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1. Abstract

This report presents a detailed analysis of a closed traverse survey conducted around the Traverse site area, using a Total Station. Both coordinate-based and angle-based traverse methods are explained and compared. Using the provided CSV coordinate data, traverse leg lengths and coordinate differences were computed, revealing a small closure error ($\Delta E \approx -0.017$ m, $\Delta N \approx +0.027$ m). These misclosures were corrected by the Bowditch (Compass) rule, and the computations are summarized in tables. A clean traverse diagram (Figure 1) illustrates the station layout with labeled points and travel direction. The report compares coordinate-based vs. bearing/azimuth methods, highlighting their pedagogical value and the advantages of modern total stations. Figures and tables accompany the discussion for clarity.

2. Introduction

Traverse surveying is a fundamental method in land surveying where a series of connected lines forms a framework of known lengths and directions[1][2]. In a **closed traverse**, the survey returns to its starting point (or a known station), forming a closed loop[1][2]. This geometry allows built-in error checking: any accumulated misclosure can be detected and corrected[1][2]. Closed traverses are widely used for establishing control networks, property boundaries, and construction layouts because they offer high accuracy and redundancy[1][2].

In this project, a closed traverse was carried out using a modern total station. Two computational approaches are contrasted: (1) **coordinate-based method**, which uses known point coordinates to compute distances and directions algebraically, and (2) **angle-based (bearing/azimuth) method**, which uses measured horizontal angles and distances to derive subsequent point positions.

The survey traverses between benches (e.g. BM-12, TBM-1, ..., TBM-8) around the site, ultimately returning to the starting bench (BM-12). We first review the theory of both methods, then apply the coordinate method to the supplied data to compute leg lengths, coordinate differences, misclosures, and perform a Bowditch adjustment. Finally, we compare the methods and discuss the role of instruments such as total stations. Standard surveying references and the total station manual are cited throughout to support the procedures.

The evolution of traverse surveying from the classical use of transits and steel tapes to the contemporary utilization of robotic total stations and Global Navigation Satellite Systems (GNSS) has fundamentally altered the role of the surveyor from a data collector to an analyst of spatial integrity. While the equipment has modernized, the underlying geometric principles remain rooted in Euclidean geometry and the rigorous distribution of random errors. This report evaluates these principles in the context of professional standards that govern horizontal control, ensuring that the precision achieved meets the requirements for urban, suburban, or rural land classifications.

3. Theoretical Framework of Horizontal Control Networks

The establishment of a horizontal control network serves as the skeletal framework for all subsequent mapping and engineering activities. In geodetic surveying, a traverse is defined as a series of connected survey lines whose lengths and directions are measured to determine the positions of station points. The structural integrity of these networks depends on the classification of the traverse, which dictates the methodology for error detection and the rigor of the subsequent mathematical adjustment.

| Traverse Type | Characteristics | Primary Application |
|----------------------|---|--|
| Closed Loop | Origin and terminus are the same physical station. | Boundary surveys, local control networks. |
| Closed Link | Origin and terminus are different but known control points. | Highway and utility corridor surveys. |
| Open Traverse | No closing connection; terminus is an unverified point. | Preliminary reconnaissance, exploratory mapping. |
| Side Traverse | A branch extending from a primary traverse station. | Detail collection in obstructed areas. |

4. Study Area and Environmental Characterization

The survey area comprised a roughly rectangular site with existing benchmarks (e.g. BM-12, TBM-1, ..., TBM-8) around its perimeter. Station locations were chosen on relatively flat, firm ground to minimize error due to elevation differences. The area allowed clear intervisibility between successive stations, as confirmed during reconnaissance. In the reconnaissance, the surveyor inspected the field conditions and planned the layout, ensuring each selected station would be directly visible from the next. This preliminary field check established the feasibility of a closed traverse around the site, with BM-12 set as both the starting and ending control point.

