University of Southern Queensland

Faculty of Health, Engineering and Sciences

Investigation of Dam Wall Deformation Surveys

A dissertation submitted by

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Abstract:

Dam walls are monitored by surveyors periodically to ensure that there is no deformation movement within the dam wall. Surveyors have been doing these for years but what determines the quality of these measurements. This research project aims to evaluate Hunter and Fells guidelines using monitoring data and how this guideline can be enhanced with a survey field procedure to produce the best results in the shortest time.

Dam Walls are extremely important assets to the community but pose a large threat to both the environment and people living downstream if the dam wall were to fail. Cressbrook Dam, Cooby Dam and Lake Perseverance are all maintained by Toowoomba Regional Council all situated to the North of Toowoomba. These dam walls need to be monitored using qualitative and quantitative data to ensure they don't have a breach.

There are many varying opinions on what is the best survey method to conduct a valid deformation survey. The case study data will be utilised to evaluate whether or not Hunter and Fells movement guidelines can be applied for the general surveyor to use. This will involve developing a spreadsheet that can interpret coordinates and organise them in a way to aid the process.

Secondly observations have been done using a robotic and a non-robotic total station. The data has been processed so that the different methods of survey can be analysed in a least squares adjustment using Starnet Software. These survey methods will then be applied to the literature guidelines to determine the most effective procedure of dam wall monitoring.

The key outcomes of this project have been that a suitable excel spreadsheet has been created for easy analysis of survey data to Hunter and Fells guideline. The field work has been completed and the result processed. Some interesting patterns emerged with the robotic total station being much easier to measure, record and export the data. The non-robotic total station produced substandard results but partially produced results similar to the robotic machine. An interesting outcome was that the stations below the monitoring points delivered a height that was differing to the station situated above the monitoring points.

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Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, 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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Chapter 1 Introduction

1.1 Introduction

The role of a dam is to essentially store large amounts of water to utilise in times of need. These days they are used for many principles such as hydro-electric schemes to produce electricity, irrigation plans to help farmers as well as flood control. All these uses and more are vital to a comfortable mankind existence in a developed country. Dams are classified normally under what materials they are made of. A couple of the main types are; rock fill with earth core/clay core, earth fill with concrete face or rock protection, and full concrete dam walls (Singh, 1996). Each of these dams has their own accompanying issues and challenges. Each dam wall site has the main distinguisher of topographic and geological attributes that determine the suitability of a particular dam wall to an area. These things are also the main characteristics that can influence the severity of dam wall movement that can be measured from a total station. For example if a dam wall with a large amount of concrete on the face the expansion and shrinkage values will be far greater than a earth fill wall with rock protection. The core strength of a dam wall is contained in the capabilities of the foundations to withstand the forces acting against it. (Singh, 1996)

Dam Walls have a large catastrophic outcome in the risk matrix but have a rare chance of happening in the scheme of things. The issue with a dam wall breakage is that so much large scale damage will be done and therefore inspections and monitoring will need to occur frequently so to lower the risk even more to virtually nothing. In history, dam walls have broken and this extreme danger will be experienced by all living things downstream including loss of life to humans, therefore dam safety programs have been introduced worldwide since the 19^{th} century. (Singh, 1996) ICOLD is the international committee on large dams and oversees many organisations within respective countries such as the Australian Committee on Large dams incorporated (ANCOLD) for an example of the Australian representative.

Monitoring Surveys have been around for a very long time. Originally they were done using a level for heights and a theodolite and chain for angles and distances to create coordinate tables, these tables were then compared to the original measured values. This is the fundamental principle concerning monitoring surveys and is still done to this day. Now days the equipment has rapidly advanced to automated total stations measuring horizontal angles, vertical angles as well as Electronic distance measurement to obtain coordinate lists for comparison to original values. Also with this technology came with it corresponding software to reduce the complicated raw data stored on data loggers. This software uses statistical analyses to produce results. These results are usually accompanied by check shots on control marks that are in natural ground and are significantly stable. For example a concrete pillar to certify your data. What I intend to research is what survey procedures will have an effect on the reduced data using the least squares algorithms available through the Starnet software. This will hopefully allow me to determine what method will produce the best results in the shortest time and therefore the minimal cost to the client. In the 21^{st} century as surveying is becoming more automated an increasing amount of pressure is placed on surveyors to produce accurate results that are cheap and this research should hopefully answer these questions.

Toowoomba Regional Council is the custodian of three dams that supply water to the people of the darling downs. These dams carry high risk and large volumes of water storage. This year is the 5 yearly comprehensive inspections carried out by external contractors. Part of this was our team producing monitoring values for the dams in a technical report. The task was to look into TRC dam wall monitoring survey procedures and to test and evaluate different methods for us to use in the future with the research to back up the claims. Toowoomba Regional Councils current survey method has the potential to be improved and to be made much safer. As time constraints didn't allow me to apply the results in this year's technical report hopefully they will be utilised next year but as the data was still obtained and it is within the dissertation's scope of works therefore I chose to do this research project on this topic.

1.2 Aims and Objectives

The aim of this project is to test Gavan Hunter and Robin Fell's guidelines against the monitoring data of Cressbrook Dam, Cooby Dam and Lake Perseverance Dam wall. Also an investigation of the specific surveying standards in my literature review, concerning monitoring surveys and determine where faults could be in the data from survey procedure. Two different total stations will be field tested using three different methods.

A report will be produced on the differences and how these could determine whether a dam is producing normal or abnormal qualities using quantified data. Through critical analysis of the deliverables comparisons will be able to produce in my dissertation such; whether or not Hunter and Fell's guidelines work on my case study data, what differences each respective method and technology make to whether a dam wall fits the guidelines concerning survey procedure as well as produce a recommended survey procedure for deformation monitoring of dam walls. This procedure could possibly be used as a guideline in the industry to produce the most accurate, reliable data which then would allow correct analysis to Hunter and Fell's guidelines across all surveyors who monitor their corresponding dams. My project will look at the dam wall moving as a whole using an average of all the movement data sets for that particular wall on a sample of survey monitoring points.

The scope of work has been taken into account from allowable work resources as well as my ability as a surveyor. Most of all the scope is to do a comprehensive evaluation of survey procedure of measuring a dam wall with the brief of only using available equipment as well as time resources.

1.3 Research Limitations

The corresponding research project has some limitations to the results. In surveying no measurement is 100% the true value and therefore when comparing coordinates that have multiple decimal points how realistic they are in a real world context is questioned as a surveyor can only measure to 1mm in practice. Another limitation to this work is that when three stations analysis was done there was only line of sight to half the monitoring points, therefore only points 6-10 have been readjusted in the least squares adjustment. This is of no major concern as it represents a real world scenario. Another limitation was that both total stations used were 3” machines and it could be argued that as we are reading fairly long distances the results are within the accuracy limit of the total station. For the purpose of the research project this was mitigated by taking the average over ten points in the analysis. Due to time and resources limits a 1” total station wasn’t utilised to measure the points. It would be interesting to note what effect this would have against our control values.

1.4 Overview of Dissertation

This research project contains 5 main chapters and a brief summary is provided below.

1. **Introduction –** An introduction to the concept of dam wall movement and monitoring surveys as well as the objectives of this project.
2. **Literature review** – This section provides an in-depth view into the current literature relating to dam wall deformation surveys as well as a review of current movement guidelines.
3. **Methodology –** The chapter details the methodology that is going to be required to complete the research objectives. It includes the process of how the data will be collected as well as how it will be processed to for analysis.
4. **Results and Discussion –** This chapter is where the results will be displayed for comparison and analysed with discussion relating to the results.
5. **Conclusions and Recommendations –** Recommendations will then be stated for future monitoring surveys in the context of a dam wall situation.

Chapter 2 Literature Review

2.1 Introduction

A literature review will be undertaken to achieve exceptional knowledge about the particular subject so these skills can be applied to thoroughly examine my results that are backed by relating literature.

One potential source will be analysed greatly as the research project incorporates some of the associated theories published in the book. Gavan Hunter and Robin Fell are university lectures from University of New South Wales and have produced a book "The deformation behaviour of embankment dams." This book details what characteristics is expected movement of a dam wall and provides case studies to back up this research to produce a guideline of what should be expected and what is considered "abnormal" behaviour. Within this research quantitative results are obtained and detailed below. These results give expected movement values for a dam wall when taking into consideration of time and dam wall height to make each dam wall comparable to another.

2.2 Monitoring Surveys

Monitoring Surveys can also be known as deformation surveys. Structures such as bridges and dam walls need to be monitored for horizontal and vertical displacement over a period of time at a predetermined point that should only move if the structure moves with it. (MainRoads, 2014) All monitoring survey work must be sufficient to accurately measure horizontal and vertical movement to up to + or – 2mm. (MainRoads, 2014) Control Networks should be established so the integrity of the monitoring data can be guaranteed. A three tiered network should be employed. This should consist of a major control network (MCN), a secondary control network (SCN) close to the structure and the monitoring points themselves. (MainRoads, 2014) Basically they are just levels of checks to ensure quality of results. A first order mark should be used to establish these points. Horizontal reduction is required using least squares adjustment with the major control network as fixed. (MainRoads, 2014)

Multiple Arcs and distance are to be read to each monitoring point as well as to the Main Control Network to ensure sufficient proof of movement as well as to minimise measurement errors. Angles should not have a standard deviation greater than 3 seconds and distance standard deviation of 2 mm. It is essential that correct atmospheric corrections are entered into the total station. (MainRoads, 2014) Due to these factors I will be reading multiple angles and distances as well as carrying a thermometer with me to ensure the surveyor inputs the correct temperature in. The reason for all these observations is that when they are put through a least squares adjustment using Starnet software, a very statistically precise and accurate position will be gained.

A high precision total station should be used in monitoring surveys to increase reliability and validity especially since monitoring is a high accuracy survey. Two different totals stations will be testing two different total stations in my methodologies. A Trimble S6 fully robotic total station which is a 3” machine will be the first trialled. It will be compared to a Sokkia Set 3x total station that is 3” machine which isn’t robotic at all and observations will be recorded by hand. Then the method will be to determine what difference it makes depending robotic or non-robotic total station. Please see appendix B and C for their corresponding data sheets of the specifications.

For example a total station will have the below specifications which are input into the adjustment software. In prism mode it has a standard measurement error of 1 mm + 1 ppm and a standard deviation in distance measurement of 0.8mm + 1ppm. (Trimble, 2014) For example let’s say our backsight is 450m away for example. This means that 1+1*0.450 = 0.0009m (0.9mm) of error over 450m. Now most of our monitoring points are within 150m therefore there is 1+1*0.150 = 0.3mm or 0.0003m of measurement error. This proves that we are measuring an accuracy of under one mm therefore we can sufficiently say that the monitoring points have moved x amount.

The ANZILIC Committee on Surveying and Mapping (ICSM) produces standards for the surveying community. The procedure for Control Surveys is detailed in the Standard for the Australian Survey Control Network Special Publication 1 (SP1 V2.1). This standard was adhered to concerning the establishment of the control network surrounding the dam.

The control network at the dam site will need to be re-established. The control needs to be the highest class and order as possible. The control will be aiming for a Class A survey with a 1st order allowable limit. A Class A survey network is adjusted in a constrained least squares process which satisfies appropriate statistical tests. (ICSM, 2007) The datum will be placed in an arbitrary coordinate system and the constraints that will be held in the network adjustment is the direction across the wall for the control so that the upstream side is on the right and the downstream is on the left. To determine if the control is of the correct order the below equation and procedures will be utilised.

$$r = c(d + 0.2) \quad (1.1)$$

R = length of the 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 between the stations in kilometers.

Equation1.1 is ICSM 2007, p.A-9 which is standards of accuracy guidelines for surveyors. This will allow a test for the quality of the control against a standardized guideline.

ORDER	**C value** (for one sigma)
00	1
0	3
1	7.5
2	15
3	30
4	50
5	100

Table 1: Order of Horizontal Control Surveys (ICSM, 2014)

Above is the constant to be used depending on the class of survey for the desired control network. Also the Survey Practice Standard 1 Version 2.1 also explains that the vertical datum should be used should be AHD. As the original survey was done before the AHD as it is known today. The datum is actually AHD71, state datum where a level run was done from the Mean Sea level of Brisbane. I will be doing the field surveys on an arbitrary datum so the measurements and coordinates are different to what is currently being used.

The error sources of a high precision survey are instrumental errors, natural errors and personal errors. Furthermore there are also errors are classified as random or systematic errors. Systematic errors can be predicted and therefore mitigated in the adjustment process. Random errors are much harder to predict and can't be 100% quantified therefore a plus or minus accuracy value is placed on them. (Gihilani, 2010) Random Errors must be dealt with by using the mathematical theory of probability. Normally these errors are commonly defined as mistakes or accidents but there is only so much accuracy a measurement can have. (Gihilani, 2010) For example a human's ability to exactly centre a tripod over a mark looking through an optical plummet.

2.3 Soil Settlement Rates

Saturation of Soils defines as the amount of air and water mixture contained in the pores of the soil. For example a significant immediate settlement may occur in unsaturated soil with the application of external loads. (Ausilio & Conte, Oct 1999)

The survey monitoring points are built like house foundations in unsaturated soil. Therefore the following paper allows us to determine an equation for soil settlement, thus allowing us to gain a relatively close expectation of what the monitoring points should be doing.

However significant differences arise during the early stages of consolidation, when settlement is affected by the more instantaneous dissipation of air pressure. As the more Transient process develops the amount of deformation to be ascribed to water flow become much more significant. (Ausilio & Conte, Oct 1999) This document also shows the effect that pressure placed on pores in kPa makes the soil move up to 180mm once the full load is placed upon it and the soil reaches full compaction. (Ausilio & Conte, Oct 1999)

Leaks in earth filled dams that lead to failures are often of inadequate compaction levels. Therefore it is important that effective compaction is achieved (WaterResources, 2008). The dam should be constructed in layers no greater than 150mm. The compaction effort achieved should be on average 98% standard Maximum Dry Density as in context to modified maximum dry density as per Australian Standard: AS1289.0-2000 Methods for testing soils for engineering purposes. (WaterResources, 2008) Moisture Content should be in the range of -1% to +3% of optimum moisture content. (WaterResources, 2008) What they are trying to say here is that the dam wall needs to be built like a road to gain maximum compaction so it doesn’t fail. After each layer is applied it needs to have water added to it and compacted sufficiently, for example with a roller. It is the Dam owner’s responsibility to maintain the dam in a safe condition at all times including the maintenance of an adequate spillway able to pass the specified flood flows. (WaterResources, 2008)

Hunter & Fell (2003) explain that there are Empirical and Numerical Predictive methods to produce an expectation of what deformation should occur. These models and formulas are derived from historical deformation performance from relevant databases. ICOLD (1993) made a general formula among other people based on the linear relationship between stress and strain of the materials in the dam wall. This formula also accountants for the time as well to predict the deformation movement of the dam, as a certain time in the future. The formula is listed below.

$$e = \frac{\sigma}{E_M} + \sigma \frac{t}{\theta + \lambda t} \qquad (1.2)$$

e = *relative strain*

$\sigma = vertical\ stress\ (in\ MPA)$

$E_m = modulus\ of\ instantaneous\ strain\ of\ the\ rockfill\ (in\ MPA)$

$\theta\ \&\ \lambda\ are\ parameters\ describing\ creep\ strain\ in\ \frac{MPA}{year}\ and\ MPA\ respectivly.$

Equation 1.2 is a simplified form of this equation and there is a much more complete explanation and derivation explained in ICOLD (1993). There are many different formulas to predict deformation movements. All of them come with warnings due to the range of case studies around them. This part of the literature review looks from a more civil engineering view point as this project will not be going into too much detail with this side of the investigation as the project will focus on a surveyor's viewpoint. Further work for an engineer would be to utilise the data to prove these formulas and critical evaluate them and their reasoning. It is of tradition that surveyors produce the data and reports for engineers to make decisions off.

2.4 Dam wall Design specifications for a clay core dam

Each Dam needs to be maintained and monitored to ensure the safety of the downstream population. Dams under the ANCOLD committee have specific hazard category ratings. The hazard category is based on the risk to the downstream community and environment if the dam failed. In general terms the more higher the category the more maintenance and monitoring are required to assure that the risk to the downstream community is minimised. (WaterResources, 2008) The specific level of work required to be undertaken to address the hazard category of a dam is detailed in. Please see appendix one for Cress brook Dam designs.

Berms are generally placed between embankments and any below ground excavations such as borrow pits or sumps. Berms are required in case the batter of the excavation becomes saturated and slumps, which can threaten the stability of the embankment. Berms are generally 5 to 10m wide. (FSA, March 2001) As you can see CressBrook Dam has multiple berms above a sump area. These berms are 10m high also. There is a relevant standard produced by ANCOLD on the building procedures of an Embankment Dam but I was unable to obtain a version of this due to financial limitations.

2.5 Redundant Measurements

If a monitoring point is not on stable ground then it must be verified prior to a monitoring cycle using a combination of terrestrial and static GPS observations. (MainRoads, 2014)

Significant checks need to be made on marks to ensure they haven't moved before you use it as control to measure monitoring points.

First you need to connect to a vertical and horizontal datum that is transformable. GPS uses derived AHD heights to AHD level from the ellipsoid. These can be converted using a transformation file such as AUSGeoid09 to account for the misalignment. (ICSM, 24 September 2014) With the use of multiple baselines and independent occupations a surveyor can significantly improve the repeatability of his results. (ICSM, 24 September 2014) This then can be a reliable check on the Major Control Network as it is the most unlikely to move.

AUSPOS online GPS processing Software hosted by Geoscience Australia allows users to submit GPS files observed in static mode and receive the coordinates with respect with GDA94 and ITRF. (ICSM, 24 September 2014) This thesis won't be able to use static GPS to check the marks as time at work just doesn't allow this to happen. The reason it have included it in the literature review is that static GPS can be used to establish and check control networks for monitoring surveys.

Also redundant checks can be done with a total station. These checks include measuring multiple measurements to the control network to ensure nothing has moved and as a validation of the data. This was done by setting up on differing stations as well as reading the monitoring points from different measurements. This will provide redundant checks especially when incorporated with the checks with the GPS to ensure the quality, reliability and the validity of the control network.

2.6 The Deformation Behaviour of Embankment Dams

Gavan Hunter and Robin Fell are lectures at the University of New South Wales and are this report on Deformation behaviour of dams. The main objectives of their study are listed below:

- Broadly define "normal" deformation behaviour and from this platform to then identify potentially "abnormal" deformation behaviour in terms of magnitude, rate or trend. (Hunter & Fell, 2003, p. 1)
- Provide some guidance on the trends in deformation behaviour that are potentially indicative of a marginally stable to unstable slope condition, and precursors to slope instability. (Hunter & Fell, 2003, p. 1)

Hunter & Fell (2003) used a database of 134 embankment dams all with extensive survey monitoring data as well as characteristic reports to obtain there guideline. Deformation behaviour of dam walls can be described in two ways, the settlement of the wall and the displacement of the wall. Settlement is the vertical movement of the wall and the displacement is the horizontal movement of the wall compared to the original values (Hunter & Fell, 2003). A total station will be used to gain these values, by a surveyor. Hunter & Fell (2003) also notes that settlement is used in terms of percentage.

Equation 1.3 shows how to determine the settlement percentage:

$$Deformation\ Settlement\ (\%) = \frac{\Delta\ monitoring\ difference\ from\ original\ values\ (m)}{Height\ of\ SMP\ from\ foundation\ of\ Wall\ (m)}$$

(1.3)

Hunter and Fell (2003) refer to horizontal movement as lateral displacement. This displacement is referenced to in terms of mm from the original monitoring point. Please see an example below to see how my survey monitoring data can be translated to their equations for comparison. Lateral Displacement can also be put in terms of % compared to height of dam. The reason the percentage value is utilised is so that comparisons can be made between dam walls and relevant factors are standardised so true comparisons can be made.

For example if a point on the crest of a dam has the original coordinates of X1 = 100, Y1 = 200, and Z1 = 50 but the monitoring values were X2 = 101, Y2 = 200.050 and Z2 = 49.750. The Surface Monitoring point is 50m from the foundation of the dam wall. First we need to take away Z1 from Z2 to find the settlement in metres. This equates to 0.250m in settlement. Therefore 0.250m/50m = 0.005 = 0.5% settlement. A negative value would mean that the dam wall has risen. To calculate lateral displacement use equation 1.4 which is an equation to find a distance between to Cartesian coordinates.

$$Distance\ between\ cartisian\ coordinates\ (m) =$$

$$\sqrt{[(X2 - X1)^2 + (Y2 - Y1)^2]} \qquad (1.4)$$

There using the above values the lateral displacement of the survey monitoring point is 1.02469m.

Core Width	Core Properties		No. Cases	Crest Settlement (% of dam height) *[1]		
	Class[n]	Moisture content		3 years	10 years	20 to 25 years
Thin to medium	CL/CH	Dry	9	0.05 to 0.55	0.10 to 0.65	0.20 to 0.95
		Wet	11	0.04 to 0.75	0.08 to 0.95	0.20 to 1.10
	SC/GC	Dry	5	0.10 to 0.25	0.10 to 0.40	< 0.5
		Wet	18	0.15 to 0.80	0.20 to 1.10	< 1.1
Thin to Thick	SM/GM	All	16	0.06 to 0.30	0.10 to 0.65	< 0.5 to 0.7
Thick	CL/CH	all (most dry)	12	0.02 to 0.75	0.10 to 1.0	0.5 to 1.0
	SC/GC	all (most dry)	5	0.05 to 0.20	0.10 to 0.35	0.10 to 0.45
Very Broad	all	all (most dry)	18	0.0 to 0.60	0.0 to 0.80	0.05 to 0.76

Note: *[1] excludes possible outliers.

Table 2: Typical Range of post construction crest settlement. (Hunter & Fell, 2003, p.80)

These values can be separated so both the downstream and upstream shoulders so they can be analysed.

As it can be seen from Table 2 it shows what the expected rate of settlement are over a longer period of time using averages from case studies. Other trends of the data show that most dams experience less than 0.5% in the first three years and less than 0.75% after 20 to 25 years (Hunter & Fell, 2003).

Also nearly all dam walls experience less than 1% crest settlement after construction for periods up to 20 to 25 years and longer after construction (Hunter & Fell, 2003).

From this table expected values for your particular dam wall can be calculated and therefore administrators of dam walls can compare their dam to these averaged values to see if the dam is showing positive or negative deformation traits.

"The data shows that for most cases the displacement post first filling is generally in the range of 35mm upstream to 100-150mm downstream, indicating that post first filing crest displacements are generally small and are not dependent on dam

height. Displacements outside this range may be indicative of "abnormal" deformation behaviour." (Hunter & Fell, 2003, p.108)

This statement demonstrates what sought of range we are looking for in the general displacement in our dams. These two main points from their report are used later in their report to demonstrate what abnormal qualities of a dam wall are.

The statement of:

"For zoned earth fill embankments, total displacements are up to 0.15 to 0.2% of the embankment height at 20 to 30 years after end of construction."

Source: Hunter and Fell, 2013, p.222)

This evaluation statement is what the project is going to use in the criteria of the Dam Wall case studies that are going to be obtained concerning the horizontal displacement.

2.7 Prediction of Abnormal behaviours

Overall Dam walls are very safe and stable structures with only 58 major dam wall breaches recorded in Singh (1996). There are many Empirical and Mathematical Models listed in Singh (1996) but Hunter & Fell (2003) look at the potential for a dam wall breach through a deformation viewpoint. While Singh (1996) investigates the dam wall failures after they are finished and what effect it will have on the areas below the dam wall. Singh's work is worth mentioning in this literature review as it looks at what happens when dam walls fail. This provides anybody doing further work to look at preventing dam failures using mathematical modelling technology together with survey monitoring data to get the predictions and assessment of safety to a much more accurate and precise evaluation for potential of a dam wall breach.

Abnormal behaviours of a dam wall might be subject to one area of the dam wall whilst the overall stability isn't in question of the dam wall. Deformation characteristics are used to identify if further investigation is necessary. (Hunter & Fell, 2003) Therefore from this statement my methods of analysing the survey monitoring data will be indicative for further investigation from qualified civil engineers. The scope will be applying the data to see if it is usable to compare to their statistics of their relevant case studies so that surveyors have a way of easily analysing the data to decide what to include in the monitoring report to their engineers. Hunter & Fell (2003) on page 143 demonstrates that when a dam wall is accelerating deformation movement it is indicating the onset of failure and needs to have a detailed look at it, to ensure safety of the dam.

An example of the type of movements that should be expected is presented in South East Queensland Water, Dam Surveillance Report in 2006. The maximum settlement value is 132mm over 22 years on the upstream edge of the crest. The maximum recorded movements in the X direction were 24mm with the general behaviour leading towards the right of the dam. The maximum displacement in the y direction was 87mm with the trend being in the general downstream direction. (SEQWater, 2006, p.41) This statement also shows an example of what format the reporting style is with the full monitoring data presented at the end of the report in the appendices. I gained these reports through a request for information through SEQWater.

In this Comprehensive inspection report SEQWater also present data from inclinometer readings. Now an inclinometer goes down a hole drilled in the dam and is brought back up and measure the path it took. (SEQWater, 2006, p.41) This is excellent for measuring core displacement as inside the dam might be accelerating from underneath at a faster rate than the surface monitoring points. Toowoomba Regional Council doesn't have the resources to do this type of data collection. Although it would be a great monitoring tool combined with the surface monitoring data to demonstrate the complete deformation behaviour of the wall compared to just the surface.

2.8 Issues related to Dam Wall deformation Surveys and Importance

When the dam wall is first filled the displacement and settlement of the dam wall experienced the greatest acceleration of deformation. Therefore this shows that water loading can have a huge effect on the monitoring points for a surveyor depending on the capacity of the dam. (Hunter & Fell, 2003, p.55) Also it is of general knowledge in the industry that dam walls can expand as well as shrink depending on the temperature of the environment it is in. As well as it is of general knowledge that concrete expands and shrinks due to temperature changes. This demonstrates that there will be potential errors in the survey monitoring points due to the fact that they are made of concrete and steel. Both affected by temperature. This shows that survey monitoring should be done to each point with the temperature around the same value of the original monitoring values. This will ensure overall repeatability and validity of data.

The principle causes of earth core dam failures are overtopping, piping, foundation and wave action. Also 40% of dams failed due to foundation problems although another 10% failed due to uneven settlement. (Singh, 1996, p. 29) This demonstrates to us how important deformation monitoring can be at potentially saving lives as well as economic savings with a potential of 50% of dam failures being able to be prevented.

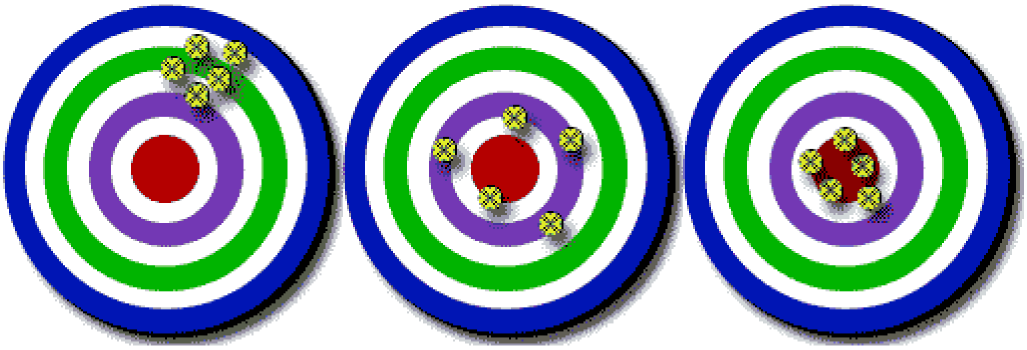
2.9 Least Squares Adjustment

A least squares adjustment is a technique of fitting numerous observations together to satisfy a defined mathematical structure. For example each station moves a little bit to best fit the fixed stations. (University of Southern Queensland, 2014) Basically it moves all observations a little bit to suit the mathematical model. This will be essential for our monitoring stations as they are going to determine the effect of what happens when a different control station is implemented in the mathematical model along with the associated observations from the different stations. When adding these parameters into the mathematical model, it will essentially make the final coordinates of the monitoring points satisfactory and in the most realistic position. Statistical tests such as the F Distribution Test as well as the Chi-Squared Distribution test are used to validate results. (University of Southern Queensland, 2014) These tests allow the observation quality to be analysed and therefore the exact validity of the whole survey can be tested, including the monitoring points, as multiple rounds are read between them. An output file from a least squares adjustment report should be produced from software to show how good the qualities of observations are. The observation data should at least be able to pass a Chi-Squared test and if unable to the standard residuals monitored to ensure the highest possible quality of data.

