CHAPTER 6

Horizontal Control Surveys

CE 316
March 2011
6.1 Introduction

- Angle, Bearings and Azimuths
- Adjustments for use in plane surveying
- Compass Surveys
- Traverse Surveys
- Triangulation and Trilateration
- Accuracy
- Electronic Distance Measurement
6.2 Angles, Bearings, and Azimuths

Units of Angle Measurement

Direction of turning (+)

Angular distance

Reference or Starting Line

Figure 15-9 A sextant. 1, frame; 2, index arm; 3, handle; 4, graduated arc; 5, horizon mirror; 6, opening over mirror; 7, telescope holder; 8, telescope; 9, index mirror; 10, micrometer screw; 11, graduated drum; 12, finger levers; 13, gear teeth; 14, filters. (U.S. Navy.)
6.3 Adjustments for Use in Plane Surveying

Spherical Excess ($\varepsilon$) [i.e. in excess of 180°]

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{\text{Area}_1}{\text{Area}_2}, \text{ or } \frac{2\pi}{\pi} = \frac{1}{8} \frac{4\pi r^2}{4\pi r^2}$$

$$\varepsilon = \text{Area} \left[ \frac{\varepsilon_1}{A_1} \right] = \text{Area} \frac{\pi}{2} \frac{1}{4\pi r^2} = \frac{\text{Area}}{r^2}$$

Example

Calculate the spherical excess in surveying a right-triangle with adjacent sides 20 miles long.
6.4 Horizontal Datums

The North American Datum of 1927 (NAD 27)

NAD 1983

- The horizontal control datum for North America that was defined by an azimuth on the Clarke 1866 ellipsoid with its origin at Meades Ranch, Kansas.

\[ \phi = 39^\circ 13' 26.686'' \ N \]
\[ \lambda = 98^\circ 32' 30.506'' \ W \]

- The result of the most recent adjustment
- Based on GRS80 Ellipsoid
- Compatible with GRS84
Magnetic Declination: The ____________in which the compass needle points is referred to as ________________, and the angle between magnetic north and the true north direction is called magnetic declination, magnetic variation, or compass variation.
Secular Variation: The magnetic declination changes______________, and unpredictably with time. This change is known to as secular variation. Because of this, declination values shown on old maps need to be updated if they are to be used without large errors.

Annual Variation
Local Variation

Movement of the Magnetic North Pole
If accurate declination values are needed, and if recent editions of the charts are not available, up-to-date values for Canada may be obtained from the most recent geomagnetic reference field models produced by the Geological Survey of Canada. It is produced with numerous observations of the magnetic field made on the ground, at sea, in the air, and at satellite altitudes between 1960 and 1994. The latest CGRF is for 1995, but contains time terms that enable it to be used over the time interval 1960 to 2000.
6.5 Compass Surveys

6.5.1 Canadian Geomagnetic Reference Field (CGRF)

The compass becomes increasingly erratic and eventually unusable as one approaches the North Magnetic Pole.
REQUESTED:
The magnetic declination in 1999 at Latitude 52 ° 08' N Longitude 106 ° 40' W:

CALCULATED:
The magnetic declination in 1999 at Latitude 52 ° 08' N Longitude 106 ° 40' W:

13° 57' E
6.5 Compass Surveys

6.5.2 Compass Survey Application

Excerpt from field notes of the final survey of the bank of the Sacramento River through Rancho Capay Josepa Sota by A.W. Von Schmidt, 1856

<table>
<thead>
<tr>
<th></th>
<th>Direction</th>
<th>Distance</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>S.84° E.</td>
<td>0.87</td>
<td>Leave thick undergrowth, timber scattering</td>
</tr>
<tr>
<td>8</td>
<td>S.79-3/4° E.</td>
<td>4.90</td>
<td>To a cottonwood with 4 trunks. Marked the south one, 54 inches diameter,</td>
</tr>
<tr>
<td>9</td>
<td>N.79-1/2° E.</td>
<td>4.24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C.R.S.10.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>S.81-1/2° E.</td>
<td>14.54</td>
<td>Enter thick undergrowth, bears off northeast.</td>
</tr>
<tr>
<td>11</td>
<td>S.71-1/4° E.</td>
<td>6.45</td>
<td>To a cottonwood 24 inches diameter, marked “C.R.S.12”.</td>
</tr>
<tr>
<td>12</td>
<td>N.84-1/2° E.</td>
<td>3.12</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>South</td>
<td>2.10</td>
<td>Cross a slough 1 chain 50 links wide, course southwest.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.50</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>N.83-1/4° E.</td>
<td>25.00</td>
<td></td>
</tr>
</tbody>
</table>

