Geodetic Networks
And Survey Control For
Large Projects

Maryland Society of Surveyors
Spring Technical Conference

By: Alan R. Dragoo
Maser Consulting P.A.

March 2, 2015
Maritime Institute of Technology
Training and Conference Center
Linthicum Heights, Maryland
Survey Control For Large Projects

Maryland Society of Surveyors

2015 Spring Technical Conference
March 2, 2015
Maritime Institute of Technology
Linthicum Heights, Maryland

Alan R. Dragoo PLS
Maser Consulting
Sterling, Virginia

Agenda

• Accuracies
• Advantages, Disadvantages and best practices for the following
  – GPS Static
  – OPUS Static
  – OPUS Rapid Static
  – Conventional Traverse
  – Conventional Leveling
How are your accuracies going to be evaluated

- Absolute
- Relative
- Point to Point

How much confidence do you need

<table>
<thead>
<tr>
<th>Name of error</th>
<th>Value</th>
<th>% Certainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probable</td>
<td>0.6745σ</td>
<td>50%</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1 σ</td>
<td>68.3%</td>
</tr>
<tr>
<td>Two sigma or 95% error</td>
<td>2 σ</td>
<td>95%</td>
</tr>
</tbody>
</table>
What Accuracy Do You Need

- Horizontal
  - 3 Feet
  - 0.03 Feet

- Vertical
  - 6 Feet
  - 0.01 Feet

If Someone Else Is Going To Evaluate Your Data......

- You better develop a way to test it before they do.
What Standards and Specifications are Available

• Standards and Specifications for Geodetic Control Networks
• Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques
• Guidelines for Establishing GPS Derived Ellipsoid Heights (NOS NGS 58)

What Standards and Specifications are Available

• Guidelines for Establishing GPS Orthometric Heights (NOS NGS 59)
• National Geodetic Survey User Guidelines for Single Base Real Time GNSS Positions
• National Geodetic Survey Guidelines for Real Time GNSS Networks
• Minimum Standard Detail Requirements For ALTA/ACSM Land Title Survey 2011
Standards and Specifications

• Is there a project requirement that the survey conform to a specific set of published “Standards and Specifications”.

Planning The Survey
So You Can Price The Survey

• Investigate what existing NGS control is available.
• Recover existing NGS control.
• If necessary develop a plan to densify the primary control so that error propagation will not exceed your specifications.
• Plan your project survey control.
Error Propagation Due To Centering Errors

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Horz Angle</td>
<td>$\theta$</td>
<td>180 Deg</td>
<td></td>
</tr>
<tr>
<td>Back Dist</td>
<td>$D_1$</td>
<td>600 Ft</td>
<td></td>
</tr>
<tr>
<td>Fwd Dist</td>
<td>$D_2$</td>
<td>600 Ft</td>
<td>$\sigma_{\theta t}$ 2.4 &quot;</td>
</tr>
<tr>
<td>Target Centering Error</td>
<td>$\sigma_t$</td>
<td>0.005 Ft</td>
<td>$\sigma_{\theta c}$ 3.4 &quot;</td>
</tr>
<tr>
<td>Inst Centering Error</td>
<td>$\sigma_c$</td>
<td>0.005 FT</td>
<td></td>
</tr>
<tr>
<td>Trav Dist</td>
<td>$\sigma_t$</td>
<td>5280</td>
<td>4.2 &quot;</td>
</tr>
<tr>
<td></td>
<td>$\sigma_c$</td>
<td>206265</td>
<td></td>
</tr>
<tr>
<td>Trav Dist</td>
<td>$\sigma_c$</td>
<td>1 / 48,990 = Precision</td>
<td></td>
</tr>
</tbody>
</table>

What Accuracies Can Be Expected

GPS Static Relative Accuracies

- Horizontal 0.02 to 0.03 feet
- Vertical 0.03 to 0.04 feet

WITH PROOF THAT IT’S RIGHT
Static GPS Network Design

OPUS - Static

• OPUS – Static Absolute Accuracies
• 2 Hours to 24 Hours

- Results are at a 95% level of confidence
  With Good Conditions & No Proof
What to Look For In a Quality OPUS – Static Solution

- Orbit used = precise or rapid
- > 90% observations used
- > 50% ambiguities fixed
- Correct antenna and antenna height
- Static: overall RMS < 3 cm,
- Peak to peak errors < 5 cm.
How Can The OPUS – Static Positional Error Be Calculated to a 95% Confidence

$$HzAccuracy = \sqrt{(latitude \ peak \ to \ peak)^2 + (longitude \ peak \ to \ peak)^2}$$

VertAccuracy = height peak to peak value

OPUS – Rapid Static
How Accurate Is It?

