CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents results of the experimental work and field measurements, and discusses the findings of this research. The results consist of total station calibration, datum verifications, error propagation in angle, distance, elevation and, sight shot observations for monitoring data and statistical analysis for slope deformation monitoring.

4.2 Total Station Calibration

It could not be denied that measurement with electronic measurement tools such as Electronic Distance Measurement (EDM) or Total Station is more accurate relative to other methods of measurement such as Global Positioning System(GPS), close range photogrammetry, precise leveling, Total Station, laser scanning (terrestrial survey), Very Long Baseline Interferometic(VLBI), Image by Interferometic Survey(IBIS) and Satellite Laser Ranging (SLR), because the electronic measurement tool is able to produce a higher precision and has smaller discrepancies. However, this higher precision does not necessarily prove that the electronically measured data set is implicitly more accurate than the values of taped or other measurement methods. In fact, the opposite may be true if the reflector constant had been entered incorrectly, which could cause a large systematic error to be present in all of the electronically measured distances.

The calibration was accomplished on standardized permanent calibration bench marks, in which true distances between the pillars are known as published by Malaysia's leading certification, inspection and testing body (SIRIM) and the Survey and Mapping Malaysia Department (JUPEM) as described in Table 3.1 in chapter 3. In this calibration, each distance between the pillars was measured for five times by the Total Station. An example of the measurement data is shown in Appendix I**.** The materials of target surface can be categorized into two classes, based on colour and natural material. The average of the measured distances was used in the detection of deformation. The preferred approach is a parametric least square adjustment method that simultaneously determines a zero error, a constant value, and scaling factor of the calibration-target and the Total Station (as systematical errors can be computed).

4.2.1 Result of Zero Error Estimation

Once the adjustment computation is completed, the global test is then applied to ensure the compatibility of the aposteori and apriori variances. The result of the global test is presented in Table 4.1. The critical value is obtained from Fisher table with 95% significance level and 14 degrees of freedom whereby the numbers of observations is 21 less 7(unknown parameters). Table 4.1 shows that F-computed is lower than 1.700 which indicates that there is no outliers in the data. The result of the zero error and its precision is given in Table 4.2.

Table 4.1 F-computed for global test

Prism	**Red**	**White**	**Black**	**Concrete**	**Wood**	**Homo. Tile**
0.592	0.089	0.189	0.127	0.450	0.381	0.145

Table 4.2 Zero error and standard deviation for various targets

Prism		**Red**		**White**		**Black**		**Concrete**		**Wood**		**Homo. Tile**	
z_o	σz_o	z_o	σz_o	z_o	σz_o	z_o	σz_o	z_o	σz_o	z_o	σz_o	z_o	σz_o
millimetres													
0.09	7.1E-4	4.20	1.9E-3	1.85	1.7E-3	7.05	2.2E-3	3.14	1.2E-3	3.14	1.1E-3	2.85	2E-3

The results of these measurements were compared with the published distances, as summarized in Figure 4.1 and Figure 4.2. From the measurement results, the difference between measured distance and published distance for pillars less than 10 meters is below 5mm for all tested materials. Based on the colour shown, the differences between the measured and published distances are also quite small for distances in the range below than 200 meters; however there is a drastic increase for distances in the range above 200 meters. Black coloured targets mostly show larger differences than other colours, due to low reflectivity. For natural materials, the differences between the measured and publishes distances is not constant in all range of distances due to the texture of the surface. But the differences are still within the acceptable tolerance, according to the specification of the instruments used 10mm ± 10ppm.

The TS is equipped with dual laser optics, which means it has two option beams, one narrow beam for non-prism function and a broader beam for use with prism. The function is to stabilize the beam when measuring over long distances to provide more accuracy in the measurement. The experiments conducted revealed that reflector-less TS measurements are characterized by the range of distance measured. In order to receive a strong reflected signal, small incident angles should be avoided [45]; and in order to get the measurements of highest quality the zero error and the constant value of the various targets must be identified to correct the distance readings.

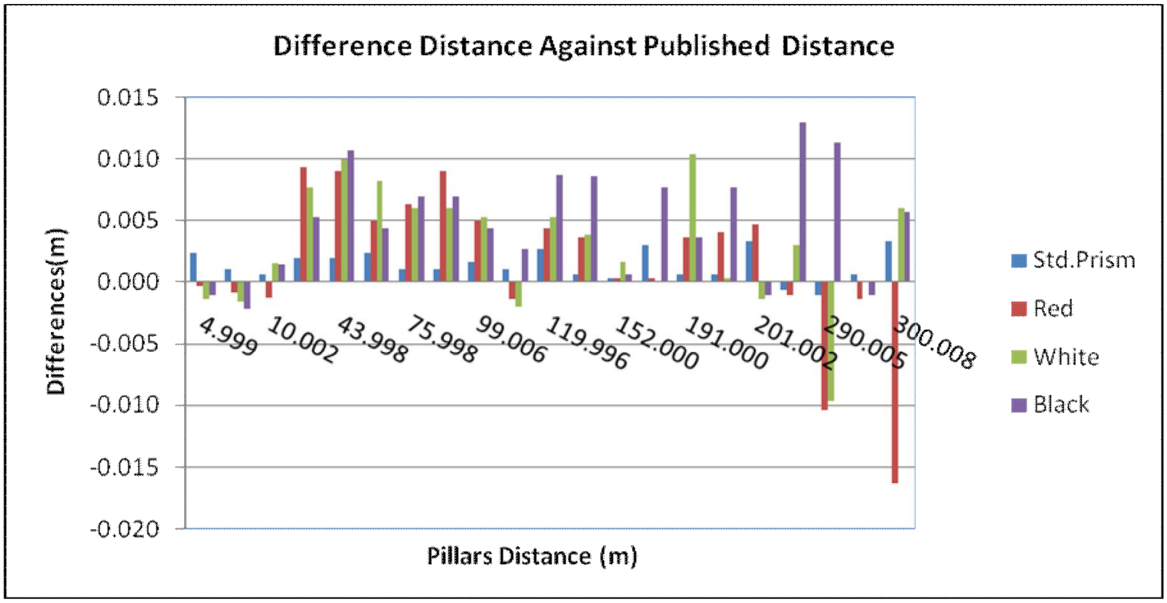

Figure 4.1 Distance differences based on colours

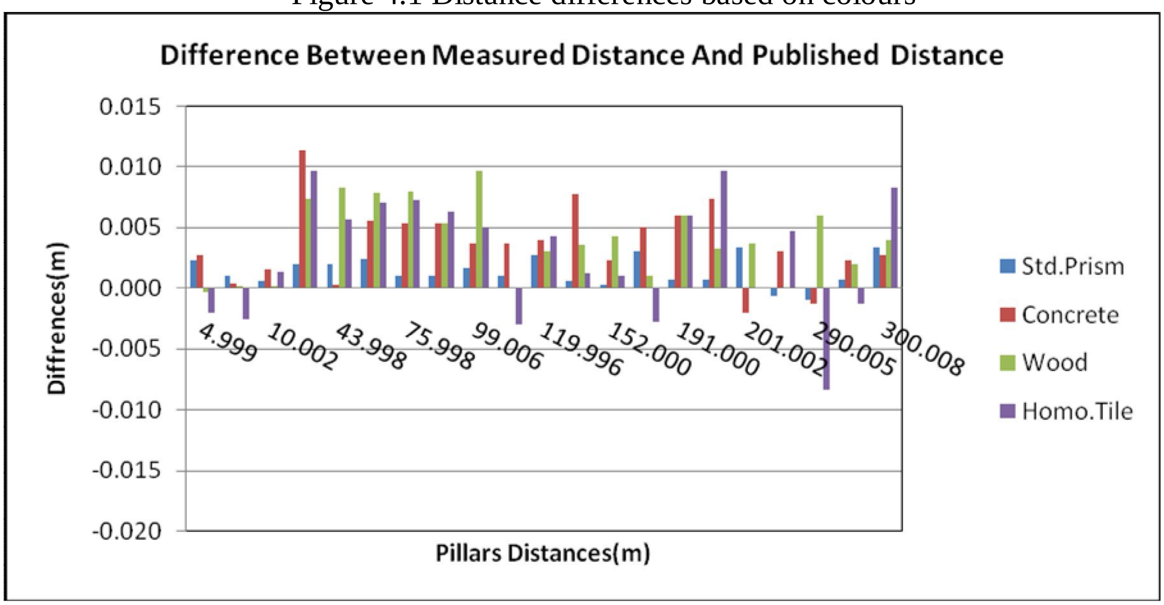

Figure 4.2 Distance differences based on natural materials

Referring to the result in the Table 4.2, black material target yields the biggest value of zero error (7.054 ± 0.002 millimeters), while prism target gives the smallest value (0.093 ± 0.001millimeters). To check the significance of the zero error value, t-student statistical test was carried out in this study. The critical value of t-table is 2.145 with 95% significance level and 14 degrees of freedom. The results of t-test for zero error are tabulated in Table 4.3. The table shows that t-computed for all targets are larger than

2.145, which indicates that the zero error is significant in this baseline measurement. It implies that the error had occurred in the instrument; therefore the appropriate correction value should be applied to each baseline reading that was observed using this instrument.

Table 4.3 T-computed from significant test for zero error correction

Prism	Red	White	Black	Concrete	Wood	Homo. Tile
2.299	3.358	2.301	2.805	2.491	2.620	2.629

The adjusted baseline between two various benchmarks is given in Table 4.4. It can be seen that the difference of adjusted baseline between various targets is in millimeters scale. The accuracy of the adjusted baseline is inversely proportional to the difference in the distance measurements, with respect to the adjusted baseline of prism reflector. From the results it seems that textured material requires higher adjustments than coloured material, except for black coloured material, which depends on the distance. If the distance is longer the value of the zero errors is larger.

Table 4.4 Adjusted sub baseline for various material targets

Baseline	Prism	Red	White	Black	Concrete	Wood	H. Tile
P0-P1(m)	5.003m ±0.000mm	5.009m ±0.408mm	5.007m ±1.817mm	5.013m ±0.837mm	5.007m ±0.894mm	5.007m ±0.894mm	5.009m ±0.894mm
P0-P2(m)	10.001m ±0.548mm	10.007m ±2.588mm	10.002m ±1.517mm	10.008m ±2.302mm	10.004m ±2.702mm	10.005m ±2.702mm	10.004m ±1.996mm
P0-P3(m)	49.000m ±0.894mm	49.001m ±2.000mm	48.996m ±2.168mm	49.005m ±2.702mm	49.000m ±2.881mm	48.997m ±2.881mm	48.998m ±4.301mm
P0-P4(m)	124.999m ±0.894mm	125.001m ±3.286mm	124.998m ±1.304mm	124.998m ±4.506mm	124.995m ±3.564mm	125.000m ±3.564mm	125.002m ±2.394mm
P0-P5(m)	200.999m ±0.577mm	201.002m ±0.577mm	201.005m ±2.309mm	201.010m ±1.000mm	201.007m ±6.083mm	201.001m ±6.083mm	201.005m ±1.000mm
P0-P6(m)	300.005m ±0.577mm	300.029m ±1.155mm	300.004m ±1.000mm	300.009m ±6.429mm	300.008m ±4.163mm	300.007m ±4.163mm	300.003m ±4.041mm

4.2.2 TS Calibration Factors for Different Types of Target

Based on the adjusted sub baseline result for all types of target used in this work, and the parametric least-square adjustment formula as mentioned in Equation 3.9 and Equation 3.10, the constant value and scaling factor (symbolized by a and b respectively) are obtained. The computed calibration factors of the constant value (a) and scaling factor

(b) for the TS for each type of target are presented in Table 4.5.

Table 4.5 TS constant value and scaling factor for various types of target

	Constant Value		**Scaling Factor**	
	***a* (mm)**	**σ *a* (mm)**	***b* (ppm)**	**σ *b* (ppm)**
Prism	1.031	0.009	2.040	1.721
Red	2.316	0.027	7.196	2.699
White	2.311	0.009	3.891	1.335
Black	0.552	0.015	14.987	2.369
Concrete	0.616	0.008	5.978	0.822
Wood	2.751	0.013	12.130	1.383
Homo. Tile	0.745	0.012	4.681	1.420

Referring to the calibration result in Table 4.5, black coloured and wood targets yield the two largest scaling factor (14.987 ppm and 12.130 ppm) than the value specified for the instrument specification (10.000 ppm); while the prism target gives the smallest value (1.031 for *a*, and 2.040 ppm for *b*) but the scaling factor is still larger than the specification. To check the significance of the calibration result, t-student statistical test was performed in this research. The critical value of t-table is still the same as the previous t-test calculation (2.145 with 95% significance level and 14 degrees of freedom). Table 4.6 shows that the t-computed for all targets (except for prism target) are larger than 2.145 accept the value for prism, which is lower than 2.145. This indicates that no error is present in the distance measurement tool in the TS and its standard prism. The error mainly exists in the reflector target made of various materials. Therefore the appropriate correction factors should be applied to all distance observations made by this instrument.

Table 4.6 T-computed for significant test of TS calibration

	Prism	**Red**	**White**	**Black**	**Concrete**	**Wood**	**Homo. Tile**
a (mm)	0.118	0.087	0.271	0.036	0.078	0.207	0.064
b (ppm)	1.359	2.531	2.915	6.327	7.268	8.769	3.296

4.3 Datum Verifications

In order to assess the stability and the system coordinate used by MTD, GPS and TS observations were carried out to check the angles and distances of the three marks according to Malaysian standard survey regulation [60]. According to the regulation, the difference in angles and distances between new observations and old values adopted by MTD must not exceed 30" in angle and 1/8000 in distance for lines exceeding 40 m or 30” in bearing and 0.006 m per 20 m with a maximum of 0.03 m.

4.3.1 Baselines by GPS Observation

Successively to check the existing coordinate system used by MTD, GPS observation was made as presented in Table 4.7. The observation was done using static method. From the GPS coordinates, the bearing distances was computed and compared with the MTD control point data in order to check that the tolerances are within the limits; the results are shown in Table 4.8. The lines have been used as the baselines for this research and they are located outside the deformable body.

