# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

Nowadays, the increasing incidents of disaster due to slope failures and landslides along the roads and highways in Malaysia need serious and continuous monitoring. This is vital especially in new and hilly area projects such as at the Cameron Highland - Gua Musang highway. A continuous control and monitoring effort is very important in order to keep track of any displacement and its trend. This is as a precautionary measure to ensure public safety and to avoid sudden disasters, which could potentially cause losses of lives, property damages and disruption of economic activities.  Early detection can reduce both the economic and social losses.

This research is aimed to determine the potentials of the Reflector-less Total Station method in slope deformation monitoring applications and the effectiveness of the instrument. This method has been identified as suitable for high risk and inaccessible areas.

This chapter describes the details of the experimental research on slope monitoring by using Reflector-less Total Station. The experiment presented in this work covers the calibration of the instrument to determine zero errors and the accuracy of measurement using various types of materials as reflectors. After the instrument has been calibrated and verified to be in good condition, monitoring work began with the preliminary investigation such as field reconnaissance, topographic investigation, collection of existing data and data collection from Reflector-less Total Station with three sessions epoch observation. These measurements data were adjusted to the error sources, which include instrument placing and leveling, target placing, circle reading, and target pointing in order to determine the error propagation in angle, distance and elevation measurements. These measurements data were used to analyze the kinematics of the deformation, the response of the triggering conditions, and possibly the effectiveness of Reflector-less TS in slope deformation monitoring. After the adjustments have been done, the final task is to decide the points that have significant and real displacements by conducting the testing on the consistency of displacement and directions, on consecutive survey periods.

### 3.2 Description of Study Area

The site lies within the State of Perak at Longitude 101˚ 20’ 43”; Latitude 4˚ 35’ 27”, Malaysia National Grid coordinates N508008; E372623 [50]. It is situated at the second East-West Highway federal route 145 at CH 23 + 800, a highway in Peninsular Malaysia that connects Simpang Pulai in Perak to Gua Musang in Kelantan as shown in Figure 3.1. The highway is expected to be extended further east to Kuala Terengganu in the future. This highway features a four-lane carriageway from Simpang Pulai to Cameron Highlands and a two-lane carriageway from Cameron Highlands to Gua Musang.


Figure 3.1 Location Map
(Source: M. Ismail, 2008)

### 3.3 Reflector-less TS Calibration

Most of the manufacturers claim that their Reflector-less Total Station has good features and the best in measurement. For the distance measurement the accuracy is ± (*a* + *b ppm*, part per million), where *a* is generally in the range of 1 to 10 mm, and *b* is a scalar error that typically has the range of 1 to 10 *ppm* (part per million) [51]. However, this value is computed from calibration or tests in a lab environment, meaning in ideal conditions, without the influence of systematic biases, example like refraction, which occur in the real life situations. Therefore, the quoted accuracy value is very precise and can be treated as the precision of the instrument.

Due to those mentioned errors, periodical calibration of the Total Station is required in order to determine errors of the instrument, and to check performance of the Total Station and its related reflectors as well. If the calibration of the Total Station is performed over a certified baseline to prescribe level of precision, it is considered to be standardized. In Malaysia, Total Station calibration is being practiced for all types of cadastral survey. This is according to the survey regulation of Malaysia. All states in Malaysia have certified baseline, which is controlled by the Department of Survey and Mapping of Malaysia (JUPEM). In Perak state the certified baseline is located at Kinta Golf Club, Batu Gajah, as used in this work.

#### 3.3.1 Apparatus

The experimentation consists of apparatus preparation, data collection in the field and data processing as well as analysis. The apparatus used in this Total Station calibration work consist of three main instruments: Total Station; related prism and various material reflectors; and standardized calibration pillars. In order to perform the calibration, permission and information about the standard value of the distance between pillars must be updated. An appointment with the officer from Survey Department and Mapping Malaysia (JUPEM) was required when the calibration needs to be carried out because they are responsible to keep the pillars key.

*3.3.1.1 Total Station*

Figure 3.2 Topcon GPT3007 N/LN Reflector-less Total Station used in this research

The Total Station used in this research is a Topcon GPT3007 N/LN Reflector-less Total Station, as shown in Figure 3.2. According to the specification, this instrument can provide distances in non-prism long mode with an accuracy of ± (10mm + 10ppm x D) mean squared error (m.s.e) [52]. This instrument uses the invisible laser beam pulse laser technology for precise measurements on narrow beam such as building corners, or an object through a chain link fence. As common Total Station, this type of TS also consists of an electronic Theodolite and an electronic distance meter. A standard Theodolite is basically a telescope with cross-hairs for sighting a target. The telescope is attached to scales for measuring the rotation angle and the inclination angle of the telescope. The electronic Theodolite provides a digital read-out of those angles instead of a certain scale. The scale of this kind of instrument is seen as the minimum reading for both angles (seven second). By the digital read-out and recording device in the Total Station, errors because of interpolation reading and miss-recording can be avoided. A detail specification for the Total Station is given in Appendix A. The specification describes the accuracy of the distances and angles measurements. Where the manufacturer claim that the measuring range for non prism mode in diffusing surface is 1.5m to 250m and for long mode is about 5m to 1,200m. In which the measuring accuracy in fine mode is ± (10mm +10ppm) mean squared root (m.s.e). With the minimum angle reading is at 5"/10" and the accuracy of 5".

