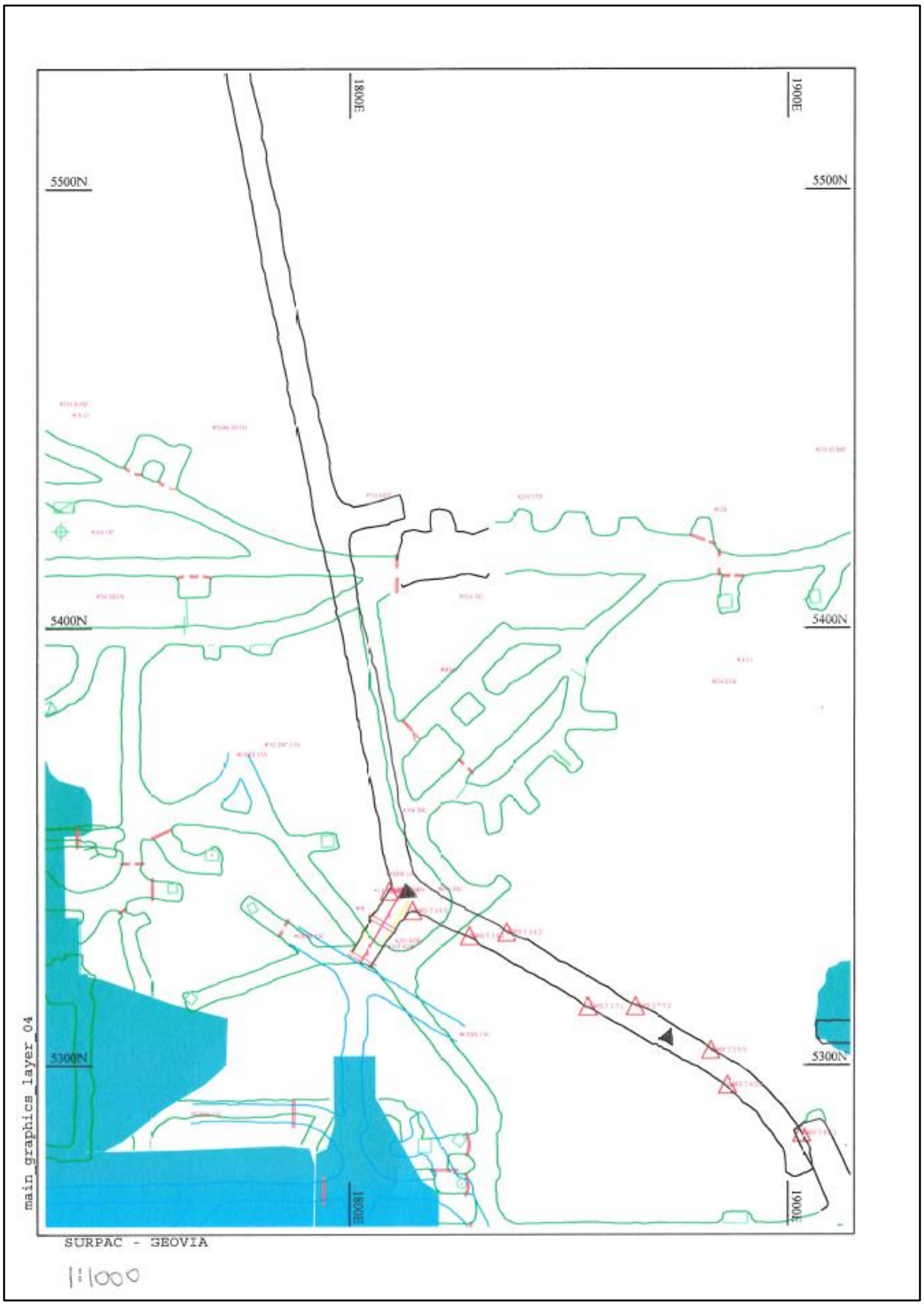
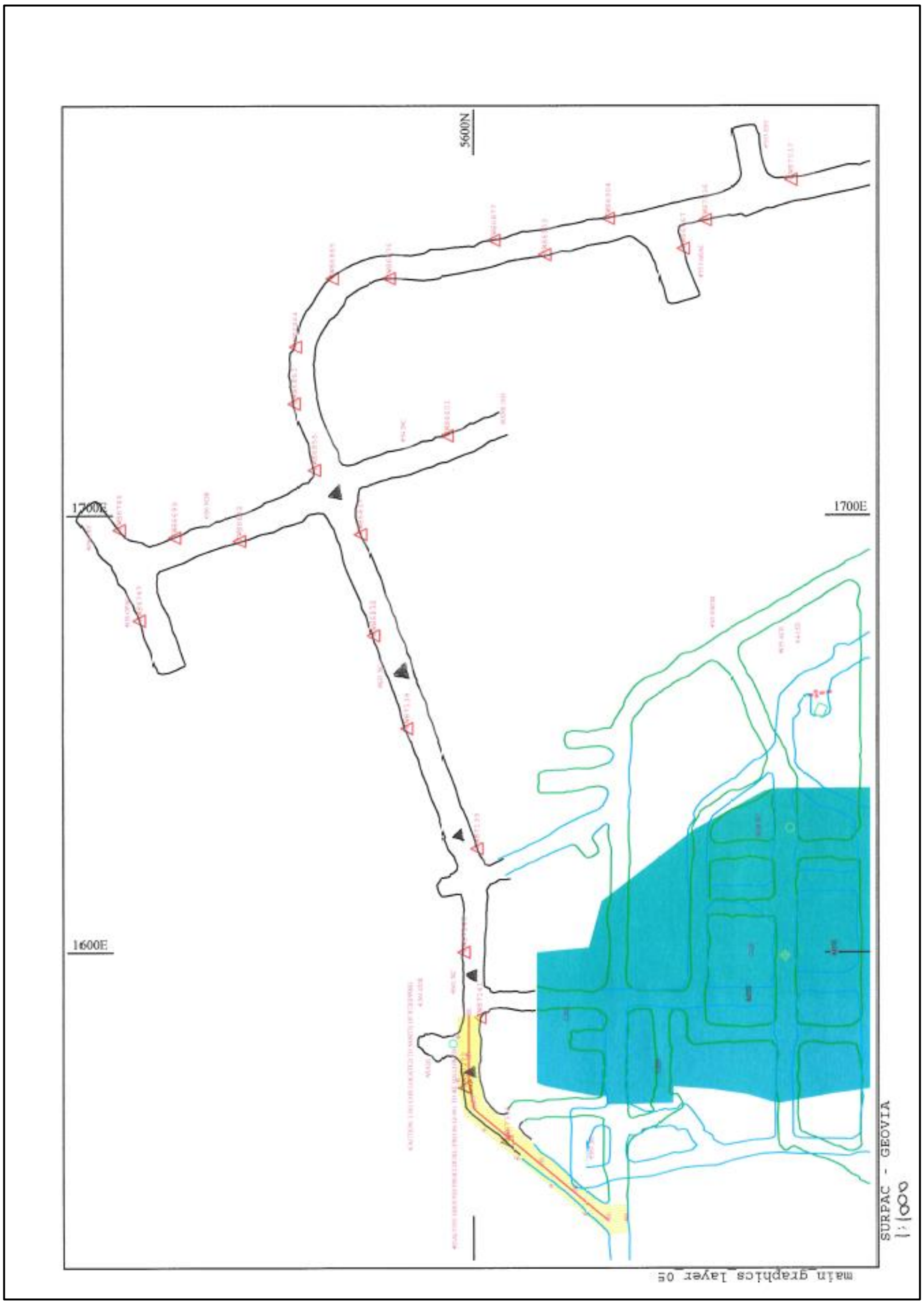
SURPAC - GEOVIA
1:1500