Table 4.7 GPS Coordinates

SUBNET 'Session' POINTS: ADJUSTED COORDINATES in Malaysia_RSO(Grid, Zone Malysia)			
Station No. 43(Base Station)			
MTD Coordinates	Northing (m)	Easting (m)	Height (m)
	507987.39300	372618.16800	1310.84300
	Northing (m)	Easting (m)	Height (m)
Coordinates	507987.39300	372618.16800	1310.84300
	S (N)	S (E)	S (U)
Sigmas(mm)	0.0	0.0	0.0
	N-E	N-U	E-U
Corr.(%)	0.0	0.0	0.0
Station No. 44(Unknown Station)			
MTD Coordinates	Northing (m)	Easting (m)	Height (m)
	372720.072	507780.809	1299.214
	Northing (m)	Easting (m)	Height (m)
Coordinates	372719.90979	507780.82692	1299.15213
	S (N)	S (E)	S (U)
Sigmas(mm)	0.4	0.6	1.1
	N-E	N-U	E-U
Corr. (%)	14	-41	-37

Table 4.8 Comparison of Coordinates between GPS and MTD

	Easting	**Northing**	**Height**
MTD	372720.072	507780.809	1299.214
GPS	372720.0558	507780.8269	1299.1521
Different	0.0162m	-0.0179m	0.0619m

From the table above, the difference between GPS and MTD coordinates is only in centimeters (Easting 1.6cm, Northing 1.7cm and height 6cm). This indicates that the station is still stable and has been using the same coordinate system. The possibility error occurred because of centering when the instruments were set up, and the precision differences between the instruments.

4.3.2 Datum Verifications by TS Observations

All three marks of the control station are located adjacent of each other, and to prove that the points is still in good condition, angular and linear measurements must be done; calculation is a normal practice applied by the Survey and Mapping Department (JUPEM).

Table 4.9 Datum Verification between MTD on 12/02/03 and Epoch 1 on 07/02/08

Line	**Difference**		**Remarks**
	Bearing	**Distance**	**12/02/03 and 07/02/08**
44-43	0”	+0.003	
44-45	-20”	-0.002	
Angle Difference	-20”		
Verified Distance Note; 1/x = Linear Measurements	Line 44-43 0.006 x 11 = 0.066m or 1/x 0.003/ 230.351= 1:76784 Line 44-45 0.006 x 5 = 0.06m or 1/x 0.002/ 115.510 = 1:57755		

Referring to the result in Table 4.9, the inner angle difference between data obtained from MTD on 12/12/03 and TS data observed on 05/01/08 is 20”; this shows that the angle is below the 30” stipulated in the survey regulation. The ratio distances are 1:76784 for line 44-43 and 1:57755 for line 44-45. The results show that the ratio is better than 1:8000 as described by the survey regulation. The bearing and distance measurements at epoch 1 obtained by a former survey and epoch 2 captured by the same TS are tabulated in Table 4.10. From the result, the angular and the distance ratios are still in good conditions based on the satisfactory of datum specified by the survey regulation.

Table 4.10 Datum Verification between Epoch 1on 07/02/08 and Epoch 2 on 07/07/08

Line	**Difference**		**Remarks**
	Bearing	**Distance**	**07/02/08 and 07/07/08**
44-43	0”	+0.008	
44-45	-15”	-0.013	
Angle Difference	-15”		
Verified Distance Note; 1/x = Linear Measurements	Line 44-43 0.006 x 11 = 0.066m or 1/x 0.008/ 230.348 = 1:28794 Line 44-45 0.006 x 5 = 0.06m or 1/x 0.013/ 115.512 = 1:8886		

Table 4.11 Datum Verification between Epoch 2 on 07/07/08 and Epoch 3 on 7/12/08

Line	**Difference**		**Remarks**
	Bearing	**Distance**	**07/07/08 and 07/12/08**
44-43	0”	+0.005	
44-45	-15”	-0.014	
Angle Difference	-15”		
Verified Distance Note; 1/x = Linear Measurements	Line 44-43 0.006 x 11 = 0.066m or 1/x 0.005/ 230.340 = 1:46068 Line 44-45 0.006 x 5 = 0.06m or 1/x 0.014/ 115.525 = 1:8252		

Before carrying out the deformation monitoring observation, it is important to ensure that the control station has remained stable. From the calculation, the result show that the angular measurement is better than 30’’ and the linear measurement is better than1:8000 for distance. Thus it can be concluded that all the control stations established by MTD are still in good condition and suitable to be used as reference stations.

4.4 Error Propagation

In this study, propagation of errors was analyzed to see the influence on the observed data when integrated with angles, distance and elevations. An amount of adjustments need to be applied to the observation data in order to obtain the best fit. This is the residual that is being minimized. If there are large residuals in the calculations, then it may indicate a blunder in the observation data.

4.4.1 Error Sources in Horizontal Angles

The inner angle value is calculated based on the reference object and the monitoring target points, an example of the measurement data is presented on Appendix 11. The error sources in the horizontal angle measurements for the TS in this research is the sum of errors of the target and instrument centering errors, and the standard deviation value based on DIN 18723 of the instrument specification for reading and pointing errors. From the computation, there is not much difference in the error for every epoch. This is because the angles and the distance do not change so much, the calculation data is presented on Appendix K. Based on the graph in Figure 4.3, below the average angle the error source is very small and the values are almost the same. From the calculations all the monitoring points have 03” of errors in horizontal angle measurements, the results are shown on Appendix K. It can be concluded that the horizontal angles contain larger errors if sights are shorter (setup error) as shown in Figure 4.4, and also contain a constant error related closely to the least count of the instrument. It is also found that the errors are also influenced by the target size. The finer the sight of the target points, then the lesser potential angular error in the sight.