### *3.3.1.2 Reflector Targets*

The reflectors used in this research are made of various materials. This is due to every material and colour has specific characteristic in wave reflection. The materials tested here are concrete, wood, and homogenous tile, and the coloured reflectors are black, white and red as shown in Figure 3.3. The measurements on different targets and at different distances should therefore be used to estimate the constants of each surface reflector. The observed distance was compared to a standard prism, and this process was repeated for different distances covering the whole nominal range at the National Standard EDM baseline [53]. This is intended to provide a reference for statistical test. The standard prism reflector is shown in Figure 3.4.

Black colour material

White colour material

Red colour material

Concrete material

Wood material

Homogenous tile material

Figure 3.3 Various target reflectors used in this research

Figure 3.4 A standard single prism used in this research

### *3.3.1.3 Calibration Pillars*

The calibration of TS is performed to determine both the instrument and reflector errors. Standardization refers to the comparison of the measured length by the instrument to a standard length, traceable to national standard. The standard length was transferred to calibration pillars through standard tapes or EDM as prescribed by the national standards commission. The calibration pillars used in this research are presented in Figure 3.5, which is one of the certified calibration baselines in Malaysia. The pillars are continuously controlled by JUPEM, and periodically measured by using Leica TCA2003 TS; the measurements are confirmed to the standards by the National Standards Commission of Malaysia (SIRIM). These pillars are located at Kinta Golf Club, Batu Gajah, Perak, Malaysia. There are ten calibration pillars available, but for the purpose of this research only seven of them were used. Those are pillar-1, pillar-2, pillar-3, pillar-4, pillar-6, pillar-8, and pillar-10 because some of the pillars cap cannot open.

Figure 3.5 Calibration Pillars used in this research

### 3.4 Total Station Calibration

The calibration data observation was accomplished by measuring a series of distances on one standardized baseline and the standard value provided by Survey Department and Mapping Malaysia (JUPEM) as shown in table 3.1 below.

Table 3.1 The Standard Value between Pillars Provided by JUPEM

| Pillar No | | Horizontal Distance(m) |
|---|---|---|
| From | To | |
| 1 | 2 | 5.004 |
| 1 | 3 | 9.996 |
| 1 | 4 | 48.993 |
| 1 | 5 | 86.992 |
| 1 | 6 | 124.998 |
| 1 | 7 | 162.995 |
| 1 | 8 | 200.999 |
| 1 | 9 | 250.989 |
| 1 | 10 | 300.012 |
| 2 | 2 | 4.999 |
| 2 | 3 | 43.998 |
| 2 | 4 | 81.987 |
| 2 | 5 | 119.983 |
| 2 | 6 | 157.995 |
| 2 | 7 | 195.990 |
| 2 | 8 | 245.985 |
| 2 | 9 | 295.002 |
| 2 | 10 | 5.004 |

(Source: JUPEM, 2008)

The scenario of the data measurement is illustrated in Figure 3.6. Each sub baseline was measured for ten times, therefore the standard deviation of each sub baseline can be determined more accurately. The measurements were carried out using the Topcon GPT3007 N/LN Reflector-less TS. Where x is the vector of unknown parameters distances and *l* is vector of observations.