No measurement is 100% absolutely correct and surveyors need to be able to recognise these errors to be able to mitigate them. If these errors can't be fully mitigated the deliverables to the client needs to have a disclaimer determining the accuracy value of the measurements. For example in the context Permanent Survey Marks on their published coordinates they are a relevant class and order applied to them so that the user can determine how reliable the mark is. This idea of the accuracy of data needs to be measured and a least squares adjustment will determine the accuracy of a set of measurements. Below in this section it will go into what attributes are measured in a least squares adjustment as well as what the relevant statistical description mean. These statistical descriptions are utilised in the results section.

Another fundamental concept of a least squares adjustment is whether or not a measurement is accurate or precise. Accuracy is defined as how close a quantity is to its true value. (Ghilani, 2010) Although as an absolute value is never 100% correct so therefore a plus or minus value of a confidence region can be given to the measurement. Precision is the repeatability of a measurement and is measured by the consistency of the results. (Ghilani, 2010) A descriptor is used to quantify this attribute which will be discussed below. A representation of precision and accuracy can be seen below.

Please see Appendices D and E for Sample Input and Output Files for Microstation Starnet Least Squares adjustment Program.



Low Accuracy
High Precision

Low Accuracy
Low Precision

High Accuracy
High Precision

Figure 1: Precision v. Accuracy Measurement Qualities
(Source: Accuracy and Precision, 2016)

Statistics are used to determine the quality of a dataset. This can be applied to survey measurements to determine how accurate they are. The descriptors that are often used are listed below:

- Mean
  The mean is the Most Probable number of the data set and is calculated by the sum of number divided by the count of the data set. The mean is often used to determine accuracy of a dataset as it is considered the closest value to a true value. (Gihlani, 2010)

- Range
  The range is the difference between the lowest and highest value of a particular data set and is an indication of how precise a dataset is. This will be compared in the results to ensure a high quality result is obtained. (Gihlani, 2010)

- Median

  The median is the middle value in a dataset lying in between the highest and lowest value if the values were placed in chronological sequence. There is equal probability for a result to fall above or below it. The value combined with a frequency graph such as a histogram determines if there is a skew in the data, whether positive or negative. (Gihlani, 2010)

- Standard Deviation

  The standard deviation is the measurement of how precise a dataset is. It is commonly known as the description of the standard error associated with a dataset. Residuals are used in the adjustment against the most probable value to determine a practical expression of standard error. It is an indication of how our much the values differ from the mean. (Gihlani, 2010)

- 1st Quartile Analysis

  The 1st Quartile is the middle value between the start and median value of a dataset. (Gihlani, 2010)

- 3rd Quartile Analysis

  The 3rd Quartile is the middle value between the median value and the last value. (Gihlani, 2010)

- Interquartile Range

  Is a measure of dispersion of a dataset and shows the variance between the quarters of a dataset. Combined with the median these values can determine the skew of the data to show any patterns that are present. (Gihlani, 2010)

Please refer to Page 5.27 of Survey Computations B, USQ study book for detailed formula and explanation of statistical tests and deriving of formula for a least squares adjustment. This information hasn't been included as it has been deemed out of the project scope to include a full evaluation of the mathematical computation that the Starnet program does automatically.

2.10 Error Propagation

Error propagation is where a measurement is taken with a specific error associated to that measurement. For example a rule is read at 25cm with an error of ±0.001m. Now imagine if this error were to happen over and over again in a set of observations the error value would propagate. (Error Analysis, 2016) This propagation doesn't occur at a standard rate and a formula needs to be used to find what the actual error is going to be. This formula is:

$$Associated\ Error\ (\pm) = \sqrt{a^2 + b^2 + c^2}$$

This is formula is for the addition of errors and therefore is utilised in the accuracy formula to determine the accuracy value of a dam wall. (Error Analysis, 2016)

2.11 Conclusion

As it can be seen from this literature review there is extensive research into deformation surveying the relevant issues surrounding the topic. Although we are using industry accepted procedures we are going to test exactly what effects deformation surveying quality has on the overall deformation report of the dam wall as a whole. This literature review will be used to build a spreadsheet that will analyse survey data to produce deliverable results. Using this spreadsheet will compare the survey data and different techniques to see what effect it has on meeting dam wall specifications. The literature review shows examples of what should be expected deformation movement of a dam wall, which can be compared to the data sets to enable determination of Hunter & Fells analysis expressively if it is correct and can be applied to the real word.

Chapter 3 Methodology

3.1 Introduction

This chapter will detail the methodology used to meet the project objectives as stated in chapter 1. The methodology was produced with help of my supervisor and University of Southern Queensland technical staff to determine what the best procedures would be. The adopted project methodology will feature the following topics:

- Study Area and Data Collection
- Methods and Survey Procedures

3.2 Study Area and Data Collection

Using the survey data obtained from Toowoomba Regional Council it will be determined whether or not it meets the standard set by Hunter and Fell. They will be critically analysed as to why the case study did or did not meet the standards. If time and resources permit possibly more case study data could be gained through SEQ water to further test their guidelines and determine whether or not Hunter and Fell's guidelines are usable within the industry. For this section there is monitoring data for the Toowoomba Regional Council Dams but they will be refer to as Dam A, Dam B and Dam C so there is no confidentially issues or potential for defaming claims as no one knows exactly what dam is being used to evaluate Hunter & Fells process.

There are Survey Monitoring points on Cressbrook Wall and it will be the location of the field survey. The goal will be to determine the differences between two different total stations and three different methods to investigate what effect this has on whether the Dam wall is showing normal or abnormal movement patterns. Please see Project methodology to find detailed survey procedure for testing this objective. For the field survey Cressbrook Dam Wall will be the location although the survey datum will be placed on an arbitrary datum to ensure confidentiality of the current datum used. Please see figure 1 for a Google earth image of the site with the stations identified in the image.

Figure 2: Google Earth Image of Field Survey Site Location

3.3 Method and Survey Procedure

3.3.1 Introduction

The methodology consists of data collection from archived monitoring values as well as field collected from a deformation survey. These two combined procedures will allow me to determine what true movement in a dam wall is and what is due to survey error.

Figure 3: Trimble S6 Total Station Looking over Survey Site

3.3.2 Data Collection

The monitoring values for the last 30 years of Cressbrook, Cooby and Perseverance Dam Wall are able to be accessed for the scope of this dissertation. These will be analysed using the spreadsheet to see what Displacement and Settlement values there are for the Dam Wall as a whole. This will allow the data to be put into the same format as Hunter and Fell in their research. This will allow me to determine if the data fits there models of expectant movement rate. Other dam wall owners have been contacted and there is potential to gain more data but with large issues with confidentiality. This is not hugely important as there is enough data in the three dams to be able to develop a working spreadsheet that can be utilised to compare to Hunter and Fells data. Using Hunter and Fells research and guidelines to critically analyse why or why not the dam walls adhered to the research and possible reasons as to why not. Toowoomba Regional Council swapped from a Sokkia to an S6 at a certain date so to determine what accuracy values changed as they swapped to the more modern technology. This analysis will allow a determination if the dam wall is moving because of new technology, survey procedure or what is more likely the true movement value of the dam wall.

If time and Resources permit it would be ideal to get averages for Hunter and Fells case study data to create a working scale so that Dam operators can determine how far or close their dam wall is to the expected average.

The method will include building a spreadsheet that utilises survey monitoring data in the form of coordinates for all the comparisons of original values against the recently measured values.

Two different total stations will be used for comparisons. A Sokkia set 3x and a Trimble S6. These two different total stations are both 3” machines. Please see literature review section for a brief analysis of each total station and justification of why they are being used. Toowoomba Regional Council is submitting data to an independent reviewer of the dam walls and therefore possible new survey procedures are to be research for possible implementation with current procedures. Below are a couple different methodologies that will be analysed to see what differences each would make on the averages on the dam, using the spreadsheet to average all of the observations. This averaging will be able to put the dam wall into displacement and settlement values the same as Hunter and Fell and will allow us to investigate what properties the dam wall is showing compared to their findings. Common to all three methods is that 2 rounds will be read between each monitoring point and the closest station that will be held fixed in the least squares adjustment. A least squares adjustment will be applied to each method just to have a statistical mean and standard deviation as a way of quantifying the quality of the data. During field recon it was noted that the grass hasn’t been cut for a while and there is limited view from the control marks at the top of the dam. Therefore 10 points were picked that can be seen from two stations and 5 of them can be seen from a third station. These points will be used as the sample data set to see what effect this has on the overall results. The S6 will be used to re-establish the control so that it is extremely accurate for the rounds data to be fixed in the adjustment.

Initial comparisons that will be made are:

- There will be two rounds from each point to the backsight but only the Face 1 observations will be used in the least squares adjustment.
- There will still be two rounds but both F1/F2 observations will be used in the least squares adjustment.
- Whether observations from one station are enough, and what the effect is when each station is added to the least squares adjustment. This test is to see if all the effort to measure from 4 stations gives the same result from one station.

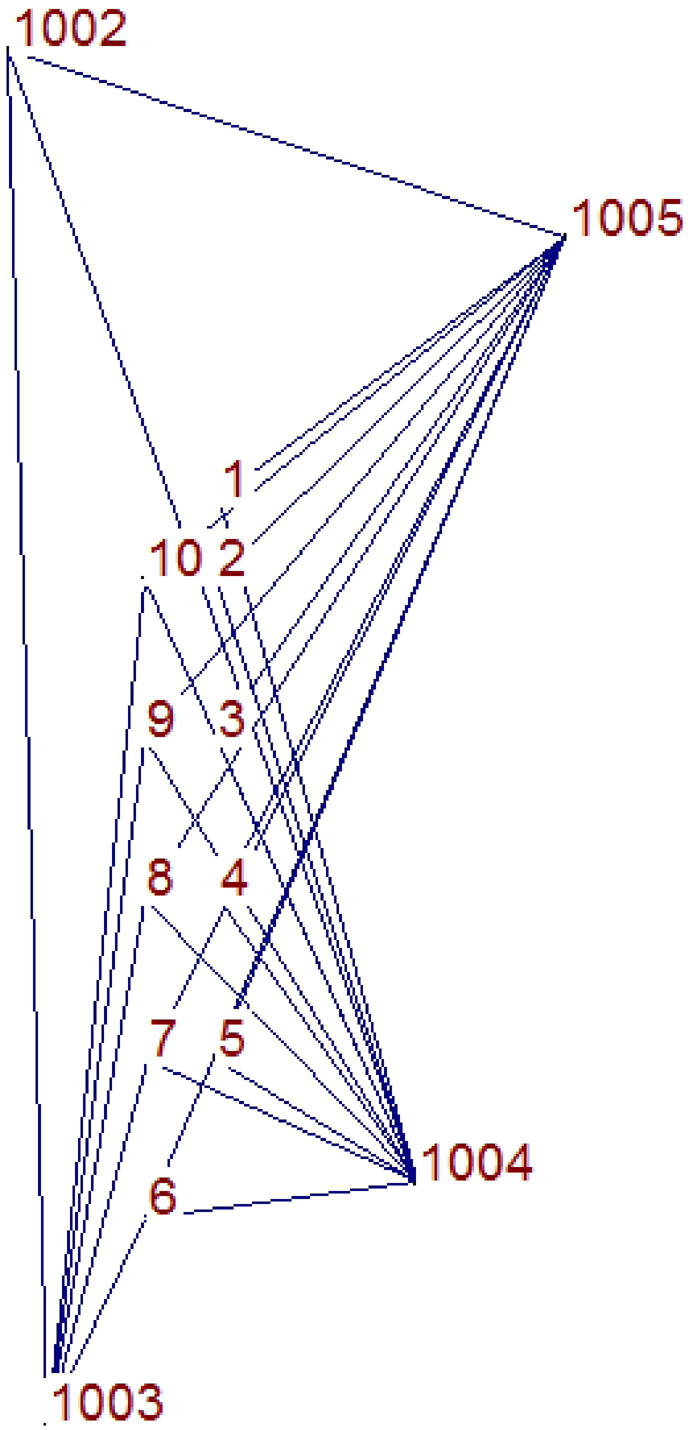


Figure 4: Network Plot of Control and Monitoring Points

As it can be seen from Figure 4 which is a corresponding network plot of the field survey. Included are the control stations and the corresponding monitoring points. This figure also demonstrates which monitoring points where measured from each station.

3.3.3 Deliverables for Comparison and Analysis

Hunter and Fells method of Dam wall comparison will see the coordinates compared in excel with the averages as well as statistical descriptors will be published of the averages of the wall. This will then be applied to their theory of movement and we can determine if the Dam Wall predictive methods are effective and correct to be used by the surveyor.

The deliverables of the data collection are going to be coordinates in excel spreadsheets from the particular methods against the controlled coordinates. From these graphs of the residuals will be created in both displacement and settlement comparisons. From this analysis, statistical descriptors will be created to determine the results of the overall comparison. From this our conclusions, can be established.

Figure 5: Survey Monitoring Point Example

The monitoring points for the council are essentially a house footing with a 0.450 by 0.450m footing that is 0.9 deep. With this there is a steel pip placed inside the concrete with is also filled with concrete for stability. A sleeve has then be placed for a plug to be inserted to establish the correct position. From this a large cap is screwed to the top of the pipe to ensure the point isn't affected by the weather conditions. Please see figure 4 for a picture of the relevant monitoring points.

The control stations are permanent survey marks currently which consist of a deep driven star picket in a concrete collar with surrounding star pickets for a barricade for protection. These marks are susceptible to move due to heat transfer properties of steel and concrete i.e. the materials will shrink and expand due to temperature fluctuations. The field survey component of the data collection coordinates will be placed onto a different datum to what council use currently to ensure no false representation on Council data.

Quality Assurance will involve field check measurements on Control throughout the survey as well as analysis of the adjustment output files to ensure no blunder errors have emerged. The adjustments might not always pass the chi square test but these will still be accepted as it will be the best possible solution for the inadequate solutions. The results are run through Starnet so that coordinates can be easily outputted and a percentage of errors mitigated. Also QA will include reading the data all at 2 rounds from fixed control stations and reduced back to the substandard method for analysis. This will be done by exporting ISO rounds reports from a Trimble TSC 3 Controller and macros used in excel to place the corresponding methods into .dat file format. The same thing will be done from the sokkia readings but a different set of macros will be used as the data is in a different format. An example of the input file format can be seen in Appendix C.

The average difference from the true value for both the horizontal and vertical component will be utilised over the ten points for the error propagation formula. The average is the first indication of the accuracy of the data and the average movement from the control data also known as the true value. Although the standard deviation is a practical description of the standard errors relating to a dataset it is not an appropriate description when comparing coordinates as the average difference is more appropriate descriptor. The standard deviations shows the precision of a set of data and isn’t appropriate for this analysis as we are more concerned with the accuracy for this thesis. The standard deviation was still calculated as it is an extremely good check on the quality of the data to ensure the average is a reliable value. This check is extremely important considering things can go wrong in excel spreadsheets when the process is fully automated.

Chapter 4 Results and Discussion

4.1 Introduction

Following the methodology and the parameters set out in the above sections the three case studies provided by Toowoomba Regional Council Were analysed to complete the aim. Also the field analysis of corresponding survey methods was completed and detailed in the below sections.

The case study data has to remain confidential. Therefore the Dam Wall's will be known as A, B, and C. It was decided not to continue to follow up on SEQ Water ability to provide more monitoring data as the confidentially issues were too great and there wouldn't be enough time to sought these out.

Although the above three case studies have no known abnormal movement attributes to date and will provide control values to determine if Hunter and Fells Guidelines are correct to be able to be applied to survey procedures.

Some of the monitoring points have either been knocked out or covered by water throughout their time, and therefore that is there are some values missing from the data.

4.2 Dam A

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	-0.0201	0.0256	0.0693	226° 31' 15"	0.042290996
MINIMUM VALUE	-0.2950	0.0000	-0.0040	0° 0' 0"	0.002236068
MAXIMUM VALUE	0.0320	0.0780	0.1290	352° 8' 48"	0.295027117
RANGE	0.3270	0.0780	0.1330	352° 8' 48"	0.292791049
MEDIAN	-0.0130	0.0190	0.0670	296° 33' 54"	0.04110961
ST DEV.	0.04910977	0.0189	0.0352	136° 6' 28"	0.044942557
1ST QUART	-0.027	0.011	0.0425	39° 34' 18"	0.017719544
THIRD QUART	0.0035	0.04	0.0965	322° 5' 1"	0.056721466
INTERQUARTILE RANGE	0.0305	0.029	0.054	282° 30' 42"	0.039001921

Table 3: Average Movement Values of Dam A

From the above table it is clear to see that the median values are quite low and therefore it seems the dam wall is moving very little when the whole dam wall is examined. It is also evident that there are a few outliers as well which is affecting the data.

For the vertical movement the median is close to the average therefore a visual representation of the data isn't needed as there are no extreme values.

Now the data can be applied to determine if Hunter and Fells guideline will work. Please see the literature review section for an overview of this guideline.

Hunter and Fells Guideline				
Settlement (% of dam height)			**Our Values**	**Difference**
Downstream	Crest	Upstream		
0.0 to 0.7	0.2 to 0.95	0.1 to 0.7		
average = 0.78%	0.78		0.11552845	0.6644715
Displacement (% of dam height)				
0.15 to 0.2	0.2		0.07048499	0.1295150

Table 4: Applying Dam A Data to Hunter and Fells Guideline

Table 4 shows us that the maximum allowable movement is 0.78% of the dam wall height. Our value is 0.12% of the dam wall height. Therefore it has come under the expected settlement rate by 400mm. This data demonstrates how well the dam was compacted during construction.

Now for horizontal displacement there is a much smaller allowable limit of 0.2% of dam wall height and Dam A achieves a value of 0.07%. Therefore Dam A comes under the expected value by 77mm. Please be aware that this data included that extreme outlier to test the effectiveness of the guideline.

4.3 Dam B

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	-0.0114	0.000375	0.0259	219° 56' 5"	0.0137225
MINIMUM VALUE	-0.05	-0.003	-0.006	18° 26' 6"	0.001
MAXIMUM VALUE	0.007	0.006	0.101	314° 59' 60"	0.05001
RANGE	0.057	0.009	0.107	296° 33' 54"	0.04901
MEDIAN	-0.0035	0	0.0065	268° 51' 15"	0.005465
ST DEV.	0.01732	0.0020	0.0355	88° 7' 46"	0.0156375
1ST QUART	-0.0245	-0.001	0.002	139° 36' 31"	0.0029119
THIRD QUART	0.001	0.002	0.05525	273° 52' 21"	0.0245637
INTERQUARTILE RANGE	0.0255	0.003	0.05325	134° 15' 50"	0.0216518

Table 5: Average Movement Values for Dam B

From the above table it is clear to see that the movement values are a bit more representative of a normal acting dam wall, and will give a true representation compared to Hunter and Fells Guideline. Now from these statistics it can be seen that the dam wall is moving down stream at a rate of less than 1mm per year since end of construction time. It is interesting to see that there has been much more vertical displacement than horizontal displacement. This confirms Hunter and Fells guidelines giving more evidence that it is the correct guideline.

Hunter and Fells Guideline				
Settlement (% of dam height)			Our Values	Difference
Downstream	Crest	Upstream		
0.0 to 0.7	0.2 to 0.95	0.1 to 0.7		
average = 0.78%	0.78		0.086333333	0.693666667
Displacement (% of dam height)				
0.15 to 0.2	0.2		0.045741708	0.154258292

Table 6: Applying Dam B Data to Hunter and Fells Method

Now this is more proof that Hunter and Fells guideline is correct. From the above table it can be seen that the dam has only moved vertically 0.086% compared to dam height. This equates to be about 416mm under the maximum expected movement. This dam has had various external and internal inspections and there has been no report of abnormal behaviours demonstrated. Combined with the fact the quantitative values match it is increasing the evidence that Hunter and Fells guideline is actually correct.

4.4 Dam C

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	0.0194	0.0092	0.1387	98° 44' 50"	0.026399
MINIMUM VALUE	-0.008	-0.029	0.049	0° 0' 0"	0.002828
MAXIMUM VALUE	0.043	0.037	0.236	323°58'21"	0.053009
RANGE	0.051	0.066	0.187	323°58'21"	0.050181
MEDIAN	0.023	0.008	0.142	71° 33' 54"	0.030232
ST DEV.	0.0132	0.0177	0.0530	83° 9' 20"	0.014637
1ST QUART	0.011	-0.003	0.086	48° 30' 34"	0.014081
THIRD QUART	0.029	0.023	0.186	126°20'49"	0.037723
INTERQUARTILE RANGE	0.018	0.026	0.1	77° 50' 15"	0.023642

Table 7: Average Movement Values for Dam C

As it can be seen from the above table there has been relatively low horizontal and vertical movement patterns depicting an extremely well built dam. See below for the corresponding analysis to determine if Hunter and Fells guideline applies to the dam wall.

Hunter and Fells Guideline				
Settlement (% of dam height)			Our Values	Difference
Downstream	Crest	Upstream		
0.0 to 0.7	0.2 to 0.95	0.1 to 0.7		
average = 0.78%	0.78		0.46260869	0.3173913
Displacement (% of dam height)				
0.15 to 0.2	0.2		0.087997	0.112003

Table 8: Applying Dam C data to Hunter and Fells Method

From the above table it is 0.31% from the maximum value before abnormal behaviours. This roughly equates to about 400mm in settlement before it gets to abnormal behaviours. For horizontal movement there is 77mm before it gets to abnormal behaviour. This demonstrates a relatively normal dam wall.

As it can be seen from the results of the above data, Hunter and Fells guideline has been tested using a dam wall showing abnormal behaviours, one with large settlement and no displacement as well as values from a dam wall that has considerably normal attributes. Thus this have proved that Hunter and Fells guideline will work as all these three dam walls are considered extremely safe through inspections. They have been proved safe through quantitative data as well thus confirming that the prescribed guideline is correct. Now it will be able to test this guideline over the field data.

4.5 Survey Measurements

The field study consisted of using two total stations to measure each monitoring point using two rounds and reduce the data back to its first measurements to decrease the accuracy of the machine by taking away all its averaging ability and comparing the results. This is done by using four different measurement techniques. These are two rounds, two faces and F1 Observations. It will start the coordinate comparisons from one station at a time and add stations accordingly. This will show exactly what difference each station will give. At the end of all this an accuracy limitation at the end of each set will allow for overall comparison of methods.

The dam wall datum has been set up so that between stations 1002-1003 the angle is extremely close to 180° therefore setting the dam wall up to have an axis close to a perfect xyz plane. This is easier for data analysis and visual representation of the data especially with downs stream on the right and upstream on the left. This is enhanced as North for the bearing runs in line with the crest of the dam wall and it can be determined through bearings which direction the dam wall is moving.

The project will use the Trimble Measurements from 2 rounds for all three stations as the control therefore giving the best idea of the exact coordinates of the monitoring points for comparison of methods. This method was chosen as it was the only method that passed the chi square test in a fully constrained network, in the starnet software.

4.6 Two Rounds Data

4.6.1 Trimble 1 Station – 2 Rounds

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	-0.000489	0.002262	0.000613	161° 16' 24"	0.003692
MINIMUM VALUE	-0.00454	-0.0011	-0.00404	14° 45' 45"	0.000966
MAXIMUM VALUE	0.00239	0.00711	0.00341	334° 38' 24"	0.007945
RANGE	0.00693	0.00821	0.00745	319° 52' 38"	0.006979
MEDIAN	0.000485	0.00128	0.00025	119° 10' 14"	0.002078
ST DEV.	0.0025	0.0033	0.0022	128° 46' 21"	0.002945
1ST QUART	-0.003385	-0.0006175	-0.00039	25° 51' 13"	0.001454
THIRD QUART	0.0016775	0.006655	0.002765	309° 56' 20"	0.007557
INTERQUARTILE RANGE	0.0050625	0.0072725	0.003155	284° 05' 7"	0.006103

Table 9: Statistical Description of Trimble 1 Station 2 Rounds

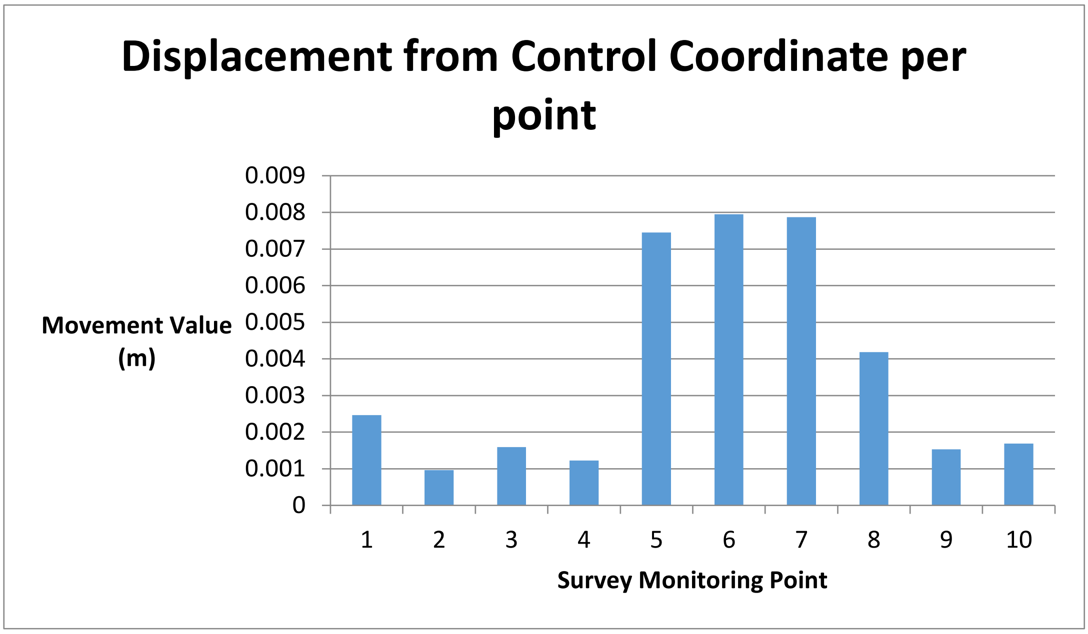


Figure 6: Graphical Summary of Horizontal Movement for Trimble 1 Station 2 Rounds

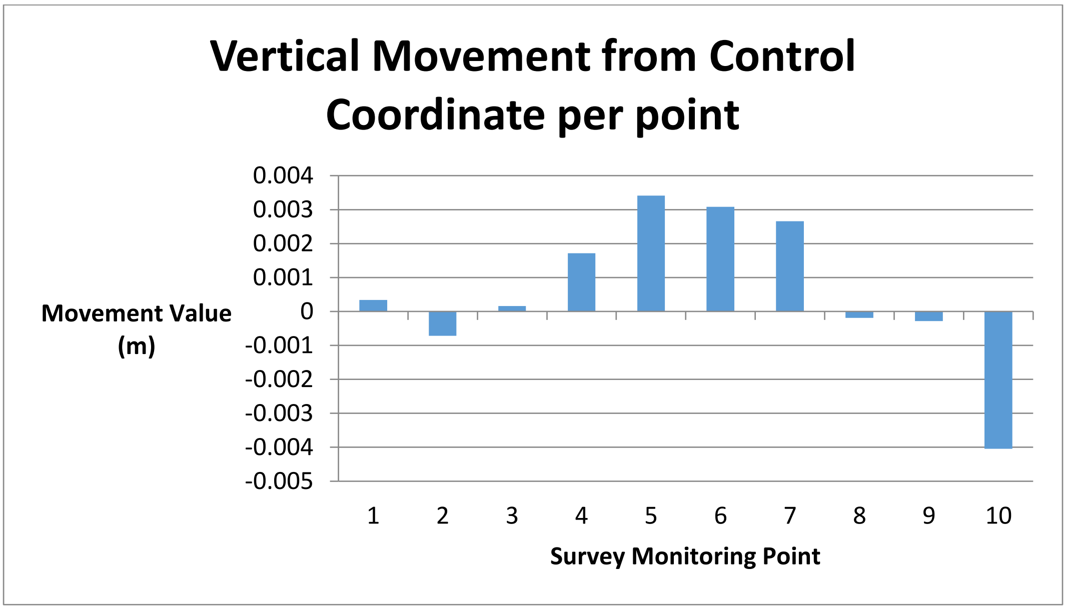


Figure 7: Graphical Summary of Vertical Movement for Trimble 1 Station 2 Rounds

4.6.2 Trimble 2 Stations – 2 Rounds

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	-0.00176	0.000255	-0.001017	276° 47' 46"	0.003659
MINIMUM VALUE	-0.00531	-0.00073	-0.00556	259° 43' 58"	0.002072
MAXIMUM VALUE	0	0.00182	0	297° 0' 46"	0.005504
RANGE	0.00531	0.00255	0.00556	37° 16' 48"	0.003433
MEDIAN	-0.00102	0	-0.000215	278° 19' 32"	0.004007
ST DEV.	0.00203	0.00077	0.0017639	15° 23' 20"	0.001353
1ST QUART	-0.00368	-7.25E-05	-0.0014725	261° 41' 3"	0.002344
THIRD QUART	0	0.0005875	0	291° 8' 35"	0.0048
INTERQUARTILE RANGE	0.003685	0.00066	0.0014725	29° 27' 32"	0.002456

Table 10: Statistical Description of Trimble 2 Station 2 Rounds

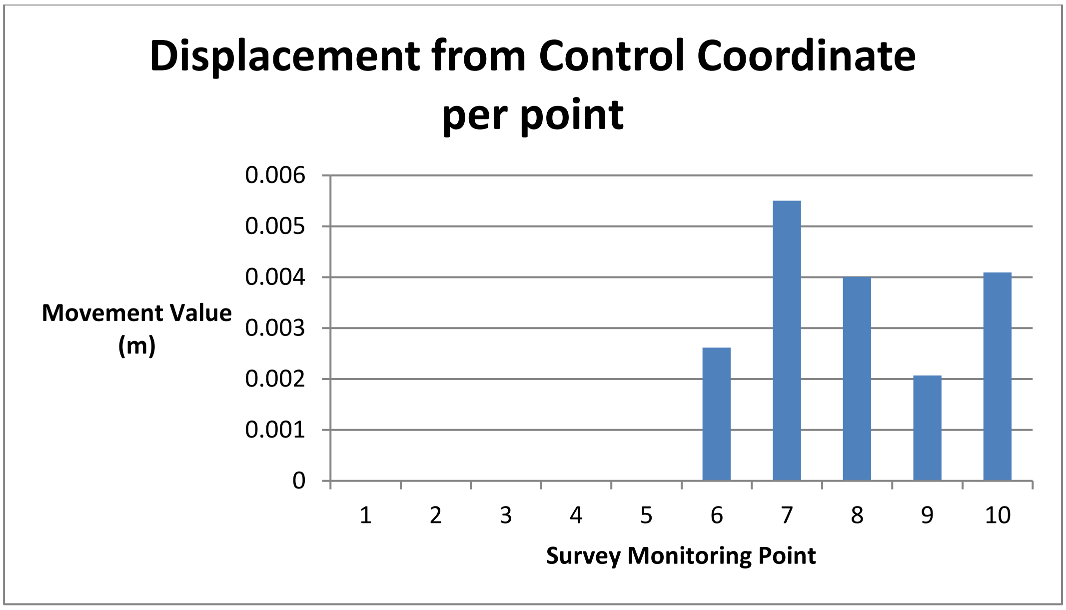


Figure 8: Graphical Summary of Horizontal Movement for Trimble 2 Stations 2 Rounds

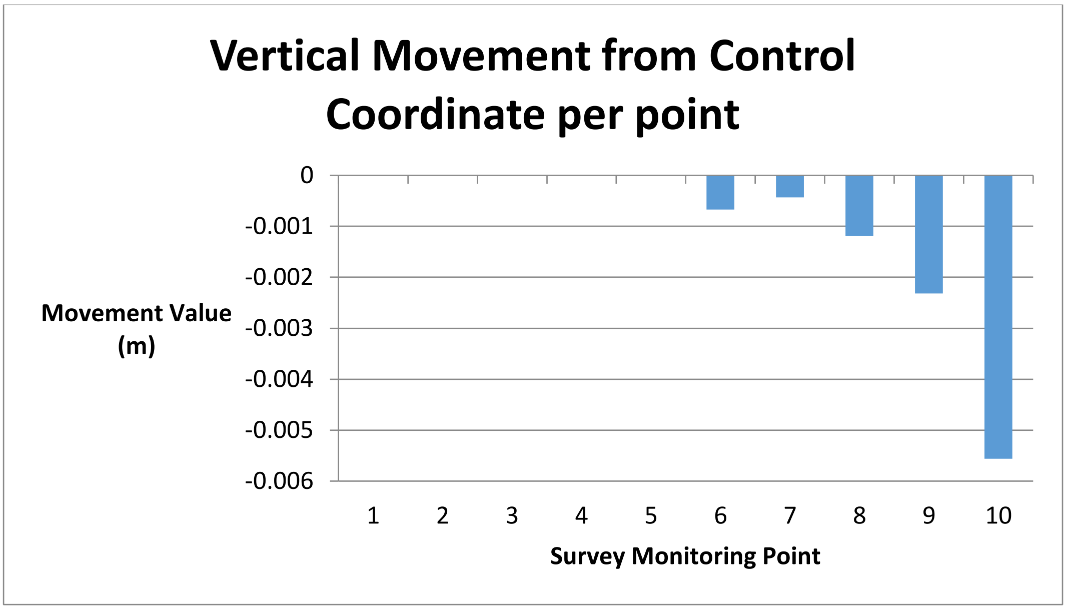


Figure 9: Graphical Summary of Vertical Movement for Trimble 2 Station 2 Rounds

This analysis is from two stations compared to the three stations used in the control so it is expected very similar results in all these points. As it could only see half the monitoring points from one station the above data only shows differences experienced by this station. This is due to the fact that starnet reduced the coordinates in the same way as the control and there were no differences. It is interesting to see the differences of what happens when the third station is added. The difference between two stations and three stations to a point on average seems to be 3mm in distance and 1mm in height. This initially shows that potentially it may not be needed to set up on three stations to monitor values. There could potentially be a pattern between this set of data. As it can be seen there are much larger values in the movement for the x direction. This demonstrates that a potential angle difference is the reason for this horizontal movement.

It is interesting to note that as more stations were added that all the standard deviation values of the comparison got lower results. This could potentially be a pattern forming and will need to evaluate this further. This is to be expected as 2 rounds are the preferred more accurate method although by what quantitative data is this difference. It is also interesting to note that the averages are fluctuating and haven't presented any relevant pattern as of yet. This can be expected due to the fact that the 2 rounds data was used as the control coordinates, and therefore these results were used to create the control. It is still worth looking at to see what difference having read the measurements from differing amount of stations to see what the difference is. This will add results to our error propagation to give an amount to each method.

The range of differences between the coordinates has come decreased as the station number has increased, which is to be expected.

The delta Y differences are much lower than the delta x differences and this difference demonstrates an angle difference in the data, which any number of errors could cause a reaction from this.

4.6.3 Sokkia 1 Station – 2 Rounds

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	0.004473	0.001584	-0.00603	163° 9' 17"	0.007966
MINIMUM VALUE	-0.00279	-0.00677	-0.01345	4° 1' 38"	0.003613
MAXIMUM VALUE	0.01886	0.00735	0.00095	356° 12' 47"	0.020038
RANGE	0.02165	0.01412	0.0144	352° 11' 10"	0.016425
MEDIAN	0.003845	0.002595	-0.00512	114° 54' 8"	0.00719
ST DEV.	0.006261	0.005301	0.005464	131° 35' 25"	0.004671
1ST QUART	-0.0005	-0.00393	-0.0108	78° 40' 14"	0.005228
THIRD QUART	0.00749	0.006405	-0.00166	336° 32' 53"	0.008971
INTERQUARTILE RANGE	0.00799	0.010337	0.009138	257° 52' 39"	0.003743

Table 11: Statistical Description of Sokkia 1 Station 2 Rounds

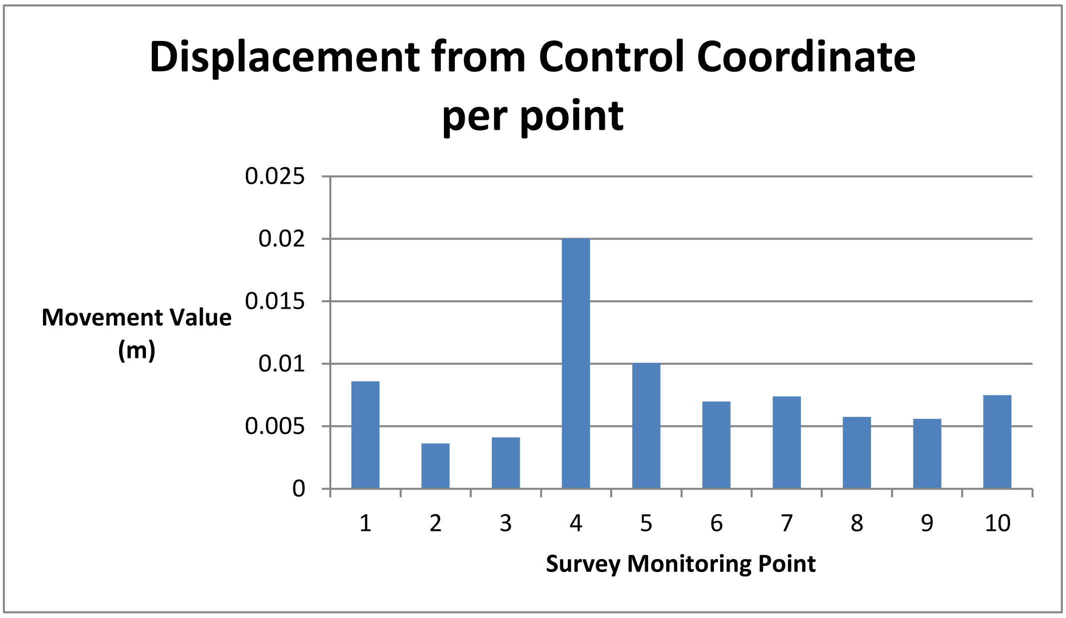


Figure 10: Graphical Summary of Horizontal Movement for Sokkia 1 Station 2 Rounds

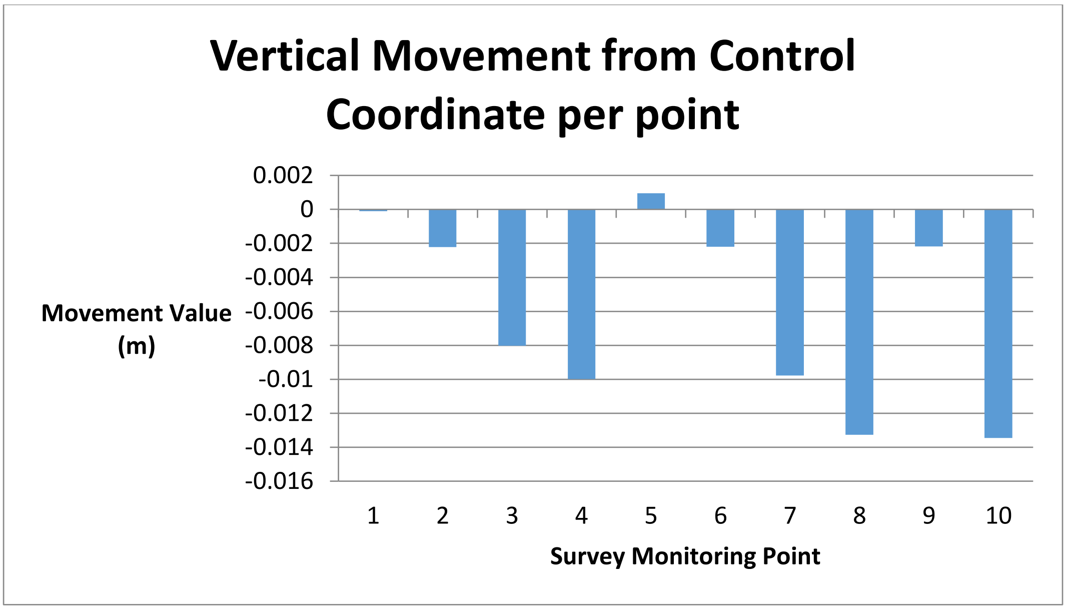


Figure 11: Graphical Summary of Vertical Movement for Sokkia 1 Station 2 Rounds

4.6.4 Sokkia 2 Stations – 2 Rounds

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	0.004217	0.00059	0.000109	193° 19' 54"	0.007056
MINIMUM VALUE	-0.00195	-0.00677	-0.0112	51° 49' 13"	0.001551
MAXIMUM VALUE	0.01886	0.00713	0.01633	349° 20' 23"	0.020038
RANGE	0.02081	0.0139	0.02753	297° 31' 9"	0.018487
MEDIAN	0.003845	0.000655	0.00042	125° 18' 34"	0.00663
ST DEV.	0.006348	0.004856	0.008667	123° 20' 52"	0.005357
1ST QUART	-0.00112	-0.0045	-0.00851	94° 20' 1"	0.003192
THIRD QUART	0.00749	0.006017	0.004912	329° 32' 55"	0.008971
INTERQUARTILE RANGE	0.00861	0.010517	0.013422	235° 12' 54"	0.005779

Table 12: Statistical Description of Sokkia 2 Stations 2 Rounds

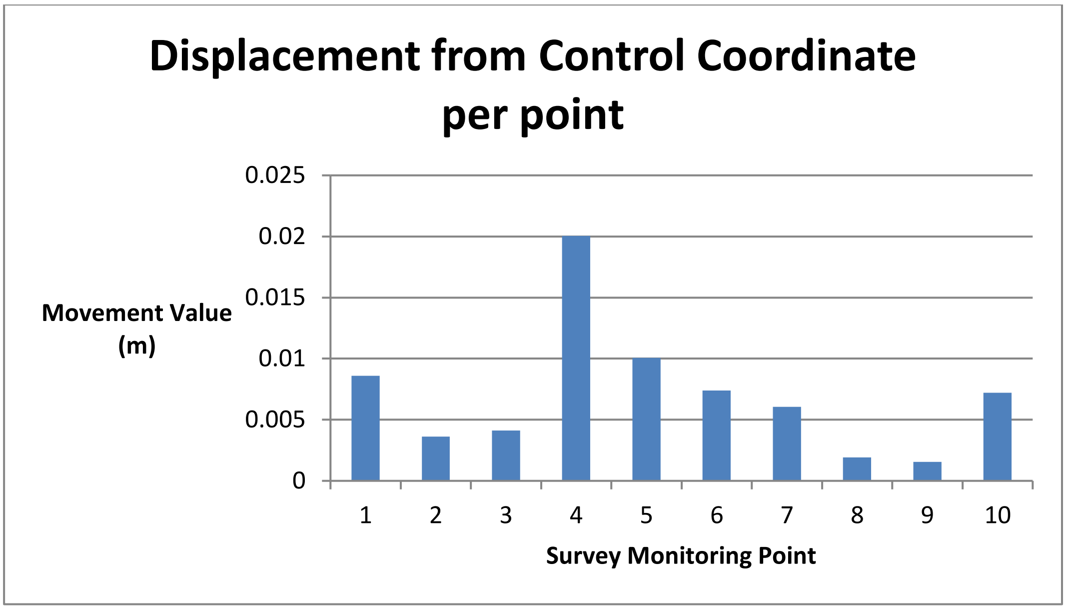


Figure 12: Graphical Summary of Horizontal Movement of Sokkia 2 Stations 2 Rounds

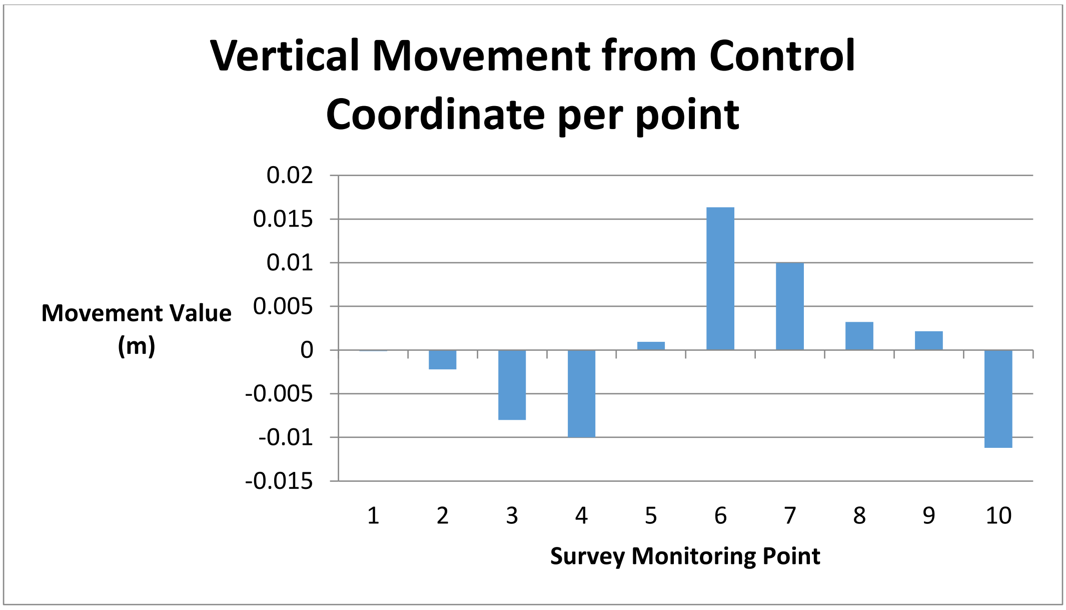


Figure 13: Graphical Summary of Vertical Movement of Sokkia 2 Stations 2 Rounds

4.6.5 Sokkia 3 Stations – 2 Rounds

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	0.001754	-0.00071	-0.00043	173° 57' 47"	0.004499
MINIMUM VALUE	-0.00286	-0.00474	-0.01049	54° 14' 46"	0.000924
MAXIMUM VALUE	0.01035	0.00461	0.02948	346° 48' 54"	0.011136
RANGE	0.01321	0.00935	0.03997	292° 34' 8"	0.010212
MEDIAN	0.001005	-0.00117	-0.0043	149° 22' 5"	0.004593
ST DEV.	0.003971	0.003164	0.011547	101° 0' 27"	0.002696
1ST QUART	-0.00133	-0.00361	-0.00629	93° 57' 33"	0.002557
THIRD QUART	0.003988	0.001902	0.00131	257° 48' 57"	0.004929
INTERQUARTILE RANGE	0.005315	0.005517	0.007605	163° 51' 24"	0.002372

Table 13: Statistical Description of Sokkia 3 Stations 2 Rounds

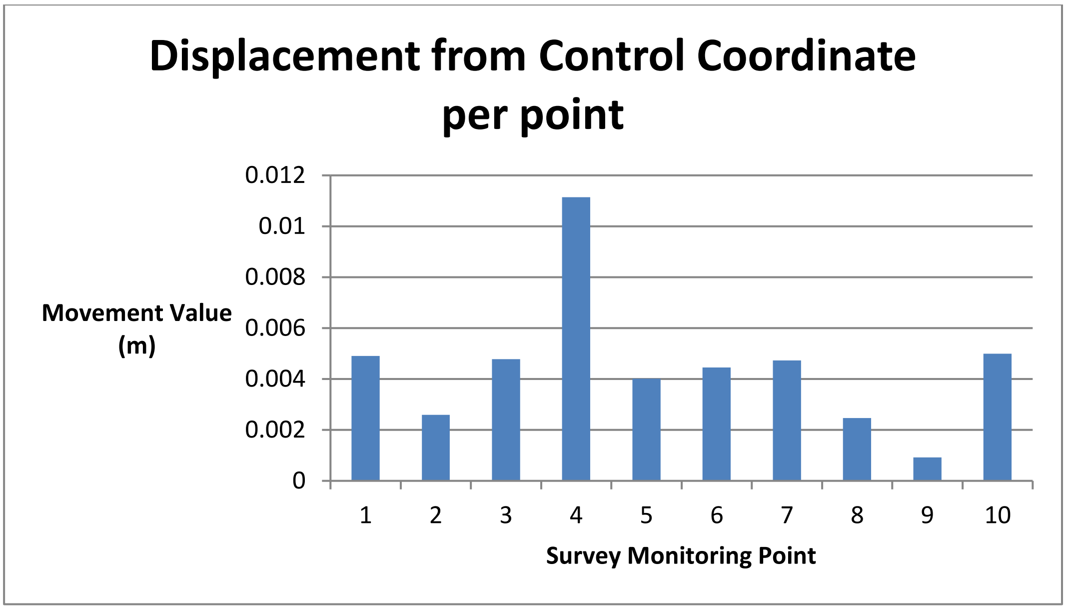


Figure 14: Graphical Summary of Horizontal Movement for Sokkia 3 Stations 2 Rounds

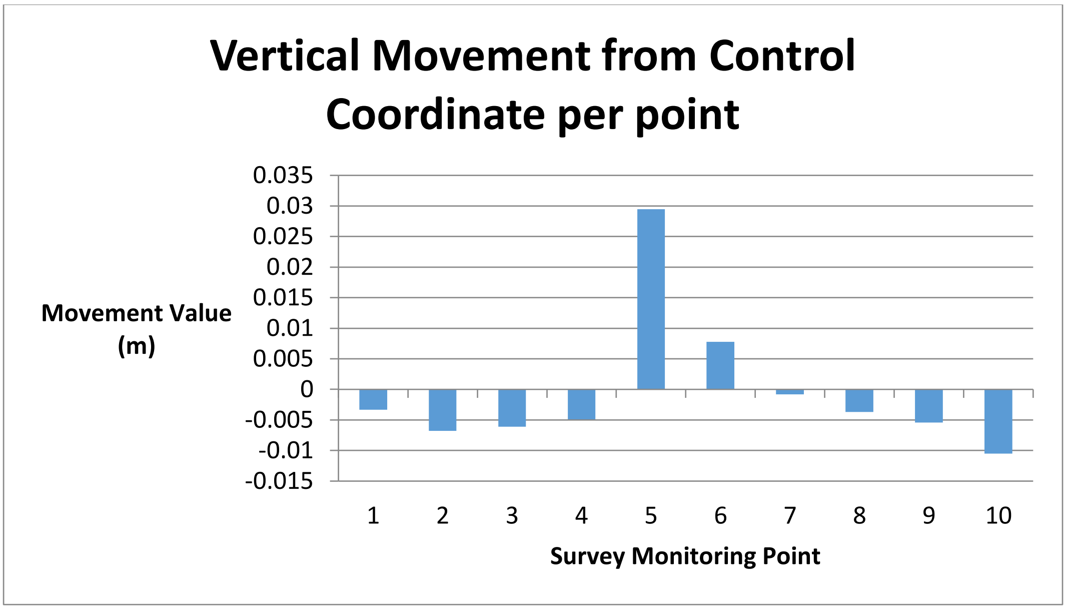


Figure 15: Graphical Summary of Vertical Movement for Sokkia 3 Stations 2 Rounds

The comparison from the above three tables is the sokkia results when comparing between each station and method. Hopefully some patterns will start to emerge as this data is independent of the control coordinates.

Specifically the averages have all decreased as the station number has increased. This is expected as the control data was adjusted using three stations. Although it is interesting to note that the differences in averages don't have an exact difference as another station is added to the coordinates. As the delta Y averages are much lower it confirms that most of the differences in values are due to angle differences.

The standard deviation has shown that between one and town stations it is fluctuating between the statistical analysis of the coordinates. When the third station is added there is a significant decrease in standard deviation. It is unsure as to why this is but the possible reason could potentially be small measurement errors in either one of the data.

The range of the distance using two stations is 2 mm more than that of using 1 station and 8 mm more than using three stations. The range has come down from 1 station to 3 stations but has increased in the middle. These results combined with the standard deviation show that the results aren't as good using two stations in the adjustment. It will be interesting to note if these patterns continue throughout the remaining data.

The delta y differences are the same as above with the statistical results are much lower than the delta x differences. This prevailing angle issue of the delta x values demonstrates that there is much more error with the angles than there is with the distances.