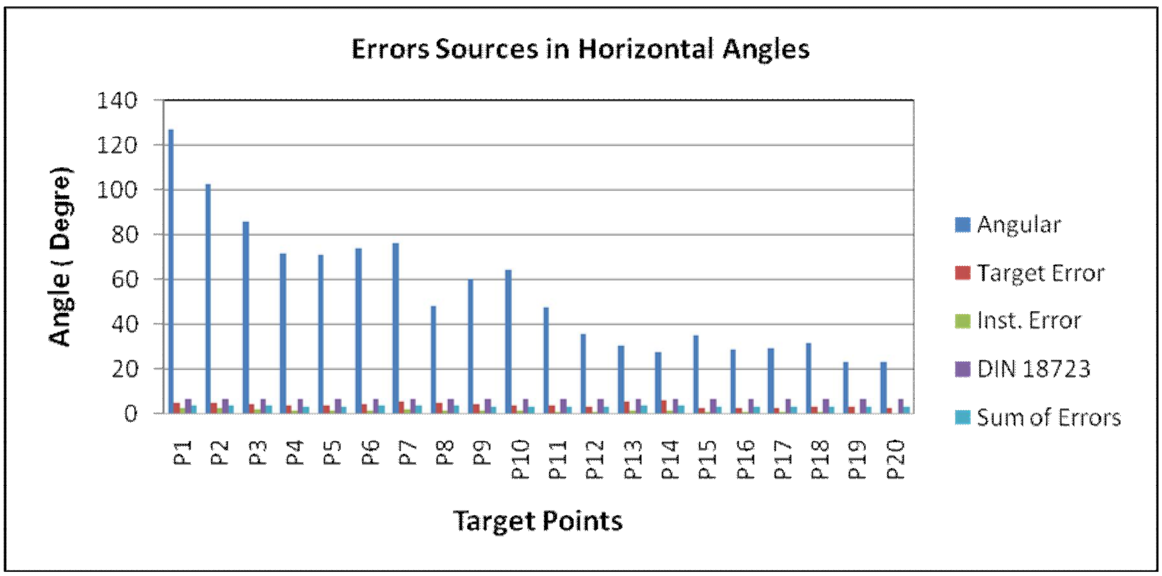

Figure 4.3 Mean of angle effect on standard deviation of angles sources errors

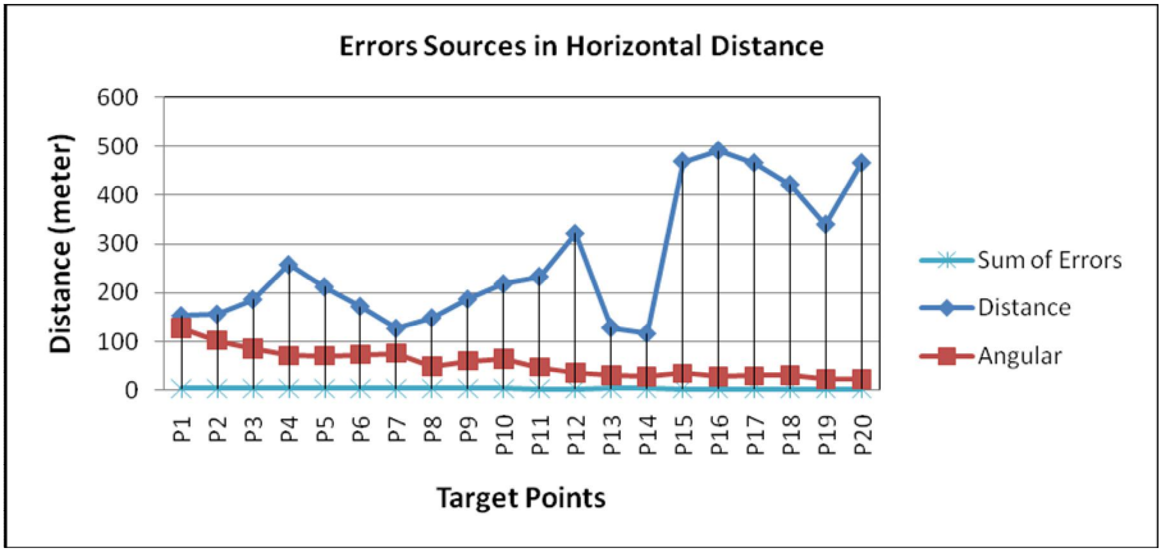

Figure 4.4 Mean of angle and distance effect of sum of angles sources errors

4.4.2 Errors Sources in Electronic Distance Observations

The error propagation in distance was determined during the calibration work. The zero constant value and scaling factor of each type of targets were calculated during the calibration. In this research, the monitoring target was a prism pole which has been permanently planted at the slope by the MTD survey team, for monitoring purpose. Therefore the correction in the observed distance observation depends on the colour of the aimed target, which is the prism pole; the pole is in white and red stripes. Based on the graph shown in Figure 4.4, it is observed that the standard deviation is directly proportional to the measured distance, the longer the distance measured, the larger the standard deviation. This means that the zero and scale error are linearly proportional to the length of the measured line. The calculated data are presented on Appendix L.

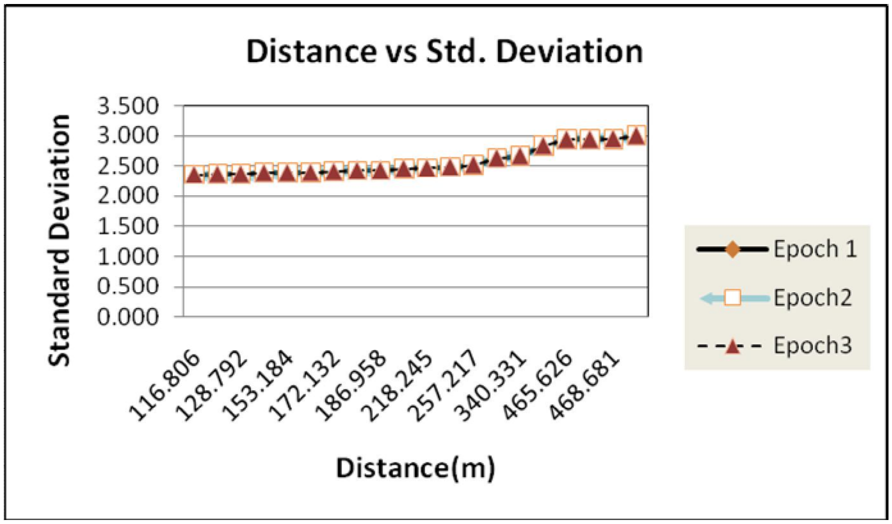

Figure 4.5 Standard Deviation against the Measured Distance

4.4.3 Error Sources in Trigonometric Leveling

In the determination of leveling by trigonometric method, there are some factors which can influence the results. This includes the accuracy of the instrument mainly the measuring accuracy of slope distance and vertical angles, and external factors such as earth curvature and refraction. The results show small differences in the values of standard deviation of elevation of each epoch because there is minimal difference in slope distances on each monitoring target points. The results are tabulated in Table 4.12 below.

Table 4.12 Standard deviation of elevation

Target No.	Epoch1		Epoch2		Epoch3	
	Elevation(m)	$\sigma\Delta h(m)$	Elevation(m)	$\sigma\Delta h(m)$	Elevation(m)	$\sigma\Delta h(m)$
P1	1373.64226	0.0097079	1373.64051	0.0097079	1373.64176	0.0097078
P2	1424.86011	0.0111189	1424.86061	0.0111189	1424.86161	0.0111190
P3	1474.29992	0.0139317	1474.29617	0.0139319	1474.29892	0.0139317
P4	1546.44583	0.0194719	1546.44433	0.0194719	1546.44758	0.0194719
P5	1484.95358	0.0155681	1484.95183	0.0155682	1484.95783	0.0155684
P6	1439.82369	0.0123251	1439.82294	0.0123251	1439.82044	0.0123251
P7	1388.46845	0.0086678	1388.46470	0.0086679	1388.46870	0.0086680
P8	1389.26734	0.0098484	1389.26834	0.0098485	1389.27084	0.0098487
P9	1435.79221	0.0130234	1435.79496	0.0130234	1435.80071	0.0130235
P10	1485.51989	0.0159056	1485.52214	0.0159056	1485.53089	0.0159060
P11	1451.86924	0.0158965	1451.86999	0.0158964	1451.87514	0.0158967
P12	1439.01837	0.0203134	1439.10627	0.0203120	1439.12782	0.0203118
P13	1364.43646	0.0081755	1364.43621	0.0081756	1364.43621	0.0081759
P14	1343.97245	0.0070381	1343.97095	0.0070381	1343.97295	0.0070382
P15	1458.09244	0.0286898	1458.17598	0.0286883	1458.16009	0.0286887
P16	1415.11050	0.0288447	1415.26130	0.0288434	1415.15035	0.0288444
P17	1414.74927	0.0274831	1414.73156	0.0274830	1414.75011	0.0274829
P18	1416.60317	0.0251341	1416.60083	0.0251340	1416.67149	0.0251333
P19	1384.97678	0.0200325	1385.00245	0.0200323	1385.02200	0.0200320
P20	1372.84092	0.0264677	1372.84568	0.0264677	1372.85176	0.0264675

