DEFORMATION MONITORING USING TOTAL STATIONS: AN EVALUATION OF SYSTEM PERFORMANCE

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Abstract

The importance of carrying out an accurate and efficient monitoring of long-term movements in structures cannot be over-emphasized. Advances in surveying technology have brought about greater operational flexibility, high precision of data capturing and computational technique such that monitoring of small movements is now possible using geodetic instruments.

Total stations are one of the equipments that have been widely used for monitoring of deformations in structures. They are increasingly gaining more prominence due to their relatively economical nature and level of accuracy achievable. Other monitoring equipments include GPS, accelerometers, pseudolites and geotechnical sensors.

This study investigates the potential for the use of three different types of total station namely Leica TCA2003, Leica TS30 and Trimble S6 for structural deformation monitoring. Static tests trials were carried out by simulating a dam around the Nottingham Geospatial Building (NGB) at the University of Nottingham Jubilee Campus. The results were then compared in terms of the actual accuracies obtainable, precision of measurement as well as the speed of monitoring.

Keywords: Total Stations, Deformation, Monitoring, Precision

1.0 Introduction

In recent years, the use of geodetic techniques such as the Global Positioning System and Total stations in deformation monitoring have gained widespread acceptance. The accuracy, versatility and capacity for self-checking make survey measurements from equipment such as total station, a popular choice in deformation monitoring (Chen, 1983). Furthermore, the relative economical nature of total stations in terms of cost of execution, as well as the high accuracy level achievable from total stations measurements has made it an important data acquisition tool for monitoring purpose.

While many geotechnical and other non-geodetic devices for deformation measurements are readily adapted for automated measurements (Chrzanowski,1986), geodetic surveying techniques involving - angle and distance measurements have traditionally been a labour- intensive task with high dependence on the skill and experience of the operator. However, advances in the technology of total stations which has led to the use of precise servomotors, MagDrive technology, piezo technology, combined with automatic target recognition (ATR) capabilities has enabled the new generation of robotic total stations such as the Trimble S6, Leica TS30 and TM30 to achieve angular accuracies of 1", 0.5" and 0.5" respectively at high frequency. Furthermore, the introduction of supportive automated monitoring data processing software such as the Leica GeoMoS (Geodetic Monitoring Software) and APSWin (Automatic Polar System for Windows) has enhanced the use of total stations, as automated measurements can be carried out at a predetermined schedule.

This paper focuses on tests conducted at the University of Nottingham to evaluate the system performance of three types of total stations, as data acquisition tool, for the deformation monitoring of structures. Static trials were designed to compare the attainable accuracies and precisions from data collected by the Leica TCA2003, Leica TS30 and Trimble S6 total stations as a means to evaluating their use for monitoring purpose such as dam monitoring as well as investigating the effect of different prisms, distance and weather conditions on the precision and accuracy of measurements from the total stations.

2.0 Deformation Monitoring Using Total Stations

Total stations have been used to measure the movement of structures and natural processes with good results (Hill and Sippel 2002; Kuhlmann and Glaser 2002; Beshr 2012). Robotic total stations (RTS) can track moving objects and make automatic measurements at rates up to 1Hz. Prisms are mounted on each of the points to be monitored, acting as targets. The total station measures the horizontal and vertical angles and slope distance to each target. From the observations obtained, the easting, northing and height values as well as displacements in the three dimensions are computed. The targeting of the total station to each station is usually achieved by using automatic target recognition (ATR) or signal scan.

The accuracy with which the position of a prism can be determined with ATR is dependent on several factors such as the internal accuracy of the ATR itself, instrument angle accuracy (external accuracy), type of prism, selected EDM measuring program and the external measuring condition. The external accuracy is attained if the measurement is repeated at intervals. The internal accuracy of the ATR depends on the resolution of the CCD (Charge-coupled device) camera, on the time for the measurement, on the condition and position of the prism, and on other factors. It is the accuracy obtainable under optimum conditions at one particular time. Also, the range of ATR is limited by atmospheric conditions (such as rain, fog and dust), the design of the optics, the power of the laser and to a lesser extent, the resolution of the CCD (Leica geosystems, 2009)

If the prisms are outside the range of ATR, the signal scan technique can be used. Signal scan uses the return signal strength from the electronic distance meter (EDM) to identify the edges of the prism. Once the left, right, top and bottom edges of the prism have been found using a horizontal and vertical scan, the centre of the prism can be calculated. With a suitable EDM, the effective range signal scanning is approximately 4 km to a single prism. However, the angular accuracy of the signal scan method is proportional to the range and, due to the characteristics of the EDM signals (whether based on infrared or red laser), is generally at the decimetre level. Also the search procedure makes the measurement process slow, typically taking about two minutes per point compared to 3-4 seconds for ATR (Brown, 2007).