Topographic Survey
Stadia Survey
6.5 Compass Surveys

6.5.2 Compass Survey Application

Surveyors Compass

Brunton Compass
6.6 Transverse Surveys

- Traverse - a series of lines connecting successive established points along the route of a survey

- With stand alone EDM devices or theodolites, the traverse is done in two dimensions. With total station equipment, the traverse can be done in three dimensions.

- Two general classes of traverses
  1) Open Traverse
     - There is no way to check the values in this type of traverse and therefore should not be readily used.
  2) Closed Traverse
     - A traverse that originates and terminates on a known point is called a closed-loop traverse.
6.6 Transverse Surveys

6.6.1 Kinds of Horizontal Angles

interior angles \[\text{sum} = (n-2)180^\circ\]
angles to the right
deflection angles
6.6 Transverse Surveys

6.6.2 Direction of Lines

Horizontal angle from reference line

- astronomic
- magnetic
- assumed
6.6 Transverse Surveys

6.6.3 Bearings

One system for designating direction

- acute angle between reference meridian and line. (N 46° E)
  - True - local astronomic (true) meridian
  - Magnetic - ________________
  - Assumed - any adopted meridian Back bearings
6.7 Triangulation

- Consists of the measurement of the angles of a series of overlapping triangles, polygons, or quadrilaterals. The lines of this system that ties together all triangulation stations at the vertices of the triangles. These sides vary in length from 5 to 160 km with an average of 25 km.

- All angles are measured precisely. Instrumental errors are either removed or predetermined and more rigorous procedures are employed to reduce observational errors.
6.7 Triangulation

The scale of the network is controlled by measuring the lengths of certain lines called *base lines*. The latitude, longitude and azimuth of one point on the base line are found and from this, the latitude and longitude of all points in the network can be computed.

Thus, figures must be geometrically strong and permit each side to be calculated two ways (great care needed in selecting stations).
6.7 Triangulation

- Strength of figure R is computed from the formula:

\[
R = \left[ \left( \frac{D-C}{D} \right) \left( \delta^2_A + \delta_B \delta_A + \delta^2_B \right) \right] \times 10^{12}
\]

where:
- \(D\) is the number of new direction observed in the figure (obtained by inspection)
- \(C\) is the number of independent mathematical conditions to be satisfied in the figure.
- \(d\) are the common differences per second in log sin of the angles opposite the side to be calculated.
6.7 Triangulation

Known Data
- length and azimuth of base line AB
- Latitude and longitude of points A and B

Measured Data
- angles to new control points

Computed Data
- Latitude and longitude of point C, and other new points
- length and azimuth of line AC
- length and azimuth of all other lines
6.7 Triangulation
6.7.1 Simple Chain Triangulation

- Simplest and quickest method.
- Used for lower order surveys
6.7 Triangulation

6.7.2 Polygon Triangulation
6.7 Triangulation

6.7.3 Quadrilateral Triangulation

- highest accuracy
6.8 Trilateration

**Known Data**
- Length and azimuth of base line AB
- Latitude and longitude of points A and B

**Measured Data**
- Length of all triangle sides

**Computed Data**
- Latitude and longitude of point C and other new points
- Length and azimuth of line AC
- Length and azimuth between any two points
6.8 Trilateration

1905:
First triangulation station

The first geodetic triangulation is started in the Ottawa area by the Dominion Observatories Branch. The first station is established on King Mountain near Kingsmere, Quebec and observation towers are used for the first time.
6.8 Trilateration
6.8 Trilateration

6.8.1 Shoran Trilateration (1949-1957)

- Continuous readings of the microwaves as the plane flies across a line connecting the two points. From which the distance between the two points can be calculated.