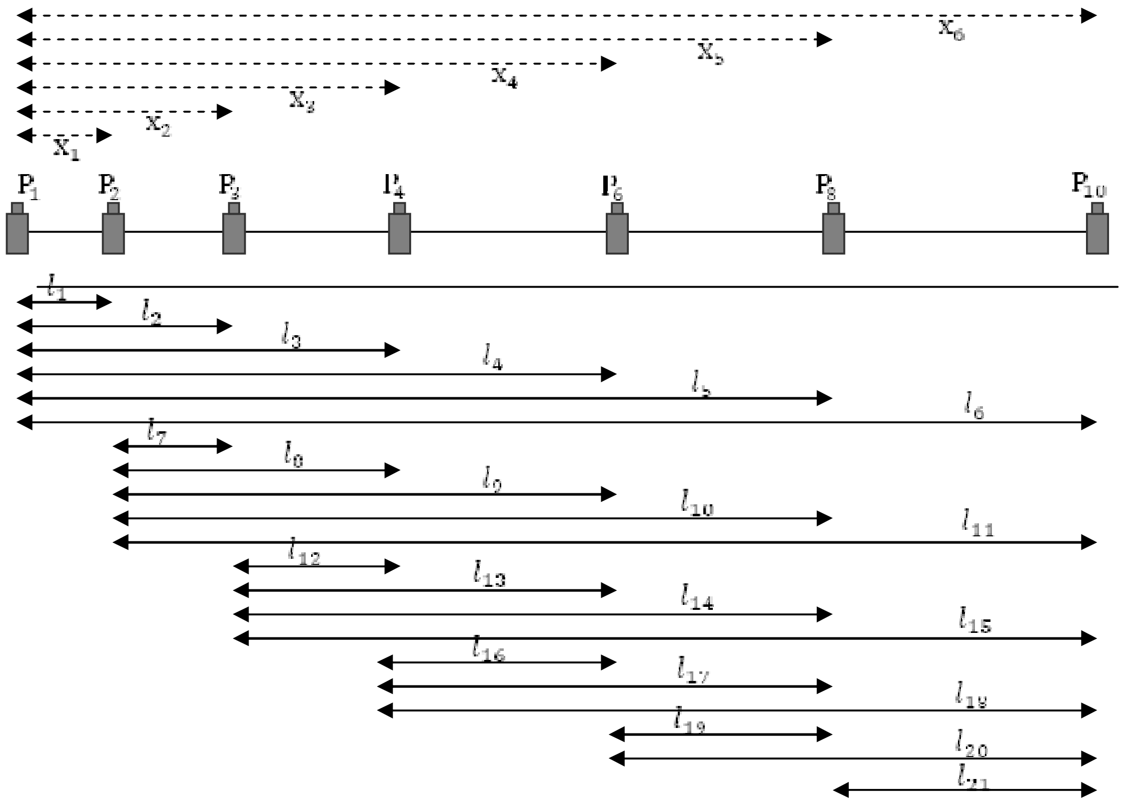


Figure 3.6 Illustration of the calibration scenario; calibration pillars (middle), standard sub baselines (top), and measured distances (bottom)

The methods used in this research were based on the division of a baseline into sub baselines, and measuring all possible distances between the marked pillars and the calculation were based on least-square formula. Mean while the Survey Department and Mapping Malaysia (JUPEM) were using sufficient reading of at least 17 readings involving all the pillars. This method adopted by JUPEM was necessary to establish and ascertain that the constant error of the instrument is within the working limit of 10 mm.

### 3.5 Data Processing

Traditionally, the evaluation of the zero and the scale errors is the purpose of the calibration process. In this latter work, the test simultaneously solves for the zero and the scale corrections based on a system of equations. The solution to this system is very similar to the fit of a straight line to a series of pillars since it contains only two unknown parameters in a linear form. The only assumption that one needs to estimate the scale error (or simultaneously the scale and the zero errors) is the requirement of a sequence of long and known baselines. But a long and known distance is not required to compute the instrument constant (zero error) separately. This can be achieved simply by measuring all distances between pillars on line, which follows by assuming a zero errors $(z_0)$ a measured distance ($l$) must be corrected and where $l^c$ = corrected distance by applying the following correction:

$$l^c = l + z_0 \qquad \text{Eq.3.1}$$

The calculations used in this research to determine zero error and Total Station calibration were adjusted using parametric least-square formula. In the parametric least-square adjustment method, the observation equations are formulated by the quantity of measurement that relates to both independent observational residuals and unknown parameters. One equation is written for each observation. If the number of equations equals to the number of unknowns, a unique solution of the unknowns will be given. By and large, the number of observations is more than the unknowns. This condition permits determination of the most probable values for the unknowns based on the principle of least squares adjustment. Generally linear observation parametric model can be expressed as in the following equations [54]:

$$L + V = AX \qquad \text{Eq.3.2}$$

Where $A$ is design matrix, $X$ is vector of unknown parameters, $L$ is vector of observations and $V$ is vector of residuals. The least-squares solution $\hat{X}$ of equation (3.2) is given below:

$$\hat{X} = (A^T PA)^{-1} A^T PL \qquad \text{Eq.3.3}$$

$$\sum X = \hat{\sigma}_0^2 (A^T PA)^{-1} \qquad \text{Eq.3.4}$$

$$\hat{\sigma}_0^2 = \frac{(V^T PV)}{n-u} \qquad \text{Eq.3.5}$$

$$P = \sigma_0^2 \left[\begin{pmatrix} \frac{1}{\sigma_{l1}^2} & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{\sigma_{l2}^2} & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{\sigma_{l3}^2} & 0 & 0 \\ \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & 0 & \frac{1}{\sigma_{l21}^2} \end{pmatrix}\right] \qquad \text{Eq.3.6}$$

Where ***P*** is weight matrix, $\sigma_0^2$ is an apriori variance, $\sum X$ is variance-covariance matrix of parameters, $\hat{\sigma}_0^2$ is an aposteori variance, *n* is number of observation, and *u* is number of unknown parameter.

### 3.6 Zero Error Estimation

The least square adjustment is applied for determining the zero error and its precision of all materials used in this research. The number of observed distances and sub baselines are required in the determination of least-square equation. The number of observed distances was used to define the number of the model equations, while the number of unknown parameters was the same as the number of unknown sub baselines plus zero error. Elements of the zero error computation model is: n = 21 ($l_1, l_2, l_3, l_4, l_5, \dots l_{21}$); u = 6 +1 ($x_1, x_2, x_3, x_4, x_5, x_6, z_0$);