4.7 F1/F2 Data

4.7.1 Trimble 1 Station – F1/F2

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	-0.003295	-0.00022	-0.00049	258° 7' 20''	0.003863
MINIMUM VALUE	-0.00763	-0.00384	-0.0049	181° 13' 8''	0.001403
MAXIMUM VALUE	-4E-05	0.00346	0.00165	308° 33' 47''	0.007659
RANGE	0.00759	0.0073	0.00655	127° 20' 39''	0.006256
MEDIAN	-0.00326	-0.00013	-8.5E-05	268° 59' 8''	0.003431
ST DEV.	0.002186	0.001923	0.001855	39° 27' 3''	0.002004
1ST QUART	-0.004585	-0.00134	-0.00136	220° 12' 9''	0.002247
THIRD QUART	-0.001885	0.000768	0.00081	284° 19' 53''	0.005384
INTERQUARTILE RANGE	0.0027	0.002107	0.002165	64° 7' 45''	0.003137

Table 14: Statistical Description of Trimble 1 Station F1/F2

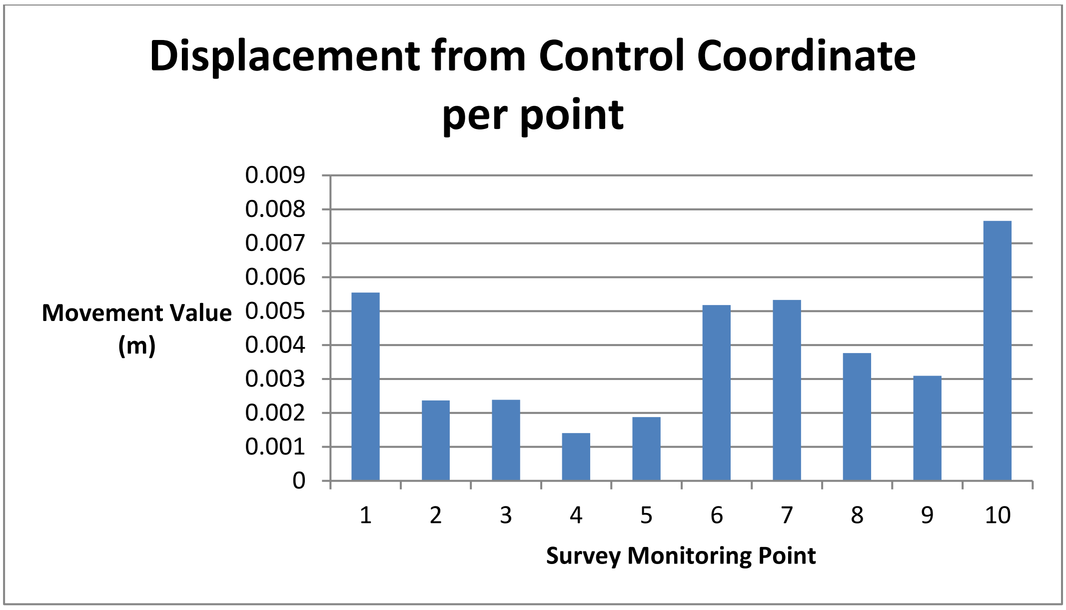


Figure 16: Graphical Summary of Horizontal Movement for Trimble 1 Station F1/F2

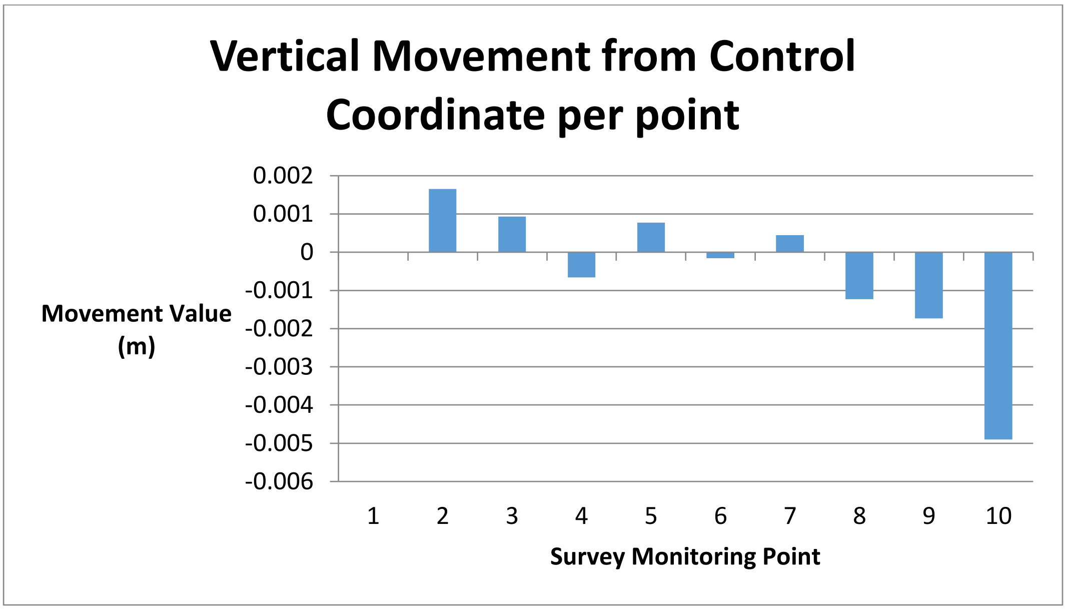


Figure 17: Graphical Summary of Vertical Movement for Trimble 1 Station F1/F2

4.7.2 Trimble 2 Stations – F1/F2

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	-0.00189	-0.00028	-0.00114	249° 18' 1"	0.002129
MINIMUM VALUE	-0.0052	-0.00246	-0.00576	182° 29' 22"	0.00019
MAXIMUM VALUE	-2E-05	0.00092	0.00021	290° 50' 27"	0.005281
RANGE	0.00518	0.00338	0.00597	108° 21' 5"	0.005091
MEDIAN	-0.00143	-0.00032	-0.00068	253° 55' 22"	0.001505
ST DEV.	0.001761	0.001009	0.001757	33° 26' 30"	0.001772
1ST QUART	-0.00329	-0.00068	-0.00154	228° 59' 26"	0.000661
THIRD QUART	-0.00048	0.000718	-7.7E-05	281° 34' 30"	0.003532
INTERQUARTILE RANGE	0.002805	0.001398	0.00146	52° 35' 4"	0.002871

Table 15: Statistical Description of Trimble 2 Station F1/F2

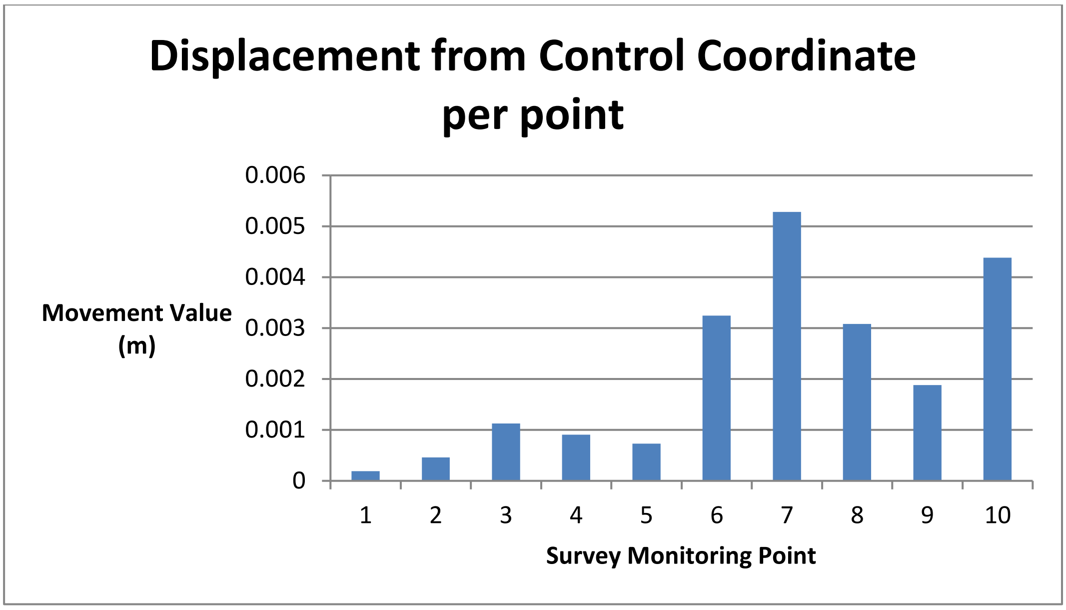


Figure 18: Graphical Summary of Horizontal Movement for Trimble 2 Stations F1/F2

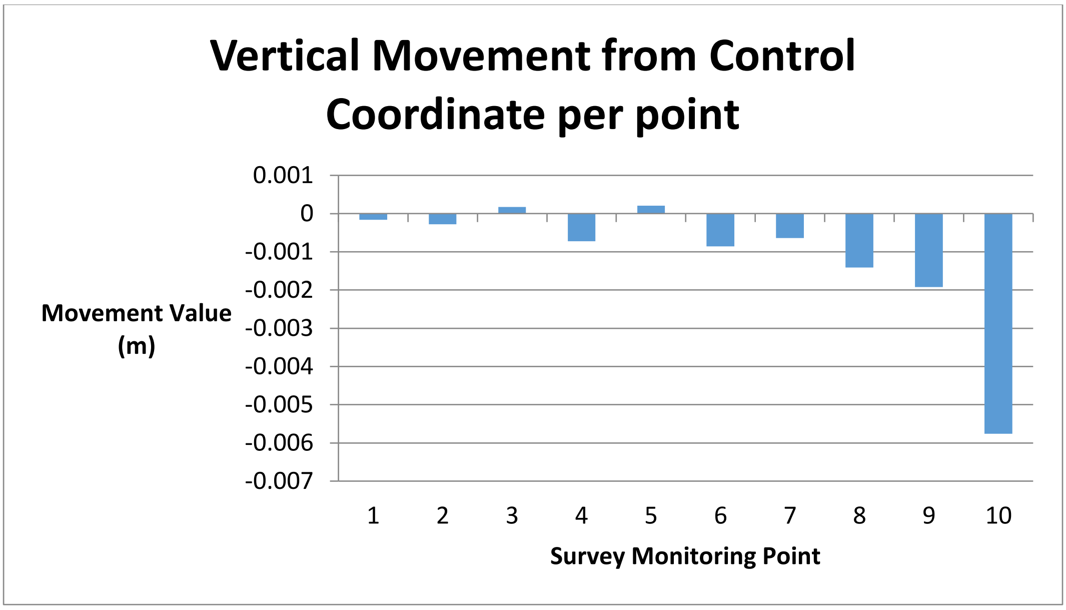


Figure 19: Graphical Summary of Vertical Movement for Trimble 2 Stations F1/F2

4.7.3 Trimble 3 Station – F1/F2

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	-0.00018	-0.00048	-9.6E-05	192° 16' 13"	0.000766
MINIMUM VALUE	-0.00111	-0.00175	-0.00072	72° 15' 19"	0.00019
MAXIMUM VALUE	0.0006	0.00016	0.00071	260° 17' 12"	0.001812
RANGE	0.00171	0.00191	0.00143	188° 1' 53"	0.001622
MEDIAN	-0.00018	-0.00045	-0.00018	202° 28' 57"	0.000672
ST DEV.	0.000552	0.000512	0.000385	58° 41' 10"	0.000462
1ST QUART	-0.00061	-0.00059	-0.0003	145° 26' 52"	0.000441
THIRD QUART	0.000372	-0.00016	0.00018	237° 30' 10"	0.000967
INTERQUARTILE RANGE	0.000985	0.000435	0.00048	92° 3' 18"	0.000527

Table 16: Statistical Description of Trimble 3 Stations F1/F2

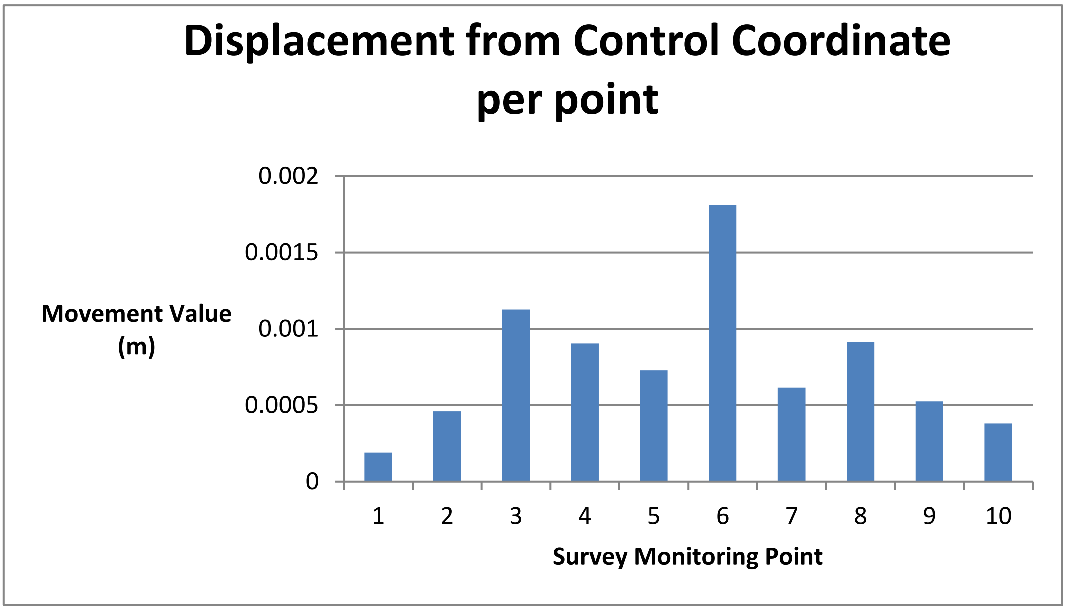


Figure 20: Graphical Summary of Horizontal Movement for Trimble 3 Stations F1/F2

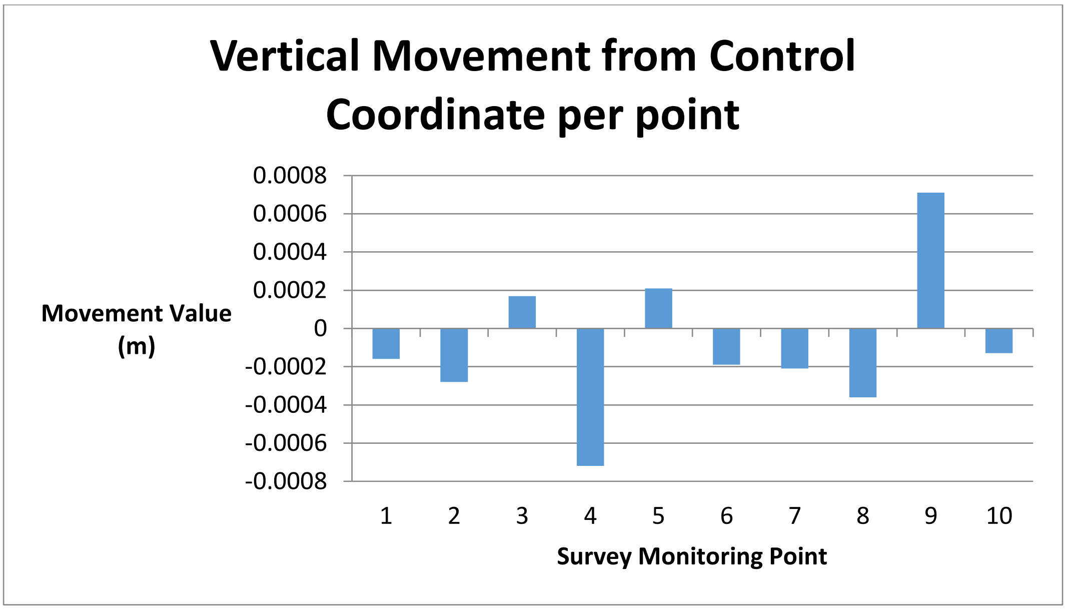


Figure 21: Graphical Summary of Vertical Movement for Trimble 3 Stations F1/F2

The Trimble data again using F1/F2 of measurement has produced the same patterns that were apparent in the first set of data although the accuracy isn't as great which is to be as expected. The range has changed 1mm between using 1 station and 2 stations but have fallen 3 mm when using 3 stations. These have presented the same pattern as demonstrated above with three stations bringing the range down much lower.

The standard deviation actually comes down when using each station the same as presented by the Trimble data in the first comparison. It is interesting to note that F1/F2 with 1 station has a standard deviation of maximum 2 mm across all facets of the statistical values. This shows not a great deal of difference between the control values and the measured values just by using 1 station when adjusted through starnet.

The averages have all decreased as station number has increased but when using 1 station with F1/F2 on average; each point is 4mm in distance difference per point which is sufficient enough for monitoring values of an extremely large dam wall especially when combined with the standard deviation is such a low value as well.

As it can be seen by the data presented above the delta Y statistical values are much lower therefore showing that there is still much more error prevailing in the angle readings.

4.7.4 Sokkia 1 Station F1/F2

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	0.000665	-0.00036	-0.0056	120° 54' 4"	0.004372
MINIMUM VALUE	-0.00885	-0.00352	-0.0092	4° 45' 49"	0.000757
MAXIMUM VALUE	0.00606	0.0048	-0.00132	255° 51' 26"	0.009127
RANGE	0.01491	0.00832	0.00788	251° 5' 37"	0.008369
MEDIAN	0.00048	-0.001	-0.00654	112° 40' 37"	0.004546
ST DEV.	0.004499	0.002572	0.002779	84° 59' 39"	0.0025
1ST QUART	-0.00144	-0.00225	-0.00776	52° 53' 25"	0.002124
THIRD QUART	0.004165	0.001592	-0.00246	203° 10' 4"	0.005704
INTERQUARTILE RANGE	0.0056	0.003845	0.005297	150° 16' 39"	0.00358

Table 17: Statistical Description for Sokkia 1 Station F1/F2

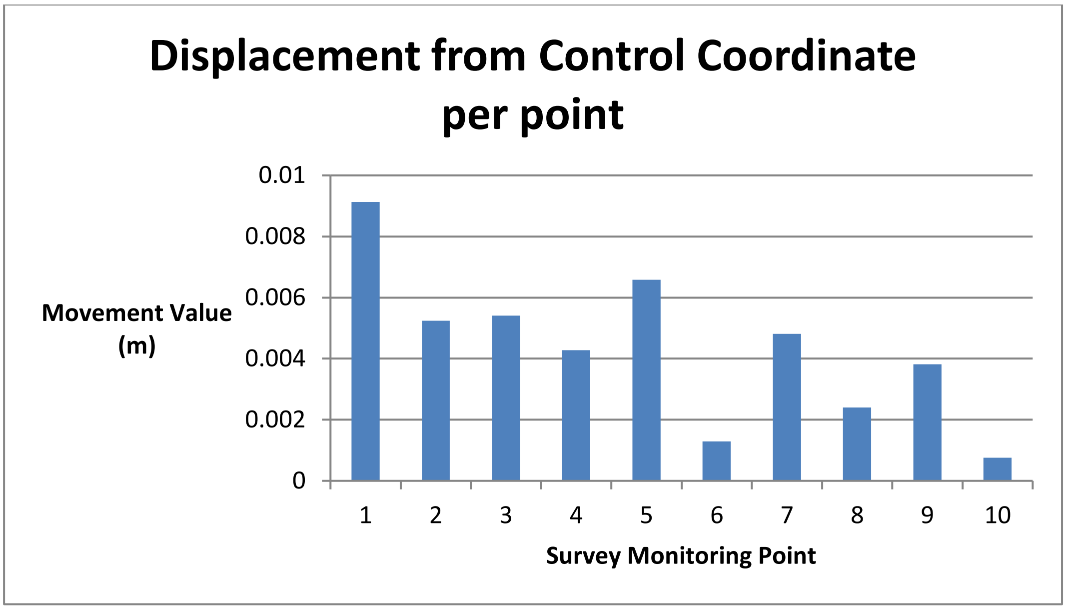


Figure 22: Graphical Summary of Horizontal Movement for Sokkia 1 Station F1/F2

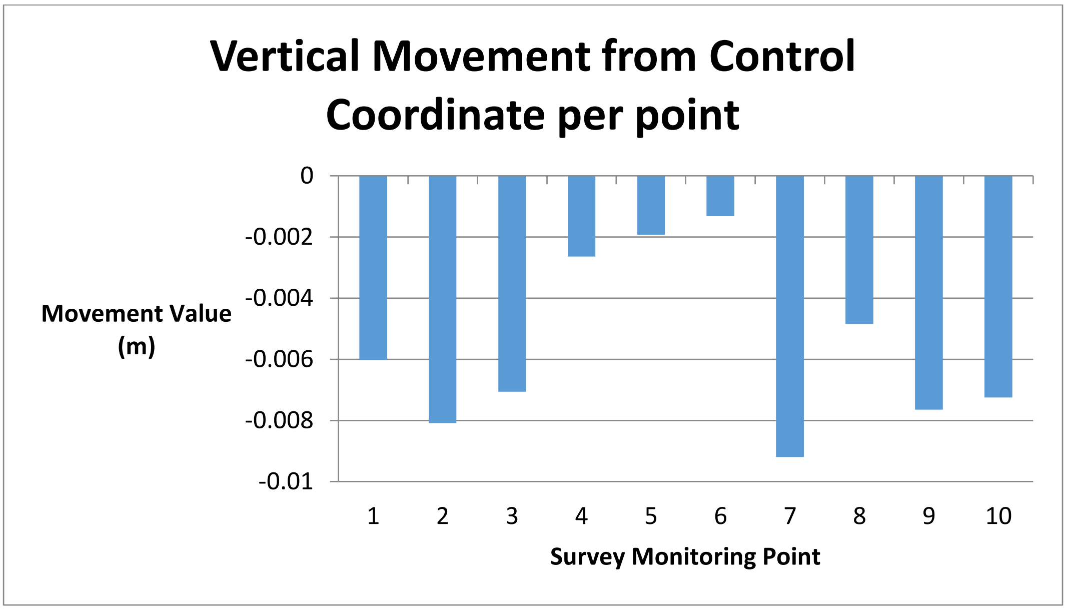


Figure 23: Graphical Summary of Vertical Movement for Sokkia 1 Station F1/F2

4.7.5 Sokkia 2 Station – F1/F2

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	0.003344	-0.00095	-0.0059	109° 46' 50"	0.005565
MINIMUM VALUE	-0.00151	-0.00545	-0.00992	5° 11' 40"	0.001546
MAXIMUM VALUE	0.01222	0.00497	-0.00218	282° 19' 40"	0.012228
RANGE	0.01373	0.01042	0.00774	277° 8' 0"	0.010682
MEDIAN	0.001095	-0.00102	-0.00584	114° 19' 31"	0.005321
ST DEV.	0.004367	0.003677	0.003169	87° 1' 42"	0.003406
1ST QUART	0.000372	-0.00478	-0.00936	12° 17' 15"	0.002758
THIRD QUART	0.006177	0.00248	-0.00238	167° 14' 30"	0.007808
INTERQUARTILE RANGE	0.005805	0.007265	0.006982	154° 57' 15"	0.005049

Table 18: Statistical Description for Sokkia 2 Stations F1/F2

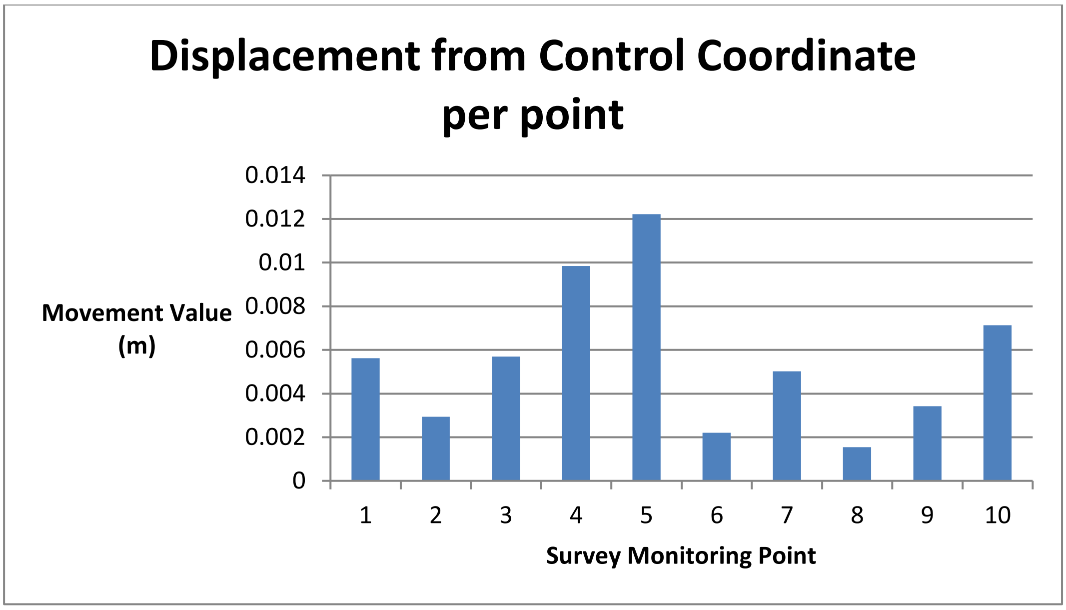


Figure 24: Graphical Description of Horizontal Movement for Sokkia 2 Stations F1/F2

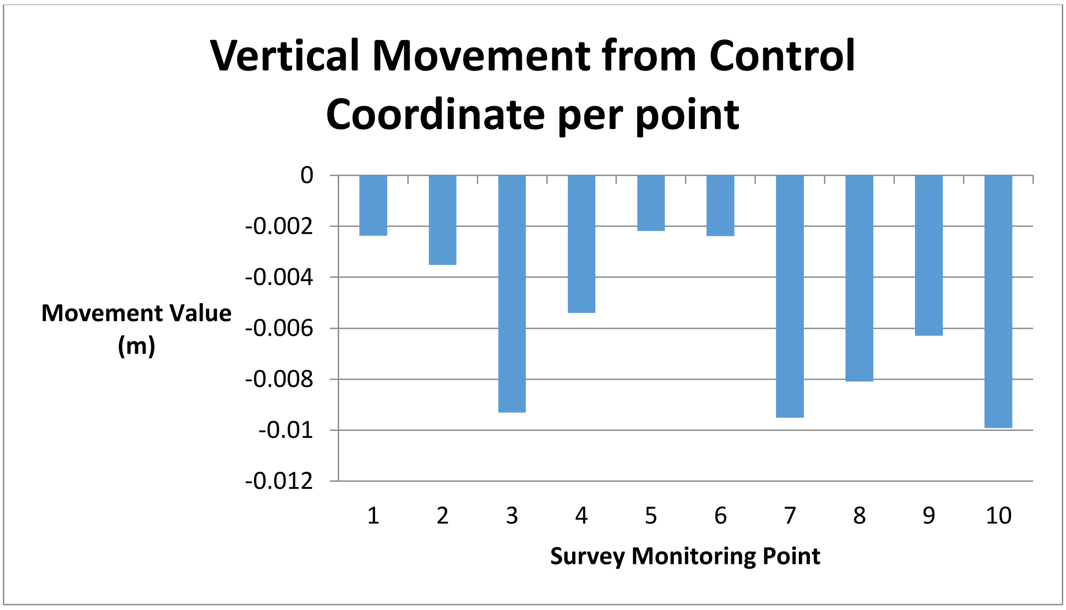


Figure 25: Graphical Description of Vertical Movement for Sokkia 2 Station F1/F2

4.7.6 Sokkia 3 Stations – F1/F2

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	0.003005	-0.00127	-0.00282	169° 14' 44"	0.005353
MINIMUM VALUE	-0.00126	-0.00545	-0.00931	5° 54' 22"	0.001076
MAXIMUM VALUE	0.01222	0.00512	0.00738	347° 46' 4"	0.012228
RANGE	0.01348	0.01057	0.01669	341° 51' 42"	0.011151
MEDIAN	0.000905	-0.00124	-0.00228	149° 40' 33"	0.00543
ST DEV.	0.004589	0.003493	0.004678	105° 42' 17"	0.00364
1ST QUART	-0.00074	-0.00495	-0.00624	102° 49' 33"	0.002305
THIRD QUART	0.006177	0.001462	-0.00122	244° 22' 32"	0.00774
INTERQUARTILE RANGE	0.00692	0.006412	0.005013	141° 32' 59"	0.005435

Table 19: Statistical Description of Sokkia 3 Stations F1/F2

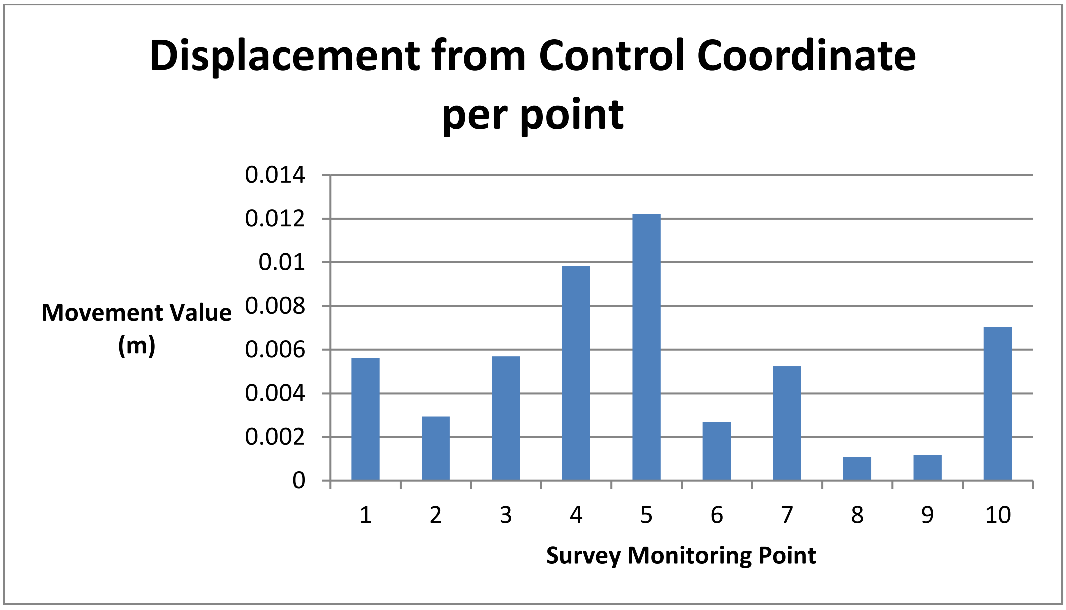


Figure 26: Graphical Summary of Horizontal Movement for Sokkia 3 Stations F1/F2

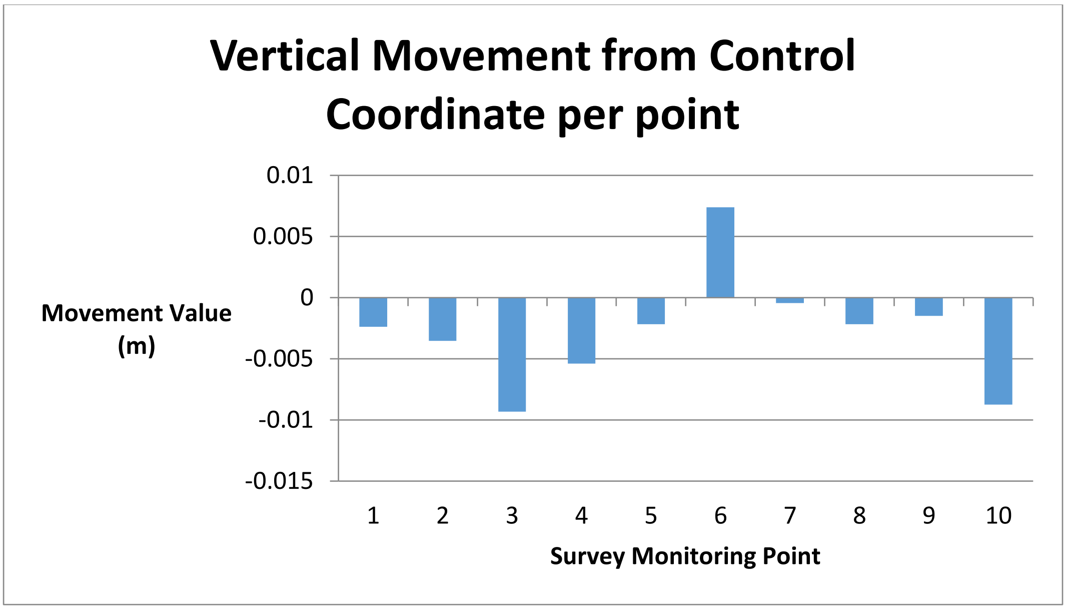


Figure 27: Graphical Summary of Vertical Movement for Sokkia 3 Station F1/F2

The sokkia values fluctuate greatly and aren’t presenting any values that are consistent with the values that the Trimble is presenting. From the above data the range is at its lowest when using 1 station with the sokia. This is showing the opposite data as the Trimble with the accuracy increasing as the amount of stations increase as well.

The sokkia values have shown the same thing again with the standard deviation increasing as the stations increase within the least squares adjustment. The same pattern above has shown us that the best results were gained from only using 1 station in the least squares adjustment. Again with the sokkia it is resulting that the first initial measurements are much closer to the control data and that the other readings are just hindering the results.

The delta Y differences are corresponding with the above patterns thus proving that the largest error in dam wall monitoring is angle difference although there is sufficient evidence to argue that when more redundant measurements to the adjustment the angle error and overall data should be statistically better.

The averages present the same error as the other numerical descriptions of the statistics that the average also are increasing and fluctuating as the station number increases. This is extremely unexpected behaviour and doesn’t agree with the patterns presented by the Trimble especially when the Trimble agrees with expected results.

4.8 Face 1 Observations

4.8.1 Trimble 1 Station – F1

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	-0.00354	-0.00096	0.001285	253° 13' 30"	0.004363
MINIMUM VALUE	-0.01019	-0.00716	-0.0019	193° 55' 22"	0.001631
MAXIMUM VALUE	-0.00059	0.0031	0.00431	300° 5' 23"	0.010446
RANGE	0.0096	0.01026	0.00621	106° 10' 0"	0.008815
MEDIAN	-0.00312	-0.0003	0.00124	262° 12' 5"	0.003203
ST DEV.	0.00276	0.002685	0.001791	34° 12' 9"	0.002947
1ST QUART	-0.00489	-0.00232	-8E-05	220° 37' 14"	0.001996
THIRD QUART	-0.00154	0.000447	0.002245	276° 1' 21"	0.0066
INTERQUARTILE RANGE	0.00335	0.002767	0.002325	55° 24' 7"	0.004604

Table 20: Statistical Description for Trimble 1 Station F1

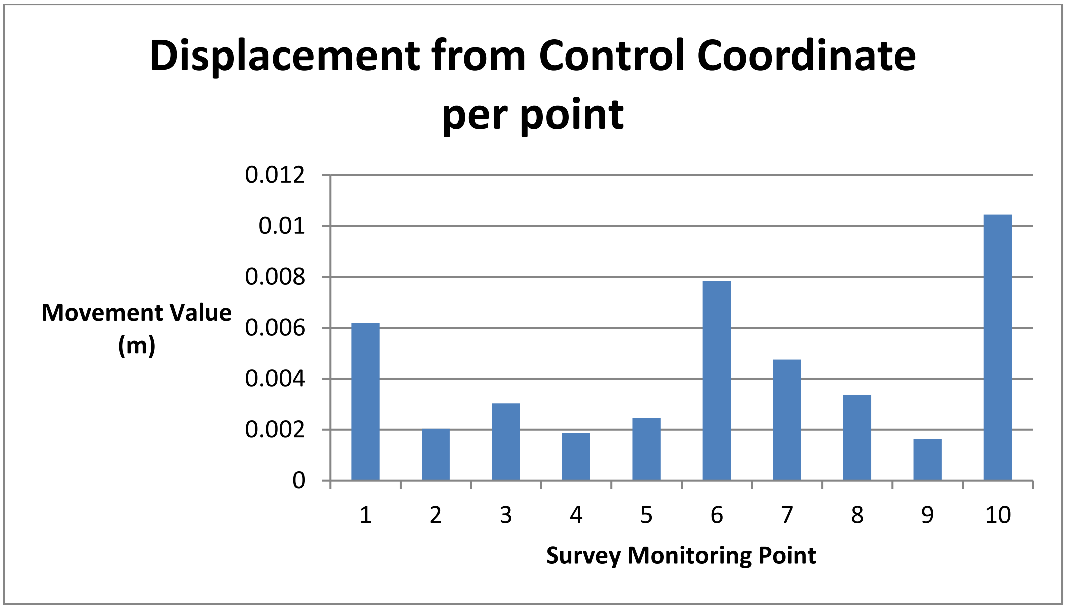


Figure 28: Graphical Summary of Horizontal Movement for Trimble 1 Station F1

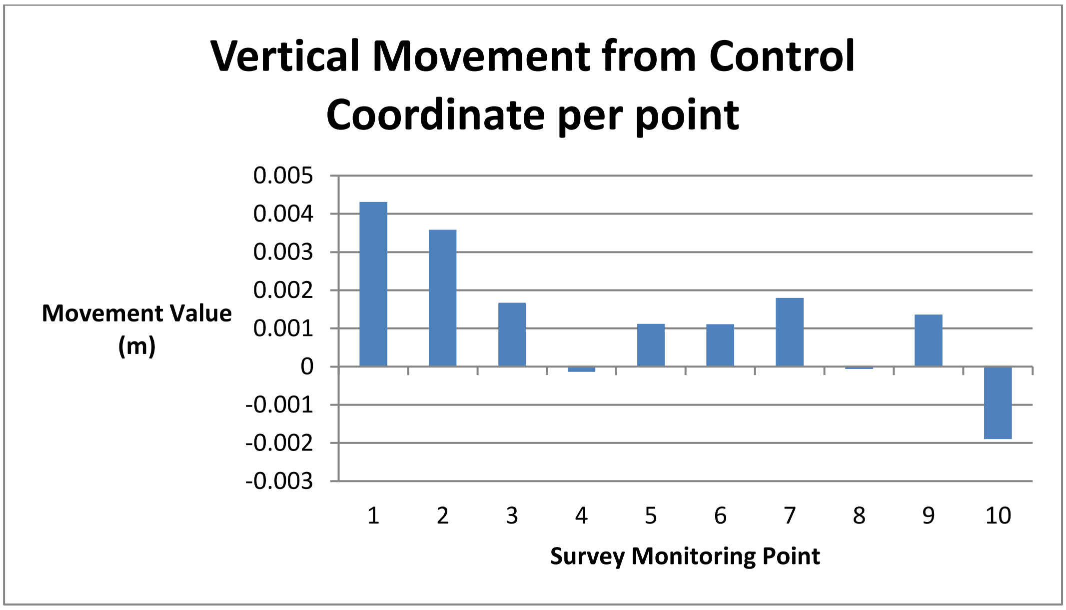


Figure 29: Graphical Summary of Horizontal Movement for Trimble 1 Station F1

4.8.2 Trimble 2 Station – F1

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	-0.00161	-0.00096	-0.00067	233° 36' 33"	0.002567
MINIMUM VALUE	-0.00508	-0.0053	-0.00469	138° 31' 32"	0.00101
MAXIMUM VALUE	0.00099	0.00108	0.00129	291° 29' 8"	0.005505
RANGE	0.00607	0.00638	0.00598	152° 57' 35"	0.004494
MEDIAN	-0.00113	-0.00085	-0.00042	241° 17' 22"	0.00151
ST DEV.	0.001823	0.001797	0.001669	50° 20' 40"	0.001772
1ST QUART	-0.00306	-0.00137	-0.00127	185° 41' 35"	0.001276
THIRD QUART	-0.00045	0.000443	0.000575	283° 53' 34"	0.004389
INTERQUARTILE RANGE	0.002612	0.001812	0.001842	98° 11' 59"	0.003113

Table 21: Statistical Description for Trimble 2 Stations F1

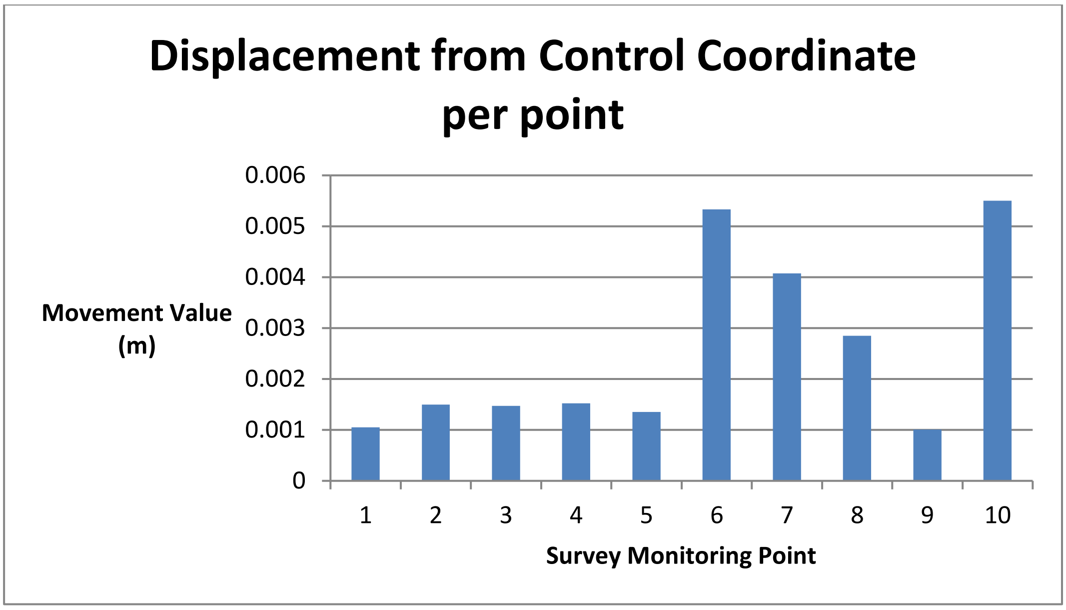


Figure 30: Graphical Summary of Horizontal Movement

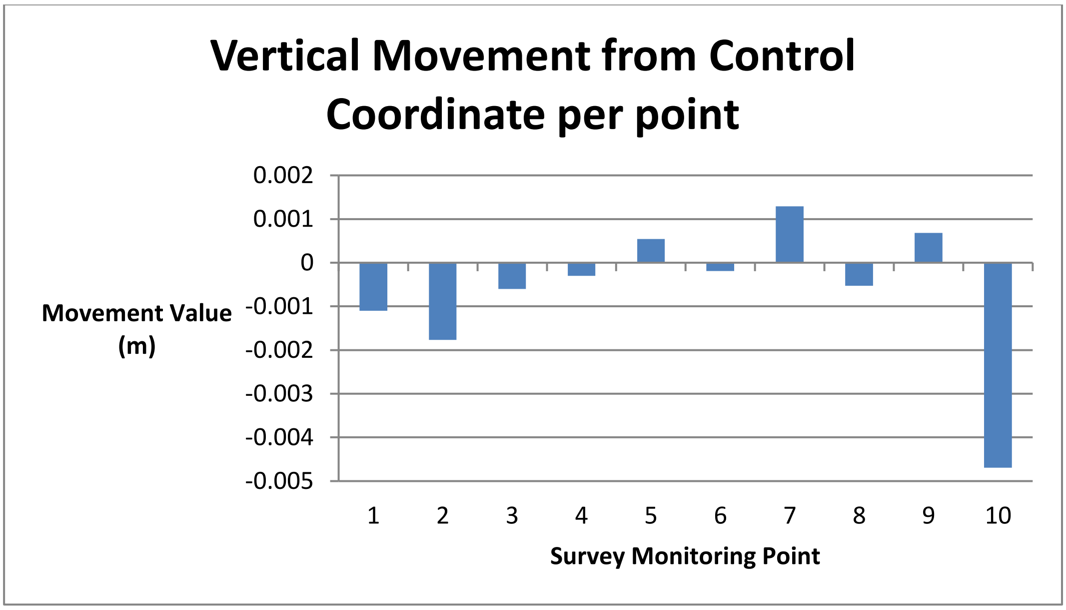


Figure 31: Graphical Summary of Vertical Movement

4.8.3 Trimble 3 Stations – F1

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	-5E-06	-0.00104	0.000388	173° 30' 10"	0.001578
MINIMUM VALUE	-0.00146	-0.00412	-0.00177	79° 22' 49"	0.001026
MAXIMUM VALUE	0.0012	0.00021	0.00349	253° 13' 44"	0.004136
RANGE	0.00266	0.00433	0.00526	173° 50' 54"	0.00311
MEDIAN	-0.00015	-0.00085	0.000265	184° 40' 31"	0.001343
ST DEV.	0.001034	0.001156	0.001515	58° 24' 13"	0.000916
1ST QUART	-0.00109	-0.00107	-0.00073	123° 36' 11"	0.001118
THIRD QUART	0.001053	-0.00041	0.001435	232° 3' 52"	0.001502
INTERQUARTILE RANGE	0.002142	0.000653	0.00216	108° 27' 42"	0.000384

Table 22: Statistical Description of Trimble 3 Stations F1

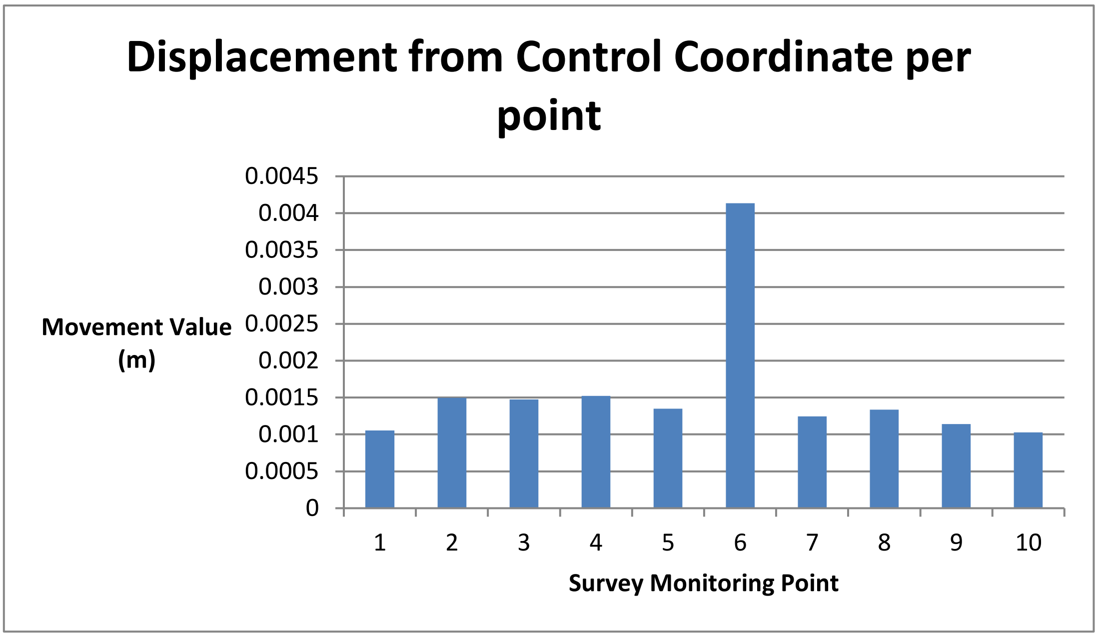


Figure 32: Graphical Description of Horizontal Movement for Trimble 3 Stations F1

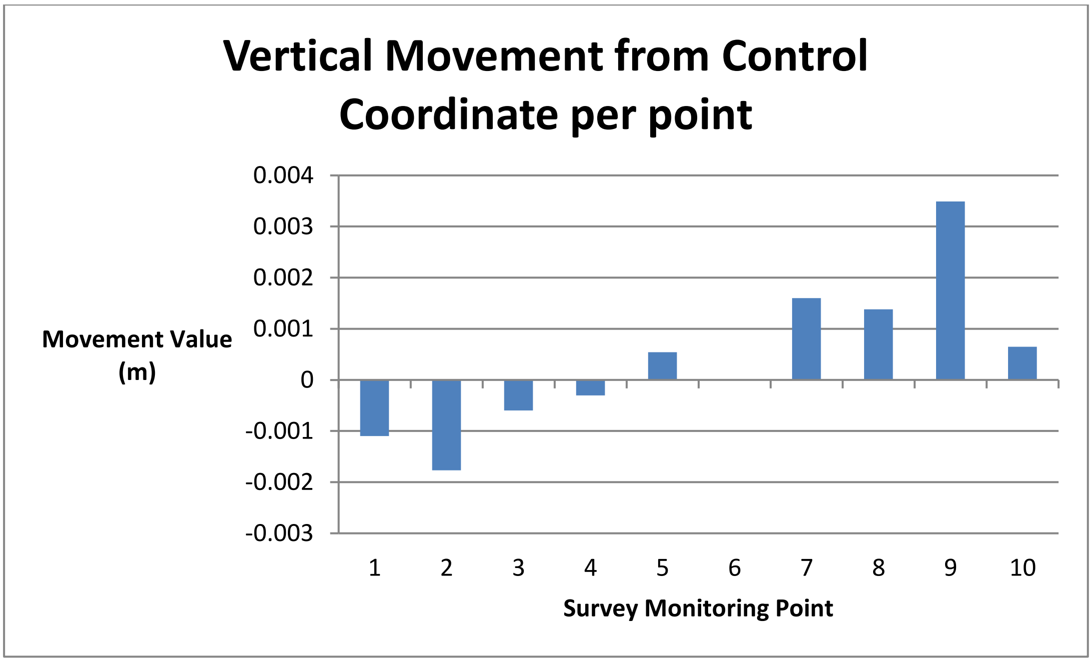


Figure 33: Graphical Summary of Vertical Movement for Trimble 3 Station F1

The range demonstrates the patterns that have presented themselves so far in the other Trimble results as well as what the expected results are. It is consistent with the fact that the data should get better as you add more results.

The averages are producing results that are consistent with what is expected. It is interesting to note that the averages are the worst for the Trimble when considering that this is considered the worst survey method. So the worst survey method if a point is only measured from 1 station has an average difference of 4.3mm from the control coordinates.

The standard deviation of the Trimble is consistent with the patterns already presented with the worst method having a standard deviation of less than 3mm for all statistical analysis variables with an average distance of 5mm therefore that is relatively close to the best method.

The delta Y values are slightly higher than the delta x values and it seems to present errors are constant with this method of analysis between both the angles and the distance.

4.8.4 Sokkia 1 station – F1

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	0.001956	-0.0001	0.001135	106° 29' 57"	0.004927
MINIMUM VALUE	-0.00757	-0.00461	-0.00439	9° 44' 13"	0.001715
MAXIMUM VALUE	0.00771	0.00286	0.01202	253° 56' 38"	0.008863
RANGE	0.01528	0.00747	0.01641	244° 12' 25"	0.007149
MEDIAN	0.003255	0.00013	-0.00099	87° 53' 57"	0.004716
ST DEV.	0.00474	0.00233	0.005678	81° 25' 9"	0.002279
1ST QUART	-0.00081	-0.00186	-0.00365	54° 19' 49"	0.003103
THIRD QUART	0.005263	0.00191	0.00589	143° 8' 39"	0.006879
INTERQUARTILE RANGE	0.00607	0.00377	0.00954	88° 48' 50"	0.003776

Table 23: Statistical Description of Sokkia 1 Station F1

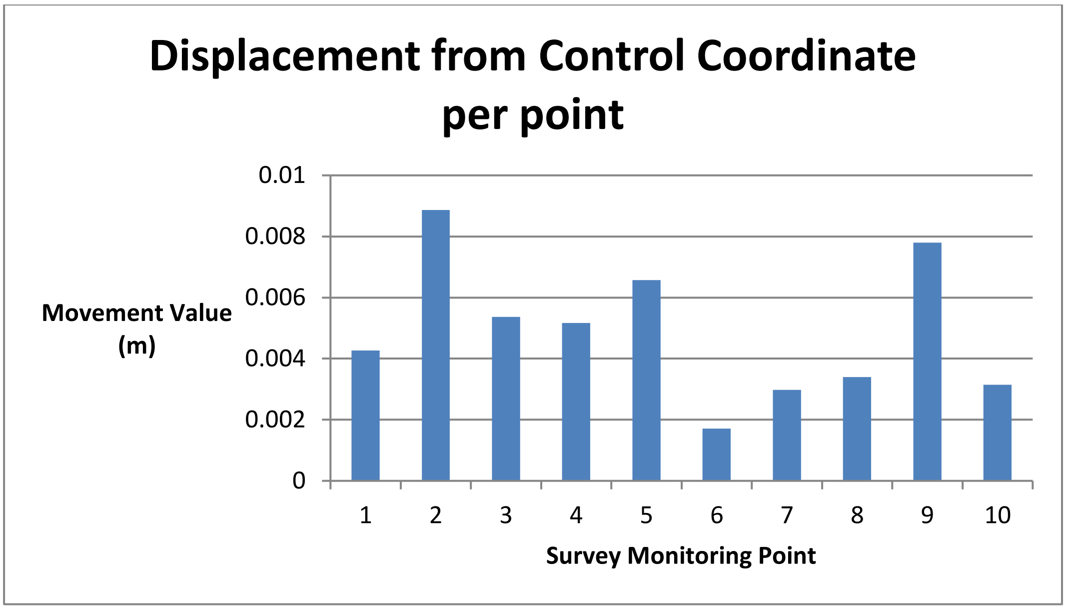


Figure 34: Graphical Summary of Horizontal Movement for Sokkia 1 Station F1

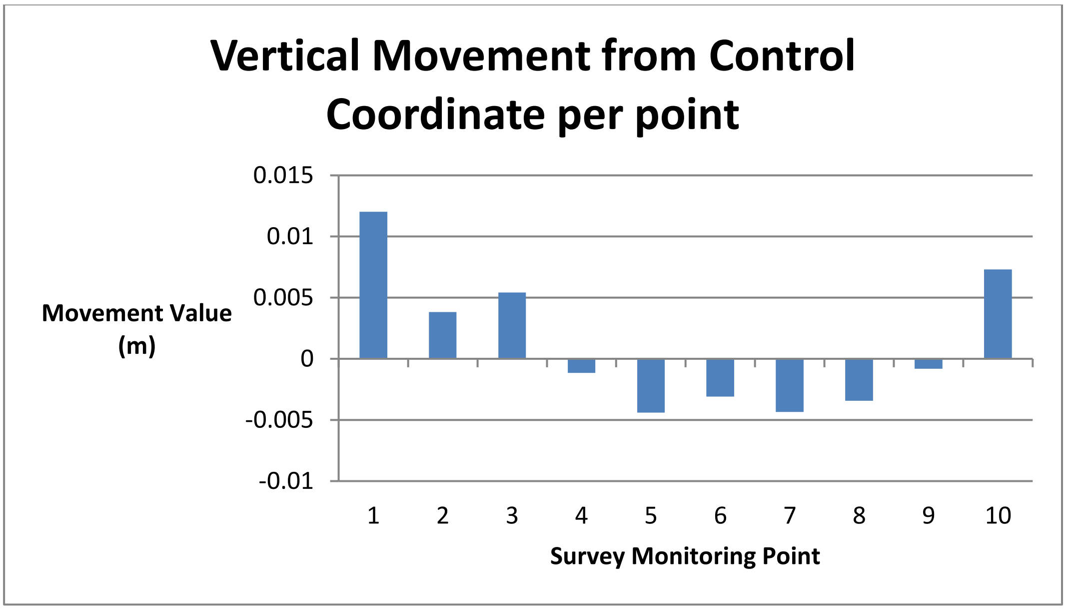


Figure 35: Graphical Summary of Vertical Movement for Sokkia 1 Station F1

4.8.5 Sokkia 2 Station – F1

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	0.004452	-0.00041	0.001121	124° 17' 26"	0.006195
MINIMUM VALUE	-0.00175	-0.0046	-0.00428	12° 59' 0"	0.002741
MAXIMUM VALUE	0.0122	0.00458	0.00695	338° 52' 31"	0.012205
RANGE	0.01395	0.00918	0.01123	325° 53' 31"	0.009463
MEDIAN	0.003445	-0.00096	0.00142	110° 27' 21"	0.005119
ST DEV.	0.00458	0.003334	0.00429	94° 5' 34"	0.003415
1ST QUART	0.00039	-0.00346	-0.00353	61° 50' 51"	0.003398
THIRD QUART	0.008857	0.002912	0.004892	155° 25' 8"	0.009957
INTERQUARTILE RANGE	0.008468	0.00637	0.00842	93° 34' 17"	0.006559

Table 24: Statistical Summary of 2 Stations F1

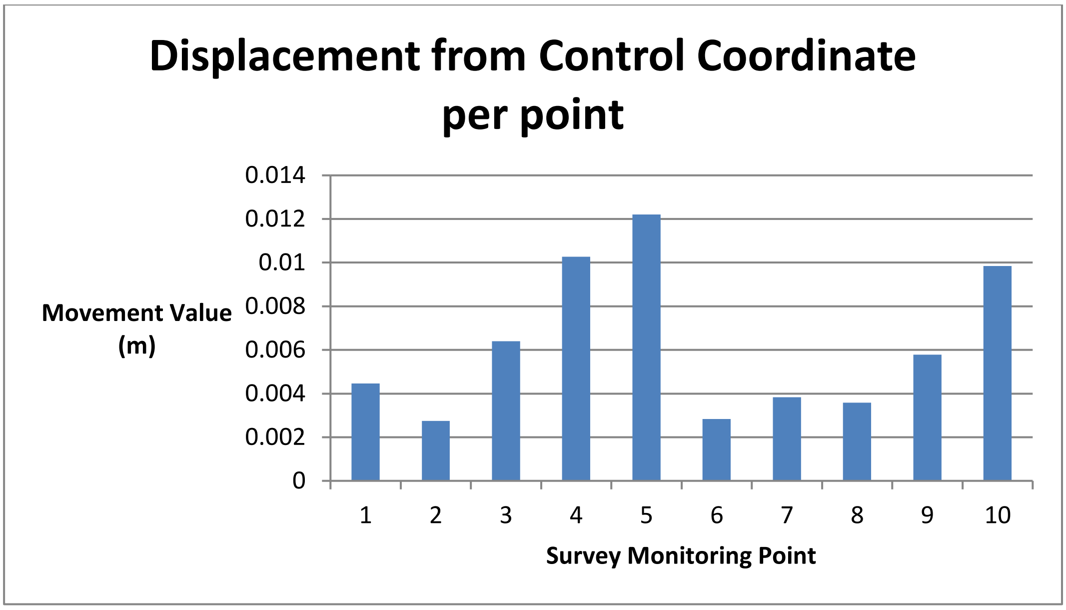


Figure 36: Graphical Summary of Horizontal Movement for Sokkia 2 Station F1

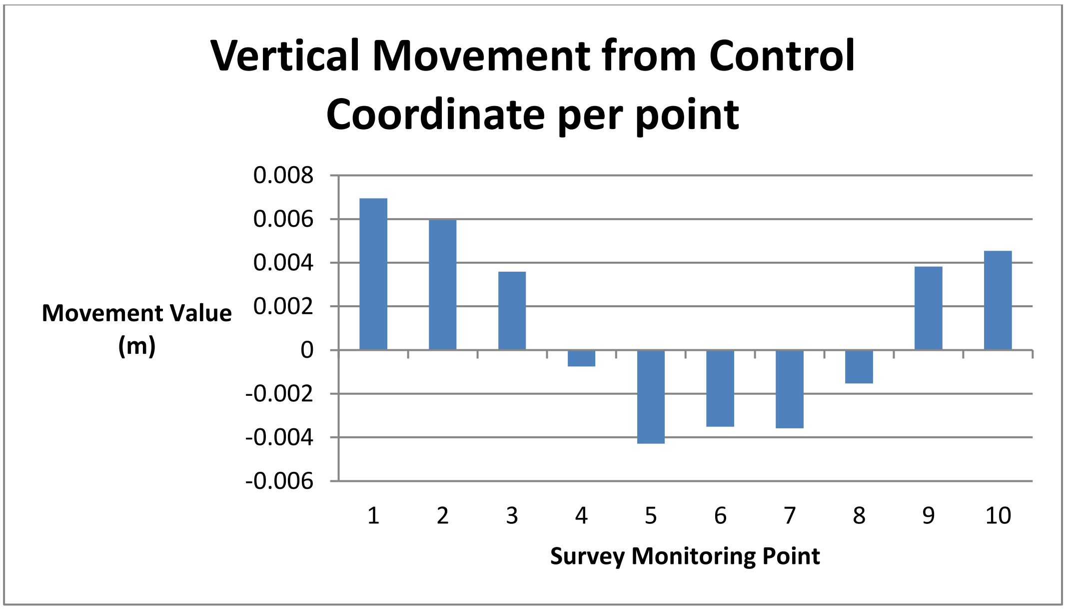


Figure 37: Graphical Summary of Vertical Movement for Sokkia 2 Station F1

4.8.6 Sokkia 3 Station – F1

	DELTA X	DELTA Y	DELTA Z	BEARING	DISTANCE
MEAN	0.00385	-0.00052	0.004495	157° 24' 46"	0.006312
MINIMUM VALUE	-0.00411	-0.00463	-0.00428	62° 46' 51"	0.002606
MAXIMUM VALUE	0.0122	0.00472	0.00959	344° 15' 48"	0.012205
RANGE	0.01631	0.00935	0.01387	281° 28' 57"	0.009599
MEDIAN	0.003695	-0.00096	0.005825	117° 57' 30"	0.005141
ST DEV.	0.005239	0.00327	0.00452	99° 36' 22"	0.00326
1ST QUART	-0.00144	-0.00347	0.000847	86° 33' 14"	0.004032
THIRD QUART	0.008483	0.00248	0.007835	242° 17' 50"	0.009662
INTERQUARTILE RANGE	0.009918	0.005955	0.006988	155° 44' 37"	0.00563