- 2.5 million mi$^2$ measured in Canada’s North were surveyed in this manner to give 119 2nd order stations at average of 400 km spacing
  - Lines of 150 km to 500 km are used
  - Has an standard dev. of 7.3m ±16ppm for a single reading
6.8 Trilateration

6.8.1 Shoran Trilateration (1949-1957)
6.8 Trilateration

6.8.2 Aerodist Trilateration (1965-1973)

- Similar to Shoran trilateration but the microwaves have a higher frequency and a smaller wavelength (1/4 m)
- This was used to create 185 1st order stations in Canada’s North
- Has an standard dev. of 1.0m ±8ppm for a single reading
6.9 Accuracy and Precision in Horizontal Surveys

A survey station of a network is classified according to whether the semi-major axis of the 95 percent confidence region, with respect to other stations of the network, is less than or equal to: $r = C(d + 0.2)$.

Where:
$r$ is in centimeters
$d$ is distance in kilometers to any station
$C$ is a factor assigned according to the order of survey.

<table>
<thead>
<tr>
<th>Order</th>
<th>$C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>2</td>
</tr>
<tr>
<td>2nd</td>
<td>5</td>
</tr>
<tr>
<td>3rd</td>
<td>12</td>
</tr>
<tr>
<td>4th</td>
<td>30</td>
</tr>
</tbody>
</table>

For a required order classification of the connection between stations the semi-major axis must be less than $r = C(d + 0.2)$.
Figure 4. Variance-covariance relationship for angle.

Figure 3. Standard ellipse.

Figure 5. Mohr's circle solution for principal variances.
6.10 Horizontal Survey Equipment

6.10.1 Transit

<table>
<thead>
<tr>
<th>ENGINEERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Vertical Circle</td>
</tr>
<tr>
<td>▪ Cross hair reticule</td>
</tr>
<tr>
<td>▪ with capstan screws</td>
</tr>
<tr>
<td>▪ Telescope bubble</td>
</tr>
<tr>
<td>▪ Vertical tangent screws</td>
</tr>
<tr>
<td>▪ Vernier “A” scale</td>
</tr>
<tr>
<td>▪ Upper clamp</td>
</tr>
<tr>
<td>▪ Upper tangent screw</td>
</tr>
<tr>
<td>▪ Threaded tripod plate</td>
</tr>
<tr>
<td>▪ Focus knob</td>
</tr>
<tr>
<td>▪ Vertical clamp</td>
</tr>
<tr>
<td>▪ Standard</td>
</tr>
<tr>
<td>▪ Plate level</td>
</tr>
<tr>
<td>▪ Vernier “B” Scale</td>
</tr>
<tr>
<td>▪ Horizontal circle housing</td>
</tr>
<tr>
<td>▪ Optical Plummet (n/a)</td>
</tr>
<tr>
<td>▪ Levelling screws (4)</td>
</tr>
<tr>
<td>▪ Sliding base</td>
</tr>
</tbody>
</table>
6.10 Horizontal Survey Equipment

6.10.1 Transit

Fig. 6.30 Vernier styles. (a) One-minute double direct vernier. (b) Thirty-second double direct vernier. (c) Twenty-second double direct vernier. (Courtesy Keuffel & Esser Co.)
6.10 Horizontal Survey Equipment

6.10.2 Theodolite

- Vertical Circle
- Cross hair reticule
- with capstan screws
- Eye piece focus
- _______________________
- Vertical tangent screw
- Optical vertical scale
- Vertical Clamp
- Upper tangent screw
- Telescope
- Focus knob
- Horizontal clamp
- Rough horizontal adjustment

- Optical Plummet
- Levelling screws (3)
- Automatic Vertical circle indexing

Wild T-3 0.2” Theodolite
6.10 Horizontal Survey Equipment

6.10.2 Theodolite

Automatic vertical circle indexing
- Compensator and prism refer readings to direction of gravity

V-type (K&E)
- Four hinged system of reduced pendulum length
- Relatively insensitive to vibrations during observations.
- Efficient air-damped system, composed of a piston and cylinder provides excellent stabilizing characteristics.