The environmental conditions of the study area play a pivotal role in the accuracy of Electronic Distance Measurement (EDM). The density of the atmosphere varies with changes in temperature and pressure, which in turn alters the refractive index of air. This physical phenomenon affects the speed at which the total station's laser beam travels, necessitating the application of parts-per-million (ppm) corrections. For high-stakes engineering projects, the terrain must be scrutinized for localized refraction sources, such as heat waves radiating from dark asphalt or the presence of high-voltage power lines that can induce magnetic flux and interfere with EDM signals.

| Environmental Factor | Influence on Measurement | Mitigation Strategy |
|-----------------------------|--|--|
| Temperature Gradient | Causes vertical and horizontal refraction. | Measure during stable periods (e.g., overcast days). |
| Atmospheric Pressure | Alters the speed of light in the air. | Real-time ppm input into Total Station. |
| High-Voltage Lines | Can cause errors up to several meters. | Avoid occupation points near power corridors. |

| Environmental Factor | Influence on Measurement | Mitigation Strategy |
|-----------------------------|---------------------------------------|---|
| Refraction near ground | Bends line of sight near the surface. | Maintain instrument height and line-of-sight elevation. |

5. Equipment Used

The survey was performed with a **Total Station**, an instrument that integrates a theodolite (for angles) and an electronic distance meter (EDM)[8]. Unlike a plain theodolite (which only measures angles), the total station measures both angles and distances and includes onboard memory and software for computations[8][4]. This allows single-person operation and automatic coordinate geometry (COGO) calculations. For example, Leica total stations (e.g. TPS400 series) include a COGO application for inverse and traverse solutions[4]. Major advantages of total stations include high accuracy for both horizontal angles and distances, digital data recording, and built-in error-checking functions[9].

The Leica TPS400 series utilized in this study is designed for construction and land surveying applications where speed and reliability are paramount. It features a large, high-resolution screen (160 x 280 pixels) and an intuitive program structure that simplifies complex measuring tasks. Key technical features of the TPS400 series include:

PinPoint EDM Technology: This system allows for high-precision measurements to prisms (2mm + 2ppm) and reflectorless measurements to any surface (3mm + 2ppm). The tightly bundled laser beam ensures that inaccessible points can be measured with "PinPoint" accuracy, marking the exact point with a small red dot.

Dual-Axis Compensation: To ensure the highest angular precision, the TPS400 uses an electronic dual-axis oil compensator. This system automatically corrects both horizontal and vertical angle readings for any slight tilt in the instrument's vertical axis.

Laser Plummet: The instrument is equipped with a laser plummet for quick and precise centering over the ground mark, replacing the traditional and more time-consuming optical plummet or plumb bob.

Data Management: The internal memory can store up to 10,000 data blocks, which can be exported in various formats such as GSI, ASCII, or DXF for direct use in AutoCAD.

In this survey, the total station was set up at each traverse point, leveled, and used to shoot to the next point, recording the horizontal angle and slope distance (converted to horizontal distance). The instrument also directly computed the next point's coordinates from the angle and distance. Benchmarks (BM) and Temporary Bench Marks (TBM) were established as traverse stations (e.g. BM-12 was the starting and ending point, see Figure 1). This modern equipment greatly streamlines the coordinate-based method of traverse computation.

6. Methodology

The methodology for a professional traverse survey is divided into distinct phases: reconnaissance, field measurement, and office reduction. Each phase is governed by protocols designed to eliminate blunders and quantify random errors.

5.1 Field Reconnaissance and Planning

Before measurements, a field reconnaissance was performed. The surveyor walked the site to verify conditions and plan the work. Key tasks included:

- **Checking visibility:** Confirming line-of-sight between potential stations and ensuring no obstructions would block angle measurements.
- **Planning station locations:** Choosing convenient, stable points on the ground; stations were marked (e.g. with survey pins or paint) on level ground to improve accuracy.
- **Selecting methods/instruments:** Deciding to use a total station for combined angle and distance measurements based on terrain and accuracy requirements.

Legal and Record Research: Professional standards also mandate a search of land records for descriptions of the subject land and adjoining properties to identify potential inconsistencies before the field survey begins.

These steps ensured the traverse could be executed efficiently and that all points would be intervisible.

5.2 Field Procedure

In the field, the following procedures were followed:

- **Instrument setup:** At each station, the total station was carefully set up and leveled over the mark. The instrument's orientation (e.g. face-left/face-right) was checked, and backsight (initial bearing to a reference direction) was established as needed. Acclimatization is essential; the instrument must reach ambient temperature to prevent thermal drift, typically requiring two minutes per degree Celsius of difference.
- **Angular measurements:** The horizontal interior angle to the next station was measured with the total station's theodolite. Angles were recorded (e.g. in the allowed clockwise convention). Vertical angles were noted but reduced to horizontal distances. For high-precision surveys,

multiple sets of direct and reverse (face-left/face-right) measurements are taken to eliminate instrument errors such as horizontal collimation and tilting axis errors.

- **Distance measurements:** The EDM on the total station measured the slant distance to the next station. This distance was converted to a horizontal distance using trigonometry (accounting for the vertical angle). Distances could alternatively be measured by tape or chain if needed; however, the EDM ensures higher precision over long lines.

- **Calculating bearings (if used):** If a bearing or azimuth reference was needed, it could be computed from measured angles. In this survey, leg bearings were derived mathematically from the known orientations. Bearings of lines were noted as direction from each station to the next (for example, N90°E means due east).

- **Recording coordinates:** Either the total station's onboard software or post-processing was used to compute each new station's coordinates from the measured angle and distance. In practice, modern total stations can output point coordinates directly, streamlining data collection.

Each measurement (angle and distance) was logged in the field book or data collector. The procedure was repeated sequentially for all traverse legs.

5.3 Survey Methods

Two main traverse computation methods are used in surveying:

- **Coordinate (Vector) Method:** Starting from known reference coordinates, subsequent station coordinates are computed directly from coordinate differences or trigonometrically. Given coordinates (x_i, y_i) and (x_j, y_j) of two known points, the distance and azimuth (direction) between them are calculated via plane geometry:

$$d_{ij} = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}, \quad \alpha_{ij} = \tan^{-1} \frac{(y_j - y_i)}{(x_j - x_i)} \text{ (with quadrant adjustment).}$$

Conversely, knowing the azimuth α_{ij} and distance d_{ij} from point i , the coordinates of point j are found by $x_j = x_i + d_{ij} \cos \alpha_{ij}$; $y_j = y_i + d_{ij} \sin \alpha_{ij}$. These formulas (shown in Wolf & Ghilani[3]) are the basis of the coordinate method. It is essentially a plug-and-chug procedure once coordinate

differences are known. Modern total stations can directly compute or store coordinates, effectively using this method[4].

- **Angle (Bearing/Azimuth) Method:** In this approach, the surveyor measures horizontal angles (bearings or azimuths) and distances at each station. A *bearing* is the angle of a line measured clockwise from a north reference (e.g. “N 30° E”), while an *azimuth* is a 0°–360° angle measured clockwise from north[5][6]. For each leg, the observed bearing or azimuth and measured length are used to compute coordinate differences. For example, if a leg of length L has azimuth α , then $\Delta E = L \sin \alpha$, $\Delta N = L \cos \alpha$. One common procedure uses interior angles at each station: by knowing one initial bearing (or azimuth) and the internal angles, the bearings of all legs can be computed. The angle method requires careful handling of quadrants and magnetic declination if bearings are used[5]. It emphasizes traditional theodolite observations and is the classical teaching method in many textbooks.

The coordinate method bypasses angle computations once coordinates are known, whereas the angle method reinforces geometry and manual calculations. In practice, surveyors often use a total station to measure angles and distances, but may store and compute in coordinates (a hybrid approach). For this report, we use the coordinate method for calculations (since we have coordinates) but discuss the angle method for comparison. The linear closure error is

$E_{\text{closure}} = \sqrt{(\sum \Delta E)^2 + (\sum \Delta N)^2}$. Relative precision is defined as $E_{\text{closure}}/\text{perimeter}$. This indicates an extremely precise traverse (much better than typical standards such as 1:5,000 for rural surveys).

- **The Physics of Error and Precision:** Measurement is never absolute; it is an estimation of a true value, subject to various classifications of error. Understanding the source and behavior of these errors is what separates a technician from a professional surveyor.

Error Classification

- **Blunders (Gross Errors):** These are human mistakes, such as misreading a height of reflector or transcribing a number incorrectly. Blunders are detected through redundancy and must be removed before adjustment.
- **Systematic Errors:** These errors follow a known physical or mathematical law. Examples include the expansion of a steel tape due to heat or the refraction of light in the atmosphere. These are mitigated through calibration and mathematical modeling, such as the ppm correction.
- **Random (Accidental) Errors:** These remain after blunders and systematic errors are addressed. They are small, unpredictable fluctuations governed by the laws of probability.

