University of Southern Queensland

Faculty of Engineering and Surveying

Measuring and monitoring of grain silos using laser scanning and total stations

A dissertation submitted by

Mr Oliver Kelman

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Abstract

In the last 10 years the laser scanning industry has grown to become a useful surveying tool in many industries. Laser scanning is now used in many areas such as mining, engineering, architecture and industrial pipe plant surveys.
A laser scanner is a powerful survey tool that is able to survey and record upwards of fifty thousand points a second. This given today's surveyor the option of recording vast amounts of field data in a fast and accurate manor.

For this project I will be conducting deformation surveys on a concrete grain silo. I will be comparing the methods and accuracies of monitoring the grain silo for deformation using both the Leica ScanStation2 and the Trimble S6 robotic total station. The monitoring of deformation in grain silos was chosen because silos in general are subject to failure and deformation than most other structures. This can be contributed to the vast amounts of pressure the silos suffer during loading, storage and unloading. Other factors that contribute to silo failure and deformation in silos include poor maintenance, incorrect storage materials and incorrect silo design.

This project used a Leica ScanStation2 to scan the silo and survey specified targets. The Trimble S6 total station was then used to survey the specified targets and use the laser scanning function to scan the silo. The results from the scan sessions were then analysed to compare the accuracies.

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ENG4111 & ENG4112 *Research Project*

Limitations of Use

Candidates Certification

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

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

Oliver Kelman
Student Number: 0050041973

Oliver Kelman

29/10/2008

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Oliver Kelman

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Chapter 1

Introduction

1.1 Background

Laser scanning is a relatively new technology to the surveying industry. Terrestrial Laser Scanners are able to record thousands of points a second and produce accurate 3D models of surfaces and structures in a short period of time. Terrestrial Laser Scanners are now used by the mining, architecture and archaeology disciplines.
Two case studies in which Terrestrial Laser Scanners were used to capture and monitor objects were those of P Smith (2006) on boat hulls and G. Bitelli et al (2005) on land slippage. These two projects analyse the use of Terrestrial Laser Scanners but they did not compare the accuracies of this method with those of traditional surveying.

Previously, deformation monitoring of structures has been done by traditional surveying methods such as reflector-less measurements by total station and by GPS monitoring of benchmarks. The major advantages provided by Terrestrial Laser Scanners are speed and accuracy of measurement, safe data capture, and the ability to model a structure or surface in 3D.

In this project, reflector-less measurements (distance and angle) to targets on the grain silo will be measured by total station over time, and the results analyzed to identify any movement in the grain silo structure. Using a Terrestrial Laser Scanner for the same analysis will require 4 setups to capture the grain silo and targets in a dense point cloud, using software to generate a 3D model of the structure.

For this project I plan to compare the accuracies of the Terrestrial Laser Scanners with those of traditional surveying methods. Comparing the expected accuracies described the manufacturer specifications of laser scanners and total stations, it is expected that the total station with an expected reflector-less accuracy of ± 5mm will be more accurate than the laser scanner that has an accuracy that is more variable, being dependant upon distance and reflectance of the target.

I also plan to investigate the problem of fixing the position of the laser scans in the most accurate way possible, so that all laser scans have a best fit within the 3D model of the grain silo. The best way to do this is by least squares adjustment.

1.2 Research Aims and Objectives

1.2.1 Research Aim

The research aim for this project is to compare the accuracy of using a laser scanner to monitor grain silos and comparing it to the results obtained by using a total station with laser scanning capabilities.

1.2.2 Research Objectives

1. Review the use of laser scanning in structural modeling.
2. Use survey control methods to obtain the best possible results from laser scanning.
3. Analyze differences between the laser scanning results and those obtained by traditional reflector-less technology using a total station.
4. Research publications on the structure of grain silos.
5. The reduction of laser scanning data in software packages.
6. Investigate the technical aspects of both laser scanning and total station reflectorless readings in deformation modeling.

1.3 Justification

Grain silos in the Darling Downs district are subject to failure and a fast and accurate method of deformation monitoring must be carried out to ensure that any structural failures are identified before dangerous and costly breakdown occurs.

1.4 Scope of Research

A Trimble S6 will be used to measure in survey control for the survey control station that the laser scanner and Trimble S6 will be setup on. The survey control stations will be adjusted by a least squares method.
The laser scanner will be setup on each survey station and a laser scan of 100mm horizontal point spacing by 100mm vertical point spacing will be taken of the grain silo. The Trimble S6 will also be set up on each survey station and a surface scan taken with a point separation of around 125mm.
Data collected by the Leica laser scanner will be downloaded and analysed in the Lieca Cyclone software that is especially designed for the Lieca Laser Scanner. Data collected by the Trimble S6 will be downloaded into the civil and survey 12D program.

1.5 Conclusion

This dissertation aims to compare the accuracy of the Trimble S6 in conducting a deformation survey against using a Leica ScanStation2 to conduct a deformations survey.

A literature review will be conduct to gain a better understanding of the complexities of the recent technology that is laser scanning. The literature review will also examine reflectorless measurements using a total station and also review deformation surveys. The literature review will also examine the issues of why grain silo fails and the factors that cause them to suffer deformation or failure. A wide variety of references will be sourced to aid in the understanding of laser scanning, total stations, deformations surveys and grain and industrial silos.

After the literature review has been completed the field work for the project will be conducted. This will involve a network control survey, two survey sessions monitoring deformation and two laser scanning sessions. The results of the survey and scanning sessions will be analyzed in the office to try and indentify any movement in the grain silo and to compare the accuracy between the two instruments.

Chapter 2

Literature Review

2.1 Introduction

This literature review will examine the technical aspects of how a laser scanner works, its accuracies, different applications and different scanners that are available. The review will also cover reflector-less measurements using a total station, deformation and movement monitoring, grain silo structures and why they fail.

2.2 Equipment

2.2.1 Leica ScanStation2

The laser scanner that will be used in this project will be the Leica ScanStation2. The ScanStation2 is a pulsed time of flight scanner that has the ability to scan up to 50,000 points a second. The ScanStation2 has a range of up to 300 metres with a position accuracy of ±6mm and a distance accuracy of ±4mm.
The ScanStation2 has the ability to setup over a known survey station and back sight to a known point. The scanner is also able to calculate a resection off 2 or more known points and is even able traverse (reference). The ScanStation2 is also able to stake out known points. See appendix A for more ScanStation2 specifications.

Figure 2.1: Leica ScanStation2

2.2.2 Trimble S6

The total station that will be used in this project will be the Trimble S6. The S6 is a fully robotic one man total station. The S6 has a angular accuracy of ±3’’ and a distance EDM accuracy of ±3mm and 2ppm.
The S6 runs on the Trimble Controller Version 12.22 survey software. This software allows the S6 to store points, read round automatically and do surface scans.
The S6 has Direct Reflex technology that allows it to measure to surfaces or objects without the need of a survey target.

Figure 2.2: Trimble S6

2.3 Laser Scanner Overview

Laser scanners are a new surveying technology that has expanded greatly in the last 5 years. Laser scanners are able to conduct rapid and very dense surveys of a structure within an hour (Hirst and Roberts, 2005). The laser scanner can capture and record hundreds and thousands of angles and distances. The distance and angles recorded are transformed in to a dense point cloud of millions of x,y,z points that represent the object being scanned. Laser scanners record up wards of 500000 points a second and the finished point cloud contain many millions of x,y,z points.

The point cloud is displayed in a software package such as Leica’s Cyclone or Maptek’s Vulcan. Many conventional survey software packages have been upgraded to have the ability to view or edit point clouds.
The laser scanner works somewhat like an automated total station in that it can be force-centred over a mark and back-sighted to a target. Unlike a total station, where the operator selects all the points for measuring and recording, the laser scanner uses a time of flight measurement or pulsed diode laser for measuring the distance of the transmitted laser and an internal angle recorder to measure the angle that the laser

transmits and the angle the laser is received at. The laser scanner has an automated system that programs the scanner to rotate 360° in the horizontal plane and up to 90° in the vertical plane. This depending on what brand of laser scanner is being used. This is because different brands of laser scanners have different fields of view (Lichti et al, 1999).

The laser that is transmitted hits the surface of the structure being scanned and reflects back to the laser scanner. The laser scanner measures the intensity of the return beam. This intensity is dependent on the reflectivity of the surface. A high reflectivity surface such as a white smooth wall, will give good results while a dark or wet surface will have the least reflectivity.

Most laser scanners are able to take a 360 degree panoramic photo of the area being scanned and this photo can provide real colour to the point cloud. This is done by providing coordinates of the digital photo. This allows the user to interpret the point cloud more easily. This allows the user to interpret the point cloud more easily (Bornaz et al, 2004).

The spot size of the transmitted laser is an important factor to consider when discussing laser scanning. When a laser is transmitted the laser spot size will increase in size the further the laser has to travel to meet its reflective surface. In the instance of Leica's new HDS6000 the spot size is 8mm at 25 metres and 14mm at 50 metres.

Edges of structures will also affect the transmitted laser beam. When only part of the laser beam reflects back off a surface, the other part of the laser will continue until it hits a reflective object and reflects back to the scanner. These edge points will be incorrect. The best way to eliminate this problem is to conduct 2 set ups of the laser scanner from different view points of the edge.

2.4 Types of laser Scanners

There are 3 different methods of capturing laser scanner data: phase modulation, pulsed time of flight, and laser triangulation.

Phase modulation involves the laser light being intensity modulated with a sinusoidal signal. The laser light is sent out by the laser scanner and reflected back off the object and received by a photodiode. The time of flight is measured by the laser scanner and is proportional to the phase difference between the transmitted and received laser light, which is proportional to the range and laser modulation frequency. The amplitude of the received reflected laser light is proportional to the reflectivity and distance to the object (Uren & Price, 2007).
The intensity of the reflected laser can be recorded by the laser scanner and shows the reflection characteristics of the surfaces being scanned. Some scanners even provide a passive channel that records colour information about each scanned point in the point cloud.

Pulsed time of flight is when the laser scanner sends out short pulses to the object or surface being scanned. The time recorded for the pulse to reflect back to the scanner is proportional to the distance travelled (Uren & Price, 2007). The laser pulse is scanned horizontally and vertically by rotating mirrors in the laser scanner. Like the phase modulation, true colour and laser intensity can be recorded.

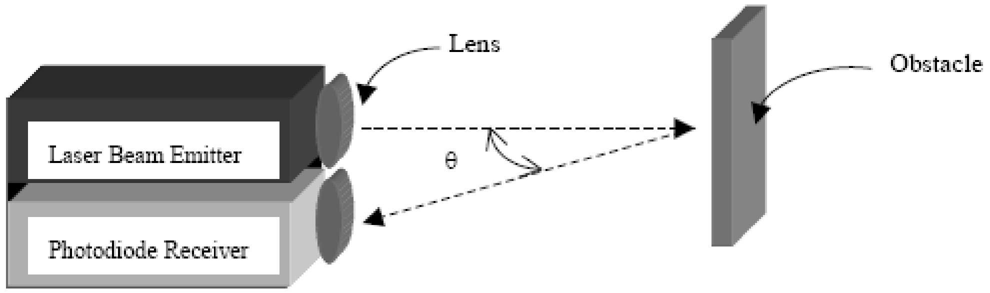

Figure 2.1: Time of flight method.
(Source:http://repository.upenn.edu)

Laser triangulation involves a laser source and a digital camera positioned a known distance from the object being scanned. The laser beam is sent out in a plane of laser light projected onto the object by an internal mirror. The laser is reflected from the object and recorded by the digital camera. The camera also records the colour of the scanned line and is used for texture mapping. The contour of the surface is calculated by the shape of the image of each reflected laser scan line (Uren & Price, 2007).

The triangulation method is the most accurate method but can only be used for a range of 0.6 to 2.5 metres. The triangulation method can achieve accuracies of sub millimeter standard. The phase modulation method is the fastest and can scan far greater ranges compared to the pulsed time of flight method. Pulsed time of flight can usually scan ranges from 1.5 to 1oo meters, with an accuracy of ±6mm.

2.5 Accuracy

The accuracy of a laser scanner varies with each different laser scanner available. The distance to a target will affect the accuracy of a distance measurement as well as the reflectivity of the surface of the object being scanned.
The new Leica HDS6000 has a reported single distance accuracy of <4mm for a range of 1 to 25 meters and <5mm for a range to 50 meters. The angle accuracy is ± 3” and the overall position accuracy is 6mm in the 1 to 25 meter range and 10mm to the 50mm range. The I-SiTE4000LR has a reported range precision (1SD) of 50mm and an angle accuracy of ± 0.04°.
Various publications describe the accuracies of the laser scanner in regards to distance. Early studies by Lichti et al (1999) achieved single point distance range accuracies of 30-50mm over a calibration range. Chow (2007) conducted distance tests using a Leica HDS3000 laser scanner. Distances were measured in 10 meter increments from 10 to 100 meters and compared to known values for the distance. The target used was a sheet of white paper mounted against the known distance. The following results were obtained.

Table 2.2: Laser scanner distance accuracy

Interval (m)	Known Distance Ro (m)	Measured Distance Rm (m)	Difference Ro – Rm (mm)	Interval (m)	Known Distance Ro (m)	Measured Distance Rm (m)	Difference Ro – Rm (mm)
0 – 10	10.000	9.998	+2	0 – 60	59.997	59.993	+4
0 – 20	20.000	19.995	+5	0 – 70	70.000	69.997	+3
0 – 30	30.000	29.996	+4	0 – 80	79.998	79.997	+1
0 – 40	39.998	39.992	+6	0 – 90	89.990	89.991	-1
0 – 50	50.002	49.998	+4	0 – 100	99.985	99.990	-5

(Source: www.fig.net)

The results showed that the expected accuracy of ± 4mm to a range of 50m from the manufacturer were correct. With the continuing development of laser scanners the accuracy will increase. The Riegl LMS Z420i has a measurement range of 2-800 meters with an accuracy of ± 10mm (Bitelli et al, 2004).

2.6 Laser Scanning Applications

Due to its fast and accurate ability to scan objects and surfaces, the laser scanner is being utilized in many industries including mining and archeology. The ability of the laser scanner to pick up points without having to have an assistant place a target on the surface or object means that it is perfectly suited to survey dangerous features like busy highways (Chow, 1999) and landslide surveys (Bitelli et al, 2004).

Bitelli et al (2004) used laser scanning to monitor a land slip site in Northern Italy (Fig. 1). Usually this type of work would be done by aerial photogrammetry methods. The traditional method of airborne surveying was compared to terrestrial laser scanning of the land slip site, which was 40,000 square meters in size. The authors found that the laser scanner provided a fast, accurate and relatively cheap way to monitor mid-size landslide areas compared to airborne survey techniques. A problem Bitelli et al (2004) found with the laser scanner that if the area had been heavily vegetated laser scanning would have been nearly impossible.

Figure 2.2: Using laser scanning to monitor land slides.
(Source: http://www.cartesia.org)

Chow (2004) used a Leica HDS3000 laser scanner to pick up surfaces on high-speed highways in Hong Kong (Fig. 2). Using traditional surveying methods, this would have involved the closure of roads and would have been costly. It would have been unlikely to be approved by the road transport authority of the Hong Kong Police. Laser scanning allowed the safe and accurate, non-contact survey of the highway surfaces and features without the closure of roads and the risk to survey personnel. Compared to the traditional method of reflectorless measurements to features, and the time taken due to false measurements caused by traffic, the laser scanner produced sub-centimeter accuracy. A ground model was formed and a 1:500 topographical map of the area was produced.

Figure 2.3: Picture of area to be laser scanned and the point cloud
(Source: www.fig.net)

Chow (2004) was also able to use the Leica HDS3000 to survey the headroom of over hanging high voltage power lines over the Fang Lin Highway. Traditional survey methods would have been impossible, due to the danger of the power lines and reflector-less measurements would have involved many measurements along the power line and corresponding points on the Highway surface. Using the laser scanner, the author was able to quickly and safely survey the power lines and road surface. Furthermore, because the geo referencing was not required, the heights could easily be calculated in the office. Again sub-centimeter accuracy was achieved, which was well within the accuracy requirements of the project.

Schmid et al (2005) utilized laser scanning to monitor soil erosion in logging areas in south west Germany (Fig. 3). Laser scanning was used to scan the surface before logging, immediately after logging , and 1 year after logging. The scanner produced surface models of the area that showed the affect of the logging equipment tracks on the soil. This information was used to predict soil erosion patterns. A laser scan taken 1 year after logging showed the weather exposure to the surface area and any erosion that occurred during the year. By analyzing the surface models, the volume of soil removed by erosion was calculated.

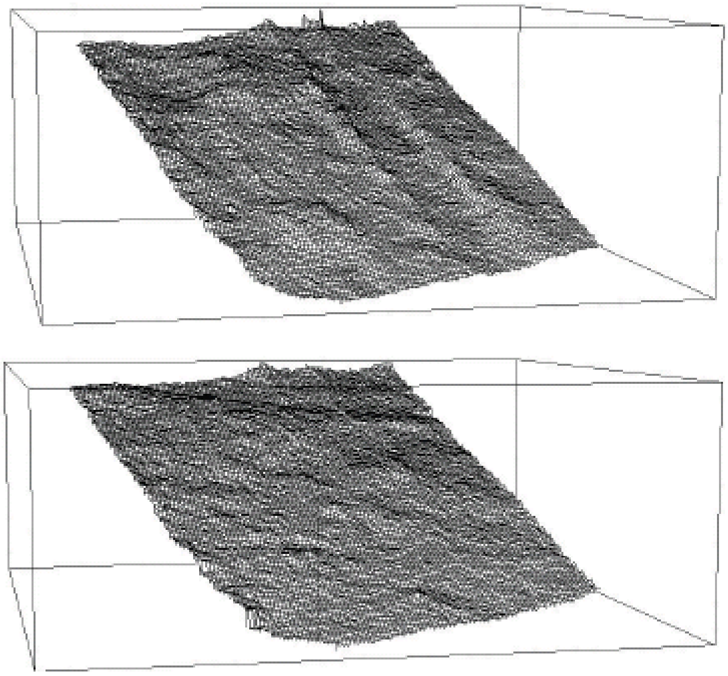

Figure 2.4: Monitoring heavy machinery tracks using laser scanning.
(Source: www.isprs.org)

Figure 3 shows that the laser scanner produced accurate surface models of the logged area and was also able to model the track marks of the logging equipment. One draw back of the laser scanner was the need to clear any vegetation on the ground, so an accurate surface model could be produced.

2.8 Reflectorless Measuring

Today nearly every total station available on the market is able to take reflectorless measurements. Reflectorless measuring is much like laser scanning in that it does not require a prism to obtain a measurement. This means that non contact measurements can be made to hard-to-reach or dangerous places. Reflectorless measurements can be used for many applications some examples of which are:

- Monitoring of deformation on bridges and other large structures
- Measuring volumes in underground and open cast mines.
- Tunnel Profiling.
- Recording elevations on elevated objects such as facades and roofs.
- Surveys of roads, avoiding road closures.

There are 2 methods used to take reflectorless measurements. These are phase shift and pulsed laser. Phase shift measurements using a laser carrier wave taking to a prism have been found to be the most accurate, with measurements of between 3 to 5 kilometers (Uren and Price, 2007). Using no prisms or targets, a phase measurement can measure up to 100 meters in range.
Total Stations use 2 different measuring techniques. Phase measuring system and pulsed

laser distance measurement. The sinusoidal wave has a frequency value of 10-100MHz. The intensity modulated wave is transmitted from the total station to the target

Total stations that use pulsed laser technology can measure greater distances than the phase shift method. In reflectorless mode the range can reach several hundred meters. The disadvantage is that the accuracy of the measurement is less than that of a phase shift measurement; however, the difference is small enough to be ignored for most work.

An important factor to consider when conducting reflectorless measurements is the reflectivity of the surface being measured to. A smooth white surface will produce the best results because white has a high reflectivity value. Dark and wet surfaces have the least reflectivity and measurements to these types of surfaces can be difficult.

Another important factor is that the laser source in most total stations diverges as it is travels out from the instrument. When the lased hits a target or reflector it leaves what is called a 'footprint'. A large laser footprint at a long range can produce differing results. An advantage of a large laser foot print is that small objects like power lines can be measured, and a disadvantage is that it has a reduced signal strength and thus a lower chance of a successful measurement.

Pulsed laser measurements is faster than phase shift measurements in reflectorless mode, because the phase shift measurement time increases as a function of the distance being measured.

2.9 Deformation Monitoring

Deformation monitoring is carried out on many large structures such as bridges, dams, mines and large buildings. Traditional surveying techniques involved placing targets over the structure being monitored and distance and angle measurements made at various epochs in time. This process is costly and labor intensive.

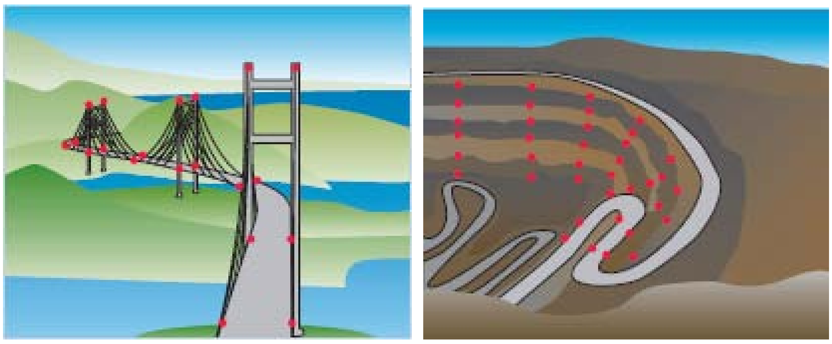

Figure 2.5: Bridge and Mine monitoring
(Source: www.leica-geosystems.com)

As shown in figure 4, the deformation monitoring on a bridge requires the capture of many individual points (red dots) on the bridge using a total station. However, only selected parts of the bridge would be monitored. A laser scanner could easily capture a more accurate 3D model of the bridge for analysis. The second example is a mine face. Using traditional techniques, a total station would be used to take measurements to the targets or the face of the mine. A laser scanner would be able to model a complete and accurate 3D model of the face in a short time and large soil movements could also be identified.

The Increased accuracies possible with GPS make it a common method used to monitor deformities in large structures and some of these, such as dams, are now being continual monitored using GPS. This means that instead of deformation monitoring being performed once a week or once a month, the structure can be monitored on an hourly basis (Behr et al, 1999).

Laser scanning is now being used to monitor deformation. While it is accepted that traditional surveying practices are more accurate than laser scanning. The laser scanning can achieve acceptable accuracies ranging from ± 2mm to ± 50mm (Tsakiri et al, 2006). The benefit of using a laser scanner is that a dense 3D point cloud of the object being monitored can be formed and this can show any change in shape of the object.

As an example, a laser scanner was used to monitor the deformation of a lock that connected a shipping channel to the North Sea near Amsterdam. The aim of the project was to monitor deformation caused by changes in water level. Two scans were done of the lock from a fixed position. Because the scans were both taken from the same point a point (?) analysis was done. The results showed that there was movement in the lock. A best fit plane was also applied to the point cloud for both epoch measurements and this confirmed movement of the lock (Berh et al, 1999).

2.10 Grain Silos

Industrial and grain silos fail with a frequency that is higher than almost any other industrial or civil structure (Carson, 2004). Failure is when the grain silo suffers some type of damage to either the inside or outside of the structure that can lead to silo being deemed unsafe to use or in a worst case scenario the complete collapse.

Most of the time the failure is not catastrophic, but involves some type of deformation of the grain silo structure. Some deformations are easy to identify, such as an external crack on a concrete silo wall or a dent in the surface of a sheet metal silo, whereas other faults, such as internal cracks in silo walls or structural changes in the silo due to internal pressures are much harder to identify.

The following is a review of the 4 categories that contribute to silo failures:

- Design
- Silage Acids
- Construction
- Usage
- Maintenance

2.10.1 Design

The design of any kind of storage silo is a complicated process and requires specialized knowledge of silo experts. Some factors that need to be considered in silo design are flow patterns and flow channels, material the silo will store, material used to construct silo, and thermal loading. One of the most common causes of design related silo failure is when the withdrawal point is not located on the vertical centerline of a circular silo

(Carson, 2004). When silos are unloaded, eccentric flow patterns can develop and cause stress and tension on the silo wall that the eccentric flow intersects (Figure 5). This in turn will lead to horizontal and vertical bending of the silo structure.

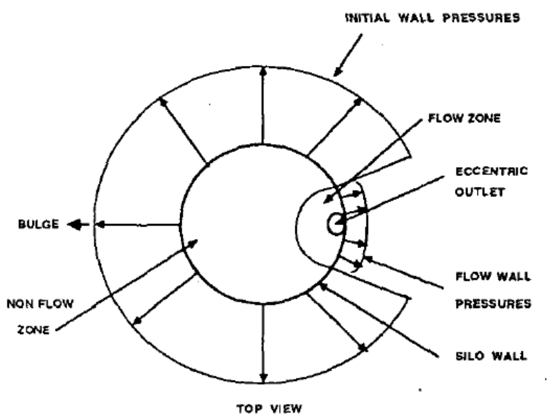

Figure 2.6: Silo Bending
(Source: www.jenike.com)

Stress on internal structures, such as support beams, can lead to lead to non symmetric pressures on silo walls and cause bending stresses in the structure.
Concrete silos are much stronger than sheet metal silos and can withstand more internal pressure and wear and tear. However, concrete silos do present their own set of problems. One of the major causes of deformation in concrete silos is poorly designed concrete walls. If a silo wall is constructed with only a single horizontal layer of reinforced steel, the silo will have very little bending resistance and will cause internal cracking of the walls. These cracks are hard to indentify in general maintenance.

Temperature and moisture effects are an important consideration in the design process and are often overlooked. During the heat of the day the silo will expand out and during the cold of the night the silo will contract in again. Problems arise when the silo is storing material for an extended period of time. When the silo expands the material will settle, and when the silo contracts back in, the material cannot be pushed back up. Pressure in the horizontal plane is exerted on the silo walls and causes bending. Moisture can also cause silo deformation or collapse. This happens when moisture migrates between stagnant particles (Carson, 2004), causing the stored material to expand and thus increase horizontal pressure on the silo walls.

2.10.2 Silage Acids

Silage acid deterioration occurs when moist plant material is stored in a concrete silo. Hydrated plant material produces lactic and acetic acids. The higher the moisture content of the material being stored in the silo, the higher is the rate of silage acid produced (Figure 6). When acids come into contact with the Portland cement, concrete strength decreases (Bellman, 1996).

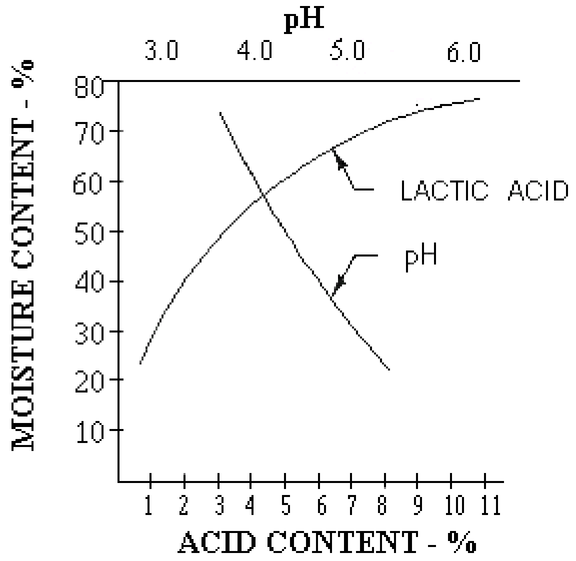

Figure 2.7: Acid content in grain silos
(Source: http://www.omafra.gov.on.ca/english/engineer/facts/90-235.htm)

The effect of acid deterioration is very serious because the acids attack the bottom of the silo which is the part of the wall that carries the greatest vertical pressure (Bellman, 1996). Silage acids reduce the thickness of concrete silo walls and this can lead to complete failure of the structure (Figure 7).

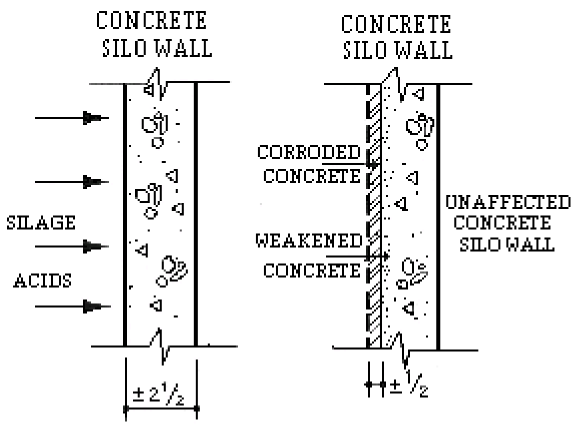

Figure 2.8: Silo wall Damage
(Source: http://www.omafra.gov.on.ca/english/engineer/facts/90-235.htm)

During unloading of a silo up to 50% of the contained weight of the silo will be transferred to the bottom of the silo wall. If the walls have been reduced due to silage acids the chance of failure greatly increases.

To prevent silage acid the bottom 1/3 of the inside of the silo should be coated with a suitable acid-resistant coating, which should be renewed on a yearly basis. Another step to take to prevent silage acid build-up is the moisture control of the silage material being stored. Also, if the moisture content is controlled during the harvest period, it will prevent seepage during storage (Bellman, 1996).

2.10.3 *Construction*

Construction errors and incorrect use of construction materials can greatly increase the likelihood of silo failure. The use of incorrect materials such as bolts, concrete and rebar, in attempts to cut construction costs on the stage of a silo, will ensure that the silos working life will be greatly shortened and increase the chances of deformation or failure.

Incorrect construction of the foundation of the silo can cause deformation, especially when the silos centre of gravity is elevated off the ground. If the foundation is uneven, the pressure on the silos legs is greatly increased. Cracking in the foundation is a sign of immanent failure (McLean, 1988).

Unauthorized design changes by construction crews also contribute to deformation and failure. Even minor changes in the design can have a devastating impact on the structural integrity of the silo. It is clear that construction should be monitored during all stages of construction to avoid any such problems.

2.10.4 Usage

A silo should have a long working life but factors such as wear and tear and change of storage materials will inevitably have negative effects. The changing of storage materials can change flow patterns from funnel flow to a mass flow and increase polishing of the inside surface of the silo. Polishing of the surface decreases the thickness of silo walls causing failure or deformation.

2.10.5 Maintenance

Silo maintenance is the responsibility of the owner or operator of the grain silo. It is an important factor in identifying and preventing signs of silo failure or deformation.
The first area of silo maintenance involves the upkeep of the silo liner. This is important because the liner protects the wall from polishing by the storage material. , The roof of the silo must also be inspected for leakage and maintained on a regular basis. Water and moisture can infiltrate the silo and cause expansion to the material being stored in the silo.

The second area of maintenance involves the checking for cracks, tilting and wall deformation (Carson, 2004). This should be done on a regular basis by all staff.

2.10.6 Other factors

Accidental silo damage by farm or industrial mobile equipment can also contribute to silo failure. Equipment backing into or damaging silo walls can decrease the working life of a silo (McLean, 1988).

A particular problem that has been identified is “base rafting”, which occurs when the foundation of the silo becomes buoyant due to fluctuating ground water levels. Wind loading can also be a factor in high- wind areas (Mclean, 1988).

2.11 Conclusion

This literature review has drawn upon research that has been conducted over the last 9 years. A general understanding of laser scanning, its accuracies and uses was presented and an overview of deformation monitoring and reflectorless measurements was discussed.

Evidence was presented that grain silos are potentially unstable structures and 4 major factors contributing to risk of deformation and failure were discussed. Monitoring of these structures is essential for the safety of the public and people working around industrial and grain silos.

This review has provided a background to some of the issues in laser scanning that will be useful in the field as well as in the office.

Chapter 3

Methodology

3.1 Introduction

In this chapter the field work and office work will explained in depth. It will provide additional information to how the field work and office work will be conducted.
The aim of this chapter is to provide the reader to gain a better understanding of the testing methods that will be used in this project and why the testing methods were used to gain the best possible results.

3.1 Test Site

The grain silo site that will be used will be the Graincorp grain facility at Cambooya. The facility is equipped with two 30 metre tall grain silos with a diameter of 10 metres. There are also 2 large prefabricated steel silos to the east of the main concrete silos and a large grain shed behind the steel silos.

Figure 3.1: Cambooya Test Site

Figure 3.2: Cambooya test site

A road runs along south of the concrete grain silos and a railway line runs to the north. This presents position problems for survey the control network due to safety and line of site difficulties.

3.2 Survey Control

3.2.1 Survey Stations/Targets

The main survey control will be half star pickets driven until refusal. The star pickets will driven flush to the ground to prevent people from tripping over them or lawn mowers damaging their blades during contact. The star pickets will then have a centre marked in them by a nail punch and then painted pink so that they are easy to find and identify.

The targets to be used for monitoring positions on the will be the Leica survey targets are included in the ScanStation2. These survey targets are able to be automatically recognised by the ScanStation2 while also be able to be used as a target by the Trimble S6.

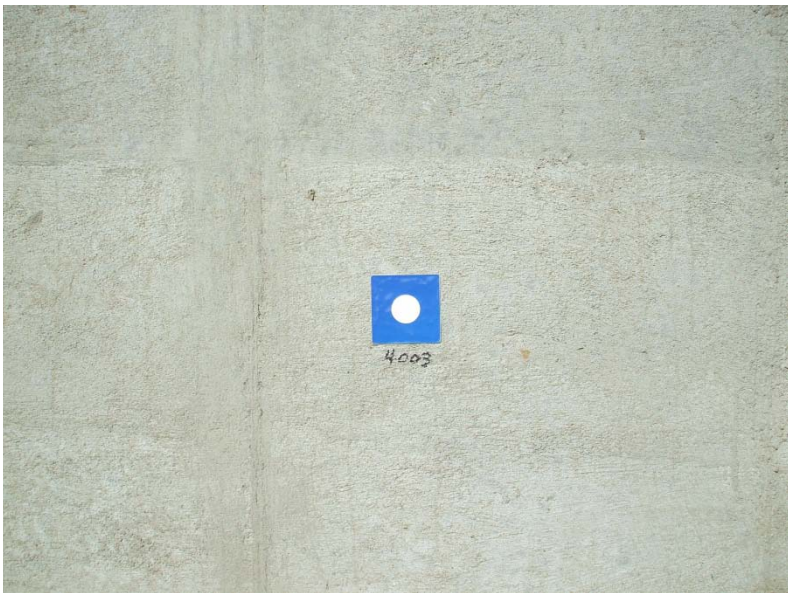

Figure 3.3: Leica HDS target

Unfortunately due to safety reasons I will not be able to access the top of the concrete grain silo to place targets around the top part. To overcome this problem i have decided to fine scan bolts from the safety railings. After the fine scan has been done by the ScanStation2 will be analysed using the Leica Cyclone software to calculate a centre coordinate. The Trimble S6 will then be able to measure to the bolt using direct reflectorless mode.

3.2.2 Horizontal Control

The 3 main survey stations will be coordinated using Trimble survey controller software in the Trimble S6 total station. This will involve face left and face right measurements being taken from a start point, which will be survey station 1. From Survey Station 1001, 3 faces of measurement will be taken to survey station 2, distance measurements will also be taken. The Trimble software calculates and stores the relevant information such as distance and measured angle and calculates a coordinate for station 2. From there the Trimble S6 will be set up on Survey Station 2 back sited to Survey Station 1 and 3 rounds read to Survey Station 3. The same process from the first set up will calculate coordinates for Survey Station 3. The S6 will then be set up on survey Station 3 back sighted to Survey Station 2 and 3 rounds read to Survey Station 1.
The Trimble controller software will then do a least squares adjustment close on the survey net work of Survey Stations 1, 2 and 3.

Due to a grain shed located close to the eastern side of the grain silo the middle of the 2 grain silos will not be visible from the 3 main survey stations. 2 intermediate stations will be placed on either side of the blind spot on the silo. During the traverse the stations will be sighted to and adjusted within the least squares calculation of the main survey stations.

The control will be measured using the Trimble S6 and the Trimble traverse kit with prism constant of -35mm.

3.2.3 Vertical Control

Survey Stations 1, 2 and 3 will be traversed using a digital level. An arbitrary height of 100.000 will be given to Survey Station 1, a levelling traverse of the control network will then be done using the digital level, closing back onto Survey Station 1.
The height deltas will be calculated between the stations and entered into the survey adjustment program StarNet. The distances that were calculated in the horizontal control network will then be entered into the StarNet adjustment program and a least squares adjustment of the survey control network.

These new vertical values for the Survey control network will be entered into a notepad document for use in the Lieca Cyclone software package and 12D survey software package. The adjusted survey network will help with the accuracy and integration of the different scans from the different survey stations.

3.3 Field Procedures

The laser scanner will be set up over all the survey control stations. The first step will be to take a digital picture of the grain silo. The next step will be to adjust the exposure of the digital photo so that the grain silo and other features can be easily identified. Once the exposure has been adjusted accordingly the ScanStation2 is ready to perform a laser scan. This step involves the selection of the point separation. This is done in the Leica Cyclone software. The horizontal spacing and the vertical spacing can be set in millimetres. The point separation for my project will be 150mm horizontally and 30mm vertically. The vertical separation is much smaller than the horizontal separation due to the fact that the horizontal point separation controls how long it will take for a scan to be completed.

Once the scan has been completed it is viewed in a Modelspace. A Modelspace is window in Leica Cyclone that allows the user to view the scan that has just been completed. It is also where any editing of the scan is done. The Leica survey targets on the grain silo are then fine scanned at a point separation of 1mm. This procedure allows the laser scanner to recognize the centre of the survey targets and calculate a coordinate for each survey target. The target acquisition is done in the Leica Cyclone program using the function TARGET AQUSITION. The type of target is selected and the area is selected on the digital photo. A point close to the centre of the target is selected using the single point selection arrow. The laser scanner is able to recognize the target from a 150mm radius. This procedure is done for every visible target from every survey station.

The S6 will be set up on every survey station like the scan station. One of the survey stations will be the backsight and the other visible survey station will be a check shot. The back sight will be used to calculate the azimuth and correct horizontal position. The check shot will be taken to make sure that the setup station has not moved or been tampered with.

Once the position of the S6 has been satisfied the next step will be to scan the grain silo using the S6 scan surface function. The top left corner of the visable silo is measured and stored and then the right corner of the grain silo is measured. The point separation is then calculated using the angle separation and the distance from the survey station to the surface of the grain silo. This will be on average about 100mm to 125mm in the horizontal and vertical separation. The S6 does all the pointing and measuring automatically. Each scan should take approximately 5 minutes and after the scan is taken a check shot is taken to the back sight to make sure the S6 has not moved or been dislodged while scanning. Each point measure and stored by the S6 will be given a point number and a field coding of SL (Surface Level). The next step will be to point and measure to the individual Leica survey targets placed around the base of the silo.

All the survey targets will be stored as their actual survey names. Once this has been completed the S6 will take a check shot to its back sight to confirm the instrument has not been bumped or taken out of level. This procedure for the surface scan and the measuring to the Leica survey targets will be done on each of the survey stations to ensure an accurate scan of the grain silo is picked up.

3.4 Office Procedures

All data that is collected by the ScanStation2 will be stored in the Leica Cyclone software in a data base that has the location and the date of the scans that are being taken. For example a scan taken at Cambooya on the 9 of September will be called CAMBOOYA080909. The scan worlds for each set up station will be recorded in a field book for later reference. For example a scan taken from survey station 1000 has a scan record of Scan World1 will be recorded as STN1000 Scan World1. This means that in the office the different scans from the different survey stations can be easily identified.

The database for the day’s work will then be copied onto a usb device. In the computer labs the database will be copied into the relevant windows file and a new model space will be opened. The Scan Worlds from the survey stations will then merged into one Scan World to show a representation of the entire grain silo structure. The coordinates of the acquired targets will then be obtained by the single pick function and recorded in a Microsoft Excel worksheet to compare with the results obtained by the S6.

The data that is collected by the S6 will be downloaded into 12D survey software using the Trimble CU controller. The Survey stations will be downloaded first and put in a separate model or layer called survey. The next step will be to download the actual scan data. Because all the points were giving a field coding of SL (Surface level) all the points will come in and be put in the STRUCTURE SL model. The final step will be to download the Leica survey target points. These will have been stored with a field coding of PSM (Permanent survey station). Once all the data has been downloaded the coordinates of the Leica survey targets will be analysed and transferred into a Microsoft Excel so that it may be compared to the ScanStation2 coordinates.

The surface scans by the S6 will be merged together by importing the models from the different jobs. This will give a 3D model of the grain silo scanned by the S6 that can be compared to the scan that was done by the ScanStation2. The points will then be made into a tin so that it may be rended, and a more representative model of the grain silo produced from the points.

3.5 Conclusion

By making sure the survey control network is properly adjusted it will ensure that any differences in between the data scanned by the ScanStation2 and the S6 will be identifiable. It will also make sure that the Scan Worlds done by the ScanStation2 from different survey stations will fit easily together in the merged Scan World. This will also apply to data collected by the S6 and downloaded and merged in the 12D survey software package.