X-type (K&E)
- Two plane-parallel plates that combine the two read-outs.

Compensator is arrested when the instrument is set for horizontal readings.
6.10 Horizontal Survey Equipment

6.10.3 Transit Readings

Transit Adjustments

Vertical circle perpendicular to horizontal
6.10 Horizontal Survey Equipment

6.10.4 Digital Theodolites

**ROTARY ENCODER SYSTEM FOR ELECTRONIC THEODOLITES AND TRANSITS**

- Photoelectric converter A
- Photoelectric converter B
- Slit A: A phase difference of 1/4th pitch or slit B: 90° exists between slits A and B
- Collimator lens

Topcon electronic theodolites (ETL-1 and DT-05/05A) and electronic transit (DT-30) measure horizontal and vertical angles with an incremental encoder detection system that reads to 1, 5, 10 or 30 seconds. Alternate dark and light patterns etched on the circles are detected by a light source and received by a photo detector, converting the beam into an electrical signal. The signal is converted to a pulse signal corresponding to the angle turned and the pulse signal is passed on to the microprocessor which displays an angle on the LCD.
6.10 Horizontal Survey Equipment

6.10.4 Digital Theodolites
AZIMUTH BY GYRO ATTACHMENT

- Gyro motor suspended by a thin metal tape from one end of a sealed tube that can be mounted vertically on the standards of a theodolite.
- Tube, enclosure, gyro motor and suspension are so designed that, when the unit is attached to the horizontal axis of a leveled theodolite, the metal tape holding the rotating gyro coincides with the vertical axis of the instrument and also with the direction of gravity.
- Gyro motor spinning at 22,000 rpm about this horizontal axis tries to maintain in space its initial random spinning plane created by its moment of inertia.
- The gyro, fixed to the instrument, which is earth-bound, is pulled out of its original spinning plane by the _________________.
- This interference causes the gyro to oscillate around the plumb line until the spin axis is oriented in the north-south plane and the rotation of the gyro correspond to the rotation of the earth.
- The gyro attachment is orientated on the instrument so that the gyro spin axis and the telescopic line of sight fall in the same vertical plane when the light mark is centered on the index.
- When this is achieved, the telescope is pointed orientated toward true or ________________ north.
6.10 Horizontal Survey Equipment

6.10.5 Gyro-Theodolites

Equator

North Pole

South Pole

H=0
V=E

H=Ecosφ
V=Esinφ

E=Vector of angular velocity of the Earth spinning on its axis
6.10 Horizontal Survey Equipment

6.10.6 Optical Plummets

Wild ZNL Zenith Nadar Plummet (up/down)

GDF3 Tribrach

Std. Dev. For plumbing
4-direction
1:30,000
Wild ZL Automatic Plummet (down version for precise plumbing)

Two Pendulum compensators working at right angles to each other.

Requires special tribrach and tripod

Std. Dev. For plumbing 4-direction
$\pm 1:200,000$
6.10 Horizontal Survey Equipment

6.10.7 Targets
6.10 Horizontal Survey Equipment

6.10.8 GDF3 Tribrach
6.11 Bench Marks for Horizontal Control
6.12 Inertial Surveying Systems (ISS)

6.12.1 Operating Principles of ISS

[Inertial Measurement Unit (IMU)]

- Measurements of accelerations over time
- Done while instrument is carried from point to point
- Acceleration and time measurements are taken independently in three mutually orthogonal planes which are oriented:
  1) north - south
  2) east - west
  3) direction of gravity
6.12 Inertial Surveying Systems (ISS)

6.12.2 Mobile Leveling

- Vertical accuracy approx. 0.15 to 0.5 m in 60 to 100 km respectively.
- High cost - only suitable for large projects
6.13 Alignment Surveys

A Fresnel Zone Plate Lens

\[ f^2 + r_n^2 = \left( f + \frac{n\lambda}{2} \right)^2 \]  \hspace{1cm} (9.8)

\[ r_n^2 = n\lambda f + \frac{n^2\lambda^2}{4} \]  \hspace{1cm} (9.9)

\[ r_n \approx \sqrt{n\lambda f} \]  \hspace{1cm} (9.10)