1800E
1900E
5500N
5500N
5400N
5400N
5300N
5300N
1800E
1900E
main graphics layer 04
SURPAC - GEOVIA
1:1000


5600N
1700E
1700E
1600E
SURPAC - GEOVIA
1:1000
main graphics layer 05

Appendix F: <u>ADJUSTED COORDINATES</u>

Station	Std Dev E	Std Dev N	Std Dev H
CTS5555	0	0	0
CTS5572	0	0	0
CTS5573	0	0	0
CTS5529	0	0	0
CTS5480	0	0	0
CTS5488	0	0	0
CTS5469	0	0	0
CTS5441	0	0	0
CTS5468	0	0	0
CTS5424	0	0	0
CTS5389	0	0	0
CTS5440	0	0	0
CTS6369	0.0004	0.0003	0.0002
CTS4296	0.0004	0.0003	0.0002
CTS6473	0.0004	0.0003	0.0002
CTS6449	0.0004	0.0004	0.0002
CTS6474	0.0004	0.0005	0.0002
CTS6507	0.0009	0.0007	0.0003
CTS6545	0.0015	0.0009	0.0003
CTS6506	0.0007	0.0006	0.0003
CTS6549	0.0024	0.0013	0.0003
CTS6550	0.0029	0.0014	0.0003
CTS6546	0.0021	0.001	0.0003
CTS6600	0.0035	0.0017	0.0003
CTS4297	0.0047	0.002	0.0003
CTS6601	0.004	0.0017	0.0003
CTS6837	0.0044	0.0022	0.0003