By comparing the grain silo models made by the ScanStation2 and S6 the differences between the two such as accuracy of the grain silo model and the overall model of the grain silo may be analysed and compared.
By comparing the two methods I will be able to recommend the best method to be used in the survey and deformation survey of a grain silo.

Chapter 4

Results

4.1 Introduction

This chapter discusses the results that were obtained by the ScanStation2 and the Trimble S6. The differences between the coordinates of the Leica survey targets calculated from the data obtained by the ScanStation2 and the Trimble S6 will be shown in a table and the differences and shown as Δ easting and Δ northing. The distance between the different coordinates will be calculated by the equation √Δ Easting + Northing. The unadjusted and adjusted coordinates of the survey stations will be presented in table format. The mean turned angle and the Δ heights will also be presented in table format as well as the adjusted angles and changes in height.

The aim of this chapter is that reader will be able to analyse the differences in the data captured by the Trimble S6 and ScanStation2. These will be presented in tables and screenshots of Scan Worlds and screenshots of 3D views from 12D. Each comparison table will be followed by a short paragraph explaining the results obtained.

4.2 Horizontal Adjustment of Traverse of Survey Stations

As explained in Chapter three the traverse was undertaken using the Trimble S6. The following unadjusted coordinate results were obtained.

Table 4.1: Unadjusted Coordinate Table

Station	Easting	Northing
1000 (Fixed)	1000.000	5000.000
1001	962.455	4882.582
1002	921.224	4998.304
2000 (Fixed)	903.923	5055.47

The mean turned angle was obtained by using the measure round function in the Trimble Survey Controller Version 12.22. The averaged distances were also obtained and the information was inputted into a notepad document. The directions and distances to each of the survey stations were inputted into a CONTROL.dat file as shown in appendix B.
The Control.dat file was then run through the StarNet program. To run the least squares adjustment the instrument errors were put in the project specifications. The least squares adjustment was then run and the corrected coordinates came out as the following.

Table 4.2: Adjusted Coordinates

Station	Easting	Northing
1000 (Fixed)	1000.0000	5000.00000
1001	962.45514	4882.58253
1002	921.22433	4998.30377
2000 (Fixed)	903.92300	5055.47000

The full least squares adjustment summary using the StarNet program can be found in Appendix C.

4.2 Vertical Adjustment of Survey Stations

The reduced levels of the survey control network were adjusted using the StarNet program. The differences in height were calculated by using an automatic level and stave. The backsights and foresights were kept to a minimum so as to reduce error in the automatic level.
The unadjusted reduced levels are shown in the table below.

Table 4.1: Unadjusted Reduced Levels.

Station	Reduced Level
1000 (Fixed)	100.000
1001	98.521
1002	99.089
2000	98.498

The difference in height was calculated using the backsight minus foresight formula and the following values are shown in the table below.

Table 4.2: Differences in Height Between Survey Stations.

Station	Δ Height	Distance
1000-1001	-1.479	123.274
1001-1002	0.568	122.847
1002-2000	-0.592	59.727
2000-1000	1.502	110.940

The above values were put into a .DAT file for use in StarNet. The .DAT file can be found in appendix D. A least squares level adjustment was done on the survey control network and the following results were obtained.

Table 4.3: Adjusted Reduced Levels

Station	Adjusted Reduced Level
1000 (Fixed)	100.000
1001	98.52130
1002	99.08959
2000	98.49773

From the above results the levels do not change much and stay quite close to the unadjusted levels.

4.3 Survey Control File

With a least squares adjustment done on both the horizontal and vertical control a survey file was able to be produced. A .CSV file was produced to be used in the Trimble Survey Controller Version 12.22. The Coordinates typed into a .TXT file to be used in the Leica Cyclone software package. The TXT file is comma delimited so that it may be read by the software.

4.4 Leica ScanStation2 Scan Worlds. First Session

4.4.1 Scan World1000

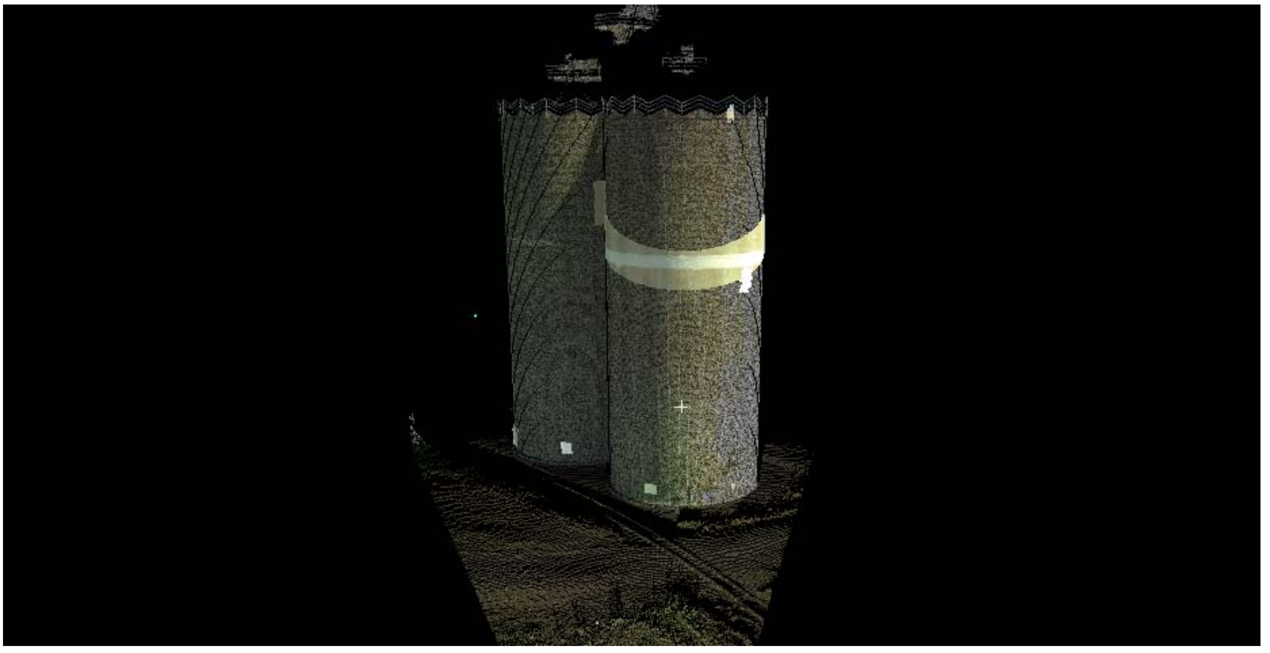

Figure 4.1: Scan from survey control station 1000

4.4.2 Scan World1001

Figure 4.2: Scan from control station 1001

4.4.3 Scan World 1002

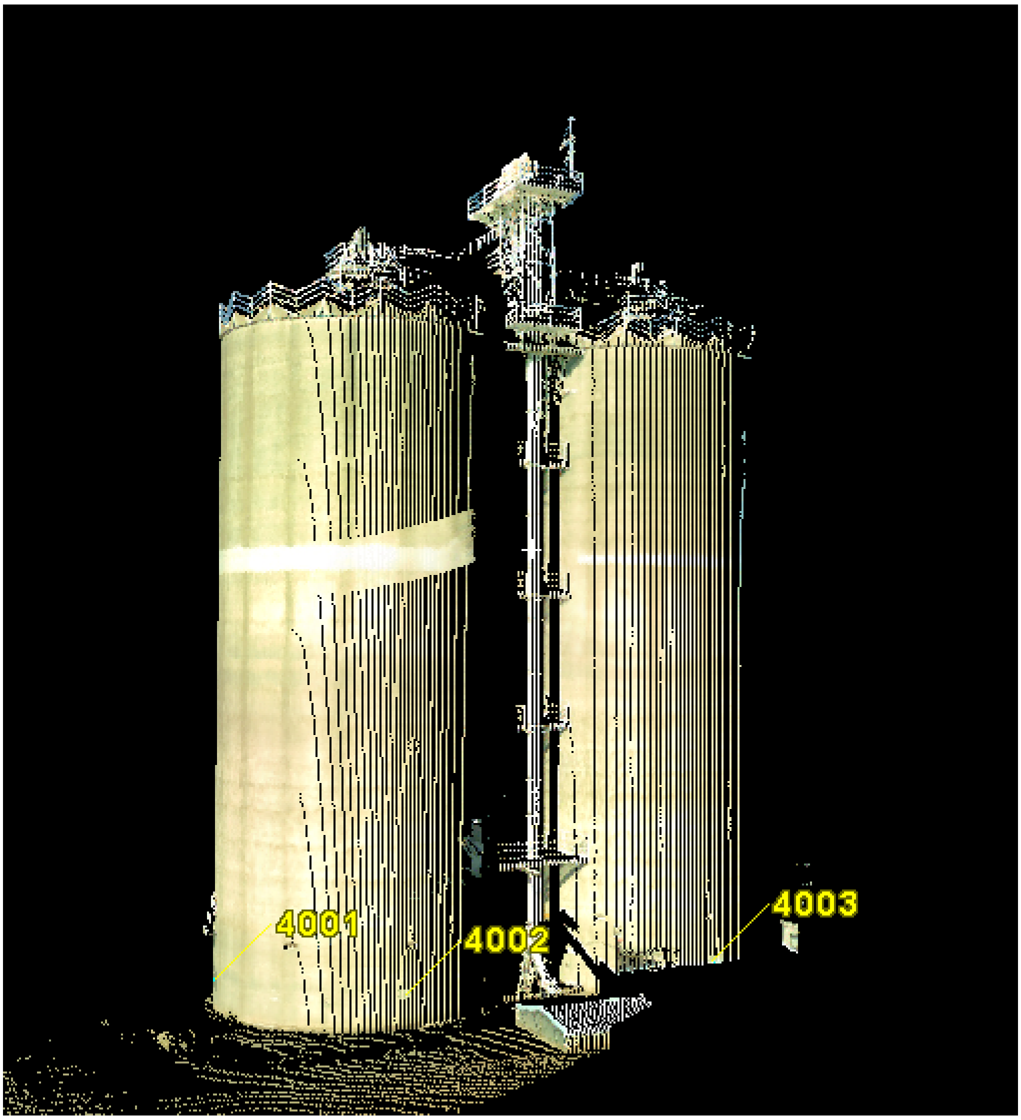

Figure 4.3: Scan from survey control station 1002

As can be seen in figures 4.0, 4.1 and 4.2, the Leica ScanStation2 was able to successfully scan the grain silo from the three survey control stations. The three Scan Worlds were then registered to together to form a complete 4D model of the grain silo.

4.4.4 Registered Scan World

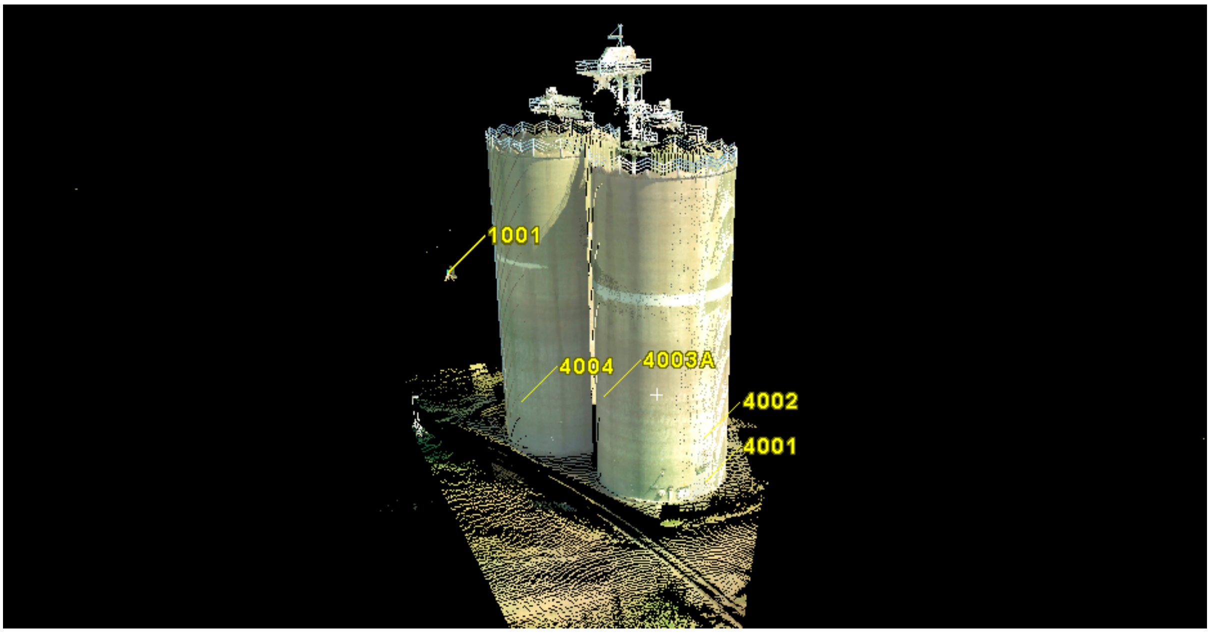

Figure 4.4: Registered Scan World

The 3 Scan Worlds were successfully registered together and figure 4.3 shows the complete 3D model of the structure.

4.4.5 Registration Errors for scan session 1

The Leica ScanStation2 performs a least squares adjustment on all the survey control targets and the HDS targets located in the Scan Worlds. The following errors were obtained in the first session.

Table 4.1: Registration Errors

Constraint I.D	Scan Worlds	Weight	Error	Error Vector
1001	1 and 3	1	0.003	(0.000, -0.001, 0.003)m
1002	1 and 3	1	0.001	(0.001, 0.001, 0.001)m
1002	1 and 2	1	0.002	(-0.001, 0.000, -0.002)m
1002	2 and 3	1	0.002	(0.002, 0.001, 0.001)m
1001	2 and 3	0.5	0.016	(-0.011, 0.005, -0.011)m

4.5 ScanStation2 Scan Worlds. Second Session

4.5.1 Scan World 1000

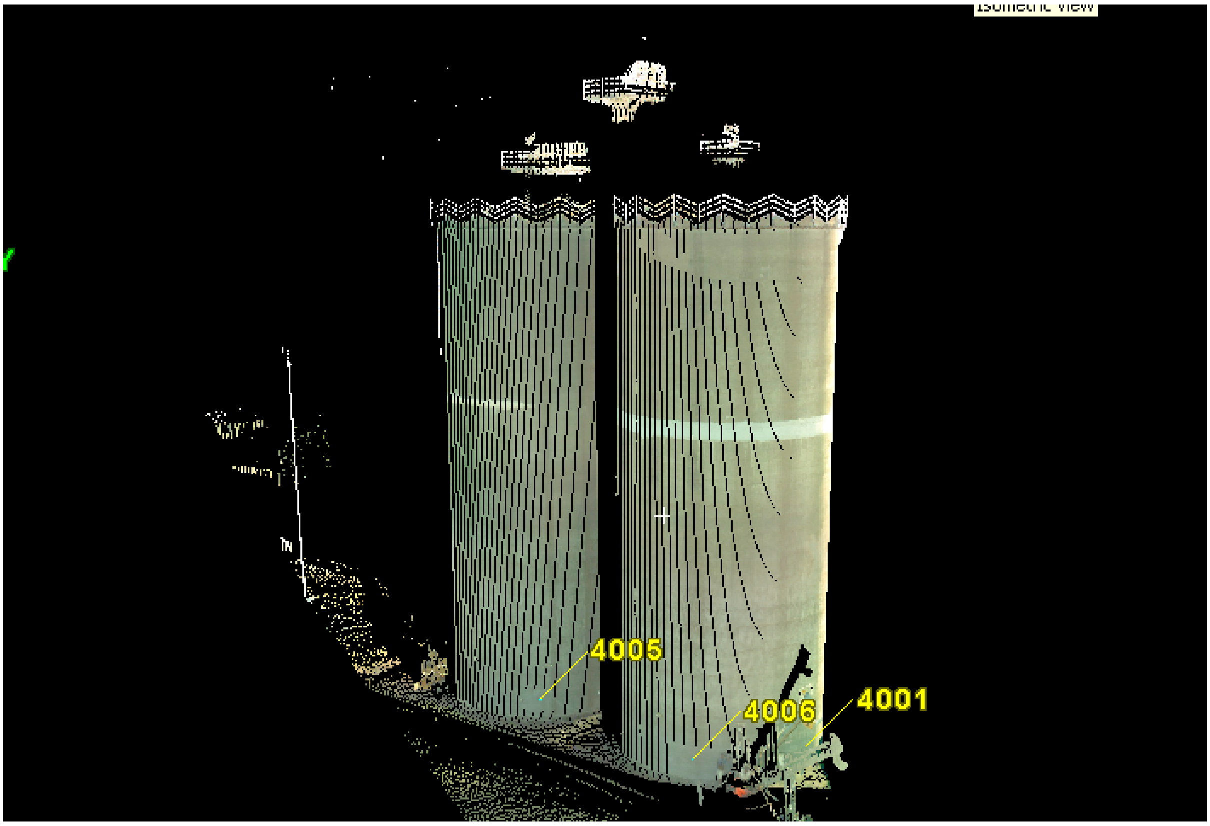

Figure 4.5: Scan World 1000

Scan World 1000 is the second scanning session from the control survey station 1000. As can be seen the HDS survey targets 4001, 4005 and 4006 were acquired during the scan. As can be seen a large portion of the eastern side of both the northern and southern grain silos was acquired.

4.5.2 Scan World 1001

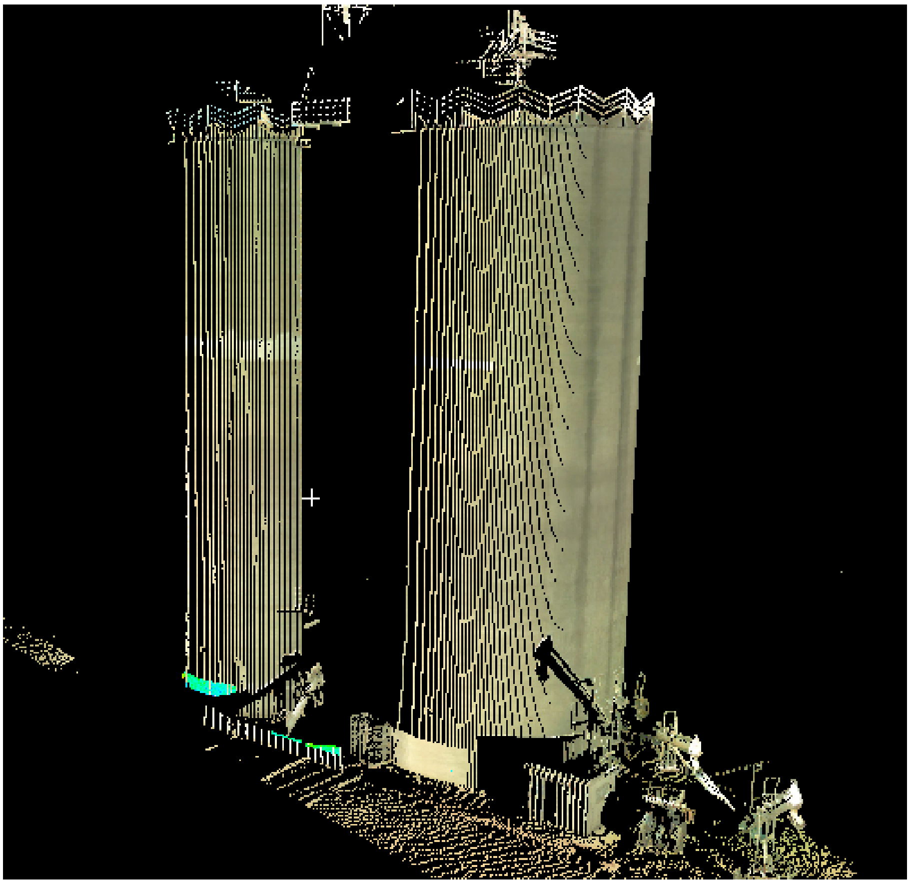

Figure 4.6: Scan World 1001

Due to the machinery being parked in front of target 4004 i was unable to obtain any results for the HDS target 4004. The HDS target 4003 was able to be obtained in Scan World 1001. This obstruction has affected both the Scanstation2 and the Trimble S6 which was also unable to obtain any readings for 4004.