Table 25: Statistical Description for Sokkia 3 Station F1

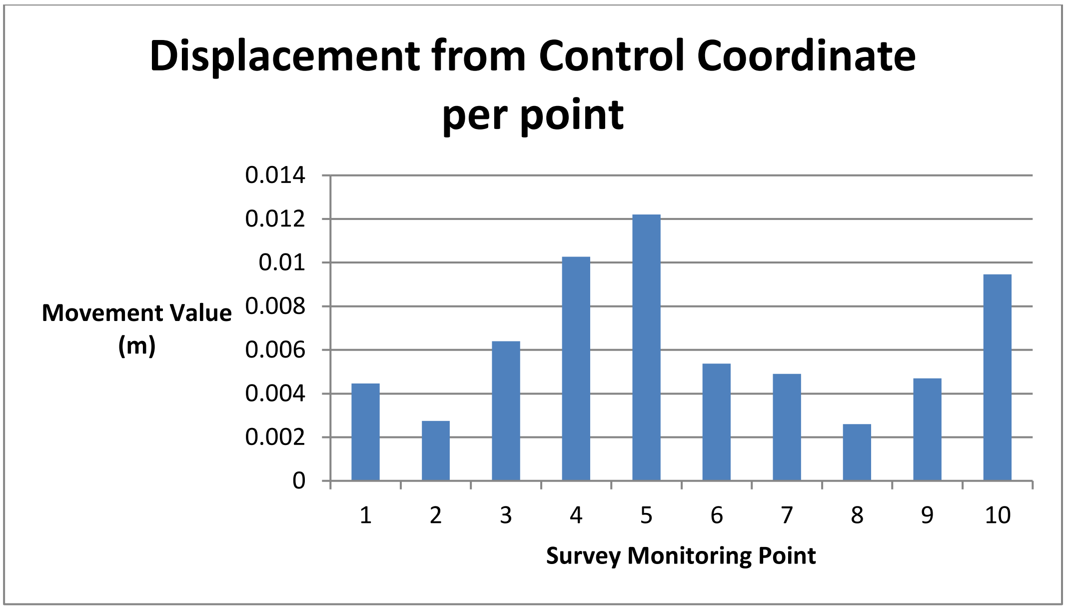


Figure 38: Graphical Summary of Horizontal Movement for Sokkia 3 Station F1

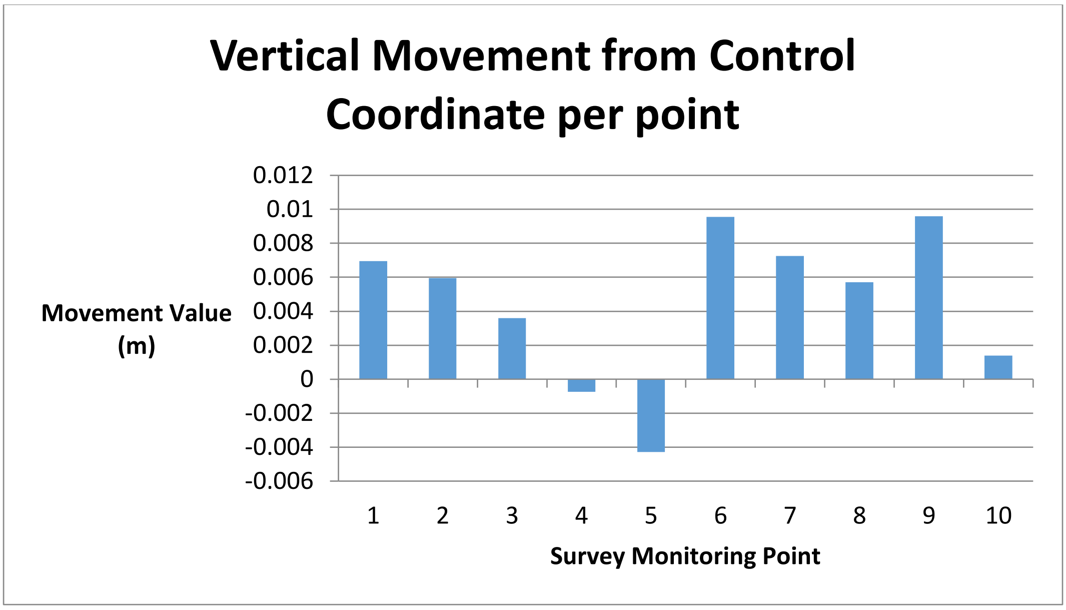


Figure 39: Graphical Summary of Vertical Movement for Sokkia 3 Stations F1

This data has shown the same patterns as the consistent with the sokkia results described above. The more stations that are added it makes the results further away from the controlled coordinates. This is only by a couple of mm but it should be consistent with the Trimble that the patterns it should be providing. It is interesting to note that the Sokkia with one station has an average distance of 5mm with a standard deviation of 2.2mm overall with the distance from the control coordinates.

The Trimble is producing results that are consistent with the expected residuals from all the different methods compared to the controlled data and the expected results. The sokkia was producing results that aren't consistent with the Trimble. These results aren't so far out that it is considered a blunder rarther than the low quality which is to be expected of this method. This is ok as they are only out by millimetres but this does make me second guess the analysis process and possibly the survey method. The Starnet program didn't identify any large errors and the standards residuals in the adjustments were all of an expected nature. The only difference that can be obtained from the data is that there were human errors due to the fact the total station isn't robotic and the manual entering of data. The standard deviations of each set are extremely low and therefore show that this representation of the precision of the data has validated the data to be correct. (Adjustment computations, pg. 20) Since each set of the data has been validated it was acceptable to use these values in the error propagation formulas. Although each set of data didn't pass the chi square test it was able to be ignored as long as the standard residuals weren't too high as to show invalid data. Visual Inspection of these standard residuals as well as standard deviation analysis will prove that the values are correct in the way of survey method but this is to be expected of the substandard methods.

4.7 Error Propagation Analysis

Now that the results of the field study have been obtained it is able to look at the in depth data analysis of what all this data represents. This will involve looking at the data and determine if any patterns are appearing so we can determine an accuracy value for particular methods. Once these patterns have been analysed we can determine using error propagations methods to determine an accuracy value for a particular method over a set time frame. For example it will be able to determine that over 35 years there will be plus or minus 40mm in the accuracy of each single point by looking at them as a whole to determine the average difference. The analysis will be done using the average of the distance from the coordinates for computation ease as due to the bearing results it seems that the direction of movement is random.

The data analysis will look at each method of survey to determine an average of their results and therefore an accuracy level using error propagation methods to determine a formula to work out the accuracy of the dam wall analysis.

Now a formula needs to be created that can determine what accuracy the dam wall has been measured at over a period of time. The formula that is going to be used relates to error propagation techniques and determines the sum of errors in measurements or any data for that matter with an error value. The formula can be seen on the next page along with an example. The average distance from each method has been used as the parameter for the equation as well. Also, the average vertical height has been incorporated to determine settlement errors associated with the dam wall.

The Tables for the average distance and height difference are below. These are the values that will be incorporated into the error propagation formula to determine an accuracy of an overall dam wall.

Horizontal	**1 Station**		
	F1	**FR/FL**	**2 Rounds**
Non Robotic Machine	0.004927	0.004372	0.007966
Robotic Machine	0.004363	0.003863	0.003692

Table 26: Average Difference from Control Coordinates from 1 Station

Horizontal	**2 Station**		
	F1	**FR/FL**	**2 Rounds**
Non Robotic Machine	0.006195	0.005565	0.007056
Robotic Machine	0.002567	0.002129	0.003659

Table 27: Average Difference from Control Coordinates from 2 Stations

Horizontal	3 Station		
	F1	**FR/FL**	**2 Rounds**
Non Robotic Machine	0.006312	0.005353	0.004499
Robotic Machine	0.001578	0.000766	0 (Control Data)

Table 28: Average Difference from Control Coordinate from 3 stations

Vertical	1 Station		
	F1	**FR/FL**	**2 Rounds**
Non Robotic Machine	0.001135	-0.0056	-0.00603
Robotic Machine	0.001285	-0.00049	0.000613

Table 29: Average Difference in height from 1 Station

Vertical	2 Station		
	F1	**FR/FL**	**2 Rounds**
Non Robotic Machine	0.001121	-0.0059	0.000109
Robotic Machine	-0.00067	-0.00114	-0.00102

Table 30: Average Difference in height from 2 Stations

Vertical	3 Station		
	F1	**FR/FL**	**2 Rounds**
Non Robotic Machine	0.004495	-0.00282	-0.00043
Robotic Machine	0.000388	-0.0000096	0 (Control Data)

Table 31: Average Difference in height for 3 Stations

As you can see from the above tables this is the accuracy value expected for the corresponding method. Now use the formula below to work out the associated error for your dam wall using either the vertical correspondent or the horizontal values.

$$\boldsymbol{Error\ Propagation\ Analysis} = \sqrt{[(\boldsymbol{n^2}) * \boldsymbol{T}]}$$

N = number value for corresponding method.

T = time period for dam wall.

For example a dam wall that has been measured for a period of 40 years using a non-robotic total station using 1 station for F1/F2.

$$= \sqrt{[(0.004372^2) * 40]} = 0.02765m = \pm 0.013825m$$

We can always use this formula if the monitoring method has changed over time to get an analysis of what the expected movement rate is.

Imagine a company uses a non-robotic totals station for 20 years to monitor a dam wall and then buys a robotic total station and proceeds to measure the dam wall for another 15 years using the same method of using F1 observations from 2 stations. Please see below for computation example.

$$= \sqrt{[((0.006195^2) * 20) + ((0.002567^2) * 15)]} = 0.0294347\text{m} = \pm 0.014717m$$

Now that a formula has been gained for the average distance per point measured that is different from the most accurate survey method we can apply this to Hunter and Fells theory to establish the accuracy of the survey instrumentation has on the movement values on the dam wall. This accuracy value will show us the potential for the dam wall to move due to survey instrumentation errors which have been quantified to determine the error propagation of a particular dam wall and corresponding methodology.

Excel was used for overall analysis and computations of coordinates exported from Microstation Starnet Software. Excel was used as once the first spreadsheet was set up with the formulas the new coordinates were put in and the results taken out of the spreadsheet.

4.8 Discussion

An interpretation of the above results is detailed below and provides some insights into the data. There has been slight discussion about each set of data in the above sections although in this area we will summarise these patterns and there effects.

The first pattern that will be looked at is the fact that as the station were increased amount of station to the adjustment the statistical values also decreased as well. This is to be expected as the control coordinates, considered the most accurate measurement method have been done using three stations. Therefore as the more stations increase the closer the coordinates are getting to the control values and thus produce a better result.

It is interesting that only the best measurement method by the sokia is the only set of data to produce these results that form this pattern. This therefore shows that the most averages and angles required to get a valid result using a non-robotic total station is the best preferred method as the other methods showed fluctuating results and didn’t adhere to this pattern.

Now from these figures it can be seen that if you go from using 1 face to 2 rounds the residuals from the considerably best practice gets lower. This information combined with the results of more stations gets better results and therefore more accurate coordinates. The sokkia doesn’t demonstrate this theory showing that F1 results from 1 station gives the best results. This is strange as it is considered the worst survey procedure for anything accurate, although it might be the best procedure when using a non-robotic total station. The reason for this is that potentially the initial manual target aiming may be more accurate on the first angle and reduces heavily after the face is turned.

For vertical measurements it has presented itself that one face doesn’t leave a huge difference on average to the dam wall this is after the measurements have been put through a least squares adjustment. Vertically the Trimble showed much better results although it was different to see that when measurements taken from two stations showed increasing residuals as the method got better. The reason for this could potentially be that errors could potentially be occurring as all three stations sit at different heights compared to the monitoring points. Further analysis of each individual point and least squares angles could potentially be an issue. “In trigonometric levelling, a minimum of one face left and on face right reading should always be taken” (Adjustment Computations, pg 162) This is interesting to note that using two stations and just a face left reading showed to mitigate this error in both total stations after the results were put through a least squares adjustment.

4.9 Analysis of our results compared to Hunter and Fells Guidelines

If these accuracy values were to be applied to our three case studies we would get a range of accuracy values of the monitoring data between ±10 to 15mm in coordinate information and the same result in the vertical accuracy of the z values. These values are good to know the accuracy of how the dam wall has been measured over time. This has also proven that Hunter and Fells guideline can be utilised in an everyday context to compare movement values against what other dam owners are experiencing.

4.10 Limitations

When all these dams were first monitored they were done using a theodolite with an EDM attached to the top of it, as well as being levelled. This method could potentially be quantified using the methodology that was used although this would require a large amount of time and specialised equipment that is potentially hard to acquire. Therefore due to this lack of information the values detailed above haven't had this method applied to them.

The data is post processed through the adjustment by least squares application of Starnet but what are the results of the data just by using the output by Trimble is another variable? The least squares adjustment mitigates errors such as instrumentation errors and weights accordingly the random errors. Although these accuracy values maybe small in an ideal world they are meant to be zero but as no measurement is 100% correct this isn't the case. If that's the case our accuracy values are ±15mm for example with close to every error accounted for but image if a dam wall survey wasn't put through strict adjustment process or substandard control was used. The accuracy value could potentially be much larger especially since human error hasn't been accounted for in these accuracy values.

Also there is a limitation on the calibration of the equipment. Both calibration certificates were unable to be located and I am unsure what the results of the calibration are for either machine. There is a limitation here as the measurements aren't legally traceable or checked against a national standard therefore I have used the accuracy values published in the manufactures datasheets for the weighting in the least squares adjustment . Checks on control and multiple redundant observations were read throughout the measurements to ensure high quality results. A check and adjust was completed on the Trimble S6 before the measurements but due to time resources a Sokkia check and adjust wasn't able to be completed. The environmental conditions were entered into the total stations during the measurements.

4.11 Further Analysis

In the first instance these values need to be checked. These results have only been obtained from 1 set of measurements in very similar environmental conditions. A number of things need to be done to check the validity of these results which are listed below:

- Do the whole process again to the same standard on a different dam wall and determine the differences and compare against the values presented in this thesis to ensure repeatability of results.
- Use different methods such as resections or different shaped control networks to determine what this affect has on the values.

Further analysis that could be done is that Hunter and Fells Guidelines could potentially be made more adaptable for surveyors to interpret there survey information against their values, for instance a program that does all this automatically. In their book all of their case study data is listed in table format. This could potentially be imported into excel to do statistical analysis of all the dam walls and thus create another guideline developed from their case study data. Although the scope is looking at the whole dam wall there may be limitations that apply as their theory looks at the dam wall in significant areas. For example separating the upstream, downstream and crest values which would give a much more in depth look at a Dam Wall.

Possibly there needs to be a way that can separate these coordinate values for a surveyor to analyse them independently. An idea for this would be to name the monitoring points in certain ranges and setup using an 'if' function to separate the values in excel. Although this would take a fair amount of time to convert the old naming conventions to new ones, but would be worth it if a comprehensive program was built to analyse this data.

Further Work could be to use Trimble Monitoring App in their Trimble Access software and develop a dam monitoring function that incorporates Hunter and Fells Guideline and an automatic report be written. A way to set this up would be to code a new stylesheet for Trimble business centre output after TBC runs an adjustment over the adjustments.

Further analysis would also include potentially analyse the effect resections have on the coordinate values. This could be done by setting up 1st order control and resecting in from it. The control would have to be placed onside the monitoring values but most dams have already done this to ensure sufficient length of a back sight. The test variable for this would be to measure the values using one resection and do multiple resections to determine the differences in the value coordinates. This will evaluate the resection suitability for monitoring values. From this further error propagation analysis values can be given for resection methods.

More work could be given also on the effect of not using a least squares adjustment from the raw data. For example just use the automated produced values from all the average in the rounds data. This can be exported from nearly all modern day data recorders in the Form of a CSV data file.

Chapter 5 Conclusion and Recommendations

5.1 Introduction

From the previous chapter it has been identified that there is significant errors associated to a dam wall monitoring survey over a period of time especially when differing methods have been used. The results we have obtained have had nearly all errors mitigated except for random errors so therefore imagine what the potential errors could be if substandard survey procedures are used. Our accuracy values associated with the corresponding formula will give an indication of the accuracy related to a dam wall monitoring survey or any long term monitoring survey for that matter.

5.2 Recommendations

The recommendations that are made is that all data be put through a least squares adjustment process before analysing the results. In the process all control coordinates should be held fixed and the monitoring points are able to be changed to ensure the best outcomes from your surveyed monitoring points.

From my analysis the monitoring procedure depends upon the tolerance of the values the client is requesting, which in most instances will be using two face measurements from one station per monitoring point. The method also depends on the amount of monitoring points on a dam wall as Time can be a factor. I found in most instances not every monitoring point can be seen from a single station so a good control network is to be utilised to ensure high quality results, especially when moving from setup stations or using resections. If monitoring a dam wall over a significant time frame every 5 years I would read multiple arcs to each point from different setups to ensure the validity of not only the control but the monitoring point itself.

Also Gavan Hunter and Robin Fells expected movement values can be utilised by surveyors and industry professionals but caution needs to be used on the reliance of this data. Each point still needs to be analysed as well as a full engineering inspection and report produced for dam walls. This project looks at survey monitoring irrespective of all other dam wall attributes. These have been mentioned in the literature review but detailed analysis of these is outside the associated project scope.

5.3 Conclusions

The purpose and aim of this project was to determine what the accuracy value of a dam wall survey was in a dam wall context as well as to determine what the true movement is and what is due to survey error. These aims and objectives were achieved within the thesis.

From the literature review we determine what expected movement was to be expected of the dam wall case studies and when they were producing abnormal behaviours. Also survey procedures and best practice methods of monitoring surveys were researched to establish what determines a high quality monitoring survey.

From this literature review a detailed methodology was produced to reach these research objectives. This methodology produced both archived data as well as field survey data. This data was used for comparison of methods and to analyse the effectiveness of Gavan Hunter and Robin Fells dam wall movement values.

Using this data a formula was created using error propagation methods to establish a way dam wall owners can determine the measurement accuracy of their associated dam wall. It has also shown that Gavan Hunter and Robin Fells method can be applied by the average surveyor for an analysis of data.

From these error propagation formula a user is able to determine what range of movement is true movement and what is in survey accuracy tolerance over such a long time. A user can also utilise this formula between methods as well as differing types of total stations.

In conclusion of the above summary, the archived data and field survey procedures have been done to ensure an overall investigation of Dam Wall Deformation surveys and recommendations have been made to increase accuracy while not losing time on your surveys and how expected movement values can be used in a survey context.

References

Ausilio, E. & Conte, E., Oct 1999. *Settlement rate of foundations on unsaturated soils,* s.l.: Canadian Geotechnical Journal.

FSA, March 2001. *Farm Dams for the Sugar Industry,* s.l.: FSA Irrigation.

ICSM, 24 September 2014. *Guideline for Control Surveys by GNSS,* Canberra: Intergovernment Committee on Surveyong and Mapping.

MainRoads, 2014. *Settlement Monitoring.* [Online]
Available at: https://mainroads.wa.gov.au/Building Roads/StandardsTechnical/Survey/EngineeringSurveysGuidelines?pages?settlementmonitoring.aspx
Accessed 29 10 2015

Trimble, 2014. *Trimble S8 Total Station,* Las Vegas : Trimble .

WaterResources, 2008. *Guidelines for the Construction of Earth Fill Dams,* Tasmania: Department of Primary Industries and Water.

Hunter. G & Fell.R 2003, The Deformation Behaviour of Embankment Dams, University of New South Wales, Sydney

University of Southern Queensland, 2014, SVY2105 Survey Computations B, University of Southern Queensland, Toowoomba

ICSM, 2007, Standards and Practices for Control Surveys SP1, V1.7, Inter-Governmental Committee on Surveying and Mapping, Canberra

Singh. V.P 1996, Dam Breach Modeling Technology, Vol. 17, Kluwer Academic Publishers, Baton Rouge

SEQWater, 2006, Wivenhoe Dam Comprehensive Inspection, Surveillance Report Final, SEQWater, Ipswich,QLD

Ghilani, C.D. (2010) Adjustment Computations. 5th edn. New Jersey: Wiley.

Accuracy and Precision. 2016. *Accuracy and Precision*. Available at: http://www.mathsisfun.com/accuracy-precision.html. Accessed 1 September 2016

Error Analysis. 2016. *Error Analysis*. Available online at:

http://lectureonline.cl.msu.edu/~mmp/labs/error/e2.htm. Accessed 1 October 2016

Sokkia (2011) *SET X Specifications*. Available at:

http://www.sokkia.com.sg/products/electronic/uploads/SETX.pdf Accessed: 2 October 2016

Trimble (2016) *TrimbleS6 Total Station*. Available online at:

http://www.trimble.com/Survey/trimbles6.aspx Accessed: 10 October 2016

Appendices

Appendix A Project Specification

ENG4111/4112 Research Project

Project Specification

For: Joshua Lynch

Title: Investigation of Dam Wall Deformation Surveys

Major: Bachelor of Spatial Science – Major Surveying

Supervisors: Xiaoye Liu – USQ Supervisor

Jon Bradbury – Coordinator Survey at Toowoomba Regional Council

Sponsorship: Toowoomba Regional Council

Enrolment: ENG4111 – ONC S1 2016

ENG4112 – ONC S2 2016

Project Aim: To do an overall investigation into dam wall deformation surveys using movement values provided by Toowoomba Regional Council , as well as survey Cressbrook Dam wall using older techniques to see if dam walls are moving due to increased technology or if they are moving because they are actually moving. By testing this against a control set of data.

Programme: Issue B, 4th October 2016

1. Research Literature for movement values associated with earth fill clay core dam walls, and investigate if anyone has provided a value/guideline to expect a dam wall to move.
2. Examine the literature review and analyse the relevant monitoring data that I will have access to and determine if they are meeting this guideline or provide estimation for a guideline of an expected rate of movement associated with the current type of dam wall.
3. Measure Cressbrook Dam wall using a range of total stations and see what differences there are in the monitoring values using different methods to determine whether dam monitoring has changed due to an increase of accuracy/technology in monitoring instruments, or show the differences between the technology and examine what effect that has on the deformation survey data. Reduce the data and determine if it proves the guideline theory.

If Time and Resources Permit:

4. To Field test and evaluate Trimble 4D Monitoring Software and determine if it would be appropriate for clients to use to monitor dam walls within accuracy specifications.
5. Look at possible reason/standards that could be implemented to overall improve dam wall monitoring across the industry.