Where;

n is the number of observations

u is the number of unknown parameters

With the linear parametric model that relates the observation unknown parameters can be written as follows:

$$\begin{pmatrix} l_1 + v_1 = x_1 - z_0 & l_7 + v_7 = x_2 - x_1 - z_0 & l_{13} + v_{13} = x_4 - x_2 - z_0 & l_{19} + v_{19} = x_5 - x_4 - z_0 \\ l_2 + v_2 = x_2 - z_0 & l_8 + v_8 = x_3 - x_1 - z_0 & l_{14} + v_{14} = x_5 - x_2 - z_0 & l_{20} + v_{20} = x_6 - x_4 - z_0 \\ l_3 + v_3 = x_3 - z_0 & l_9 + v_9 = x_4 - x_1 - z_0 & l_{15} + v_{15} = x_6 - x_2 - z_0 & l_{21} + v_{21} = x_6 - x_5 - z_0 \\ l_4 + v_4 = x_4 - z_0 & l_{10} + v_{10} = x_5 - x_1 - z_0 & l_{16} + v_{16} = x_4 - x_3 - z_0 & \\ l_5 + v_5 = x_5 - z_0 & l_{11} + v_{11} = x_6 - x_1 - z_0 & l_{17} + v_{17} = x_5 - x_3 - z_0 & \\ l_6 + v_6 = x_6 - z_0 & l_{12} + v_{12} = x_3 - x_2 - z_0 & l_{18} + v_{18} = x_6 - x_3 - z_0 & \end{pmatrix}$$

Those observations can be written in matrix form, following Equation 3.2:

$$\begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ \dots \\ \dots \\ v_{21} \end{bmatrix} + \begin{bmatrix} l_1 \\ l_2 \\ l_3 \\ l_4 \\ \dots \\ \dots \\ l_{21} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & -1 \\ 0 & 1 & 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 1 & 0 & 0 & -1 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & 0 & 0 & 1 & -1 \end{bmatrix} * \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ z_0 \end{bmatrix} \quad \text{Eq.3.7}$$

$$V \;+\; l \;-\; A \;*\; X$$

Based on the matrix equation (3.7), the adjusted unknown parameter $\hat{X}$ could be obtained using Equation 3.2 and the covariance matrix of adjusted unknown parameter was calculated by using Equation 3.3. Furthermore, a proper statistical test (global test) was applied in order to detect any possible outliers in processing of least square adjustment. This aim of this test was to examine the compatibility of the number of estimated aposteori variance $\hat{\sigma}_0^2$ with the number of apriori variance by using *Fisher* distributions as given in Appendix B with a certain significance level $\alpha_o$ and degrees of freedom *(f=n-u)*. The *F-test* has been defined in Equation 3.7. Moreover, to examine the significance of the zero error, *t*-student statistical test was carried out in this experiment. The value of the *t* is the ratio of the zero error and the standard deviation, as shown in the following Equation 3.8. The critical value of *t*-test is referred to the *t*-table as given in Appendix C with respect to the *significance level* $\alpha$ and the appropriate *degrees of freedom (f)*.

$$\frac{\hat{\sigma}_0^2}{\sigma_0^2} > F_{1-\alpha 0,f,\infty} \quad \text{Eq.3.8}$$

$$\frac{z_0}{\sigma_{z0}} \leq t_{\alpha,f} \quad \text{Eq.3.9}$$

### 3.6.1 Calibration of Distance Measurement Tool in the TS

Value of the zero error was computed from the previous calculations (Refer section 3.5). Based on this value, corrections for zero error were made in all observed distances; therefore corrected observed distances were acquired. Calibration of the distance measurement tool is necessary to ensure confidence in the distances it measures. The calibration is not only applied for the instrument, but for its related reflectors as well. The reflectors used in this research are standard single prism, black, white, and red coloured materials, concrete, wood, and homogenous tile. The observation equation for an electronically observed distance on a calibration base line can be expressed as in Equation 3.10:

$$\left(D_O - D_p + V_{DO} - a * D_p + b\right) \qquad \text{Eq.3.10}$$

Where $a$ is scaling factor for the TS, $b$ is instrument-reflector constant, $D_O$ is the observed horizontal distance after zero error *correction*, $D_p$ is the published horizontal calibrated distance for the baseline, $V_{DO}$ is the residual error for each observation. Since Equation 3.10 is a linear equation with two unknowns ($a$ and $b$), so it can be solved by using Equation 3.2. The equation can be expressed in matrix form as presented in Equation 3.11 below:

$$\begin{bmatrix} (D_{O1} - D_{p1}) \\ (D_{O2} - D_{p2}) \\ (D_{O3} - D_{p3}) \\ (D_{O4} - D_{p4}) \\ \ldots \\ (D_{O21} - D_{p21}) \end{bmatrix} + \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ \ldots \\ v_{21} \end{bmatrix} = \begin{bmatrix} D_{p1} & 1 \\ D_{p2} & 1 \\ D_{p3} & 1 \\ D_{p4} & 1 \\ \ldots & \ldots \\ D_{p21} & 1 \end{bmatrix} * \begin{bmatrix} a \\ b \end{bmatrix} \qquad \text{Eq.3.11}$$

### 3.7 Control Points

Most deformation monitoring schemes consist of measurements made to monitored object that are referred to several reference points, which are assumed to be stable. To obtain correct object point displacements (and thus deformations), the stability of the reference points must be ensured to be in good position [55]. The network configuration should be taken into account in the network design, such as determining the location of monitoring monument points and references that are free from any air view obstacles, observation technique, instrumentation, time and cost. However in this research, the monitoring network design has been established by MTD survey team. They were situated at an ideal and stable geographical location shown in Figure 3.7. The control points covered all the targets prism points, and were visible to one another. Thus, the monitoring points could be captured very clearly. The information about the monitoring points such as station or number ID, bearing and distance coordinates were obtained from the MTD survey team.