Advantages of using total station for deformation monitoring include:

- High accuracy: Leica Geosystems (2002) quote accuracies of better than 1mm for their bridge and tunnel surveys
- The Automatic Target Recognition (ATR) which provides precise target pointing (Hill and Sippel 2002)
- Autonomous operation once lock to the target has been manually set by an operator.
- Possibility of measuring indoors and in urban canyons (Radovanovic and Teskey, 2001)

Disadvantages of using total station for deformation monitoring include:

- Low sampling rate (the total station-TCA2003, at the University of Nottingham measures at a 1Hz data rate in ATR mode, however Tsakiri, et al. (2003) used a total station that measures at 8Hz.
- An uneven measurement rate
- Problems with measurements in adverse weather condition
- Need for a clear line of sight between the total station and the prism.

3.0 Test Instrumentation

3.1 Total Stations

Three different total stations namely: a Leica TCA2003, a Leica TS30 and a Trimble S6 total station were used in this study. Figures 1a – 1c present the three types of total station used. A comparison of their stated specifications is provided in Table 1.



Fig. 1: (a) Leica TCA2003 (b) Leica TS30 (c) Trimble S6 total stations

Table 1: Comparison of Accuracy Specifications

Measurements	TCA2003	TS30	S6
Angle	0.5″	0.5″	1″
Distance (Prism mode)	1mm+1ppm	0.6mm+1ppm	2mm+2ppm
Display least count	0.1″	0.01″	1″

3.2 Targets

For the study, three types of Leica prism targets (presented in Figures 2a – 2c) were used for comparison purpose.

1) Standard circular prism- Leica GPR111 with prism constant 0 mm.
2) Mini prism- GMP111- 0 mm constant along with the GAD105 adapter.
3) 360° prism- GRZ4 reflector with prism constant +23.1 mm.

Fig. 2: (a) Leica GPR111 (b)Leica GMP111 (c) Leica GRZ4 target

3.3 Processing Software

3.3.1 Leica GeoMoS (Geodetic Monitoring Software)

Leica GeoMoS is a multi-purpose automatic deformation monitoring software that provides an integrated solution by supporting geodetic total stations such as the TCA2003 for continuous, automated measurements and monitoring of structural deformation. The Leica GeoMoS is comprised of two main applications called Monitor and Analyzer. Leica GeoMoS Adjustment is add-on software that allows the user to make decisions based on statistically optimized and validated data.

3.3.2 Leica Geo-Office Software (LGO)

This is an office software consisting of a suite of standard and extended programs for the viewing, exchange and management of data. It supports TS30 instrument as well as all other Leica TPS (Total station Positioning System) instruments.

3.3.3 Trimble Geomatics Office (TGO)

This is an office software that provides a seamless link between field collected data from Trimble S6 and third party design, CAD, and GIS packages.

4.0 Methodology

4.1 Static Tests

With the use of different total stations, targets and measurement of different points, different evaluation was possible. Static tests were undertaken to assess the relative precision and level of consistency obtainable from each of the three total stations under review. This would provide a good indication of the performance of the instruments in real-world conditions, as opposed to the factory-certified instrument ratings that do not reflect the changing atmospheric effects often encountered in practice (Zeiske, 2001).

4.1.1 Monitoring Points

The NGB01 control point at the back of the Nottingham Geospatial building (NGB) was used as the observing station for the study with the NGB02 acting as the backsight. A total of 6 points with point ID NGB02 (serving a dual purpose), 002, 004, 005, 007 and 008 were selected for monitoring during the static trials. The points were chosen in such a way that the effects of varying distance from the observation point on precision and accuracy of measurements can be investigated. Another factor taken into consideration is the stability of the points. This is to ensure that there is consistency in the coordinates computed from the observing station for the duration of the monitoring. The coordinates of the monitoring points are presented in Table 2.

Fig. 3: Google map of the study area showing the NGB and monitoring points

Table 2: Coordinates of monitoring points

PT ID	EASTINGS (m)	NORTHINGS (m)	ELEVATION (m)
NGB01	454978.481	339696.459	30.197
NGB02	454977.327	339723.635	30.521
001	454988.691	339734.062	31.148
002	454995.294	339692.881	30.092
003	455029.052	339647.630	30.063
004	455066.666	339619.002	29.963
005	455082.766	339542.284	30.133
006	455066.553	339550.023	29.920
007	454975.113	339640.303	30.550
008	454914.174	339679.486	29.909

4.2 Instrument Configuration

Leica TCA2003: The TCA2003 was configured in GeoMoS mode via a laptop. The GSI and GeoCom settings with the RS232 interface, part per million (PPM) settings, baud rate as well as the other configurations were verified on the instrument, leaving it in an online mode. At the end of the monitoring period, the results were viewed and analysed in the GeoMoS Analyzer.

Leica TS30: The onboard "set of angles" monitoring application program in the instrument was used. The configuration settings was confirmed, point list created for measurements and monitoring time set. After monitoring the points, the sets of angles and distances were computed and the result stored in the compact Flash (CF) memory card in the instrument. The data was then exported to the Leica Geo-Office (LGO) software for analysis.

Trimble S6: Monitoring of the point was done using the onboard "Measure Rounds" application program on the instrument. The instrument was locked on to all the points for monitoring. The data was then exported to the Trimble Geomatics Office (TGO) software for analysis.

4.3 Effect of Varying Distance on Precision and Accuracy of Measurements

The first static trial carried out was to investigate the effect of an increasing distance on the precision of measurement achievable from each of the instruments. A Leica circular prism was used for this comparison purpose. A summary of the average repeatability of the measurements from the three different total stations is shown in Table 3.

It can be seen from Table 3 that the repeatability of the measurements decreases as the distance increases in all the three instruments. Generally, the precision of the measurement from the TS30 is just slightly better than that of the S6 total station with the exception of point 005. The repeatability of the TCA2003 is about three times worse than both TS30.

Figures 3 and 4 depicts the variation in the easting, northing and height values over varying distance from the TS30 and S6 total stations respectively. The high precise nature of the TS30 measurements is well depicted in Figure 3, showing a fairly regularly pattern of deviations as the distance increases. A similar pattern is observed in Figure 4 for the S6, though of a less regular nature.

For the TCA2003 (Figures 5 a - c), it can be seen that the precision in height determination (vertical angle measurement) is better than the horizontal angle measurement which is why there are deviations in the longitudinal and transverse directions

Table 3: Average repeatability (σ) of the TS30, TCA2003 and S6 using standard circular prism

		TS30 (mm)			**TCA2003(mm)**			**S6 (mm)**		
PT ID	DIST.	**σE**	**σN**	**σH**	**σE**	**σN**	**σH**	**σE**	**σN**	**σH**
2	17.190	0.1	0.1	0.0	0.6	0.0	0.0	0.3	0.1	0.0
NGB02	27.200	0.1	0.1	0.1	0.5	0.0	0.0	0.0	0.2	0.1
7	56.262	0.2	0.1	0.1	0.7	0.0	0.0	0.1	0.2	0.2
8	66.450	0.1	0.2	0.2	0.5	1.0	0.0	0.2	0.2	0.2
4	117.367	0.1	0.1	0.4	0.4	0.4	0.8	0.3	0.3	0.5
5	186.127	0.7	0.5	1.4	1.0	1.0	0.5	0.4	0.5	0.7