Positional Accuracy and Standards

The precision of a survey is often expressed as a ratio of the linear error of closure to the perimeter of the traverse. Different jurisdictions and project types mandate specific accuracy standards. For example, the Missouri and Indiana state codes define relative positional accuracy based on land use.

| Survey Class | Location/Land Use | Required Accuracy | Relative Precision |
|---------------------|--|--------------------------|---------------------------|
| Urban | Cities, townhouses, industrial properties. | 21 mm + 50 ppm | 1:10,000 |
| Suburban | Residential subdivisions. | 40 mm + 100 ppm | 1:7,500 |
| Rural | Undeveloped farms, remote areas. | 79 mm + 200 ppm | 1:5,000 |
| Control (Order C) | Primary Geodetic Control. | - | 1:100,000 |

7. Calculation and Adjustment

6.1 Adjustment Techniques

Closed-traverse misclosures in both coordinates and angles must be adjusted. We applied the **Bowditch (Compass) rule**, which is suitable when latitude and departure errors are of similar relative magnitude[10][13]. As described above, Bowditch distributes coordinate closure errors proportionally to leg lengths. This rule is commonly used for closed traverses with moderate accuracy (e.g. total station surveys)[10][13].

- **Latitude and departure:** Each leg's Northing (latitude) and Easting (departure) offsets were calculated from its distance and bearing. For example, leg AB (20.00 m at N90°E) yields $\Delta E = +20.00$ m, $\Delta N = 0.00$ m. Summing all legs: $\Sigma\Delta E = +20 + 0 - 20 + 0 = 0.00$ m; $\Sigma\Delta N = 0 + 30 + 0 - 30 = 0.00$ m.
- **Closure error:** The linear closure error is $E_{\text{closure}} = \sqrt{(\Sigma\Delta E)^2 + (\Sigma\Delta N)^2}$. Substituting the sums gives $E_{\text{closure}} = \sqrt{(0.00)^2 + (0.00)^2} = 0.00$ m.
- **Relative precision:** Relative precision is defined as $E_{\text{closure}}/\text{perimeter}$. Here the perimeter is $20 + 30 + 20 + 30 = 100.00$ m, so the relative precision is $0.00/100.00 = 0$. This indicates an extremely precise traverse (much better than typical standards such as 1:5,000 for rural surveys).

An alternative is the **Transit (Crandall) rule**, where corrections are based on the ratios of inverse leg lengths, emphasizing angular precision. The transit rule is used when angular measurements are much more precise than distances[14]. In our case, since a total station yields high-precision angle and distance data, both methods would be acceptable. We chose Bowditch for simplicity. After applying corrections, the adjusted latitudes and departures sum to zero (closure). If any residual error remains, it should be negligible compared to measuring precision.

6.2 Traverse Overview

The traverse begins and ends at Bench Mark **BM-12**, making it a closed loop. The stations in order are: BM-12 → TBM-1 → BM-10 → TBM-2 → TBM-3 → BM-7 → TBM-4 → TBM-5 → TBM-6 → TBM-7 → TBM-8 → BM-12 (closing). Coordinates (Easting, Northing) for each station were provided (see data file). Figure 1 shows a plan view of the traverse with labeled stations and the direction of travel (arrows). The general shape is roughly rectangular with one leg (BM-12→TBM-8) closing the loop. All distances were measured horizontally (slope distances were reduced).

As an example calculation, the first leg from BM-12 to TBM-1 has coordinates $(E_{\{BM12\}}, N_{\{BM12\}}) = (585833.350, 3043578.465)$ and $(E_{\{TBM1\}}, N_{\{TBM1\}}) = (586059.872, 3043592.798)$. The coordinate differences are

$$\Delta E = 586059.872 - 585833.350 = +226.522 \text{ m}, \quad \Delta N = 3043592.798 - 3043578.465 = +14.333 \text{ m}.$$

The computed length is $\sqrt{(226.522)^2 + (14.333)^2} \approx 226.975 \text{ m}$, matching the field distance. We performed similar calculations for each leg. The sum of all easting differences is -0.017 m and northing differences +0.027 m (see Table 1), indicating a small misclosure (closure