Professor David Allwood
ABT 210/ECE 213
Univ. California, Berkeley
# Lieca Pipe Laser

## Lieca Pipe Specifications

<table>
<thead>
<tr>
<th>Product Specifications</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser Diode</td>
<td>635 nm (red)</td>
</tr>
<tr>
<td>Laser Output</td>
<td>4.75 mW maximum</td>
</tr>
<tr>
<td>Working Range</td>
<td>200 m (650 ft)</td>
</tr>
<tr>
<td>Grade Range</td>
<td>-10% to +25%</td>
</tr>
<tr>
<td>Self-leveling Range</td>
<td>-15% to +30%</td>
</tr>
<tr>
<td>Line Movement</td>
<td>6 m at 30 m (20 ft at 100 ft)</td>
</tr>
<tr>
<td>Battery*</td>
<td>Lithium-Ion, 7.4 V/3.8 Ah</td>
</tr>
<tr>
<td>Operation/Charge</td>
<td>40 h/4 h</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-20° to +50° C (-4° to +122° F)</td>
</tr>
<tr>
<td>Dimensions (diameter x length)</td>
<td>96 mm x 267 mm (3.8 in x 10.5 in)</td>
</tr>
<tr>
<td>Weight</td>
<td>2 kg (4.4 lbs)</td>
</tr>
<tr>
<td>Construction</td>
<td>Cast aluminium</td>
</tr>
<tr>
<td>Seal</td>
<td>IPX8</td>
</tr>
<tr>
<td>Wireless Remote</td>
<td>Front, up to 150 m (500 ft)</td>
</tr>
<tr>
<td></td>
<td>Back, up to 10 m (35 ft)</td>
</tr>
</tbody>
</table>

*Battery life is dependent upon environmental conditions
6.14 Electronic Distance Measurement

6.14.1 Introduction

- Includes electro-optical (light) and electromagnetic (microwave) instruments.
- Distance is computed based on the time taken for these waves to travel from station to station.

1st Generation (1950’s)
- Tellurometer used microwaves
- Geodimeter used light waves
6.14 Electronic Distance Measurement

- **2nd Generation (1960’s)**
  - Miniturization of electronics
  - Development of small light emitting diodes (LED) that can operate on low power.

- **3rd Generation**
  - Development of highly coherent laser light.

- **4th Generation**
  - Total Stations

- **TOPCON**
  - GTS-2
  - MA 100
  - Mekometer
  - CA 1000
  - HP 3800
  - 1mm+/- 2ppm
6.14 Electronic Distance Measurement

6.14.2 Prism

- the prism is used to reflect the _________ light source emitted from the total station back to the instrument.

- the accuracy of the measurement depends on precise alignment of:
  1) the center of total station,
  2) the prism center,
  3) the plumbing and pivot point of the prism.

- Ideally, the plumbing and pivot point and the prism center should coincide to reduce error from not perfectly pointing the prism at the total station.
6.14 Electronic Distance Measurement

6.14.2 Prism

- The plumbing and pivot point is the reference point that should be located directly above the ground mark and may be moved forward or back according to the prism centre.

- The prism centre is the visual reference point as sighted from any angle.
6.14 Electronic Distance Measurement

6.14.2 Prism

Ideal reflecting point provided by locating the plumbing and pivot point at the prism centre (-40mm prism constant)

Prism centre and plumbing and pivot point (-40 mm prism constant)

Error in pointing the prism at the instrument $5^\circ$

Line of site and ideal line

Plumbing and pivot point (-30mm prism constant)

Fog & clouds Measurements not possible
6.14 Electronic Distance Measurement

6.14.2 Prism

Magnitude of error at 100 m with zero prism constant

Error in pointing the prism at the instrument 5°

Line of sight error = 3.7 mm

Instrument

Plumbing and pivot point

Prism Center

Ideal line

Line of sight
6.14 Electronic Distance Measurement

6.14.2 Prism

Diagram showing the relationship between line-of-sight error and error in pointing prism at measuring instrument. The graph includes points at -30 mm and -40 mm.