University of Southern Queensland

Faculty of Engineering and Surveying

# Testing the Accuracy of Machine Guidance in Road Construction

A dissertation submitted by

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In fulfilment of the requirements of

**ENG 4111/4112, Research Project**

towards the degree of

**Bachelor of Spatial Science, Surveying**

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# Abstract

3D Machine Control and Guidance Systems first appeared on the market in the late 1990's. These systems put a small computer within the cab of earthwork machines that utilized Global Positioning System (GPS) satellites to relay position information to the computer (see figure 1.1). The computer evaluates the actual position relative to its location in the proposed model. The operator uses the information from the onboard computer to control the machine's equipment. In advanced cases, the onboard computer can be directly linked to the machine hydraulics, controlling their operation with minimal input from operator.

Automated machine guidance using RTS was the major new application of this advancement in technology. Robotic Total Stations (RTSs) were first introduced by Geodimeter in 1990. These instruments incorporated servomotors and advanced tracking sensors which allowed the instrument to track a target. RTS's are now utilized in the construction and extractive industries for the guidance of major earthworks machinery as well as in agriculture industry for the guidance of machinery such as tractors and harvesters.

In today's world, with the application of RTS, ATSs and now moving into real time AMG.
The accuracies and latency of both operations are still not well understood, it has become critical to understand the exact accuracies that these instruments are capable of achieving whilst operating in the field. Thus upon the completion of this project my aim is to have a better understanding of both operational accuracies of several instruments, as well as their performances.

The working specification in most of road construction are general requires the tolerance of ±0.02m. In order to achieve this tolerance required for such work we need to determine if these technologies are capable of meeting such accuracies.

Upon the completion of this project, we will have a better understanding of how the accuracies of the machine guidance works and under what conditions the contractor, engineers or surveyors can understand the performance of the AMG works better.

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# ENG4111 Research Project Part 1 & ENG4112 Research Project Part 2

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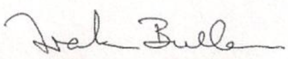

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# CERTIFICATION

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

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

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______________________________
Signature

____28-10-2010_______________
Date

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*University of Southern Queensland*

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## ABBREVIATIONS

TIN – Triangular Irregular Network

RTK – Real time Kinematic

USQ - University of Southern Queeensland

VRS – Virtual reference Station

PC – Personal Computer

GNSS – Global Position System

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PROJECT APPRECIATION

**CHAPTER 1**

# INTRODUCTION

## 1:1 Background of research

Automated Machine Guidance (AMG) is also known as Machine Control (MC). It's a process that uses continually updating measurements from:

- Robotic Total Stations (RTS)
- Real Time Kinetic (RTK) Global Positioning System (GPS)
- Laser System, or
- Sonic System

3D Machine Control and Guidance Systems first appeared on the market in the late 1990's. These systems put a small computer within the cab of earthwork machines that utilized Global Positioning System (GPS) satellites to relay position information to the computer (see figure 1.1). The computer evaluates the actual position relative to its location in the proposed model. The operator uses the information from the onboard computer to control the machine's equipment. In advanced cases, the onboard computer can be directly linked to the machine hydraulics, controlling their operation with minimal input from operator.

***Figure 1.1*: Trimble GCS900 on a Motor Grader with Dual GPS**
(*Trimble, 2010*)

The success 3D Machine control system relies upon several variables, including;

- The ability of the operator to accurately apply the design in the field
- The ability of the owner to approve and review the design
- The quality of proposed construction model.

Automated machine guidance using RTS was the major new application of this advancement in technology. Robotic Total Stations (RTSs) were first introduced by Geodimeter in 1990. These instruments incorporated servomotors and advanced tracking sensors which allowed the instrument to track a target. RTS's are now utilized in the construction and extractive industries for the guidance of major earthworks machinery as well as in agriculture industry for the guidance of machinery such as tractors and harvesters.

The accuracies and latency of both operations are still not well understood, it has become critical to understand the exact accuracies that these instruments are capable of achieving whilst operating in the field. Thus upon the completion of this project my aim is to have a better understanding of both operational accuracies of several instruments, as well as their performances.

## 1.2 Aims

The Aim of this project is to test the accuracy and reliability of Machine Guidance when used in Road construction.

## 1.3 Objectives

1. Research the background information in relation to Machine Guidance

2. Review existing literature concerned Real time and conventional or traditional guidance systems (ATS, RTSs).

3. Establish and conduct a series of testing under various conditions.

4. Undertaking analysis of test results, and

5. Determining the final accuracies of machine guidance systems.

## 1.4 Justification

In today's world, with the application of RTS, ATSs and now moving into real time AMG.
The accuracies and latency of both operations are still not well understood, it has become critical to understand the exact accuracies that these instruments are capable of achieving whilst operating in the field.

The working specification in most of road construction are general requires the tolerance of ±0.02m. In order to achieve this tolerance required for such work we need to determine if these technologies are capable of meeting such accuracies.

There will be some conditions to be achieved to meet the accuracies requirements. Such conditions are:

- Distances for ATS, RTS
- Angles for ATS, RTS
- Speed of moving targets
- Environmental obstruction on prism locks.
- Number of satellites –RTK GPS
- Environmental obstruction on GPS returning false answer
- GPS precision

Upon the completion of this project, we will have a better understanding of how the accuracies of the machine guidance works and under what conditions the contractor, engineers or surveyors can understand the performance of the AMG works better.

## 1.5 Overview of Dissertation

The brief overview of each chapter contained in the dissertation is provided below.

Chapter 2 will be mainly used for providing conclusion and comparison with the relevant or similar research which was investigated by any other part. It does this by providing the following information:

1. Research the background information in relation to Machine Guidance

2. Review existing literature concerning Real time and conventional or traditional guidance systems (ATS, RTSs), and comment on previous test undertaken.

3. Establish and conduct a series of testing, analyse the result and determining the final accuracies of machine guidance systems.

Chapter 3 provides detailed information into both the testing regime which has been implemented and the data analysis methodology.

Chapter 4 will provide analysis and discussion concerning the results obtained on chapter 3.

Chapter 5 is where the conclusion will be drawn and recommendations will be presented.

CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

In order to provide some background into the operations of Automated machine guidance, I would like to describe briefly the mechanical workings of various forms of AMG, two or three of them will be tested. These instruments or machines are Trimble ATS 5600 and ATS 600 TCS2 Total stations, GCS900 Universal Total Stations, Trimble GCS600 and GCS900: Dual or single GPS + GLONASS. Topcon's 3D-Millimeter GPS+, Millimeter GPS for paving. (See Figure 2):

TRIMBLE INSTRUMENTS

***Figure 2.2:*** **Trimble ATS 600**

***Figure 2.1:*** **the new Trimble SPS630, SPS730 and SPS930 Universal Total Stations**

***Figure 2.3:*** **Trimble Control Unit**

***Figure 2.4:*** **Trimble GCS900 on a Dozer with Single GPS and Laser Augmentation**

TOPCON INSTRUMENTS

*Figure 2.5:* **3D-MILLIMETER GPS+**

*Figure 2.6:* **MILLIMETER GPS FOR PAVING**

*Figure 2.7:* **LPS-900**

*Figure 2.8:* **Topcon Control Unit**

Throughout history, the construction industry has evolved and become more efficient as a result of technology. Frequently, engineers, surveyors are required to accommodate these new innovative construction techniques in their design. Construction techniques have changed by so much over the past 150 years including the use of network of satellites circling the earth providing real time position information. The advantage of these innovative technologies is for completion of projects in a more efficient manner. Efficiency reduces cost and schedule duration.

It believed to be one of the newest and fastest growing technology in the construction industry is Machine control and guidance systems.

### 2.1.1 Overview of Machine Control

Various forms of machine control have been around since the late twentieth century, using relevant forms of technology. The first systems relied on hydraulic valves following string lines, and subsequently lasers, for control. The technology trend is to make machine more "intelligent" providing abundant and more easily understood information to the operator. These procedures, though always improving overall efficiency, had the distinct disadvantage that they were heavily reliant upon manual survey methods. Surveyors were usually on site daily placing pegs/stakes and establishing cut and fills information using those pegs. A hard copy, hand calculated sheet was given to the crew foreman to complete the work. These technologies required someone to interpret the plans in order for construction to occur.

Automated machine guidance (AMG) links sophisticated design software with construction equipment to direct the operation of the machinery with a high level of precision, improving the speed and accuracy of the construction process. Because AMG eliminates much of the guesswork, manual control, and labour involved in traditional methods, it improves workers safety and saves agencies and contractor's time and money, enhancing their ability to deliver construction projects better, faster, and cheaper. This technology has the potential to improve the overall quality and efficiency of transportation project construction.

The second stage of the literature review will be to examine and discuss all literature relating to the testing of automated machine guidance. This will follow in conjunction with the Testing results.

## 2.2 Real Time Kinematic (RTK), Global Positioning System - GPS

**2.2.1 RTK GPS surveying** is the process of determining and recording three-dimensional coordinates of unknown points using an RTK GPS system (i.e. instrumentation and software/firmware) RTK GPS systems comprise a reference receiver and antenna set up over a point whose three dimensional coordinates (geodetic latitude, longitude and ellipsoidal height) are known with respect to a geocentric datum. The reference receiver whose antenna is situated above an unknown point. The coordinates of the unknown point, and associated internal quality indicator, are computed in 'real time' by the roving receiver and recorded by some form of data logging device.

**2.2.2 RTK receivers** are implicitly of geodetic quality and use dual-frequency carrier phase measurements as the primary GPS observables to compute positions. Fundamentally, RTK GPS systems measure the three-dimensional vector (nominally in the WGS84 geocentric Cartesian coordinate system) from the reference station to the unknown point. The computed three dimensional vectors are added to the three-dimensional coordinates of the reference station to the unknown station. Therefore, the determined position of the unknown station is dependent on:

a) The accuracy of the coordinates of the reference station;
b) The accuracy of the computed three-dimensional vector.

The coordinates of the unknown station can be transformed to any local geodetic datum; provided that the transformation parameters are known. These parameters must be input to the RTK GPS system in order to perform a 'real-time' transformation, or applied at a post-processing stage. (*Source; Department of spatial Sciences, Curtin University 2010*)

### 2.2.3 Radio Signals

RTK GPS Computes its position based on radio signals received from satellites in orbit around the earth in relation to a correction signal transmitted from a known positions on the earth. This is why we have a base unit set on a known station and a rover unit installed on the machine.

RTK GPS also requires that we have a direct radio communication link between the base and the rover. Often times this is an internal radio, but can externals as well. *(John Dillingham, P.E. USA)*

### 2.2.4 (VRS) GPS

It is kind of RTK which, in general can be called virtual Reference Station (VRS). GPS VRS is not widely used in construction, but is being tested. At first glance VRS appears that a single GPS unit is being used, but in reality, there is a base located off site that is transmitting the correction via an internet link. The most important thing is that all GPS, no matter what kind of process we are using requires a base unit and rover unit.

**2.2.5 Laser Augmented RTK GPS**. There are laser Augmented Systems (on blade) that are solid based on their ability to increase the vertical precision of RTK GPS.

- These new units must be tested by establishing known elevations with procedures that are trusted by a spatial scientist on specific points, such as points (controls) used by a stakeout personally.
- It's important to know the manufacturers specifications, accuracies and procedure to attain that accuracy during testing the survey control. Control points at the furthest distance (working distance) must also be checked.

### 2.2.6 Accuracy.

As a rule of thumb the horizontal precision of RTK is ± 10 mm and the vertical precision is ± 0. 30mm.

● Horizontal precision which stated as 10mm + 1ppm means that for any measurement we make, the precision is 10mm (for the base) and horizontally, and

● Vertical precision which stated as 15mm + 1ppm means that for any measurement we make, the precision is 15mm (for the base) and 15mm (for the rover) which add up to 30mm vertically. The manufacturer will not guarantee any measurement is more precise than the stated precision.

- ppm is part per million based on the distance from the base to the rover ppm precision is insignificant for most distances used in construction. The ppm error for 1 mile equals to 0.0053' +/: This would be added to the horizontal or vertical precision.

### 2.2.7 How good is RTK GPS?

In the table below, the most recent RTK specifications for four leading manufactures are given. Information is quoted for the 'best' dual frequency RTK systems on offer from the latest available data the manufactures. All comments below are quoted verbatim from manufacturer's information sheets. (*See figure 2.9*)

The problem with RTK GPS is that perfect observing conditions rarely occur in practice. Many variables can affect performance and it is the role of spatial scientist to minimise the negative effect of any of these variables by good survey practise.

In terms of the accuracy actually achieved in real life survey, the above specifications aren't much help, because the qualifiers added by the manufactures mean that the conditions necessary to meet the above specifications rarely occur in practice. However, these performance specifications can be used as a basis for deciding if it possible to achieve job specifications using RTK GPS.

Table 2.1

| manufacturer | Performance specifications | Baseline length | On-the-fly initialisation | Other comments |
|---|---|---|---|---|
| Ashtech | *While moving (rms)*<br>Horizontal 3cm + 2ppm<br>Vertical 5cm + 2ppm<br>*2 second static occupation (rms)*<br>Horizontal 1cm + 2ppm<br>Vertical 1.7cm + 2ppm<br>*Sub centimeter accuracy with longer occupation time* | Recommended <10km<br><br>Maximum: 40km | >99.9% reliability.<br><br>Initialisation times as short as 30 seconds following acquisition of 8 satellites | Accuracies assume miminum of 5 satellites, following procedures recommended in the product manual. High multipath areas, high PDOP values, and periods of high-activity atmospheric conditions will degrade accuracy. |
| Dassault-Sercel | Accuracy 2-3cm | Up to 50km (in open space) | | |
| Leica | Kinematic 10mm + 2ppm rms (position) | Typically up to 10km in normal conditions with standard radio. Over 10km in favourable conditions with a powerful radio | Typically 30 secs with 5 or more satellites on L1 or L2. | Baseline rms, accuracy in position and accuracy in height are dependent upon various factors including number of satellites, geometry, observation time, ephemeris accuracy, ionospheric conditions, multipath etc. Figures quoted assume normal to favourable conditions. Times can also not be quoted exactly. Time required are dependent on various factors including number of satellites etc… |
| Topcon (Javad) | Kinematic 10mm + 1.5ppm | | | |
| Trimble | Accuracy<br>Horizontal ±1cm + 1ppm<br>Vertical ±2cm + 1ppm<br><br>Performance specifications are RMS. | Range varies depending on radios used, local terrain and operating conditions. | >99.9% reliability.<br>< 1 minute<br>< 10 seconds (typical for known points) | Performance criteria are a function of the number of satellites visible, occupation time, observation conditions, baseline length and environmental effects, and are based on favorable atmospheric conditions. Assumes five satelliters (minimum) tracked continuously with the recommebded antenna using the recommended static surveying procedures….. |

*Manufacturer RTK Equipment Specifications*
(*Source; Department of spatial Sciences, Curtin University 2010*)

## 2.3 Trimble GCS500 and 600 Grade Control System Cross Slope Control

### 2.3.1 GCS500 Grade Control System Cross Slope Control

The GCS500 Grade Control System is a cross-slope control system designed to be used on motor graders for fine grading work. The system uses two AS400 angle sensors and one RS400 rotational sensor to calculate the cross slope of the blade. The system lets the operator select which side of the blade is controlled, and switch sides on the return pass. The highly flexible AS400 has 100% slope capability, making the system ideal for a wide range of applications, including cutting road slopes, ditches and embankments.

The software with a powerful range of features specifically designed for cross-slope and blade elevation on motor graders will be provided when using CB420 Control Box with the combination of GC500. The GCS500 can be upgraded to a GCS600 for cross-slope elevation control. The applications for GCS500 are for the Road Maintenance, Road Construction, Sports Fields, Embankments, and Road Ditches. *(Trimble, 2010).*

### 2.3.2 GCS600 Grade Control System Cross-Slope and Elevation Control

The GCS600 Grade Control System is a highly flexible, cross slope and elevation control system designed to be used on motor graders for fine grading work. The GCS600 uses two AS400 angle sensors and one RS400 rotational sensor to calculate the cross slope of either side of the blade, as well as an LR410 Laser receiver and ST400 Sonic Tracer to provide elevation control. Using the ST300, the system allows stringline, previous pass, or curb and gutter tracing. Using one or two LR410 laser receivers, you can use the system for fine grading plane surfaces. The GCS600 system is ideal for applications with tight tolerances and finished grade work. The application for GCS600 are for the; Small-to-Large Housing and Building Site Pads, Road Construction, Highway Construction and Maintenance, Runways, Embankments and road ditches *(Trimble, 2010).*

#### 2.3.2.1 Trimble ST400 Sonic Tracer

The Trimble ST400 Sonic Tracer uses ultra sonic signals to maintain a set distance or elevation from an object, a design surface, or the ground.

When mounted to a motor grader or dozer blade, the ST400 can be used to reference a string line, curb and gutter, or previous pass as a grade control reference.

The Trimble ST400 Sonic Tracer offers heavy and highway contractors:

- **Multicolored integrated grade display** - conveys clear grade feedback to the machine operator for higher productivity
- **Selectable sensor accuracy** - provides typical accuracy of +/- 1mm (0.04") to control elevation for even the tightest jobsite specifications

The ST400 Sonic Tracer can be used in single or dual configuration and is compatible with Trimble GCS300, GCS400, GCS600, and GCS900 Control Systems.


Figure 2.10, *(Trimble, 2010)*

# 2.4 Leica TPS 1200

**2.4.1 Introduction** Leica TPS 1200 total stations are built up for speed, accuracy, ease to use and reliability. It's better and more efficiently than ever before and they combine perfectly with GPS and the position can be calculated in the real time.

TPS and GPS have the same operation and they are very user friendly. They have similar format and data management systems, and cards can be transferred from one to the other and work in the same way. It's also accommodated with software package for visualization, conversions, quality control, processing, adjustment, reporting and export.

## 2:4:2 Power search (PS)

Power Search used during complete loss of lock due to obstructions; fast rotating laser fan finds reflector quickly and ATR fine Points. In lock mode TPS 1200 remains locked onto the reflector and follow it as it moves. Measurements can be taken at any time and, as software predicts reflector movements, TPS 1200 continues to track inspite of obstructions and short interruptions. *(Source: Leica Geosystems, 2010)*

| PowerSearch (PS) | | |
|---|---|---|
| **Range** | Round prism (GPR1): | 200 m |
| (average atmospheric conditions) | 360° reflector (GRZ4): | 200 m (perfectly aligned to instrument) |
| | Mini prism (GMP101): | 100 m |
| | Shortest distance: | 5 m |
| **Search time** | Typical search time: | < 10 s |
| **Maximum speed** | Rotating speed: | 45° / s |
| **Method** | Digital signal processing (rotating laser fan) | |

Table 2.2; PS specifications (*Source: Leica Geosystems, 2010)*

### 2:4:3 Angles

The TPS 1200's angle measurement system consists of a static line-coded glass circle, which is ready by a linear CCD array. A special algorithm is then used to determine the exact position of the code lines on the array and thus determine the precise angle measurement.

Angle measurement system operates continuously providing instant horizontal and vertical circle readings that are automatically connected for any "out of level" by a centrally located twin axis or dual axis compensator.

The compensator consists of an illuminated the pattern on a prism, which reflected twice by a liquid mirror. These form the reference horizon. The reflected image of this line pattern is read by a linear CCD array and then used to mathematically determine both of the tilt components. These calculated tilt components are the used to correct all angle measurements in real time.

**Table 2.3 TPS 1200 Series angle Accuracies (STD Dev)**

| | TPS 1201 | TPS 1202 | TPS 1203 | TPS 1205 |
|---|---|---|---|---|
| **Accuracy(Std dev)** | | | | |
| Hz, V: | 1'' | 2'' | 3'' | 5'' |
| Display resolution | 0.1'' | 0.1'' | 0.1'' | 0.1'' |
| **Method** | Absolute, continuous. | | | |
| **Compensator** | | | | |
| Working Range: | 4' | 4' | '4' | 4' |
| Setting Accuracy: | 0.5'' | 0.5'' | 1.0'' | 1.5'' |

### 2.4.4 Distance measurement.

TPS 1200 has three measuring modes which are:

1. Infrared laser measurement mode IR
2. Visible red laser measurement mode RL
3. Long range visible red laser measurement mode LO

The TPS 1200 series utilizes a phase shift measurement technique (EDM), which operates in both the reflector and reflectorless modes.

The EDM works by transmitting an invisible bean (100 MHZ modulated frequency), the beam is then reflected back by the target or prism. Photo receiver and converted into an electrical signal. Once this electrical signal is digitized and accumulated, the distance is then determined via standard phase measurement techniques.

**Table 2.4 TPS Distance measurements with (IR mode) prisms-reflectors**.

| **EDM measuring program** | Standard deviation Standard prism | Standard deviation Tape(targets) | Measurement Time, typical [s] |
|---|---|---|---|
| Standard | 2mm + 2ppm | 5mm + 2ppm | 1.5 |
| Fast | 5mm + 2ppm | 5mm + 2ppm 2’’ | 0.8 |
| Tracking | 5mm + 2ppm | 5mm + 2ppm | <0.8 |
| Averaging | 2mm + 2ppm | 5mm + 2ppm | - |

*(Source: Leica Geosystems, 2010)*

During the measurements, there may be beam interruptions, severe heat shimmer and moving objects within the beam path can result in deviations of the specified accuracy. The display resolution is 0.1mm.

### 2.4.5 ATR

Leica refers ATR as “Automatic Target Recognition” ATR/LOCK. It actively follows the prism as it moves and automatic fine pointing to prism.

The accuracy with which the position of the prism can be determined with automatic Target Recognition (ATR) depends on several factors such as internal ATR accuracy, instrument angle accuracy, prism type, selected EDM measuring program and external measuring conditions. The ATR has a basic standard deviation level of + 2mm. Above a certain distance, the instrument angle accuracy predominates and takes over the standard deviation of the ATR.

The following graph shows the ATR standard deviation based on two different prism types distance and instrument accuracies.

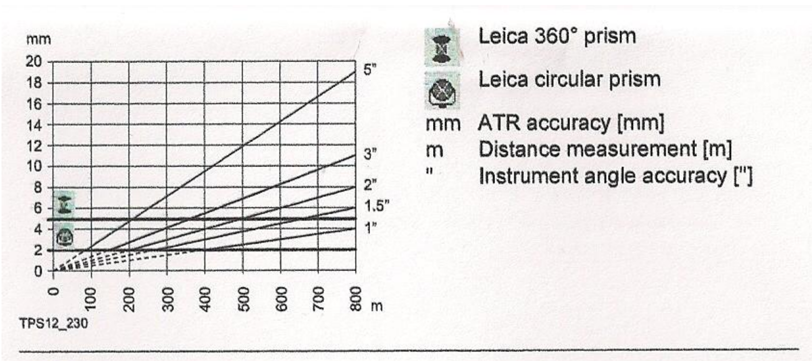



Table 2.5; (*Source: Leica Geosystems, 2010)*

*LEICA ATR Specifications*

| Automatic Target Recognition (ATR) | | |
|---|---|---|
| **Range ATR mode / LOCK mode** | Round prism (GPR1): | 1000 m / 800 m |
| (average atmospheric conditions) | 360° reflector (GRZ4): | 600 m / 500 m |
| | Mini prism (GMP101): | 500 m / 400 m |
| | Reflective tape (60 mm x 60mm): | 55 m (175 ft) |
| | Shortest measurable distance: | 1.5 m / 5 m |
| **Accuracy / Measurement time** | Positioning accuracy: | ‹ 2 mm |
| | Measurement time: | 3 – 4 s |
| **Maximum speed (LOCK mode)** | Tangential (standard mode): | 5 m / s at 20 m, 25 m / s at 100 m |
| | Radial (tracking mode): | 4 m / s |
| **Method** | Digital image processing (laser beam) | |

Table 2.6; (*Source: Leica Geosystems, 2010)*

### 2.4.6 Servo Drive.

The TPS1200 is driven by servomotors mechanically. These servomotors' are used to rotate both horizontal and vertical axis. The downside of these motors is that they use a lot more power than Mag Drive technology and they are only able to rotate at a fraction of the speeds.

## 2.5 Trimble 5600 (ATS) Total station

### 2.5.1 ATS (Advanced Tracking Sensor)

The Trimble ATS is a dual mode instrument founded on Geodimeter technology, which allows increasing productivity on site.

Automatically lock on the active target and continuously measures the target's position and transmits the data to the computer, which then determines the desired elevation and slope for that position (Trimble Data sheet, 2004).

The Trimble ATS starts with the foundation of the Trimble 5600 Total Stations and has enhanced features for high performance automatic machine tracking. In advanced tracking mode for machine tracking. In advanced tracking mode for machine control, the ATS combines with on machine controllers and operator display to guide and control machinery and vessels performing construction tasks- without need for stakes in the ground. The ATS also drives a machine control system, which allows an operator to work single handed with all design and cut/full information right in the cab.

It's designed specifically for the high speed, low latency demands of machine control; the ATS in Advance tracking made has a latency of less than 200 Kms and selectable output rate between 1 and 6HZ. Angle and distance data from the instrument are synchronized, providing a machine with precise, up to date information, increasing the accuracy and speed at which a machine works.

This low level of latency combined with the instruments turning speed enable the ATS to track a machine driving as close as 30m at a speed of 46 kph without losing a lock *(Trimble 2010)*

The instrument has built in search intelligence to locate the target if contact is temporarily interrupted by, for example, a passing vehicle. The programmable target recognition capability of ATS allows operation of several Instruments on the same site without signal interference. It can recognize one out of active targets, providing freedom to operate four machines or surveys in the same part of the construction site without radio or reflective surface interference. (Trimble 2010)

As a part of the Blade pro ® 3D grade control system, the Trimble ATS robotic total Station provides precise vertical positioning – accurate to ± 5 mm making it ideal for finished grade work. The system also gives the machine operator full control over the earth works on a site. It was display screen in the machine cab that shows the exact 3d position of the blade in relation to the design at the time.

In addition, value sensors can be added for fully automatic machine control. The slope and elevation of the blade are therefore controlled by the system, not by the machine operator reducing errors and avoiding expensive re-work.