4.5.2 Scan World 1002

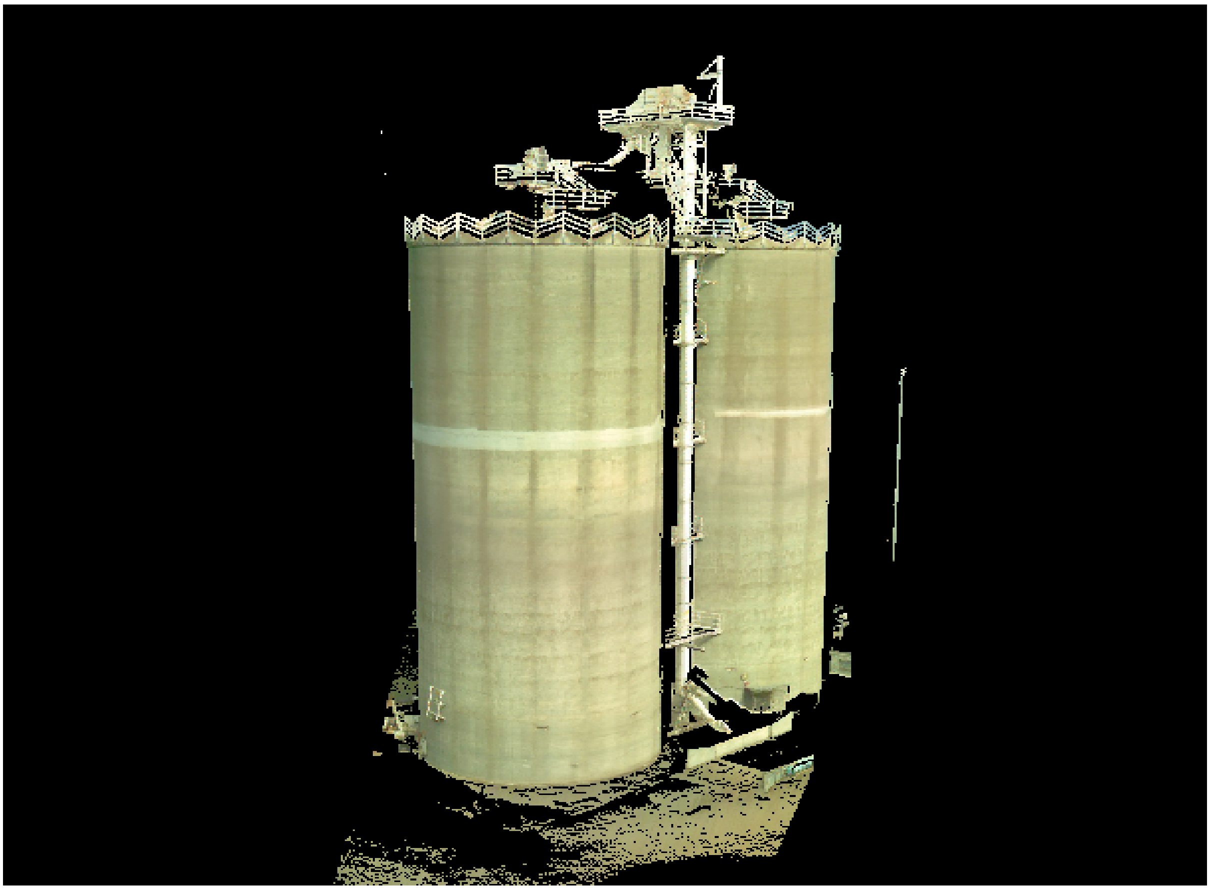

Figure 4.7: Scan World 1002

Figure 4.22 shows the resulting scan after a scan was taken from the survey control station 1002. As can be seen the scan has picked up a good proportion of the western sides of both the northern and southern grain silos as well as the access facility between the silos.

4.5.3 Registered Scan World Session 2

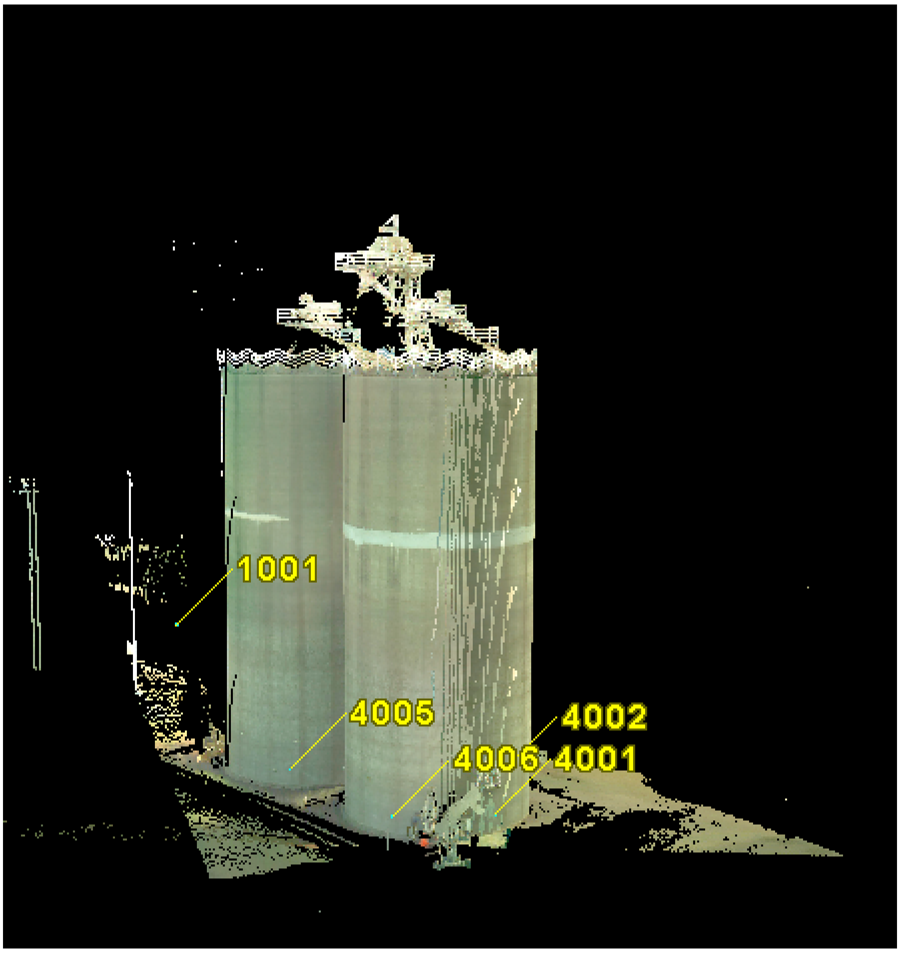

Figure 4.3: Registered Scan World

Figure 4.23 shows the 3 Scan World sessions registered together to form a complete 3d model of the grain silo. As can be seen the 3 Scan Worlds fit into each other quite well and as the error table will show in table

4.5.5 Registration Errors for scan session 1

Like in the first scan session the registration errors were able to be viewed after registration. Again these errors were quite small and showed that the survey control network was well adjusted and that the scanstation2 was able to measure accurately to each backsight and target. The registration errors can be seen below in table 4.20.

Table 4.2: Error Vectors

Constraint I.D	Scan Worlds	Weight	Error	Error Vector
1001	1 and 3	1	0.002	(0.000, 0.001, 0.002)m
1002	1 and 3	1	0.005	(0.001, 0.005, 0.001)m
1002	1 and 2	1	0.003	(-0.001, 0.000, -0.003)m
1002	2 and 3	1	0.003	(0.002, 0.001, 0.002)m
1001	2 and 3	1	0.005	(0.000, 0.005, -0.001)m

Like the first registration only the survey control network stations were used. The errors are again less than 5mm.

4.6 Comparison of HDS coordinates obtained by the Lieca ScanSation2

Figure 4.4 shows a comparison between the coordinates of the first laser scan session and the fixed coordinates for the HDS targets.

Scan session 1 comparison with fixed coordinates

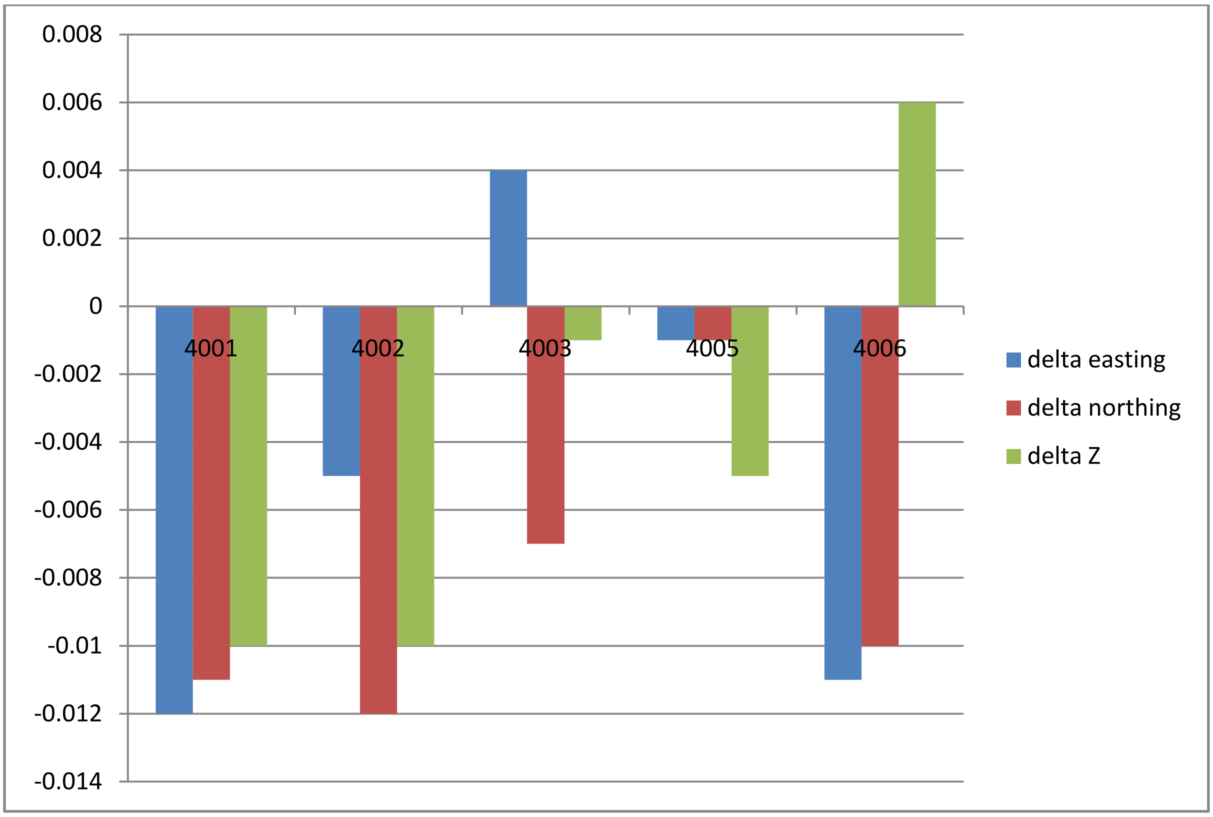

Figure 4.4: Scan session 1 comparison to fixed coordinates

As can be seen in figure 4.4 the differences are quite large compared to the differences between the coordinates picked up by the Trimble S6.

Figure 4.10 illustrates the movements between the fixed coordinates and the scan session 2 coordinates.

Scan session 2 comparison with fixed coordinates

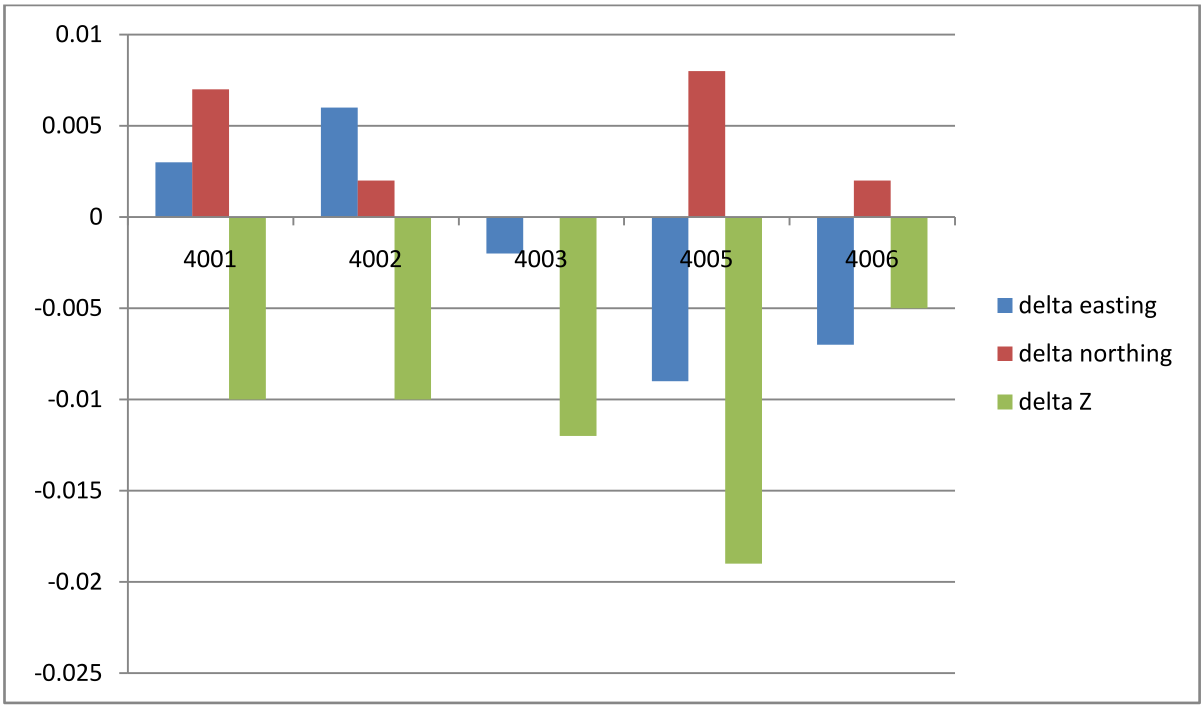

Figure 4.10: Coordinate comparison between fixed and scan session 2 coordinates

4.7 Trimble S6. First second and third survey sessions

The first deformation and scanning session using the Trimble S6 was conducted 3 days prior to the Leica ScanStation2. In an ideal situation the testing would be done on the same day but due to time constraints. The test day weather conditions were similar so this should not affect the results too dramatically.

Table 4.3 contains the coordinates that were surveyed in the first session and these coordinates will be compared to the other 3 sessions.

Table 4.3: Fixed HDS coordinates

Station	Easting	Northing	Z
4001	970.994	4962.862	100.585
4002	965.568	4955.487	100.713
4003	968.479	4940.941	100.729
4004	976.728	4936.849	100.577
4005	978.295	4947.512	100.637
4006	976.867	4960.047	100.621

The next survey of the HDS targets by the Trimble S6 was undertaken and the coordinates were subtracted from the first survey sessions.

Scan session 1 coordinates comaprision against scan session 2 coordinates

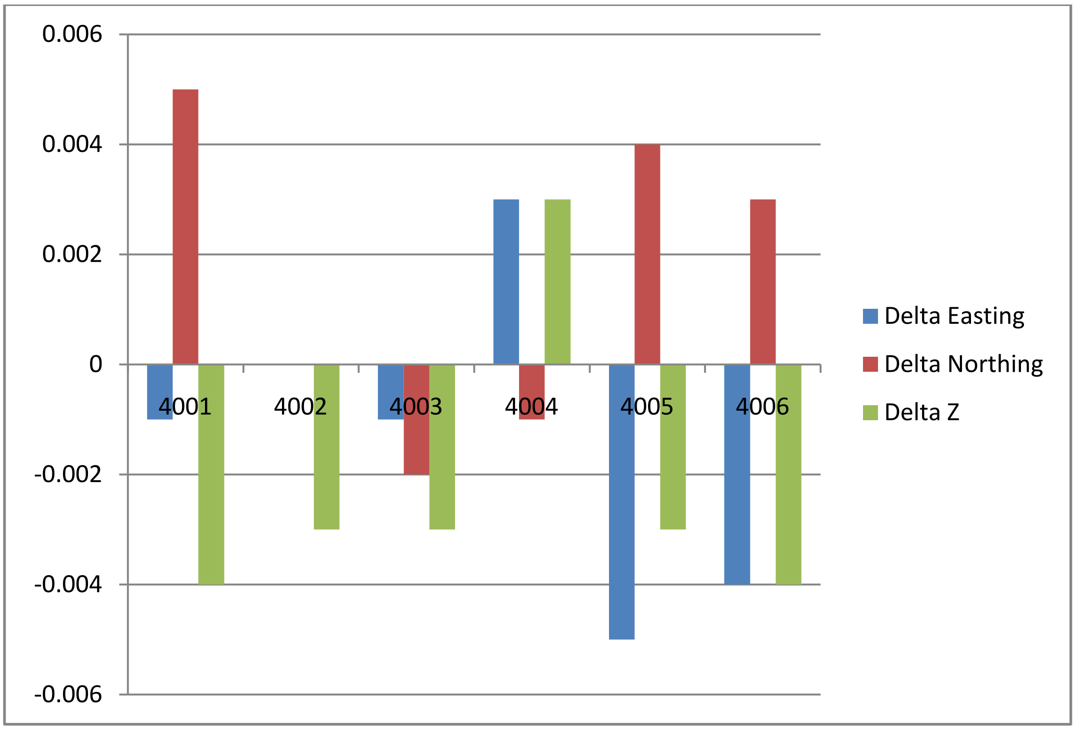

Figure 4.11: Comparison between first session coordinate and second session coordinates.

Figure 4.11 shows the coordinate differences between the first survey session and second survey session undertaken by the Trimble S6. As can be seen the differences are quite small and just from analysing these coordinates it can be concluded that minimal to no deformation around the HDS targets has occurred.

Session 1 and session 3 comparison

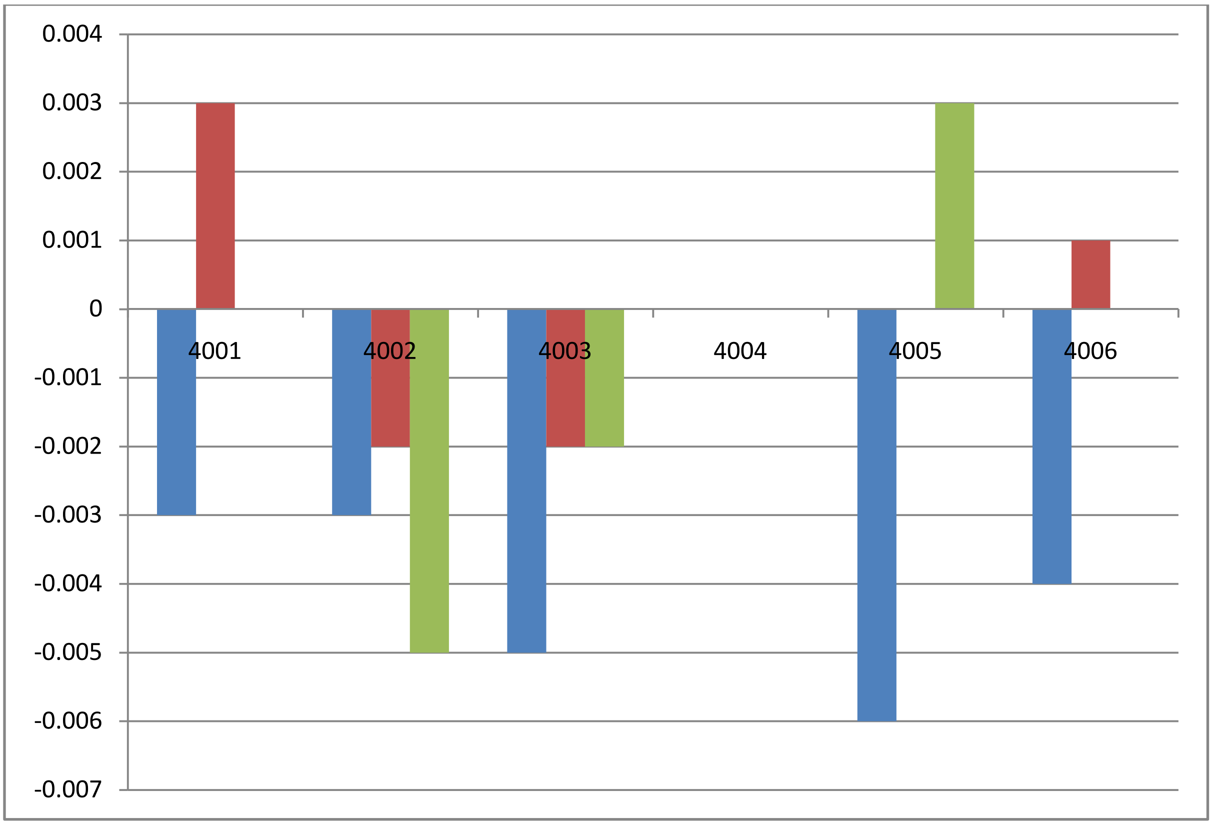

Figure 4.12: Session 1 and session 3 coordinate comparison.

Figure 4.12 shows the coordinate differences between the first deformation survey session and the third deformation survey session. As can be seen there is still minimal movement in the HDS coordinates.

Table 4.3: Range of Delta Coordinates

Delta Easting	Delta Northing	Delta Z
0.009	0.007	0.008

The range for the delta coordinates can be seen to vary by an average of 0.008m.

Table 4.4: Standard Deviation of Delta Coordinates

Delta Easting	Delta Northing	Delta Z
0.003	0.002	0.003

Table 4.5: Average Delta Coordinates

Delta Easting	Delta Northing	Delta Z
-0.002	0.001	-0.001

As can be seen in Table 4.4 and Table 4.5 the average error in the survey sessions in quite small and the distribution of the coordinates is very small. This shows that there is little of no movement in the grain silo.

4.8 Comparison between Leica ScanStation2 and Trimble S6

The next results will show the difference between the coordinates gained by the Trimble S6 using the direct reflectorless technology and the Leica ScanStation2. The Leica ScanStation2 results were obtained by using the single point pick function in the Leica Cyclone software and obtaining a coordinate for the centre of each HDS target.

Table 4.6: Leica ScanStation2 HDS coordinates

Station	Easting	Northing	Z
4001	970.991	4962.855	100.595
4002	965.562	4955.485	100.723
4003	968.481	4940.941	100.741
4004	976.721	4936.855	100.578
4005	978.304	4947.504	100.656
4006	976.874	4960.045	100.626

The differences between the obtained coordinates from the first session surveys by the Leica ScanStation2 and the Trimble S6 were then plotted against each other.

Leica ScanStation2 and Trimble S6 Coordinate Comparison

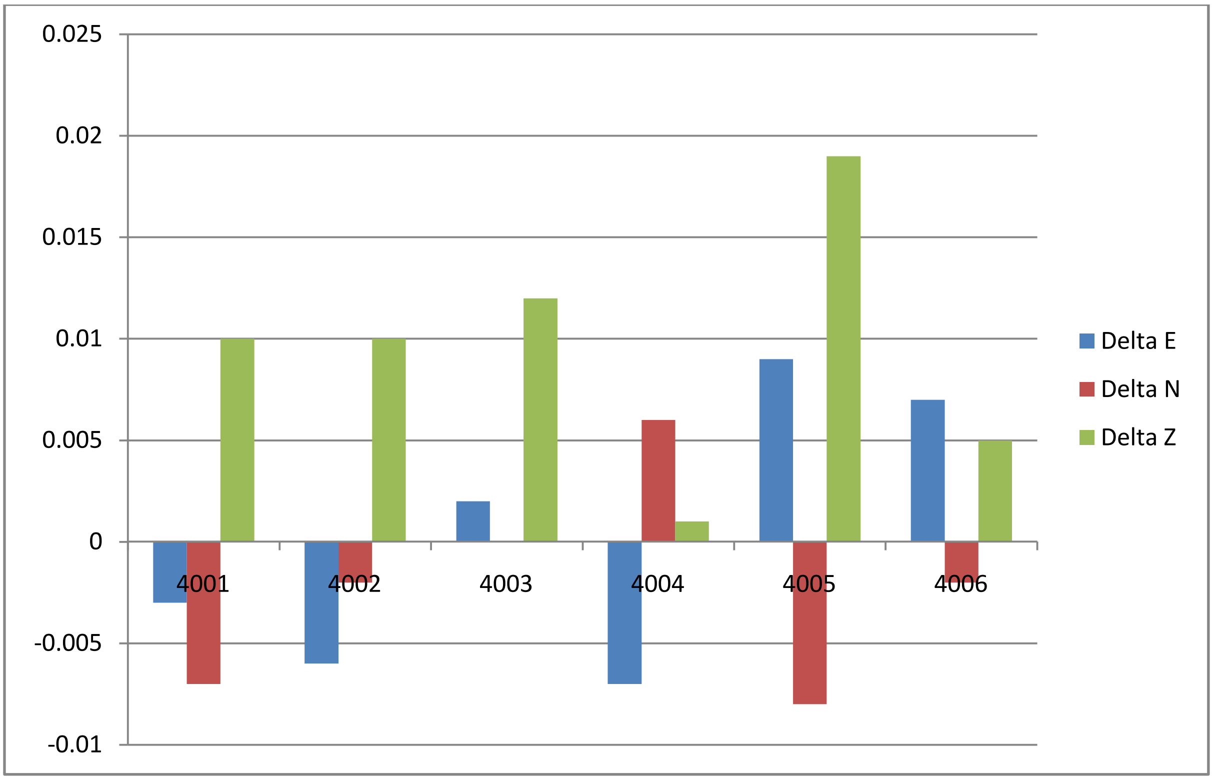

Figure 4.13: Coordinate comparison between survey session 1 using the Leica ScanStation2 and survey session 1 using the Trimble S6

The differences between the coordinates are much larger than the differences between the different survey sessions comparing the results obtained by the Trimble S6. This will be further discussed in chapter 5.

Leica ScanStation2 and Trimble S6 Coordinate Comparison

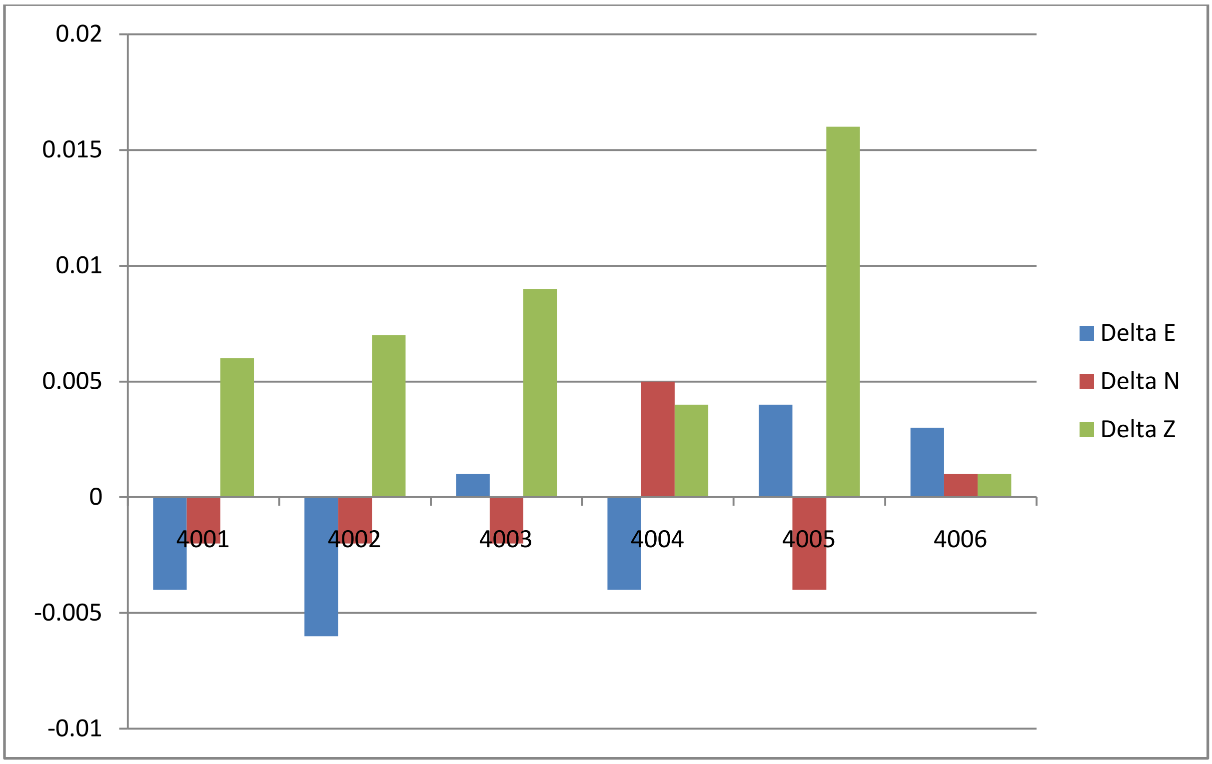

Figure 4.14: Coordinate comparison between survey session 1 using the Leica ScanStation2 and survey session 2 using the Trimble S6

The coordinate differences between these two survey and scan sessions show results that are slightly better than in the Figure 4.12.

Leica ScanStation2 and Trimble S6 Coordinate Comparison

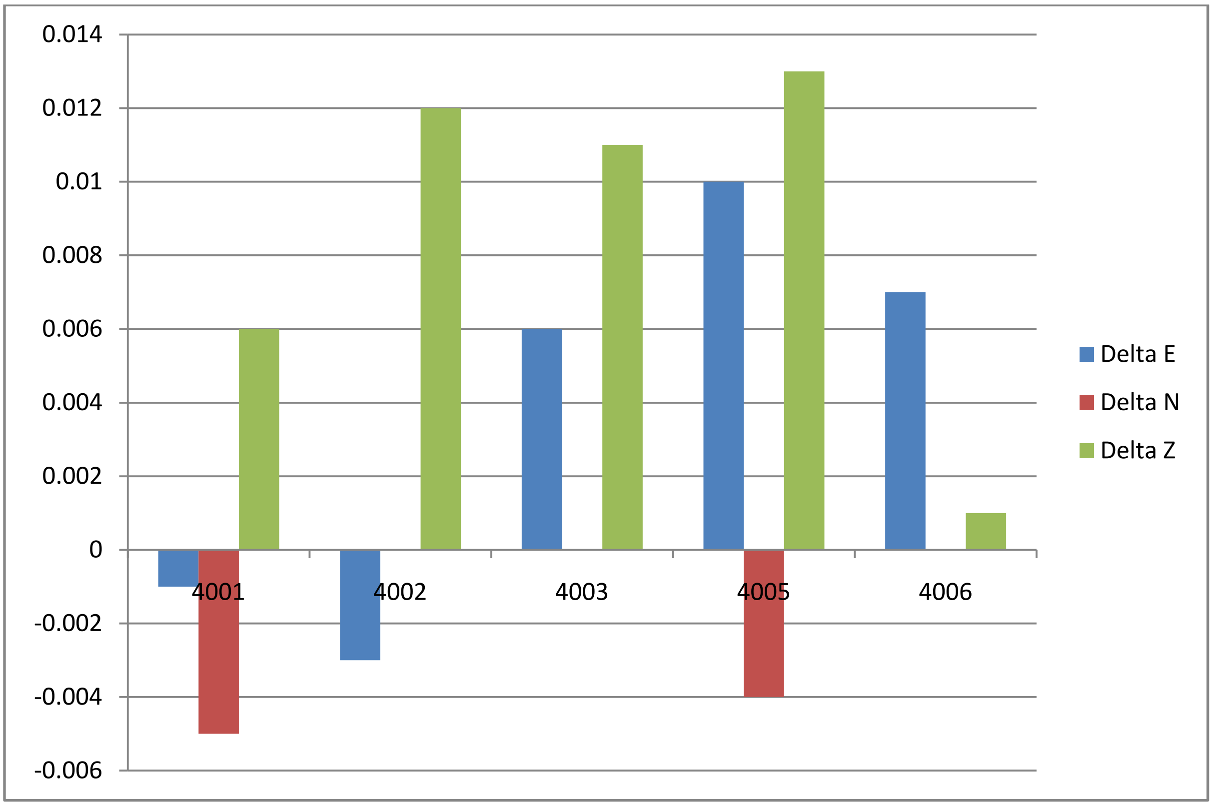

Figure 4.15: Coordinate comparison between survey session 1 using the Leica ScanStation2 and survey session 3 using the Trimble S6

Figure 4.15 shows the coordinate differences between the scan session 1 using the Leica ScanStation2 and the results obtained by using the Trimble S6 in survey session 1. As is shown the differences between the two are quite large in both the easting and Z directions.

4.9 Computer Aided Modelling

For this part of the research project the scanning sessions will be modelled in specialist software. The laser scanning sessions done by the ScanStation2 will be reduced in the specialist laser scanning software Leica Cyclone. The Trimble S6 laser scanning sessions will be downloaded into 12D.
The radiuses of the grain silo will be compared both against different scanning sessions using the same instrument and against each other.

4.9.1 Laser Scan session 1 modelling

A 20 metre section of the registered scan was selected and transferred to a new modelspace. The point cloud was then modelled into a solid cylinder using the ‘fit to cloud’ command.

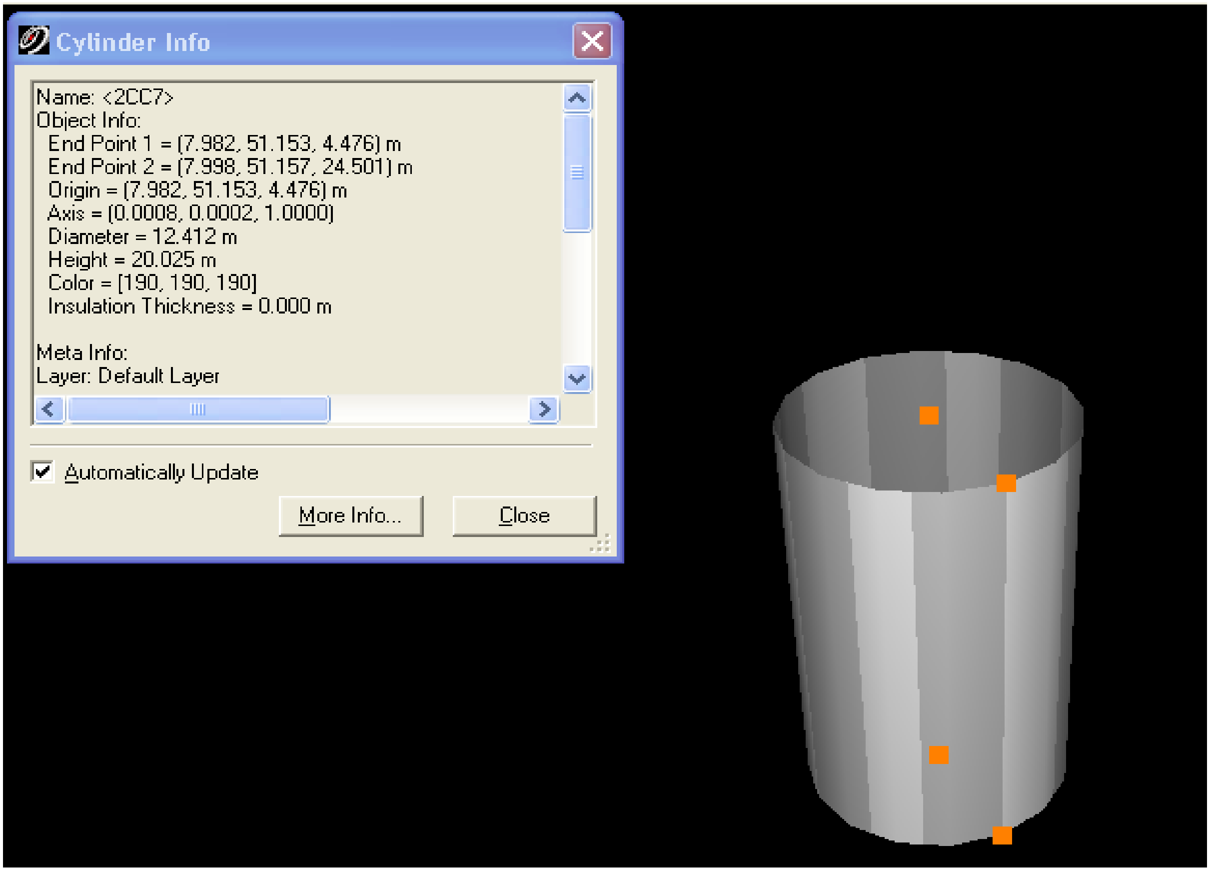

Figure 4.16: Northern grain silo solid model

A section of the southern grain silo was then selected and copied into a new model space. Like in the northern silo the command ‘Fit to Cloud’ was used to model a solid of the grain silo.

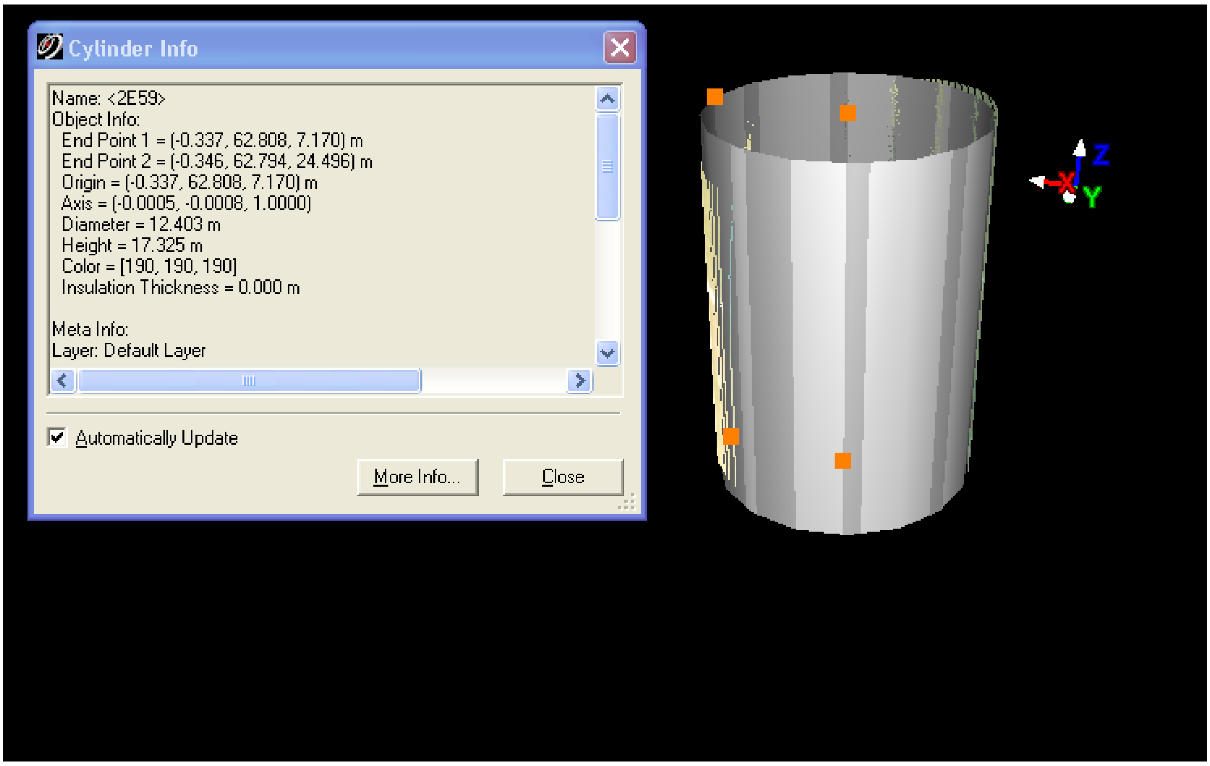

Figure 4.17: Southern grain silo solid model

The diameters of the grain silos were then calculated using the cylinder information function.

Table 4.7: First session grain silo diameters

Grain Silo	Diameter (Metres)
North Silo	12.412
South Silo	12.403

4.9.2 Laser Scan session 2 modelling

The northern silo was modelled using the same procedure as the first scan session. A 14 metre section of the silo was selected and copied to another modelspace. This was then modelled into a cylinder.

