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RESEARCH PAPER

INVESTIGATION OF HORIZONTAL AND VERTICAL CONTROLS ON KNUSTCAMPUS

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ABSTRACT
Controls are coordinated horizontal or vertical positional data for land and geographic information systems forming a framework to which surveys are started, referenced and adjusted. Controls on KNUST campus were established over three decades ago with new ones being added as and when they are required. Conventional survey methods like trilateration, triangulation and traversing were used and are still being used for densification of controls. These approaches involve the use of low precision instruments such as analogue/optical theodolites and leveling equipment. Since the establishment of these controls, they have not been investigated but they are being used for project development. A modern method that uses satellite positioning techniques such as GPS is currently in operation and has numerous advantages in the establishment of control networks. GPS control surveys were carried-out on seven controls and ellipsoidal coordinates were obtained in the World Geodetic System 84 reference frame. The Cartesian coordinates were projected onto the Universal Transverse Mercator frame. A two dimensional conformal transformation was done using existing KNUST boundary coordinates to Ghana National coordinates based on the War Office ellipsoid. Precise Level routines were carried out on the seven controls for the computations of orthometric heights. The method of least squares adjustment, root mean square errors (RMSE), standard errors (SE) and residuals derived were used to analyse the differences in horizontal positions and heights of the controls. The linear displacement between the computed and the existing coordinates were within the range of 0.015m to 0.014m. The RMSE were 0.048 and 0.106, whiles the SE were also 0.057 and 0.125 for the northings and eastings respectively. The computed and existing heights differed between -0.075m and -0.004m with a mean downward movement of 0.011m.

Keywords: *Surveying, coordinates, control points, GPS, precise level*

INTRODUCTION

Controls are coordinated horizontal or vertical position data forming a framework to which other surveys are referenced and adjusted. They form the basis or reference points for starting all kinds of survey projects. They also give locations of data for land and geographic information systems. The accuracy of survey works depends on the stability of the controls used, the instruments and methodologies employed in executing the task, the mathematical models used for data manipulation, the reference surfaces as well as the coordinate systems (Uren and Price, 2010).

Controls on KNUST campus were established as far back as1949 with conventional survey methods like trilateration, triangulation and traversing. These same methods are being used currently to control densification. Surveys carried out using these conventional techniques are done with low precision instruments such as analogue/optical theodolite and level equipment. Since the control points were established, their stabilities have not been investigated even though they are used for projects development. Modern methods for establishing and densifying control networks using satellite techniques such as satellite altimeters and global navigation satellite systems (GNSS) are in operation and their application is expanding beyond positioning. The use of these techniques gives results that are faster, easier, less expensive and with high accuracies and precisions (Poku-Gyamfi and Hein, 2006). This GNSS gives accurately the three dimensional (3D) position (latitude, longitude and ellipsoidal heights) co-ordinates of a station and system operations are free from weather conditions. In order for surveyors to attain high quality output for clients, it is necessary that all works are done with a certain high degree of precision and accuracy. The basic principle of survey requires that all works be done from whole to part and this practically leads to the use of survey controls for every work (Barlier and Lefebvre, 2001).

Horizontal controls are coordinates with precise latitudes and longitudes of stations overlarge areas. These are geodetic or rectangular coordinates. These types of controls are defined with respect to an ellipsoid of revolution. Vertical controls are the orthometric heights and are also defined with reference to a local geoid model. For high accuracy requirements, three dimensional position coordinates are always taken into consideration with the geodetic latitude and longitude referenced to the ellipsoid and the elevation to a local geoid. The geoid is the most important reference surface for height measurements. It is a level surface with a constant potential energy that coincides with mean sea level (MSL) over the oceans. The ideal datum that best approximates the MSL and used for all height establishments is the geoid (Evans *et al*., 2002).

The ellipsoids serve as a geometric reference frame for horizontal coordinates of various national geodetic networks. While it is necessary to make observations and measurements on or near the physical surface of the earth, it would be quite impossible to perform detailed and extensive computations on a surface whose definition requires several parameters. Since the sphere cannot be used for computations, an ellipsoid of revolution is chosen as the best mathematical model of the earth. The inability of the shape of the ellipsoid to fit the earth perfectly has resulted in the use of different ellipsoids in different countries. These differ in size, shape and orientation depending on where it is being used (Smith, 1997; Jackson, 1980).