**2.5.2 Synchronization** of data from angle and distance measurements sensors means that the output data is computed for a single instantaneous location of the moving machines compared with the standard total station instruments that are optimized for static prism measurement. This results in higher 3D position accuracy for dynamic measurements or machine tracking applications. *(Source; Trimble 2010).*

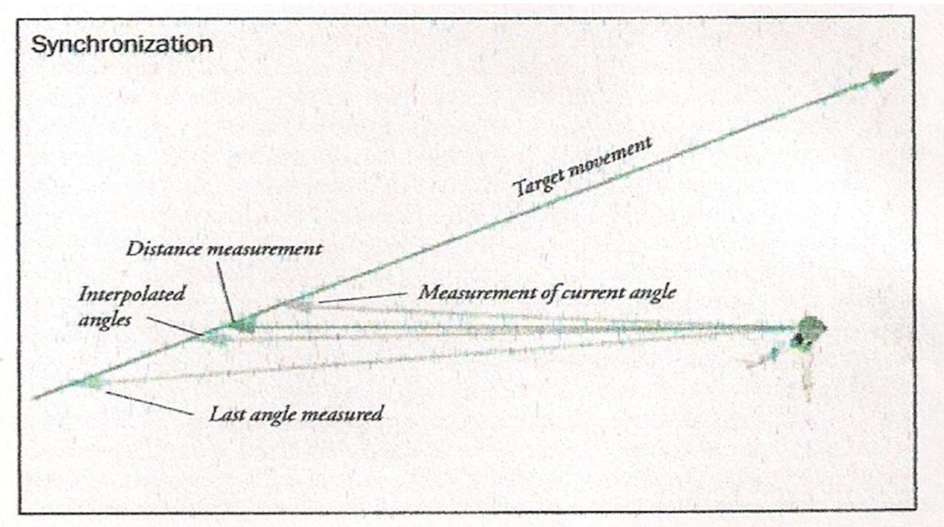
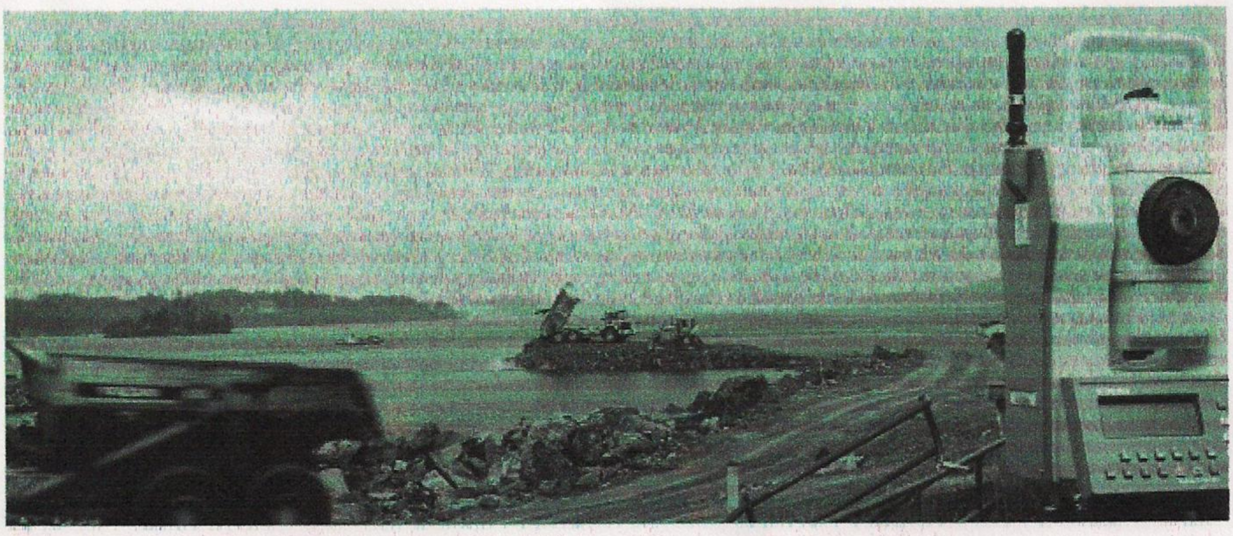



Figure 2.11, Synchronization; (*Source: Trimble, 2010)*

### 2.5.3 Latency

The precise position of the machine at any given times is dependent on the age or latency of the positioning data received. If the age of the data is small and specific, the on board application software can compensate for the errors associated with the data age giving a more accurate location of the machine in real time.



*Notes:*
*** Dependent on selected search window.*
**** The accuracy stated is valid for a static target or a target moving at constant speed. During acceleration or retardation, or a target moving with high speed >15 kph (9.3 mph) the accuracy will decrease.*

Figure 2.12; (*Source:* (*Source: Trimble, 2010)*

### 2.5.4 Servo controls.

The Trimble 5600 series Instruments are equipped with servo controlled motors for positioning of the unit. The servo is in use when performing a number of different operations, when turning the motion knobs, when positioning with the servo control keys, for automatic test and calibration or when using the tracker robotic surveying.

Trimble 5600 series (servo) instrument is equipment with an optional Tracker unit which can perform Surveying tasks using the Auto lock function, and if the instrument is upgraded with a radio, a spatial scientist will be able to perform Robot Surveying in conjunctions with RMT.

**2.5.5 RMT Super Multi Channel** consists of a prism ring with seven 1’’ prisms and an RMT with a set of active diodes forming a full 360 degree circle. It can be used for distance up to 1000m. The RMT can be set to four different target channel IDs. The RMT SUPER Multi channel has been developed for dynamic operation with the Trimble ATS Instruments.

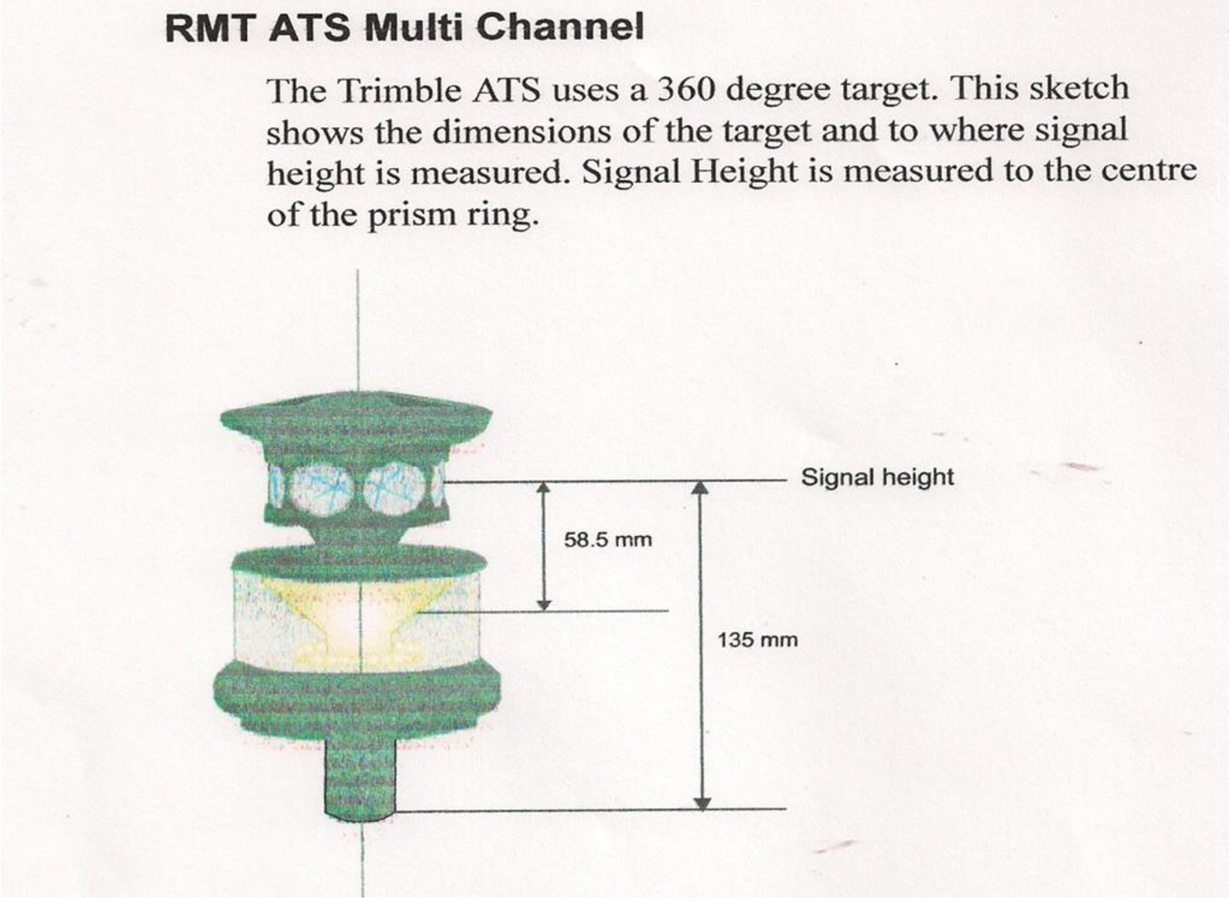



Figure 2.13, RMT ATS Multi Channel; (*Source: Leica Geosystems, 2010)*

The RMT ATS multi channel is designed for operation at distances up to 1000 m (700m in Robotic and ATS Modes). In dynamic operation at distances less than 3m, signal to distance meter may be lost depending on the rotation of the prism ring in relation to the instrument. At distance 3m up to 8m there may be an error in slope distance of up to 15mm at 3m and decreasing as the distance increases.

### 2.5.6 Distance meter Calibration.

In order to achieve as high accuracy as possible the distance meter should be calibrated regularly by application software. These distance meter will be seen as loss of signal for up to two seconds.

### 2.5.7 Auto-Search

The Trimble ATS has built in automatic search capability that is activated automatically if the signal is lost when the system is running in machine control mode. This system has to be activated by the application software in order to work as intended. If the auto search is active then it will search for the target. When the target is lost the system will search within the search sector (window) with a number of horizontal scans at the vertical angle where the signal was lost. The number of scans is set to five by default but the application software may exclude them or set any number of scans up to 50 or maximum two minutes.

If the target is not found during these horizontal scans then a spiral search will start controlled by software application. If no target is found then the Trimble ATS will return to the position where the signal was lost and report to the application software that no target was found.

### 2.5.8 Distance

The distance module of Trimble 5600 series operates within the infrared area of the electromagnetic spectrum. It transmits an infrared light beam. The reflected high beam is received by the instrument and, with the help of a comparator, the phase delay between transmitted a received signal is measured. The time measurement of the phase delay is converted and displayed a distance with the mm accuracy.

### 2.5.9 Angle measurement System.

The Trimble 5600s meets all demands for efficient and accurate angle measurement. The angle method gives a full compensation for the following:

- Automatic correction for angle sensor errors.
- Automatic correction for collimation error and Trunion Axis Tilt.
- Automatic correction for tracker collimation error.
- Arithmetic averaging for elimination of pointing errors.

The electronic angle measurement system, which eliminates the angle errors that normally occur in conventional theodolites. The principal of measurement based on reading an integrated signal over the whole surface of the angle sensor and producing a mean angular value. In this way, inaccuracies due to eccentricity and graduation are eliminated.

### 2.5.10 Dual Axis Compensator

The instrument is also equipped with a dual axis compensator which will automatically correct both horizontal and vertical angles for any deviations in the plumb line. The system warns immediately of any deviation in excess of ± 10 c (6’).

### 2.5.11 Collimation Errors

Horizontal and vertical collimation of the instrument can be quickly measured and stored by carrying out a simple pre-measurement test procedure. All angles measured thereafter are automatically corrected. These collimation correction factors remain in the internal memory until they are measured again.

### 2.5.12 Trunion axis Tilt

It is also possible to measure and store angular imperfections of the horizontal tilt axis relative to the horizontal axis during the same pre-measurement test procedure. These tests are usual carried:

- Immediately prior to high precision angle measurement.
- After transport where hard handling may have occurred.
- When temperature differs by >10C from the previous application

## 2.6 Previous Tests Undertaken

There has been a very little testing besides the manufactures testing (specifications) in relation to the dynamic accuracy of ATS, RTS and RTK GPS latencies.

Some previous tests carried out in order to ‘‘determine the dynamic accuracy and reliability of RTSs” were carried out by:

- Ceryova in 2002
- Chua in 2004, and
- Dennis Garget 2005

Other testing for RTK GPS latency were done and described in the following pages.

### 2.6.1 – Chua 2004.

Chua used the Trimble 5603 to perform the following testing:

*Simple testing of a fixed circular path with various speeds*. He used a bar with a known radius and the distance between the RTS and pillar was fixed. The bar (prism) was then rotated in a circular path at a very low speed whilst the RTS stored dynamic measurements directly to a PC.

*Straight line testing*: He set up a prism on a fixed bench and moved the prism horizontally along the bench. Using a CAD package, he determined that would be necessary to smooth his results using the Kalman Filter. He then used the filtered results to produce final outputs which he then used to draw his conclusion.

He concluded that; the reliability of RTS is greatly related to the speeds of the prism and measurement distances (Chua, 2004). Furthermore, Chua elaborated that the dynamic accuracy of an RTS is better at longer distances than at shorter distances.

He also attributes much of the results deviation to the shape of the prism, and that the tracked reflected reading is not always a true indication of the centre of prism. This consequently results in point positioning errors.

### 2.6.2 Ceryova 2002

Ceryova performed two separate tests similar to Chua except he utilized several different types of RTS in order to obtain his result. The instruments used were Leica TCA 1800, Leica TCRA 1101, and Zeiss Elta s10.

Fixed circular path test: He used a simulator for testing sensors of the circular path measurement systems. The main arm would rotate in a horizontal plane and at the end of the arm was a fixed measuring board that would rotate in the opposite direction to the spinning arm. Measurement board and prism were always facing the observer. The platform was rotated through a 0.5m radius at several speeds. The resulting measurements were then stored to a pc.

Straight line test: He incised a line with an accuracy of o.1mm) into the middle of the metal block. They then observed measurements from three separate stations all with different relationships to this line (i.e. distance and angle)

He concluded that, as the speed of rotation increased the subsequent point deviation also increased. He suggested that ‘‘measurement of the cinematic target is influenced by a certain systematic influence which is probably a result of the time slide between angular and length measurement’’

Ceryora also went further and suggest that by increasing the speed of rotation you are also increasing the mean error in the RTS automated pointing system.

### 2.6.3 Dennis Garget.

Garget performed tow similar tests which was previously done by Chua and Ceryova the only difference is that, he extended the straight line for various speeds testing.

1. Fixed circular path testing at various speeds.
2. Extended straight line testing at various speeds.

This testing was performed at several target distance and at several target speeds.

### 2.6.4 Conclusion.

There are some distinct similarities between the results obtained by Chua, Ceryova and Garget was all parties concluded that the overall accuracy of an RTS is dependent on two main factors:

1. The speed of moving target: and
2. the distance from the RTS to the target. They also concluded that, the dynamic accuracy of an RTS is improved as the target distance is increased.

They also concluded that, the dynamic accuracy of an RTS is improved as the target distance is increased.

Furthermore, Garget concluded that both the accuracy and reliability of a given instrument is further influenced by the speed at which an instrument is capable of reading distance measurements. This is evident by the fact that the Leica instrument is far more accurate and reliable than the Trimble instrument. This can be attributed to the fact that the Leica instrument is quoted to read distance in generally <0.15 seconds, this opposed to the Trimble instrument which is quoted to read distance in around 0.4 seconds. This significant difference in distance measurement time increases the point latency present within the instrument quite significantly. As a result the Trimble is far less accurate and reliable when compared to the Leica(Garget,  2005)

## 2.7 RTK GPS latency in Dynamic Environment

The use of machine guidance is becoming so popular in small and large civil construction sites. Latency is one of the primary factors presently affecting the suitability of the AMG. In order to achieve the specific requirement of the AMG, the user's operators have a requirement to know how responsive the guidance system is to changes in their spatial location on the work site.

- Latency in general may be defined simply as a measure of temporal delay *(MM Internet, 1999);* or
- (latency is the ) "Time taken to deliver a packet (of data) from the source to the receiver. Includes propagation delay (the time taken for the electrical or optical signals to travel the distance between the two points) and processing delay" *(Interoute,2005)*
- *(Raymond,2005)* defines latency as the delay between the time of fix and when it is available to the use" Hence if the GPS is in motion, the platform on which the measurements are being made will move some distance during the time when the measurement is made and the time when it is available to the user.

Latency may be divided into two component described as internal processing latency and transmission latency.

Internal latency is that quantity of time which the instrument takes to complete its internal processes and present the data ready for use or transmission. Transmission latency is the period of time to send the measurement data from the originating source to the user, in the field *(Bouvet et al, 2000)*

Given that position error due to latency is a function of the update rate (total latency) and velocity of the vehicle *(Campbell, Carney and Kantowitz, 1998)*, then for any given latency period, the dynamic platform position error will increase in a proportion with the platform speed.

The following relates to hydrographic measurements (sounding equipments as an external sensor) using GPS. Time lag latency can be experienced between when a sensor record is measured and when it is recorded by the software. Similarly, a time lag (Latency) may be experienced between when a GPS position is measured and when is recorded.

Most importantly, these two time lags may not be the same, and consequently the GPS logged position may not be exactly the same location as the depth sensor when the hydrographic data is logged. *(Gibbings and O'Dempsey, 2005).*

Previous studies to investigate the effects of latency in GPS measurements have been completed. (Smith and Thomson,2003) outlined a method to evaluate GPS position latency in the guidance system of an agricultural aircraft. The method involved reflecting a beam of sun light vertically from the ground using two mirrors.

A photo–detector circuit under the wing triggered an extra data record to be inserted into the GPS data log. This position could then be compared with the known position of the light beam to determine position latency.

The resulting latency determination of less than 9 metres for all runs of testing. The error is relatively small if you compare with an aircraft was travelling at 58 meters per second (around 208.8km/h). The authors also report a high level of consistency in their findings, stating that the differences in consecutive runs were all less than 0.7 meters (7.77% of the error distance due to latency). The use of an optional sensor is seen as a very accurate means of referencing the dynamic measurements back to the fixed frame of reference and has therefore been adopted for this research project also.

## 2.8 Trimble ATS Evolution.

In early 1995, the first tests were performed for a machine control operation using a standard optical robotic total operation Geodimeter 4400. Immediate test results indicate that, for kinetic operations compared to standard surveying applications, the instrument had to improve the way it measured and sent data to the control computer. Specifically, higher output rate of measurement and synchronized angle and distance reading were required.

Standard total stations are optimized for static prism measurement; in contrast, synchronization of data from the angle and distance measurement sensors allows output data to be computed for a single instantaneous location of the moving machine. This results in higher 3D position accuracy for dynamic measurements or machine tracking application.

Synchronization is a measure of how closely together in time the various polar coordinated that form the data pocket are measured. If the data is not synchronized, the sensor gives an incorrect position. The size of the error depends on how far apart in time the various components (angle and slope distance) are measured, and the speed and direction of the moving target.

Low latency for complete transmission the precise position of the machine at any given time depends on the age or latency of the positioning data received, if the age of the data is recent and specific.

### 2.8.2 3D Positioning Accuracy.

Total 3D positioning 3D positioning accuracy for the system is less than 2mm at 200mm. The superior accuracy is based on the high accuracy specifications of a motorized, self tracking and prism that follows the total station with an extremely precise angle reading system, accurate in both. Horizontal and vertical to 1 arc second (o.3 mgon). Additionally, the distance measured provides an accuracy of ±2 mm + 14ppm.

## CHAPTER 3

# RESEARCH APPROACH AND METHODOLOGY

## 3.1 Introduction

As previous described, the aim of this project is to test the accuracy and reliability of machine Guidance when used in road construction. In order to achieve the objectives associated with fulfilling this aim the following steps will need to be performed.

Field – Testing:

Creating the computer modal and give to the grader operator and start trimming on section of the road of approximately 200-300m. Two layers will be tested and each layer had an independent check following the approximately 50m intervals observed and checked by the operator reading on his onboard screen and the surveyor by using a Leica Total station. The testing procedure will also be explained in the following chapters.

The grader operator will be laying his blade on the ground on top of a piece of timber, he/ she will be checking the level by reading on the screen and will be recorded manual, at the same time the surveyor will be holding on the same position and the results will be recorded directly to the internal memory. The raw data will later be exported to the card and then to the pc. The observation will be observed in static motion and this will be done after the job of grading has been finished. This will be tested in according to manufacturer's specification. Final check layers will be tested by a Total station TPS 1200 for comparison.

Data Analysis:

- Comparisons between my test and manufactures specifications.
- Comprehensive analysis of the test results.

As described by the literature review in chapter 2, previous testing performed by Ceryova, Chua and Garget was based on testing the dynamic accuracy and the reliability of the robotic total stations. Also Gibbings, O'Dempsey, Raymond, Smith and others did a tremendous work in testing the RTK GPS Latency in dynamic environment. There isn't many testing measures has been done in the past in regards to the machine guidance, this will be a challenge and I think, based on the ideas and examples described on chapter 2, the successful results will be obtained.

## 3.2 Data collection and testing.

**3.2.1 - Equipment used**.

Three Instruments have been utilized throughout this project.

- Leica TPS 1202.
- Trimble 5600 ATS.
- Trimble GCS600 Grade Control System.

**3.2.2 Main components of the instruments:**

- Leica – Robotic Total Station (Itself) within internal radio.
  (1) 360 Prism (target); and
  (2) Detachable/Remote keypad.

- Trimble 5600 ATS (itself) with internal radio
  (1) Grader
  (2) 360◦ Trimble prism mounted directly above one side of the blade.

**3.2.3 Trimble GCS600 Grade Control System**

(1) Grader

(2) GPS Base on site.

(3) GPS antenna mounted directly above one side of the blade. The GPS Antenna is connected together with Laser receiver underneath and transmitter located on fixed point (within 1500). A Trimble GCS600 unit was utilized for this testing.

## 3.3 Project Planning.

They are several stages have been implemented in order to undertake this project:

1. Primary research, initial stage which involves background research and literature reviews form magazines articles, books and journals. Previous tested accuracy and reliability.

2. Data collection and Testing. It involves collecting data in the field from Leica instrument after the job being performed by Trimble ATS and Trimble GPS-AMG. The comparison of Leica 1202 will give us an idea of the accuracy.

3. Analysis. The data collected and tested during stage two of this process will be edited, plotted, reviewed and reports produced using 12d software. The reports will be printed in plans and graphical form.

4. Discussion and comparison of the system: Plans, graphs and reports are to be analysed, critical thinking and subsequent use in the entire project.

5. Conclusion: The data which has been analysed have to reflect the manufacturer's specifications and draw conclusion to the various factors upon the accuracy and reliability of the machines guidance systems.

## 3.4 Literature Contribution to Research Method

The literature review as described on chapter two has given me a basis of understanding the RTS, ATS and RTK GPS so as to achieve the best possible results. Consideration must be taken following the important aspects mentioned below:

(a) According to the manufacturer's specifications, each instrument has a different distance measurement, speed and accuracy for RTS, ATS and RTK GPSs satellites coverage.

(b) Rotation ability of different instrument is not the same. The RTS maintain a high accuracy only in the length measurement (Ceryova et al, 2002).

(c) Accuracy of the results are closely associated with the speeds of the moving target (Ceryova et al., 2002);

(d) Shorter observation ranges have larger standard deviation compared larger distances (Retscher, 2002)

(e) Circular path testing straight line testing are the key components in determining the dynamic accuracy of the RTSs (Kopacik, 1998).

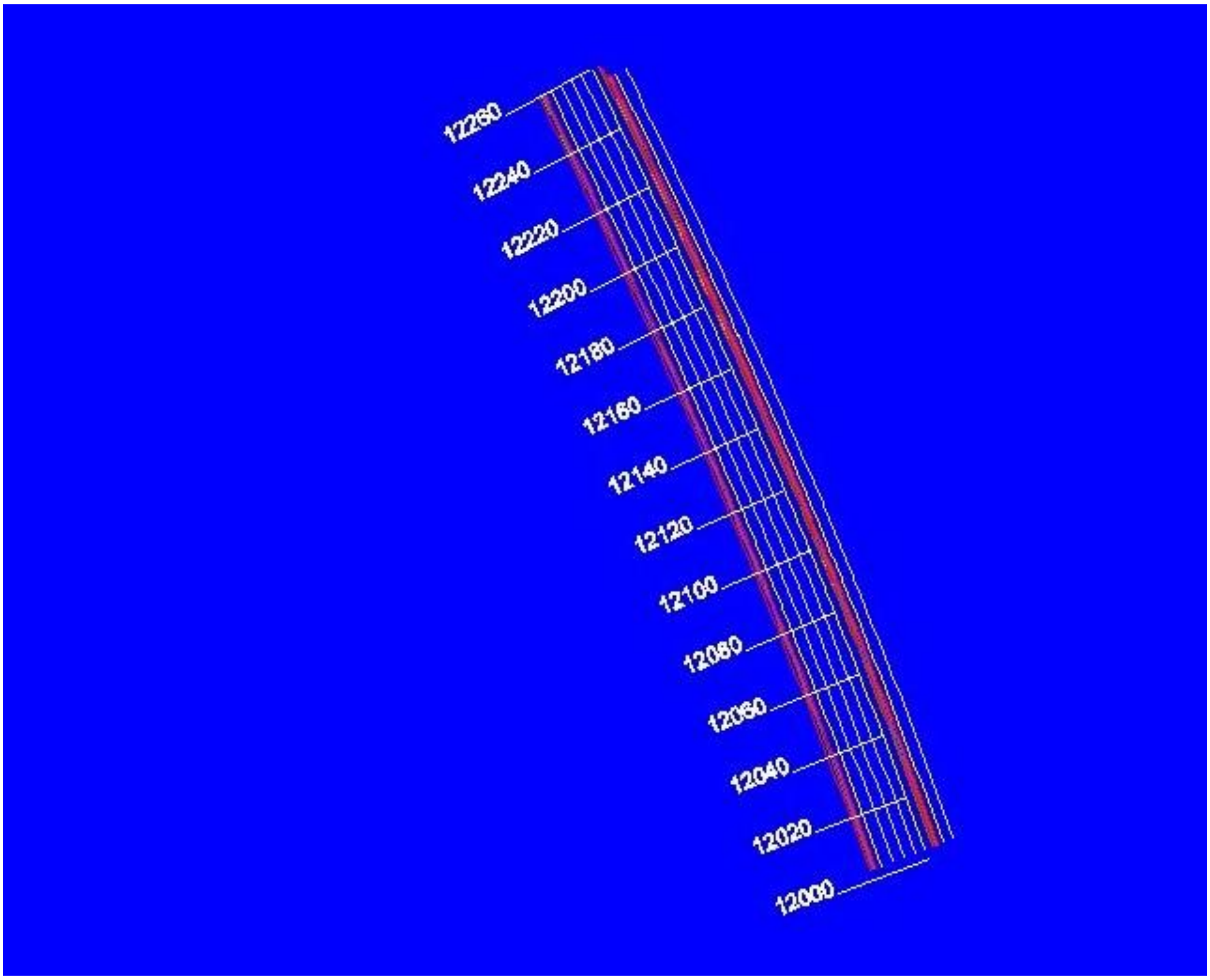
(f) Measurements are not always taken to the centre of the target; this is caused by the shape of the target (Chua, 2004).