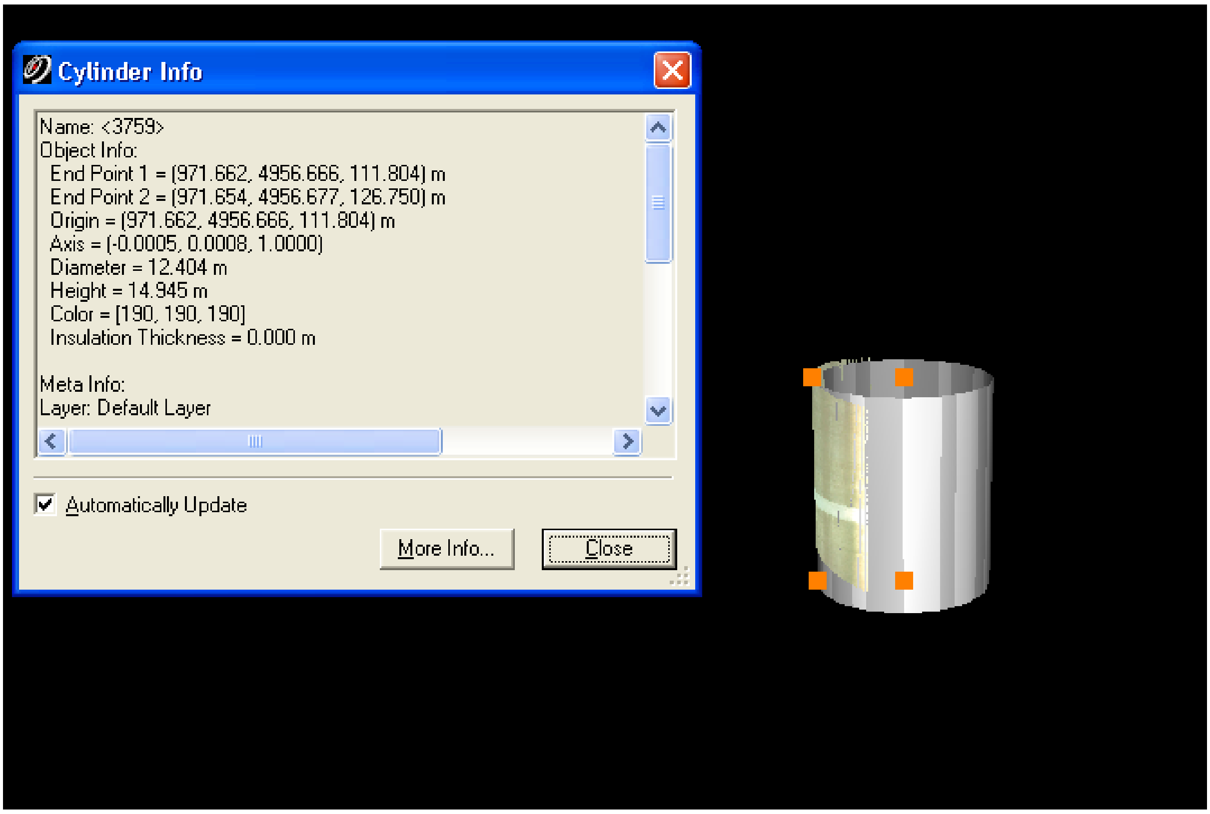

Figure 4.18: Modelled section of northern grain silo

A section of the southern silo was then selected and copied into a new modelspace. This was then modelled into a cylinder.

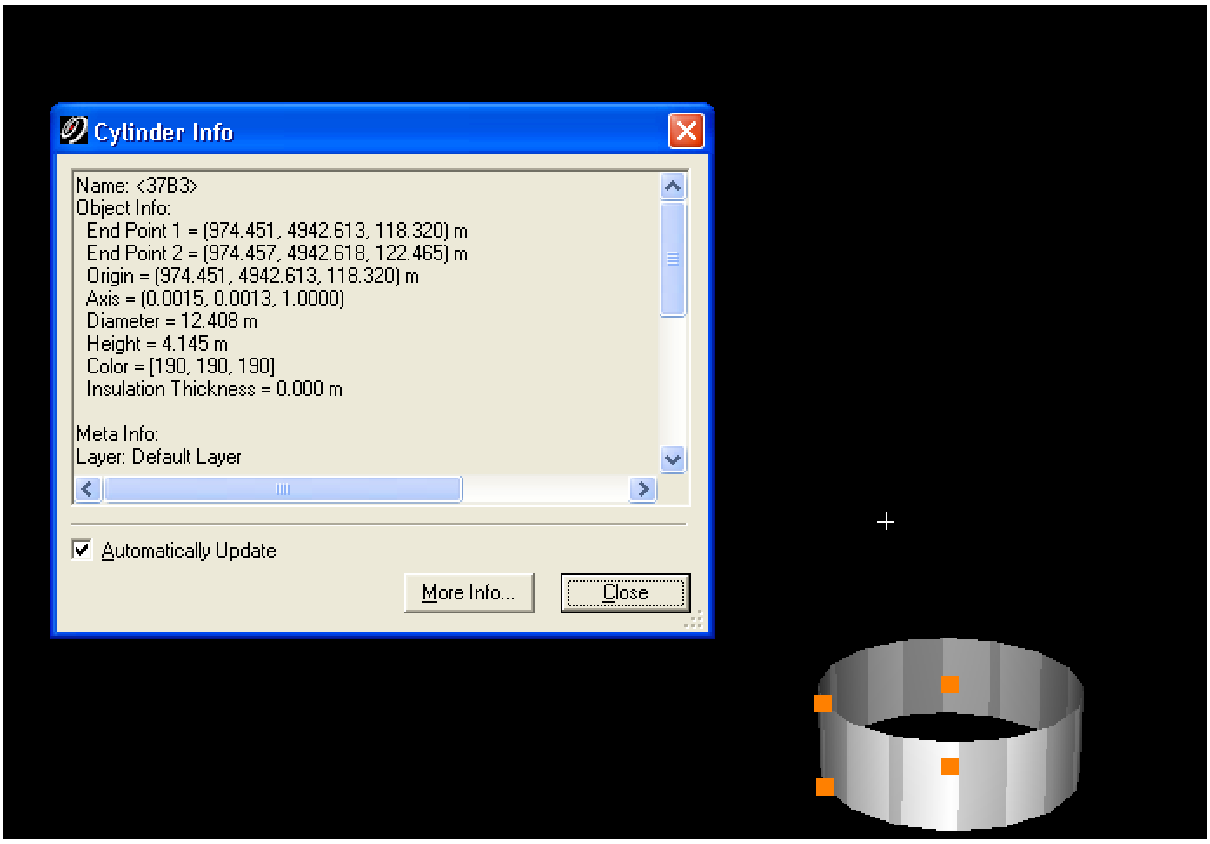

Figure 4.19: Modelled section of southern silo

The radiuses of both the northern and southern sections of the grain silos were identified by using the cylinder information function.

Table 4.8: Second session laser scan diameters

Grain Silo	Diameter (metres)
Northern	12.404
Southern	12.408

As can be seen on table 4.8 the diameters are very similar to each other and very similar to the results obtained from the first scans session. Figure 4.20 shows the differences between the first session diameters and the second session diameters.

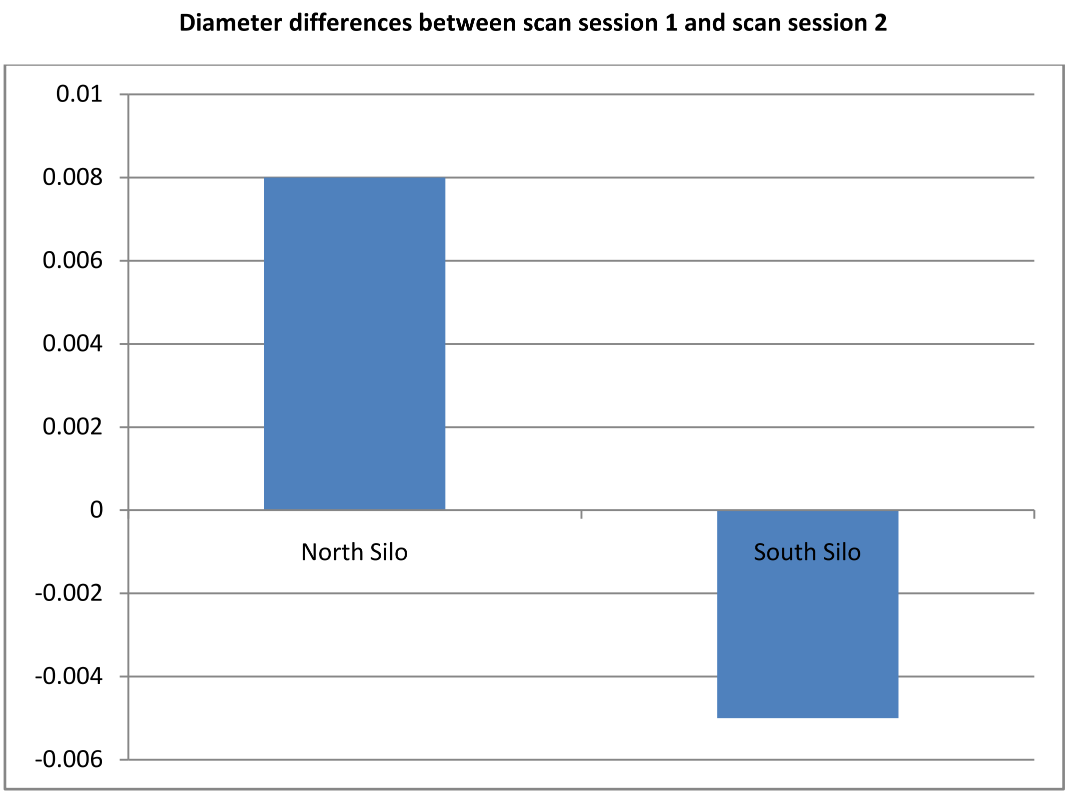

Figure 4.20: Diameter differences between scan session 1 and scan session 2.

4.10 Trimble S6 diameters

A diameter for the northern and southern grain silos was calculated using the 3 point circle function in the 12D civil and survey software. Diameters from all 3 survey sessions was calculated and shown below in table 4.14.

Table 4.15: Northern and southern silo diameters

Grain Silo	Survey session 1	Survey session 1	Survey session 1
Northern Silo	12.401	12.404	12.412
Southern Silo	12.406	12.410	12.403

As can be seen in table 4.15 the differences between the different survey sessions are minimal and do not differ much from the results obtained by the Leica ScanStation2.

Figure 4.20 shows the differences between the diameters obtained by the Trimble S6 and the Leica ScanStation2 in the first 2 survey and scan sessions.

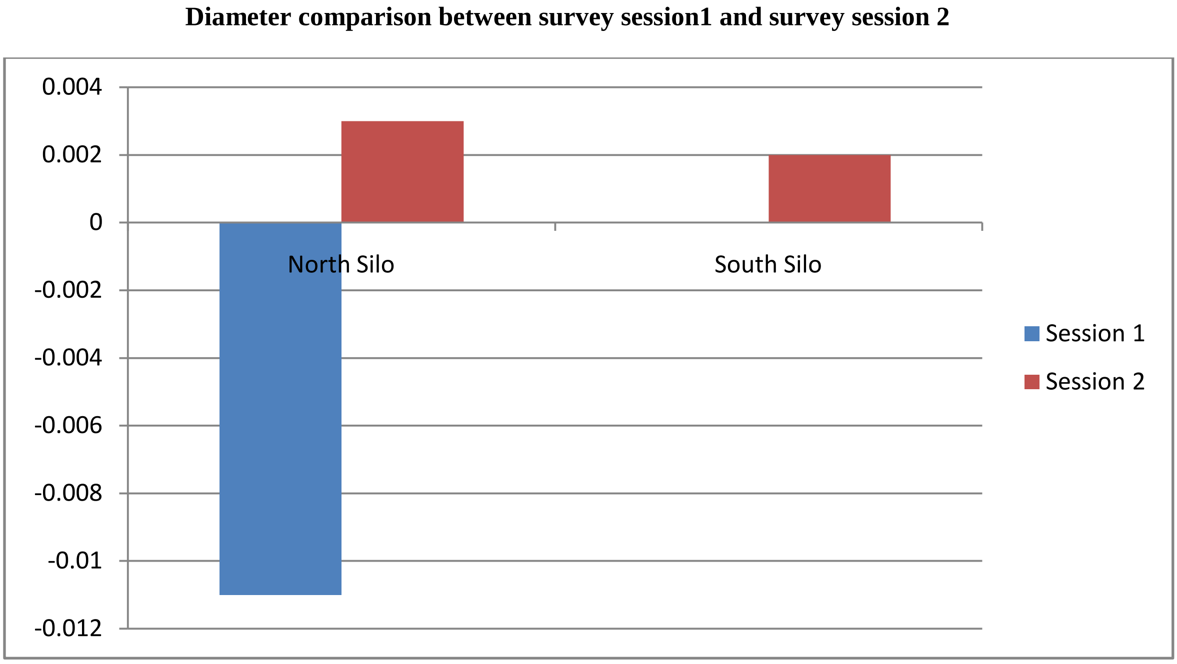

Figure 4.20: Diameter Differences between Trimble S6 calculated diameter and Leica ScanStation2 diameter.

As shown in figure 4.20 the differences between the calculated diameters of each grain silo is very small. This will be further discussed in chapter 5.

4.11 Conclusion

The figures and table shown on this chapter will be analysed in greater detail in chapter 5. The figures in this chapter will be referenced back to in chapter 5 to give a greater understanding of the results obtained by both instruments.

The results presented in this chapter can be summarised as follows; the results obtained by the Trimble S6 were very similar to the results obtained by the Leica ScanStation2. There was very little movement detected in both grain silos by both the instruments. The Leica ScanStation2 did show larger coordinate differences when comparing the two scan sessions. This was not the case when analysing the coordinates surveyed by the Trimble S6. The differences were smaller when comparing the different survey sessions.

Chapter 5

Analysis and Discussion

5.1: Introduction

The aim of this chapter is to discuss and analyse the results shown in chapter 4 in greater detail. The discussions presented in this chapter are based on the figures and tables presented in chapter 4. The main area of analysis will be in the following areas

- HDS Coordinate differences in the Trimble S6
- HDS Coordinate differences in the Leica ScanStation2
- Comparison of coordinate differences between Trimble S6 and Leica ScanStation2
- Calculated grain silo diameters

The discussions in this chapter will revolve around these 4 points.

The aim of this chapter is to allow the reader to gain a better understanding of the results obtained by the Trimble S6 and the Leica ScanStation2.After reading this chapter the reader should be able to have a good understanding of why the Trimble S6 and the Leica ScanStation2 have produced similar results in each survey or scan session.

This chapter will be divided up into sections.

- Trimble S6 results
- Leica ScanStation2 results
- Comparison of Trimble S6 and Leica ScanStation2 results

5.2 Trimble S6 results

The first survey session with the Trimble S6 was to obtain fixed coordinates of the Leica HDS targets that were placed around the two grain silos. 3 targets were placed on both the northern and southern silos around the base of the structure. The HDS targets were then measured to using the Trimble S6. The following fixed coordinate results were obtained.

Table 5.1: Fixed HDS coordinates

Station	Easting	Northing	Z
4001	970.994	4962.862	100.585
4002	965.568	4955.487	100.713
4003	968.479	4940.941	100.729
4004	976.728	4936.849	100.577
4005	978.295	4947.512	100.637
4006	976.867	4960.047	100.621

Unfortunately HDS targets were only able to be placed around the base of the northern and southern silos as the top area was inaccessible due to work place health and safety regulations. Another problem encountered was when a loading mechanism was placed in front of the HDS target 4004 after the 3rd Trimble S6 survey session and the 1st Leica ScanStation2 scanning session. HDS Target 4004 was taken out of the comparison calculations for both the Trimble S6 and the Leica ScanStation2.

Figure 5.1 compares the coordinates surveyed in survey session 1 compared to the coordinates surveyed in survey session 2.

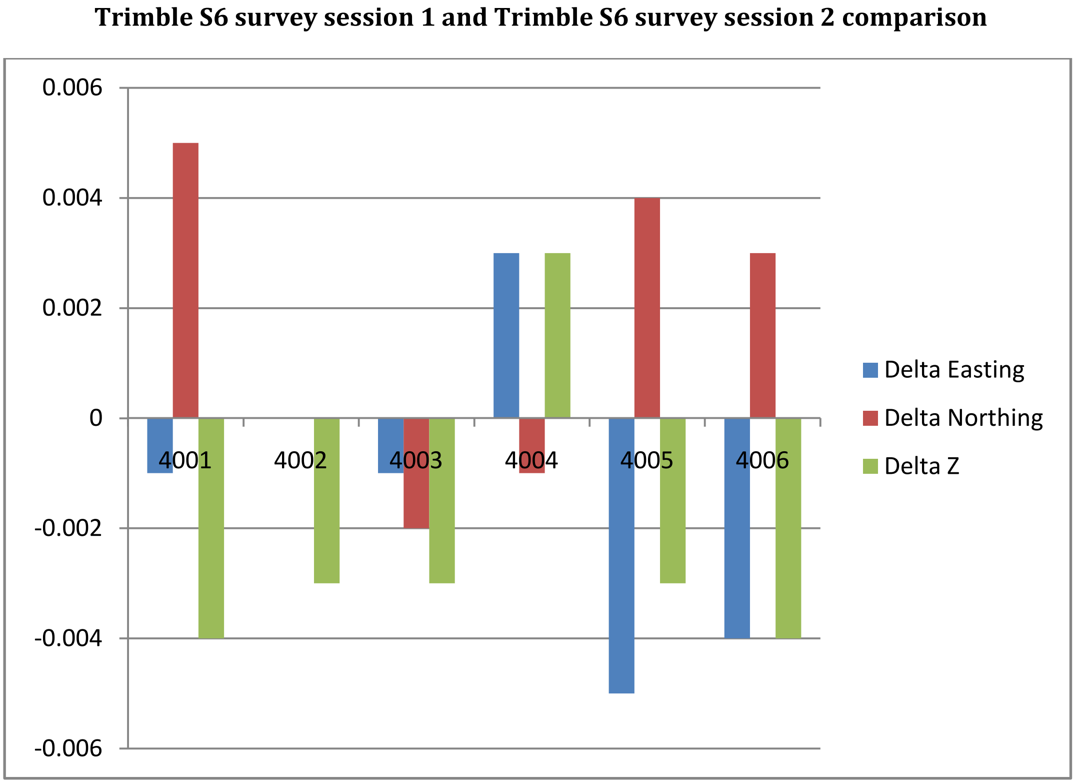

Figure 5.2: Trimble S6 survey session 1 and Trimble S6 survey session 2 comparison.

As can be seen in figure 5.2 the differences detected by the Trimble S6 between the first survey session (fixed coordinates) and the second survey session show minimal differences. The easting, northing and Z deltas are all equal to or less than 5mm. All the Z values except for HDS target 4004 were slightly down on the fixed values surveyed in the first session. While these differences were small I believe they were caused by the silo being filled with grain at the time of the second survey session. These results were not unexpected as the Trimble S6 has a stated accuracy of ±3mm and 2ppm. Because the differences in coordinates were so small it can be safely assumed that there was no or minimal deformation in the grain silo during survey session. The conditions that the survey sessions were conducted in were very similar in that there was an ambient temperature of around 20 degrees Celsius.

Figure 5.3 shows the coordinate comparison between survey session 1 and survey session 3. Again as shown in Figure 5.3 the differences were again quite small between the survey sessions.

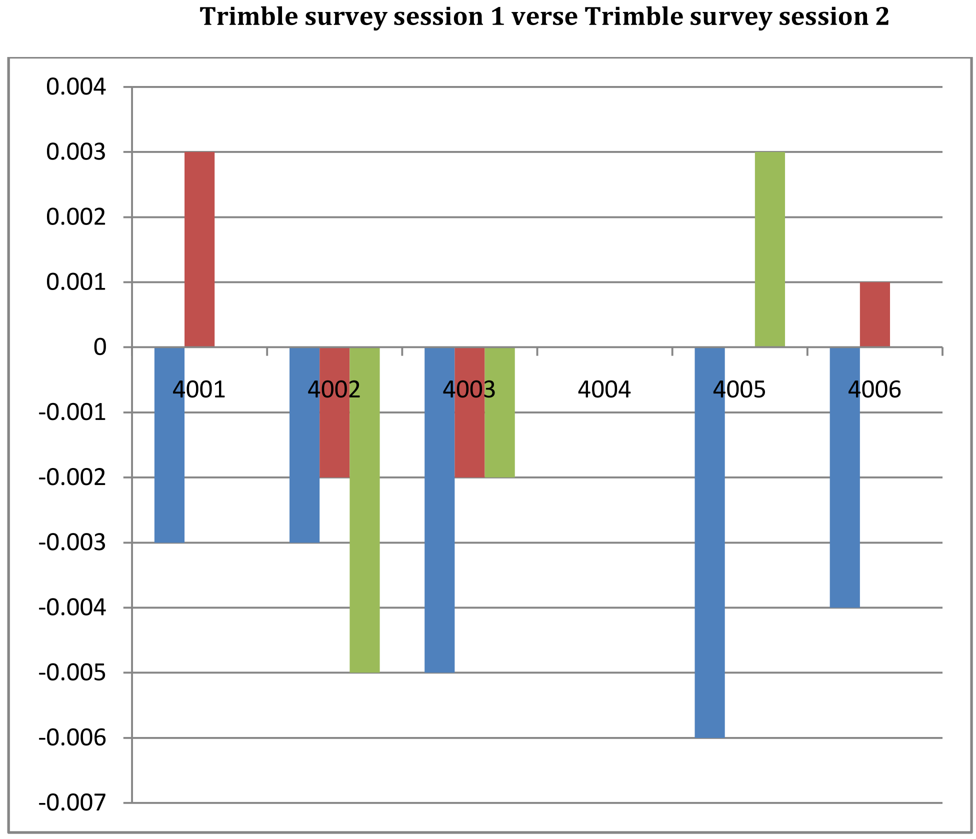

Figure 5.3: Trimble survey session 1 verse Trimble survey session 2

The differences between the survey sessions are again generally under the expected ≤5mm range. HDS target 4004 was not visible due to machinery being in the line of sight so a comparison cannot be made between the two survey sessions. Like in figure 5.2 the Z deltas were generally down from the first session apart from HDS target 4005. Again I believe although the differences are small, the negative Z deltas are due to the grain silos being in use. The deformation in survey session 3 can be safely assumed to be no deformation in both the northern and southern grain silos.