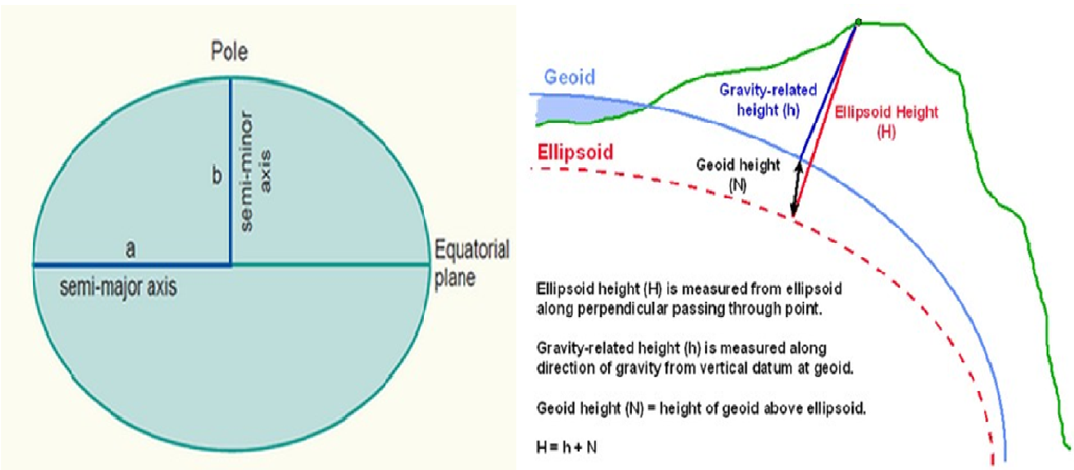
The reference frame for GPS positioning is the World Geodetic System of 1984 (WGS84). WGS84 is a three dimensional(3D) reference frame coordinated in earth centred-earth fixed X, Y, Z or in latitude ¢, longitude λ and ellipsoidal heights H. Parameters used to define this ellipsoid are the semi-major axis, (a), semi-minor, (b) and the flattening, (f). Fig. 1.

Mathematically,

$f = 1- \frac{b}{a}$ and the first numerical eccentricity, e is defined in Torge and Muller (2012) as

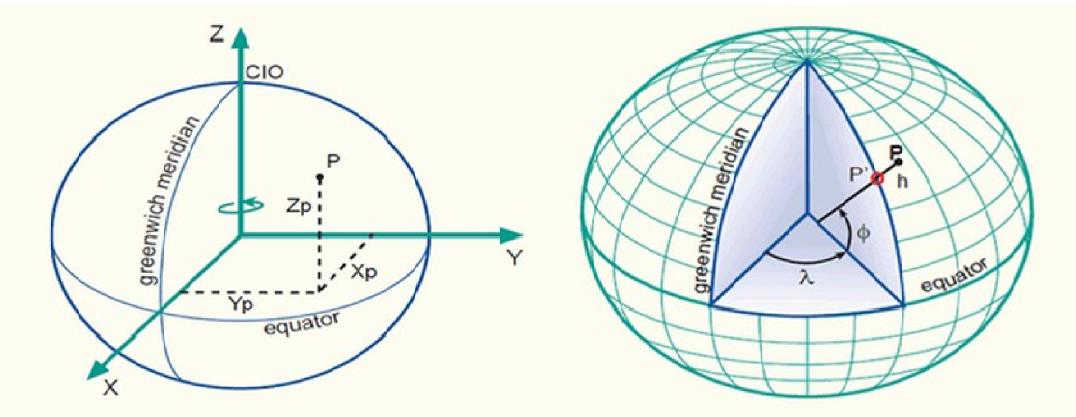
$$e^2 = \frac{a^2 - b^2}{b^2}$$

Orthometric heights are physical heights needed mainly for most engineering and other survey projects. The orthometric height (h) of a point on the Earth's surface is the distance measured from the geoid along the plumb line to the point on the earth surface. Ellipsoidal height (H) is also the distance from the reference ellipsoid to the point measured along the line which is normal to the ellipsoid (Merry, 2003). Ellipsoidal heights obtained from GPS positioning are transformed to orthomet-



(a) The ellipsoid (Knippers, 2009) (b) Relationship between the ellipsoid and geoid

Fig. 1: Models of the Earth



(a) Geo centric coordinate system (X,Y,Z) (b) Geodetic coordinate system (¢,A,H)

Fig. 2: Ellipsoidal reference coordinate systems (Knippers, 2009)

ric heights before usage. Problems normally associated with these conversions are errors in the geoid ellipsoid separation, which translate fully into orthometric height errors. In order to achieve high accuracy of control coordinates one requires the use of well-defined coordinate systems (Figs. 2a and b). The specific coordinate systems used are the geographic coordinates in a 2D or 3D space and the geocentric coordinates (3D Cartesian coordinates).