## 3.5 Field Testing.

There were some tests undertaken for fixed circular extended straight line tests and latency on GPS RTK as described on chapter 2.

To determine the fixed path, straight lines and latency associated with the above testing equipments the measurements have been made in a dynamic sense. A detailed description of this method is given in chapter 4 although a brief introduction to the testing method is provided below.

Figure 3.1 Showing a plan view of the road at Gateway Project




The testing regime for this projects requires a section of road way. Chainage 12000 to 12280 was selected for this project (see a view plan above). The signal from the antenna is corrected by whichever means is been used, when the operator initialize the GPS RTK on his onboard screen. The fixed points provide a static reference and position data is recoded in conjunction with the model supplied for travel in each direction past the fixed points at a range of consistent speeds. By comparing the measured location with the known fixed position the latency of the system can be calculated.

The testing is conducted over a range of speeds to better determine the relationship between dynamic platform speed\ and latency error. These can be related to the example given by *Raymond 2005* as described on page 32 chapter 2.7

On ATS and RTS the testing will be conducted as descried on survey operations. During the check up and pickup survey using a Leica RTS 1202 and cutting and fill operation using ATS 5600, these instruments have a similar operation of a moving targets during a survey operation as described by (Garget, 2005) during his fixed circular path test. The target 360

Leica and 360 Trimble RTS were used for test in accordance to the manufacturer's specifications. All this tests were carried during the day time.

## 3.6 Operation of RTS (leica1200), ATS (5600s) and RTK GPS

**3.6.1 RTK GPS** and Machine Controls that can assist in construction accuracies and efficiencies. The GPS receiver on earth can "triangulate" its position from a minimum number of 4 satellites. However, the standalone accuracy of any GPS receiver is only about ± 15mm. In this case, at least more than 5 satellites and by using a radio to broadcast corrections from the base station to other rovers, and accuracy increases to 10mm.

The construction site where the testing has occurred has at least 3 base stations which are adequate enough to achieve the requirements of the Main roads. According to the company policies, they have decided to use the GPS grader when they are doing a rough grading (such as Subgrade layer) and for the excavation purposes.

An RTK base station was set (fixed) near the test site to allow for the RTK correction information to be obtained. The methodology designed in this research utilizes Trimble GPS equipments only and no other testing is done using other GPS receivers from other manufactures.

### 3.6.2 Operating on GPS (AMG)

Project contractor provided control points (primary or secondary controls) and conventional grade stakes at critical points such as, but not limited to all PCs, PTs and super elevation points begin full super, half level plane inclined etc.

The contractor set to utilize (RTK) GPS where the tolerances are within 20mm. a Trimble GCS 600 GPS unit was utilized for this testing. It features an antenna with built in GPS receiver and RTK radio. The GCS 600 uses tow AS400 angle sensors and an RS400 rotation sensor to calculate the cross slope of either side of the blade.

Similar to ATS 5600 processes, but with this is more to be done by the grader operator. The processed data (DTM in the flash card) from the surveyor will be handed over to the grader operator who will insert onto on board screen panel. The operator will start – initialize the GPS system and set the layer he/she is working on. The operator will check the blade by laying the blade on the piece of timber or stake, and the surveyor will double check the timber by taking or holding the prism pole on top of it. The results must coincide with the operator so that everybody is happy with the outcome.

Also, the surveyor may put some benchmarks with relevant RL's (Reduced Levels) close to the working area where by the operator can reach his blade for check without any problem. Since we were working on the subgrade layer level with GCS 600, hence there was no requirement for the surveyor to do a random check because of the series of benchmarks installed on site and good enough for the grader operator to check on. Finally, the surveyor observed or picked up the asbuilt survey and ready for the asbuilt report.

### 3.6.2 Operation of an ATS5600 (Field)

The ATS5600 operates by creating a new job in the card at anytime prior the data collection. Scale factor distance unit and coordinate system was set or changed onto the instrument. Pre-surveyed datum's which were done by the surveyors on site was keyed in the instrument.

**3.6.2.1 Setup the instrument**. The instrument was set on the tripod and observes at least three known point by resection (free station) normal surveying procedures. The large battery connected to the instrument usually last longer up to three days when it's new. Radio was connected and turned in conjunction with the grader.

After the instrument was turned on the survey controlled software on data logger was opened and wait for radios to establish communication, which takes up to three minutes and the level screen appears after everything goes well. The instruments calibrate itself and rotates two times and it beeps.

ACTIVE 360 TRACKER and TARGET INDICATION using a special designed prism called ''Tracker Target 360 Multi channel''. The Tracker target includes a combination of the set of standard corner prism which allows distance measuring from 15m to the maximum range. The active 360 Remote Target sends a special signal to the ATS tracker unit.

The ATS tracker is located below the optical scope of the instrument. The signal is detected and tracked after the Trimble ATS Tracker automatically indicates its location. The Trimble ATS Total stations checks the availability of both parts of the tracker target throughout the complete operation and only tracks the combination of both parts. To ensure that only the tracker target to the Trimble ATS is continually detected and monitored, the Target features a channel setting function. Set the ATS total station using the controlling software and the telemetric link of the specific indication channel.

After surveyors job being completed, i.e. preparing DTM (TIN) modal which would be handed to the grader operator. The instrument and job operation will be ready to go. The surveyor will ensure that, the grader operator is happy by checking his levels how they read on the screen. Surveyors usually use a piece of timber laid on the ground where the operator can reach his/her blade. The operator will lay a blade on top of the timber or stake and will read on the screen some levels which will be confirmed by a surveyor. In this case, the surveyor will set the second set of the instrument (Leica 1202) and ultimately the level which read by the operators grader screen will be confirmed otherwise adjusted. This is a traditionally way were most operators follow the same system.

Another way, the surveyor would place a couple of Benchmarks near the site on the firm ground, or stakes were by the operator will reach his/her blade for checks. The levels must be written clearly on the Benchmarks or stakes. Say RL 10.000m. They also prefer to turn on the modal and set the layers they are working on, and lay a blade on the road work in order to compare with the surveyors numbers i.e. CUT/FILL 0.005m and both must read the same numbers unless otherwise, or else the adjustments must be made. The checks between operator and surveyor can be done in two to three occasions at different distances, say 10m 20 and 50m. After that the surveyor will not be required, only the machine will be working and the credibility of the operator.

Walk talkies radios or mobile phones are used for communication between the surveyor and the operator. The surveyor will be going to the field from time to time, just to check the Trimble 5600 if it's still operating without troubles, flat batteries, and setup a Leica 1202 (for quick or random) check the layer works if it correspond with the graders operation. If there is a problem, then the job can be stopped for a while and attend the problem before more damage occurs. One of the problems which is likely to occur are the instrument being disturbed by windy, or wrong modal (DTM) or it wasn't checked properly, or the grader operator reset the wrong layer and also a surveyor could contribute to errors or blunder.

Finally, after the whole section has been completed by machine guidance. The duty of spatial scientist will be to pick up the asbuilts survey check and reporting.

## 3.7 Operation of a Leica 1202 (Field)

The Leica 1202 was utilized on this operation, and the purpose was to check and compare with the ATS5600 and GCS 600 equipments.

After the instrument was setup by resection, the first step will be to check the control benchmarks or existing levels from the benchmark. The reason of doing this is because of the errors during the setup and also, we are dealing with position verticals (heights) and we need to be perfect in order to achieve the pavement thickness.

Then the instrument was used during the checks with grader operator, random checks and finally pickup surveys for asbuilt checks and reporting.

**Conclusion**

All the tests mentioned in this chapter have been completed successfully and the result will be discussed in the next chapter.

Two instruments were used for testing the accuracies in the form of layers, and instrument was used to check and record the data. It was difficult to use all the equipments as it was described in the previous chapter, due to the time constraints.

Following the outcome of the result, the conclusion will be drawn and the recommendations will be presented.

## CHAPTER 4

# DATA ANALYSIS AND DISSCUSSION

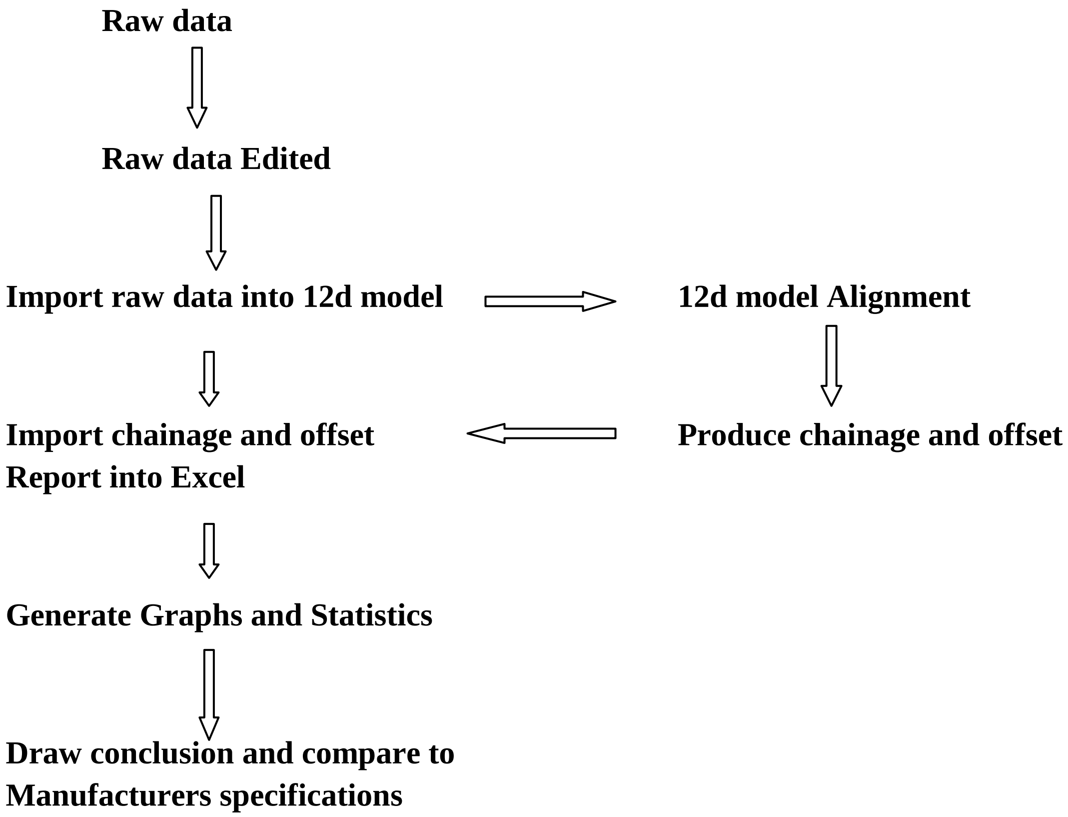
## 4.1 Introduction

The previous chapter fully described the method of measuring and how the latency could occur during field operations. The methods were also providing comparisons between the measurements observed by the leica1202 instrument with ATS5600 and GSC600.

This chapter is talking about analysis of the data used to obtain useful information resulting from the information of the testing regime. The result will give a benchmark for this ongoing research and discussion. It will also, be noted that the data analysis process for ATS5600 data is exactly the same as GSC600 because they have an identical format and their corrections are automatically applied before the data is recorded.

As it was described earlier, the RTS Leica is an addition unit required during checks inspection and record keeping for this project. Majority of analysis is performed using Microsoft excel spreadsheet program. The program statically analysis and evaluation of the test result, then reports as shown on the chart below.

Figure 4.1; *Analysis process*




## 4.2 Data Analysis

### 4.2.1 Raw data collection and Transfer

The initial raw data collected was recorded in the internal memory of Leica 1202 using Leica formats and code lists according to the Main roads standards. The instrument is capable of storing atleast one thousand points or shots. Asbuilt survey (survey points) were taken in chainages by estimating three meters counting in each layer at the exactly position. During the field operation, the raw data captured was viewed and checked on site to see if whether are sufficient and well captured, or there some missing points during operation. Leica1202 has a map screen used to check the captured points in real time by scrolling and zooming a touch screen. All this is done to ensure the data captured is right.

The ATS data transfer and GSC 600 don't store any data although they are capable of. Leica 1202 instrument was used to store all the data in all different layers. The data was then exported to the flash card (Internal memory to the card) using a special formatted files designed for downloading or exporting data. Inside the flash card, there is a folder called Data, the folder stores a reduced files in the form of radians or Easting, Northing, Reduced Levels (RL) and point name or description format.

### 4.2.2 Data transfer to a personal computer

The data was then transferred to a PC for analysis. The Flash card was plugged into the PC and imported data into 12d software using an ASCII import command. In 12d software, the data could be seen and edited and changes could be made. Also the 12d software was used to smooth the data and adjust them.

## 4.3 Software utilised and outputting data for analysis

Two main software packages below were utilised whilst undertaking the analysis of the test data.

- 12d Software; and
- Microsoft Excel spreadsheet

12d model received a raw data from the instrument and converted into a spatial format. This spatial data was then used to produce, E, N chainage and offsets and final reporting. Since the 12d model had an electronic design given by the contractor, the job of obtaining the chainage and offset was very easy. The 12d software was also doing the TIN (DTM) creation for the grader operators.

In 12d format there is (file 1/0 –Data output-12da/4a data) facility enables to exchange and backup complex string data in an open documented manner. 12d ASCII format caters 12d Model string types including 2d, 3d, 4d, pipeline, roads alignment and super strings.

## 4.4 Analysing the Database information

The analysis of data is performed using the Microsoft Excel spreadsheet program. Raw data relating to the measured positions (for both Trimble Total station and GPS was exported to the 12d for processing before transferred to the Excel), and the example of extracted data which produces the graph is shown below.

*Table 4.1 showing an example of database information on spreadsheet.*

| Point Chainage | Point Offset | Point Survey | Design Design | Error (m) | Design |
|---|---|---|---|---|---|
| 12020.00 | 6.669 | 11.997 | 12.011 | 0.014 | 0 |
| 12029.75 | 6.342 | 11.877 | 11.887 | 0.01 | 0 |
| 12039.77 | 6.499 | 11.757 | 11.763 | 0.006 | 0 |
| 12049.48 | 6.068 | 11.603 | 11.614 | 0.011 | 0 |
| 12059.47 | 6.396 | 11.467 | 11.473 | 0.006 | 0 |
| 12069.3 | 6.097 | 11.314 | 11.305 | -0.009 | 0 |
| 12079.38 | 6.759 | 11.145 | 11.149 | 0.004 | 0 |
| 12089.03 | 6.194 | 10.954 | 10.953 | -0.001 | 0 |
| 12099.22 | 6.074 | 10.739 | 10.749 | 0.01 | 0 |
| 12108.32 | 6.087 | 10.55 | 10.561 | 0.011 | 0 |
| 12118.69 | 6.002 | 10.321 | 10.331 | 0.01 | 0 |
| 12127.66 | 6.147 | 10.14 | 10.136 | -0.004 | 0 |

### 4.4.1 Analysing the GCS600 GPS

The latency of each run by machine GPS grader can be calculated from the raw position data. Averages of the distance error can be computed for the run which are made at speed (i.e. rejecting any outliers) Thus results in average latency distance errors for each run.

To ensure the distance over time is equal to speed. The calculation performed as each run at each speed share a constant speed. If the majority are at the same speed but one run pair is significantly different, then the run should be omitted from calculation of average latency for that speed range. Higher speed observations will show a larger distance error due to latency, and if the outlying machine run is included, it will distort the average latency computed for that speed.

The previous pages defined the latency as the “delay between the time of fix and when it’s available to the user”. If the GPS is in motion, the platform on which the measured values are being made will move some distance during the time when it is available to the user.

During the testing regime, they were some selected positions with an interval of 50m. Each point were tested by the GPS and ATS onboard machine by laying the blade on the ground and checked by a surveyor (me) with Leica Total station (see Table 4.4), and all this were done after a very good setup, initialisation for all equipments and the comparisons were made on site between the grader operator and Surveyor. In general the overall results are shown on tables (4.8 and 4.9).

*Table 4.2 showing analysis of data for Trimble GCS600, captured by leica instrument and compared with levels from machine operator's readings*

GCS600 GPS data

---------------------------------------------------------------

| Point Desc | Point Chainage | Point Offset | Point Level | Design Level | Point Conformance |
|---|---|---|---|---|---|
| UCE | 12000.016 | 13.698 | 12.015 | 12.021 | -0.006 |
| UCE | 12057.920 | 13.998 | 11.345 | 11.326 | 0.019 |
| UCE | 12047.626 | 14.323 | 11.512 | 11.489 | 0.024 |
| UCE | 12097.197 | 13.970 | 10.637 | 10.627 | 0.010 |
| UCE | 12146.973 | 13.849 | 9.563 | 9.537 | 0.026 > 0.025 ( 0.001) |
| UCE | 12197.815 | 13.721 | 8.418 | 8.403 | 0.015 |
| UCE | 12236.665 | 13.636 | 7.547 | 7.536 | 0.011 |

*Table 4.3 showing readings from GPS machine operator booked manual in stop and go motion by laying the blade on the UCE layer after the final trimming.*

---------------------------------------------------------------

| Point Desc | Point Chainage | Point Offset | Point Level | Design Level | Point Conformance |
|---|---|---|---|---|---|
| UCE | 12000.016 | 13.698 | 12.018 | 12.021 | -0.003 |
| UCE | 12057.920 | 13.998 | 11.339 | 11.326 | 0.013 |
| UCE | 12047.626 | 14.323 | 11.513 | 11.489 | 0.024 |
| UCE | 12097.197 | 13.970 | 10.637 | 10.627 | 0.010 |
| UCE | 12146.973 | 13.849 | 9.569 | 9.537 | 0.032 |
| UCE | 12197.815 | 13.721 | 8.417 | 8.403 | 0.014 |
| UCE | 12236.665 | 13.636 | 7.553 | 7.536 | 0.017 |

Table 4.4
COMPARISON OF DATA EXTRACTED FROM TABLE 4.2 and 4.3

| CHAINAGE | OFFSET From CL | GPS GRADER(onboard operator's readings) | LEICA TOTAL STATION (surveyors recording) | DIFFERENCE |
|---|---|---|---|---|
| | | Vertical Levels | Vertical Levels | Vertical Levels |
| 12000.016 | 13.698 | 12.018 | 12.015 | 0.003 |
| 12057.920 | 13.998 | 11.345 | 11.339 | 0.006 |
| 12047.626 | 14.323 | 11.513 | 11.512 | 0.001 |
| 12097.197 | 13.970 | 10.637 | 10.637 | 0.000 |
| 12146.973 | 13.849 | 9.569 | 9.563 | 0.003 |
| 12197.815 | 13.721 | 8.417 | 8.418 | -0.001 |
| 12236.665 | 13.636 | 7.553 | 7.547 | 0.006 |

### 4.4.2 Analysing the Trimble ATS5600

The trimble ATS total station were done in a similar fashion as explained in the previous sub section. Also the interval of 50m were used to check the vertical levels. As described in an earlier chapters, several softwares were utilised. Among those, 12d were used to remove and smoother the observation results.

Outliers were taken into consideration during analysis of measured values. Those measured values which could be analysed due to lose of lock or any other uncertainty of the ATS grader were eliminated from further analysis. The test of this regime was similar to cirlcular path test which were done by Chua and Garget. Having a Trimble ATS being setup somwhere and the observation of the grader movement will obviously give the horizontal and vertical results. Measurements were observed in various distances at different speeds.

The distance between the setup station and the moving grader was less than 200m of either side of the road, and the higher speed of the ATS was used which tends not to loose the lock quite easily. The operator will have a runs up and down until he achieves the results before he calls the surveyor to check. The analysed results are shown on table -------- below.

*Table 4.5 showing analysis of data for Trimble ATS5600, captured by leica instrument and compared with levels from machine operator's readings*

Trimble ATS5600 data

---------------------------------------------------------------

| Point Desc | Point Chainage | Point Offset | Point Level | Design Level | Point Conformance |
|---|---|---|---|---|---|
| CTB | 12000.095 | 13.466 | 12.410 | 12.413 | -0.003 |
| CTB | 12049.490 | 13.477 | 11.842 | 11.837 | 0.005 |
| CTB | 12098.919 | 13.526 | 10.992 | 10.979 | 0.014 |
| CTB | 12148.351 | 13.493 | 9.898 | 9.896 | 0.002 |
| CTB | 12197.979 | 13.515 | 8.798 | 8.792 | 0.006 |
| CTB | 12257.391 | 13.524 | 7.486 | 7.472 | 0.015 |

*Table 4.6 showing readings from ATS machine operator booked manual in static motion by laying the blade on the CTB layer after the final trimming.*

Trimble ATS5600 data

---------------------------------------------------------------

| Point Desc | Point Chainage | Point Offset | Point Level | Design Level | Point Conformance |
|---|---|---|---|---|---|
| CTB | 12000.095 | 13.466 | 12.412 | 12.413 | -0.001 |
| CTB | 12049.490 | 13.477 | 11.842 | 11.837 | 0.005 |
| CTB | 12098.919 | 13.526 | 10.994 | 10.979 | 0.015 |
| CTB | 12148.351 | 13.493 | 9.898 | 9.896 | 0.002 |

| | | | | | |
|---|---|---|---|---|---|
| CTB | 12197.979 | 13.515 | 8.798 | 8.792 | 0.006 |
| CTB | 12257.391 | 13.524 | 7.489 | 7.472 | 0.017 |

Table 4.7
COMPARISON OF DATA EXTRACTED FROM TABLE 4.5 and 4.6

| CHAINAGE | OFFSET From CL | ATS5600 GRADER(onboard operator's readings) | LEICA TOTAL STATION (surveyors recording) | DIFFERENCE |
|---|---|---|---|---|
| | | Vertical Levels | Vertical Levels | Vertical Levels |
| 12000.095 | 13.466 | 12.412 | 12.410 | 0.002 |
| 12049.490 | 13.477 | 11.842 | 11.842 | 0.000 |
| 12098.919 | 13.526 | 10.994 | 10.992 | 0.002 |
| 12148.351 | 13.493 | 9.898 | 9.898 | 0.000 |
| 12197.979 | 13.515 | 8.798 | 8.798 | 0.000 |
| 12257.391 | 13.524 | 7.489 | 7.486 | 0.003 |

### 4.4.3 Further Analysis for the Trimble ATS5600 and GPS grader

Furthermore, both layers were recorded by Leica Total station following the chainages and offsets to clarify the analysis of results. The reports from table 4.4 and 4.7 show what has been achieved on the pavement layers when using both equipments.

*Table 4.8 Showing the analysis of data for Trimble GCS600 GPS*

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Original Survey File : Z2 UCE Ch 12000 to 12260 sk
Lot Number : Ch 12000 to 12260
Instrument : Trimble GPS GC600
Lot Description : UCE 710mm below Comformance check

Project : Gateway student
Control String : "Z2 M2AS GUP FLOG->FLOG"
Design Pavement Tin : "Z2 M2AS GUP FLOG dtm"

Depth From Design : 0.710 (vertical)

Tolerances Measured : vertical
Upper Tolerance : 0.025
Lower Tolerance : -0.025

---------------------------------------------------------------

| Point Desc | Point Chainage | Point Offset | Point Level | Design Level | Point Conformance | |
|---|---|---|---|---|---|---|
| UCE | 11999.842 | 6.158 | 11.829 | 11.797 | 0.033 > | 0.025 ( 0.008) |
| UCE | 11999.939 | 7.969 | 11.858 | 11.850 | 0.007 | |
| UCE | 12000.005 | 10.878 | 11.941 | 11.937 | 0.004 | |
| UCE | 12000.016 | 13.698 | 12.015 | 12.021 | -0.006 | |
| UCE | 11999.965 | 15.322 | 12.085 | 12.070 | 0.014 | |
| UCE | 11999.865 | 18.958 | 12.163 | 12.181 | -0.018 | |
| UCE | 11999.947 | 23.810 | 12.302 | 12.325 | -0.024 | |
| UCE | 12000.055 | 26.576 | 12.387 | 12.407 | -0.020 | |
| | | | | | | |
| UCE | 12010.077 | 6.487 | 11.727 | 11.710 | 0.016 | |
| UCE | 12009.986 | 8.900 | 11.817 | 11.784 | 0.033 > | 0.025 ( 0.008) |
| UCE | 12009.950 | 11.582 | 11.867 | 11.864 | 0.003 | |
| UCE | 12009.840 | 13.749 | 11.945 | 11.931 | 0.014 | |
| UCE | 12009.895 | 15.538 | 11.997 | 11.983 | 0.014 | |
| UCE | 12009.832 | 19.020 | 12.068 | 12.089 | -0.021 | |
| UCE | 12009.840 | 23.462 | 12.234 | 12.222 | 0.012 | |
| UCE | 12009.771 | 26.586 | 12.314 | 12.317 | -0.002 | |
| | | | | | | |
| UCE | 12020.405 | 6.247 | 11.626 | 11.594 | 0.032 > | 0.025 ( 0.007) |
| UCE | 12020.903 | 9.327 | 11.715 | 11.680 | 0.035 > | 0.025 ( 0.010) |
| UCE | 12021.047 | 11.545 | 11.778 | 11.745 | 0.032 > | 0.025 ( 0.007) |
| UCE | 12019.051 | 15.156 | 11.855 | 11.876 | -0.021 | |
| UCE | 12019.344 | 18.739 | 11.962 | 11.980 | -0.019 | |
| UCE | 12019.524 | 23.802 | 12.117 | 12.130 | -0.013 | |
| UCE | 12019.841 | 26.676 | 12.200 | 12.213 | -0.013 | |
| | | | | | | |
| UCE | 12027.262 | 6.323 | 11.534 | 11.516 | 0.018 | |
| UCE | 12027.346 | 8.113 | 11.592 | 11.569 | 0.023 | |
| UCE | 12027.312 | 11.177 | 11.683 | 11.661 | 0.021 | |
| UCE | 12026.860 | 14.130 | 11.773 | 11.755 | 0.017 | |
| UCE | 12026.999 | 15.647 | 11.821 | 11.799 | 0.021 | |
| | | | | | | |
| UCE | 12029.936 | 18.781 | 11.835 | 11.858 | -0.023 | |
| UCE | 12029.954 | 23.310 | 11.972 | 11.993 | -0.022 | |
| UCE | 12029.852 | 26.764 | 12.081 | 12.098 | -0.017 | |
| | | | | | | |
| UCE | 12037.640 | 6.250 | 11.394 | 11.384 | 0.011 | |
| UCE | 12037.717 | 8.298 | 11.461 | 11.444 | 0.017 | |
| UCE | 12037.706 | 11.023 | 11.535 | 11.526 | 0.009 | |
| UCE | 12037.607 | 13.674 | 11.623 | 11.607 | 0.017 | |
| UCE | 12039.127 | 15.202 | 11.627 | 11.633 | -0.006 | |
| UCE | 12039.275 | 18.917 | 11.724 | 11.743 | -0.019 | |
| UCE | 12039.530 | 23.552 | 11.868 | 11.878 | -0.010 | |

---------------------------------------------------------------

| Point Desc | Point Chainage | Point Offset | Point Level | Design Level | Point Conformance |
|---|---|---|---|---|---|
| UCE | 12039.608 | 26.689 | 11.992 | 11.971 | 0.021 |
| | | | | | |
| UCE | 12048.037 | 6.004 | 11.253 | 11.233 | 0.019 |
| UCE | 12047.962 | 8.043 | 11.324 | 11.296 | 0.028 > 0.025 ( 0.003) |
| UCE | 12047.842 | 10.754 | 11.391 | 11.379 | 0.013 |
| UCE | 12047.626 | 14.323 | 11.512 | 11.489 | 0.024 |
| | | | | | |
| UCE | 12050.272 | 15.384 | 11.473 | 11.482 | -0.009 |
| UCE | 12050.276 | 18.721 | 11.560 | 11.582 | -0.022 |
| UCE | 12050.236 | 23.437 | 11.722 | 11.724 | -0.002 |
| UCE | 12050.120 | 26.510 | 11.803 | 11.818 | -0.016 |
| | | | | | |
| UCE | 12058.084 | 5.802 | 11.100 | 11.077 | 0.022 |
| UCE | 12058.011 | 8.143 | 11.171 | 11.149 | 0.023 |
| UCE | 12057.976 | 10.938 | 11.257 | 11.233 | 0.024 |
| UCE | 12057.920 | 13.998 | 11.345 | 11.326 | 0.019 |
| UCE | 12058.800 | 15.423 | 11.352 | 11.355 | -0.003 |
| UCE | 12059.308 | 19.568 | 11.448 | 11.471 | -0.023 |
| UCE | 12059.309 | 23.930 | 11.604 | 11.602 | 0.003 |
| UCE | 12059.456 | 26.452 | 11.669 | 11.675 | -0.006 |
| UCE | 12066.748 | 6.074 | 10.971 | 10.946 | 0.025 |
| UCE | 12066.673 | 8.376 | 11.043 | 11.017 | 0.026 > 0.025 ( 0.001) |
| UCE | 12066.547 | 11.373 | 11.130 | 11.109 | 0.022 |
| UCE | 12066.384 | 14.292 | 11.218 | 11.199 | 0.019 |
| UCE | 12066.376 | 16.087 | 11.265 | 11.253 | 0.012 |
| | | | | | |
| UCE | 12069.556 | 19.172 | 11.284 | 11.292 | -0.009 |
| UCE | 12069.576 | 22.927 | 11.390 | 11.405 | -0.015 |
| UCE | 12069.383 | 26.269 | 11.492 | 11.508 | -0.016 |
| | | | | | |
| UCE | 12076.496 | 6.125 | 10.804 | 10.781 | 0.022 |
| UCE | 12076.585 | 8.611 | 10.879 | 10.854 | 0.025 |
| UCE | 12076.578 | 11.181 | 10.941 | 10.932 | 0.010 |
| UCE | 12076.603 | 14.038 | 11.032 | 11.017 | 0.016 |
| UCE | 12076.570 | 16.146 | 11.093 | 11.081 | 0.012 |
| | | | | | |
| UCE | 12078.816 | 19.137 | 11.110 | 11.131 | -0.021 |
| UCE | 12079.021 | 23.892 | 11.246 | 11.270 | -0.024 |
| UCE | 12079.096 | 26.297 | 11.320 | 11.341 | -0.021 |
| | | | | | |
| UCE | 12087.366 | 6.352 | 10.588 | 10.589 | -0.001 |
| UCE | 12087.333 | 8.231 | 10.676 | 10.646 | 0.029 > 0.025 ( 0.004) |
| UCE | 12087.209 | 10.919 | 10.751 | 10.729 | 0.021 |
| UCE | 12087.115 | 13.746 | 10.830 | 10.816 | 0.014 |
| UCE | 12087.076 | 16.210 | 10.902 | 10.891 | 0.011 |
| UCE | 12088.784 | 18.857 | 10.921 | 10.938 | -0.017 |

| | | | | | |
|---|---|---|---|---|---|
| UCE | 12088.616 | 22.568 | 11.030 | 11.053 | -0.023 |
| UCE | 12088.543 | 26.384 | 11.157 | 11.169 | -0.012 |
| | | | | | |
| UCE | 12097.411 | 6.427 | 10.391 | 10.396 | -0.005 |
| UCE | 12097.315 | 9.002 | 10.499 | 10.475 | 0.024 |
| UCE | 12097.250 | 11.595 | 10.564 | 10.554 | 0.010 |
| UCE | 12097.197 | 13.970 | 10.637 | 10.627 | 0.010 |
| UCE | 12097.156 | 16.186 | 10.690 | 10.694 | -0.004 |
| UCE | 12098.797 | 19.084 | 10.728 | 10.749 | -0.021 |
| UCE | 12098.838 | 23.363 | 10.864 | 10.876 | -0.013 |
| UCE | 12098.854 | 26.348 | 10.979 | 10.965 | 0.014 |

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| Point Desc | Point Chainage | Point Offset | Point Level | Design Level | Point Conformance |
|---|---|---|---|---|---|
| UCE | 12106.557 | 6.656 | 10.233 | 10.215 | 0.018 |
| UCE | 12106.545 | 8.729 | 10.296 | 10.277 | 0.019 |
| UCE | 12106.544 | 11.347 | 10.385 | 10.356 | 0.029 > 0.025 ( 0.004) |
| UCE | 12106.543 | 13.771 | 10.456 | 10.428 | 0.028 > 0.025 ( 0.003) |
| | | | | | |
| UCE | 12108.986 | 15.586 | 10.410 | 10.431 | -0.021 |
| UCE | 12108.892 | 18.805 | 10.505 | 10.529 | -0.025 |
| UCE | 12108.842 | 23.212 | 10.639 | 10.662 | -0.023 |
| UCE | 12108.818 | 26.212 | 10.737 | 10.753 | -0.016 |
| | | | | | |
| UCE | 12116.195 | 6.422 | 10.027 | 9.999 | 0.028 > 0.025 ( 0.003) |
| UCE | 12116.373 | 8.764 | 10.069 | 10.065 | 0.004 |
| UCE | 12116.378 | 11.566 | 10.169 | 10.149 | 0.020 |
| UCE | 12116.362 | 14.477 | 10.262 | 10.237 | 0.025 |
| | | | | | |
| UCE | 12118.432 | 15.508 | 10.203 | 10.222 | -0.019 |
| UCE | 12118.683 | 19.095 | 10.310 | 10.323 | -0.013 |
| UCE | 12118.818 | 23.222 | 10.450 | 10.444 | 0.006 |
| UCE | 12118.756 | 26.168 | 10.552 | 10.534 | 0.018 |
| | | | | | |
| UCE | 12126.769 | 6.402 | 9.790 | 9.763 | 0.026 > 0.025 ( 0.001) |
| UCE | 12126.715 | 8.059 | 9.835 | 9.814 | 0.021 |
| UCE | 12126.719 | 10.884 | 9.906 | 9.899 | 0.007 |
| UCE | 12126.737 | 13.840 | 10.012 | 9.987 | 0.025 |
| | | | | | |
| UCE | 12129.312 | 15.514 | 9.960 | 9.980 | -0.020 |
| UCE | 12129.256 | 18.842 | 10.078 | 10.081 | -0.003 |
| UCE | 12129.005 | 22.870 | 10.220 | 10.207 | 0.013 |
| UCE | 12128.815 | 26.241 | 10.319 | 10.312 | 0.006 |

| | | | | | |
|---|---|---|---|---|---|
| UCE | 12137.033 | 6.136 | 9.552 | 9.527 | 0.025 |
| UCE | 12137.049 | 8.503 | 9.622 | 9.598 | 0.024 |
| UCE | 12136.839 | 11.238 | 9.703 | 9.684 | 0.019 |
| UCE | 12136.773 | 14.048 | 9.789 | 9.770 | 0.019 |
| UCE | 12136.766 | 16.020 | 9.854 | 9.829 | 0.024 |
| UCE | 12138.288 | 19.081 | 9.872 | 9.888 | -0.016 |
| UCE | 12138.427 | 23.288 | 10.022 | 10.011 | 0.011 |
| UCE | 12138.567 | 26.213 | 10.112 | 10.095 | 0.018 |
| | | | | | |
| UCE | 12147.081 | 6.135 | 9.332 | 9.304 | 0.028 > 0.025 ( 0.003) |
| UCE | 12147.086 | 8.208 | 9.389 | 9.366 | 0.023 |
| UCE | 12147.012 | 11.200 | 9.474 | 9.457 | 0.017 |
| UCE | 12146.973 | 13.849 | 9.563 | 9.537 | 0.026 > 0.025 ( 0.001) |
| UCE | 12146.996 | 16.088 | 9.616 | 9.604 | 0.012 |
| UCE | 12148.351 | 18.801 | 9.634 | 9.655 | -0.021 |
| UCE | 12148.351 | 23.092 | 9.779 | 9.784 | -0.005 |
| UCE | 12148.289 | 26.386 | 9.863 | 9.885 | -0.022 |
| | | | | | |
| UCE | 12157.162 | 6.441 | 9.110 | 9.089 | 0.021 |
| UCE | 12157.294 | 9.370 | 9.194 | 9.173 | 0.020 |
| UCE | 12157.279 | 11.518 | 9.255 | 9.238 | 0.017 |
| UCE | 12157.168 | 14.088 | 9.341 | 9.318 | 0.024 |
| UCE | 12157.128 | 15.970 | 9.397 | 9.375 | 0.021 |
| UCE | 12158.134 | 19.697 | 9.440 | 9.465 | -0.025 |
| UCE | 12158.356 | 23.890 | 9.560 | 9.585 | -0.025 |
| UCE | 12158.325 | 26.423 | 9.638 | 9.661 | -0.023 |

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| Point Desc | Point Chainage | Point Offset | Point Level | Design Level | Point Conformance |
|---|---|---|---|---|---|
| UCE | 12167.588 | 6.638 | 8.865 | 8.863 | 0.003 |
| UCE | 12167.528 | 8.969 | 8.942 | 8.934 | 0.008 |
| UCE | 12167.399 | 11.302 | 9.026 | 9.007 | 0.020 |
| UCE | 12167.332 | 13.594 | 9.098 | 9.077 | 0.021 |
| UCE | 12167.381 | 15.928 | 9.156 | 9.146 | 0.010 |
| UCE | 12168.226 | 18.254 | 9.174 | 9.196 | -0.022 |
| UCE | 12168.276 | 22.430 | 9.296 | 9.320 | -0.024 |
| UCE | 12168.120 | 26.290 | 9.423 | 9.441 | -0.018 |
| | | | | | |
| UCE | 12177.302 | 6.379 | 8.657 | 8.639 | 0.018 |
| UCE | 12177.550 | 8.782 | 8.700 | 8.705 | -0.005 |
| UCE | 12177.771 | 11.405 | 8.784 | 8.779 | 0.005 |
| UCE | 12177.773 | 13.861 | 8.878 | 8.853 | 0.025 |

| | | | | | | |
|---|---|---|---|---|---|---|
| UCE | 12177.820 | 15.798 | 8.933 | 8.910 | 0.023 | |
| UCE | 12177.958 | 18.941 | 8.978 | 9.001 | -0.023 | |
| UCE | 12178.065 | 23.125 | 9.100 | 9.123 | -0.024 | |
| UCE | 12178.117 | 26.332 | 9.203 | 9.218 | -0.015 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| UCE | 12187.804 | 6.229 | 8.427 | 8.401 | 0.026 > | 0.025 ( 0.001) |
| UCE | 12187.756 | 8.580 | 8.500 | 8.472 | 0.028 > | 0.025 ( 0.003) |
| UCE | 12187.685 | 10.695 | 8.558 | 8.537 | 0.020 | |
| UCE | 12187.556 | 13.493 | 8.651 | 8.624 | 0.027 > | 0.025 ( 0.002) |
| UCE | 12187.555 | 15.186 | 8.651 | 8.675 | -0.024 | |
| UCE | 12187.509 | 17.884 | 8.736 | 8.757 | -0.021 | |
| UCE | 12187.760 | 22.471 | 8.866 | 8.889 | -0.023 | |
| UCE | 12187.925 | 26.210 | 8.980 | 8.997 | -0.017 | |

| | | | | | |
|---|---|---|---|---|---|
| UCE | 12197.860 | 6.334 | 8.203 | 8.180 | 0.023 |
| UCE | 12197.788 | 8.663 | 8.261 | 8.252 | 0.009 |
| UCE | 12197.811 | 11.160 | 8.338 | 8.326 | 0.011 |
| UCE | 12197.815 | 13.721 | 8.418 | 8.403 | 0.015 |
| UCE | 12197.772 | 15.580 | 8.465 | 8.460 | 0.006 |
| UCE | 12198.024 | 19.433 | 8.554 | 8.569 | -0.015 |
| UCE | 12197.962 | 23.321 | 8.671 | 8.687 | -0.016 |
| UCE | 12197.952 | 26.115 | 8.748 | 8.771 | -0.022 |

| | | | | | |
|---|---|---|---|---|---|
| UCE | 12207.368 | 6.314 | 7.976 | 7.968 | 0.008 |
| UCE | 12207.345 | 8.245 | 8.049 | 8.027 | 0.023 |
| UCE | 12207.300 | 10.660 | 8.105 | 8.100 | 0.005 |
| UCE | 12207.201 | 13.318 | 8.207 | 8.182 | 0.025 |
| UCE | 12207.035 | 15.694 | 8.282 | 8.257 | 0.025 |
| UCE | 12207.482 | 18.095 | 8.300 | 8.319 | -0.020 |
| UCE | 12207.414 | 21.764 | 8.410 | 8.431 | -0.021 |
| UCE | 12207.652 | 25.882 | 8.526 | 8.549 | -0.023 |

| | | | | | |
|---|---|---|---|---|---|
| UCE | 12217.343 | 6.246 | 7.738 | 7.744 | -0.006 |
| UCE | 12217.260 | 8.445 | 7.814 | 7.812 | 0.002 |
| UCE | 12217.256 | 11.220 | 7.901 | 7.895 | 0.005 |
| UCE | 12217.242 | 13.884 | 7.980 | 7.976 | 0.004 |
| UCE | 12217.217 | 15.586 | 8.023 | 8.027 | -0.004 |
| UCE | 12217.766 | 18.438 | 8.077 | 8.100 | -0.023 |
| UCE | 12217.794 | 22.044 | 8.183 | 8.207 | -0.024 |
| UCE | 12217.734 | 24.740 | 8.268 | 8.290 | -0.021 |

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| Point Desc | Point Chainage | Point Offset | Point Level | Design Level | Point Conformance |
|---|---|---|---|---|---|
| UCE | 12226.649 | 6.316 | 7.551 | 7.539 | 0.011 |

| | | | | | |
|---|---|---|---|---|---|
| UCE | 12226.590 | 7.904 | 7.597 | 7.588 | 0.008 |
| UCE | 12226.557 | 10.589 | 7.674 | 7.670 | 0.005 |
| UCE | 12226.554 | 13.561 | 7.767 | 7.759 | 0.008 |
| UCE | 12226.666 | 15.619 | 7.835 | 7.818 | 0.017 |
| UCE | 12227.500 | 18.177 | 7.854 | 7.876 | -0.022 |
| UCE | 12227.392 | 22.063 | 7.977 | 7.996 | -0.019 |
| UCE | 12227.375 | 25.025 | 8.070 | 8.085 | -0.015 |

| | | | | | |
|---|---|---|---|---|---|
| UCE | 12237.001 | 6.443 | 7.316 | 7.313 | 0.003 |
| UCE | 12236.845 | 8.664 | 7.389 | 7.383 | 0.006 |
| UCE | 12236.827 | 11.276 | 7.484 | 7.462 | 0.022 |
| UCE | 12236.665 | 13.636 | 7.547 | 7.536 | 0.011 |
| UCE | 12236.570 | 15.477 | 7.594 | 7.594 | 0.001 |
| UCE | 12237.391 | 18.056 | 7.630 | 7.653 | -0.023 |
| UCE | 12237.394 | 22.539 | 7.765 | 7.787 | -0.022 |
| UCE | 12237.394 | 25.032 | 7.851 | 7.861 | -0.011 |

| | | | | | |
|---|---|---|---|---|---|
| UCE | 12246.376 | 6.714 | 7.111 | 7.112 | -0.002 |
| UCE | 12246.279 | 8.288 | 7.157 | 7.162 | -0.005 |
| UCE | 12246.310 | 10.585 | 7.233 | 7.230 | 0.003 |
| UCE | 12246.275 | 12.770 | 7.306 | 7.296 | 0.010 |
| UCE | 12247.312 | 14.728 | 7.312 | 7.332 | -0.020 |
| UCE | 12247.287 | 17.806 | 7.406 | 7.425 | -0.019 |
| UCE | 12247.220 | 21.779 | 7.523 | 7.546 | -0.023 |
| UCE | 12247.231 | 24.930 | 7.620 | 7.640 | -0.021 |

| | | | | | |
|---|---|---|---|---|---|
| UCE | 12255.324 | 7.035 | 6.945 | 6.923 | 0.022 |
| UCE | 12255.303 | 9.287 | 7.018 | 6.991 | 0.027 > 0.025 ( 0.002) |
| UCE | 12255.129 | 11.489 | 7.073 | 7.061 | 0.012 |
| UCE | 12255.197 | 13.811 | 7.121 | 7.129 | -0.008 |
| UCE | 12255.223 | 15.063 | 7.170 | 7.166 | 0.004 |

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12D MODEL - SURVEY CONFORMANCE REPORT: PAVEMENT
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POINTS PROCESSED : 221

VERTICAL SUMMARY

| | | |
|---|---|---|
| Points Tested | : | 212 |
| Within Tolerance | : | 194 ( 91.5%) |
| Too High | : | 18 ( 8.5%) |
| Too Low | : | 0 ( 0.0%) |
| Maximum Conformance: | | 0.035 |
| Minimum Conformance: | | -0.025 |
| Average Conformance | : | 0.003 |
| Standard Deviation | : | 0.018 |

----------------------------------------------------------------

Signed: ________________________________________

Said Kiongoli
USQ student Final year 2010
Tue 17-Aug-2010 14:45:08

*Table 4.9 Showing analyses of data for Trimble ATS 5600*

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12D MODEL - SURVEY CONFORMANCE REPORT: PAVEMENT

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Original Survey File : Z2 CTB Ch 12000 to 12260 sk
Lot Number : Ch 12000 to 12260
Instrument : Trimble ATS 5600
Lot Description : CTB 310mm below Comformance check

Project : Gateway student
Control String : "Z2 M2AS GUP FLOG->FLOG"
Design Pavement Tin : "Z2 M2AS GUP FLOG dtm"

Depth From Design : 0.310 (vertical)

Tolerances Measured : vertical
Upper Tolerance : 0.015
Lower Tolerance : -0.015

| Point Desc | Point Chainage | Point Offset | Point Level | Design Level | Point Conformance |
|---|---|---|---|---|---|
| CTB | 12000.473 | 6.540 | 12.194 | 12.202 | -0.008 |
| CTB | 12000.227 | 8.040 | 12.247 | 12.250 | -0.002 |
| CTB | 12000.430 | 10.021 | 12.320 | 12.307 | 0.012 |
| CTB | 12000.095 | 13.466 | 12.410 | 12.413 | -0.003 |
| CTB | 12000.427 | 17.096 | 12.523 | 12.519 | 0.004 |
| CTB | 12000.159 | 20.964 | 12.635 | 12.638 | -0.003 |
| CTB | 12000.098 | 24.383 | 12.752 | 12.741 | 0.011 |
| CTB | 12000.153 | 26.743 | 12.818 | 12.811 | 0.006 |

| | | | | | |
|---|---|---|---|---|---|
| CTB | 12009.984 | 6.548 | 12.109 | 12.113 | -0.004 |
| CTB | 12009.940 | 8.023 | 12.169 | 12.158 | 0.012 |
| CTB | 12010.053 | 9.985 | 12.212 | 12.215 | -0.003 |
| CTB | 12010.043 | 13.507 | 12.326 | 12.321 | 0.005 |
| CTB | 12010.150 | 17.150 | 12.444 | 12.429 | 0.014 |
| CTB | 12010.030 | 21.000 | 12.555 | 12.546 | 0.009 |
| CTB | 12009.920 | 24.540 | 12.653 | 12.653 | 0.000 |
| CTB | 12009.902 | 26.738 | 12.705 | 12.719 | -0.014 |
| | | | | | |
| CTB | 12019.996 | 6.669 | 11.997 | 12.011 | -0.014 |
| CTB | 12019.934 | 8.143 | 12.060 | 12.056 | 0.004 |
| CTB | 12019.790 | 10.016 | 12.128 | 12.114 | 0.014 |
| CTB | 12019.794 | 13.499 | 12.218 | 12.218 | 0.000 |
| CTB | 12019.852 | 17.190 | 12.326 | 12.328 | -0.002 |
| CTB | 12019.811 | 21.024 | 12.450 | 12.443 | 0.007 |
| CTB | 12019.817 | 24.492 | 12.559 | 12.547 | 0.012 |
| CTB | 12019.868 | 26.769 | 12.611 | 12.615 | -0.004 |
| | | | | | |
| CTB | 12029.751 | 6.342 | 11.877 | 11.887 | -0.010 |
| CTB | 12029.858 | 8.073 | 11.940 | 11.938 | 0.002 |
| CTB | 12029.956 | 9.807 | 11.986 | 11.988 | -0.002 |
| CTB | 12029.635 | 13.547 | 12.106 | 12.105 | 0.001 |
| CTB | 12029.785 | 17.271 | 12.221 | 12.214 | 0.006 |
| CTB | 12029.681 | 21.091 | 12.341 | 12.330 | 0.010 |
| CTB | 12029.740 | 24.496 | 12.435 | 12.432 | 0.004 |
| CTB | 12029.738 | 26.888 | 12.489 | 12.503 | -0.014 |
| | | | | | |
| CTB | 12039.772 | 6.499 | 11.757 | 11.763 | -0.006 |
| CTB | 12039.711 | 8.030 | 11.814 | 11.810 | 0.004 |
| CTB | 12039.778 | 10.111 | 11.887 | 11.871 | 0.016 > 0.015 ( 0.001) |
| CTB | 12039.579 | 13.502 | 11.978 | 11.976 | 0.002 |
| CTB | 12039.619 | 17.206 | 12.077 | 12.086 | -0.009 |
| CTB | 12039.651 | 20.878 | 12.211 | 12.196 | 0.016 |
| CTB | 12039.474 | 24.447 | 12.318 | 12.306 | 0.012 |
| CTB | 12039.602 | 26.828 | 12.376 | 12.375 | 0.001 |

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| Point Desc | Point Chainage | Point Offset | Point Level | Design Level | Point Conformance |
|---|---|---|---|---|---|
| CTB | 12049.484 | 6.068 | 11.603 | 11.614 | -0.012 |
| CTB | 12049.509 | 8.067 | 11.673 | 11.674 | -0.001 |
| CTB | 12049.542 | 9.994 | 11.740 | 11.731 | 0.009 |
| CTB | 12049.490 | 13.477 | 11.842 | 11.837 | 0.005 |
| CTB | 12049.538 | 16.431 | 11.911 | 11.924 | -0.013 |

| | | | | | | |
|---|---|---|---|---|---|---|
| CTB | 12049.496 | 20.659 | 12.061 | 12.052 | 0.009 | |
| CTB | 12049.451 | 24.354 | 12.176 | 12.163 | 0.013 | |
| CTB | 12049.697 | 26.612 | 12.224 | 12.227 | -0.003 | |
| | | | | | | |
| CTB | 12059.474 | 6.396 | 11.467 | 11.473 | -0.007 | |
| CTB | 12059.429 | 8.047 | 11.537 | 11.524 | 0.014 | |
| CTB | 12059.575 | 10.030 | 11.597 | 11.581 | 0.017 > | 0.015 ( 0.002) |
| CTB | 12059.350 | 13.510 | 11.698 | 11.689 | 0.010 | |
| CTB | 12059.325 | 16.159 | 11.772 | 11.768 | 0.004 | |
| CTB | 12059.421 | 17.480 | 11.807 | 11.807 | 0.001 | |
| CTB | 12059.308 | 20.793 | 11.907 | 11.908 | -0.001 | |
| CTB | 12059.360 | 24.511 | 12.029 | 12.018 | 0.011 | |
| CTB | 12059.338 | 26.686 | 12.070 | 12.084 | -0.014 | |
| | | | | | | |
| CTB | 12069.301 | 6.097 | 11.314 | 11.305 | 0.010 | |
| CTB | 12069.328 | 8.041 | 11.377 | 11.363 | 0.014 | |
| CTB | 12069.440 | 10.006 | 11.419 | 11.420 | 0.000 | |
| CTB | 12069.202 | 13.446 | 11.537 | 11.527 | 0.010 | |
| CTB | 12069.267 | 17.233 | 11.631 | 11.639 | -0.008 | |
| CTB | 12069.187 | 20.942 | 11.750 | 11.752 | -0.002 | |
| CTB | 12069.297 | 24.571 | 11.864 | 11.859 | 0.006 | |
| CTB | 12069.389 | 26.478 | 11.901 | 11.914 | -0.013 | |
| | | | | | | |
| CTB | 12079.383 | 6.759 | 11.145 | 11.149 | -0.004 | |
| CTB | 12079.364 | 8.102 | 11.200 | 11.190 | 0.010 | |
| CTB | 12079.252 | 10.148 | 11.262 | 11.253 | 0.009 | |
| CTB | 12079.319 | 13.516 | 11.370 | 11.353 | 0.017 > | 0.015 ( 0.002) |
| CTB | 12079.487 | 17.185 | 11.470 | 11.460 | 0.010 | |
| CTB | 12079.189 | 20.688 | 11.569 | 11.570 | -0.001 | |
| CTB | 12078.967 | 24.658 | 11.705 | 11.694 | 0.011 | |
| CTB | 12079.222 | 26.501 | 11.732 | 11.744 | -0.012 | |
| | | | | | | |
| CTB | 12089.030 | 6.194 | 10.954 | 10.953 | 0.001 | |
| CTB | 12089.063 | 8.033 | 11.012 | 11.008 | 0.004 | |
| CTB | 12089.198 | 10.021 | 11.082 | 11.065 | 0.017 > | 0.015 ( 0.002) |
| CTB | 12088.996 | 13.550 | 11.185 | 11.174 | 0.010 | |
| CTB | 12089.092 | 17.225 | 11.275 | 11.283 | -0.008 | |
| CTB | 12089.002 | 20.714 | 11.393 | 11.389 | 0.004 | |
| CTB | 12089.133 | 24.793 | 11.516 | 11.509 | 0.007 | |
| CTB | 12089.073 | 26.453 | 11.561 | 11.560 | 0.001 | |
| | | | | | | |
| CTB | 12099.222 | 6.074 | 10.739 | 10.749 | -0.010 | |
| CTB | 12099.108 | 8.011 | 10.818 | 10.809 | 0.009 | |
| CTB | 12099.032 | 10.071 | 10.882 | 10.873 | 0.009 | |
| CTB | 12098.919 | 13.526 | 10.992 | 10.979 | 0.014 | |
| CTB | 12099.014 | 16.314 | 11.074 | 11.060 | 0.014 | |
| CTB | 12099.048 | 16.731 | 11.083 | 11.072 | 0.011 | |
| CTB | 12098.942 | 20.772 | 11.197 | 11.195 | 0.001 | |
| CTB | 12098.979 | 24.337 | 11.316 | 11.302 | 0.014 | |
| CTB | 12099.167 | 26.290 | 11.356 | 11.356 | -0.001 | |

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| Point Desc | Point Chainage | Point Offset | Point Level | Design Level | Point Conformance |
|---|---|---|---|---|---|
| CTB | 12108.315 | 6.087 | 10.550 | 10.561 | -0.010 |
| CTB | 12108.777 | 8.091 | 10.626 | 10.611 | 0.015 |
| CTB | 12108.777 | 10.003 | 10.681 | 10.668 | 0.013 |
| CTB | 12108.777 | 13.521 | 10.783 | 10.774 | 0.010 |
| CTB | 12109.115 | 16.492 | 10.859 | 10.855 | 0.004 |
| CTB | 12109.062 | 20.696 | 10.989 | 10.982 | 0.007 |
| CTB | 12108.658 | 24.639 | 11.123 | 11.110 | 0.013 |
| CTB | 12108.977 | 26.388 | 11.161 | 11.155 | 0.006 |
| | | | | | |
| CTB | 12118.689 | 6.002 | 10.321 | 10.331 | -0.010 |
| CTB | 12118.688 | 8.010 | 10.401 | 10.391 | 0.010 |
| CTB | 12118.670 | 9.975 | 10.463 | 10.451 | 0.012 |
| CTB | 12118.670 | 13.562 | 10.571 | 10.558 | 0.013 |
| CTB | 12119.340 | 15.462 | 10.604 | 10.600 | 0.004 |
| CTB | 12119.271 | 16.784 | 10.641 | 10.641 | 0.000 |
| CTB | 12119.182 | 20.699 | 10.762 | 10.760 | 0.002 |
| CTB | 12118.881 | 24.525 | 10.890 | 10.882 | 0.008 |
| CTB | 12119.013 | 26.220 | 10.919 | 10.930 | -0.010 |
| | | | | | |
| CTB | 12127.658 | 6.147 | 10.140 | 10.136 | 0.004 |
| CTB | 12127.599 | 8.024 | 10.178 | 10.194 | -0.015 |
| CTB | 12127.565 | 10.030 | 10.231 | 10.254 | -0.024 < -0.015 (-0.009) |
| CTB | 12127.690 | 13.511 | 10.350 | 10.356 | -0.006 |
| CTB | 12129.290 | 15.372 | 10.384 | 10.376 | 0.008 |
| CTB | 12129.372 | 17.152 | 10.426 | 10.428 | -0.002 |
| CTB | 12129.243 | 20.725 | 10.548 | 10.537 | 0.010 |
| CTB | 12129.361 | 24.409 | 10.657 | 10.645 | 0.011 |
| CTB | 12129.313 | 26.429 | 10.714 | 10.707 | 0.008 |
| | | | | | |
| CTB | 12138.522 | 6.501 | 9.900 | 9.905 | -0.005 |
| CTB | 12138.472 | 7.963 | 9.939 | 9.950 | -0.011 |
| CTB | 12138.510 | 10.049 | 10.003 | 10.011 | -0.009 |
| CTB | 12138.530 | 13.385 | 10.093 | 10.111 | -0.018 < -0.015 (-0.003) |
| CTB | 12139.426 | 16.704 | 10.203 | 10.190 | 0.013 |
| CTB | 12139.284 | 20.423 | 10.288 | 10.305 | -0.018 < -0.015 (-0.003) |
| CTB | 12139.214 | 24.974 | 10.444 | 10.443 | 0.001 |
| CTB | 12139.185 | 26.421 | 10.485 | 10.487 | -0.002 |
| CTB | 12139.194 | 26.438 | 10.485 | 10.487 | -0.002 |
| | | | | | |
| CTB | 12148.356 | 6.516 | 9.677 | 9.686 | -0.009 |

| | | | | | |
|---|---|---|---|---|---|
| CTB | 12148.353 | 7.975 | 9.720 | 9.730 | -0.011 |
| CTB | 12148.232 | 9.933 | 9.781 | 9.792 | -0.011 |
| CTB | 12148.351 | 13.493 | 9.898 | 9.896 | 0.002 |
| CTB | 12148.725 | 17.079 | 10.003 | 9.995 | 0.008 |
| CTB | 12148.498 | 20.806 | 10.118 | 10.112 | 0.006 |
| CTB | 12148.351 | 24.478 | 10.238 | 10.225 | 0.013 |
| CTB | 12148.427 | 26.395 | 10.271 | 10.281 | -0.009 |
| | | | | | |
| CTB | 12158.509 | 6.058 | 9.437 | 9.447 | -0.010 |
| CTB | 12158.513 | 8.079 | 9.496 | 9.507 | -0.011 |
| CTB | 12158.348 | 10.065 | 9.562 | 9.570 | -0.009 |
| CTB | 12158.385 | 13.530 | 9.676 | 9.674 | 0.002 |
| CTB | 12158.252 | 16.526 | 9.772 | 9.766 | 0.005 |
| CTB | 12158.283 | 20.481 | 9.892 | 9.884 | 0.008 |
| CTB | 12158.324 | 25.207 | 10.027 | 10.025 | 0.002 |
| CTB | 12158.266 | 26.467 | 10.050 | 10.064 | -0.014 |

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| Point Desc | Point Chainage | Point Offset | Point Level | Design Level | Point Conformance |
|---|---|---|---|---|---|
| CTB | 12168.184 | 6.111 | 9.225 | 9.233 | -0.008 |
| CTB | 12168.200 | 8.181 | 9.277 | 9.295 | -0.018 < -0.015 (-0.003) |
| CTB | 12168.189 | 10.023 | 9.341 | 9.350 | -0.009 |
| CTB | 12168.262 | 13.558 | 9.463 | 9.455 | 0.008 |
| CTB | 12168.548 | 17.221 | 9.559 | 9.558 | 0.001 |
| CTB | 12168.678 | 20.977 | 9.658 | 9.668 | -0.010 |
| CTB | 12168.704 | 24.416 | 9.760 | 9.770 | -0.010 |
| CTB | 12168.708 | 26.506 | 9.827 | 9.833 | -0.006 |
| | | | | | |
| CTB | 12178.168 | 6.189 | 9.021 | 9.013 | 0.008 |
| CTB | 12178.157 | 8.159 | 9.072 | 9.073 | -0.001 |
| CTB | 12178.154 | 10.022 | 9.122 | 9.129 | -0.007 |
| CTB | 12178.112 | 13.544 | 9.243 | 9.235 | 0.008 |
| CTB | 12178.164 | 17.224 | 9.350 | 9.344 | 0.006 |
| CTB | 12178.087 | 21.018 | 9.450 | 9.460 | -0.009 |
| CTB | 12177.967 | 24.534 | 9.558 | 9.569 | -0.011 |
| CTB | 12178.077 | 26.423 | 9.617 | 9.622 | -0.005 |
| | | | | | |
| CTB | 12188.052 | 6.051 | 8.780 | 8.790 | -0.010 |
| CTB | 12187.982 | 8.100 | 8.835 | 8.852 | -0.018 < -0.015 (-0.003) |
| CTB | 12187.956 | 10.018 | 8.909 | 8.911 | -0.002 |
| CTB | 12188.056 | 13.495 | 9.021 | 9.013 | 0.008 |
| CTB | 12188.070 | 17.095 | 9.130 | 9.120 | 0.010 |
| CTB | 12188.248 | 21.016 | 9.246 | 9.234 | 0.012 |
| CTB | 12188.548 | 24.532 | 9.333 | 9.333 | 0.001 |

| | | | | | |
|---|---|---|---|---|---|
| CTB | 12188.656 | 26.353 | 9.371 | 9.385 | -0.014 |
| | | | | | |
| CTB | 12198.023 | 6.961 | 8.583 | 8.595 | -0.012 |
| CTB | 12197.943 | 8.165 | 8.627 | 8.633 | -0.006 |
| CTB | 12197.840 | 10.143 | 8.693 | 8.694 | -0.001 |
| CTB | 12197.979 | 13.515 | 8.798 | 8.792 | 0.006 |
| CTB | 12198.079 | 17.210 | 8.909 | 8.901 | 0.008 |
| CTB | 12197.942 | 20.955 | 9.011 | 9.016 | -0.005 |
| CTB | 12197.819 | 24.470 | 9.124 | 9.125 | -0.001 |
| CTB | 12197.919 | 26.343 | 9.167 | 9.178 | -0.012 |
| | | | | | |
| CTB | 12207.869 | 6.197 | 8.341 | 8.353 | -0.013 |
| CTB | 12207.855 | 8.265 | 8.394 | 8.415 | -0.022 < -0.015 (-0.007) |
| CTB | 12207.864 | 9.990 | 8.466 | 8.467 | 0.000 |
| CTB | 12207.883 | 13.555 | 8.585 | 8.573 | 0.011 |
| CTB | 12207.891 | 17.214 | 8.695 | 8.683 | 0.012 |
| CTB | 12207.911 | 20.862 | 8.794 | 8.792 | 0.002 |
| CTB | 12208.032 | 24.309 | 8.888 | 8.892 | -0.004 |
| CTB | 12207.952 | 25.559 | 8.919 | 8.932 | -0.013 |
| | | | | | |
| CTB | 12217.800 | 6.236 | 8.139 | 8.133 | 0.006 |
| CTB | 12217.734 | 8.081 | 8.177 | 8.190 | -0.013 |
| CTB | 12217.724 | 10.008 | 8.255 | 8.248 | 0.007 |
| CTB | 12217.677 | 13.521 | 8.362 | 8.355 | 0.008 |
| CTB | 12218.160 | 17.266 | 8.472 | 8.456 | 0.015 |
| CTB | 12217.984 | 20.773 | 8.579 | 8.565 | 0.014 |
| CTB | 12217.715 | 24.389 | 8.679 | 8.679 | -0.001 |
| CTB | 12217.795 | 25.508 | 8.708 | 8.711 | -0.003 |

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| Point Desc | Point Chainage | Point Offset | Point Level | Design Level | Point Conformance |
|---|---|---|---|---|---|
| CTB | 12227.680 | 6.102 | 7.900 | 7.910 | -0.010 |
| CTB | 12227.615 | 8.135 | 7.978 | 7.972 | 0.006 |
| CTB | 12227.609 | 10.029 | 8.038 | 8.029 | 0.009 |
| CTB | 12227.699 | 13.492 | 8.148 | 8.131 | 0.017 > 0.015 ( 0.002) |
| CTB | 12227.574 | 17.301 | 8.261 | 8.248 | 0.013 |
| CTB | 12227.573 | 20.795 | 8.363 | 8.352 | 0.011 |
| CTB | 12227.500 | 24.502 | 8.471 | 8.465 | 0.006 |
| CTB | 12227.532 | 25.802 | 8.505 | 8.503 | 0.001 |
| | | | | | |
| CTB | 12237.642 | 6.239 | 7.692 | 7.692 | -0.001 |
| CTB | 12237.579 | 8.216 | 7.770 | 7.753 | 0.017 > 0.015 ( 0.002) |
| CTB | 12237.530 | 10.095 | 7.818 | 7.810 | 0.007 |
| CTB | 12237.406 | 13.558 | 7.932 | 7.917 | 0.015 |

| | | | | | |
|---|---|---|---|---|---|
| CTB | 12237.626 | 17.355 | 8.033 | 8.026 | 0.008 |
| CTB | 12237.534 | 20.950 | 8.144 | 8.136 | 0.008 |
| CTB | 12237.552 | 24.421 | 8.244 | 8.239 | 0.004 |
| CTB | 12237.562 | 25.043 | 8.270 | 8.258 | 0.012 |
| | | | | | |
| CTB | 12247.013 | 6.310 | 7.476 | 7.486 | -0.010 |
| CTB | 12247.291 | 8.115 | 7.533 | 7.534 | -0.001 |
| CTB | 12247.310 | 10.002 | 7.594 | 7.590 | 0.004 |
| CTB | 12247.399 | 13.523 | 7.703 | 7.694 | 0.010 |
| CTB | 12247.420 | 17.290 | 7.816 | 7.806 | 0.010 |
| CTB | 12247.563 | 20.971 | 7.917 | 7.913 | 0.004 |
| CTB | 12247.705 | 24.931 | 8.021 | 8.029 | -0.007 |
| | | | | | |
| CTB | 12257.326 | 6.275 | 7.248 | 7.256 | -0.007 |
| CTB | 12257.299 | 8.049 | 7.319 | 7.309 | 0.010 |
| CTB | 12257.390 | 10.001 | 7.381 | 7.366 | 0.015 |
| CTB | 12257.391 | 13.524 | 7.486 | 7.472 | 0.015 |
| CTB | 12257.408 | 15.182 | 7.535 | 7.521 | 0.015 |
| CTB | 12257.205 | 22.195 | 7.731 | 7.736 | -0.005 |
| CTB | 12257.293 | 23.197 | 7.744 | 7.764 | -0.020 < -0.015 (-0.005) |

--------------------------------------------------------------

12D MODEL - SURVEY CONFORMANCE REPORT: PAVEMENT
File: Z2 CTB Ch 12000 to 12260 sk .rpt
Page: 6

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POINTS PROCESSED : 223

VERTICAL SUMMARY

| | | |
|---|---|---|
| Points Tested | : | 219 |
| Within Tolerance | : | 206 ( 94.1%) |
| Too High | : | 6 ( 2.7%) |
| Too Low | : | 7 ( 3.2%) |
| Maximum Conformance | : | 0.017 |
| Minimum Conformance | : | -0.024 |
| Average Conformance | : | 0.002 |
| Standard Deviation | : | 0.010 |

--------------------------------------------------------------

Signed: ________________________________________

Said Kiongoli
USQ student Final year 2010
Frid 20-Aug-2010 14:26:59

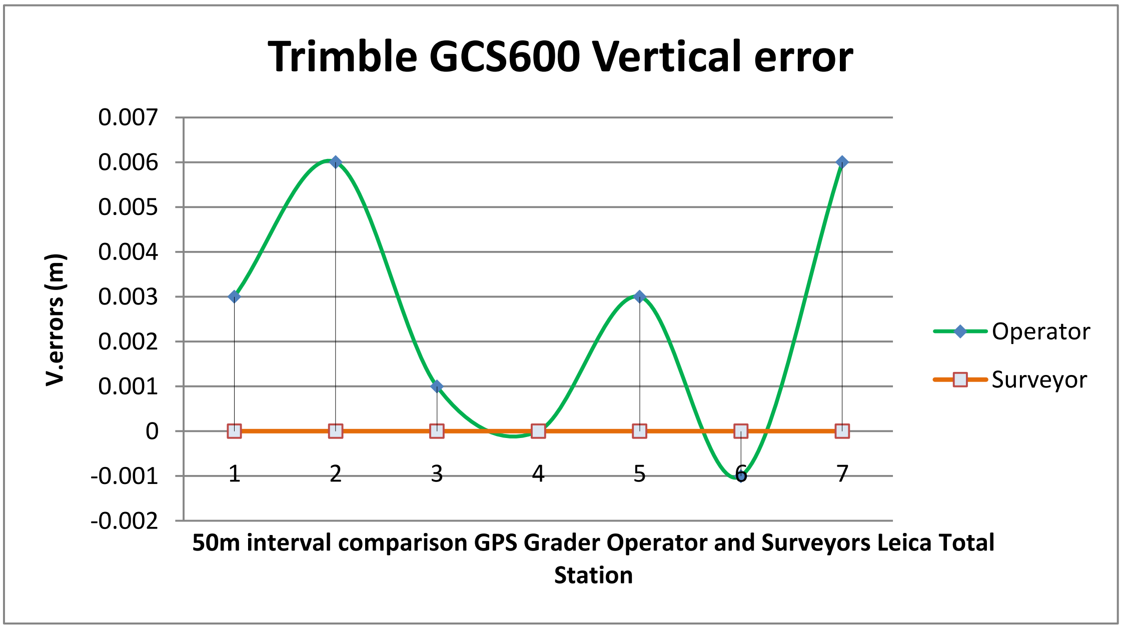
## 4.5 Results

### 4.5.1 GCS600 GPS

Finally, following the hard work by the grader operator and the clarity of surveyor the pleasant results were obtained. The results can be graphed graphically presentation of the latency error for machine runs over the range of different speeds (GCS600 GPS). This was done in 50m intervals as figure 4.2 shows and general result for the whole road section in both layers are graphically shown on figures 4.3 to 4.11. The figures clearly show the errors in position vertical due to latency increases with speed.

*(Raymond,2005)* defines latency as the delay between the time of fix and when it is available to the use" Hence if the GPS is in motion, the platform on which the measurements are being made will move some distance during the time when the measurement is made and the time when it is available to the user. It is clear to see from the graphical representations of the error which is affecting the vertical (height) solution of these dynamic RTK measurements, especially when the speed is considered to be higher.

Figure 4.2; *Latency errors-50m interval*




The graphical results below shows that, a significant errors affecting the position vertical (heights) measurements during field work. The results raises some important questions which will become focused of ongoing research projects.

1. Why are we getting some bad errors during machine movement, and we get the same errors during checks when the machine is not in a motion.

2. To what extent does the RTK base station which is fixed in the office somewhere affect the vertical accuracy at which the machine guidance is measured.

3. How much of this latency error is attributed to the GPS machine guidance component and how much is accounted for within the road constrution during operation.

The first point could be easier to determine, that when the machine was in motion the number of factors could have been contributed to the poor accuracy, this factors such as satelites were elaborated on chapter 2. It could be an operator as well by regrading more material or filling them. Sometimes the grader operator would follow what reads on the screen, and the screen would tell the operator either to fill or cut more, but in real fact that could be the less number of satelites or something else which may affect the tolerance or it could even be machines itself, tires, width, weight etc.

The second point is also easier to predict. The base station may happen to sink or raise due to rain or wind, but this is doesnt happen very often and checks are always done before and after the field operations.

The third part is a bit difficult to determine, it requires more time, however further investigations will be needed due to time contraints.

Given the results using this methods, it becomes clear that the testing which was conducted does not really provide a satsifactory means of relating the dynamic measurements from RTK base in the moving machine. Future testing at a higher speeds will require a better method of providing this results in a moving machine.

- Figure 4.3; *Latency errors-combined GPS machine runs*

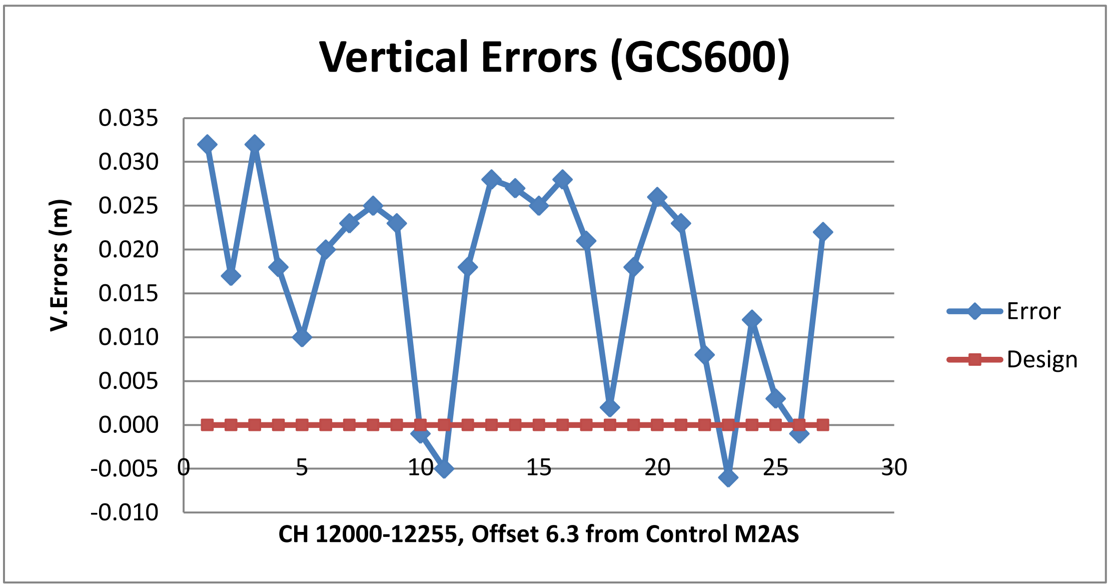


Figure 4.4; *Latency errors-combined GPS machine runs*

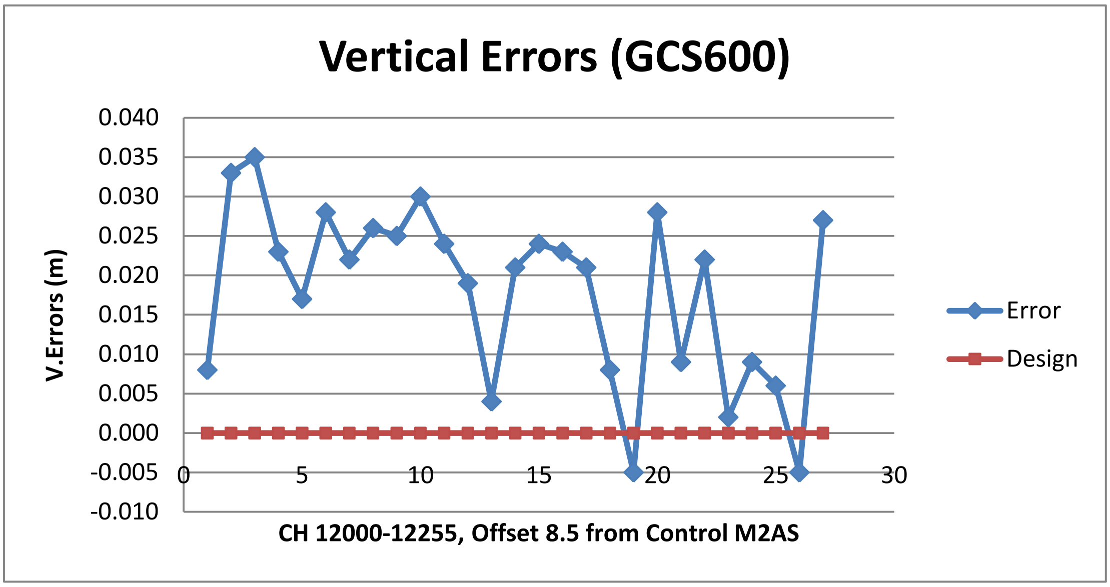



Figure 4.5; *Latency errors-combined GPS machine runs*

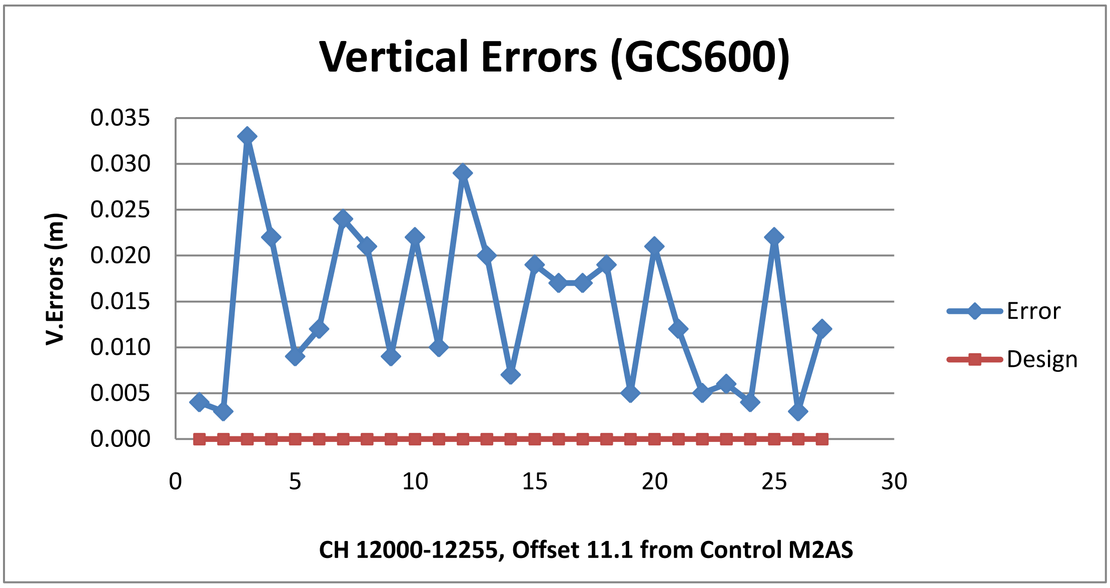


Figure 4.6; *Latency errors-combined GPS machine runs*

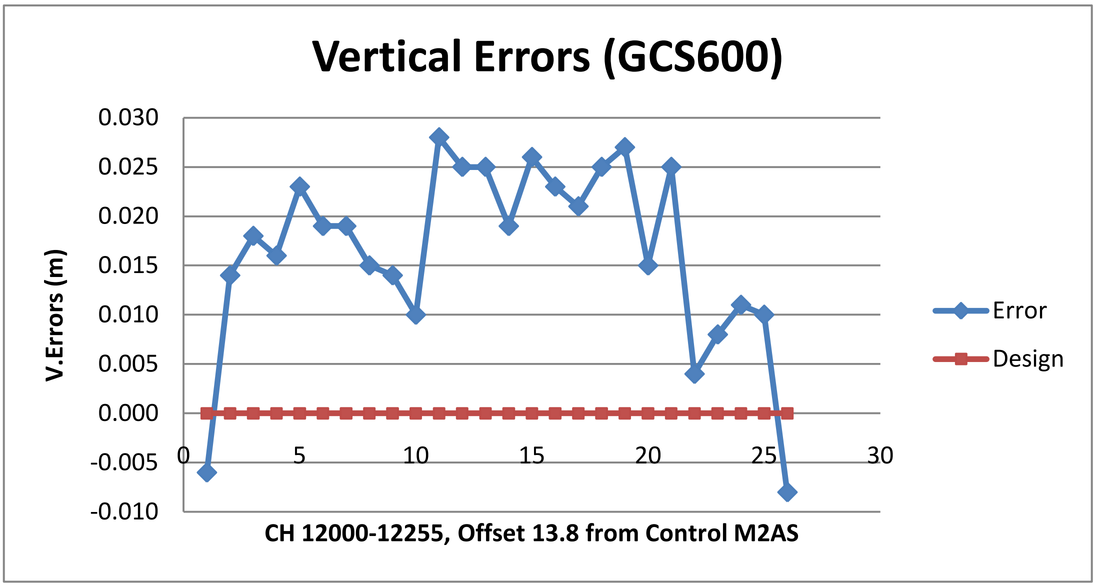



Figure 4.7; *Latency errors-combined GPS machine runs*

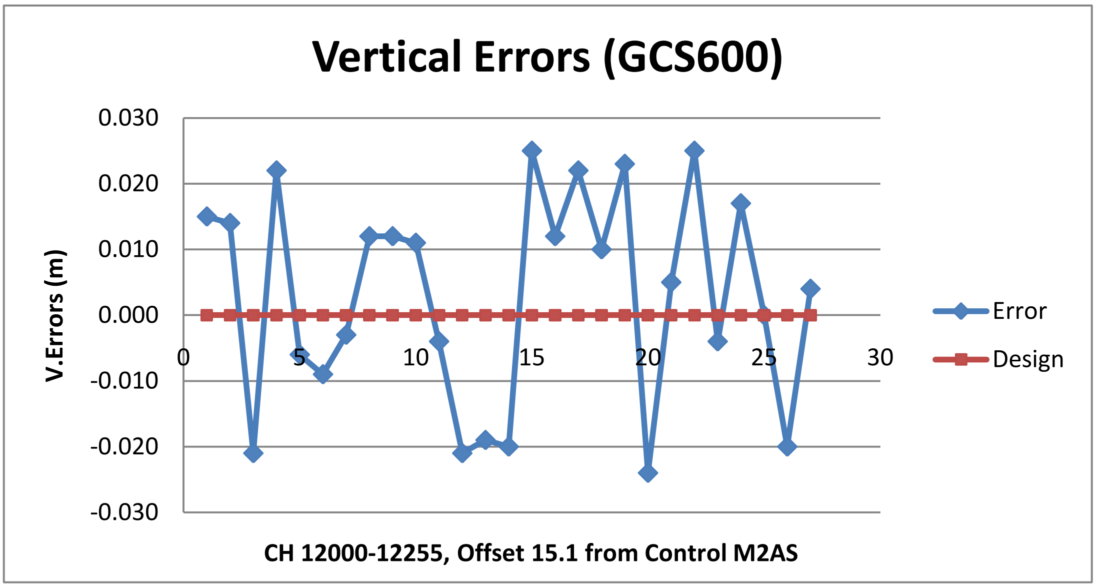


Figure 4.8; *Latency errors-combined GPS machine runs*

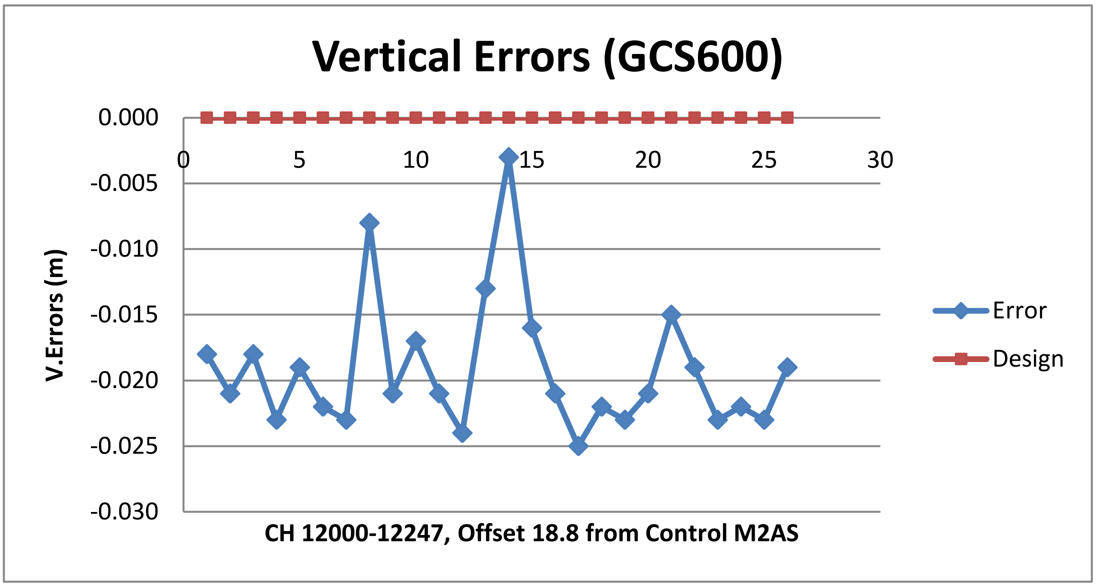



Figure 4.9; *Latency errors-combined GPS machine runs*

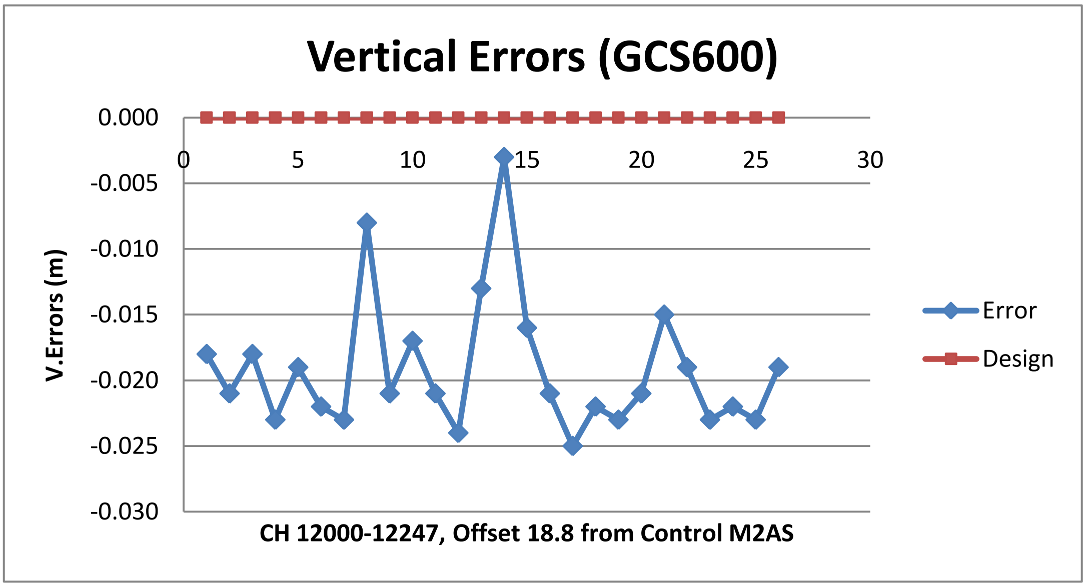


Figure 4.10; *Latency errors-combined GPS machine runs*

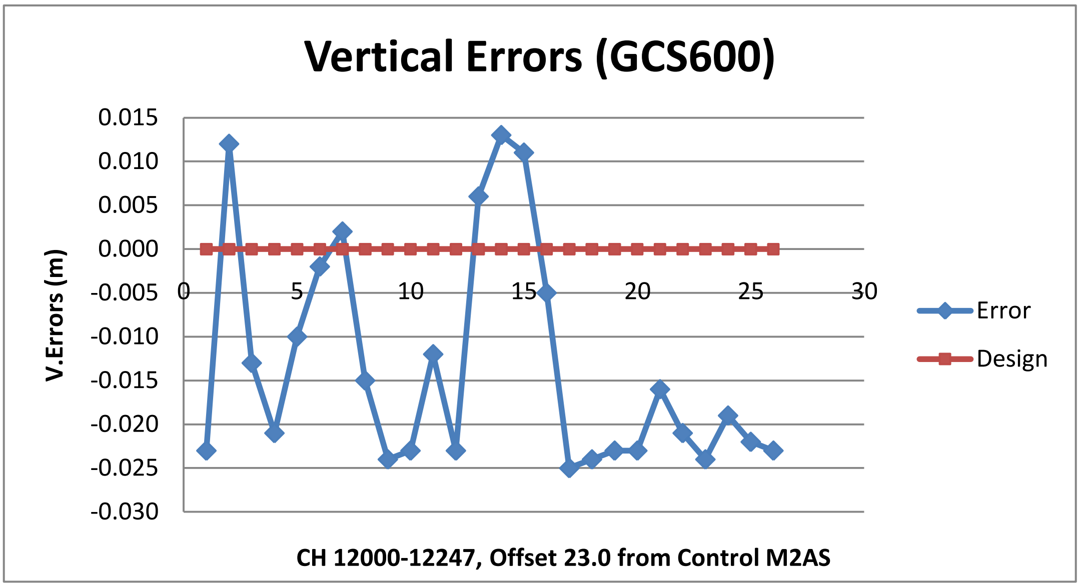
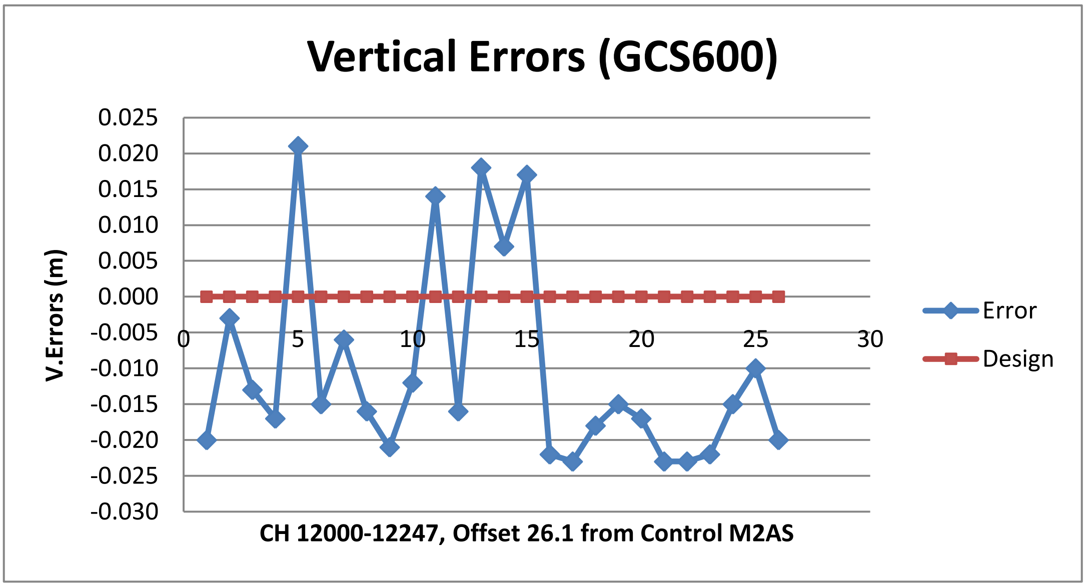



Figure 4.11; *Latency errors-combined GPS machine runs*




### 4.5.2 Trimble ATS5600 results

Figure 4.12 illustrates the errors associated with each point captured during testing. It highlights that there is no systematic error present and the data was ranging between 0.000m to 0.003 as figure 4.12 shows. Also figures 13 to 18 which are general capture, showing the errors in the whole section.

Synchronization is a measure of how closely together in time the various polar coordinated that form the data pocket are measured. If the data is not synchronized, the sensor gives an incorrect position. The size of the error depends on how far apart in time the various components (angle and slope distance) are measured, and the speed and direction of the moving target.

The graph also clearly illustrate that, as the tracking speed of the instrument is increased the accuracy of points captured decreases because of the fact that the instrument is set far away from the moving machine , although it does not appear to be significant at this stage.

*Figure 4.12, vertical errors during 50m interval check.*

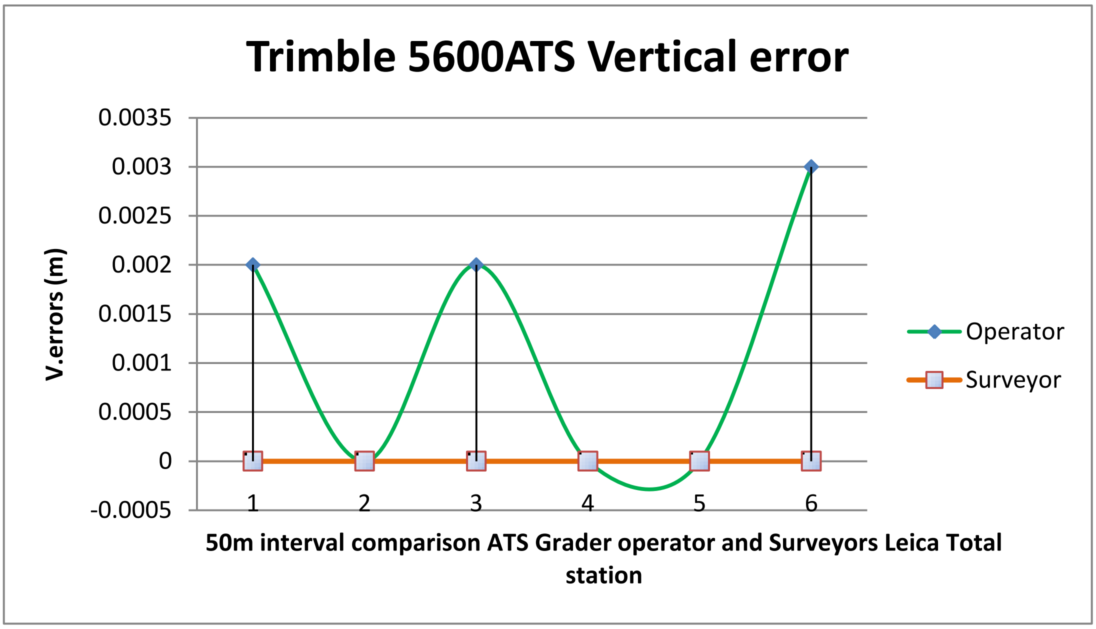



Figure 4.13; *Latency errors-combined ATS Total stations machine runs*

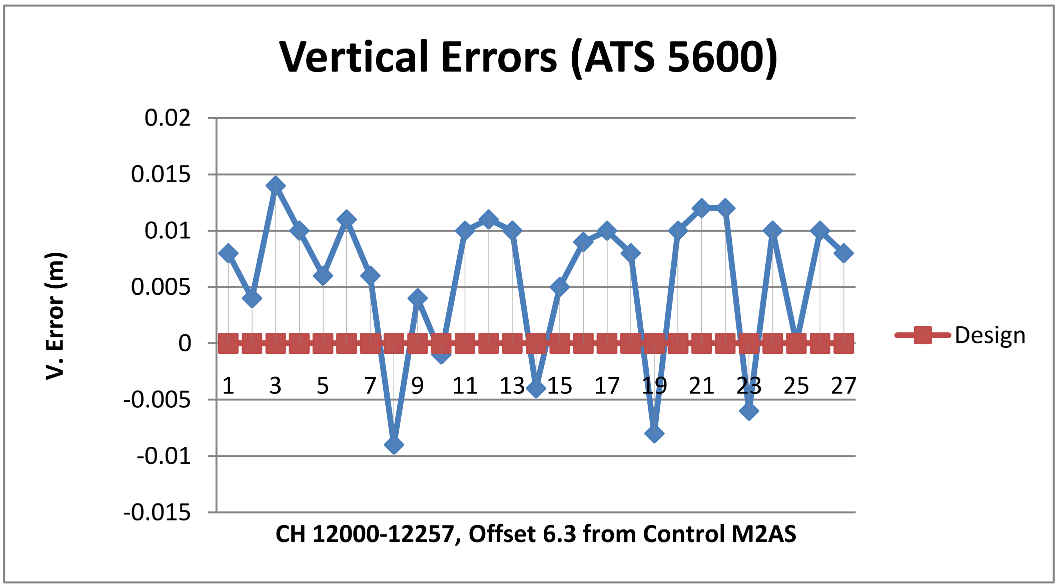


Figure 4.14; *Latency errors-combined ATS Total stations machine runs*

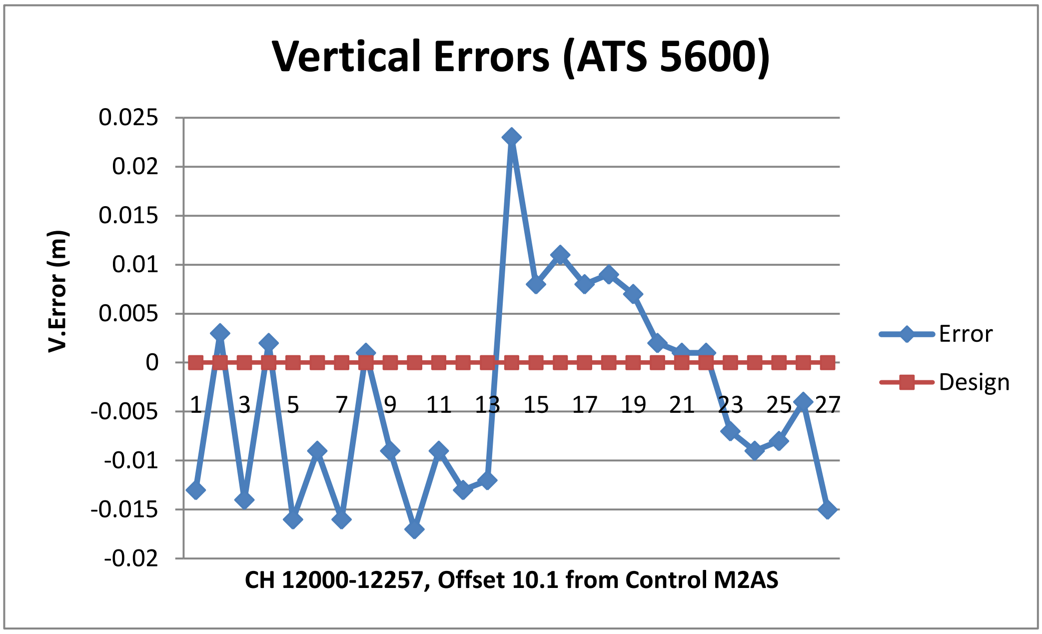



Figure 4.15; *Latency errors-combined ATS Total stations machine runs*

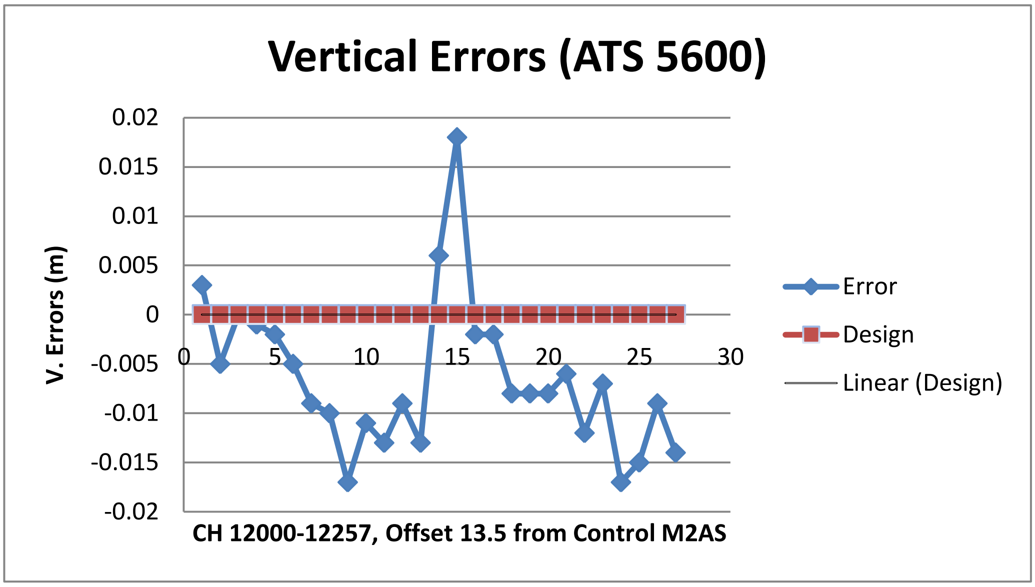


Figure 4.16; *Latency errors-combined GPS machine runs*

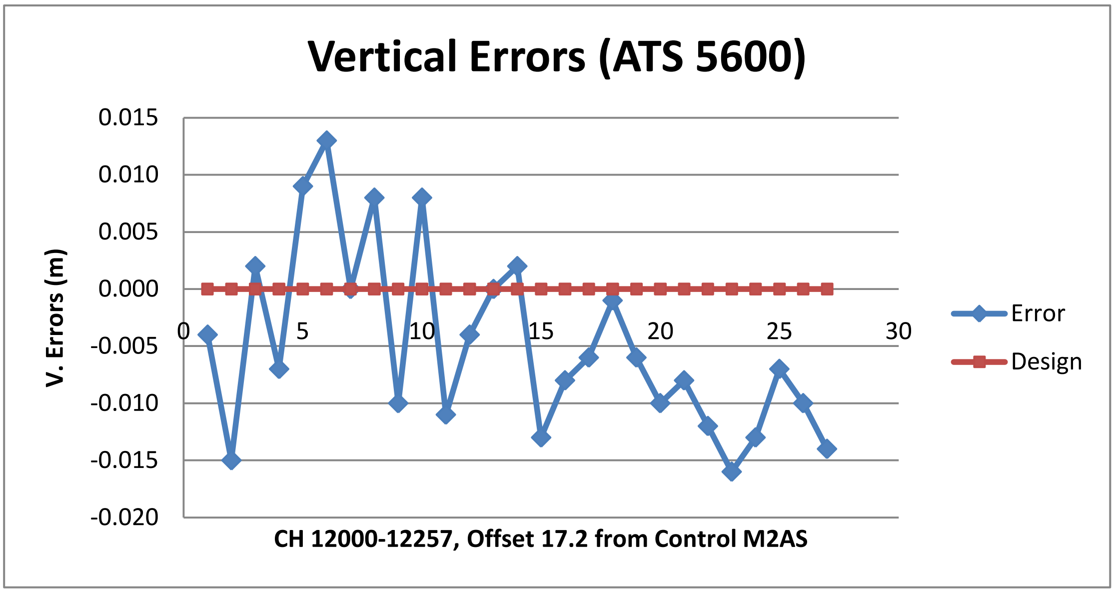



Figure 4.17; *Latency errors-combined ATS Total stations machine runs*

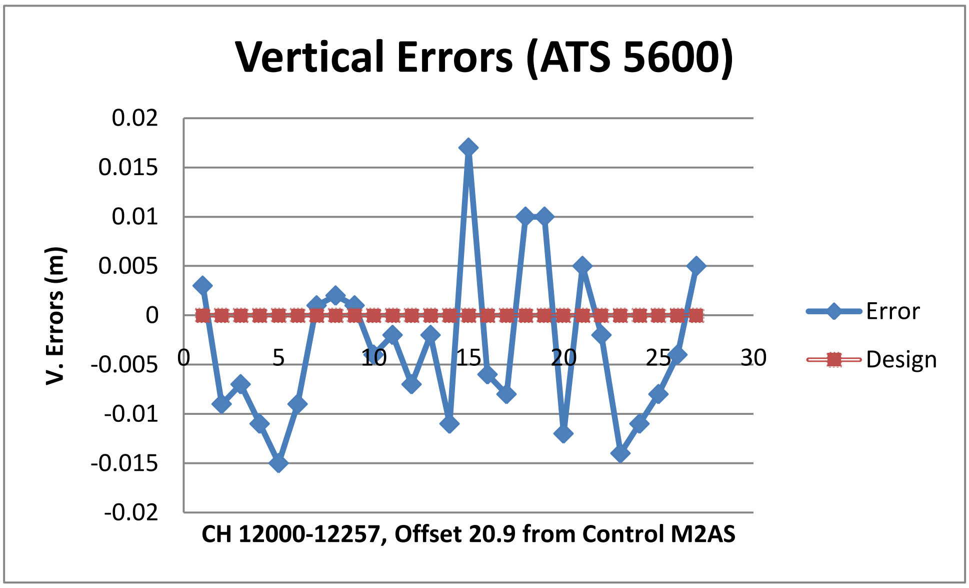
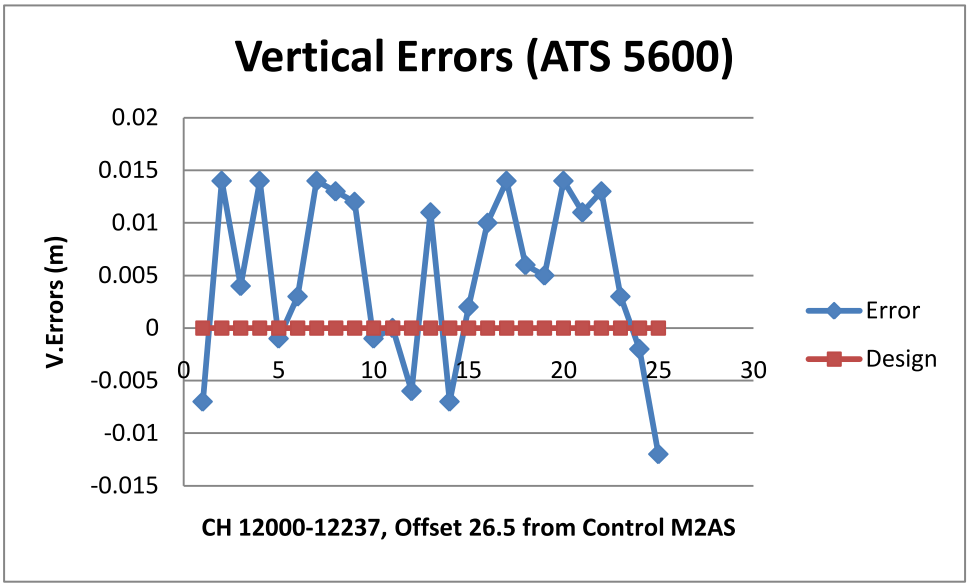


Figure 4.18; *Latency errors-combined ATS Total stations machine runs*




## 4.6 Summary of results

A brief summary of GPS and ATS Total station tests are described on this section. Chapter 4 has presented the method of data analysis that has applied to the data captured as a result of implementation of the methodology and examples outlined on chapter 3. This is the complete description of the methods required to extract useful information regarding latency, position vertical errors in dynamic RTK and ATS total station measurements from raw data files attained in the implementation of the research methodology.