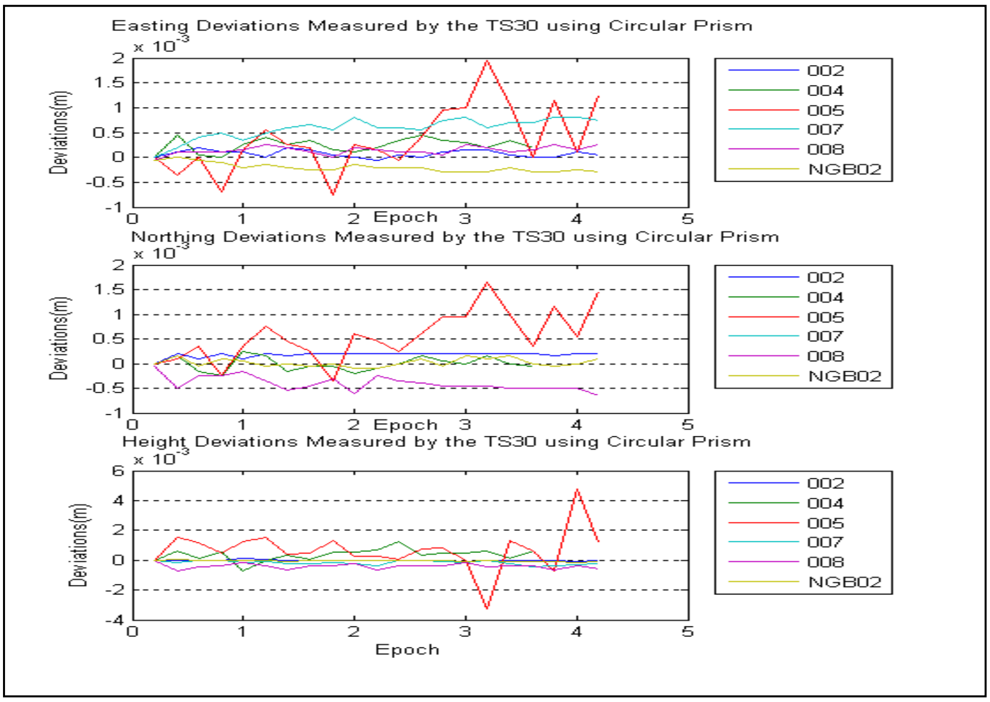

Fig. 3: Deviation pattern in 3D coordinates over varying length for TS30

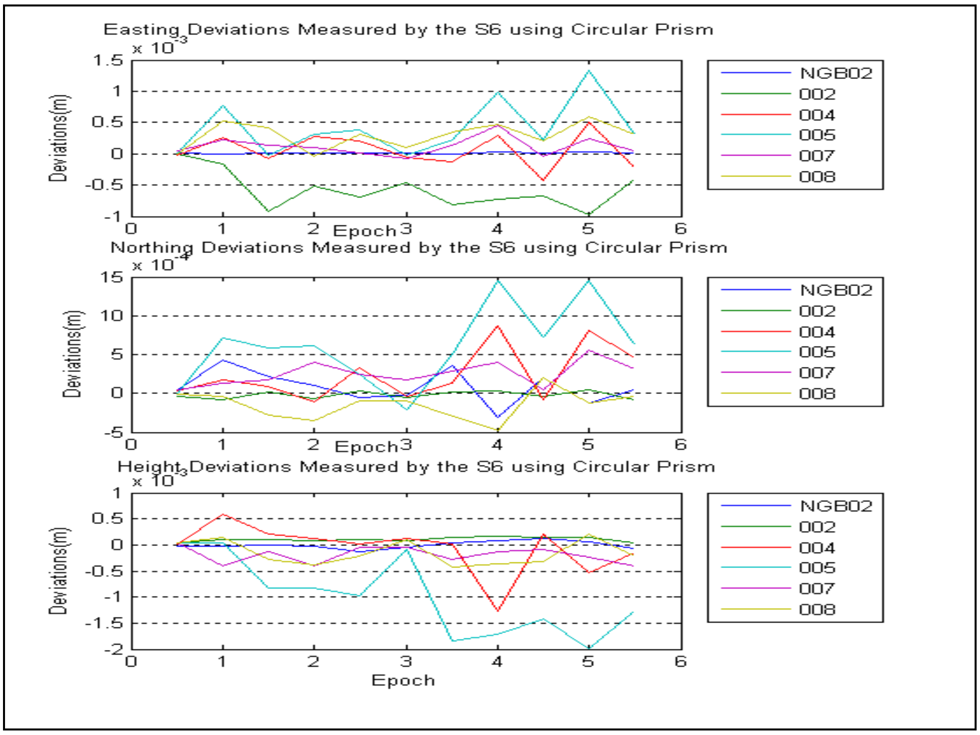

Fig. 4: Deviation pattern in 3D coordinates over varying length for S6

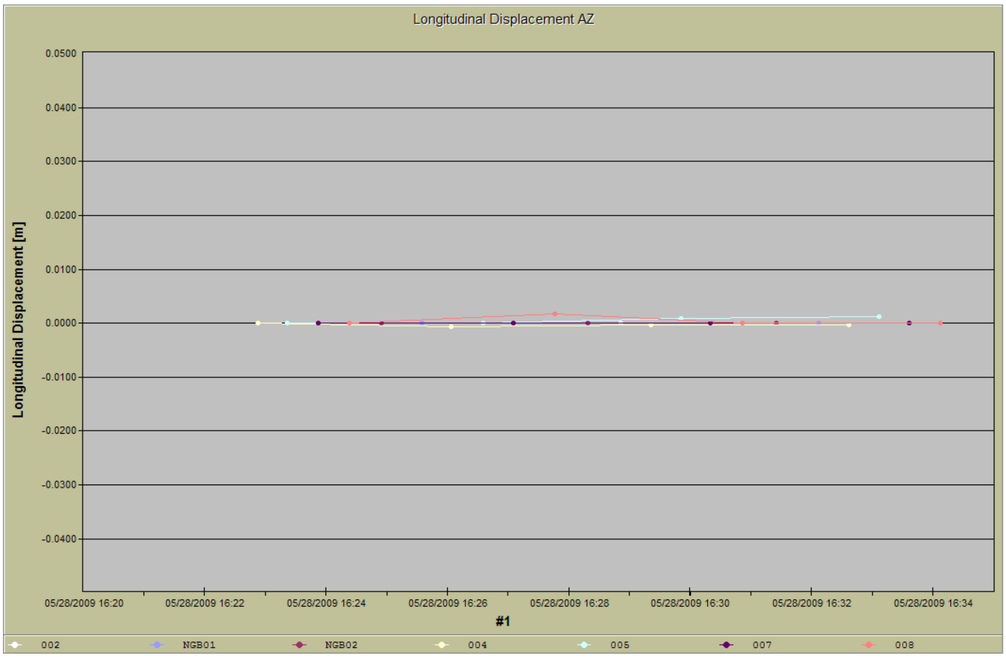

Fig. 5 (a): Longitudinal displacement over varying length for the TCA2003

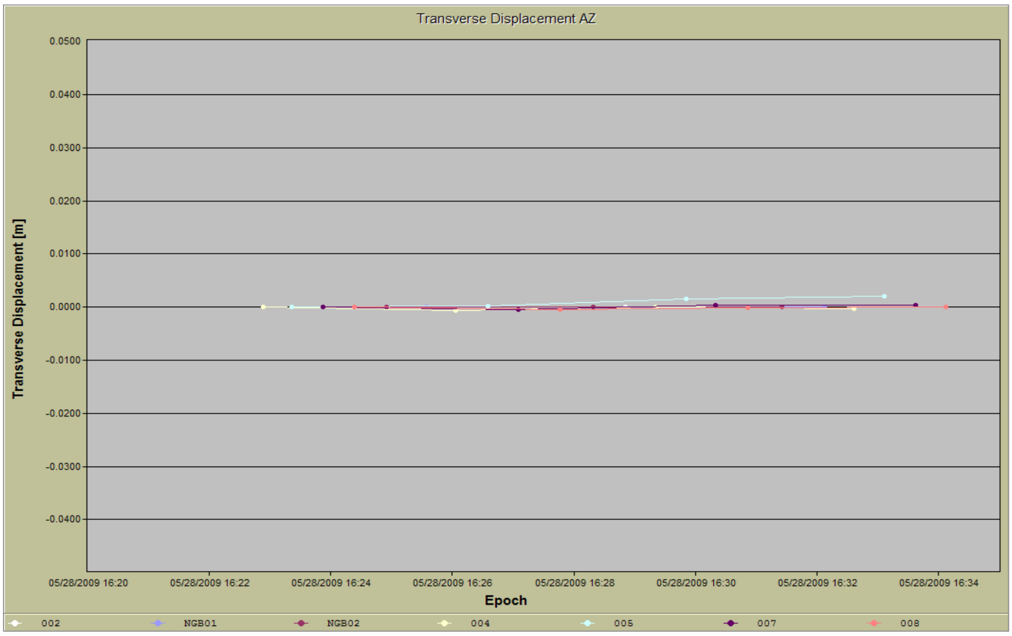

Fig. 5 (b): Transverse displacement over varying length for the TCA2003

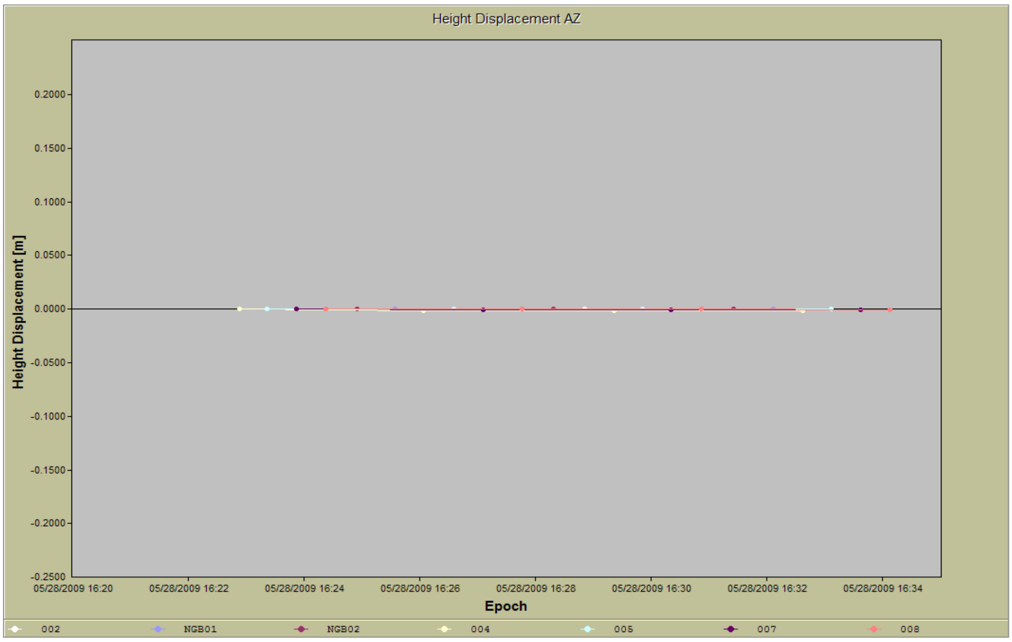

Fig. 5(c): Height displacement over varying length for the TCA2003

4.4 Effects of Different Prisms on Precision and Accuracy of Measurements

In order to compare the effects of the prism type on the precision and accuracy of measurement for monitoring, the TS30 and the TCA2003 were used for this purpose. Three different prisms i.e. the standard circular prism, the mini circular prism and the 360° prism were used. However, due to the fact that only one 360° prism was available; comparison was only possible at one point. A summary of the average repeatability of the measurements using the different prisms for the TCA2003 and TS30 are shown in Tables 4 and 5 respectively.

Judging from the result in Tables 4 and 5, irrespective of the type of prism used, the precision of the measuring instrument decreases as the distance increases. This is a further confirmation of the result obtained in section 4.3 in which the precision of the three measuring instrument decreases as the distance increases. Similarly, over a particular short distance such as 17.19m, the type of prism used does not have a noticeable effect on the precision or repeatability of measurements. However, as the distance increases, the impact of the prism type becomes more pronounced. The TS30 presented a better precision over longer distance with the use of a circular prism than the mini-prism. Surprisingly, the TCA2003 presented slightly better precision values with the mini prism than the standard circular prism over a short distance, which is a little bit strange. However, over a longer length, the precision of the circular prism was better. On a closer look at the results, it was discovered that the reason for the slight deviation from the normal was the shorter number of observations made with the circular prism used compare to the number of observations from the mini prism.