The range for the delta easting, northing and Z values are shown in table 4.3.

Table 4.3: Range of Delta Coordinates

Delta Easting	Delta Northing	Delta Z
0.009	0.007	0.008

The ranges for the coordinate deltas are very similar. They are all below 10mm and this shows that the Trimble S6 was very consistent over both the survey sessions. This again proves that there was minimal to no deformation in the grains silos over the deformation survey period.

The standard deviation for both the Trimble S6 survey session 1and the Trimble S6 survey session 2 are shown in table 4.4.

The average delta difference is shown in table 4.10. This highlights the fact that the Trimble S6 was able to survey the HDS targets very accurately.

Table 4.10: Average Delta Coordinates

Delta Easting	Delta Northing	Delta Z
-0.002	0.001	-0.001

A shown in table 4.20 the average deltas were very small and showed no evidence of movement in either the northern or southern silo. Again this was to be expected as the grain silos are more stable and less likely to fail than industrial silos.

Table 4.4: Standard Deviation of Delta Coordinates

Delta Easting	Delta Northing	Delta Z
0.003	0.002	0.003

The standard deviation for HDS targets shows that there was minimal to no deformation movement in both the southern and northern grain silos. As can be seen in table 4.4 the standard deviations are all below 5mm proving minimal movement in the grain silos.

In conclusion the Trimble S6 was able to survey the HDS targets quite easily and as can be seen for the previous tables and figures there was no sign of any major movement or deformation in the northern or southern grain silos. These results were to be expected as the Trimble S6 has a distance error of 3mm and 2ppm in distance in direct reflectorless mode.

5.3 Leica ScanStation2 Results

There were two scan sessions done with the Leica ScanStation2. These scans were done on different days but done in similar weather conditions. The Leica ScanStation2 has a built in thermometer and pressure reader so the weather conditions were able to be factored into both the scan sessions.

The Leica Scanstation2 has a manufactures claim of a distance accuracy of 4mm and a position accuracy of 6mm. Due to this fact it is expected that the Leica ScanStation2 will produce error results that will be larger than those obtained by the Trimble S6.

The Leica ScanStation2 data was compared against the Trimble S6 first session fixed coordinates. Figure 4.9 shows the coordinate differences between the fixed coordinates and the coordinates obtained by the Leica ScanStation2 in the first scan session.

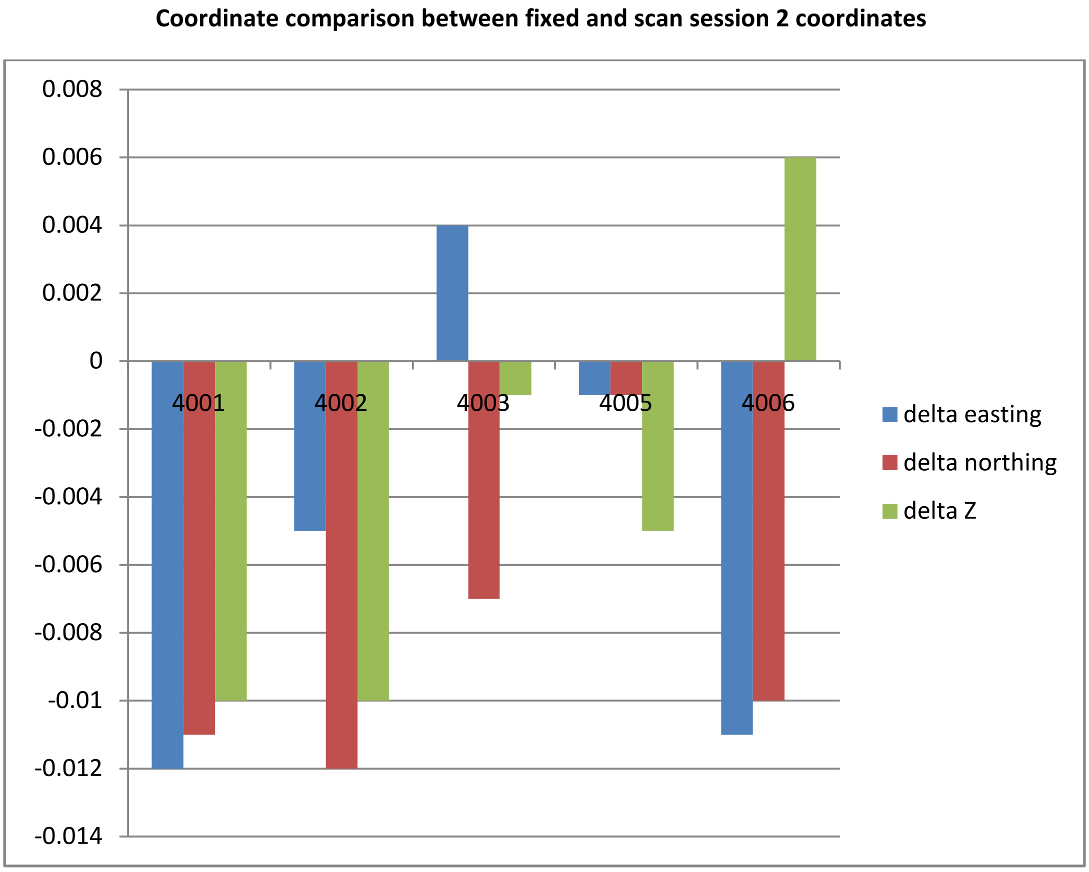

Figure 4.9: Coordinate comparison between fixed and scan session 2 coordinates

The results in Figure 4.9 show that the difference in coordinates between the fixed values and the Leica ScanStation2 coordinates is much higher than the Trimble S6 coordinate differences. The coordinate differences are on average ≥5mm different than the fixed values. This result was not unexpected and showed that the Trimble S6 was indeed more accurate than the Leica ScanStation2.

Although the coordinate differences were larger it was still not large enough to show any signs of definite movement or deformation in the grain silos.

Figure 4.10 shows the coordinate differences between the fixed coordinates and the coordinates obtained in scan session 2.

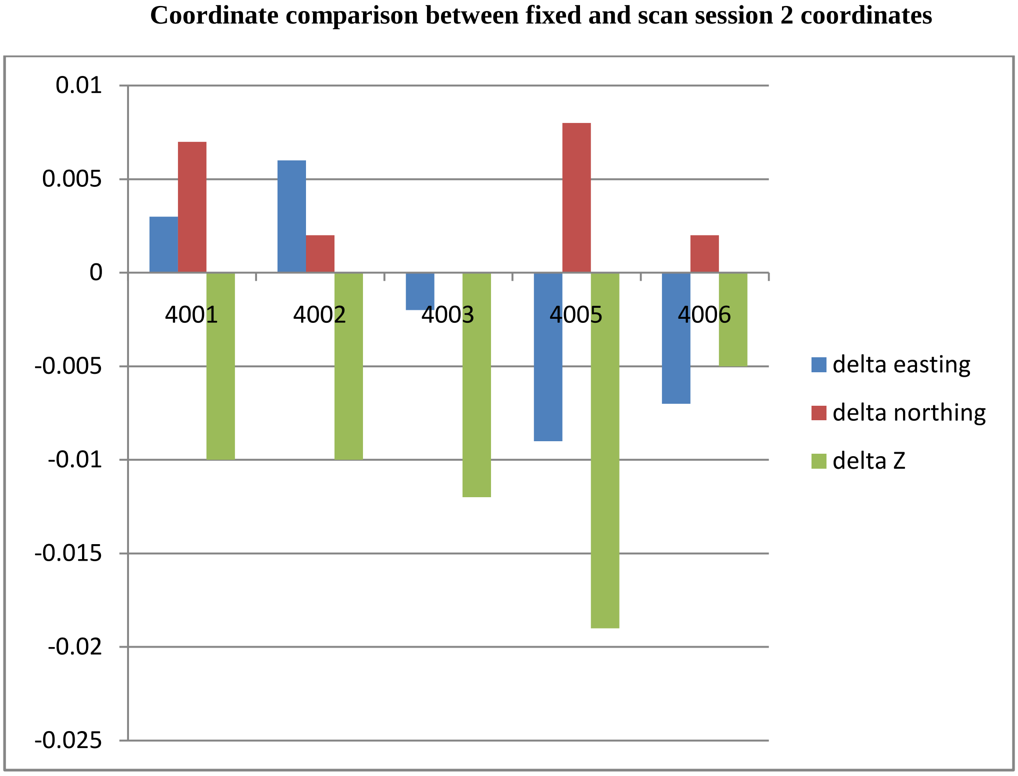

Figure 4.10: Coordinate comparison between fixed and scan session 2 coordinates

As in Figure 4.10 the differences in the coordinates are again quite large. As in the Trimble survey session 2 HDS target 4004 was not able to be surveyed as machinery was in the way. The delta differences are again around the 10mm difference. Again this result was not unexpected and again showed that the Trimble S6 was more accurate in the survey of the HDS targets. It was interesting to note that all the Z deltas were in the negative. This was similar in the Trimble survey session 2 and I believe that this shows a slight downward movement in the silos foundations when the silo is loaded with grain. This movement in the silo is very small and is not unexpected in structures of this size.

Table 4.30 shows the average change in coordinate between the scan session and the fixed coordinates.

Table 4.22: Average coordinate difference

Delta Easting	Delta Northing	Delta Z
-0.003	-0.002	-0.008

From the results shown in Table 4.30 the average change in coordinates for the Leica ScanStation2 was not unexpected. I expected the average coordinate difference to be large than 5mm. This is true in the delta Z category but the delta easting and delta northing was quite small over the entire data range.

The range in the coordinates is shown below in Table 4.31

Table 4.23: Delta Coordinate Range

Delta Easting	Delta Northing	Delta Z
0.018	0.020	0.018

Table 4.31 shows that the ranges of the coordinates are quite large. This is due to that fact that the captures of some of the HDS targets were on an acute angle and not always front on to the Leica ScanStation2. The large variation in the coordinate ranges shows that the target acquisition was not as accurate as traditional surveying methods as the user has little control of the pointing and measuring of the target.

Table 4.24 shows the standard deviation of the delta coordinates obtained by the Leica ScanStation2

Table 4.24: Standard deviation of delta coordinates

Delta Easting	Delta Northing	Delta Z
0.006	0.007	0.006

The standard deviation of the coordinate changes in the Leica ScanStation2 was expected as the horizontal and positional errors of the instrument was around the 5mm value. The results in Table 4.24 prove that the Leica ScanStation2 provides results that while not as accurate as traditional surveying methods gives a good indication of any or in this case minimal or no deformation or movement in the grain silo.

5.4 Trimble S6 and Leica ScanStation2 Comparison

As stated in chapter 4 the Trimble S6 is expected to provide more accurate results than the Leica ScanStation2. The horizontal and positional errors in the Leica ScanStation2 are 6mm and 4mm respectively. This is nearly more than the distance error of 3mm and 2ppm for the direct reflectorless method for the Trimble S6 and an angular error 3 seconds in both the horizontal and vertical planes.

Figure 4.12 shows the coordinate differences in between the data collected in the Trimble S6 survey session 1 and the data collected in the scan session 1.

Leica ScanStation2 and Trimble S6 Coordinate Comparison

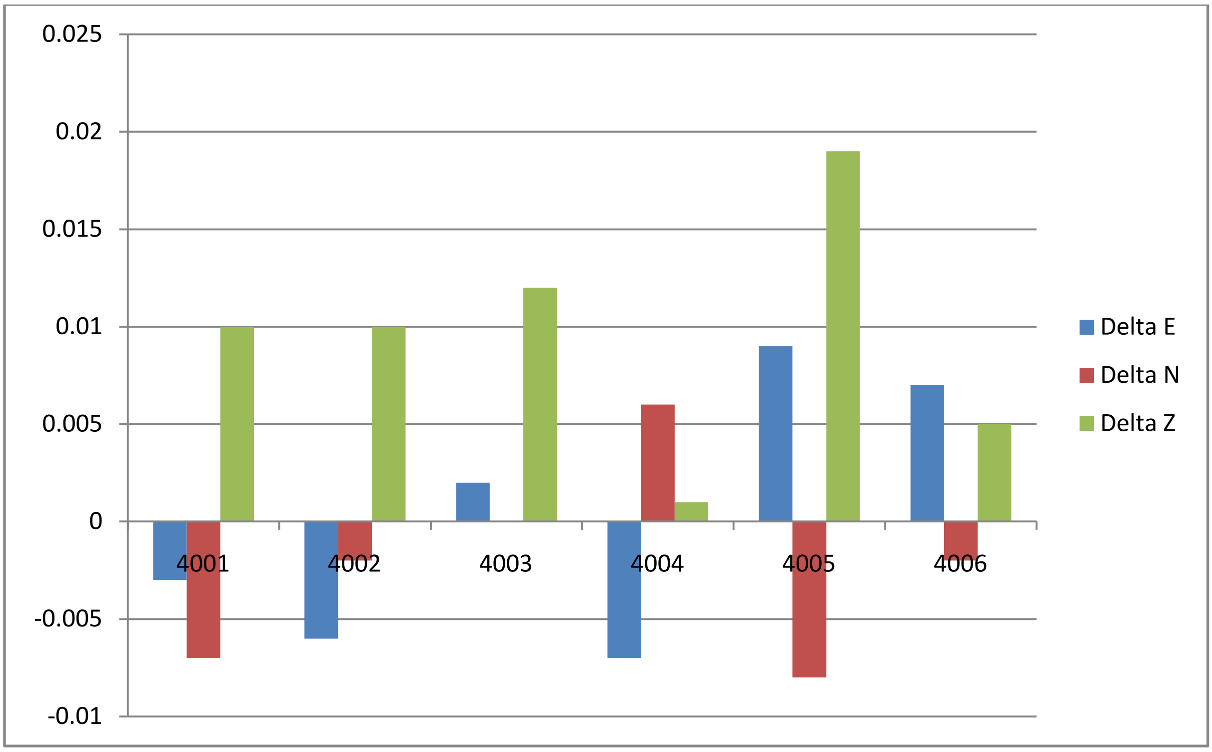

Figure 4.12: Coordinate comparison between survey session 1 using the Leica ScanStation2 and survey session 1 using the Trimble S6

As shown in figure 4.12 the differences in coordinates quite profound. While the survey sessions weren't conducted on the same day the sessions were conducted in similar weather conditions and around the same time of day. As discussed in section 5.2 and 5.3, both the Trimble S6 and the Leica ScanStation2 showed little movement of deformation in the grain silo structures but as shown above the difference in coordinates is quite different. Most of this can be contributed to the fact that the Leica Scan Station2 is not as accurate as the Trimble S6 when surveying HDS targets.

Figure 4.13 shows the coordinate differences between the Trimble S6 survey session 2 and the Leica ScanStation2.

Coordinate comparison between survey session 1 using the Leica ScanStation2 and survey session 2 using the Trimble S6

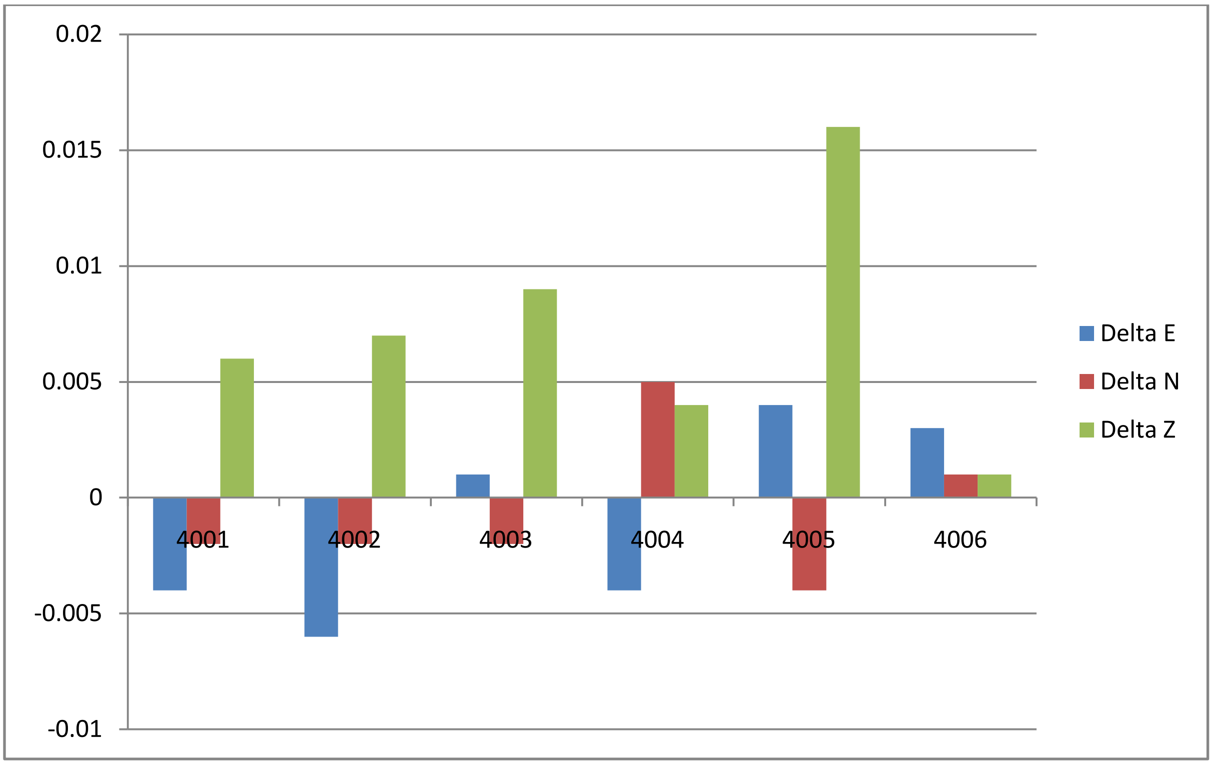

Figure 4.13: Coordinate comparison between survey session 1 using the Leica ScanStation2 and survey session 2 using the Trimble S6

As shown in Figure 4.13 the coordinate differences between to survey and scan session are quite small. Unlike the results obtained in figure 4.12 the differences are quite small and apart from the Z delta for HDS target 4005 the delta coordinates were all below ±10mm. This shows that the Leica ScanStation2 is able to provide results that are comparable to the Trimble S6. An interesting fact to note is that unlike in figure 4.12 all the differences in the Z coordinate are positive. I believe this is because when the second scan session was conducted the grain silos were in the process of being unloaded and were nearly empty. During the first scan session the grain silos were full so the weight of all the grain was cause the foundations to sink slightly. During the second scan session the grain silos were near empty weight on the foundation had decreased.

5.4.1 Statistical analysis of Trimble S6 and Leica ScanStation2 coordinate differences

5.4.1.1 Range Comparison

The range of the coordinate differences for the Trimble S6 is summarised in section 5.2, table 8. As discussed the range of the coordinates were all under ±10mm. The range for the coordinate differences for the Leica ScanStation2 was much larger and was around the ±20mm mark. The differences in ranges are shown in table 5.3

Table 5.3 Range Comparison

Instrument	Delta Easting	Delta Northing	Delta Z
Trimble S6	0.009	0.007	0.008
ScanStation2	0.018	0.020	0.018

Table 5.3 shows that the range in the coordinates surveyed by the Leica ScanStation2 was nearly double that of the range in the coordinates surveyed by the Trimble S6. This shows that the capture of the HDS targets by the ScanStation2 was far less accurate than the Trimble S6. I believe that this is due to the fact that you cannot point and measure to the centre of the HDS target. You must fine scan the general area of the HDS target area and rely on the target recognition software in the scanner.