4.4.4 Estimated Error in Latitude and Departure

The estimated errors in latitude and departure depend on the value of estimated errors in distance and angle from observation data which have been computed previously. This is due to the correlation between latitude and departure against the distance or azimuth of the observation. This estimated error is very useful in order to estimate the monitoring point coordinates.

4.5 Magnitude of Movements

The first stage of data analysis is concerning the coordinates of each epoch. The coordinates are shown in the Table 4.16 below, and Figures 4.5, 4.6 and 4.7 shows the precision of latitude, departure and height, respectively. These figures indicate there are a slight difference in the standard deviation among the first, second and third epochs. Figure 4.6 shows that of the three epochs have more or less the same value of precision in latitude, departure and height. The largest value in latitude is at target point P7 whereby the smallest value is at target point P20. Target point P16 has the largest value in departure and P14 has the smallest value. Whereas, target point P16 has the largest value in height and P13 has the smallest value.

Table 4.16 The N, E and H Coordinate in meters of the 20 Monitoring Targets object

Target No.	Epoch 1			Epoch 2			Epoch 3		
	North(m)	East(m)	Height(m)	North(m)	East(m)	Height(m)	North(m)	East(m)	Height(m)
P1	508015.065	372467.503	1373.642	508015.065	372467.502	1373.641	508015.064	372467.504	1373.642
P2	507950.006	372466.300	1424.860	507950.007	372466.300	1424.861	507950.007	372466.300	1424.862
P3	507893.237	372457.161	1474.300	507893.237	372457.154	1474.296	507893.237	372457.160	1474.299
P4	507805.468	372436.332	1546.446	507805.467	372436.332	1546.444	507805.469	372436.333	1546.448
P5	507836.866	372468.587	1484.954	507836.864	372468.587	1484.952	507836.865	372468.584	1484.958
P6	507870.719	372491.613	1439.824	507870.719	372491.612	1439.823	507870.718	372491.613	1439.820
P7	507905.430	372520.980	1388.468	507905.427	372520.978	1388.465	507905.427	372520.978	1388.469
P8	507849.418	372562.532	1389.267	507849.418	372562.531	1389.268	507849.418	372562.531	1389.271
P9	507832.254	372513.834	1435.792	507832.255	372513.835	1435.795	507832.255	372513.835	1435.801
P10	507814.634	372484.809	1485.520	507814.634	372484.811	1485.522	507814.634	372484.806	1485.531
P11	507769.743	372534.317	1451.869	507769.743	372534.317	1451.870	507769.743	372534.312	1451.875
P12	507670.243	372566.671	1439.018	507670.308	372566.680	1439.106	507670.318	372566.698	1439.128
P13	507858.949	372608.785	1364.436	507858.947	372608.785	1364.436	507858.943	372608.785	1364.436
P14	507870.615	372615.636	1343.972	507870.614	372615.636	1343.971	507870.614	372615.636	1343.973
P15	507523.906	372548.249	1458.092	507523.971	372548.249	1458.176	507523.951	372548.293	1458.160
P16	507496.875	372598.204	1415.111	507496.964	372598.273	1415.261	507496.894	372598.287	1415.150
P17	507522.352	372592.793	1414.749	507522.346	372592.797	1414.732	507522.355	372592.818	1414.750
P18	507567.867	372581.144	1416.603	507567.866	372581.147	1416.601	507567.912	372581.156	1416.671
P19	507647.523	372636.456	1384.977	507647.540	372636.475	1385.002	507647.555	372636.465	1385.022
P20	507522.557	372645.445	1372.841	507522.561	372645.467	1372.846	507522.569	372645.486	1372.852