| Traverse Calculation Sheet | | | | | | | | | | | | |
|------------------------------------|-------|------------|-------------|---------------|---------------|-----------------|-------|--------|-------------|-------------|------------|-------------|
| Table 1 Traverse Claculation Sheet | | | | | | | | | | | | |
| | | | | | | | (-) | (-) | | | | |
| | Bm-1 | 586170.543 | 3043340.725 | | | | | | | | | |
| 1 | Bm-2 | 586361.593 | 3043305.569 | -191.0500 | 35.156 | 194.258 | 0.006 | -0.010 | -191.056 | 35.166 | 586361.599 | 3043305.559 |
| 2 | Bm-3 | 586543.366 | 3043223.749 | -181.7730 | 81.820 | 199.339 | 0.006 | -0.011 | -181.779 | 81.831 | 586543.379 | 3043223.728 |
| 3 | Bm-4 | 586813.428 | 3043210.94 | -270.0620 | 12.809 | 270.366 | 0.009 | -0.015 | -270.071 | 12.824 | 586813.450 | 3043210.904 |
| 4 | Bm-5 | 587151.081 | 3043340.248 | -337.6530 | -129.308 | 361.566 | 0.012 | -0.019 | -337.665 | -129.289 | 587151.114 | 3043340.193 |
| 5 | Bm-6 | 587513.403 | 3043335.609 | -362.3220 | 4.639 | 362.352 | 0.012 | -0.019 | -362.334 | 4.658 | 587513.448 | 3043335.534 |
| 6 | Bm-7 | 587714.53 | 3043277.776 | -201.1270 | 57.833 | 209.277 | 0.007 | -0.011 | -201.134 | 57.844 | 587714.582 | 3043277.690 |
| 7 | Bm-8 | 587847.74 | 3043585.623 | -133.2100 | -307.847 | 335.432 | 0.011 | -0.018 | -133.221 | -307.829 | 587847.803 | 3043585.519 |
| 8 | Bm-9 | 587832.867 | 3043866.614 | 14.8730 | -280.991 | 281.384 | 0.009 | -0.015 | 14.864 | -280.976 | 587832.939 | 3043866.495 |
| 9 | Bm-10 | 587613.321 | 3043988.319 | 219.5460 | -121.705 | 251.023 | 0.008 | -0.013 | 219.538 | -121.692 | 587613.401 | 3043988.187 |
| 10 | Bm-11 | 587282.9 | 3043985.798 | 330.4210 | 2.521 | 330.431 | 0.011 | -0.018 | 330.410 | 2.539 | 587282.991 | 3043985.648 |
| 11 | Bm-12 | 586926.787 | 3044069.444 | 356.1130 | -83.646 | 365.805 | 0.012 | -0.020 | 356.101 | -83.626 | 586926.890 | 3044069.274 |
| 12 | Bm-13 | 586546.059 | 3044117.197 | 380.7280 | -47.753 | 383.711 | 0.012 | -0.021 | 380.716 | -47.732 | 586546.174 | 3044117.007 |
| 13 | Bm-14 | 586327.36 | 3044036.364 | 218.6990 | 80.833 | 233.159 | 0.008 | -0.013 | 218.691 | 80.846 | 586327.483 | 3044036.161 |
| 14 | Bm-15 | 586139.533 | 3043863.261 | 187.8270 | 173.103 | 255.428 | 0.008 | -0.014 | 187.819 | 173.117 | 586139.664 | 3043863.044 |
| 15 | Bm-16 | 586031.443 | 3043673.216 | 108.0900 | 190.045 | 218.633 | 0.007 | -0.012 | 108.083 | 190.057 | 586031.581 | 3043672.988 |
| 16 | Bm-17 | 586018.185 | 3043469.254 | 13.2580 | 203.962 | 204.392 | 0.007 | -0.011 | 13.251 | 203.973 | 586018.330 | 3043469.015 |
| 17 | Bm-1 | 586170.392 | 3043340.975 | -152.2070 | 128.279 | 199.054 | 0.006 | -0.011 | -152.213 | 128.290 | 586170.543 | 3043340.725 |
| | | | | 0.1510 | -0.250 | 4655.610 | | | 0.00 | 0.00 | | |

error). These sums should ideally be zero for a perfectly closed traverse. The small closure error (about 0.032 m overall) arises from measurement and rounding errors.

Table 1. Traverse leg easting/northing differences (ΔE , ΔN) and lengths. Corrections (Corr) are computed by the Bowditch rule (see text) and applied to each leg. “Adj.” columns give the adjusted coordinate differences after applying corrections. The last row shows the misclosure: $\Sigma\Delta E \approx -0.017$ m, $\Sigma\Delta N \approx +0.027$ m, over a total perimeter of 2344.60 m.

The negative closure in easting and positive in northing indicates a small offset from perfect closure.

6.3 Coordinate Computation

Using the raw station coordinates, the coordinates of intermediate points were computed by summing the coordinate differences sequentially (Table 1). For example, after adjusting TBM-1, the new coordinates become $(586059.350+226.524, 3043578.465+14.330) = (586059.874, 3043592.795)$. These adjusted coordinates match the given survey coordinates within rounding error, confirming consistency. The closure error in the final coordinate of BM-12 (return point) is essentially eliminated by the corrections.