Figure 3.7 Control point established by MTD

A good network design must take serious consideration into matters like reference datum and coordinate system being used in order to prevent any failure during observation operation and also to predict the results obtained from the observation activity. Therefore in order to assess the stability and the coordinate system used by MTD survey team, GPS and TS observations were carried out to verify the angles and distances of the three marks according to Malaysian standard survey regulation [56]. (Figure 3.8 shows the author and his team carrying out GPS observation). According to the standard survey regulation, the difference between new observations and old values adopted by MTD must not exceed 30” in angle, 1/8000 in distance or lines exceeding 40 m, 30” in bearing and 0.006 m per 20 m with a maximum of 0.03 m.

Figure 3.8 Checking control point using GPS

**3.8 Reflector-less Monitoring Points**

The reference mark used for the monitoring points was a mini prism as shown in Figure 3.10, which has been planted by MTD survey team. These monitoring points were installed at the strategic locations, which are safe from landslide (minimum risk), enough and scattered across the slope study area. There were 18 monitoring points planted permanently at the slope and can be observed from the control station shown in Figure 3.9. In this research, the poles of the mini prism have been used as target points. The monitoring points are located within less than 1km working range from the control point. Unfortunately some of the prisms have either been stolen or damaged during the construction, according to the MTD project manager, [57].To overcome this problem new reference targets were identified as aimed points as shown in Figure 3.10.

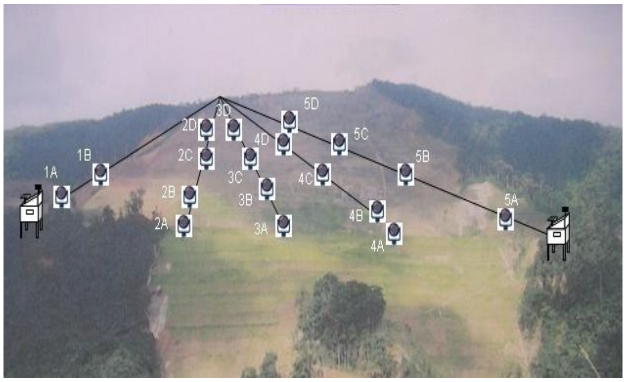


Figure 3.9 Monitoring Points

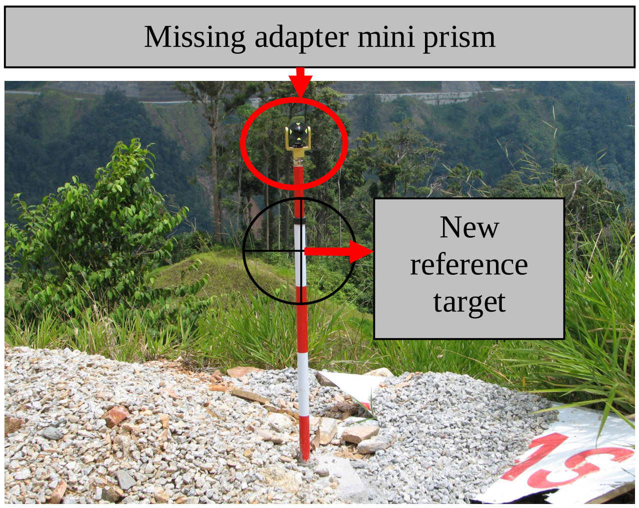


Figure 3.10 New Reference Target

### 3.9 Data Collection

Parameter observation angle and distance measurements are very important in this research because the accuracy of this project depends on the observations. Before the observation was made all the prism constants must be keyed into the internal memory of the Reflector-less TS as shown in Figure 3.11. The value was calculated during calibration works. This means that all the observation distances are corrected data.

```
PRISM CONST. SET
 PRISM →0.0 mm
 N-PSM :0.0 mm
INPUT --- --- ENTER
```

Figure 3.11 Setting the prism/non-prism constant value

The procedures and methodology of data collection are summarized as follows.

Firstly, the instrument was set-up at station 44 as the initial benchmark as shown in Figure 3.12, and back sight at station 43 as the reference point, and station 45 as the forward reference point as shown in Figure 3.13. The angle and tie distance were checked to identify that the control station was still in good condition base on JUPEM standard. And then the monitoring points were sight shot accordingly in the clock wise manner as shown in Figure 3.14. For greater accuracy, each observation was measured four times, two measurements in the circle left reading and the other measurements in the circle right reading, therefore the standard deviation of each observation can be determined. All captured were stored in the internal memory of the instrument.

The first epoch observation was taken on 05/01/08 and the second epoch observation was taken on 07/06/08 using Reflector-less TS, and the third epoch was recorded on 12/12/08. As shown in Appendix D**,** The old values were provided by MTD survey team and the observation were made using TS set Sokkia SET 5B [58] with the accuracy of ± (5mm + 5ppm) with prism, and was taken on 12/02/03.

Figure 3.12 Station No. 44.