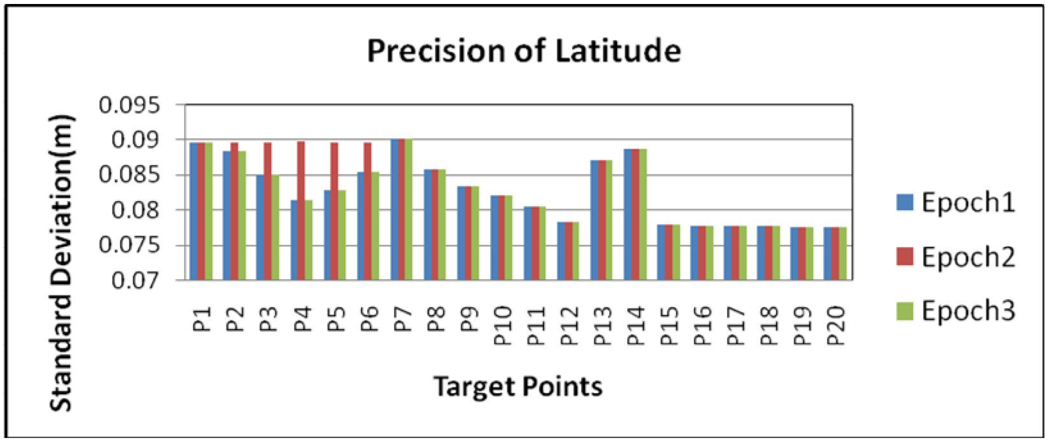

Figure 4.6 Standard Deviation of Latitude

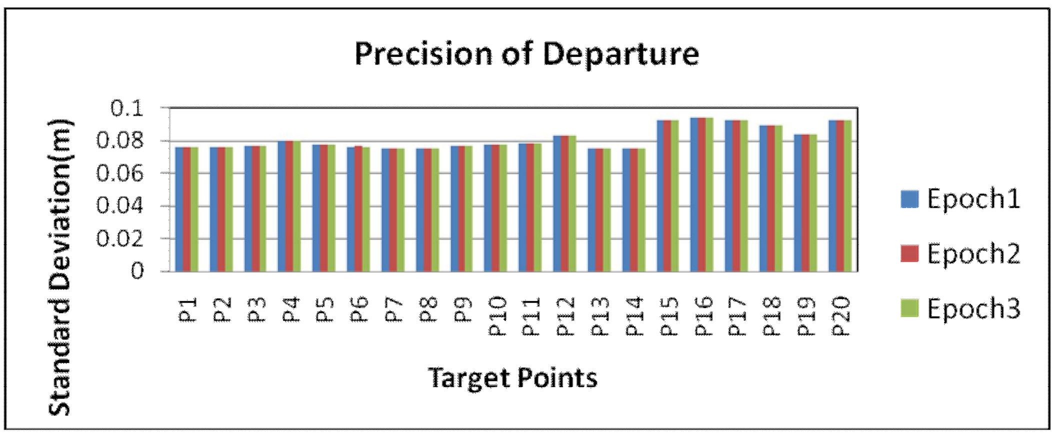

Figure 4.7 Standard Deviation of Departure

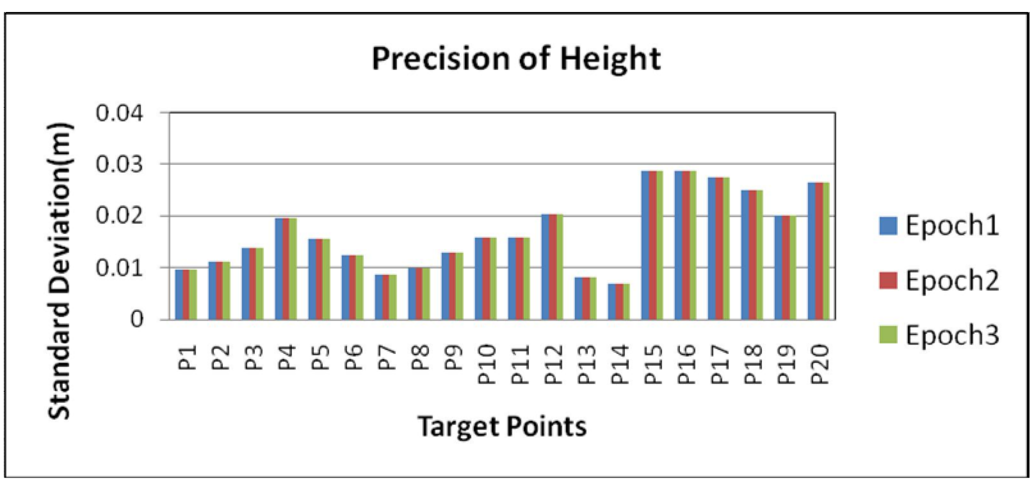

Figure 4.8 Standard Deviation of Height

4.6 Displacement Test

As can be seen in Figures 4.8, 4.9 and 4.10, there are coordinate differences in the north, east and height components between each pair of epoch. The magnitude of coordinate difference in general is within a few centimeters. There is a minor variation in the number of N, E and U coordinates of each monitoring points as shown in Figures 4.8, 4.9 and 4.10. From those figures, the target points P12, P15, P16, P17, P18, P19 and P20 are identified as slightly active points. Figure 4.11 shows the graphic of the direction of the azimuth within the scale; because the magnitude is too small only target points P12, P15, P16, P17, P18, P19 and P20 can be seen.