Planar coordinates which are in the form of-Cartesian and polar are also used to locate objects on maps in a 2D space. These coordinate systems are with reference to the ellipsoid and not the earth. Coordinates are normally transformed from either X, Y, Z to ¢, A,H or vice versa. The conversion models as defined in Torge and Müller (2012), Hofmann-Wellenh of and Moritz (2006) and Seeber (2003) are as follows:

$$X = (\bar{N} + H)\cos ¢ \cos A \quad (1)$$

$$Y = (\bar{N} + H)\cos ¢ \sin A \quad (2)$$

$$Z = (1 - e^2)\bar{N} + H)\sin ¢ \quad (3)$$

$\bar{N}$ is the radius of curvature in the prime vertical:

$$\bar{N} = \frac{a}{\sqrt{1-e^2 \sin^2 \emptyset}} = \frac{a}{\sqrt{1-f(2-f)\sin^2 \emptyset}}$$

The inverse computation is given by these expressions:

$$H = \frac{\sqrt{X^2+Y^2}}{\cos\emptyset} - \bar{N} \quad (4)$$

$$\emptyset = \arctan \frac{z}{\sqrt{X^2+Y^2}}\left(1 - e^2 \frac{\bar{N}}{\bar{N}+H}\right)^{-1} \quad (5)$$

$$\lambda = \arctan \frac{Y}{X} \quad (6)$$

Adjustments in surveying are done for quality control of measurements and allows for the application of necessary corrections to get the measurements right within specifications. This makes it important for redundant measurements to be taken on the field, so as to detect gross errors and increase the precision of the computed unknowns. Again, it helps in the estimation of standard deviations of the observations and the unknowns, test the Mathematical and Stochastic models and compute the reliability of the system (Ghilani, 2010).

MATERIALS AND METHODS

The study was carried out on seven control points on KNUST campus. These were KNUST/TP1 (base station), KNUST/TP6,SGA/P130/13/2 (Administration roundabout), SGAP130/13/1 (opposite Main Library), SGA/P130/13/3 (Unity Hall roundabout), SGA/P130/13/12 (KNUST Printing Press roundabout), SGA/P130/13/13 and KNUST/TP6A.

The materials used were, Sokkia Radian IS@ Geodetic GPS (a base and a rover receivers) and accessories, digital level with barcode, Hi-Target Geomatics Office software package, version1,tape, stop watch and existing horizontal and vertical coordinates from Geomatic Engineering Department. The method applied was the static differential GPS techniques as defined in USACE-Editors (2003). The traverse began with the setting up of a GPS receiver on KNUST/TP1 as the base station and all other controls as rovers. The observation sessions lasted for a period of twenty (20) minutes. The instrument height was measured and recorded at every station. The start and end times for every session were logged in addition to instrument serial numbers. The traverse was closed on KNUST/TP6A. Two data sets of readings were captured. The precise leveling was also carried out in four phases. The first phase was between control points SGA/P130/13/12 and SGA/P130/13/13. The second was SGA/

P130/13/2 and SGA/P130/13/1. The third-phase was SGA/P130/13/2 and SGA/P130/13/3 and the fourth was between KNUST/TP1 and KNUST/TP6.

computed coordinates were determined and their Root Mean Square Errors (RMSE), Standard Errors (SE) and Radial Displacements were determined. An excel programme was

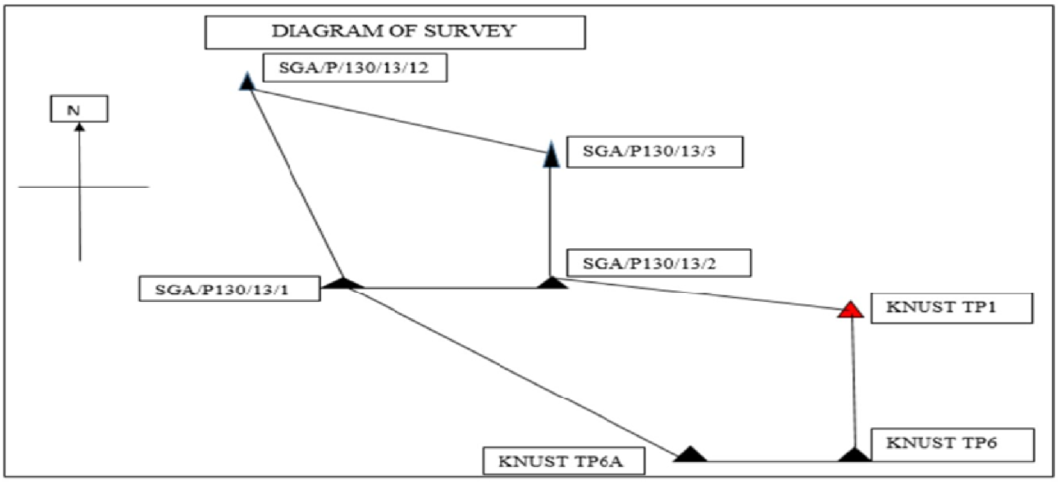


Fig. 3: Diagram of survey

Data reduction and statistical analysis

The logged GPS data were processed using the Hi-Target Geomatics Office software (Hi-Target, 2014). The geographic (horizontal) coordinates obtained in the WGS 84 were projected to the Universal Transverse Mercator (UTM). From the UTM coordinates, two dimensional (2D) conformal projection was done using existing KNUST boundary coordinates by converting the ellipsoidal coordinates to National coordinates (refer Acheampong, 2008). Baselines were then computed from the natural coordinates for two sections of the traverse and their averages were determined. Vectors were also extracted and used for loop closure computations. The sum of the loop closure was equal to zero and therefore least square adjustment could not be applied. Instead, the differences between the existing and customized using the precise level formula to compute the orthometric heights for the control points. The method of least squares adjustment (refer Ghilani, 2010: 211) was used to analyse the processed results from which corrections (ε), most probable values (mpv) and SE were determined. Statistical analyses were conducted for estimated true values at 95% confidence level for the orthometric heights. The checks on estimated true values were obtained from:

A_m-$E_{95\%}$,a,A_m+$E_{95\%}$ where A_m is the mean of observation/observed height and a is the observation/observed height before adjustments.

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RESULTS AND DISCUSSION

The existing coordinates of the seven control points used in the study were established in 1989. They were resurveyed and renamed in 2013. Table 1 gives details of the control points.

The results of the means of the processed coordinates in UTM were transformed into the Ghana National mapping framework using 2D conformal transformation parameters and presented in Table 2.

According to Uren and Price (2010), since true values are rarely known, standard errors and residuals are computed to determine the probability of true value of measured quantities lying within a certain range for the reliability of estimated true values. Since the standard errors are relatively small as compared to their corresponding quantities, it can be inferred from the 95% confidence level that the adjusted measurements lie within the range of their true values and can therefore be accepted.

The results in Table 3 clearly indicates shifts in all control stations with the maximum displacement in the Northing direction being 0.121 and the Easting direction being 0.127. In combining both easting and northing movements, the linear displacements of the various horizontal coordinates are shown in

Table 1: Existing coordinates of controls on KNUST

Pillar ID	Coordinates	Heights		
	Northings (Ne)	Eastings (Ee)	H	Location on Campus
KNUST/TP1	221746.252	211793.243	262.690	Beside Social Science Block
KNUST/TP6	221658.988	211813.558	263.725	Behind old "N" block
SGA/P130/13/1	221778.027	211035.196	261.379	Opposite KNUST Library
SGA/P130/13/2	221776.863	211182.024	248.956	Administration Roundabout
SGA/P130/13/3	222160.429	211179.571	252.335	Unity Roundabout
SGA/P130/13/12	222520.887	210641.280	274.904	Printing Press roundabout
SGA/P130/13/13	222588.306	210508.666	274.773	Bomso Roundabout

Source: Survey Unit, Geomatic Engineering Department, KNUST

Table 2: Results of processed coordinates in UTM and transformed Ghana coordinates

Pillar ID	UTM		Transformed Coordinates	
	Northings (Nu)	Eastings (Eu)	Northings (Nt)	Eastings (Et)
KNUST/TP1	738036.462	658582.178	221746.230	211793.352
KNUST/TP6	737949.296	658602.576	221658.992	211813.398
SGA/P130/13/1	738065.200	657823.963	221778.012	211035.337
SGA/P130/13/2	738064.520	657970.601	221776.742	211181.956
SGA/P130/13/3	738448.231	657966.802	222160.426	211179.698
SGA/P130/13/12	738806.592	657426.899	222520.917	210641.294
SGA/P130/13/13	738873.451	657294.002	222588.303	210508.681

column 4 of table 3. The maximum displacement is 0.160m with the least being 0.015m with four out of the seven controls shifting in the North-Western direction. The RMSE and SE are also shown with the Eastings component recording greater shifts. The displacements in the coordinates could be attributed to several factors such as instrumental, environmental and techniques used during measurement. Satellite position applications are of better accuracies than that of the optical instrument because errors in the horizontal circle graduation, focusing and bisection of targets are not encountered.

The techniques employed in the establishment of the Controls years ago were quite different from today where application of modern technologies make data collection, processing and management easy. Most importantly GPS offers numerous redundant observations for the application of least squares minimization techniques. Four of the controls were linearly displaced towards North-West, whiles the remaining two, one shifted in the South-Eastern and the other in the South-Western direction.

Analysis of orthometric heights

The mean orthometric height differences obtained from the precise levelling operation were computed and presented in Table 4. The differences in height between the control points are presented in Fig.4. Using KNUST/TP1 as the known station and constrained in the least-squares adjustments, observation equations were formed and shown in equation 7.

The orthometric height for KNUST/TP1from the Departmental Archives was used in conjunction with mean height differences to compute the 'provisional heights' for the control stations.

Table 3: Differences between existing and computed horizontal coordinates

Pillar ID	$\delta N = Ne - Nt$	$\delta E = Ee - Et$	Linear Displacement (m)	Direction
KNUST/TP1	0.02	-0.109	0.111	North-West
KNUST/TP6	-0.004	0.160	0.160	South-East
SGA/P130/13/1	0.01	-0.141	0.141	North-West
SGA/P130/13/2	0.12	0.068	0.138	North-East
SGA/P130/13/3	0.00	-0.127	0.127	North-West
SGA/P130/13/12	-0.030	-0.014	0.033	South-West
SGA/P130/13/13	0.00	-0.015	0.015	North-West

RMSE=0.048and 0.106 for Northings and Eastings directions respectively.
Standard Errors (SE) in Northings, SEn=0.057and Eastings, SEe=0.125

Table 4: Differences in elevation between successive controls stations using Precise Levelling approach

Level line	δH_1	δH_2	δH_3	Mean height differences
KNUST/TP1-P130/13/2	-14.204	-14.202	14.203	-14.203
P130/13/2–P130/13/3	4.370	4.373	4.373	4.373
P130/13/3–P130/13/12	21.819	21.823	21.821	21.821
P130/13/12–P130/13/13	0.137	0.136	0.135	0.135
P130/13/13–P130/13/1	-13.150	-13.155	-13.154	-13.153
P130/13/1-KNUST/TP6	2.075	2.074	2.074	2.074
KNUST/TP6-KNUST/TP1	-1.034	-1.032	-1.033	-1.033

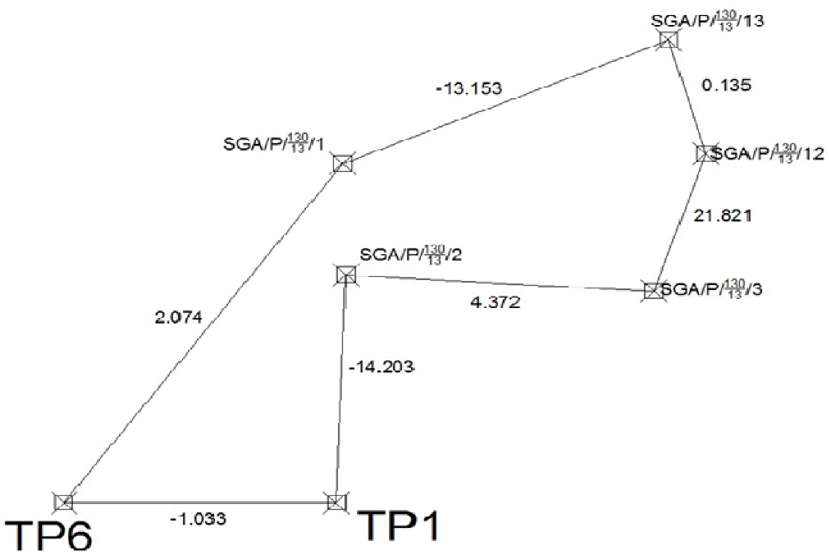

Fig. 4: Diagram of survey showing differences in heights between control points

$$
\begin{aligned}
H_2 - H_{TP1} &= -14.203 + V_1 \\
H_3 - H2 &= 4.372 + v2 \\
Hl2 - H3 &= 21.821 + v3 \\
Hl3 - Hl2 &= 0.135 + v4 \\
Hl - Hl3 &= -13.153 + v5 \\
HTP6 - Hl &= 2.074 + v6 \\
HTP1 - HTP6 &= -1.033 + v7
\end{aligned}
\qquad (7)
$$

As shown in Ghilani (2010), using least squares adjustment techniques and the matrix notation for systems of observation equations (i.e. $AX=L+V$), and re-arranging Equation 7 these matrices were extracted:

$$[X] = \begin{bmatrix} SGA/P130/13/2 \\ SGA/P130/13/3 \\ SGA/P130/13/12 \\ SGA/P130/13/13 \\ SGA/P130/13/1 \\ KNUST/\ TP6 \end{bmatrix}, \quad [A] = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ -1 & 1 & 0 & 0 & 0 & 0 \\ 0 & -1 & 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & 0 & -1 & 1 & 0 \\ 0 & 0 & 0 & 0 & -1 & 1 \\ 0 & 0 & 0 & 0 & 0 & -1 \end{bmatrix} \quad [L] = \begin{bmatrix} 248.487 \\ 4.372 \\ 21.821 \\ 0.135 \\ -13.153 \\ 2.074 \\ -263.723 \end{bmatrix}$$

Solving for X in the equation $X=(ATA)-I$ (ATL), the final adjusted heights of the controls and their corresponding values from survey records are shown in Table 5.

Results in Table 5 shows that apart from control point KNUST/TP6, there were height differences between the archives and adjusted heights for the remaining control points. All the values indicated onward movement of the controls, with the greatest downward movement of 0.075min SGA/P130/13 whiles the smallest depression of 0.004m was in SGA/P130/2. The remaining controls: SGA/P130/1, SGA/P130/3and SGA/P130/12 encountered downward movements of 0.063m, 0.048m and 0.073m respectively.

These differences indicate a mean downward movement of 0.011m in the five control points that were affected.

There was no correlation in the shifts obtained for both the horizontal and vertical controls. The greatest movement that occurred in SGA/P130/13 could be attributed to activities around the pillar.

CONCLUSION

The study has revealed that investigations done on the stability of controls on KNUST-campus using modern equipment and computational techniques clearly shows that all pillars have shifted either horizontally and/or vertically. From the study, movements in the horizontal plane showed maximum linear displacement of 0.160m with the least being 0.015m. The RMSE and SE in the Easting direction were 0.106m and 0.125m respectively whiles that for the Northing were also 0.048m and 0.075m respectively.

Table 5: Heights of controls from archives and computed from precise leveling operation

Pillar ID	Archive Heights (Ar)	Adjusted Heights (Ad)	(Ad-Ar)
KNUST/TP6	263.725	263.725	0.000
SGA/P130/13/1	261.716	261.653	-0.063
SGA/P130/13/2	248.489	248.485	-0.004
SGA/P130/13/3	252.903	252.855	-0.048
SGA/P130/13/12	274.747	274.674	-0.073
SGA/P130/13/13	274.883	274.808	-0.075

RMSE and SE in the Easting direction were 0.106m and 0.125m respectively whiles that for the Northing were also 0.048m and 0.075m respectively. In the vertical plane, all the controls encountered negative movement or settlements except KNUST/TP6 that was stable. The downward movements were between 0.004m to 0.750m, with a mean downward movement of 0.011m. In view of this finding, there is the need for all remaining controls on campus and else where to be investigated with modern technology so as to avoid positioning errors in our plans and also prevent vertical errors from deformation measurement.

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