This chapter has also demonstrated that latency is affecting the results that have been obtained from the testing carried out as an integral component of this research. As such, it becomes more important that a further investigation of this effect is thoroughly undertaken; over a greater range of speeds allow potential users to achieve their goals in real time.

As the first chapters elaborated the aim of this project is to determine the accuracy and reliability of machine guidance. Since this project is dealing with one type of instruments; i.e. Trimble ATS5600 Total station and GCS600 GPS systems, it's hard to draw a final conclusion of the errors and reliability during and after field operations.

However, based on the above tests it can be concluded that, the reliability of ATS is greatly related to the speeds of the prism and measurements distances. The ATS tends to lose lock in the higher speed environment at short distance. Also the ATS may not reflect the true centre of the target and this may result in false or bad answer.

Chapter 5 summarises the current status of this research and makes recommendations regarding the continuation of this research project, and also the adaption of methodology described on chapter 3 to different level of speed application.

## 4.7 Discussion

### 4.7.1 Reliability

The reliability of ATS is closely associated with the movement speeds and the distance between setup station and observations area (grader). It has been described earlier that, ATS tends to lose locks in higher speed environment or shorter distance or any other factor.

The accuracy of the results it depends upon the speed of the prism and the experience of the grader operator. The accuracy of the observed data will reduce and sometimes may lead to the dropout signal. The ATS may resume lock to the target within a very short period of time but the result obtained as the asbuilt survey will be affected as there is a lapse in observation result caused by loose lock.

Chapter 4 has also outlined the data analysis process required to extract useful information from the data that collected upon implementation of testing regime developed on this research project, to quantify the latency error in speed environment when using a moving GPS. Chapter 4 also demonstrated that there is some latency error in the gathered data.

### 4.7.2 Accuracy of Tracking

The accuracy of the ATS it's widely depends on prism pointing. If the ATS is not pointing towards the centre of the prism, as described by *Stempfhubber at al*. (2001), it may lead to large variations in the observation results. As pointed out by *Kopacic*, (1998), the ATS should always be measuring to the centre of the prism, see also figure 2.13 and notes 2.5.7 Auto search.

If the prism is moving along the path and the ATS is not pointing directly to the prism, then the measured value will have a large variations impact when analysis of results takes place.

Standard total stations are optimized for static prism measurement; in contrast, synchronization of data from the angle and distance measurement sensors allows output data to be computed for a single instantaneous location of the moving machine. This results in higher 3D position accuracy for dynamic measurements or machine tracking application.

Synchronization is a measure of how closely together in time the various polar coordinated that form the data pocket are measured. If the data is not synchronized, the sensor gives an incorrect position. The size of the error depends on how far apart in time the various components (angle and slope distance) are measured, and the speed and direction of the moving target.

Low latency for complete transmission the precise position of the machine at any given time depends on the age or latency of the positioning data received, if the age of the data is recent and specific.

# CHAPTER 5

# CONCLUSION AND RECOMENDATIONS

## 5.1 Introduction

Several issues have been arisen during this research project and needs to be addressed in the future to come. Chapter five provides an outline of the current status of the research, and also makes the recommendations regarding the continued research and investigation of latency errors in RTK and ATS.

## 5.2 Further Research and Recommendations

### 5.2.1 Testing GCS600 GPS

Following the methodology described in chapter 3, this dissertation has only been possible to utilise GC600 conventional RTK GPS due to the time constraints. Further research efforts required in this specific field of Machine guidance latency measurements, to implement this testing in similar fashion, to analyse the resulting data (in accordance with the practice described herein) to give potential Machine guidance users and understand the effect of latency in high and low speed environment. These effects should then be compared to the results obtained in this research.

### 5.2.2 Additional device (Laser augmented RTK GPS)

As previously mentioned, this research project has also led to the discovery that it is possible to utilise the addition devices that are solid based on their ability to increase the vertical precision of RTK GPS. Such devices are; Laser Augmented Systems (on blade), see also *chapter 2.2.5*.

It is therefore that part of future recommendations on this research project is to have a future version of Laser Augmented RTK GPS which is attached in an onboard software package than having an external devices which increases the weight of the blade if can (this information has been passed on to the manufacturer) .

In advanced cases, the onboard computer can be directly linked to the machine hydraulics, controlling their operation with minimal input from operator.

In addition, value sensors can be added for fully automatic machine control. The slope and elevation of the blade are therefore controlled by the system, not by the machine operator reducing errors and avoiding expensive re-work. These methods are still new in the market and needs more future research because the accuracies and tolerances are still not yet known.

### 5.2.3 Testing at Speeds

According to previous testes described in the previous chapters that, testing is required up to 250km per hour in order to be of use to the precision agricultural community. Therefore future testing is required to investigate latency's and its effect on speeds application to gain more understanding of the relationship. The use of an optional sensor is seen as a very accurate means of referencing the dynamic measurements back to the fixed frame of reference and has therefore been adopted for this research project also.

The methodology and techniques may be used for future testing based on what is described in this dissertation. But it is recognised that modification of this equipment configuration and testing regime is required to facilitate this.

### 5.2.4 Testing Trimble ATS5600

As mentioned earlier in the previous chapters that, due to the time constraints there was only one type of ATS Total station being tested throughout duration of this project and backed up by Leica Total station for data recording. The results shown on chapter 4 were based on Trimble ATS total station.

Similar testes have been conducted before and more research investigations are recommended should be undertaken in order to obtain more accurate results.

It has been recommended by *Trimble (2004),* that the minimum distance to the survey instrument should be atleast 100m for a moving speed of less than 5m/sec. During testing , the moving speed was almost the same as stated speed however the ATS seemed to achieve a great results regardless to the changes of weather.

## 5.3 Conclusion

These days, the major applications of 3D machines guidance can be found in the construction and mining industries for the guidance of dozers, rollers, graders, excavators and tractors. As mentioned earlier, the ATS, RTS have been in the market since 1990s and yet still a little information's available about their real time operations.

It has been pointed out by *Retscher, (2002)* that for the guidance of road and paving machine, high precision requirement for the height components are still very challenging for the 3D machine guidance systems. In order to achieve this level of precision and replace conventional labour intensive in this type of application, present 3D systems require further improvement.

There is a limitation of ATS when carrying out measurements. The ATS does not point direct to the centre of the prism. This could be one of the causes of the errors during field operations.

Approximately 94% of the measured value tests have passed the manufactures specification for ATS total stations and 91% for the Trimble GPS. The accuracies achieved by ATS5600 Total station and GPS would comply with the majority of construction accuracy requirements. The reliability of the instruments is also good under these conditions with only 10 percent falling outside the manufactured specifications.

Chapter 5 presents various recommendations regarding possible future direction for ongoing research into the effect of latency when using machine guidance. The methodology developed in this dissertation required for future continuation of further research to investigate the effect of latencies when using machines guidance.

In conclusion, the author believes that the latency caused by distance time measurements in ATS is the most critical factor associated with an ATS performance in terms of accuracy and reliability.

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# APPENDICES

## APPENDIX A; Project Specification

# University of Southern Queensland

## FACULTY OF ENGINEERING AND SURVEYING

## ENG 4111/4112 Research Project

## PROJECT SPECIFICATION

FOR: **Said Kiongoli**

TOPIC: TESTING THE ACCURACY OF MACHINE GUIDANCE IN ROAD CONSTRUCTION.

SUPERVISOR: Mr Shane Simmons

SPONSORSHIP: Multi Surveying Company

PROJECT AIM: The aim of this project is to test the accuracy and reliability of Machine Guidance when used in road construction.

**PROGRAMME: (Issue A, 23rd March 2010)**

1. Research the background information in relation to Machine Guidance

2. Review existing history concerned Real time and manual guidance systems.

3. Establish and conduct a series of testing under various conditions.

3. Undertaking analysis of test results and determining the final accuracies of machine guidance systems.

6. Conclusion and submit an academic dissertation on the research.

*As time permits:*

7. Research a better system (Machine Guidance) that will reduce the errors in road construction industry.

AGREED:

Said Kiongoli (Student) _________________, _________________ (Supervisors)

23/03/2010 ___/___/______ ___/___/______

Examiner/Co-examiner: ________________________________________

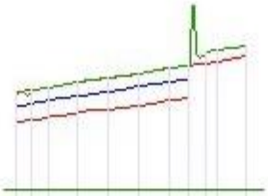
## APPENDIX B; Safe Work Method Statement and Risk Assessment

## Safe Work Method Statement and Risk Assessment

| Activity | Possible Hazards | Risk Ranking | Procedure and Controls | Who insures it happens | Risk ranking (Post Control) |
|---|---|---|---|---|---|
| Travelling to and From site | Vehicle accident | 1A | • Comply with road rules<br>• Comply with company drugs and Alcohol policy<br>• Check vehicle oil and water regularly<br>• Vehicle maintained regularly | Driver (Me) | 1C |
| Driving-around site | Vehicle accident | 1A | • Do not drive across the steep slopes<br>• Be aware of vehicle capabilities<br>• Engage low gear when travelling down steep grades<br>• Follow contractors traffic control directions and speeds<br>• Wear seat belts at all times while in the vehicle | Driver (Me) | 1C |
| Working in the sun | U/V exposure<br>Heat stress<br>Cancer/skin | 2A | • Wear sunglasses and sunscreen<br>• Wear neck covers under safety helmets or wide brimmed hats<br>• Wear long sleeve shirt and long pants<br>• Replace fluids | Spatial scientist (me) | 3C |
| Working on slippery unstable surface | Slipping, tripping<br>Falling | 2A | • If possible avoid the area; otherwise inspect the surface carefully before proceeding with the survey or access.<br>• Do not work in areas "tapped off" or otherwise | Spatial scientist (me) | 3C |

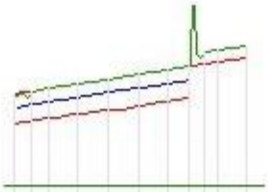
| | | | | | |
|---|---|---|---|---|---|
| Working near machinery | -Vehicle impact<br><br>-Respiratory irritation | 1B<br><br>3A | indicated as unstable.<br>• Wear high visibility vests<br>• Wear safety boots and helmets<br>• Wear dust mask<br>• Make the operator aware of your presence<br>• Observe safety signs and follow specific direction from contractor<br>• Work outside operating range of machine while in operation | Spatial scientist (me) | 1C<br><br>3C |

## APPENDIX C;   Cross Sections

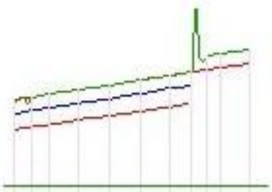
Datum 10

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| design 12030 Control M2AS | 12.218 | 12.308 | 12.368 | 12.473 | 12.584 | 12.698 | 12.801 | 12.873 | 13.198 | 13.238 | 13.343 |
| FL on Grade | 12.248 | 12.308 | 12.368 | 12.473 | 12.584 | 12.696 | 12.801 | 12.873 | 12.931 | 12.973 | 13.078 |
| CTB Layer ATS PLaced | | 11.998 | 12.064 | 12.163 | 12.275 | 12.392 | 12.498 | 12.552 | | | |
| UCE Layer GPS Placed | | 11.624 | 11.685 | 11.786 | 11.874 | 11.964 | 12.072 | | | | |
| Offsets Control M2AS | -24.166 | -22.156 | -20.156 | -16.656 | -12.956 | -9.256 | -5.756 | -3.356 | -1.400 | 0.000 | 3.500 |



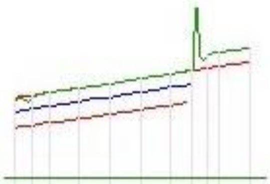
Datum 10

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| design 12040 Control M2AS | 12.098 | 12.188 | 12.248 | 12.353 | 12.464 | 12.575 | 12.680 | 12.752 | 13.095 | 13.137 | 13.242 |
| FL on Grade | 12.127 | 12.188 | 12.248 | 12.353 | 12.464 | 12.575 | 12.680 | 12.752 | 12.811 | 12.853 | 12.958 |
| CTB Layer ATS PLaced | | 11.879 | 11.942 | 12.043 | 12.152 | 12.276 | 12.377 | 12.434 | | | |
| UCE Layer GPS Placed | | 11.501 | 11.556 | 11.667 | 11.756 | 11.843 | 11.954 | | | | |
| Offsets Control M2AS | -24.176 | -22.166 | -20.166 | -16.666 | -12.966 | -9.266 | -5.766 | -3.366 | -1.400 | 0.000 | 3.500 |



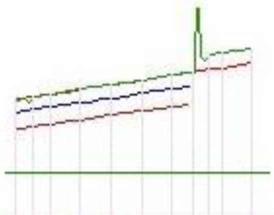
Datum 10

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| design 12050 Control M2AS | 11.988 | 12.056 | 12.116 | 12.221 | 12.332 | 12.443 | 12.548 | 12.620 | 12.985 | 13.027 | 13.132 |
| FL on Grade | 11.995 | 12.056 | 12.116 | 12.221 | 12.332 | 12.443 | 12.548 | 12.620 | 12.679 | 12.721 | 12.826 |
| CTB Layer ATS PLaced | | 11.746 | 11.817 | 11.913 | 12.011 | 12.144 | 12.249 | | | | |
| UCE Layer GPS Placed | | 11.368 | 11.418 | 11.518 | 11.619 | 11.729 | 11.826 | | | | |
| Offsets Control M2AS | -24.185 | -22.175 | -20.175 | -16.675 | -12.975 | -9.275 | -5.775 | -3.375 | -1.400 | 0.000 | 3.500 |



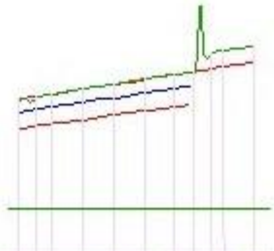
Datum 10

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| design 12060 Control M2AS | 11.822 | 11.912 | 11.972 | 12.078 | 12.189 | 12.300 | 12.405 | 12.477 | 12.864 | 12.906 | 13.011 |
| FL on Grade | 11.852 | 11.912 | 11.972 | 12.078 | 12.189 | 12.300 | 12.405 | 12.477 | 12.536 | 12.578 | 12.683 |
| CTB Layer ATS PLaced | | 11.606 | 11.674 | 11.774 | 11.872 | 11.993 | 12.105 | | | | |
| UCE Layer GPS Placed | 11.162 | 11.225 | 11.286 | 11.374 | 11.479 | 11.574 | 11.690 | | | | |
| Offsets Control M2AS | -24.194 | -22.184 | -20.184 | -16.684 | -12.984 | -9.284 | -5.784 | -3.384 | -1.400 | 0.000 | 3.500 |



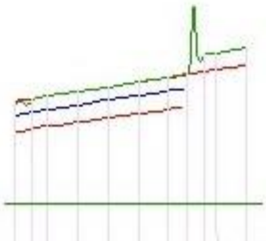
Datum 10

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| design 12070 Control M2AS | 11.668 | 11.758 | 11.818 | 11.923 | 12.034 | 12.145 | 12.250 | 12.322 | 12.733 | 12.775 | 12.860 |
| FL on Grade | 11.698 | 11.758 | 11.818 | 11.923 | 12.034 | 12.145 | 12.250 | 12.322 | 12.382 | 12.424 | 12.529 |
| CTB Layer ATS Placed | | 11.462 | 11.525 | 11.621 | 11.723 | 11.833 | 11.947 | | | | |
| UCE Layer GPS Placed | 11.011 | 11.072 | 11.131 | 11.225 | 11.324 | 11.416 | 11.533 | | | | |
| Offsets Control M2AS | -24.204 | -22.194 | -20.194 | -16.694 | -12.994 | -9.294 | -5.794 | -3.394 | -1.400 | 0.000 | 3.500 |



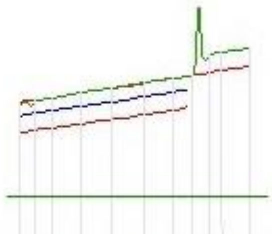
Datum 9

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| design 12080 Control M2AS | 11.502 | 11.592 | 11.652 | 11.757 | 11.868 | 11.980 | 12.085 | 12.157 | 12.591 | 12.633 | 12.738 |
| FL on Grade | 11.532 | 11.592 | 11.652 | 11.757 | 11.868 | 11.980 | 12.085 | 12.157 | 12.217 | 12.259 | 12.364 |
| CTB Layer ATS Placed | | 11.298 | 11.361 | 11.459 | 11.560 | 11.667 | 11.781 | | | | |
| UCE Layer GPS Placed | | 10.906 | 10.958 | 11.050 | 11.162 | 11.251 | 11.354 | | | | |
| Offsets Control M2AS | -24.213 | -22.203 | -20.203 | -16.703 | -13.003 | -9.303 | -5.803 | -3.403 | -1.400 | 0.000 | 3.500 |



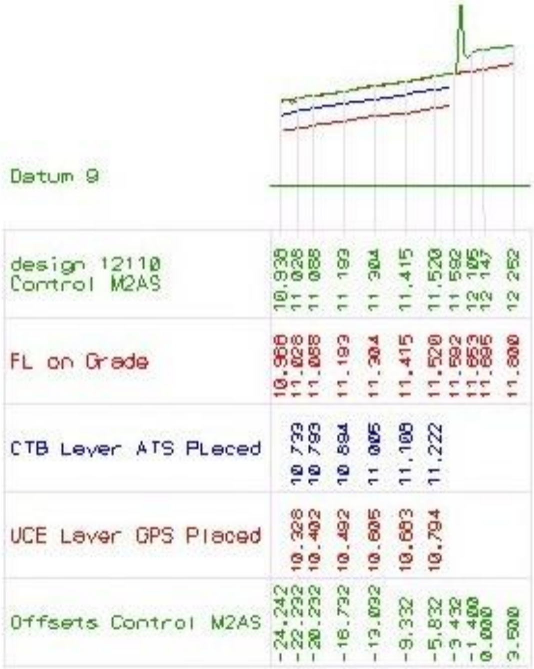
Datum 9

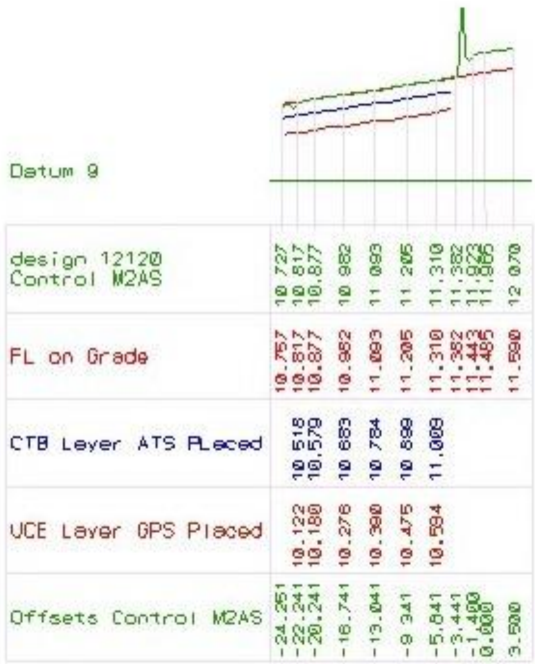
| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| design 12090 Control M2AS | 11.325 | 11.415 | 11.475 | 11.581 | 11.692 | 11.803 | 11.908 | 11.980 | 12.440 | 12.482 | 12.587 |
| FL on Grade | 11.355 | 11.415 | 11.475 | 11.581 | 11.692 | 11.803 | 11.908 | 11.980 | 12.040 | 12.082 | 12.187 |
| CTB Layer ATS Placed | | 11.115 | 11.182 | 11.283 | 11.382 | 11.493 | 11.605 | | | | |
| UCE Layer GPS Placed | | 10.726 | 10.787 | 10.887 | 10.981 | 11.069 | 11.177 | | | | |
| Offsets Control M2AS | -24.223 | -22.213 | -20.213 | -16.713 | -13.013 | -9.313 | -5.813 | -3.413 | -1.400 | 0.000 | 3.500 |

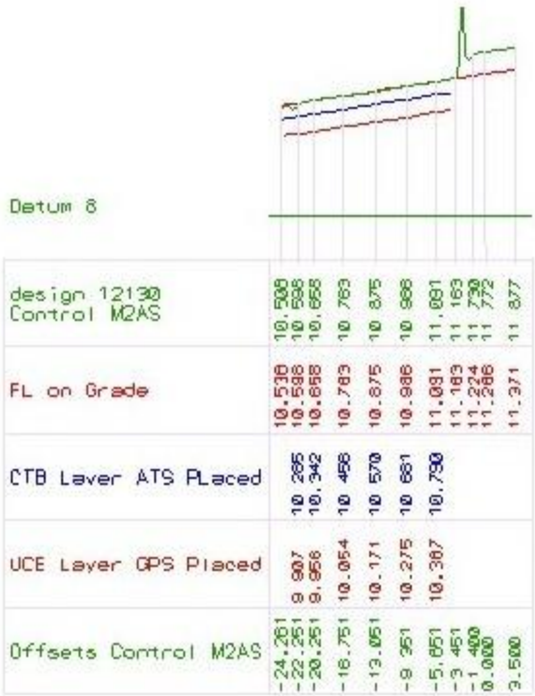


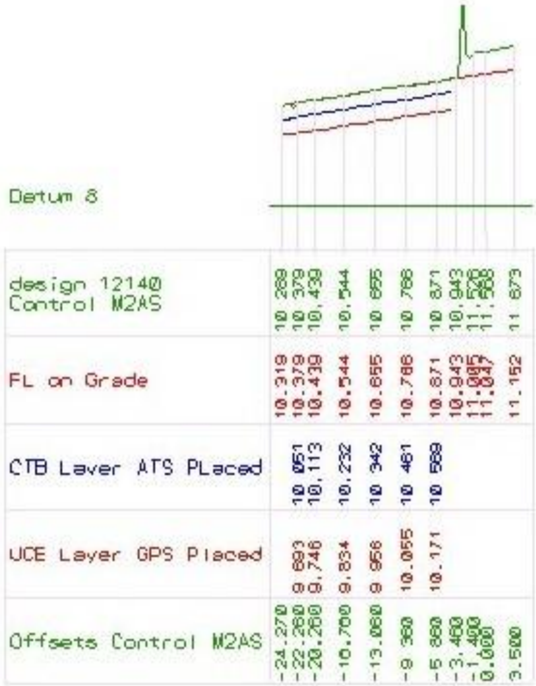
Datum 9

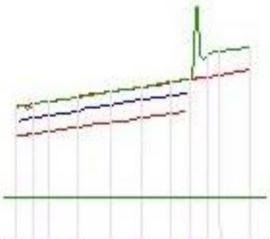
| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| design 12100 Control M2AS | 11.137 | 11.227 | 11.287 | 11.392 | 11.503 | 11.615 | 11.720 | 11.792 | 12.278 | 12.320 | 12.425 |
| FL on Grade | 11.167 | 11.227 | 11.287 | 11.392 | 11.503 | 11.615 | 11.720 | 11.792 | 11.852 | 11.894 | 11.999 |
| CTB Layer ATS Placed | | 10.927 | 10.994 | 11.093 | 11.192 | 11.306 | 11.418 | | | | |
| UCE Layer GPS Placed | | 10.534 | 10.597 | 10.683 | 10.783 | 10.881 | 10.995 | | | | |
| Offsets Control M2AS | -24.232 | -22.222 | -20.222 | -16.722 | -13.022 | -9.322 | -5.822 | -3.422 | -1.400 | 0.000 | 3.500 |


Datum 9
design 12110 Control M2AS
10.938 11.028 11.088 11.193 11.304 11.415 11.520 11.592 12.105 12.147 12.252
FL on Grade
10.968 11.028 11.088 11.193 11.304 11.415 11.520 11.592 11.653 11.695 11.800
CTB Layer ATS PLaced
10.733 10.793 10.894 11.005 11.108 11.222
UCE Layer GPS Placed
10.328 10.402 10.492 10.605 10.683 10.794
Offsets Control M2AS
-24.242 -22.232 -20.232 -16.732 -13.032 -9.332 -5.832 -3.432 -1.400 0.000 3.500