http://www.ngs.noaa.gov/OPUSI/Plots/Gmap/OPUSR5_sigmap.shtml
Absolute Accuracy With Good Conditions and No Proof
What to Look For In a Quality OPUS – Rapid Static Solution

- Orbit used = precise or rapid
- Correct antenna and antenna height
- Observations Used > 60%
- Quality Indicator > 3 for both the “Network mode adjustment” and the “Rover mode adjustment”
- Normalized RMS < 1
- Accuracies should be < 0.050

OPUS – Rapid Static Quality Indicators

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NAV FILE: brdc3240.14n</td>
<td>OBS USED: 3915 / 4518 : 87%</td>
</tr>
<tr>
<td>ANT NAME: TRMR10</td>
<td>NONE</td>
</tr>
<tr>
<td>QUALITY IND: 3.12/23.79</td>
<td></td>
</tr>
<tr>
<td>ARP HEIGHT: 2.000</td>
<td>NORMALIZED RMS: 0.455</td>
</tr>
</tbody>
</table>

| X: 1300498.484(m) 0.007(m) | 1300498.446(m) 0.007(m) |
| Y: -4685942.957(m) 0.024(m) | -4685941.516(m) 0.024(m) |
| Z: 4113049.625(m) 0.021(m) | 4113049.577(m) 0.021(m) |
| LAT: 40 24 48.70377 0.006(m) | 40 24 48.73648 0.006(m) |
| E LON: 285 30 39.74762 0.007(m) | 285 30 39.72971 0.007(m) |
| W LON: 74 29 20.25238 0.007(m) | 74 29 20.27023 0.007(m) |
| EL HGT: -6.326(m) 0.032(m) | -7.585(m) 0.032(m) |
| ORTH HGT: 26.605(m) 0.034(m) | [NAVD88 (Computed using GEOID12a)] |

<table>
<thead>
<tr>
<th>UTM COORDINATES</th>
<th>STATE PLANE COORDINATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>UTM (Zone 18)</td>
<td>SPC [2900 NJ ]</td>
</tr>
<tr>
<td>Northing (N) [m]</td>
<td>4873781.876 175427.540</td>
</tr>
<tr>
<td>Easting (E) [m]</td>
<td>543358.118 150937.028</td>
</tr>
<tr>
<td>Convergence [degrees]</td>
<td>0.3321288 0.0071788</td>
</tr>
<tr>
<td>Point Scale</td>
<td>0.99962314 0.99990001</td>
</tr>
<tr>
<td>Combined Factor</td>
<td>0.99962413 0.99990100</td>
</tr>
</tbody>
</table>
Accuracy for OPUS – Rapid Static Related Information

- Positions are reported at a 95% level of confidence.
- Accuracies are reported at a 1 sigma level

Be Sure To Get Your Antenna Height Right

It is not always obvious
Network RTK

- Network Accuracies
- Typical
  - Horizontal 2 – 3 cm (0.06 – 0.10 feet)
  - Vertical 3 – 5 cm (0.10 – 0.16 feet)

With Good Conditions
- Observation Time 3 minutes

Conventional Traverse

Your Accuracy and Confidence Will Depend On Many Things:
- Density and accuracy of existing control
- Accuracy of angles and distances measured
- Quality of measurements
- Quality of setups
- Equipment properly adjusted
- Properly set stations for distance and visibility
- Type of adjustment performed
Avoiding Problems With Refraction

- Sighting over or next to object that are warmer than the surrounding air. Especially those that are closer to the instrument.
- Sighting over areas that have vertical air flow close to the instrument.

Solving A Refraction Problem

1. Compute approx position of point 1 from Azimuth 1 for astro
2. Compute astro azimuth Point 1 to Az Mk 3
What Do The Specifications Say?

Table 2.1 - Distance accuracy standards

<table>
<thead>
<tr>
<th>Classification</th>
<th>Minimum distance accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>First-order</td>
<td>1:100,000</td>
</tr>
<tr>
<td>Second-order, class I</td>
<td>1: 50,000</td>
</tr>
<tr>
<td>Second-order, class II</td>
<td>1: 20,000</td>
</tr>
<tr>
<td>Third-order, class I</td>
<td>1: 10,000</td>
</tr>
<tr>
<td>Third-order, class II</td>
<td>1: 5,000</td>
</tr>
</tbody>
</table>

Directions

<table>
<thead>
<tr>
<th>Order</th>
<th>First</th>
<th>Second</th>
<th>Second</th>
<th>Third</th>
<th>Third</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
<td>I</td>
<td>H</td>
<td>I</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Number of positions</td>
<td>16</td>
<td>8 or 12‘</td>
<td>8 or 8 *</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Standard deviation of mean not to exceed</td>
<td>0.4”</td>
<td>0.5”</td>
<td>0.8”</td>
<td>1.2”</td>
<td>2.0”</td>
</tr>
<tr>
<td>Rejection limit from the mean</td>
<td>4”</td>
<td>5”</td>
<td>5”</td>
<td>5”</td>
<td>5”</td>
</tr>
</tbody>
</table>

* 8 if 0.2”, 12 if 1.0” resolution.
* 6 if 0.2”, 8 if 1.0” resolution.