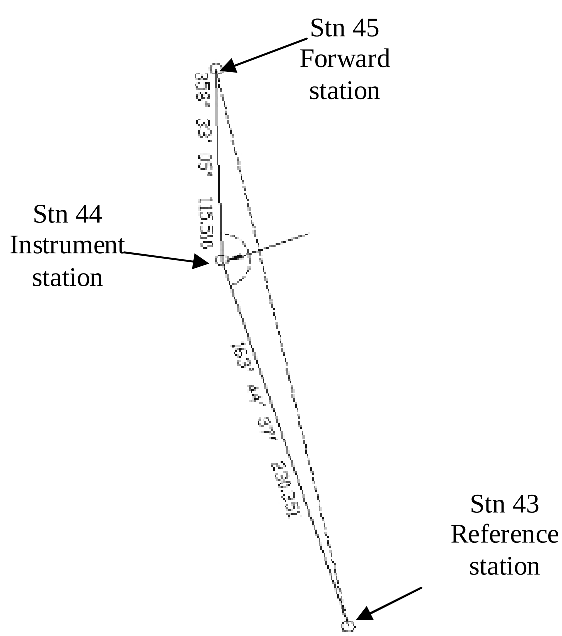


Figure 3.13 Control Point Station

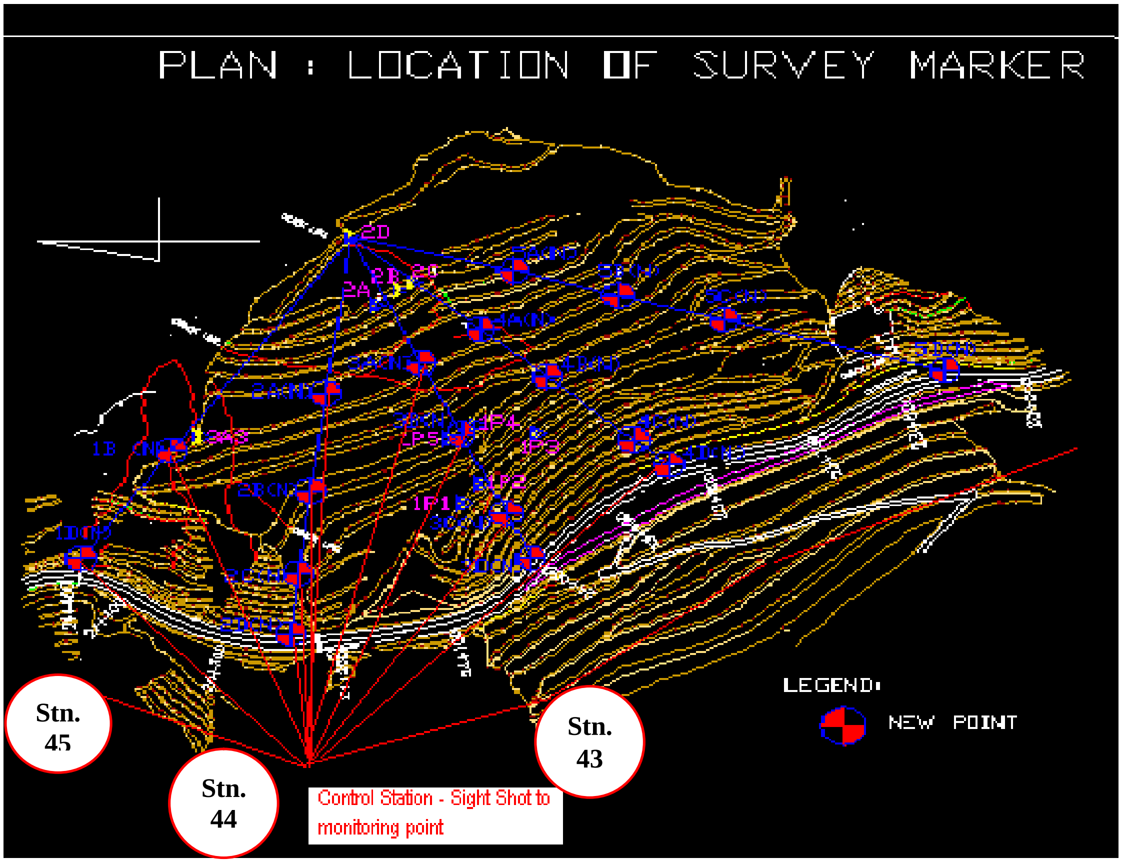

Figure 3.14 Set-up for field work

### 3.10 Data Reductions

To appreciate fully the need for adjustments, the major observational error sources must be identified and their effects on the measurements known. The sources of the errors must be modeled. The actual observations by the Reflector-less TS are horizontal and vertical angles (Hz and V), and slope distance (Sd). These are called fundamental measurements. From these data, the relative coordinates of the target and elevation or height difference by trigonometric leveling can be determined. The measured data were downloaded into the computer with Topcon Tool Software. Then the raw data were converted into an EXCEL file.

### 3.11 Observations Errors

Conventionally, observation errors are classified into random errors, gross errors and systematic errors. Since the observation from Reflector-less TS involves fundamental measurements, therefore it needs to be corrected. The variance of the observation is useful in order to get the accuracy of the measurements. These include the distance, angle and elevation. Mostly the random errors will not exceed a certain amount and it can be positive or negative, and it may occur at the same frequency [59].

