A Study into the Distinction between Ellipsoid and Planar Computations in a Geodetic Traverse Network

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Keywords*: *Direct Indirect problem, Geodetic traverse, Ellipsoidal model, Planar Model.

Summary (Abstract)

In carrying out measurements and computations spanning large distances, it is imperative to make some geodetic considerations such as the curve nature of the earth's surface. In general, these distances are computed in relation to the reference spheroid. On the reference ellipsoid/spheroid such length is a geodesic. A geodesic is the line of least curvature between two points on the surface of an ellipsoid. This study seeks to explore and showcase the distinctions between computations carried out with ellipsoidal considerations and computations with planar considerations as well as the effect of attempting to utilize planar computation methods on ellipsoidal/curvilinear traverses. The ellipsoidal computations were accomplished using the Vincenty solutions.

Examination of the forward and reverse azimuths of the geodesic shows that unlike in the case of a plane line, the difference between these azimuths does not amount to 180^o but varies per geodesic. Further analysis into possible trends in this deviation indicates that longer lengths experience greater deviations. The formulated geodetic traverse possessed a linear misclosure of 2.291e-07m. However, attempting to utilize planar computation model on the geodetic traverse gave rise to a linear misclosure of 3646.43454738m. When the computed co-ordinates from each of the methods were compared with their corresponding true values, the differences produced absolute positional discrepancies, whose computed root mean square values are respectively 9.289e-08m for Ellipsoidal model and 2179.00433902m for Planar model, thus indicating that planar computation methods are not suitable for geodetic traverses. The results of this study serve to showcase the effect of attempting to compute and adjust the formulated geodetic traverse using planar computation methods.

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1. INTRODUCTION

A traverse is a series of consecutive lines whose ends have been marked in the field and whose lengths and directions have been determined from observations. In traditional surveying by ground methods, traversing; the act of marking the lines, that is, establishing traverse stations and making the necessary observations, is one of the most basic and widely practiced means of determining the relative locations of points. (Ghilani and Wolf 2012; Jekeli 2006). Traversing is an orderly sequence of determining the lengths and directions of lines between points on the earth's surface. The basic principle of traversing is that the position of a point on the ground can be established if it's bearing and distance from another fixed point are measured or known.

Geodesy is the science that deals with the Earth's figure and the interrelationship of selected points on its surface (Smith 1997). It is a branch of mathematics dealing with the shape and area of the earth or large portions of it. Geodesy takes care of the following scientific tasks: determination of the size and shape of the earth; establishment and maintenance of national and global three-dimensional geodetic networks; determination of earth's surface displacements; measurement and representation of geodynamic phenomena; and earth's external gravity field determination (Fajemirokun 2006). Figure of the earth refers to the size and the shape that is used to model the earth. The earth is generally taken as a sphere, however, in reality; the shape of the earth is not a perfect sphere. The earth is actually flattened at the poles and thus bulges at the equator.

One of the functions of geodesy is the determination of the exact positions of points on the earth surface. The earth's surface, where measurements obtained from various techniques are carried out directly, is highly irregular for computational purposes. To overcome this problem, various mathematical surfaces or models have been defined by geodesists to approximate the irregular shape and size of the earth to various degrees of precision. These include the topography, geoid, the sphere and the ellipsoid or spheroid. An ellipsoid is obtained by rotating an ellipse about its minor axis (Rapp 1991). Here, the major axis of the ellipsoid is in the equatorial plane while the minor axis of the ellipsoid coincides with the earth's spin axis. This is the most commonly used approximate of the geoid. Although the Earth is not an exact ellipsoid, the equipotential ellipsoid furnishes a simple, consistent and uniform reference system for all purposes of geodesy as well as geophysics. It is a convenient mathematical surface generated by choosing a proper sized ellipse and rotating it about its minor axis which approximately coincides with the rotation axis of the earth. It is a reference surface for geometric use such as map projections and satellite navigation.

In carrying out measurements and computations spanning large distances, it becomes imperative to make some geodetic considerations such as the curve nature of the earth's surface. In general, these distances are computed in relation to the reference spheroid. Whenever spheroidal computations are attempted, one is faced with a choice of various short line formulae, long line formulae, medium line formulae, and more recently, extensions of long line formulae, all of which have accuracy limitations, and all of which are basically unnecessary. They arise from the requirement to compute distances, and on the spheroid, there is no such thing as a distance, or at least its meaning has to be defined. The definition used is that of length of a geodesic (King 1971). A geodesic is the line of least curvature between two points on the surface of an ellipsoid (King 1971; Rainsford, H. F. 1955). A Geodesic curve as defined by (Rapp 1991) is a curve which gives the shortest distance, on a surface, between any two points. On a plane, that could be a straight line, on a sphere, the geodesic would be a great circle. On the ellipsoid however, the geodesic is a curve having a double curvature and is thus not a plane curve.

If we had two points A and B, we could construct the geodesic between two points if we knew the appropriate azimuth of a starting segment. There exist two major problems in geometric geodesy which are generally referred to as "The Geodetic Problems". These problems are the Direct and Inverse Geodetic problems. In looking at the Direct Problem, we assume that we are given the coordinates of a starting point, a distance and azimuth to a second point, we now desire to compute the coordinates of the second point, as well as the azimuth from the second point to the first (Omogunloye, et al., 2021; Rapp 1991). He also defines the Inverse Geodetic problem as the case where the coordinates of the end points of the line are given and we desire to find the azimuth from point one to point two, the azimuth from point two to point one and the distance between the two points.

Many solutions exist for these problems and these solutions are classified based on the type of length they consider in their computations i.e., whether the Normal Section or the Geodesic. For the purpose of the study, more emphasis is laid on the Geodesic. They are also classified based on the range of distances for which they are valid. These solutions can also be classified into iterative and non-iterative groups. In selecting a formula for the solution of geodesics, it is of primary importance to consider the length of the program, i.e., the amount of core which it will occupy in the computer along with trigonometric and other required functions. This solution should also give complete accuracy over lines of any length, from a few centimeters to nearly 20,000 km (Vincenty 1975). This study thus seeks to explore and showcase the distinctions between computations carried out with ellipsoidal considerations and computations with planar considerations as well as the effect of attempting to utilizing planar computation methods on ellipsoidal/curvilinear traverses.

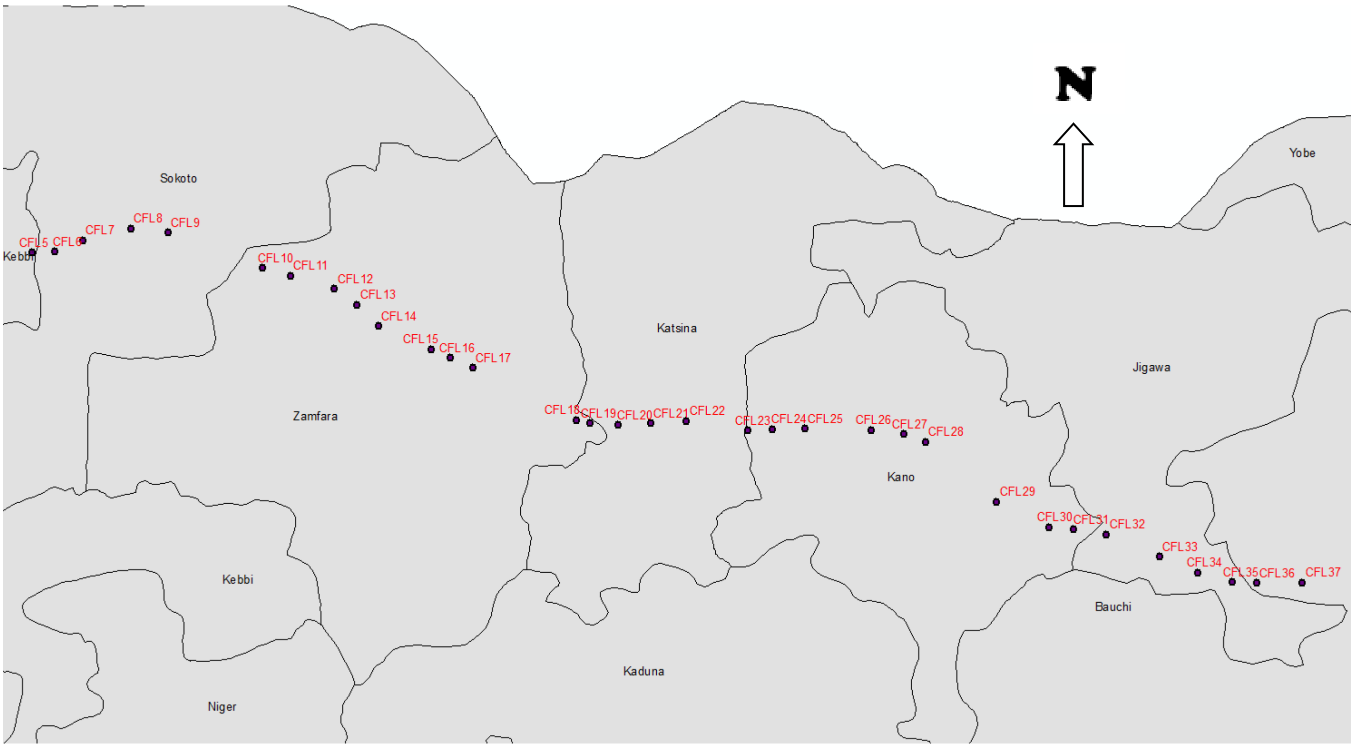
2. MATERIALS AND METHODS

----Description of CFL geodetic network

For the purpose of this project work, the data used was a set of coordinates from the Nigerian Network of CFL Traverse Survey (Omogunloye, 2010), spanning from Kebbi state through Sokoto, Zamfara, Katsina and Jigawa state then ending at Bauchi state. A total of 33 station points are used for this study. These coordinates serve as the true coordinates of station points and it is from these coordinates that the traverse formation was carried out to produce the observation traverse data to used in this study (Omounloye et. Al., 2021). The distribution of the CFL Traverse stations across Nigeria is presented in **Fig. 1.**

According to Nwilo (2013), early developments in Nigeria during colonial times provided the impetus for the establishment of survey controls. This was later followed by the establishment of

framework controls using methods such as traversing, triangulation, trilateration, geodetic levelling and trigonometric levelling (Nwilo et al., 2016). Nigeria dropped the Clarke 1858 projection in 1926 and adopted the modified Clarke 1880 Transverse Mercator projection in the same year (Adalemo, 1990; Adewola, 1990; Nwilo et al., 2016). In 1975, the Nigeria



Transverse Mercator (NTM) was replaced by the Universal Transverse Mercator (UTM) which was introduced in Nigeria by the Federal Surveys Department (Uzodinma and Ezenwere, 1993).

Fig. 1 Distribution of CFL Traverse stations across Nigeria

----Data Acquisition (Formulation of Geodetic Traverse)

A traverse is a series of consecutive lines whose ends have been marked in the field and whose lengths and directions have been determined from observations (Ghilani and Wolf 2012). By virtue of this definition, it becomes obvious that to form a traverse network, the desired observables would be a set of distances and their corresponding direction measurements. It is for this reason that the point station data (the geodetic coordinates) are used to compute for a set of distances and Azimuths which would serve as the field observation data for this study. This constitutes the inverse geodetic problem, and was solved using the Vincenty solution to the inverse geodetic problem (Vincenty 1975).

$$s = b * A(\sigma - \Delta\sigma)$$

$$tan\ \alpha_{12} = \frac{cos\ U_2 * sin\ \lambda}{cos\ U_1\ sin\ U_2 - sin\ U_1\ cos\ U_2\ cos\ \lambda}$$

$$tan\ \alpha_{21} = \frac{cos\ U_1\ sin\ \lambda}{-sin\ U_1\ cos\ U_2 + cos\ U_1\ sin\ U_2\ cos\lambda}$$

It should be noted that ordinarily the distances and forward azimuths would need to be observed but owing to the aim of this study, the generated distances and Azimuths would suffice.

We then computed for the traverse stations' coordinates using both ellipsoidal and planar considerations. We compare the adjusted co-ordinates from each method with their corresponding true values. The differences will give us the absolute positional discrepancies of each method. We can then see from these absolute discrepancies which method really gives the best results for the formulated geodetic traverse.

The type of traverse formed for this project work can best be described as a link traverse. It originates/starts on one station and terminates on another station, both of which are known points. Such a traverse may not be geometrically closed but is definitely mathematically closed (Ghilani and Wolf 2012). To achieve such a mathematically closed traverse, stations CFL 5 & CFL 37 are held fixed. The formulated geodetic traverse has a total of 32 distances and 32 azimuths and 33 included angles.

----Computation of Station Coordinates for the geodetic traverse using ellipsoidal considerations

A set of coordinates was calculated for all traverse station points using the fixed coordinates of station CPL 5 with the observed distances and forward azimuths. Thus, such coordinates are generated for all stations from CPL 6 to CPL 37. In computing these coordinates, ellipsoidal considerations are made and thus, this constitutes the “Direct Geodetic Problem” and was solved using the Vincenty solution to the Direct geodetic problem (Vincenty 1975).

Given the coordinates of a starting point (CPL 5), a distance and azimuth to a second point, we desire to compute the coordinates of the second point, as well as the azimuth from the second point to the first. Here, the coordinates obtained for CPL 6 using CPL 5 with the distances and azimuth between them is thereafter used as the starting coordinates in computing for the coordinates of CPL 7. This process is repeated for all such points, (Omounloye et. Al., 2018 and 2019).

$$tan\phi_2 = \frac{sin\,U_1\,cos\,\sigma + cos\,U_1\,sin\,\sigma\,cos\,\alpha_1}{(1-f)[sin^2\,\alpha + (sin\,U_1 \cdot sin\,\sigma - cos\,U_1\,cos\,\sigma\,cos\,\alpha_1)^2]^{\frac{1}{2}}}$$

$$tan\lambda = \frac{sin\,\sigma\,sin\,\alpha_1}{cos\,U_1\,cos\,\sigma - sin\,U_1\,sin\,\sigma\,cos\,\alpha_1}$$

$$C = \frac{f}{16}cos^2\alpha\,[4 + f\,(4 - 3\,cos^2\,\alpha)]$$

$$L = \lambda - (1-C)f sin\,\alpha\,\{\sigma + C\,sin\,\sigma\,[cos\,2\sigma_m + C\,cos\,\sigma(-1 + 2\,cos^2\,2\sigma_m)]\}$$

$$\lambda_2 = \lambda_1 + L$$

Where:

ϕ_2, λ_2 is destination point.

----Computation of Station Coordinates for the geodetic traverse using planar considerations

A set of coordinates was calculated for all traverse station points using the fixed coordinates of station CPL 5 with the observed distances and forward azimuths. However, in these computations, no curvilinear considerations were made and the station coordinates were simply calculated using conventional forward computations. In order to achieve this, the geodetic coordinates of the traverse start station were projected to the UTM Zone 32.

$\Delta N = l\,cos\alpha$

$\Delta E = lsin\alpha$

$N_2 = N_1 + \Delta N$

$E_2 = E_1 + \Delta E$

---- Accuracy assessment

In order to allow for comparison between the ellipsoidal computations and the planar computation, the geodetic coordinate outputs of the ellipsoidal computations are also projected to UTM Zone 32. Their true coordinates are also projected.

To check the relative accuracies of the two considerations, the computed coordinates were compared with the initial/true coordinates. In the accuracy assessment, the coordinate differences and rms value of absolute discrepancies (Obenson 1975 and Olunlade et. al. 2019) were computed using Microsoft Excel 2007.

$$\text{rms value of absolute discrepancies} = \left(\sum\left(v_x{}^2 + v_y{}^2\right)/2n\right)^{\frac{1}{2}}$$

where n is the number of stations to be adjusted;

v_x, v_y are the differences between the expected and adjusted x-and y-coordinates respectively.

3. RESULTS AND DISCUSSION

---- Difference between Forward and Reverse Azimuths for the adopted geodetic traverse

It is expected that on a plane surface, the difference between the forward and the backward bearing or azimuth between any two points would give a constant value of180°, however, this is not the case on the ellipsoid as the difference between forward and reverse azimuth isn't 180°, but rather it varies per geodesic. For this reason, it is important to take cognizance of this distinction when handling surveying/traverse data. **Table 1** showcases the deviation that exists in the case of geodesics, between their forward and reverse azimuths.

Table 1 Difference between Forward and Reverse Azimuths for the adopted geodetic traverse

Line	Forward Azimuth (°)	Reverse Azimuth (°)	Azimuth Difference (°)	Deviation from 180 (°)
5-6	87.258895650704	267.279768897821	180.020873247117	0.020873247117
6-7	67.938491282761	247.964457928657	180.025966645896	0.025966645896
7-8	76.083441026939	256.128752691940	180.045311665001	0.045311665001
8-9	95.793040185810	275.828029290562	180.034989104752	0.034989104752
9-10	110.881904240690	290.970934676406	180.089030435716	0.089030435716
10-11	105.217987835324	285.244016127268	180.026028291944	0.026028291944
11-12	106.995919038849	287.036328203850	180.040409165001	0.040409165001
12-13	125.919978154903	305.940889794788	180.020911639885	0.020911639885
13-14	135.310290603304	315.330064555211	180.019773951907	0.019773951907
14-15	113.972378333271	294.020079867808	180.047701534536	0.047701534536
15-16	114.607250058855	294.624259539770	180.017009480914	0.017009480914

16-17	113.664990734286	293.685854649134	180.020863914849	0.020863914849
17-18	117.140952536882	297.233432681287	180.092480144405	0.092480144405
18-19	102.463652094435	282.475612125037	180.011960030602	0.011960030602
19-20	93.331725641423	273.356541764768	180.024816123345	0.024816123345
20-21	87.703574747342	267.732254956743	180.028680209401	0.028680209401
21-22	85.960839544118	265.992364132301	180.031524588184	0.031524588184
22-23	98.825889993742	278.880101271388	180.054211277645	0.054211277645
23-24	87.135410345743	267.156748224787	180.021337879044	0.021337879044
24-25	88.682545974133	268.711242088408	180.028696114276	0.028696114276
25-26	91.267073473837	271.326025405755	180.058951931918	0.058951931918
26-27	97.915343876758	277.943608991520	180.028265114762	0.028265114762
27-28	108.933055170633	288.952205922013	180.019150751380	0.019150751380
28-29	130.489664426700	310.551361175108	180.061696748408	0.061696748408
29-30	116.288553150924	296.333144738590	180.044591587666	0.044591587666
30-31	95.806067466874	275.827324162271	180.021256695396	0.021256695396
31-32	98.261051983509	278.288902335300	180.027850351791	0.027850351791
32-33	113.329679245272	293.374434692535	180.044755447263	0.044755447263
33-34	112.343634419385	292.376125480019	180.032491060634	0.032491060634
34-35	105.752474643964	285.781273619486	180.028798975522	0.028798975522
35-36	91.764952081854	271.785085972098	180.020133890245	0.020133890245
36-37	89.359138014730	269.397118982746	180.037980968016	0.037980968016

As can be seen in **Fig. 2** below, wrongfully deploying the planar computation methods without proper inquiry into field procedures and surface considerations can lead to erroneous and misleading results.

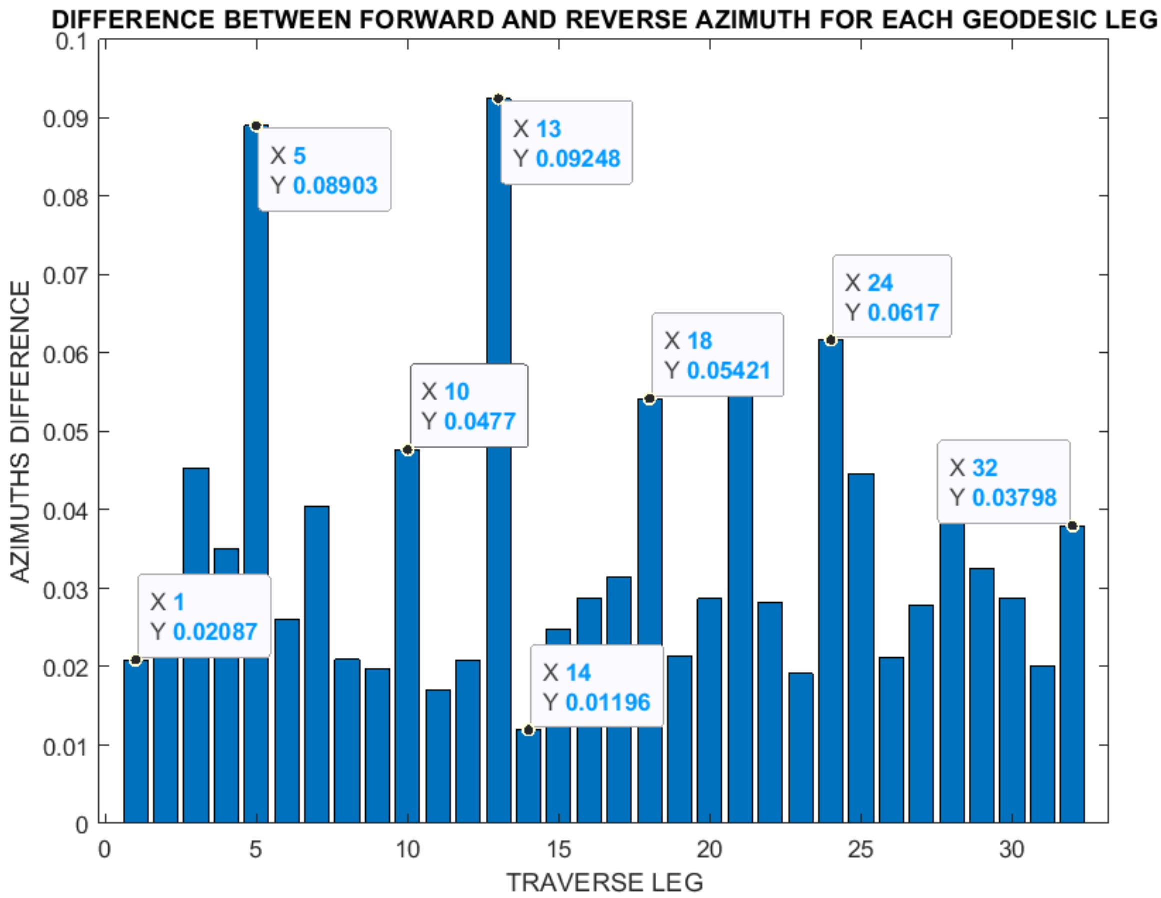


Fig. 2 Deviation of difference between forward and reverse azimuth for each traverse leg from 180°

It is also observed that the longer the line the more its deviation from180°, i.e. the longer the geodesic the more the difference in its forward and reverse azimuths.

---- Comparison of Prediction Error in the Adjustment Models

Statistical analysis is carried out on the adjusted coordinates from both approaches considered using the rms value of absolute discrepancies. This value aids in evaluating the accuracy of the models. In computing for these values, all geodetic coordinates are projected using the UTM Zone 32. The overall linear misclosure was also examined. The rms values given in **Table 2** show that the computing geodetic traverses with curvilinear approaches offers coordinates which are closer to the expected coordinates.

Table 2 Results of statistical analysis on computed coordinates

Station ID	True/Expected Coordinates		Ellipsoidal Computations Coordinates		Planar Computations Coordinates	
	x	y	x	y	x	y
CFL5	1407004.44622822	43472.88151284	1407004.44622822	43472.88151284	1407004.44622822	43472.88151284
CFL6	1407332.39243359	53815.84278926	1407332.39243359	53815.84278925	1407498.27906809	53787.31827429
CFL7	1412328.22386166	66725.46733975	1412328.22386166	66725.46733975	1412687.22920459	66590.83008975
CFL8	1417508.23377982	89102.67553053	1417508.23377982	89102.67553051	1418201.49967084	88845.38003184
CFL9	1415512.74607169	106266.13678112	1415512.74607169	106266.13678110	1416460.22061422	106008.68947858
CFL10	1398099.55736420	150067.42937705	1398099.55736420	150067.42937701	1399681.07044572	149990.61616378
CFL11	1394413.42507543	162988.92467077	1394413.42507543	162988.92467073	1396157.70209232	162942.69359437
CFL12	1388001.44392494	183114.94843390	1388001.44392494	183114.94843385	1389989.14270144	183124.28330709
CFL13	1380275.14613044	193536.68315657	1380275.14613044	193536.68315652	1382384.35568221	193622.17614702
CFL14	1370060.41405489	203429.42971387	1370060.41405489	203429.42971381	1372282.34582025	203615.35757449
CFL15	1359003.04107372	227630.70060590	1359003.04107372	227630.70060583	1361478.26278987	227913.24340160
CFL16	1354930.33716556	236309.41708352	1354930.33716557	236309.41708345	1357488.30371452	236625.15717364
CFL17	1350133.73768187	246993.02323997	1350133.73768187	246993.02323989	1352789.66024010	247346.76079947
CFL18	1325073.18931725	294871.25221704	1325073.18931726	294871.25221693	1328143.69166356	295424.43768130
CFL19	1323642.54564612	301140.56245319	1323642.54564613	301140.56245309	1326756.01098914	301702.70662193
CFL20	1322797.34312630	314173.68344124	1322797.34312631	314173.68344114	1325997.02038638	314740.37437384
CFL21	1323308.53075417	329245.37911251	1323308.53075417	329245.37911240	1326601.28612874	329808.72271779
CFL22	1324383.18581101	345801.78448666	1324383.18581101	345801.78448654	1327770.03023461	346359.96803775
CFL23	1319812.54712477	374275.52100821	1319812.54712478	374275.52100808	1323344.61608484	374861.21307594
CFL24	1320327.73080188	385509.58011674	1320327.73080188	385509.58011661	1323906.76049278	386095.51354437
CFL25	1320617.62864703	400610.00170854	1320617.62864704	400610.00170840	1324254.10132085	401198.62576402
CFL26	1319829.19742332	431629.82910258	1319829.19742332	431629.82910243	1323567.73038808	432230.56458746
CFL27	1317725.27481097	446514.89063706	1317725.27481098	446514.89063691	1321496.80407297	447125.62508838
CFL28	1314239.33233435	456619.09784926	1314239.33233435	456619.09784910	1318027.45068983	457239.73278396
CFL29	1286024.68956175	489571.32940475	1286024.68956175	489571.32940457	1289848.67486438	490244.89439330
CFL30	1274050.73196417	513790.46169663	1274050.73196418	513790.46169644	1277878.08444616	514477.73086988
CFL31	1272875.66688580	525397.42135050	1272875.66688580	525397.42135031	1276697.43693186	526088.75909985
CFL32	1270677.07187202	540627.11103713	1270677.07187203	540627.11103694	1274485.64259548	541322.54598791
CFL33	1260098.21640338	565243.18743991	1260098.21640339	565243.18743971	1263871.18600952	565933.93795324
CFL34	1252740.26960805	583250.09957490	1252740.26960806	583250.09957469	1256473.77119683	583931.64569721
CFL35	1248261.83777319	599286.97341588	1248261.83777320	599286.97341566	1251952.13046016	599961.52425268
CFL36	1247950.83293577	610513.52405808	1247950.83293577	610513.52405786	1251606.13606247	611190.01492438
CFL37	1248260.99692591	631690.42540348	1248260.99692591	631690.42540348	1251843.07505110	632372.48200914
Linear Misclosure (m)			2.291e-07		3646.43454738	
rms residual (m)			9.289e-08		2179.00433902	

As seen in Table 2, the forward computation carried out on the geodetic traverse using the curvilinear approach (Vincenty Direct Solution) produced minimal linear misclosure (2.291e-07m). This misclosure is a function of the direct solution utilized. However, the forward computation carried out using planar considerations produced a linear misclosure of 3646.43454738m.

A plot of the output coordinates as given in **Fig. 3** shows clearly the deviation of the planar computation results from the expected coordinates.

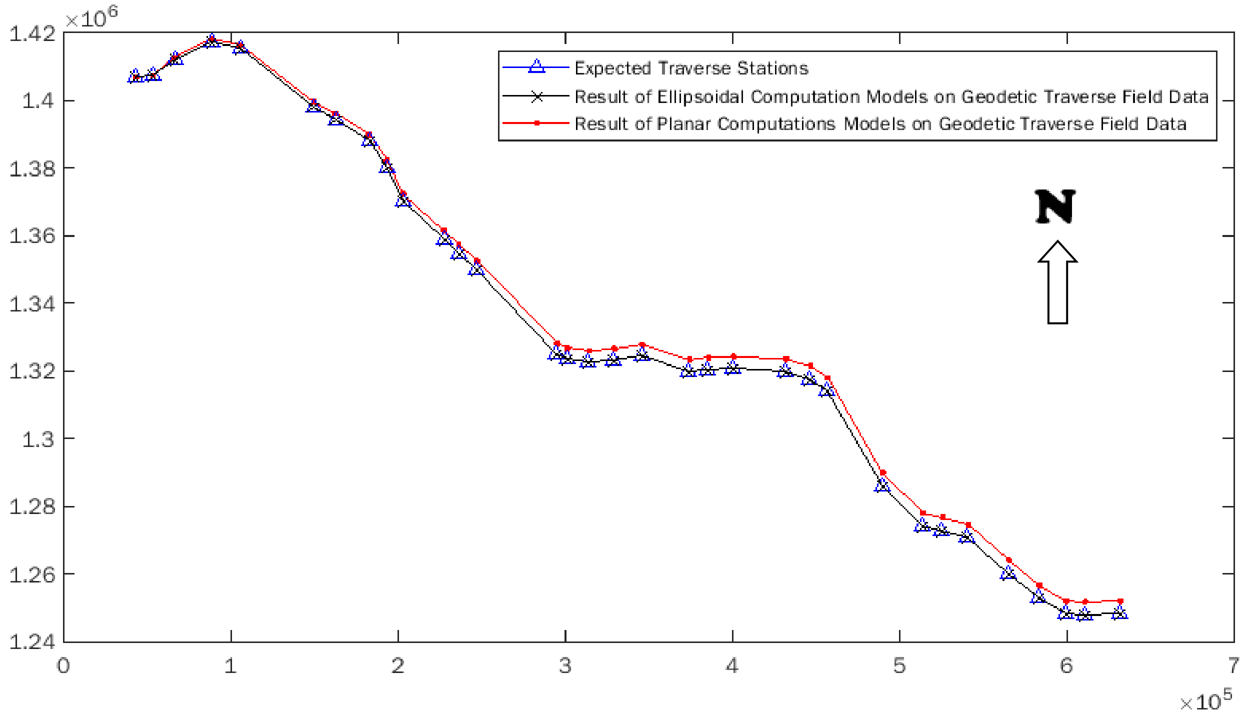


Fig. 3 Plot of the computed coordinates against their expected value

4. CONCLUSION AND RECOMMENDATIONS

The formulated geodetic traverse possessed a misclosure of 2.291e-07m. However, attempting to utilize planar computation models on the geodetic traverse gave rise to a linear misclosure of 3646.43454738m. The computed co-ordinates from each method are compared with their corresponding true values. The differences produced the absolute positional discrepancies of each method. The root mean square value of absolute positional discrepancy for the Ellipsoidal computation model was computed as 9.289e-08m. The Planar computation model yielded rms value of absolute positional discrepancies as 2179.00433902m, thus indicating that planar computation methods are not suitable for geodetic traverses. The results of this study serve to showcase the effect of attempting to compute and adjust the formulated geodetic traverse using planar computation methods. It is recommended that similar studies be conducted to investigate the intrinsic error associated with the Vincenty solution in relation to other solutions.

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