Table 4: Average repeatability in 3D coordinates for the TCA2003 using various prisms

PT ID	DIST.	Circular Prism (mm)			Mini Prism (mm)			360° Prism (mm)		
		σE	**σN**	**σH**	**σE**	**σN**	**σH**	**σE**	**σN**	**σH**
2	17.190	0.6	0.0	0.0	0.0	0.0	0.0	-	-	-
NGB02	27.200	0.5	0.0	0.0	0.4	0.0	0.0	-	-	-
7	56.262	0.7	0.0	0.0	0.5	0.0	0.0	-	-	-
8	66.450	0.5	1.0	0.0	0.0	1.0	0.0	0.0	0.5	0.5
4	117.367	0.4	0.4	0.8	0.7	0.4	0.5	-	-	-
5	186.127	1.0	1.0	0.5	1.4	1.0	1.0	-	-	-

Table 5: Average repeatability in 3D coordinates for the TS30 using various prisms

PT ID	DIST.	Circular Prism (mm)			Mini Prism (mm)			360° Prism (mm)		
		σE	**σN**	**σH**	**σE**	**σN**	**σH**	**σE**	**σN**	**σH**
2	17.190	0.1	0.1	0.0	0.1	0.1	0.0	-	-	-
NGB02	27.200	0.1	0.1	0.1	0.1	0.1	0.1	-	-	-
7	56.262	0.2	0.1	0.1	0.2	0.1	0.1	-	-	-
8	66.450	0.1	0.2	0.2	0.1	0.2	0.2	0.1	0.2	0.2
4	117.367	0.1	0.1	0.4	0.3	0.4	0.8	-	-	-
5	186.127	0.7	0.5	1.4	0.9	0.7	0.8	-	-	-

4.4 Effects of Weather on the Precision of Measurements

All the previous static trials were carried out under a sunny weather condition. In order to verify the effect of a changing weather condition on the precision of measurements, a trial was carried out on a rainy day. The TCA2003 and the S6 were used for this purpose with a standard circular prism as target. The result is shown in Tables 6 and 7 as well as Figure 5. This is compared with the result depicted in Figure 4.

Table 6: Effect of weather on precision of TCA2003 using circular prism

PT ID	DIST.	SUNNY			RAINY		
		σE(mm)	σN(mm)	σH(mm)	σE(mm)	σN(mm)	σH(mm)
002	17.194	0.6	0.0	0.0	0.0	0.0	0.0
NGB02	27.200	0.5	0.0	0.0	0.5	0.0	0.0
007	56.262	0.7	0.0	0.0	1.0	0.0	0.0
008	66.450	0.5	1.0	0.0	0.5	0.8	0.3
004	117.367	0.4	0.4	0.8	0.9	0.9	0.3
005	186.127	1.0	1.0	0.5	1.7	1.0	0.9

Table 7: Effect of weather on precision of S6 using circular prism

PT ID	DIST.	SUNNY			RAINY		
		σE(mm)	σN(mm)	σH(mm)	σE(mm)	σN(mm)	σH(mm)
002	17.194	0.3	0.1	0.0	0.2	0.3	0.4
NGB02	27.200	0.0	0.2	0.1	0.0	0.2	0.2
007	56.262	0.1	0.2	0.2	0.2	0.2	0.1
008	66.450	0.2	0.2	0.2	0.1	0.2	0.1
004	117.367	0.3	0.3	0.5	0.2	0.4	0.3
005	186.127	0.4	0.5	0.7	0.5	0.3	0.6