5.4.1.2 Coordinate difference average comparison

Table 5.4: Average coordinate difference comparison

Instrument	Delta Easting	Delta Northing	Delta Z
Trimble S6	-0.002	0.001	-0.001
ScanStation2	-0.003	-0.002	-0.008

Table 5.4 shows the comparison between the average coordinate differences in both instruments. As can be seen the delta easting and northing values show that there is little difference between the two instruments. The delta Z average change shows a definite movement in the Z values for the coordinates surveyed by the Leica ScanStation2. This shows that the apart from a few outliers as shown in the range comparison in table 5.3, the Leica ScanStation2 is able to survey the HDS coordinates nearly as well as the Trimble S6.

5.4.1.3 Standard Deviation Comparison

Table 5.5: Standard Deviation Comparison

Instrument	Delta Easting	Delta Northing	Delta Z
Trimble S6	0.003	0.002	0.003
ScanStation2	0.006	0.007	0.006

The standard deviation comparison is shown in table 5.5. As shown the standard deviation for the coordinate differences for the Trimble S6 are quite small and all under 5mm. This shows that the HDS targets surveyed by the Trimble S6 were able to be accurately captured during each survey session and there was no major movement in that grain silo.

The Leica ScanStation2 had a much larger standard deviation. The standard deviation was nearly 3 times larger than the Trimble S6. This showed that the Leica ScanStation2 was not as accurate in the survey of the HDS targets as the Trimble S6. The standard deviation results for the Leica ScanStation2 were all under 10mm, so although it was not as accurate as the Trimble S6 it still produced good results that could be used in a deformation or movement survey.

5.5 Calculated Grain silo diameters

The aim of this section is to compare the radiuses of both the northern and southern grain silos to indentify weather any bulging in the silos had occurred. The grain silo diameters were calculated around the base of the silo near the HDS targets. The silo diameters were calculated using the scanner software Cyclone for the data surveyed by the Leica ScanStation2 and the civil and surveying software 12D for the data captured by the Trimble S6.

5.5.1 Trimble S6 silo diameters

The Trimble S6 grain silo diameters were calculated in 12D using the function ‘3 point circle’. This function allows the user to select three points to define a circle. In the 12D model software I selected the 3 HDS target points from each survey session and from this a circle was able to be produced. Table 5.6 shows the resulting silo diameters for each survey session.

Table 4.15: Northern and southern silo diameters

Grain Silo	Survey session 1	Survey session 1	Survey session 1
Northern Silo	12.401	12.404	12.412
Southern Silo	12.406	12.410	12.403

As shown in Table 4.15 the diameter differences were very minimal and it can be safely assumed that no bulging of either the northern or southern grain silo was evident in any of the scan sessions. This result was to be expected as grain silos do not experience the pressure both internal and external that industrial grain silo experience.

5.5.2 Leica ScanStation2 silo diameters

The grain silo diameters were calculated using the scanner software Cyclone. In Cyclone a section of the base of the silo was selected and copied into a new modelspace. The section of the grain silo was then edited to delete any outlying points that would affect the accuracy of the cylinder modelling. The section of silo was then modelled into a cylinder and a diameter was calculated from the cylinder properties information box.

Table 5.6 Leica ScanStation2 grain silo diameter comparisons

Grain Silo	Scanning session 1	Scanning session 2
Northern Silo	12.412	12.404
Southern Silo	12.403	12.408

As seen in Table 5.6 the grain silo diameters for both the northern and southern grain silos are very similar inn both scanning sessions. The diameters for both the northern and southern silo was around the 12.410 value, ±10mm. The diameters calculated showed no major movement in the grain silo diameters. The highest movement was in the northern silo during scan session 1 and scan session 2 when the silo diameter decreased by 8mm. The southern silo only had a 5mm increase in the diameter size during the 2 scan sessions.

5.5.3 Trimble S6 and Leica ScanStation2 diameter comparison

As shown in tables 5.6 and 4.14 the grain silo diameters for each survey session and scan session were very similar. Both 12D and Cyclone calculated diameters of 12.410 ±10mm. This showed that both instruments and software were able to produce very similar results. The diameter results also showed that both instruments did not detect any major movements in either grain silo. This in turn showed that there was no bulging around the base of the grain silo.

Table 5.7 shows the difference in the diameters between the Trimble S6 and t6he Leica

ScanStation2.

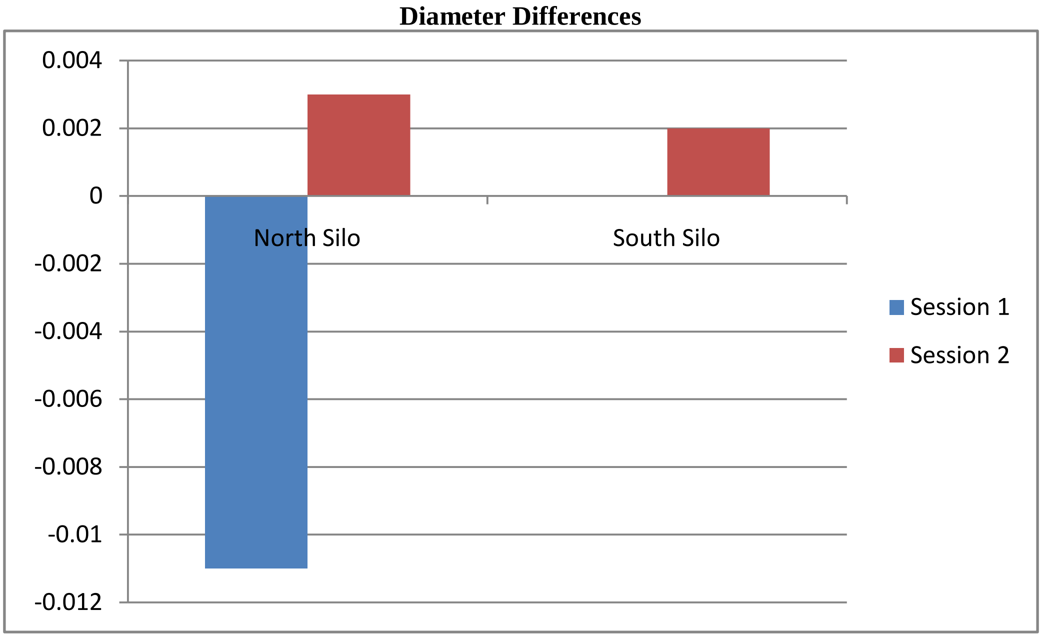

Figure 4.21: Coordinate differences between Trimble S6 calculated diameter and Leica ScanStation2 diameter.

As shown in figure 4.21 the differences in the silo diameter are small and apart from the first session surveying the north silo all the diameter differences were below 5mm. This shows that the surveyed data by both instruments was accurate enough to produce similar diameter results using either instrument.

5.6 Conclusion

The Trimble S6 was able to produce more accurate survey readings to the HDS targets placed around the base of the grain silos. The coordinate standard deviation, average change and range was much lower than the results obtained by the Leica ScanStation2. The Leica ScanStation2 while not as accurate was still able to produce comparable results to the Trimble S6. The standard deviation, range and average coordinate difference was larger than the results obtained by the Trimble S6. This was not unexpected as the Trimble S6 had greater accuracy than the Leica ScanStation2. The results showed that the ScanStation2 had more difficulty producing accurate traditional surveying results. This was mainly because unlike the Trimble S6 where the user is able to manually identify and point to the HDS target, the Leica ScanStation2 HDS survey method is fully automated and the user must trust the target recognition software in the scanner.

Overall the comparison between the Trimble S6 and the Leica ScanStation2 was very good. While the Leica ScanStation2 was less accurate the results were still good enough to be able to identify any major deformation or movement in the grain silo.

The diameter differences were, like the coordinate differences, very similar. Both 12D and Cyclone produced very similar grain silo diameters. Both software packages calculated silo diameters of 12.410, ±10mm. This showed that not only was the data collected by both instruments accurate, they both produced similar results in the calculation of a diameter value.

Due to the fact that the silo being surveyed for deformation was used to store grain there was an expectation that little of no deformation or movement in the structure would be detected. This was expectation was met when the results from the Trimble S6 showed over all movement in the silo of <5mm overall. The Leica ScanStation2 data was not expected to produce the same accuracy of the Trimble S6 but its results showed no conclusive evidence of any deformation or movement in either the northern or southern grain silo.

Chapter 6

Conclusions and Recommendations

6.1 Introduction

The aim of this chapter is conclude the results found during the course of this project. These results will relate to the findings of the coordinate differences in both the Trimble S6 and the Leica ScanStation2, the diameter differences for both the Trimble S6 and the Leica ScanStation2 and any deformation found during the survey and scan sessions conducted. The other aim of this chapter is to provide the reader with a summary of results found during this project. It is hoped that upon reading this chapter the reader will have a greater understanding of the results and analysis done in the previous chapters of this project.

To aid in the readers understanding of this chapter it will be divided into two parts; Conclusions and recommendations. The conclusion section will give a summary of the results discussed in chapter 5 and the recommendations section will discuss some of the problems experienced during this project and recommend areas of future research.

6.2 Conclusion

6.2.1 Trimble S6 coordinate differences

The Trimble S6 was expected to provide the most accurate results in the survey of the HDS targets. This proved to be true with the standard deviation of the HDS target coordinate difference being less than 5mm. The reason the Trimble S6 was the most accurate method to conduct the deformation survey was because its distance error was 3mm and 2ppm in direct reflectorless mode. The Trimble S6 also had an angular accuracy of 3’’ in both the horizontal and vertical plane.

6.2.2 Leica ScanStation2 coordinate differences

The Leica ScanStation2 has an accuracy error that was greater than the Trimble S6. The Leica ScanStation2 had a positional error of 6mm and a distance error of 4mm. The angular accuracy is better than the Trimble S6 with an error of 60µrad in both the horizontal and vertical planes. As expected the coordinate differences of the HDS targets were much larger than the Trimble S6. The standard deviation of the coordinate differences was nearly 3 times that of the Trimble S6 standard deviation. While the errors were large than that of the Trimble S6 they were still mostly under ±10 millimetres and still good enough to detect slight changes in the movement of the grain silo.

I believe one of the main reasons that the Leica ScanStation2 produced less accurate results was the target recognition software in the scanner. As seen in the range statistics the scanner was more likely to produce larger more random errors. I believe this was due to the target recognition software producing erroneous results due to weathering of the HDS targets on the grain silo.

6.2.3 Trimble S6 and Leica ScanStation2 coordinate difference comparison.

The coordinate difference between the Trimble S6 and the Leica ScanStation2 was quite large. This was not unexpected due to the fact that the Trimble S6 i9s a more accurate instrument. The coordinate errors were again under ±10mm; this showed that while the Trimble was more accurate the Leica ScanStation2 was capable of capturing survey data at an accuracy that would be acceptable in deformation surveys.

6.2.4 Grain Silo Diameter comparison

The diameter comparison was designed to not only test the accuracy of both instruments in respect to measuring surface points on the grain silo; it was also designed to test the software of each of the instruments. As shown in chapter 5 the differences between the calculated grain silos was minimal with a both silos have a calculated diameter of 12.410 ±10 millimetres. This showed that not only was the survey control network working well; the two software packages were able to produce comparable results. The cyclone scanner software was able to model a cylinder from a point cloud selected around the base near the HDS targets. From the modelled cylinder a radius value was able to be extracted. The 12D model software calculated a circle by least squares from three points. These points were the HDS targets that were surveyed in each survey session. Both methods produced similar diameter value. This showed that both methods were accurate enough to identify any major movements in the grain silo structure.

6.3 Recommendations

The Leica ScanStation2 has many advantages over the Trimble S6. The ScanStation2 is able to perform normal surveying tasks such as traversing, resections and point set out with the added advantage of being able to produce accurate point clouds of objects. As shown in this project while the accuracy was not of a traditional robotic total station it was still good enough to be considered for a deformation survey. The main issue with the Leica ScanStation2 is the output HDS target coordinates and the point cloud. I found that to identify the HDS target coordinates was a tedious process either done in the field with great difficulty or conducted in the office. This involved selecting the HDS target area close to the target centre and then writing down the coordinates by hand. This was in contrast to the 12D software is able to produce tables of selected coordinates.

The cyclone software is able to model large point clouds but I believe that the output of point cloud is still a major issue. For example in this project the point cloud looks wonderful but what the client wants is to know if there is any movement in the grain silos. So in this regard the Trimble S6 is still the best option for conducting this type of work. It was faster to set up the Trimble S6, measure all the HDS targets, do a rough scan and then move onto the next survey control station. I found by timing myself it took me 2 hours to conduct the deformation survey using the Trimble S6 while the Leica ScanStation2 to me 5 hours. This was mainly due to process of adjusting the exposure of the digital photo for the scan. Another major factor in the Leica ScanStation2 was the truck and car ‘noise’ about the silo during the scan session. Noise is excess data inadvertently captured during the scanning process that must be removed back in the office.

A major hindrance for my project was the fact that I could not place any of the HDS targets near the top of the grain silos due to work place health and safety reasons. The results obtained from the base HDS targets proves that if the HDS targets were able to be placed near the top of the silo the same accuracies would be achieved.

I believe that more research and development needs to be done on the Leica Cyclone software. While the scanner is capable of conducting survey tasks the software lags behind in general survey out put such as coordinate table and general presentation for a client.

In conclusion this project met its aim of comparing the accuracy of using a traditional surveying instrument to conduct a deformation survey against using a laser scanner to conduct a deformation survey. The results that were expected were met with the robotic total station being more accurate in the survey of individual survey targets while the laser scanner was able to capture vast amounts of points in a short period of time. Further research and development needs to be conducted to bring laser scanner software up to a standard that is acceptable to surveying standards.

References

Alba M, Fregonese L, Prandi F, Scaioni M, Valgoi P, 2005, Structural Monitoring Of A Large Dam By Terrestrial Laser Scanning, Close Range Sensing: Anaylsis and Applications, Commision 5,Viewed 11 March 2008, < http://www.isprs.org/commission5/proceedings06/paper/1271_Dresden06.pdf.>

Bae K, Lichti D, On-Site Self-Calibration Using Planar Features for Terrestrial Laser Scanners, Viewed 12 April 2008, www.spatial.curtin.edu.au

Behr J.A, Kenneth, Hudnut K.W and King N.E, 1999, Monitoring Structural Deformation at Pacoima Dam California Using Continuous GPS, Seismological Reasearch Letters, Vol. 69, Issue No. 4, pp299-308, Viewed 7 April 2008, < http://pasadena.wr.usgs.gov/office/hudnut/SRL/>

Baker A, Bannister A and Raymond S, 1998, *Surveying*, 7^{th} Edition, Longman Publishing, London

Bellman H.E, 1996, Deterioration of Concrete Tower Silos, Viewed 20 April 2008, www.omafra.gov.on.ca

Bitelli G, Dubbini M, Zanutta A, Terrestrial Laser Scanning and Digital Photogrammetry
Techniques to Monitor Landslide Bodies, Viewed 8 April 2008, http://www.cartesia.org

Boehler W, Marbs A, 2004, Investigating Laser Scanner Accuracy, Viewed 5 April 2008, www.leica-geosystems.com

Bornaz L, Rinaudo F, 2005, Terrestrial Laser Scanner Data Processing, Close Range Sensing: Analysis and applications, Commission 5, Viewed 3 April 2008, http://www.isprs.org/istanbul2004/comm5/papers/608.pdf.

Carson J.W, 2004, Silo Failures: Case Histories and Lessons Learned, Viewed 18 April 2008, www.jenike.com

Chow K, 2007,Engineering Survey Applications of Terrestrial Laser Scanner in Highways Department of the Government of Hong Kong Special Administration Region (HKSAR), Commission 6 – Engineering Surveys, FIG Working Week 2007 / TS 6F – Terrestrial Laser Scanning I [7TS6F], Viewed 5 April 2008, www.fig.net

Code of Practice, 2008, Queensland Board of Surveyors Code of Practice, Viewed 7 April 2008, www.surveyorsbiard.com.au

Deformation Measurement, 2008, Case Studies, Viewed 9-May 2008, www.aamhatch.com

I-Site 4400LR, 2008, I-Site Fact Sheet, Viewed 20 April 2008, www.isite2D.como

Leica HDS6000, A new generation of ultra-high speed laser scanner, 2008, Product brochure, Viewed 2008, www.leica-geosystems.com

Leica HDS6000, A new generation of ultra-high speed laser scanner, 2008, Product Data Sheet, Viewed 9-April 2008, www.leica-geosystems.com

Lichti D.D, Stewart M.P, Tsakiri M, A. J. Snow A.J, 1999, Benchmark Tests on a Three-dimensional Laser Scanning System, Viewed 5 April 2008, www.cage.curtin.edu.au

McLean A.G, 1988, Silo Design: Current and Future, Viewed 13 April 2008, http://search.informit.com.au/documentSummary;subject=Law;dn=666985246371692;res=IELENG

Price W.F and Uren J, 2006, *Surveying for Engineers*, 4th Edition, Palgrave McMillan, London

Roberts G, Hirst L, 2005, Deformation Monitoring and Analysis of Structures Using Laser Scanners, Commission 6 – Engineering Surveys, FIG Working Week 2005 / TS38 – Using Laser Scanning in Engineering Surveys, Viewed 6 April 2008, www.fig.net

Schmid T, Schack-Kirchner H, Hildebrand E, 2005, A Case Study Of Terrestrial Laser Scanning In Erosion Research: Calculation Of Roughness And Volume Balance At A Logged Forest Site,Remote Sensing Applications, Comission 8,Viewed 1 April 2008, www.isprs.org

Tsakiri M, Lichti D, Pfeifer N, 2006, Terrestrial Laser Scanning For Deformation Monitoring, Viewed 9 March 2008, www.spatial.curtin.edu.au

van Gosliga R, Lindenbergh R and Pfeifer N, 2007, Deformation Analysis Of A Bored Tunnel By Means Of Terrestrial Laser Scanning, Viewed 11 March 2008, www.ipf.tuwien.ac.at

Appendix A: Project Specification

Faculty of Engineering and Surveying

ENG 4111 / 4112 Research Project

PROJECT SPECIFICATION

FOR: **Oliver Kelman**

SUPERVISOR: Dr Kevin McDougall / Mr Shane Simmons

TOPIC: Measuring and monitoring of silos using laser scanning and total stations

PROJECT AIM: Use Laser scanning techniques to monitor deformation of Grain Silo structures and to compare the laser scanning results with results obtained by using traditional survey methods. Methods of survey control to obtain the best laser scanning results will also be investigated.

PROGRAMME: **Issue A, 17th of March 2008**

1. Investigate the use of laser scanning to monitor deformation of grain silos.
2. Use survey control methods to obtain the best possible results of the laser scanning.
3. Analyze differences between the laser scanning results and results obtained thorough traditional reflector-less technology using a total station.
4. Academic Dissertation of final results.

Appendix B: Trimble S6 Specifications

Physical

Weight

Instrument	5.25kg
Tribrach	0.7kg
Height	196mm
Internal Battery	0.35kg

Performance

Angular accuracy	3”
Distance accuracy -Standard	±3mm and 2ppm
-DR	±3mm and 2ppm
Range –Standard	2500m (1 prism)
DR	300-400m (concrete)

General Specifications

Light Source	Laser Class 1
Laser point coaxial	Laser Class 2
Beam divergence -Vertical	80mm/100m
-Horizontal	40mm/100m
Operating Temperature	-20℃ to 50℃
Atmospheric Corrections	-135ppm to 160ppm

Appendix C: Leica ScanStation2 Specifications

General

Instrument Type:	Pulsed, dual axis compensator, very high speed laser scanner, with survey grade accuracy, range and field of view.
User Interface:	Notebook or tablet PC
Scanner Drive:	Servo motor
System Performance	
Accuracy of single measurement	
Position:	6mm
Distance:	4mm
Angle (Horizontal / Vertical)	60µrad/60µrad
Target Aqusition:	2mm Standard deviation
Laser Scanning System	
Type:	Pulsed
Range:	300 metres
Scan Rate:	Up to 50,000 points per second
Electrical	
Power supply:	36 V; AC or DC power supply units
Battery type:	Sealed lead acid
Typical duration:	> 6 hours
Power Status:	5 LED indicator bars
Indicators:	Charging status and power levels
Scan Resolution	
Spot size:	0-50 metres, 4mm
Point Spacing:	< 1mm minimum spacing
Maximum sample density:	<1mm
Field of View	

Horizontal:	360 ° (maximum)
Vertical:	270° (maximum)

Environmental

Operating Temp:	0 °C to +40°C
Storage Temp:	-25°C to +65°C
Lighting:	Fully operational between bright sunlight and complete darkeness
Humidity:	Non-condensing
Shock:	40 G's (max to scanner transport case)

Physical

Dimensions:	10.5" × 14.5" × 20"
Weight:	18.5 kg