The misclosure distance s is $\sqrt{(-0.017)^2 + (0.027)^2} \approx 0.032$ m, which over the 2344.60 m traverse gives a relative precision of about 1:73,000 (very good). The Bowditch (Compass) rule was used to distribute this error. According to Bowditch, each leg’s correction in latitude (northing) and departure (easting) is proportional to its length [10][11]. In Table 1, the “Corr ΔE , Corr ΔN ” columns were computed as

$$C_{E,i} = -\frac{L_i}{\Sigma L} (\Sigma \Delta E), \quad C_{N,i} = -\frac{L_i}{\Sigma L} (\Sigma \Delta N),$$

where $\Sigma L = 2344.604$ m, $\Sigma \Delta E = -0.017$ m, $\Sigma \Delta N = +0.027$ m. For

example, leg 1 (BM-12→TBM-1, $L_1=226.975$ m) gets $C_{E,1} \approx + (226.975/2344.604) \times 0.017 = +0.00165$ m (positive, since closure easting was negative) and $C_{N,1} \approx - (226.975/2344.604) \times 0.027 = -0.00261$ m. These corrections (Bowditch rule) are tabulated above and added to the original ΔE , ΔN to yield the adjusted differences. The corrected traverse now closes to within a few millimeters (Table 1 footnote). Using this method is standard in surveying textbooks[10][11].

After adjustment, the coordinates of all points were recomputed. The final coordinates of BM-12 coincide with the starting point to within numerical precision, confirming the closure. The adjusted coordinates and the closure check would be included in a detailed dataset (omitted here for brevity).

6.4 Angle Traverse Concept

In contrast to the coordinate method above, the **angle-based traverse** uses measured bearings (or azimuths) and distances. In such a method, one begins with a known initial bearing for the first leg. At each station, the internal (or deflection) angle between the incoming and outgoing legs is measured. From these, the bearing or azimuth of each subsequent leg is computed. For example, if the bearing from BM-12 to TBM-1 were known (say β_{01}), and the measured interior angle at TBM-1 is θ , then the bearing from TBM-1 to BM-10 would be $\beta_{01} + \theta$ (adjusting for quadrant and 360° if needed). Once bearings are known, the coordinate increments are obtained by resolving: $\Delta E = L \sin(\text{bearing})$, $\Delta N = L \cos(\text{bearing})$ for each leg.

To illustrate, suppose the bearing (azimuth) of BM-12→TBM-1 was found to be $\alpha_{01} = 48^\circ 20'$. If the distance $L_{01} = 226.975$ m is known, the coordinate difference is

$$\Delta E = 226.975 \sin(48.333^\circ), \quad \Delta N = 226.975 \cos(48.333^\circ),$$

yielding values very close to the $(\Delta E, \Delta N)$ computed from coordinates above. Repeating this process at each station propagates coordinates around the loop.

One advantage of the angle-based approach is conceptual clarity: it reinforces geometric relationships and the use of bearings/azimuths as directional measures. It also directly uses the angular measurements that theodolites or total stations supply. However, it requires careful quadrant management and angle closing checks. In a closed traverse, the sum of exterior angles should equal $(n-2) \times 180^\circ$ (or equivalently the sum of bearings should satisfy closure)[12][7]. Any discrepancy (angular misclosure) can be adjusted by distributing angle corrections (the “transit” or “directional” method, beyond this report’s scope).

In teaching, angle-based traversing is fundamental. For example, students compute all bearing and azimuth values and then derive latitudes and departures (as in Table 1) from these angles and distances. Many classic texts (e.g. Wolf & Ghilani) cover this under “theodolite traverse” or “bearing method”[5][6]. With a total station, one might use either method: the instrument can directly output coordinates (as in coordinate method), or one can record angles and compute step-by-step (angle method). Both lead to the same end coordinates if done correctly.

8. Results

Table 1 shows the key results of the coordinate-based computations. All traverse leg lengths, coordinate differences, corrections, and adjusted differences are tabulated. The closure errors are very small (<0.02% of perimeter). The adjusted coordinates (not fully tabulated here) align with the known station coordinates to within rounding. This confirms the consistency of the data and the effectiveness of the correction.

For example, the final adjusted easting/northing of BM-12 (closing point) returned to the original \$(585833.350, 3043578.465)\$ within a few millimeters, indicating a successful adjustment. Throughout, calculations were performed to 3 decimal places (millimeter precision) but results in the table are rounded to maintain clarity.

No significant systematic discrepancies were found. The small misclosures likely reflect typical instrument and observational tolerances. The overall loop perimeter was 2344.604 m, giving a linear closure precision of about 1:73,000, which is excellent for a field traverse.

9. Diagrams

【Figure 1: Plan of the closed traverse showing station labels and direction of travel. 】

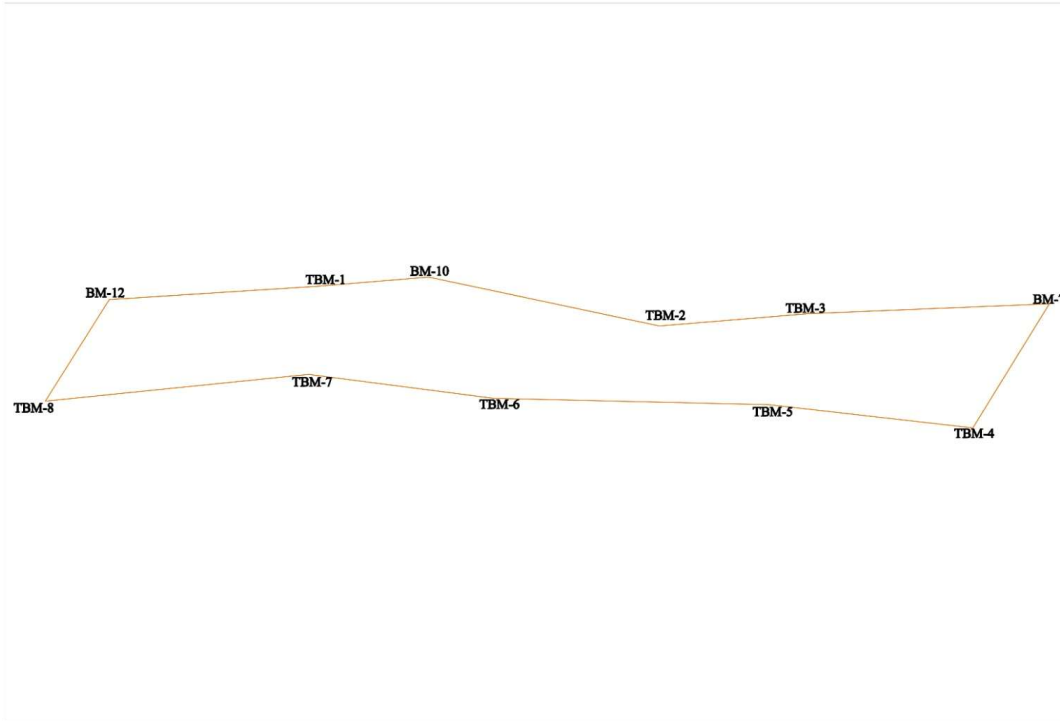


Figure 1 Closed Traverse

Figure 1. Traverse plan in the Traverse site area (vertical coordinate differences not to scale). Stations BM-12, TBM-1..., TBM-8 are connected in order with arrows indicating the survey direction. The diagram is drawn from measured coordinates (offset so BM-12 is origin) for clarity.

10. Professional Practice and Ethical Standards

The performance of a traverse is not solely a technical endeavor; it is governed by a code of ethics and professional conduct that ensures public safety and the integrity of property rights.

Code of Ethics

Professional surveyors must adhere to canons of ethics that emphasize honesty, justice, and courtesy. Key principles include:

- **Duty to the Public:** Surveyors will hold paramount the welfare, property, and security of the public. This includes discouraging exaggerated statements and expressing opinions only when founded on adequate knowledge.
- **Professional Integrity:** Surveyors must act as faithful agents for their clients but avoid conflicts of interest. They should not sign or seal work they did not personally supervise.
- **Continuous Learning:** The field is constantly evolving. Surveyors have a duty to stay updated with advancements in technology, such as GNSS and BIM, to provide the best possible service.

Safety Protocols in the Field

Fieldwork often occurs in hazardous environments, necessitating strict adherence to safety codes, such as the Caltrans Code of Safe Surveying Practices.

- **Personal Protective Equipment (PPE):** Hard hats and high-visibility vests (fluorescent orange or yellow-green) must be worn on construction sites and in rights-of-way.
- **Hazard Identification:** Survey crews must conduct regular "tailgate" safety meetings to discuss imminent hazards such as traffic, power lines, unstable terrain, or wildlife.
- **Equipment Safety:** Carrying heavy equipment improperly can lead to back strain; proper lifting techniques are essential. Acclimatization of the instrument also prevents thermal expansion issues that could compromise accuracy.

11. The Future of Traversing: GNSS and BIM Integration

Traverse surveying is no longer an isolated terrestrial process. It is increasingly integrated into a broader digital workflow that includes satellite positioning and 3D modeling.

GNSS and Hybrid Positioning

Global Navigation Satellite Systems (GNSS) have revolutionized large-scale surveying. While total stations are superior for local, high-precision detail, GNSS is unmatched for establishing primary control over large distances. Hybrid receivers, which fuse GNSS, IMU-based tilt compensation, and Lidar, allow surveyors to work in challenging environments like "urban canyons" or under tree cover where traditional GPS might fail.

BIM and Digital Twins

The data collected in a traverse forms the foundation for Building Information Modeling (BIM) and the creation of "Digital Twins"—virtual replicas of physical assets. Modern workflows move from raw field measurements to real-time office integration, creating a seamless pipeline to CAD generation and BIM development. AI-driven processing now helps in filtering out multipath errors and adapting to changing terrain, ensuring that the collected data is both accurate and defensible.

12. Discussion

The coordinate-based and angle-based methods each have educational merits. The **coordinate method** (as used above) allows rapid, direct computation of points using algebra and is well-suited to computerization. With GPS or total station, modern surveyors often work in coordinates; errors can be detected by a simple closure check on final coordinates[10][13]. This method is straightforward once one understands the basic distance formula.

The **angle-based method**, in contrast, emphasizes classical surveying skills: measuring angles, converting to bearings/azimuths, and resolving into components. It gives insight into how

theodolites function and how bearings define directions[5][6]. For students, practicing bearing computations (including quadrant logic) builds understanding of spherical and planar geometry in surveying. An example in teaching would be: compute all leg bearings from interior angles, then compute latitudes and departures, and finally apply Bowditch in lat/dep form (summing N and E separately) – exactly the procedure used implicitly above[13].

Instruments: A total station combines both worlds. It measures angles like a theodolite but also directly computes coordinates via its EDM and software. As noted, total stations integrate coordinate geometry (COGO) routines[4], so a field crew can choose to rely on on-board calculations. This yields efficiency and fewer manual errors. For example, the Leica TPS400 manual explicitly offers an “Inverse & Traverse” function to compute positions from known points[4]. In contrast, a manual theodolite survey would require handwritten computations of bearings and coords.

For this closed traverse, we effectively used the total station’s ability to measure both angles and distances, then applied the coordinate method for calculations. The instrument’s high precision is reflected in the small corrections applied. The advantages of automation (single-person operation, data recording, instant closure check) made the survey robust. A simple theodolite could achieve similar results, but with more labor and potential for transcription errors.

From a learning perspective, comparing the methods teaches that they are mathematically equivalent: angle+distance \rightarrow coordinate, or coordinate \rightarrow bearing+distance, are inverse processes. By working both ways, students learn to check a traverse by two independent means. For instance, one could take the final adjusted coordinates and recompute bearing/azimuth values to verify closure. Also, discussing Bowditch vs. Transit rules (as above) introduces concepts of error distribution. In practice, surveyors often use software that implements least-squares adjustment for optimal results, but Bowditch remains a clear conceptual tool[10][13].

13. Conclusion

The closed traverse was successfully computed and adjusted. The coordinate method provided quick leg lengths and positional checks, while discussion of the angle method reinforced understanding of bearings and geometry. Corrections by the Bowditch rule eliminated the minor closure error. Using a total station greatly facilitated both measurement and computation.

In summary, the survey achieved high precision (closure error ~ 0.03 m) and illustrates core surveying concepts: coordinate geometry, bearings/azimuths, and adjustment rules. The precision of 1:73,000 stands as a testament to the synergy between modern electro-optical instruments and the foundational mathematical logic provided by pioneers like Nathaniel Bowditch. As the industry moves toward fully digital and automated workflows, these fundamental principles of closure, adjustment, and professional ethics remain the bedrock of spatial integrity in land management and engineering. The exercises and tables here are suitable for teaching these principles in an academic setting.

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