Appendix B Trimble S6 Specifications

TRIMBLE S6 DR PLUS

PERFORMANCE

Angle measurement
Sensor type. . . . Absolute encoder with diametrical reading
Accuracy (Standard deviation based on DIN 18723) . . . . 2" (0.6 mgon) 3" (1.0 mgon), or 5" (1.5 mgon)
Angle Display (least count) . . . . 0.1" (0.01 mgon)
Automatic level compensator
Type. . . . Centered dual-axis
Accuracy . . . . 0.5" (0.15 mgon)
Range . . . . ± 5.4' (±100 mgon)
Distance measurement
Accuracy (RMSE)
Prism mode
Standard. . . . 2 mm + 2 ppm (0.0065 ft + 2 ppm)
Standard deviation according to ISO17123-4 . . . . 1 mm + 2 ppm (0.003 ft + 2 ppm)
Tracking . . . . 4 mm + 2 ppm (0.013 ft + 2 ppm)
DR mode
Standard. . . . 2 mm + 2 ppm (0.0065 ft + 2 ppm)
Tracking . . . . 4 mm + 2 ppm (0.013 ft + 2 ppm)
Measuring time
Prism mode
Standard. . . . 1.2 sec
Tracking . . . . 0.4 sec
DR mode
Standard. . . . 1–5 sec
Tracking . . . . 0.4 sec
Range
Prism mode (under standard clear conditions[1,2])
1 prism . . . . 2500 m (8202 ft)
1 prism Long Range mode . . . . 5500 m (18,044 ft) (max. range)
Shortest range . . . . 0.2 m (0.65 ft)

DR mode

	Good (Good visibility, low ambient light)	Normal (Normal visibility, moderate sunlight, some heat shimmer)	Difficult (Haze, object in direct sunlight, turbulence)
White card (90% reflective)[3]	1,300 m (4,265 ft)	1,300 m (4,265 ft)	1,200 m (3,937 ft)
Gray card (18% reflective)[3]	600 m (1,969 ft)	600 m (1,969 ft)	550 m (1,804 ft)

Shortest range . . . . 1 m (3.28 ft)
DR Ranges (typically)
Concrete. . . . 600 m–800 m (1968–2624 ft)
Wood construction . . . . 400 m–800 m (1312–2624 ft)
Metal construction . . . . 400 m–500 m (1312–1640 ft)
Light rock . . . . 400 m–600 m (1312–1968 ft)
Dark rock . . . . 300 m–400 m (984–1312 ft)
Reflective foil 20 mm . . . . 1000 m (3280 ft)
DR Extended Range Mode
White Card (90% reflective)[3]. . . . 2000 m–2200 m
Gray Card (18% reflective)[3]. . . . 900 m–1000 m
Accuracy. . . . 10 mm + 2 ppm (0.033 ft + 2 ppm)
Camera
Chip . . . . Color Digital Image Sensor
Resolution. . . . 2048 x 1536 pixels
Focal length . . . . 23 mm (0.07 ft)
Depth of field . . . . 3 m to infinity (9.84 ft to infinity)
Field of view . . . . 16.5° x 12.3° (18.3 gon x 13.7 gon)
Digital zoom 4-step (1x, 2x, 4x, 8x)
Exposure . . . . Automatic
Brightness . . . . User-definable
Contrast . . . . User-definable
Image storage . . . . Up to 2048 x 1536 pixels
File format. . . . JPEG

Source: Trimble (2016)

Appendix C Sokkia Set 3x Specifications Sheet

SETX Total Stations

SET1X · SET2X · SET3X · SET5X

SPECIFICATIONS

Model		SET1X	SET2X	SET3X	SET5X
Telescope		Fully transiting, coaxial sighting and distance measuring optics			
		Length: 173mm (6.8in.), Objective aperture: 45mm (1.8in.) (EDM 48mm (1.9in.)), Magnification: 30x, Resolving power: 2.5", Image: Erect, Field of view: 1°30' (26m/1,000m), Minimum focus: 1.3m (4.3ft.), Reticle glass: = mark printed, Reticle illumination: 5 brightness levels			
Angle measurement		Absolute encoder scanning. Both circles adopt diametrical detection.			
Unit		Degree / Gon / Mil, selectable			
Display resolutions (selectable)		0.5" / 1", 0.0001 / 0.0002gon, 0.002 / 0.005mil		1" / 5", 0.0002 / 0.001gon, 0.005 / 0.02mil	
Accuracy (ISO 17123-3:2001)		1" / 0.3mg / 0.005mil	2" / 0.6mg / 0.01mil	3" / 1mg / 0.015mil	5" /1.5mg / 0.025mil
IACS (Independent Angle Calibration System)		Provided		n/a	
Measurement mode		H: Clockwise / Counterclockwise, selectable. V: Zenith 0 / Horizontal 0 / Horizontal 0±90° / Slope in %, selectable			
Automatic dual-axis compensator		Dual-axis liquid tilt sensor, Working range: ±4' (±74 mg)			
Collimation compensation		Yes / No, selectable			
Fine motion screws		Fine / Coarse 2-speed motion			
Distance measurement		Modulated laser, phase comparison method with red laser diode.			
Laser output		Reflectorless mode: Class 3R (max. 5mW), Prism/Sheet mode: Class 1 equivalent (max. 0.22mW)			
Unit		Meters / feet / US feet, selectable			
Measuring range (slope distance)	Reflectorless*1 (using Kodak Gray Card)	0.3 to 500m (1 to 1,640ft.) (White side, 90% reflective) 0.3 to 250m (1 to 820ft.) (Gray side, 18% reflective)			
	With reflective sheet target*2	RS90N-K: 1.3 to 500m (4.3 to1,640ft.)			
	With mini prisms	Under average conditions*3: w/ CP01: 1.3 to 2,500m (4.3 to 8,200ft.), w/OR1PA: 1.3 to 500m (4.3 to 1,640ft.)			
	With 1 AP prism	Under average conditions*3: 1.3 to 5,000m (4.3 to 16,400ft.), Under good conditions*4: 1.3 to 6,000m (4.3 to 19,680ft.)			
	With 3 AP prisms	Under average conditions*3: to 8,000m (to 26,240ft.), Under good conditions*4: to 10,000m (to 32,800ft.)			
Display resolutions	Fine mode	0.0001 / 0.001m (0.001 / 0.01ft.)		0.001m (0.01ft.)	
	Rapid single / Tracking	Rapid single: 0.001m (0.01ft.) / Tracking: 0.01m (0.1ft.)			
Accuracy (ISO 17123-4:2001) (D=measuring distance, unit:mm)	Reflectorless*1 (Fine mode)	0.3 to 200m (1 to 660ft.): (3 + 2ppm x D)mm Over 200 to 350m (over 660 to 1,140ft.): (5 + 10ppm x D)mm Over 350 to 500m (over 1,140 to 1,640ft.): (10 + 10ppm x D)mm			
	Reflectorless*1 (Rapid mode)	0.3 to 200m (1 to 660ft.): (6 + 2ppm x D)mm Over 200 to 350m (over 660 to 1,140ft.): (8 + 10ppm x D)mm Over 350 to 500m (over 1,140 to 1,640ft.): (15 + 10ppm x D)mm			
	With reflective sheet target*2	Fine: (3+2ppm x D)mm, Rapid: (6+2ppm x D)mm			
	With prism Fine mode	(2+2ppm x D)mm			
	With CPS12 precision prism system	(1.5+2ppm x D)mm	n/a		
	With prism Rapid mode	(5+2ppm x D)mm			
Measuring time	Fine mode / Rapid / Tracking	0.9s (initial1.5s) / 0.6s (initial 1.3s) / 0.4s (initial 1.3s)			
Measuring mode		Fine (single, repeat, average), Rapid (single, repeat), Tracking			
Atmospheric correction, Prism constant correction		Temperature, Pressure, Humidity, ppm input available / -99 to +99mm (1mm steps). 0 fixed in reflectorless mode.			
Refraction & earth-curvature correction		Yes (K=0.14 / 0.20) / No, selectable			
OS, data storage and transfer					
Operating system / Application		Microsoft Windows CE / SDR Data Collection Software			
Data storage	Internal memory	64MB (More than 1MB available for data)			
	Memory card drive	Support up to 4GB CF Type II (3.3V only), SD card (max. 1GB) with CF type adapter, USB flash memory up to 4GB (FAT32 format)			
Interface		Asynchronous serial RS232C compatible, Baud rate 1,200 to 38,400bps USB1.1 Type A and Type miniB			
Bluetooth wireless modem*5		Class 1, Ver.2.0 + EDR. Operating range: up to 200m (660ft.)			
SFX data transfer		Provided			
General					
Display		3.5in. Transreflective TFT QVGA color LCD on single face (Face 1) with backlight (Bright / Dim selectable), 324x240 dots (active area: 72.5mm x 49.5mm), touch screen, 2nd control panel on Face 2 is a factory option.			
Keyboard		Alphanumeric, 32 keys with backlight			
Laser-pointer function		ON / Auto Off in 1/5/10/30 minutes / OFF, selectable. (does not work simultaneously with the Guide Light)			
Guide Light		Two color LEDs, single aperture, Class 1 LED product. Operating range: 1.3 to 150m (4.3 to 490ft.)			
Sensitivity of levels	Plate level	20" / 2mm	30" / 2mm		
	Circular / Graphic	Circular level: 10' /2mm / Graphic LCD level: ±4.5' (±81mgon, ±1.36mil) / outer circle			
Optical plummet	Magnification	5.5x	3x		
Tribrach		Detachable			
Dust and water protection / Operating temperature		IP65 (IEC 60529:2001) / -20 to +50°C (-4 to +122°F)			
Instrument height / Size with handle and battery		236mm (9.3in.) from tribrach bottom / W 201 x D 202 x H 375 mm (W 8.0 x D 8.0 x H 14.8in.)			
Weight with handle and battery		Approx. 6.9kg (15.2lb.), With optional F2 control panel: approx. 7.1kg (15.7lb.)			
Power supply		7.2 to 12V DC			
Battery	BDC58 (standard)	Li-ion rechargeable battery (4.3Ah, 2pcs. included standard)			
	BDC46B (optional)	Li-ion rechargeable battery (2.45Ah) (Use with the SB178 adapter included as a standard accessory)			
	External batteries (optional)	Ni-MH rechargeable battery, BDC60 (6.5Ah), BDC61 (13Ah)			
Operating time at 20°C (68°F) (single measurement every 30 seconds)	BDC58	Approx. 14 hours			
	BDC46B	Approx. 6.5 hours			
	External batteries (optional)	BDC60: approx. 19 hours, BDC61: approx. 38.5 hours.			
Automatic power cut-off		5/10/15/30 minutes after operation / Off, selectable			

Source: Sokkia (2010)

Appendix D Sample Starnet Output File

MicroSurvey STAR*NET-PRO Version 7, 2, 2, 7

Licensed for Demo Use Only

Run Date: Sun Sep 25 2016 16:37:59

Summary of Files Used and Option Settings

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Project Folder and Data Files

Project Name 2 RDS

Project Folder C:\USERS\...\STARNET PRJECTT FILES\2 RDS

Data File List 1. C:\Users\...\2 Rounds\Trimble\160504 JL DAM.dat

2. C:\Users\...\2 Rounds\Trimble\160504 JL DAM1.dat

3. C:\Users\...\2 Rounds\Trimble\160504 JL DAM2.dat

4. C:\Users\...\2 Rounds\Sokia\sokia from 1001.dat

5. C:\Users\...\2 Rounds\Sokia\sokia from 1003.dat

6. C:\Users\...\2 Rounds\Sokia\sokia from 1004.dat

Project Option Settings

STAR*NET Run Mode : Adjust with Error Propagation

Type of Adjustment : 3D

Project Units : Meters; DMS

Coordinate System : LOCAL

Apply Average Scale Factor : 1.0000000000

Input/Output Coordinate Order : North-East

Angle Data Station Order : At-From-To

Distance/Vertical Data Type : Slope/Zenith

Convergence Limit; Max Iterations : 0.010000; 10

Default Coefficient of Refraction : 0.070000

Earth Radius : 6372000.00 Meters

Create Coordinate File : Yes

Create Ground Scale Coordinate File : No

Create Dump File : No

Instrument Standard Error Settings

Project Default Instrument

Distances (Constant) : 0.003000 Meters

Distances (PPM) : 0.002000

Angles : 3.000000 Seconds

Directions : 3.000000 Seconds

Azimuths & Bearings : 3.000000 Seconds

Zeniths : 10.000000 Seconds

Elevation Differences (Constant) : 0.015240 Meters

Elevation Differences (PPM) : 0.000000

Differential Levels : 0.002403 Meters / Km

Centering Error Instrument : 0.000000 Meters

Centering Error Target : 0.000000 Meters

Centering Error Vertical : 0.000000 Meters

Summary of Unadjusted Input Observations

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Number of Entered Stations (Meters) = 14

Fixed Stations	N	E	Elev	Description
1002	0.0000	0.0000	50.0000	
1003	-429.2226	12.0589	53.5913	
1004	-353.9338	128.0553	19.1049	
1005	-58.8156	174.9584	-2.1176	

Free Stations	N	E	Elev	Description
1	325.1100	65.5310	263.3190	
2	299.7810	65.3060	263.4880	
3	250.0060	65.3230	263.4650	
4	200.1880	65.5300	263.2600	
5	150.1140	65.1720	263.3970	
6	100.1520	43.0950	273.1700	
7	150.0760	43.1770	273.4500	
8	200.0090	42.9380	273.4720	
9	250.1160	42.8230	273.7300	
10	299.9400	42.7050	273.8870	

Number of Angle Observations (DMS) = 50

At	From	To	Angle	StdErr
1005	1002	1	304-43-09.00	3.00
1005	1002	2	297-08-56.00	3.00
1005	1002	3	286-24-12.00	3.00
1005	1002	4	279-20-27.00	3.00

1005	1002	5	274-35-10.00	3.00
1005	1002	6	274-41-47.00	3.00
1005	1002	7	278-36-11.00	3.00
1005	1002	8	283-59-25.00	3.00
1005	1002	9	291-35-00.00	3.00
1005	1002	10	302-30-50.00	3.00
1004	1002	1	3-34-19.00	3.00
1004	1002	2	1-27-11.00	3.00
1004	1002	3	355-30-52.00	3.00
1004	1002	4	344-41-17.00	3.00
1004	1002	5	321-24-33.00	3.00
1004	1002	6	282-14-59.00	3.00
1004	1002	7	314-18-09.00	3.00
1004	1002	8	335-59-25.00	3.00
1004	1002	9	348-17-38.00	3.00
1004	1002	10	355-31-03.00	3.00
1003	1002	10	8-14-08.00	3.00
1003	1002	9	9-47-38.00	3.00
1003	1002	8	12-17-06.00	3.00
1003	1002	7	16-53-47.00	3.00
1003	1002	6	27-30-45.00	3.00
1003	1002	6	27-31-00.50	3.00
1003	1002	7	16-53-57.00	3.00
1003	1002	8	12-17-13.50	3.00
1003	1002	9	9-47-44.25	3.00
1003	1002	10	8-14-14.50	3.00
1004	1002	1	3-34-23.75	3.00
1004	1002	2	1-27-16.50	3.00
1004	1002	3	355-30-45.70	3.00
1004	1002	4	344-41-07.50	3.00

1004	1002	5	321-24-24.50	3.00
1004	1002	6	282-14-51.50	3.00
1004	1002	7	314-17-56.00	3.00
1004	1002	8	335-59-29.00	3.00
1004	1002	9	348-17-30.00	3.00
1004	1002	10	355-30-57.25	3.00
1005	1002	1	304-43-17.75	3.00
1005	1002	2	297-08-58.00	3.00
1005	1002	3	286-24-14.25	3.00
1005	1002	4	279-20-44.50	3.00
1005	1002	5	274-35-14.00	3.00
1005	1002	6	274-41-49.75	3.00
1005	1002	7	278-36-12.50	3.00
1005	1002	8	283-59-24.25	3.00
1005	1002	9	291-34-56.75	3.00
1005	1002	10	302-30-58.75	3.00

Number of Distance Observations (Meters) = 101

From	To	Distance	StdErr	HI	HT	Type
1005	1002	191.7100	0.0030	1.527	1.200	S
1005	1	137.8510	0.0030	1.527	0.093	S
1005	1002	191.7110	0.0030	1.527	1.200	S
1005	2	154.3770	0.0030	1.527	0.093	S
1005	1002	191.7100	0.0030	1.527	1.200	S
1005	3	192.2150	0.0030	1.527	0.093	S
1005	1002	191.7100	0.0030	1.527	1.200	S
1005	4	234.4900	0.0030	1.527	0.093	S
1005	1002	191.7090	0.0030	1.527	1.200	S
1005	5	279.7430	0.0030	1.527	0.093	S

1005	1002	191.7100	0.0030	1.527	1.200	S
1005	6	334.9620	0.0030	1.527	0.093	S
1005	1002	191.7100	0.0030	1.527	1.200	S
1005	7	289.9670	0.0030	1.527	0.093	S
1005	1002	191.7090	0.0030	1.527	1.200	S
1005	8	247.0070	0.0030	1.527	0.093	S
1005	1002	191.7090	0.0030	1.527	1.200	S
1005	9	207.0220	0.0030	1.527	0.093	S
1005	1002	191.7090	0.0030	1.527	1.200	S
1005	10	172.5680	0.0030	1.527	0.093	S
1004	1002	377.6300	0.0030	1.463	1.200	S
1004	1	222.5190	0.0030	1.463	0.093	S
1004	1002	377.6300	0.0030	1.463	1.200	S
1004	2	198.4120	0.0030	1.463	0.093	S
1004	1002	377.6300	0.0030	1.463	1.200	S
1004	3	152.0050	0.0030	1.463	0.093	S
1004	1002	377.6300	0.0030	1.463	1.200	S
1004	4	108.4830	0.0030	1.463	0.093	S
1004	1002	377.6290	0.0030	1.463	1.200	S
1004	5	73.7870	0.0030	1.463	0.093	S
1004	1002	377.6290	0.0030	1.463	1.200	S
1004	6	86.1040	0.0030	1.463	0.093	S
1004	1002	377.6290	0.0030	1.463	1.200	S
1004	7	93.5850	0.0030	1.463	0.093	S
1004	1002	377.6300	0.0030	1.463	1.200	S
1004	8	123.0410	0.0030	1.463	0.093	S
1004	1002	377.6310	0.0030	1.463	1.200	S
1004	9	162.9020	0.0030	1.463	0.093	S
1004	1002	377.6310	0.0030	1.463	1.200	S
1004	10	206.9990	0.0030	1.463	0.093	S

1004	1002	377.6310	0.0030	1.463	1.200	S
1003	1002	429.4090	0.0030	1.327	1.200	S
1003	10	266.6740	0.0030	1.327	0.093	S
1003	1002	429.4080	0.0030	1.327	1.200	S
1003	9	217.5760	0.0030	1.327	0.093	S
1003	1002	429.4100	0.0030	1.327	1.200	S
1003	8	168.6430	0.0030	1.327	0.093	S
1003	1002	429.4090	0.0030	1.327	1.200	S
1003	7	120.8190	0.0030	1.327	0.093	S
1003	1002	429.4090	0.0030	1.327	1.200	S
1003	6	75.7330	0.0030	1.327	0.093	S
1003	1002	429.4150	0.0030	1.440	1.270	S
1003	6	75.7775	0.0030	1.440	0.093	S
1003	1002	429.4150	0.0030	1.440	1.270	S
1003	7	120.8475	0.0030	1.440	0.093	S
1003	1002	429.4150	0.0030	1.440	1.270	S
1003	8	168.6643	0.0030	1.440	0.093	S
1003	1002	429.4150	0.0030	1.440	1.270	S
1003	9	217.5940	0.0030	1.440	0.093	S
1003	1002	429.4155	0.0030	1.440	1.270	S
1003	10	266.6900	0.0030	1.440	0.093	S
1004	1002	377.6370	0.0030	1.528	1.270	S
1004	1	222.5230	0.0030	1.528	0.093	S
1004	1002	377.6370	0.0030	1.530	1.270	S
1004	2	198.4158	0.0030	1.530	0.093	S
1004	1002	377.6368	0.0030	1.530	1.270	S
1004	3	152.0108	0.0030	1.530	0.093	S
1004	1002	377.6372	0.0030	1.530	1.270	S
1004	4	108.4878	0.0030	1.530	0.093	S
1004	1002	377.6372	0.0030	1.530	1.270	S

1004	5	73.7906	0.0030	1.530	0.093	S
1004	1002	377.6380	0.0030	1.530	1.270	S
1004	6	86.1017	0.0030	1.530	0.093	S
1004	1002	377.6370	0.0030	1.530	1.270	S
1004	7	93.5833	0.0030	1.530	0.093	S
1004	1002	377.6380	0.0030	1.530	1.270	S
1004	8	123.0415	0.0030	1.530	0.093	S
1004	1002	377.6372	0.0030	1.530	1.270	S
1004	9	162.9023	0.0030	1.530	0.093	S
1004	1002	377.6377	0.0030	1.530	1.270	S
1004	10	207.0000	0.0030	1.530	0.093	S
1005	1002	191.7355	0.0030	1.528	1.270	S
1005	1	137.8530	0.0030	1.528	0.093	S
1005	1002	191.7350	0.0030	1.528	1.270	S
1005	2	154.3795	0.0030	1.528	0.093	S
1005	1002	191.7325	0.0030	1.528	1.270	S
1005	3	192.2173	0.0030	1.528	0.093	S
1005	1002	191.7355	0.0030	1.528	1.270	S
1005	4	234.4925	0.0030	1.528	0.093	S
1005	1002	191.7360	0.0030	1.528	1.270	S
1005	5	279.7445	0.0030	1.528	0.093	S
1005	1002	191.7360	0.0030	1.528	1.270	S
1005	6	334.9647	0.0030	1.528	0.093	S
1005	1002	191.7353	0.0030	1.528	1.270	S
1005	7	289.9695	0.0030	1.528	0.093	S
1005	1002	191.7350	0.0030	1.528	1.270	S
1005	8	247.0110	0.0030	1.528	0.093	S
1005	1002	191.7350	0.0030	1.528	1.270	S
1005	9	207.0248	0.0030	1.528	0.093	S
1005	1002	191.7350	0.0030	1.528	1.270	S

1005	10	172.5737	0.0030	1.528	0.093	S

Number of Zenith Observations (DMS) = 101

From	To	Zenith	StdErr	HI	HT
1005	1002	74-19-36.00	10.00	1.527	1.200
1005	1	81-55-33.00	10.00	1.527	0.093
1005	1002	74-19-38.00	10.00	1.527	1.200
1005	2	82-43-55.00	10.00	1.527	0.093
1005	1002	74-19-38.00	10.00	1.527	1.200
1005	3	84-10-32.00	10.00	1.527	0.093
1005	1002	74-19-39.00	10.00	1.527	1.200
1005	4	85-16-44.00	10.00	1.527	0.093
1005	1002	74-19-37.00	10.00	1.527	1.200
1005	5	86-00-58.00	10.00	1.527	0.093
1005	1002	74-19-38.00	10.00	1.527	1.200
1005	6	84-59-52.00	10.00	1.527	0.093
1005	1002	74-19-37.00	10.00	1.527	1.200
1005	7	84-09-48.00	10.00	1.527	0.093
1005	1002	74-19-38.00	10.00	1.527	1.200
1005	8	83-08-17.00	10.00	1.527	0.093
1005	1002	74-19-37.00	10.00	1.527	1.200
1005	9	81-43-55.00	10.00	1.527	0.093
1005	1002	74-19-37.00	10.00	1.527	1.200
1005	10	80-00-45.00	10.00	1.527	0.093
1004	1002	85-20-56.00	10.00	1.463	1.200
1004	1	90-27-48.00	10.00	1.463	0.093
1004	1002	85-20-57.00	10.00	1.463	1.200
1004	2	90-28-16.00	10.00	1.463	0.093
1004	1002	85-20-56.00	10.00	1.463	1.200

1004	3	90-37-21.00	10.00	1.463	0.093
1004	1002	85-20-56.00	10.00	1.463	1.200
1004	4	90-58-45.00	10.00	1.463	0.093
1004	1002	85-20-57.00	10.00	1.463	1.200
1004	5	91-19-55.00	10.00	1.463	0.093
1004	1002	85-20-56.00	10.00	1.463	1.200
1004	6	84-37-47.00	10.00	1.463	0.093
1004	1002	85-20-56.00	10.00	1.463	1.200
1004	7	84-53-22.00	10.00	1.463	0.093
1004	1002	85-20-56.00	10.00	1.463	1.200
1004	8	86-06-19.00	10.00	1.463	0.093
1004	1002	85-20-57.00	10.00	1.463	1.200
1004	9	86-58-07.00	10.00	1.463	0.093
1004	1002	85-20-56.00	10.00	1.463	1.200
1004	10	87-34-17.00	10.00	1.463	0.093
1004	1002	85-20-56.00	10.00	1.463	1.200
1003	1002	90-29-54.00	10.00	1.327	1.200
1003	10	95-30-34.00	10.00	1.327	0.093
1003	1002	90-29-55.00	10.00	1.327	1.200
1003	9	96-47-43.00	10.00	1.327	0.093
1003	1002	90-29-54.00	10.00	1.327	1.200
1003	8	98-52-03.00	10.00	1.327	0.093
1003	1002	90-29-55.00	10.00	1.327	1.200
1003	7	102-26-05.00	10.00	1.327	0.093
1003	1002	90-29-55.00	10.00	1.327	1.200
1003	6	110-18-52.00	10.00	1.327	0.093
1003	1002	90-30-24.00	10.00	1.440	1.270
1003	6	110-24-23.25	10.00	1.440	0.093
1003	1002	90-30-13.00	10.00	1.440	1.270
1003	7	102-29-30.75	10.00	1.440	0.093

1003	1002	90-30-13.00	10.00	1.440	1.270
1003	8	98-54-29.25	10.00	1.440	0.093
1003	1002	90-30-09.25	10.00	1.440	1.270
1003	9	96-49-30.75	10.00	1.440	0.093
1003	1002	90-30-12.25	10.00	1.440	1.270
1003	10	95-31-45.00	10.00	1.440	0.093
1004	1002	85-20-47.00	10.00	1.528	1.270
1004	1	90-28-43.00	10.00	1.528	0.093
1004	1002	85-20-52.25	10.00	1.530	1.270
1004	2	90-29-14.00	10.00	1.530	0.093
1004	1002	85-20-45.25	10.00	1.530	1.270
1004	3	90-38-45.00	10.00	1.530	0.093
1004	1002	85-20-48.25	10.00	1.530	1.270
1004	4	91-00-46.50	10.00	1.530	0.093
1004	1002	85-20-51.00	10.00	1.530	1.270
1004	5	91-24-31.00	10.00	1.530	0.093
1004	1002	85-20-47.25	10.00	1.530	1.270
1004	6	84-40-21.00	10.00	1.530	0.093
1004	1002	85-20-45.50	10.00	1.530	1.270
1004	7	84-55-29.75	10.00	1.530	0.093
1004	1002	85-20-47.50	10.00	1.530	1.270
1004	8	86-08-02.25	10.00	1.530	0.093
1004	1002	85-20-35.25	10.00	1.530	1.270
1004	9	86-59-14.25	10.00	1.530	0.093
1004	1002	85-20-46.25	10.00	1.530	1.270
1004	10	87-35-19.75	10.00	1.530	0.093
1005	1002	74-18-18.75	10.00	1.528	1.270
1005	1	81-55-34.25	10.00	1.528	0.093
1005	1002	74-18-30.00	10.00	1.528	1.270
1005	2	82-43-54.75	10.00	1.528	0.093

1005	1002	74-18-16.75	10.00	1.528	1.270
1005	3	84-10-24.50	10.00	1.528	0.093
1005	1002	74-18-14.25	10.00	1.528	1.270
1005	4	85-16-34.75	10.00	1.528	0.093
1005	1002	74-18-17.25	10.00	1.528	1.270
1005	5	86-00-57.00	10.00	1.528	0.093
1005	1002	74-18-16.00	10.00	1.528	1.270
1005	6	84-59-49.50	10.00	1.528	0.093
1005	1002	74-18-15.75	10.00	1.528	1.270
1005	7	84-09-40.00	10.00	1.528	0.093
1005	1002	74-18-25.50	10.00	1.528	1.270
1005	8	83-08-07.25	10.00	1.528	0.093
1005	1002	74-18-20.50	10.00	1.528	1.270
1005	9	81-43-54.50	10.00	1.528	0.093
1005	1002	74-18-24.00	10.00	1.528	1.270
1005	10	80-00-36.00	10.00	1.528	0.093

Adjustment Statistical Summary

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Iterations = 8

Number of Stations = 14

Number of Observations = 252

Number of Unknowns = 30

Number of Redundant Obs = 222

Observation	Count	Sum Squares of StdRes	Error Factor
Angles	50	130.689	1.722
Distances	101	204.053	1.514
Zeniths	101	97.731	1.048
Total	252	432.474	1.396

Warning: The Chi-Square Test at 5.00% Level Exceeded Upper Bound

Lower/Upper Bounds (0.907/1.093)

Adjusted Coordinates (Meters)

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Station	N	E	Elev	Description
1002	0.0000	0.0000	50.0000	
1003	-429.2226	12.0589	53.5913	
1004	-353.9338	128.0553	19.1049	
1005	-58.8156	174.9584	-2.1176	
1	-140.3803	65.5299	18.6815	
2	-165.7104	65.3052	18.8512	
3	-215.4857	65.3196	18.8282	
4	-265.3014	65.5225	18.6241	
5	-315.3722	65.1699	18.7458	
6	-365.3350	43.0882	28.5299	
7	-315.4112	43.1709	28.8127	
8	-265.4792	42.9328	28.8339	
9	-215.3753	42.8209	29.0924	
10	-165.5503	42.7002	29.2486	

Adjusted Observations and Residuals

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Adjusted Angle Observations (DMS)

At	From	To	Angle	Residual	StdErr	StdRes	File:Line
1005	1002	1	304-43-09.12	0-00-00.12	3.00	0.0	1:27
1005	1002	2	297-08-55.51	-0-00-00.49	3.00	0.2	1:28
1005	1002	3	286-24-12.72	0-00-00.72	3.00	0.2	1:29
1005	1002	4	279-20-31.88	0-00-04.88	3.00	1.6	1:30
1005	1002	5	274-35-11.51	0-00-01.51	3.00	0.5	1:31
1005	1002	6	274-41-49.94	0-00-02.94	3.00	1.0	1:32
1005	1002	7	278-36-14.37	0-00-03.37	3.00	1.1	1:33
1005	1002	8	283-59-28.08	0-00-03.08	3.00	1.0	1:34
1005	1002	9	291-35-00.77	0-00-00.77	3.00	0.3	1:35
1005	1002	10	302-30-53.28	0-00-03.28	3.00	1.1	1:36
1004	1002	1	3-34-16.10	-0-00-02.90	3.00	1.0	2:28
1004	1002	2	1-27-10.85	-0-00-00.15	3.00	0.1	2:29
1004	1002	3	355-30-48.48	-0-00-03.52	3.00	1.2	2:30
1004	1002	4	344-41-10.71	-0-00-06.29	3.00	2.1	2:31
1004	1002	5	321-24-26.06	-0-00-06.94	3.00	2.3	2:32
1004	1002	6	282-14-52.42	-0-00-06.58	3.00	2.2	2:33
1004	1002	7	314-18-00.37	-0-00-08.63	3.00	2.9	2:34
1004	1002	8	335-59-24.59	-0-00-00.41	3.00	0.1	2:35
1004	1002	9	348-17-33.51	-0-00-04.49	3.00	1.5	2:57
1004	1002	10	355-30-55.86	-0-00-07.14	3.00	2.4	2:58
1003	1002	10	8-14-16.39	0-00-08.39	3.00	2.8	3:22
1003	1002	9	9-47-42.54	0-00-04.54	3.00	1.5	3:23
1003	1002	8	12-17-13.47	0-00-07.47	3.00	2.5	3:24
1003	1002	7	16-53-54.08	0-00-07.08	3.00	2.4	3:25