CTS6652	0.0051	0.0023	0.0003
CTS6699	0.0055	0.0023	0.0003
CTS6855	0.0047	0.0019	0.0003
CTS6863	0.0048	0.0015	0.0003
CTS6864	0.0048	0.0013	0.0003
CTS6865	0.0046	0.001	0.0003
CTS4298	0.0041	0.001	0.0003
CTS4299	0.0039	0.001	0.0003
CTS6904	0.0033	0.001	0.0004
CTS7037	0.003	0.0011	0.0004
CTS7036	0.0031	0.001	0.0004
CTS6903	0.0036	0.001	0.0004
CTS6876	0.0043	0.0011	0.0004
CTS7054	0.0031	0.0012	0.0004
CTS4301	0.0037	0.0013	0.0004
CTS7099	0.0034	0.0011	0.0004
CTS4300	0.003	0.0011	0.0004
CTS7253	0.0046	0.0015	0.0004
CTS7255	0.0053	0.0016	0.0004
CTS7182	0.0041	0.0013	0.0004
CTS7282	0.0062	0.0018	0.0004
CTS7385	0.0067	0.0019	0.0004
CTS4302	0.0064	0.0017	0.0004
CTS7281	0.0057	0.0016	0.0004
CTS7254	0.005	0.0015	0.0004
CTS7342	0.0069	0.0025	0.0004
CTS4303	0.007	0.0028	0.0004
CTS7399	0.0077	0.0039	0.0004
CTS7371	0.0074	0.003	0.0004
CTS7341	0.0069	0.0022	0.0004
CTS7357	0.0066	0.0017	0.0004

CTS4304	0.008	0.0044	0.0004
CTS7401	0.0082	0.0046	0.0004
CTS7400	0.0079	0.0041	0.0004
CTS4305	0.0088	0.0047	0.0006

Appendix G: RELATIVE ELLIPSES 95%

DESCRIPTION	MAJOR AXIS	MINOR AXIS	ORIENTATION			VERTICAL
CTS5555	0	0	45–	00'	00.00"	0
CTS5572	0	0	45–	00'	00.00"	0
CTS5573	0	0	45–	00'	00.00"	0
CTS5529	0	0	45–	00'	00.00"	0
CTS5480	0	0	45–	00'	00.00"	0
CTS5488	0	0	45–	00'	00.00"	0
CTS5469	0	0	45–	00'	00.00"	0
CTS5441	0	0	45–	00'	00.00"	0
CTS5468	0	0	45–	00'	00.00"	0
CTS5424	0	0	45–	00'	00.00"	0
CTS5389	0	0	45–	00'	00.00"	0
CTS5440	0	0	45–	00'	00.00"	0
190116A	0.0007	0.0005	178–	43'	36.17"	0.0003
190116B	0.0006	0.0004	165–	31'	27.16"	0.0003
CTS6369	0.0012	0.0008	70–	55'	26.08"	0.0006
CTS4296	0.0011	0.0008	86–	44'	49.85"	0.0005
CTS6473	0.001	0.0009	90–	34'	11.47"	0.0005
190116D	0.001	0.0009	100–	19'	54.63"	0.0005
190116C	0.0007	0.0004	156–	55'	02.24"	0.0003
CTS6449	0.0012	0.0009	57–	50'	58.97"	0.0006
CTS6474	0.0014	0.0012	8–	33'	20.66"	0.0006
190116E	0.0012	0.0011	10–	57'	38.71"	0.0006
CTS6507	0.0029	0.0014	54–	44'	54.63"	0.0007
CTS6545	0.0048	0.0014	61–	05'	25.71"	0.0007
190116F	0.0044	0.0012	63–	32'	49.84"	0.0006
CTS6506	0.0022	0.0014	58–	09'	11.89"	0.0007