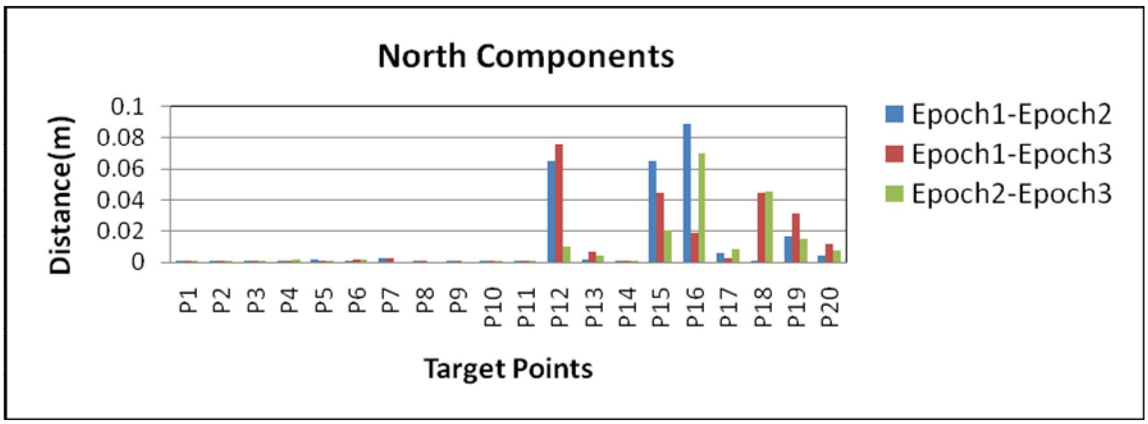

Figure 4.9 Coordinate differences in North Components

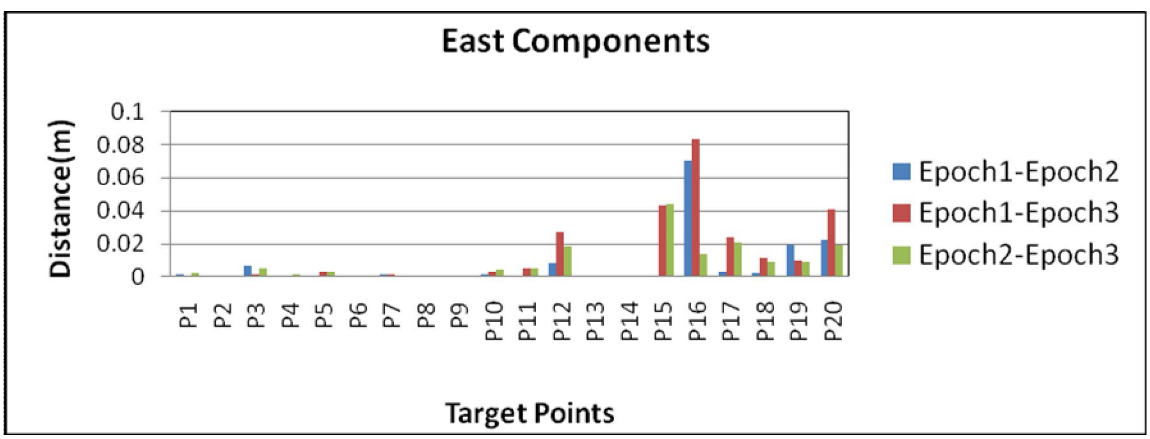

Figure 4.10 Coordinate differences in East Components

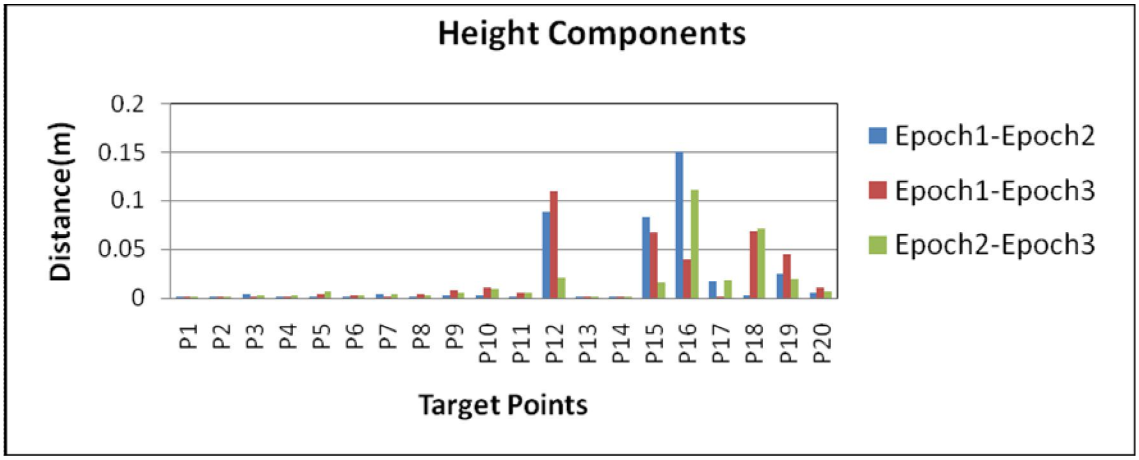

Figure 4.11 Coordinate differences in Height Components

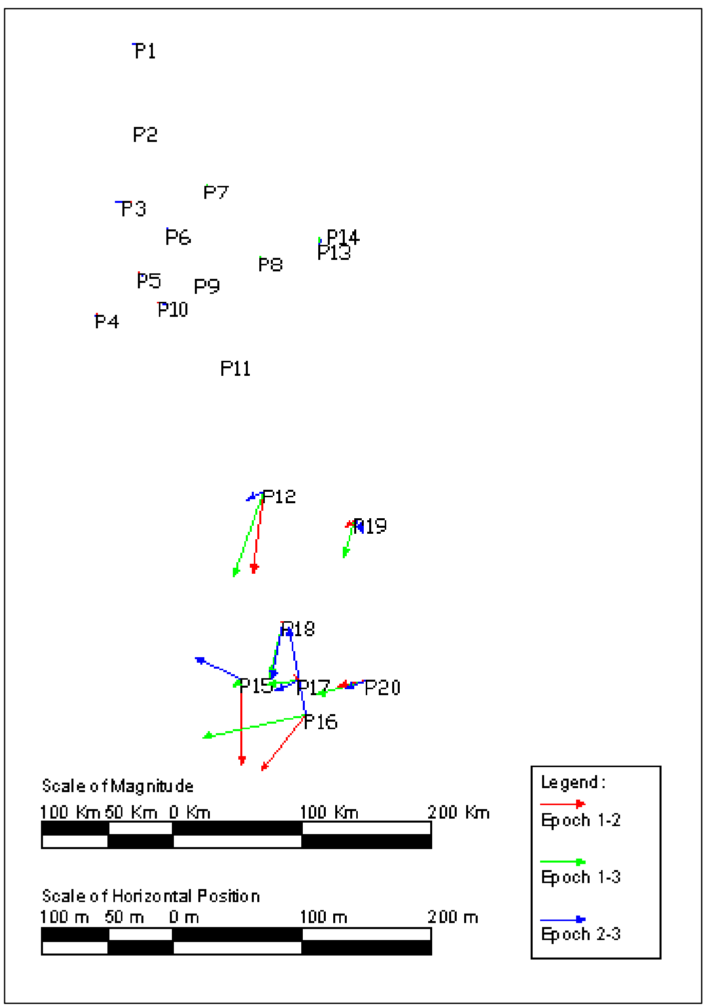

Figure 4.12 The direction is azimuth angle of monitoring target points

However the detection of mass movement cannot be carried out by pushing directly the coordinate values only. Instead, a statistical method is used to determine at which point soil movement or subsidence has occurred. Tables 4.14, 4.15 and 4.16 tabulate the results of t-test of displacement between epochs 1 and 2, epochs 2 and 3, and between epochs 1 and 3, respectively. From these tables, it can be seen that the T values at P12 and P15 between epochs 1,2, at P16 between epochs 2,3 and at P12 and P16 between epochs 1,3 are larger than 1.960. This indicates that there have been significant displacements at the particular target monitoring points. Thus, it could be declared statistically with 95% confidence level that deformation has occurred at CH 23+800, 35km section of the Simpang Pulai – Lojing Highway project as observed at the three epochs. As shown in Table 4.17 between epoch 1 and epoch 2, there are two target points P12 and P15, which has displacement deformation in the horizontal component.

Table 4.14 Horizontal and elevation displacements, and T-computed Between Epoch 1 and Epoch 2

Station	Epoch1-Epoch2(T-Test)			
	Horiz.Deform(m)	$d/\sigma d$	Elev.Deform(m)	$h/\sigma H$
P1	0.004	0.347	0.014	0.127
P2	0.003	0.150	0.016	0.032
P3	0.009	0.745	0.020	0.190
P4	0.004	0.248	0.028	0.054
P5	0.005	0.327	0.022	0.079
P6	0.003	0.121	0.017	0.043
P7	0.009	0.148	0.012	0.306
P8	0.004	0.255	0.014	0.072
P9	0.005	0.147	0.018	0.149
P10	0.004	0.360	0.022	0.100
P11	0.003	0.186	0.022	0.033
P12	0.029	2.257	0.029	3.060
P13	0.006	0.297	0.012	0.022
P14	0.003	0.206	0.010	0.151
P15	0.028	2.316	0.041	2.059
P16	0.058	0.950	0.041	3.697
P17	0.011	0.451	0.039	0.456
P18	0.007	0.296	0.036	0.066

P19	0.030	0.323	0.028	0.906
P20	0.020	1.091	0.037	0.127

Table 4.15 Horizontal and elevation displacements, and T-computed Between Epoch 2 and Epoch 3

Station	Epoch2-Epoch3(T-Test)			
	Horiz.Deform(m)	d/σd	Elev.Deform(m)	h/σH
P1	0.005	0.392	0.014	0.091
P2	0.002	0.192	0.016	0.064
P3	0.008	0.677	0.020	0.140
P4	0.009	0.074	0.028	0.118
P5	0.006	0.495	0.022	0.273
P6	0.005	0.217	0.017	0.143
P7	0.000	0.000	0.012	0.326
P8	0.000	0.000	0.014	0.180
P9	0.000	0.000	0.018	0.312
P10	0.008	0.607	0.022	0.389
P11	0.008	0.651	0.022	0.229
P12	0.020	0.769	0.029	0.750
P13	0.008	0.524	0.012	0.000
P14	0.001	0.127	0.010	0.201
P15	0.031	1.236	0.041	0.392
P16	0.030	2.268	0.041	2.720
P17	0.021	0.913	0.039	0.477
P18	0.024	1.830	0.036	1.988
P19	0.019	0.607	0.028	0.690
P20	0.020	0.893	0.037	0.162

In between epoch 2 and epoch 3, only target point P16 has been identified as having both horizontal and vertical components deformation. Other target points were indentified without any significant movement.