1003	1002	6	27-30-51.99	0-00-06.99	3.00	2.3	3:26
1003	1002	6	27-30-51.99	-0-00-08.51	3.00	2.8	4:16
1003	1002	7	16-53-54.08	-0-00-02.92	3.00	1.0	4:20
1003	1002	8	12-17-13.47	-0-00-00.03	3.00	0.0	4:24
1003	1002	9	9-47-42.54	-0-00-01.71	3.00	0.6	4:28
1003	1002	10	8-14-16.39	0-00-01.89	3.00	0.6	4:32
1004	1002	1	3-34-16.10	-0-00-07.65	3.00	2.6	5:16
1004	1002	2	1-27-10.85	-0-00-05.65	3.00	1.9	5:20
1004	1002	3	355-30-48.48	0-00-02.78	3.00	0.9	5:24
1004	1002	4	344-41-10.71	0-00-03.21	3.00	1.1	5:28
1004	1002	5	321-24-26.06	0-00-01.56	3.00	0.5	5:32
1004	1002	6	282-14-52.42	0-00-00.92	3.00	0.3	5:36
1004	1002	7	314-18-00.37	0-00-04.37	3.00	1.5	5:40
1004	1002	8	335-59-24.59	-0-00-04.41	3.00	1.5	5:44
1004	1002	9	348-17-33.51	0-00-03.51	3.00	1.2	5:48
1004	1002	10	355-30-55.86	-0-00-01.39	3.00	0.5	5:52
1005	1002	1	304-43-09.12	-0-00-08.63	3.00	2.9	6:16
1005	1002	2	297-08-55.51	-0-00-02.49	3.00	0.8	6:20
1005	1002	3	286-24-12.72	-0-00-01.53	3.00	0.5	6:24
1005	1002	4	279-20-31.88	-0-00-12.62	3.00	4.2*	6:28
1005	1002	5	274-35-11.51	-0-00-02.49	3.00	0.8	6:32
1005	1002	6	274-41-49.94	0-00-00.19	3.00	0.1	6:36
1005	1002	7	278-36-14.37	0-00-01.87	3.00	0.6	6:40
1005	1002	8	283-59-28.08	0-00-03.83	3.00	1.3	6:44
1005	1002	9	291-35-00.77	0-00-04.02	3.00	1.3	6:48
1005	1002	10	302-30-53.28	-0-00-05.47	3.00	1.8	6:52

Adjusted Distance Observations (Meters)

From	To	Distance	Residual	StdErr	StdRes	File:Line

1005	1002	191.7081	-0.0019	0.0030	0.6	1:37
1005	1	137.8493	-0.0017	0.0030	0.6	1:38
1005	1002	191.7081	-0.0029	0.0030	1.0	1:39
1005	2	154.3760	-0.0010	0.0030	0.3	1:40
1005	1002	191.7081	-0.0019	0.0030	0.6	1:41
1005	3	192.2158	0.0008	0.0030	0.3	1:42
1005	1002	191.7081	-0.0019	0.0030	0.6	1:43
1005	4	234.4897	-0.0003	0.0030	0.1	1:44
1005	1002	191.7081	-0.0009	0.0030	0.3	1:45
1005	5	279.7362	-0.0068	0.0030	2.3	1:46
1005	1002	191.7081	-0.0019	0.0030	0.6	1:47
1005	6	334.9587	-0.0033	0.0030	1.1	1:48
1005	1002	191.7081	-0.0019	0.0030	0.6	1:49
1005	7	289.9643	-0.0027	0.0030	0.9	1:50
1005	1002	191.7081	-0.0009	0.0030	0.3	1:51
1005	8	247.0059	-0.0011	0.0030	0.4	1:52
1005	1002	191.7081	-0.0009	0.0030	0.3	1:53
1005	9	207.0214	-0.0006	0.0030	0.2	1:54
1005	1002	191.7081	-0.0009	0.0030	0.3	1:55
1005	10	172.5702	0.0022	0.0030	0.7	1:56
1004	1002	377.6316	0.0016	0.0030	0.5	2:36
1004	1	222.5258	0.0068	0.0030	2.3	2:37
1004	1002	377.6316	0.0016	0.0030	0.5	2:38
1004	2	198.4144	0.0024	0.0030	0.8	2:39
1004	1002	377.6316	0.0016	0.0030	0.5	2:40
1004	3	152.0077	0.0027	0.0030	0.9	2:41
1004	1002	377.6316	0.0016	0.0030	0.5	2:42
1004	4	108.4871	0.0041	0.0030	1.4	2:43
1004	1002	377.6316	0.0026	0.0030	0.9	2:44
1004	5	73.7872	0.0002	0.0030	0.1	2:45

1004	1002	377.6316	0.0026	0.0030	0.9	2:46
1004	6	86.1062	0.0022	0.0030	0.7	2:47
1004	1002	377.6316	0.0026	0.0030	0.9	2:48
1004	7	93.5888	0.0038	0.0030	1.3	2:49
1004	1002	377.6316	0.0016	0.0030	0.5	2:50
1004	8	123.0444	0.0034	0.0030	1.1	2:51
1004	1002	377.6316	0.0006	0.0030	0.2	2:59
1004	9	162.9037	0.0017	0.0030	0.6	2:60
1004	1002	377.6316	0.0006	0.0030	0.2	2:61
1004	10	207.0044	0.0054	0.0030	1.8	2:62
1004	1002	377.6316	0.0006	0.0030	0.2	2:63
1003	1002	429.4082	-0.0008	0.0030	0.3	3:27
1003	10	266.6762	0.0022	0.0030	0.7	3:28
1003	1002	429.4082	0.0002	0.0030	0.1	3:29
1003	9	217.5757	-0.0003	0.0030	0.1	3:30
1003	1002	429.4082	-0.0018	0.0030	0.6	3:31
1003	8	168.6436	0.0006	0.0030	0.2	3:32
1003	1002	429.4082	-0.0008	0.0030	0.3	3:33
1003	7	120.8207	0.0017	0.0030	0.6	3:34
1003	1002	429.4082	-0.0008	0.0030	0.3	3:35
1003	6	75.7357	0.0027	0.0030	0.9	3:36
1003	1002	429.4086	-0.0064	0.0030	2.1	4:17
1003	6	75.7750	-0.0025	0.0030	0.8	4:18
1003	1002	429.4086	-0.0064	0.0030	2.1	4:21
1003	7	120.8451	-0.0024	0.0030	0.8	4:22
1003	1002	429.4086	-0.0064	0.0030	2.1	4:25
1003	8	168.6610	-0.0032	0.0030	1.1	4:26
1003	1002	429.4086	-0.0064	0.0030	2.1	4:29
1003	9	217.5891	-0.0049	0.0030	1.6	4:30
1003	1002	429.4086	-0.0069	0.0030	2.3	4:33

1003	10	266.6870	-0.0030	0.0030	1.0	4:34
1004	1002	377.6320	-0.0050	0.0030	1.7	5:17
1004	1	222.5263	0.0033	0.0030	1.1	5:18
1004	1002	377.6319	-0.0051	0.0030	1.7	5:21
1004	2	198.4149	-0.0009	0.0030	0.3	5:22
1004	1002	377.6319	-0.0049	0.0030	1.6	5:25
1004	3	152.0084	-0.0023	0.0030	0.8	5:26
1004	1002	377.6319	-0.0054	0.0030	1.8	5:29
1004	4	108.4883	0.0006	0.0030	0.2	5:30
1004	1002	377.6319	-0.0054	0.0030	1.8	5:33
1004	5	73.7888	-0.0018	0.0030	0.6	5:34
1004	1002	377.6319	-0.0061	0.0030	2.0	5:37
1004	6	86.0999	-0.0018	0.0030	0.6	5:38
1004	1002	377.6319	-0.0051	0.0030	1.7	5:41
1004	7	93.5829	-0.0004	0.0030	0.1	5:42
1004	1002	377.6319	-0.0061	0.0030	2.0	5:45
1004	8	123.0398	-0.0017	0.0030	0.6	5:46
1004	1002	377.6319	-0.0054	0.0030	1.8	5:49
1004	9	162.9002	-0.0021	0.0030	0.7	5:50
1004	1002	377.6319	-0.0059	0.0030	2.0	5:53
1004	10	207.0015	0.0015	0.0030	0.5	5:54
1005	1002	191.7267	-0.0088	0.0030	2.9	6:17
1005	1	137.8491	-0.0039	0.0030	1.3	6:18
1005	1002	191.7267	-0.0083	0.0030	2.8	6:21
1005	2	154.3758	-0.0037	0.0030	1.2	6:22
1005	1002	191.7267	-0.0058	0.0030	1.9	6:25
1005	3	192.2157	-0.0015	0.0030	0.5	6:26
1005	1002	191.7267	-0.0088	0.0030	2.9	6:29
1005	4	234.4896	-0.0029	0.0030	1.0	6:30
1005	1002	191.7267	-0.0093	0.0030	3.1*	6:33

1005	5	279.7361	-0.0084	0.0030	2.8	6:34
1005	1002	191.7267	-0.0093	0.0030	3.1*	6:37
1005	6	334.9587	-0.0061	0.0030	2.0	6:38
1005	1002	191.7267	-0.0085	0.0030	2.8	6:41
1005	7	289.9642	-0.0053	0.0030	1.8	6:42
1005	1002	191.7267	-0.0083	0.0030	2.8	6:45
1005	8	247.0058	-0.0052	0.0030	1.7	6:46
1005	1002	191.7267	-0.0083	0.0030	2.8	6:49
1005	9	207.0213	-0.0035	0.0030	1.2	6:50
1005	1002	191.7267	-0.0083	0.0030	2.8	6:53
1005	10	172.5700	-0.0037	0.0030	1.2	6:54

Adjusted Zenith Observations (DMS)

From	To	Zenith	Residual	StdErr	StdRes	File:Line
1005	1002	74-19-38.36	0-00-02.36	10.00	0.2	1:37
1005	1	81-55-29.61	-0-00-03.39	10.00	0.3	1:38
1005	1002	74-19-38.36	0-00-00.36	10.00	0.0	1:39
1005	2	82-43-51.22	-0-00-03.78	10.00	0.4	1:40
1005	1002	74-19-38.36	0-00-00.36	10.00	0.0	1:41
1005	3	84-10-28.61	-0-00-03.39	10.00	0.3	1:42
1005	1002	74-19-38.36	-0-00-00.64	10.00	0.1	1:43
1005	4	85-16-40.31	-0-00-03.69	10.00	0.4	1:44
1005	1002	74-19-38.36	0-00-01.36	10.00	0.1	1:45
1005	5	86-01-06.02	0-00-08.02	10.00	0.8	1:46
1005	1002	74-19-38.36	0-00-00.36	10.00	0.0	1:47
1005	6	84-59-52.32	0-00-00.32	10.00	0.0	1:48
1005	1002	74-19-38.36	0-00-01.36	10.00	0.1	1:49
1005	7	84-09-45.60	-0-00-02.40	10.00	0.2	1:50
1005	1002	74-19-38.36	0-00-00.36	10.00	0.0	1:51

1005	8	83-08-15.50	-0-00-01.50	10.00	0.2	1:52
1005	1002	74-19-38.36	0-00-01.36	10.00	0.1	1:53
1005	9	81-43-52.48	-0-00-02.52	10.00	0.3	1:54
1005	1002	74-19-38.36	0-00-01.36	10.00	0.1	1:55
1005	10	80-00-44.00	-0-00-01.00	10.00	0.1	1:56
1004	1002	85-20-55.38	-0-00-00.62	10.00	0.1	2:36
1004	1	90-27-45.42	-0-00-02.58	10.00	0.3	2:37
1004	1002	85-20-55.38	-0-00-01.62	10.00	0.2	2:38
1004	2	90-28-10.74	-0-00-05.26	10.00	0.5	2:39
1004	1002	85-20-55.38	-0-00-00.62	10.00	0.1	2:40
1004	3	90-37-16.54	-0-00-04.46	10.00	0.4	2:41
1004	1002	85-20-55.38	-0-00-00.62	10.00	0.1	2:42
1004	4	90-58-40.45	-0-00-04.55	10.00	0.5	2:43
1004	1002	85-20-55.38	-0-00-01.62	10.00	0.2	2:44
1004	5	91-20-35.02	0-00-40.02	10.00	4.0*	2:45
1004	1002	85-20-55.38	-0-00-00.62	10.00	0.1	2:46
1004	6	84-37-57.26	0-00-10.26	10.00	1.0	2:47
1004	1002	85-20-55.38	-0-00-00.62	10.00	0.1	2:48
1004	7	84-53-20.73	-0-00-01.27	10.00	0.1	2:49
1004	1002	85-20-55.38	-0-00-00.62	10.00	0.1	2:50
1004	8	86-06-18.30	-0-00-00.70	10.00	0.1	2:51
1004	1002	85-20-55.38	-0-00-01.62	10.00	0.2	2:59
1004	9	86-58-05.90	-0-00-01.10	10.00	0.1	2:60
1004	1002	85-20-55.38	-0-00-00.62	10.00	0.1	2:61
1004	10	87-34-17.86	0-00-00.86	10.00	0.1	2:62
1004	1002	85-20-55.38	-0-00-00.62	10.00	0.1	2:63
1003	1002	90-29-52.06	-0-00-01.94	10.00	0.2	3:27
1003	10	95-30-16.80	-0-00-17.20	10.00	1.7	3:28
1003	1002	90-29-52.06	-0-00-02.94	10.00	0.3	3:29
1003	9	96-47-35.38	-0-00-07.62	10.00	0.8	3:30

1003	1002	90-29-52.06	-0-00-01.94	10.00	0.2	3:31
1003	8	98-51-59.09	-0-00-03.91	10.00	0.4	3:32
1003	1002	90-29-52.06	-0-00-02.94	10.00	0.3	3:33
1003	7	102-26-00.62	-0-00-04.38	10.00	0.4	3:34
1003	1002	90-29-52.06	-0-00-02.94	10.00	0.3	3:35
1003	6	110-18-58.82	0-00-06.82	10.00	0.7	3:36
1003	1002	90-30-12.71	-0-00-11.29	10.00	1.1	4:17
1003	6	110-23-47.28	-0-00-35.97	10.00	3.6*	4:18
1003	1002	90-30-12.71	-0-00-00.29	10.00	0.0	4:21
1003	7	102-29-08.97	-0-00-21.78	10.00	2.2	4:22
1003	1002	90-30-12.71	-0-00-00.29	10.00	0.0	4:25
1003	8	98-54-15.63	-0-00-13.62	10.00	1.4	4:26
1003	1002	90-30-12.71	0-00-03.46	10.00	0.3	4:29
1003	9	96-49-21.75	-0-00-09.00	10.00	0.9	4:30
1003	1002	90-30-12.71	0-00-00.46	10.00	0.0	4:33
1003	10	95-31-43.80	-0-00-01.20	10.00	0.1	4:34
1004	1002	85-20-52.65	0-00-05.65	10.00	0.6	5:17
1004	1	90-28-45.66	0-00-02.66	10.00	0.3	5:18
1004	1002	85-20-53.74	0-00-01.49	10.00	0.1	5:21
1004	2	90-29-20.39	0-00-06.39	10.00	0.6	5:22
1004	1002	85-20-53.74	0-00-08.49	10.00	0.8	5:25
1004	3	90-38-47.45	0-00-02.45	10.00	0.2	5:26
1004	1002	85-20-53.74	0-00-05.49	10.00	0.5	5:29
1004	4	91-00-47.81	0-00-01.31	10.00	0.1	5:30
1004	1002	85-20-53.74	0-00-02.74	10.00	0.3	5:33
1004	5	91-23-42.25	-0-00-48.75	10.00	4.9*	5:34
1004	1002	85-20-53.74	0-00-06.49	10.00	0.6	5:37
1004	6	84-40-37.07	0-00-16.07	10.00	1.6	5:38
1004	1002	85-20-53.74	0-00-08.24	10.00	0.8	5:41
1004	7	84-55-47.82	0-00-18.07	10.00	1.8	5:42

1004	1002	85-20-53.74	0-00-06.24	10.00	0.6	5:45
1004	8	86-08-10.36	0-00-08.11	10.00	0.8	5:46
1004	1002	85-20-53.74	0-00-18.49	10.00	1.8	5:49
1004	9	86-59-30.62	0-00-16.37	10.00	1.6	5:50
1004	1002	85-20-53.74	0-00-07.49	10.00	0.7	5:53
1004	10	87-35-24.56	0-00-04.81	10.00	0.5	5:54
1005	1002	74-18-26.89	0-00-08.14	10.00	0.8	6:17
1005	1	81-55-31.09	-0-00-03.16	10.00	0.3	6:18
1005	1002	74-18-26.89	-0-00-03.11	10.00	0.3	6:21
1005	2	82-43-52.55	-0-00-02.20	10.00	0.2	6:22
1005	1002	74-18-26.89	0-00-10.14	10.00	1.0	6:25
1005	3	84-10-29.68	0-00-05.18	10.00	0.5	6:26
1005	1002	74-18-26.89	0-00-12.64	10.00	1.3	6:29
1005	4	85-16-41.18	0-00-06.43	10.00	0.6	6:30
1005	1002	74-18-26.89	0-00-09.64	10.00	1.0	6:33
1005	5	86-01-06.76	0-00-09.76	10.00	1.0	6:34
1005	1002	74-18-26.89	0-00-10.89	10.00	1.1	6:37
1005	6	84-59-52.93	0-00-03.43	10.00	0.3	6:38
1005	1002	74-18-26.89	0-00-11.14	10.00	1.1	6:41
1005	7	84-09-46.31	0-00-06.31	10.00	0.6	6:42
1005	1002	74-18-26.89	0-00-01.39	10.00	0.1	6:45
1005	8	83-08-16.33	0-00-09.08	10.00	0.9	6:46
1005	1002	74-18-26.89	0-00-06.39	10.00	0.6	6:49
1005	9	81-43-53.46	-0-00-01.04	10.00	0.1	6:50
1005	1002	74-18-26.89	0-00-02.89	10.00	0.3	6:53
1005	10	80-00-45.17	0-00-09.17	10.00	0.9	6:54

Adjusted Bearings (DMS) and Horizontal Distances (Meters)

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(Relative Confidence of Bearing is in Seconds)

NOTE - Adjustment Failed the Chi-Square Test

Angular and Distance Errors are Scaled by Total Error Factor

From	To	Bearing	Distance	95% RelConfidence Brg	Dist	PPM
1	1004	S16-19-09.39E	222.5185	4.87	0.0042	18.7420
1	1005	N53-18-00.86E	136.4823	6.06	0.0054	39.4050
10	1003	S06-37-42.95W	265.4468	3.40	0.0041	15.5480
10	1004	S24-22-29.62E	206.8183	4.49	0.0040	19.2641
10	1005	N51-05-45.02E	169.9545	4.88	0.0045	26.3189
1002	1003	S01-36-33.44E	429.3920	0.00	0.0000	0.0011
1002	1004	S19-53-25.48E	376.3871	0.00	0.0000	0.0013
1002	1005	S71-25-08.26E	184.5798	0.00	0.0000	0.0026
1003	6	N25-54-18.55E	71.0243	6.50	0.0030	42.3951
1003	7	N15-17-20.64E	117.9873	5.90	0.0028	23.9845
1003	8	N10-40-40.04E	166.6286	4.69	0.0037	22.2282
1003	9	N08-11-09.11E	216.0486	3.85	0.0041	19.0191
1004	2	N18-26-14.63W	198.4077	5.14	0.0045	22.6864
1004	3	N24-22-37.01W	151.9988	5.82	0.0050	32.8681
1004	4	N35-12-14.77W	108.4713	6.46	0.0054	49.5823
1004	5	N58-28-59.42W	73.7669	6.83	0.0058	78.7935
1004	6	S82-21-26.94W	85.7286	5.98	0.0028	32.8134
1004	7	N65-35-25.11W	93.2167	6.15	0.0034	36.6772
1004	8	N43-54-00.89W	122.7601	5.53	0.0041	33.8041
1004	9	N31-35-51.97W	162.6756	4.96	0.0042	25.9559
1005	2	S45-43-47.25W	153.1350	5.80	0.0051	33.3992
1005	3	S34-59-04.47W	191.2229	5.12	0.0046	23.8613

1005	4	S27-55-23.62W	233.6935	4.48	0.0038	16.4015
1005	5	S23-10-03.25W	279.0606	4.26	0.0025	9.1277
1005	6	S23-16-41.69W	333.6823	1.41	0.0030	8.9370
1005	7	S27-11-06.11W	288.4602	2.45	0.0028	9.6063
1005	8	S32-34-19.83W	245.2359	3.42	0.0034	13.8519
1005	9	S40-09-52.52W	204.8689	4.22	0.0040	19.2896

Error Propagation

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Station Coordinate Standard Deviations (Meters)

NOTE - Adjustment Failed the Chi-Square Test

Standard Deviations are Scaled by Total Error Factor

Station	N	E	Elev
1002	0.000000	0.000000	0.000000
1003	0.000000	0.000000	0.000000
1004	0.000000	0.000000	0.000000
1005	0.000000	0.000000	0.000000
1	0.001841	0.002031	0.005520
2	0.001942	0.001922	0.005744
3	0.002020	0.001778	0.005646
4	0.001946	0.001723	0.004685
5	0.001493	0.002099	0.003405
6	0.001071	0.001097	0.002637
7	0.001215	0.001328	0.003343
8	0.001579	0.001480	0.004286
9	0.001695	0.001631	0.005107
10	0.001665	0.001806	0.005467

Station Coordinate Error Ellipses (Meters)

NOTE - Adjustment Failed the Chi-Square Test

Error Ellipses are Scaled by Total Error Factor

Confidence Region = 95

Station	Semi-Major Axis	Semi-Minor Axis	Azimuth of Major Axis	Elev

1002	0.000000	0.000000	0-00	0.000000
1003	0.000000	0.000000	0-00	0.000000
1004	0.000000	0.000000	0-00	0.000000
1005	0.000000	0.000000	0-00	0.000000
1	0.005379	0.004009	55-00	0.010819
2	0.005116	0.004308	43-20	0.011259
3	0.005006	0.004281	162-29	0.011066
4	0.005380	0.003395	143-09	0.009183
5	0.005813	0.002443	121-01	0.006673
6	0.003123	0.002081	46-44	0.005168
7	0.003431	0.002764	122-37	0.006552
8	0.004161	0.003277	142-59	0.008401
9	0.004223	0.003914	150-19	0.010009
10	0.004505	0.003984	65-49	0.010715

Relative Error Ellipses (Meters)

NOTE - Adjustment Failed the Chi-Square Test

Relative Error Ellipses are Scaled by Total Error Factor

Confidence Region = 95

Stations From	To	Semi-Major Axis	Semi-Minor Axis	Azimuth of Major Axis	Vertical
1	1004	0.005379	0.004009	55-00	0.010819
1	1005	0.005379	0.004009	55-00	0.010819
10	1003	0.004505	0.003984	65-49	0.010715
10	1004	0.004505	0.003984	65-49	0.010715
10	1005	0.004505	0.003984	65-49	0.010715
1002	1003	0.000000	0.000000	0-00	0.000000
1002	1004	0.000000	0.000000	0-00	0.000000
1002	1005	0.000000	0.000000	0-00	0.000000

1003	6	0.003123	0.002081	46-44	0.005168
1003	7	0.003431	0.002764	122-37	0.006552
1003	8	0.004161	0.003277	142-59	0.008401
1003	9	0.004223	0.003914	150-19	0.010009
1004	2	0.005116	0.004308	43-20	0.011259
1004	3	0.005006	0.004281	162-29	0.011066
1004	4	0.005380	0.003395	143-09	0.009183
1004	5	0.005813	0.002443	121-01	0.006673
1004	6	0.003123	0.002081	46-44	0.005168
1004	7	0.003431	0.002764	122-37	0.006552
1004	8	0.004161	0.003277	142-59	0.008401
1004	9	0.004223	0.003914	150-19	0.010009
1005	2	0.005116	0.004308	43-20	0.011259
1005	3	0.005006	0.004281	162-29	0.011066
1005	4	0.005380	0.003395	143-09	0.009183
1005	5	0.005813	0.002443	121-01	0.006673
1005	6	0.003123	0.002081	46-44	0.005168
1005	7	0.003431	0.002764	122-37	0.006552
1005	8	0.004161	0.003277	142-59	0.008401
1005	9	0.004223	0.003914	150-19	0.010009

Elapsed Time = 00:00:01

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01 00000001 Top of File

01 00000006 Summary of Files Used and Option Settings

02 00000009 Project Folder and Data Files

02 00000020 Project Option Settings

02 00000037 Instrument Standard Error Settings

03 00000039 Project Default Instrument

01 00000053 Summary of Unadjusted Input Observations

02 00000056 Entered Stations

03 00000058 Fixed Coordinates

03 00000064 Free Coordinates

02 00000076 Angle Observations

02 00000130 Distance Observations

02 00000235 Zenith Observations

01 00000340 Adjustment Statistical Summary

01 00000362 Adjusted Coordinates

01 00000381 Adjusted Observations and Residuals

02 00000384 Adjusted Angle Observations

02 00000438 Adjusted Distance Observations

02 00000543 Adjusted Zenith Observations

01 00000648 Adjusted Bearings and Horizontal Distances

01 00000685 Error Propagation

02 00000688 Station Coordinate Standard Deviations

02 00000708 Station Coordinate Error Ellipses

02 00000730 Relative Error Ellipses

01 00000765 End of File

0000CD17

STAR*NET

0001E11F

Appendix E Sample Starnet Input File

C 1002 0 0 50 ! ! !

C 1003 -429.22263 12.05891 53.59127 ! ! !

C 1004 -353.93377 128.05525 19.10488 ! ! !

C 1005 -58.81555 174.95837 -2.11757 ! ! !

C 1 325.110 65.531 263.319 * * *

C 2 299.781 65.306 263.488 * * *

C 3 250.006 65.323 263.465 * * *

C 4 200.188 65.530 263.260 * * *

C 5 150.114 65.172 263.397 * * *

C 6 100.152 43.095 273.170 * * *

C 7 150.076 43.177 273.450 * * *

C 8 200.009 42.938 273.472 * * *

C 9 250.116 42.823 273.730 * * *

C 10 299.940 42.705 273.887 * * *

A 1004-1002-1 3-34-19

DV 1004-1 222.5188 90-27-47 1.463/0.093

A 1004-1002-2 1-27-12

DV 1004-2 198.412 90-28-16 1.463/0.093

A 1004-1002-3 355-30-54

DV 1004-3 152.0053 90-37-22 1.463/0.093

A 1004-1002-4 344-41-19

DV 1004-4 108.483 90-58-44 1.463/0.093

A 1004-1002-5 321-24-35

DV 1004-5 73.7866 91-19-56 1.463/0.093

A 1004-1002-6 282-15-05

DV 1004-6 86.1038 84-37-47 1.463/0.093

A 1004-1002-7 314-18-10

DV 1004-7 93.5855 84-53-22 1.463/0.093

A 1004-1002-8 335-59-26

DV 1004-8 123.0414 86-06-19 1.463/0.093

A 1004-1002-9 348-17-37

DV 1004-9 162.9016 86-58-07 1.463/0.093

A 1004-1002-10 355-31-04

DV 1004-10 206.9995 87-34-18 1.463/0.093