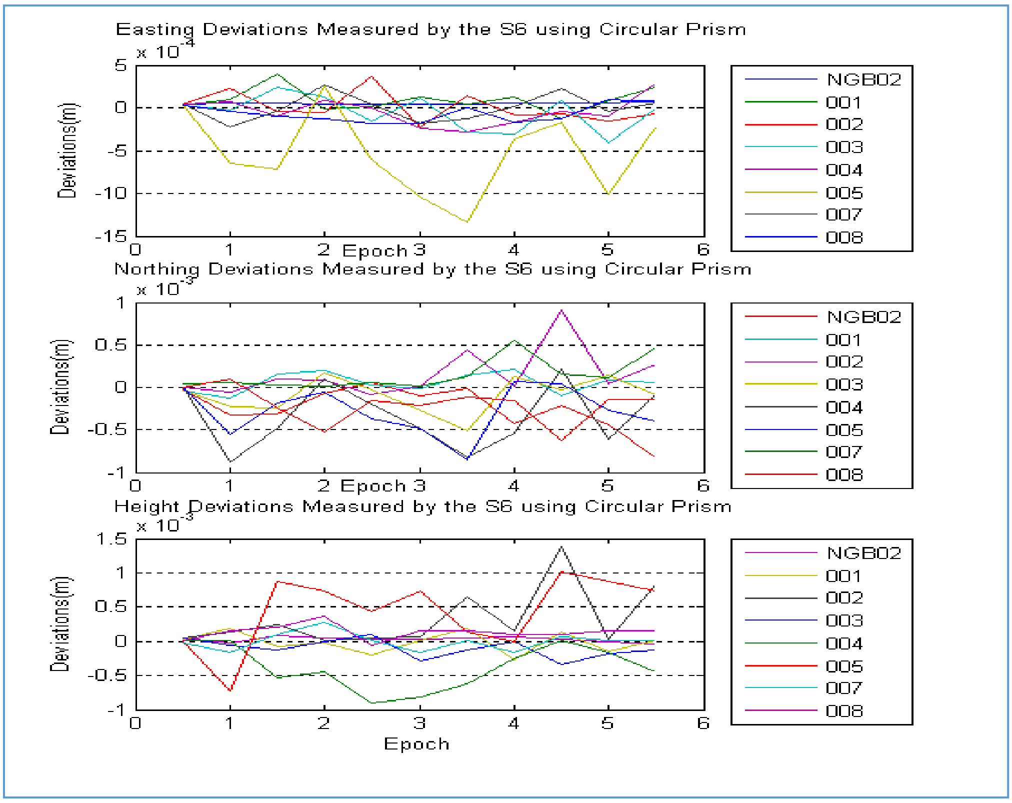

Figure 6: Deviation pattern in 3D coordinates of the S6 on a rainy day

From the result depicted in Tables 6 and 7 as well as Figure 6, it can be seen that the weather condition generally have no noticeable effect on the precision of measurement of the instruments. The major factor that influences the precision was the distance of the monitored points from the instrument station.

5.0 Conclusions and Recommendations

The benefits of carrying out deformation monitoring are enormous. It enables us to keep abreast of our continuously changing environment, preventing some hazards and been able to put in place an adequate, effective and efficient maintenance programs to prevent unforeseen circumstances. Total stations are increasing being used to serve as the bedrock of automated, continuous and accurate monitoring systems.

The primary focus of this paper has been to evaluate the performance of total stations as a precise, accurate and effective deformation monitoring tool. This was done by comparing the precision and the accuracy of measurements from three different total stations, two from Leica(TS30 and TCA2003) and one from Trimble(S6), the two leading producer of total stations of the highest precision and accuracy.

For the static trials, three different comparisons were carried out. The first comparison was in terms of the effect of varying distance on the precision of measurement. Targets were located at distances ranging between 15m to 200m. High precision values were obtained for distances less than 100m (0.1mm for the TS30 and 0.2mm for the S6) but degrades faster for length beyond it. Precision values over short distance from the TS30 were better whereas over longer distance, the precision of the S6 was better. The TCA2003 values were of relative poor precision. The second test considers the effect of the prism type of the precision of measurement. Generally, better precision values were obtained with the circular than the mini prism and the 360° prism. The third comparison was to investigate the effect of changing weather condition. It was discovered that irrespective of the weather condition, highly precise data was possible under any weather condition especially the TS30 and S6 total stations.

In order to fully maximize the benefits of total stations for automated deformation monitoring, it is recommended that dynamic tests should be carried out to investigate the performance of each of the total station in the two kinematic operating modes possible namely stop-and-go and kinematic mode.

Finally, with the increasingly high speed with which modern total stations such as the TS30 and S6 are able to make precise and accurate measurements, they have the potential of taking over from GPS as the most popular and leading geodetic technique for structural deformation monitoring in the nearest future.

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