In this research, the data were adjusted using conventional procedures to account for the value of systematic errors which was determined by calibrations of the instruments and reflector targets; in this case targets fabricated from various materials have been tested. All the measured distances corrected according to the material of the target at the steep slope. The angle errors were determined from a combination of errors from pointing and reading with the TS, target centering and TS centering, as explained earlier in Equation 2.21, and the elevation errors was computed by using Equation 2.26.

The estimated errors in distance and angle were then used in Equation 2.30 for computation of the error propagations in traverse survey, in order to arrive at the final coordinates or adjusted coordinates.

### 3.12 Displacement Test

To prove that displacement is significant, congruency statistical test is adopted in this study using t-student distribution. The number of T-computed is the ratio of the displacement and its standard deviation ($\sigma(\Delta dij)$) and can be expressed as in Equation 2.38 for horizontal displacement and Equation 2.39 for elevation.

This standard deviation is determined by error propagation approach from the standard deviation of coordinate. The region where the null hypothesis is accepted is $T < tf, \alpha/2$. The critical value of t can be found in the t-table corresponding to the relevant significance level (α) and the appropriate degrees of freedom (f). By using a confidence level of 95% ($\alpha$=5%) then the t-value ($\infty$, 0.025) is 1.960 [60] [61].

If the result shows that the horizontal and vertical components exceed the expected value of the confidence level, it is likely due to actual movement of the monitoring points.  On the other hand, if the value is smaller than the confidence level, then it does not indicate a significant magnitude of movement along the study area. It indicates some movement on the slope of the study area, but not of a significant magnitude. The null hypothesis of the test $\Delta dij = 0$ indicates there is no movement between two epochs.

### 3.13 Quality Measurement of Deformation Monitoring Points

The magnitude of movement of the points in this study area was compared to the data observed by standard prism TS by calculating the differences of the coordinates in northing, easting and elevation of the same epochs. T-student statistical test was then performed to test the significance of the result obtained.

T-Test is the ratio between the displacement of the coordinates (northing, easting and elevation)  by differences of standard prism TS (standardized) and reflector-less TS between each epochs to the square root of sum standard deviation standard prism and reflector-less TS, assuming that there were no error with standard prism TS as shown in the following Equation:

$$T_x = \frac{dx_{Prism} - dx_{RefLess}}{\sqrt{(\sigma x_{prism})^2 + (\sigma x_{RefLess})^2}} \qquad \text{Eq.3.12}$$

$$T_y = \frac{dy_{Prism} - dy_{RefLess}}{\sqrt{(\sigma y_{prism})^2 + (\sigma y_{RefLess})^2}} \qquad \text{Eq.3.13}$$

$$T_z = \frac{dz_{Prism} - dz_{RefLess}}{\sqrt{(\sigma z_{prism})^2 + (\sigma z_{RefLess})^2}} \qquad \text{Eq.3.14}$$

Whereas;

$T_{x,y,z}$ = T-test for easting, northing and elevation

$dx_{prism}, dy_{prism}, dz_{Prism}$ = difference between epochs by using standard prism TS as presented on Appendix E.

$dx_{RefLess,} dy_{RefLess,} dz_{RefLess,}$ = difference between epochs by using reflector-less TS as presented on Appendix F.

$\sigma x_{prism}, \sigma y_{prism}, \sigma z_{prism}$ = standard deviation of prism TS (assumed as standardized), therefore the value is adopted as zero

$\sigma x_{RefLess}, \sigma y_{RefLess}, \sigma z_{RefLess}$ = standard deviation of reflector-less TS, which is estimated error in latitude and departure as presented on Appendix G.

**3.14 Experimental Work Flow**

This work has been carried out in several steps, which can be classified into six steps in general.

i. Site investigations

Prior to entering the site, approval from the Jabatan Kerja Raya (JKR) of Perak must be obtained. The approval letter from Head of Road Department of JKR Perak is appended in Appendix H. The purpose of the site visit is to gather information from the contractor, MTD group, such as record of control station points, monitoring points, photo of sites developments and history of landslides occurred at the study area. This phase includes the preliminary investigation such as field reconnaissance and topographic investigation.

ii. Calibration of the Reflector-less Total Station

To ensure reliable measurements, the instrument and its targets must be calibrated. The motive is to ensure each operation observation carried out can be achieving the exact level and free from any error.

Prototypes of various surface targets and prism adapter to be used in the calibration were prepared. Prior to conducting the calibration at standard baseline approval from the Survey department of Perak (JUPEM) was obtained for the use of the calibration pillars. From these results the expected precision of the measurement system is inferred.

iii. Data collection (by the reflector-less Total Station)

One unit of reflector-less TS instrument module Topcon GPT-3005N/LN was used in data collection. According to the specification, this instrument can provide distances in non-prism long mode with an accuracy of ± (10mm + 10ppm x D) m.s.e.