Table 4.16 Horizontal and elevation displacements,and T-computed Between Epoch 1 and Epoch 3

Station	Epoch1-Epoch3(T-Test)			
	Horiz.Deform(m)	d/σd	Elev.Deform(m)	h/σH
P1	0.004	0.159	0.014	0.036
P2	0.003	0.180	0.016	0.095
P3	0.004	0.257	0.020	0.051
P4	0.004	0.233	0.028	0.064
P5	0.007	0.444	0.022	0.193
P6	0.005	0.322	0.017	0.186
P7	0.009	0.148	0.012	0.020
P8	0.004	0.255	0.014	0.251
P9	0.005	0.147	0.018	0.462
P10	0.006	0.461	0.022	0.489
P11	0.008	0.631	0.022	0.263
P12	0.034	2.098	0.029	3.810
P13	0.010	0.648	0.012	0.022
P14	0.003	0.187	0.010	0.050
P15	0.082	0.104	0.041	1.667
P16	0.040	2.045	0.041	0.977
P17	0.020	1.175	0.039	0.022
P18	0.025	1.749	0.036	1.922
P19	0.021	1.418	0.028	1.596
P20	0.028	1.420	0.037	0.290

Within the 18 months observation period, significant movements have been identified at target points P12 and P16 between epoch 1 and epoch 3. Target point P12 shows that the displacement has occurred in both horizontal and vertical components, whereby at the target point P16 the displacement has occurred in the horizontal component only.

4.7 T-Test with Standard Prism

In order to check the significant quality of the deformation monitoring, t-student statistical test was carried out. This is done by comparing the difference of the magnitude coordinates deformation monitoring by reflector-less TS and standard prism TS. The standard prism data was provided by MTD and JKR Perak, which was captured by using Sokkia SRX TS with accuracy of 2mm ± 2ppm.

The critical value of t-table is 2.086 with 95% significance level and 20 degrees of freedom. The results of t-test for the comparison between two methods are tabulated in Table 4.17, 4.18 and 4.19. The table shows that the t-computed for all targets points were lower than 2.086, which indicates that the difference between prism modes and reflector-less is not significant or acceptable.

Table 4.17 T-computed and coordinates difference between standard prism TS and reflector-less TS for Epoch 1 and Epoch 2

Station	Epoch 1 and Epoch 2(T-Test)					
	Δ Northing(m)	T_y	Δ Easting(m)	T_x	Δ Elevation(m)	T_z
P1	0.001	0.007	0.005	0.014	0.002	0.019
P2	0.000	0.003	0.006	0.018	0.002	0.012
P3	0.003	0.020	0.002	0.007	0.001	0.005
P4	0.000	0.000	0.003	0.008	0.002	0.009
P5	0.002	0.020	0.005	0.015	0.002	0.015
P6	0.002	0.014	0.007	0.020	0.001	0.006
P7	0.000	0.002	0.001	0.004	0.002	0.016
P8	0.005	0.039	0.007	0.021	0.004	0.034
P9	0.001	0.008	0.001	0.004	0.010	0.076
P10	0.005	0.042	0.002	0.007	0.004	0.392
P11	0.000	0.004	0.002	0.006	0.037	0.248
P12	0.004	0.032	0.004	0.011	0.001	0.007
P13	0.003	0.025	0.003	0.010	0.000	0.002
P14	0.003	0.027	0.010	0.031	0.007	0.065
P15	0.002	0.019	0.006	0.018	0.008	0.037
P16	0.025	0.590	0.009	0.025	0.005	0.026

P17	0.002	0.018	0.002	0.006	0.001	0.007
P18	0.028	0.255	0.047	0.132	0.031	0.163
P19	0.005	0.049	0.003	0.008	0.001	0.004
P20	0.002	0.021	0.007	0.019	0.001	0.004

Table 4.18 T-computed and coordinates difference between standard prism TS and reflector-less TS for Epoch 2 and Epoch 3

Station	Epoch 2 and Epoch 3(T-Test)					
	Δ Northing(m)	T_y	Δ Easting(m)	T_x	Δ Elevation(m)	T_z
P1	0.000	0.004	0.001	0.003	0.000	0.002
P2	0.002	0.015	0.004	0.011	0.001	0.008
P3	0.004	0.032	0.004	0.011	0.002	0.016
P4	0.002	0.013	0.011	0.032	0.003	0.020
P5	0.002	0.020	0.009	0.026	0.002	0.013
P6	0.000	0.003	0.004	0.013	0.000	0.004
P7	0.005	0.039	0.005	0.015	0.003	0.027
P8	0.011	0.091	0.002	0.006	0.002	0.013
P9	0.011	0.093	0.009	0.027	0.000	0.002
P10	0.005	0.046	0.020	0.061	0.004	0.888
P11	0.002	0.017	0.010	0.029	0.025	0.166
P12	0.005	0.047	0.019	0.055	0.008	0.050
P13	0.011	0.086	0.004	0.013	0.001	0.009
P14	0.002	0.016	0.007	0.021	0.003	0.030
P15	0.014	0.124	0.017	0.047	0.000	0.001
P16	0.005	0.042	0.002	0.005	0.025	0.015
P17	0.006	0.058	0.003	0.008	0.007	0.033
P18	0.001	0.012	0.015	0.042	0.008	0.044
P19	0.003	0.025	0.004	0.010	0.010	0.057
P20	0.006	0.056	0.008	0.022	0.000	0.000

Table 4.19 T-computed and coordinates difference between standard prism TS and reflector-less TS for Epoch 1 and Epoch 3

Station	Epoch 1 and Epoch 3(T-Test)					
	Δ Northing(m)	T_y	Δ Easting(m)	T_x	Δ Elevation(m)	T_z
P1	0.002	0.013	0.008	0.025	0.002	0.021
P2	0.002	0.019	0.010	0.030	0.000	0.004
P3	0.000	0.004	-0.001	0.004	0.001	0.007
P4	0.004	0.031	0.008	0.024	0.001	0.008
P5	0.006	0.051	0.014	0.042	0.008	0.052
P6	0.001	0.012	0.012	0.036	0.000	0.002
P7	0.005	0.037	0.000	0.001	0.001	0.007
P8	0.016	0.129	0.009	0.028	0.000	0.004
P9	0.012	0.101	0.010	0.031	0.010	0.077
P10	0.010	0.088	0.026	0.078	0.008	0.053
P11	0.002	0.021	0.012	0.036	0.002	0.014
P12	0.012	0.105	0.015	0.044	0.010	0.056
P13	0.014	0.111	0.001	0.003	0.001	0.007
P14	0.005	0.042	0.017	0.052	0.002	0.025
P15	0.026	0.233	0.010	0.026	0.024	0.121
P16	0.001	0.999	0.007	0.020	0.030	0.149
P17	0.008	0.069	0.007	0.020	0.030	0.153
P18	0.029	0.268	0.014	0.038	0.022	0.118
P19	0.003	0.024	0.025	0.073	0.010	0.061
P20	0.011	0.096	0.001	0.003	0.009	0.046

From the table 4.17, 4.18 and 4.19, the differences of the magnitude in all coordinates components between the two methods are not much different. It implies that the reflector-less TS method can be applied to slope deformation monitoring.