Datum 9
design 12120 Control M2AS
10.727 10.817 10.877 10.982 11.093 11.205 11.310 11.382 11.923 11.965 12.070
FL on Grade
10.757 10.817 10.877 10.982 11.093 11.205 11.310 11.382 11.443 11.485 11.590
CTB Layer ATS PLaced
10.518 10.579 10.683 10.784 10.899 11.009
UCE Layer GPS Placed
10.122 10.180 10.276 10.390 10.475 10.594
Offsets Control M2AS
-24.251 -22.241 -20.241 -16.741 -13.041 -9.341 -5.841 -3.441 -1.400 0.000 3.500

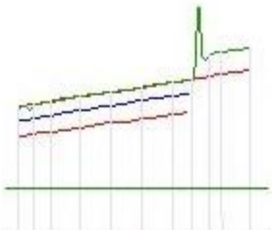

Datum 8
design 12130 Control M2AS
10.508 10.598 10.658 10.763 10.875 10.986 11.091 11.163 11.730 11.772 11.877
FL on Grade
10.538 10.598 10.658 10.763 10.875 10.986 11.091 11.163 11.224 11.266 11.371
CTB Layer ATS PLaced
10.285 10.342 10.458 10.570 10.681 10.790
UCE Layer GPS Placed
9.907 9.956 10.054 10.171 10.275 10.387
Offsets Control M2AS
-24.261 -22.251 -20.251 -16.751 -13.051 -9.351 -5.851 -3.451 -1.400 0.000 3.500


Datum 8
design 12140 Control M2AS
10.289 10.379 10.439 10.544 10.655 10.766 10.871 10.943 11.528 11.568 11.673
FL on Grade
10.319 10.379 10.439 10.544 10.655 10.766 10.871 10.943 11.005 11.047 11.152
CTB Layer ATS PLaced
10.051 10.113 10.232 10.342 10.461 10.569
UCE Layer GPS Placed
9.693 9.746 9.834 9.956 10.055 10.171
Offsets Control M2AS
-24.270 -22.260 -20.260 -16.760 -13.060 -9.360 -5.860 -3.460 -1.400 0.000 3.500



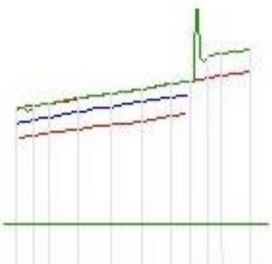
Datum 8

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| design 12150 Control M2AS | 10.099 | 10.159 | 10.219 | 10.324 | 10.436 | 10.547 | 10.652 | 10.724 | 11.313 | 11.355 | 11.460 |
| FL on Grade | 10.099 | 10.159 | 10.219 | 10.324 | 10.436 | 10.547 | 10.652 | 10.724 | 10.798 | 10.828 | 10.933 |
| CTB Layer ATS PLaced | | 9.829 | 9.895 | 9.997 | 10.137 | 10.249 | 10.347 | | | | |
| UCE Layer GPS Placed | | 9.473 | 9.530 | 9.625 | 9.726 | 9.826 | 9.940 | | | | |
| Offsets Control M2AS | -24.280 | -22.270 | -20.270 | -16.770 | -13.070 | -9.370 | -5.670 | -3.470 | -1.400 | 0.000 | 3.500 |



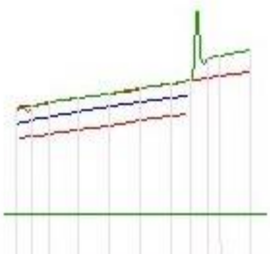
Datum 8

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| design 12160 Control M2AS | 9.850 | 9.940 | 10.000 | 10.105 | 10.216 | 10.327 | 10.432 | 10.504 | 11.089 | 11.131 | 11.236 |
| FL on Grade | 9.850 | 9.940 | 10.000 | 10.105 | 10.216 | 10.327 | 10.432 | 10.504 | 10.587 | 10.609 | 10.714 |
| CTB Layer ATS PLaced | | 9.609 | 9.670 | 9.797 | 9.912 | 10.025 | 10.131 | | | | |
| UCE Layer GPS Placed | | 9.252 | 9.309 | 9.398 | 9.507 | 9.601 | 9.704 | | | | |
| Offsets Control M2AS | -24.289 | -22.279 | -20.279 | -16.779 | -13.079 | -9.379 | -5.879 | -3.479 | -1.400 | 0.000 | 3.500 |



Datum 7

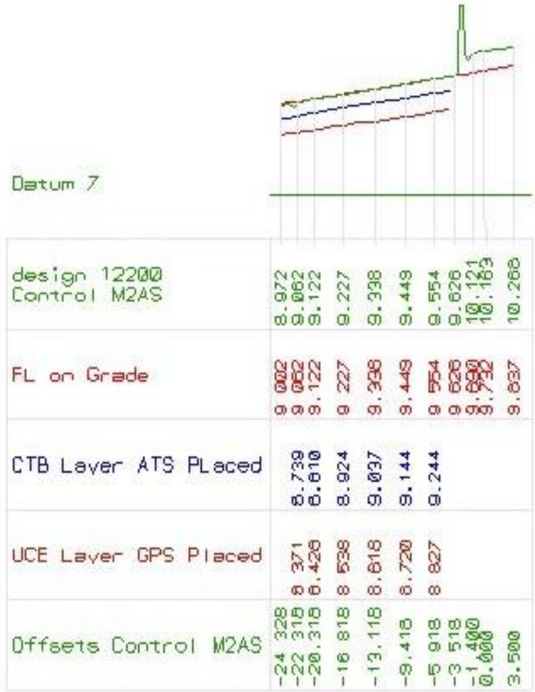
| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| design 12170 Control M2AS | 9.630 | 9.720 | 9.780 | 9.886 | 9.997 | 10.108 | 10.213 | 10.285 | 10.854 | 10.896 | 11.001 |
| FL on Grade | 9.660 | 9.720 | 9.780 | 9.886 | 9.997 | 10.108 | 10.213 | 10.285 | 10.348 | 10.390 | 10.495 |
| CTB Layer ATS PLaced | | 9.390 | 9.456 | 9.584 | 9.691 | 9.798 | 9.900 | | | | |
| UCE Layer GPS Placed | | 9.025 | 9.069 | 9.168 | 9.261 | 9.373 | 9.460 | | | | |
| Offsets Control M2AS | -24.299 | -22.289 | -20.289 | -16.789 | -13.089 | -9.389 | -5.889 | -3.489 | -1.400 | 0.000 | 3.500 |



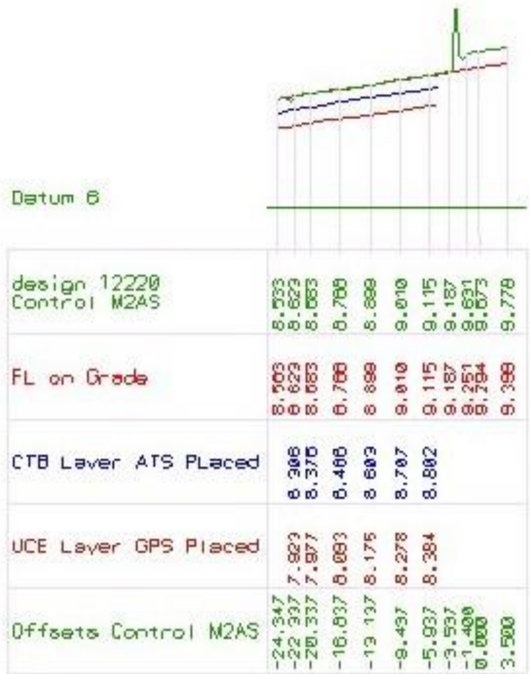
Datum 7

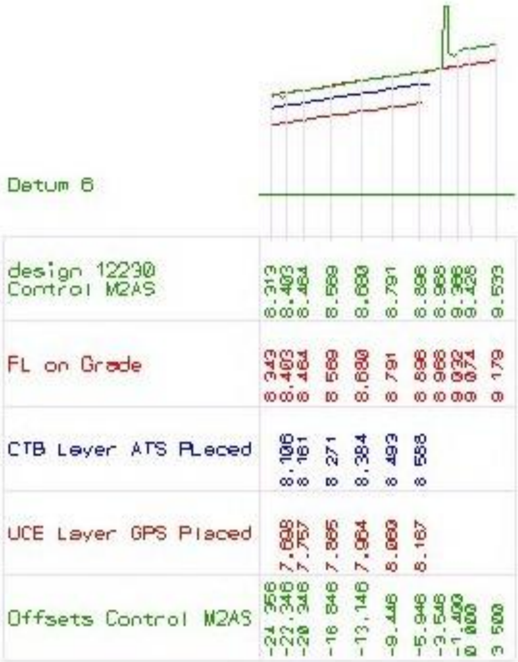
| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| design 12180 Control M2AS | 9.411 | 9.501 | 9.561 | 9.666 | 9.777 | 9.888 | 9.993 | 10.065 | 10.011 | 10.653 | 10.758 |
| FL on Grade | 9.441 | 9.501 | 9.561 | 9.666 | 9.777 | 9.888 | 9.993 | 10.065 | 10.128 | 10.170 | 10.275 |
| CTB Layer ATS PLaced | | 9.165 | 9.243 | 9.369 | 9.470 | 9.568 | 9.673 | | | | |
| UCE Layer GPS Placed | | 8.801 | 8.858 | 8.956 | 9.045 | 9.155 | 9.262 | | | | |
| Offsets Control M2AS | -24.308 | -22.298 | -20.298 | -16.798 | -13.098 | -9.398 | -5.898 | -3.498 | -1.400 | 0.000 | 3.500 |


Datum 7
design 12190
Control M2AS
9.191 9.281 9.341 9.447 9.558 9.669 9.774 9.846 10.388 10.408 10.513
FL on Grade
9.221 9.281 9.341 9.447 9.558 9.669 9.774 9.846 9.909 9.951 10.056
CTB Layer ATS PLaced
8.945 9.027 9.145 9.255 9.359 9.459
UCE Layer GPS Placed
8.582 8.640 8.761 8.844 8.936 9.043
Offsets Control M2AS
-24.318 -22.308 -20.308 -16.808 -13.108 -9.408 -5.908 -3.508 -1.400 0.000 3.500

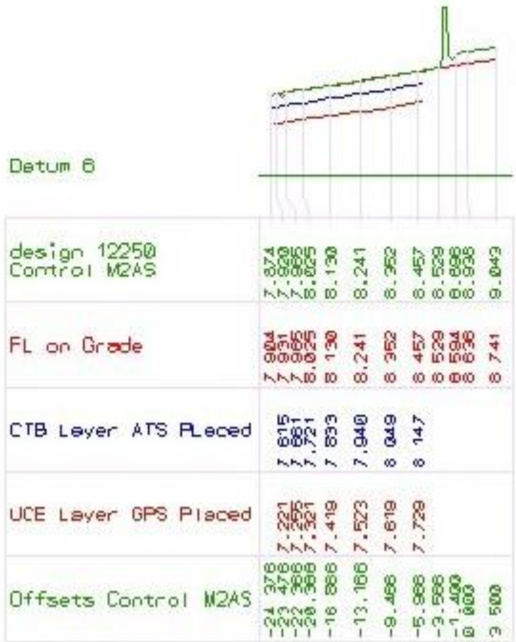

Datum 7
design 12200
Control M2AS
8.972 9.062 9.122 9.227 9.338 9.449 9.554 9.626 10.121 10.163 10.268
FL on Grade
9.002 9.062 9.122 9.227 9.338 9.449 9.554 9.626 9.690 9.732 9.837
CTB Layer ATS PLaced
8.739 8.810 8.924 9.037 9.144 9.244
UCE Layer GPS Placed
8.371 8.428 8.538 8.618 8.720 8.827
Offsets Control M2AS
-24.328 -22.318 -20.318 -16.818 -13.118 -9.418 -5.918 -3.518 -1.400 0.000 3.500


Datum 7
design 12210
Control M2AS
8.752 8.842 8.902 9.008 9.119 9.230 9.335 9.407 9.878 9.918 10.023
FL on Grade
8.782 8.842 8.902 9.008 9.119 9.230 9.335 9.407 9.471 9.513 9.618
CTB Layer ATS PLaced
8.517 8.592 8.706 8.819 8.918 9.023
UCE Layer GPS Placed
8.151 8.200 8.317 8.415 8.502 8.606
Offsets Control M2AS
-24.337 -22.327 -20.327 -16.827 -13.127 -9.427 -5.927 -3.527 -1.400 0.000 3.500


Datum 6
design 12220
Control M2AS
8.533 8.623 8.683 8.788 8.899 9.010 9.115 9.187 9.631 9.673 9.778
FL on Grade
8.563 8.623 8.683 8.788 8.899 9.010 9.115 9.187 9.251 9.294 9.398
CTB Layer ATS PLaced
8.306 8.376 8.488 8.603 8.707 8.802
UCE Layer GPS Placed
7.923 7.977 8.093 8.175 8.278 8.384
Offsets Control M2AS
-24.347 -22.337 -20.337 -16.837 -13.137 -9.437 -5.937 -3.537 -1.400 0.000 3.500


Datum 6
design 12230
Control M2AS
FL on Grade
CTB Layer ATS Placed
UCE Layer GPS Placed
Offsets Control M2AS


Datum 6
design 12240
Control M2AS
FL on Grade
CTB Layer ATS Placed
UCE Layer GPS Placed
Offsets Control M2AS


Datum 6
design 12250
Control M2AS
FL on Grade
CTB Layer ATS Placed
UCE Layer GPS Placed
Offsets Control M2AS


Datum 5
design 12260
Control M2AS
FL on Grade
CTB Layer ATS Placed
UCE Layer GPS Placed
Offsets Control M2AS

# APPENDIX C; Trimble ATS5600 Notes

## Trimble ATS

| GENERAL TRIMBLE ATS | | | |
|---|---|---|---|
| Control Unit (detachable): | 33 key Alphanumeric keyboard<br>4 row illuminated LCD screen with 20 characters per row<br><br>Standard memory of 5,000 pts<br>Optional memory of 5,000 pts | Data communication interface: | Serial port (RS232 Standard) 9,600 baud<br>Radio modem 4,800 baud<br>Radio range approx. 1,600 m (1 mile)<br>Output 100–500 mW (differs from country to country, depending on local legislation) |
| Tracklight (built-in): | A blinking guide-light which emits a red, white and a green sector. The white sector represents the measuring beam. | Telescope<br>Magnification:<br>Focusing range:<br>Field of view: | Coaxial<br>26 X (30 X optional)<br>1.7 m (5.6 ft) to infinity<br>2.6 m at 100 m (8.6 ft at 330 ft) |
| Aiming: | Servo-drive. Endless fine adjustment | Illuminated crosshair: | Yes |
| Leveling<br>Circular level in tribrach: | 8'/2 mm | Operating temperature: | –20°C to +50°C (–4°F to +122°F) |
| Electronic 2-axis level in the LC-display with a resolution of: | 6" (2 mgon) | Power Supply:<br><br>Input voltage: | External rechargeable NiMH batteries 12 V, 3.5–10.5 Ah<br>12–14 VDC |
| Centering: | Optical plummet in tribrach | Power consumption: | 4.8 W to 10.8 W |
| | | Weight<br>Instrument including Tracker and built in radio:<br>Tribrach: | <br>7.4 kg (16.5 lbs)<br>0.7 kg (1.5 lbs) |

| SURVEYING MODE | | | |
|---|---|---|---|
| Range*<br>One prism:<br>One prism long range mode:<br>Triple prism:<br>Triple prism long range mode: | <br>2,000 m (1.2 miles)<br>2,800 m (1.7 miles)<br>2,800 m (1.7 miles)<br>3,900 m (2.4 miles) | Measuring time<br>Standard measurement:<br>Fast tracking:<br><br>Range in Robotic mode*: | <br>3.5 sec<br>0.4 sec<br><br>Up to 700 m (2,300 ft) depending on type of RMT |
| Angle Measurement<br>Accuracy (standard deviation based on DIN 18723):<br>Automatic dual-axis level compensator range: | <br>1" (0.3 mgon)<br><br>± 6' (100 mgon) | Range in Autolock mode*:<br><br>Shortest search distance:<br><br>Shortest possible range: | Up to 1000 m (3,200 ft) depending on type of RMT<br>1.5 m (5 ft)<br><br>0.2 m (0.7 ft) |
| Angle reading (least count)<br>Arithmetic mean value (D-bar):<br>Standard measurement:<br>Fast tracking: | <br>0.1" (0.01 mgon) (horizontal angle)<br>1" (0.1 mgon)<br>2" (0.5 mgon) | Positioning accuracy at 200 m (1 sigma):<br><br>Search time (typical): | <2 mm (0.007 ft)<br><br><10 sec** |
| Distance Measurement<br>Accuracy<br>Standard measurement:<br>Fast tracking:<br>Light Source: | <br><br>±(3 mm +2 ppm) ±(0.01 ft +2 ppm)<br>±(10 mm +2 ppm) ±(0.03 ft +2 ppm)<br>GaAs diode | Search area:<br><br>Atmospheric correction: | 360° (400 gon), or defined search window<br>–60 to 195 ppm continuously |

*Notes:*

* *Range and accuracy are dependent on atmospheric conditions and background radiation. All specifications refer to the visibility condition "Standard clear" (23 km visibility in overcast or moderate sunlight conditions with no haze).*

** *Dependent on selected search window.*

## ATS MODE FOR MACHINE CONTROL AND DYNAMIC MEASUREMENT APPLICATIONS

| | |
|---|---|
| **Range to target 571233035:** | Up to 700 m (2,300 ft) |
| **Search time (typical):** | <10 sec** |
| **Search area:** | 360° (400 gon), or defined search window |
| **Shortest range (with 571233035 target):** | 15 m (49 ft) |
| **Maximum acceleration of target on short distance** | |
| **Radial acceleration:** | 9°/s² (10 gon/s²) |
| **Maximum velocity of target** | |
| **Radial speed:** | 23°/s (25 gon/s) |
| **Axial speed:** | 6 m/s |
| **Data output** | |
| **Rate:** | 1–6 Hz selectable |
| **Timing:** | ± 1 ms |
| **Latency:** | 183 ms (including Georadio modem)<br>83 ms (Direct RS232 connection) |
| **Synchronized measurement data:** | <5 ms |
| **Accuracy to a target moving at 1 m/s (Standard deviation) ***** | |
| **Horizontal:** | ± 2 mm + 14 ppm (0.007 ft + 14 ppm) |
| **Vertical:** | ± 2 mm + 14 ppm (0.007 ft + 14 ppm) |
| **Slope distance:** | ± 2 mm + 14 ppm (0.007 ft + 14 ppm |

## *Synchronization and Latency*

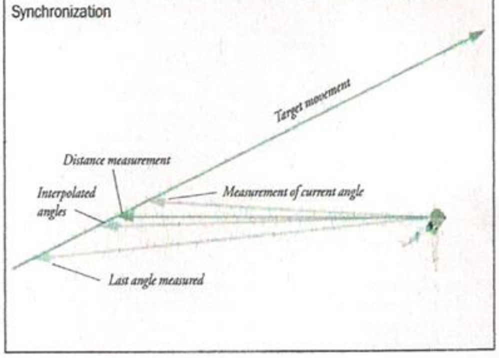
**Synchronization**

Synchonization of data from the angle and distance measurement sensors means that the output data is computed for a single instantaneous location of the moving machine, compared with standard total station instruments that are optimized for static prism measurement. This results in a higher 3D position accuracy for dynamic measurements or machine tracking applications.

**Latency**

The precise position of the machine at any given time is dependent on the age or latency of the positioning data received. If the age of the data is small and specific, the on board application software can compensate for the errors associated with the data age giving a more accurate location of the machine in real time.

Synchronization



# APPENDIX D: Trimble GC600 Notes


| Trimble System | Description | Machine Applications | Positioning Components | Applications |
|---|---|---|---|---|
| TRIMBLE GCS300: SINGLE ELEVATION | Single control system that uses a laser receiver to control the lift of the machine blade | Dozers<br>Graders | Laser<br>Laser receiver<br>Control box | Small housing pads<br>Small building sites<br>Tennis courts<br>Sports fields<br>Finish grading |
| TRIMBLE GCS400: DUAL ELEVATION, OR ELEVATION AND BLADE SLOPE CONTROL | Dual-control system that controls both the lift and tilt of the machine blade | Dozers<br>Graders | Laser<br>2 Laser receiver(s)<br>-or-<br>Laser receiver<br>Slope sensor<br>Control box | Medium/large housing pads<br>Medium/large commercial building sites<br>Road construction<br>Sports fields<br>Finish grading<br>Material balancing<br>Rough grading |
| TRIMBLE GCS500: CROSS-SLOPE CONTROL | Cross-slope control system designed to be used on motor graders for fine grading work | Graders | 2 angle sensors<br>Rotation sensor<br>Control box | Road maintenance<br>Road construction<br>Sports fields<br>Embankments<br>Road ditches |
| TRIMBLE GCS600: CROSS-SLOPE AND ELEVATION CONTROL | Highly flexible cross-slope and elevation control system designed for fine grading work | Graders | 2 angle sensors<br>Rotation sensor<br>Sonic Tracer<br>-or-<br>Laser receiver<br>Control box | Small-to-large housing and building site pads<br>Road construction<br>Highway construction and maintenance<br>Runways<br>Embankments<br>Road ditches |
| TRIMBLE GCS600: GRADE CONTROL SYSTEM FOR EXCAVATORS | Highly flexible system designed for excavation, trenching, grading and profile work | Excavators | Angle sensors<br>Control box | Excavating basements, foundations and footers<br>Flat bottom and simple slope trenching<br>Flat and simple slope grading and embankments<br>Profile excavation and canals or batters |

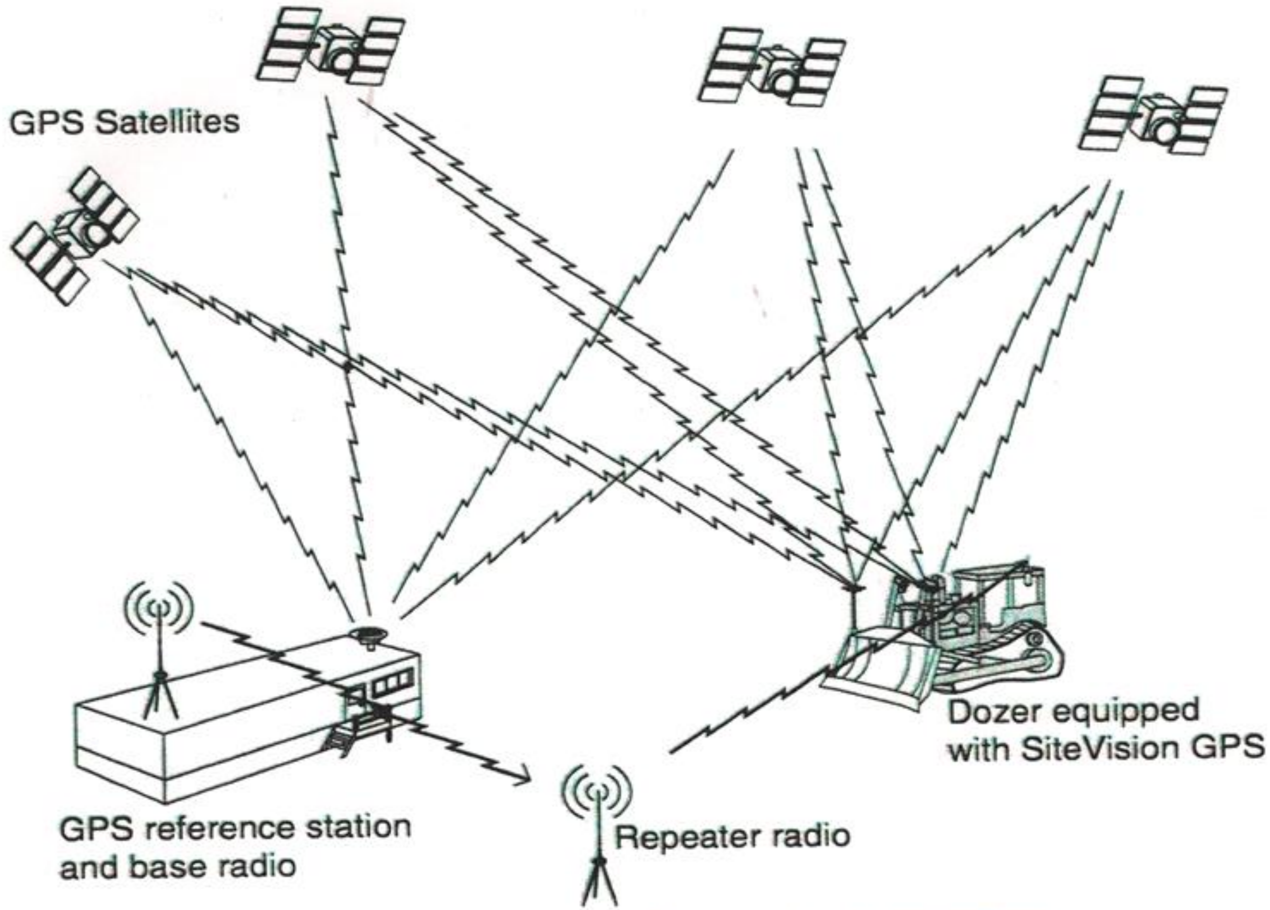
### TRIMBLE SONIC TRACERS

The Trimble ST400 Sonic Tracer mounted to the blade of the motor grader uses a physical reference such as curb and gutter, stringline, existing or previous pass as an elevation reference. Using a sonic tracer, the system can match curves and accurately get to grade in fewer passes. This reduces operator fatigue, saves material and reduces the need for grade checkers.


### TRIMBLE LASER RECEIVERS

The Trimble LR410 Laser Receiver is fully linear and has smooth corrections the full length of the receiver. It is mounted to a mast on the blade and connected to the machine hydraulics to control lift to an accuracy of 3-6 millimeters (0.01 to 0.02 feet). In auto mode, the system uses the LR410 grade information to automatically move the blade up or down to the on grade position.

# Real Time Kinemetic GPS




Repeater for difficult terrain

# APPENDIX E: Digital Terrain Modal (DTM or TIN)

Tin or DTM created using 12d software