The investigation of surface deformation is conducted to define the boundaries of the landslide, size, level of activity and directions of the movement, and to determine individual moving blocks of the main slide which was identified by the contractor. Before the observations were carried out, all the control station must be in good condition and verified according to the survey regulation. Observations were carried out in three epochs; on 07/01/2008 for the first epoch, on 08/07/2008 for the second epoch and on 12/01/2009 for the third epochs. (These included datum verification of the control station and the monitoring points observation.)

iv. Data screening

In this study, observations were made to monitor points that were captured four times in order to get redundancies of the measurements. Therefore by using the "Rule of Thumb" of three standard deviations statistical analysis is used to indicate that there is no outlier in the observation data.

v. Data processing

Two steps are involved i.e estimation of error sources and detection of slope movement.

In this phase, the processing of all observation data was carried out using the Topcon Tool Software which is communication software tools between instruments and computer or download processing software. The adjustment of the observation and the detection of slope movement were computed using EXCEL Microsoft software. The computation for the adjustment was based on a modeled formula of error propagation in angle and distance observations by reflector-less TS.

vi. Slope deformation monitoring detection

Finally, in order to indentify deformation points, T-Test is adopted to prove that the displacement is significant. This is based on the ratio of displacement and its standard deviation ($\sigma(\Delta dij)$) of error propagation in angle and distance observations.

vii. Quality measure

The quality of detecting deformation was determined by comparing with the standard prism method. T-Test statistical test was then performed to test the significance of the result obtained.

The workflow of this thesis is presented in Figure 3.15.

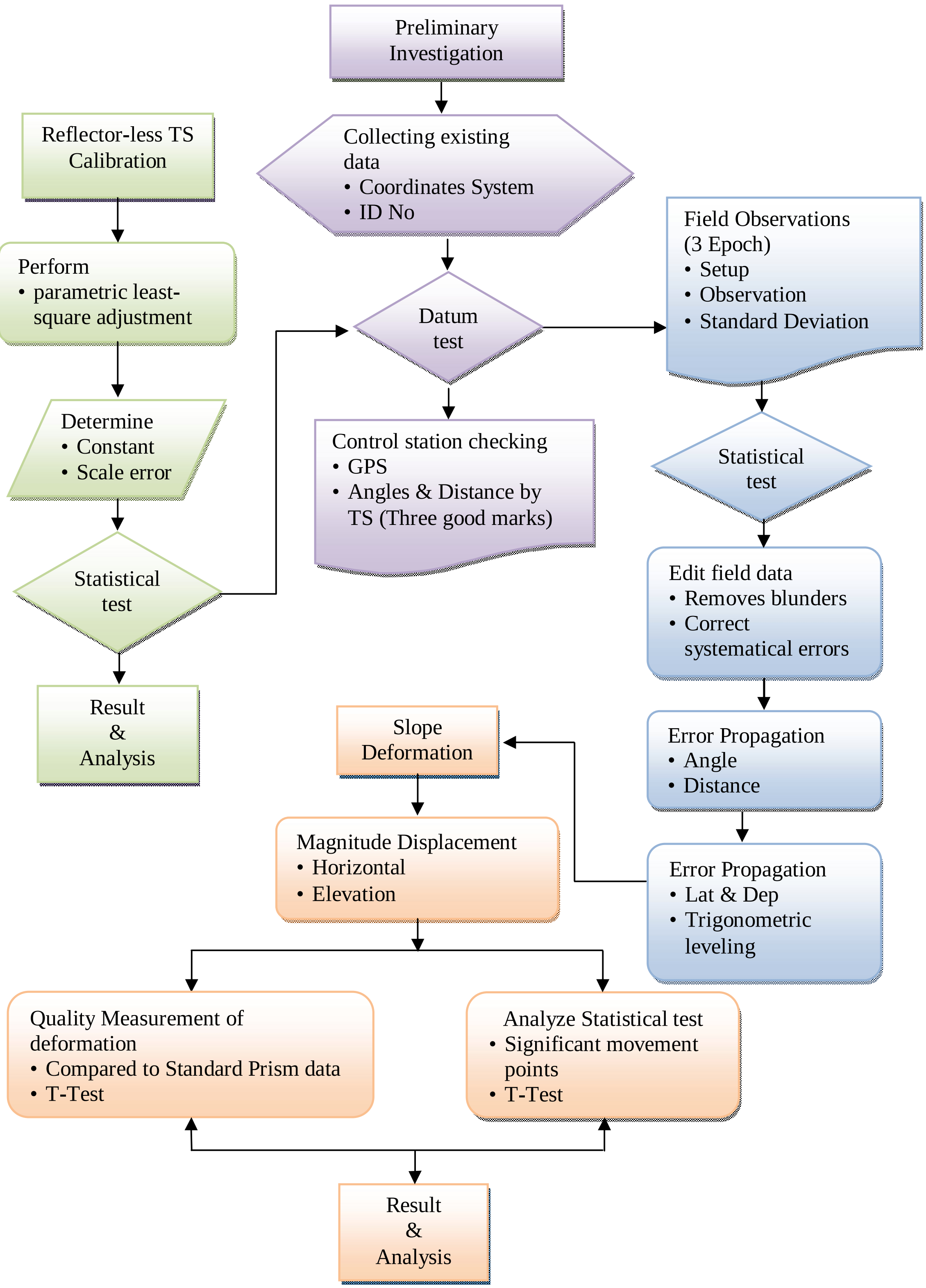


Figure 3.15 Experimental work flow of this research