CTS6549	0.0075	0.0015	64–	06'	58.86"	0.0008
CTS6550	0.009	0.0015	64–	55'	01.58"	0.0008
190116G	0.0086	0.0014	66–	12'	11.11"	0.0007
CTS6546	0.0064	0.0015	66–	15'	49.56"	0.0008
CTS6600	0.0108	0.0016	65–	39'	45.72"	0.0008
190116H	0.0139	0.0014	67–	12'	30.65"	0.0008
CTS4297	0.0143	0.0016	67–	57'	45.02"	0.0008
CTS6601	0.012	0.0017	67–	29'	51.94"	0.0008
CTS6837	0.0138	0.0015	63–	44'	28.77"	0.0009
CTS6652	0.0156	0.0019	66–	31'	12.31"	0.0009
CTS6699	0.0165	0.0019	68–	03'	29.35"	0.0009
CTS6855	0.0141	0.0015	68–	41'	47.59"	0.0009
CTS6863	0.014	0.0015	73–	09'	50.89"	0.0008
190116I	0.0139	0.0016	75–	21'	01.61"	0.0008
CTS6864	0.0138	0.0016	76–	39'	06.36"	0.0008
CTS6865	0.013	0.0019	80–	37'	30.57"	0.0009
20216A	0.0139	0.0015	67–	12'	36.95"	0.0008
20216B	0.0139	0.0016	75–	17'	25.46"	0.0008
20216C	0.0131	0.0019	79–	58'	13.80"	0.0009
CTS4298	0.0117	0.0022	80–	45'	07.73"	0.001
CTS4299	0.011	0.0022	80–	28'	27.41"	0.001
20216D	0.0112	0.002	79–	26'	37.27"	0.0009
CTS6904	0.0095	0.0024	79–	27'	10.55"	0.001
CTS7037	0.0085	0.0022	76–	43'	01.27"	0.001
20216E	0.0086	0.002	76–	57'	46.31"	0.001
CTS7036	0.0088	0.0021	77–	27'	22.06"	0.001
CTS6903	0.0102	0.0021	78–	31'	47.64"	0.001
CTS6876	0.0122	0.0021	79–	43'	39.43"	0.001
CTS7054	0.0091	0.0023	74–	27'	58.15"	0.0011
CTS4301	0.0107	0.0021	74–	02'	52.45"	0.001

20216F	0.0104	0.002	75–		03'	40.72"	0.001
CTS7099	0.0098	0.0021	75–		23'	46.05"	0.001
CTS4300	0.0086	0.0021	75–		54'	26.00"	0.001
CTS7253	0.0133	0.0022	74–		04'	10.01"	0.0011
CTS7255	0.0152	0.0022	74–		25'	49.87"	0.0011
20216G	0.0147	0.0021	75–		32'	28.87"	0.001
CTS7182	0.012	0.0021	75–		33'	51.78"	0.001
CTS7282	0.018	0.0023	75–		12'	47.32"	0.0011
CTS7385	0.0193	0.0023	75–		48'	23.67"	0.0011
20216H	0.0188	0.0021	76–		02'	17.56"	0.0011
CTS4302	0.0185	0.0022	76–		36'	40.83"	0.0011
CTS7281	0.0163	0.0023	76–		15'	13.27"	0.0011
CTS7254	0.0143	0.0022	75–		53'	02.21"	0.0011
CTS7342	0.0202	0.0024	71–		10'	48.74"	0.0012
CTS4303	0.0209	0.0026	69–		22'	55.52"	0.0012
CTS7399	0.0239	0.0031	63–		37'	08.86"	0.0012
20216I	0.0237	0.003	64–		13'	55.24"	0.0011
CTS7371	0.0221	0.0027	68–		25'	40.34"	0.0012
CTS7341	0.0201	0.0024	73–		12'	23.70"	0.0012
CTS7357	0.0189	0.0022	76–		49'	41.48"	0.0012
CTS4304	0.0253	0.0034	61–		53'	43.74"	0.0012
CTS7401	0.0262	0.0034	61–		28'	48.74"	0.0012
20216J	0.0259	0.0033	61–		48'	16.10"	0.0011
CTS7400	0.0246	0.0032	63–		34'	45.56"	0.0012
CTS4305	0.0277	0.0038	62–		39'	42.08"	0.0015
20216K	0.0236	0.003	64–		20'	10.65"	0.0011
20216L	0.0189	0.0021	76–		10'	33.17"	0.0011
20216M	0.0146	0.0021	75–		33'	58.22"	0.001
20216N	0.0103	0.0021	74–		59'	37.57"	0.001
50216A	0.0147	0.0021	74–		51'	10.89"	0.001

50216B	0.0104	0.0021	74–	18'	30.05"	0.001
50216C	0.0086	0.002	77–	00'	33.58"	0.0009
50216D	0.0112	0.0021	80–	10'	26.59"	0.0009
50216E	0.0129	0.0019	80–	25'	17.98"	0.0009
50216F	0.0139	0.0016	74–	49'	01.54"	0.0008
50216G	0.0139	0.0014	67–	07'	38.27"	0.0007
50216H	0.0085	0.0013	66–	08'	02.38"	0.0007
50216I	0.0043	0.0012	63–	23'	48.70"	0.0006
50216J	0.0012	0.0011	170–	16'	43.06"	0.0006
50216K	0.001	0.0008	98–	42'	27.03"	0.0005
50216L	0.0006	0.0004	165–	45'	50.20"	0.0003
50216M	0.0006	0.0004	158–	49'	54.88"	0.0003
50216N	0.0006	0.0005	178–	50'	14.51"	0.0003