What Is One Angle Or One Position?

- An angle is a direct and reverse pointing on each target
So How Many Angles Should You Turn

• 1 Angle (4 pointings) “NO CHECK”
• 2 Angles (8 pointings) There is a check but if something is wrong you don’t know what.
• 3 Angles (12 points) Now you have something that you can throw out if something is bad

• For large projects you should probable turn 6 angles 24 pointing. “THINGS DO GO WRONG”

Traverse Station Locations

• When setting stations for large projects set the stations as far apart as possible and still have good visibility and quality angles.
• Don’t worry about whether you can see the things you need to locate. You can set supplemental control to do this later.
Field Procedures

• Leap frog traverse (Right Way)
  – Move ahead
  – Relevel
  – Check centering
    • If acceptable continue traverse
    • If unacceptable return previous angle

• Traverse through and over stations with existing horizontal or vertical values.

• Do not take side shots to existing stations.

Use The Proper Adjustment Technique

• Compass Rule Adjustments introduce distortion errors into your traverse.

• Understand how and use a true Least Squares Adjustment. This will give you a best fit to everything you hold
Conventional Leveling

• Your Accuracy and Confidence Will Depend On
  – Density and accuracy of existing control
  – Quality of equipment used
  – Tolerances for quality of measurements
  – Field procedures used
  – Equipment properly adjusted

• It’s the little things that count

Quality of Level and Accessories

• 1<sup>st</sup> Order  Trimble DiNi 0.3
• 2<sup>nd</sup> Order  Trimble DiNi 0.7

• 1<sup>st</sup> Order  Invar Rods
• Less than 3<sup>rd</sup> Order  Folding Rods or Fiberglass Rods
## Leveling Tolerances

<table>
<thead>
<tr>
<th>Order</th>
<th>First</th>
<th>Second</th>
<th>Third</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>0.40mm</td>
<td>1.00mm</td>
<td></td>
</tr>
<tr>
<td>Class II</td>
<td>0.95mm</td>
<td>1.26mm</td>
<td>1.90mm</td>
</tr>
<tr>
<td>Class III</td>
<td>1.90mm</td>
<td>2.53mm</td>
<td>3.79mm</td>
</tr>
</tbody>
</table>

### Section misclosures (backward and forward)

- One-Setup Section
  - Two runnings of a section less than 0.10 km in length
    - Algebraic sum of all corrected section misclosures:
      - 3"D
      - 4"D
      - 6"D
      - 8"D
      - 12"D

### Algebraic sum of all corrected section misclosures of a leveling line not to exceed

- Section misclosure not to exceed (mm)
  - 2"E
  - 4"E
  - 6"E
  - 8"E
  - 12"E

### Loop misclosures

- Algebraic sum of all corrected misclosures not to exceed (mm)
  - 4"F
  - 5"F
  - 6"F
  - 8"F
  - 12"F

### Loop misclosure not to exceed (mm)

- [D – shortest length of leveling line (one-way) in km]
- [E – shortest one-way length of section in km]
- [F – length of loop in km]

### Leveling Field Procedures

- Use Leveling Pins
Leveling Without a Pin

• When leveling and the surface is not precisely flat, if the rod is not held at exactly the same location a systematic error will occur.

• Remember you are measuring to 0.3 mm

Leveling Field Procedures

• Keep Sights Balanced

• Requirements for lines of Sight and balance.
Leveling Field Procedures

• Heat Shimmer Usually Cancels in a Balanced Setup.

• Refraction does not Cancel even with Balanced Setups. “No readings less Than 1.5 ft”

Leveling Field Procedures

• Using a Plug “Errors Cancel”
Leveling Field Procedures

- When using two rods label them “Rod 1” and “Rod 2”
- Come of your known bench mark with “Rod 1” and go into your known bench mark with “Rod 1”
- Leap frog your rods

Leveling Field Procedures

- Level through and over all existing bench marks.
- Do not take side shots to existing bench marks.
Trigonometric Leveling

- Leveling Accuracy for 10 mile project
  - Normal Trig Leveling 0.15 Ft to 0.20 Ft
  - High precision Trig Leveling 0.08 Ft to 0.10 Ft
  - Careful Conventional Leveling 0.04 Ft to 0.06 Ft

- Instrument used 1.0” Robot

High Precision Trig Leveling

- Measure Hi’s in meters, centimeter and millimeters.
- Measure all setups independently
- Do not carry forward measurements
Questions: