# Geodetic Networks And Survey Control For Large Projects

Maryland Society of Surveyors
Spring Technical Conference

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March 2, 2015
Maritime Institute of Technology
Training and Conference Center
Linthicum Heights, Maryland

# Survey Control For Large Projects

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2015 Spring Technical Conference
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## 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

| Name of error | Value | % Certainty |
|---|---|---|
| Probable | 0.6745 $\sigma$ | 50% |
| Standard Deviation | 1 $\sigma$ | 68.3% |
| Two sigma or 95% error | 2 $\sigma$ | 95% |

## 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".

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## 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.

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# Error Propagation Due To Centering Errors

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Horz Angle | $\theta =$ | 180 | Deg | | | | |
| Back Dist | $D_1 =$ | 600 | Ft | | | | |
| Fwd Dist | $D_2 =$ | 600 | Ft | $\sigma_{\theta t}$ | | 2.4 | " |
| Target Centering Error | $\sigma_t =$ | 0.005 | Ft | $\sigma_{\theta c}$ | | 3.4 | " |
| Inst Centering Error | $\sigma_c =$ | 0.005 | FT | | | | |
| | Trav Dist | 5280 | | $\sigma_T$ | | 4.2 | " |
| | | 206265 | | | | | |
| | | $\sigma_T$ | = | 1 | / | 48,990 | =Precision |
| | | Trav Dist | | | | | |

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# 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

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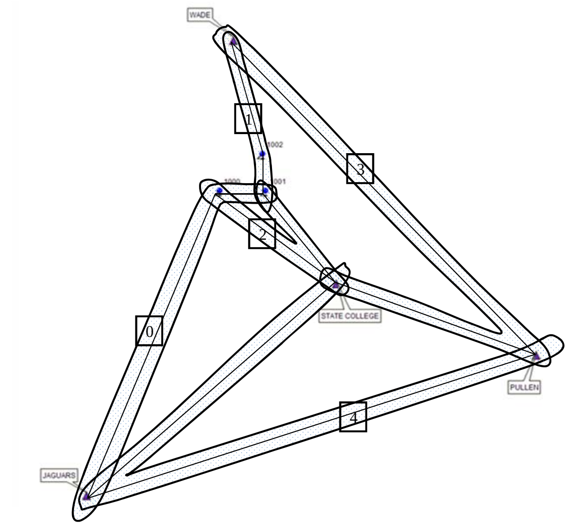
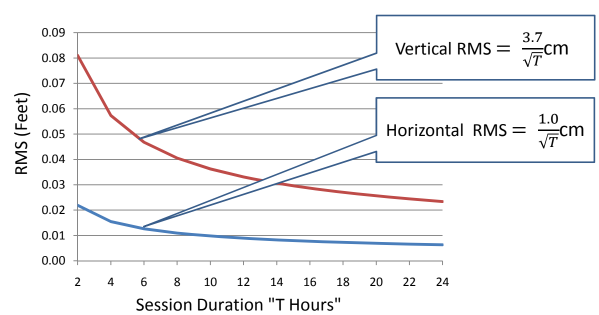
# Static GPS Network Design




# 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.

# OPUS – Static Quality Indicators

```
 SOFTWARE: page5  1209.04 master50.pl 022814      START: 2015/01/30  16:53:00
EPHEMERIS: igr18295.eph [rapid]                    STOP: 2015/01/30  19:15:00
 NAV FILE: brdc0300.15n                        OBS USED:  4693 /  5253   :  89%
 ANT NAME: TRMR10             NONE          # FIXED AMB:    31 /    32   :  97%
ARP HEIGHT: 2.050                          OVERALL RMS: 0.021(m)


 REF FRAME: NAD_83(2011)(EPOCH:2010.0000)              IGS08 (EPOCH:2015.0815)

         X:      1198861.688(m)   0.008(m)          1198860.867(m)   0.008(m)
         Y:     -4950737.662(m)   0.046(m)         -4950736.186(m)   0.046(m)
         Z:      3825507.263(m)   0.017(m)          3825507.182(m)   0.017(m)

       LAT:   37  5 30.58862      0.014(m)       37  5 30.61837      0.014(m)
     E LON:  283 36 45.34783      0.014(m)      283 36 45.32959      0.014(m)
     W LON:   76 23 14.65217      0.014(m)       76 23 14.67041      0.014(m)
    EL HGT:           -33.184(m)  0.046(m)                -34.531(m)  0.046(m)
 ORTHO HGT:             3.278(m)  0.081(m) [NAVD88 (Computed using GEOID12A)]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 18)         SPC (4502 VA S)
Northing (Y) [meters]     4105959.896          1086274.954
Easting (X)  [meters]      376699.600          3687795.606
Convergence  [degrees]    -0.83684042           1.28218738
Point Scale                0.99978728           0.99995691
Combined Factor            0.99979249           0.99996212
```

# How Can The OPUS – Static Positional Error Be Calculated to a 95% Confidence

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

$$\text{VertAccuracy} = \text{height peak to peak value}$$

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# OPUS – Rapid Static How Accurate Is It?


http://www.ngs.noaa.gov/OPUSI/Plots/Gmap/OPUSRS_sigmap.shtml

Absolute Accuracy With Good Conditions and No Proof

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# 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

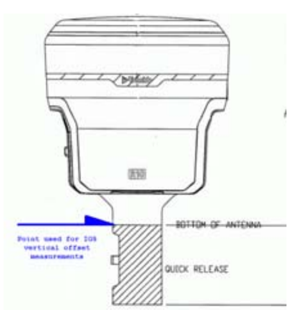
# OPUS – Rapid Static Quality Indicators

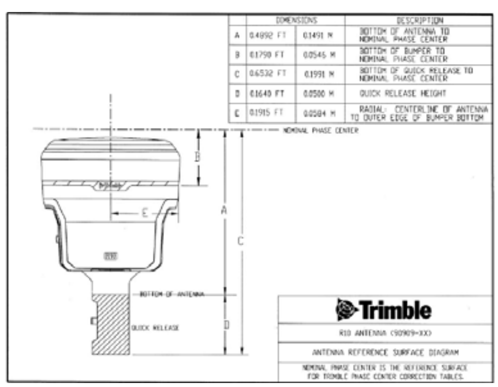
```
  SOFTWARE: rsgps  1.37 RS93.prl 1.99.2             START: 2014/11/20 21:07:00
 EPHEMERIS: igu18194.eph [ultra-rapid]               STOP: 2014/11/20 22:04:30
  NAV FILE: brdc3240.14n                         OBS USED:  3915 /  4518   :  87%
  ANT NAME: TRMR10          NONE             QUALITY IND.   3.12/ 23.79
ARP HEIGHT: 2.000                          NORMALIZED RMS:        0.455

 REF FRAME: NAD_83(2011)(EPOCH:2010.0000)              IGS08 (EPOCH:2014.88740)

         X:      1300499.484(m)   0.007(m)          1300498.646(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 20.27029      0.007(m)
    EL HGT:           -6.326(m)   0.032(m)                -7.585(m)   0.032(m)
 ORTHO HGT:           26.605(m)   0.034(m) [NAVD88 (Computed using GEOID12A)]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 18)         SPC (2900 NJ  )
Northing (Y) [meters]     4473781.876           175427.540
Easting (X)  [meters]      543358.118           150937.028
Convergence  [degrees]     0.33131288           0.00715788
Point Scale                0.99962314           0.99990001
Combined Factor            0.99962413           0.99990100
```

## 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

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## 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

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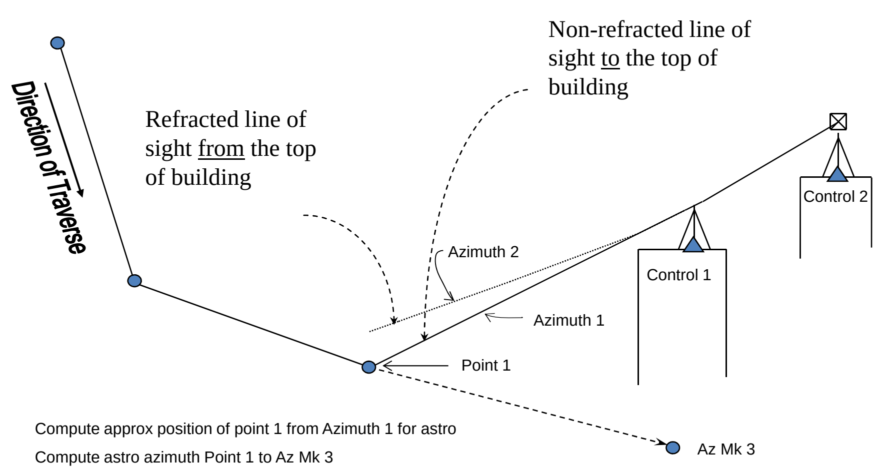
# Avoiding Problems With Refraction

- 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**

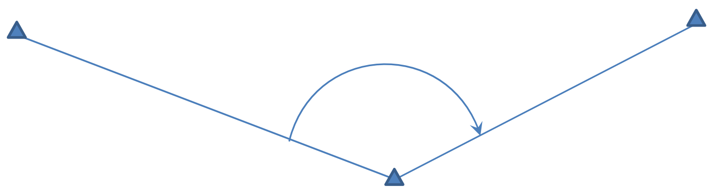
| *Classification* | *Minimum distance accuracy* |
|---|---|
| First-order | 1:100,000 |
| Second-order, class I | 1: 50,000 |
| Second-order, class II | 1: 20,000 |
| Third-order, class I | 1: 10,000 |
| Third-order, class II | 1: 5,000 |

| *Order* | *First* | *Second* | *Second* | *Third* | *Third* |
|---|---|---|---|---|---|
| *Class* | | *I* | *II* | *I* | *II* |
| **Directions** | | | | | |
| Number of positions | 16 | 8 or 12† | 6 or 8 * | 4 | 2 |
| Standard deviation of mean not to exceed | 0.4" | 0.5" | 0.8" | 1.2" | 2.0" |
| Rejection limit from the mean. | 4" | 5" | 5" | 5" | 5" |

† 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



One Angle

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| D | 0 | 00 | 10 | Mean | | | |
| R | 180 | 0 | 15 | 12.5 | | | |
| D | 132 | 26 | 35 | | Angle | | |
| R | 312 | 26 | 28 | 31.5 | 132 | 26 | 19.0 |

## 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

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# Quality of Level and Accessories

| | |
|---|---|
| • $1^{st}$ Order | Trimble DiNi 0.3 |
| • $2^{nd}$ Order | Trimble DiNi 0.7 |

| | |
|---|---|
| • $1^{st}$ Order | Invar Rods |
| • Less than $3^{rd}$ Order | Folding Rods or Fiberglass Rods |

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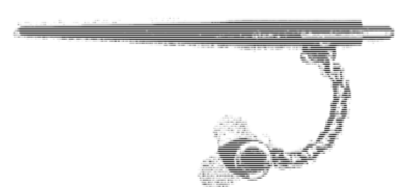
# Leveling Tolerances

| *Order* <br> *Class* | *First* <br> *I* | *First* <br> *II* | *Second* <br> *I* | *Second* <br> *II* | *Third* |
|---|---|---|---|---|---|
| **Section misclosures (backward and forward)** | | | | | |
| One-Setup Section | ±0.40mm | ±1.00mm | -- -- -- -- | -- -- -- -- | -- -- -- -- |
| Two runnings of a section less than 0.10 km in length | ±0.95mm | ±1.26mm | ±1.90mm | ±2.53mm | ±3.79mm |
| Algebraic sum of all corrected section misclosures of a leveling line not to exceed | 3√D | 4√D | 6√D | 8√D | 12√D |
| Section misclosure not to exceed (mm) | 3√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) | 4√F | 5√F | 6√F | 8√F | 12√F |
| (D -- shortest length of leveling line (one-way) in km) <br> (E -- shortest one-way length of section in km) <br> (F -- length of loop in km) | | | | | |

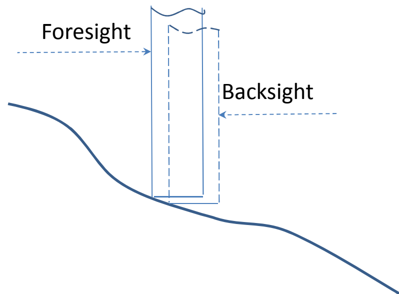
# Leveling Field Procedures

- 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

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# Leveling Field Procedures

- Keep Sights Balanced

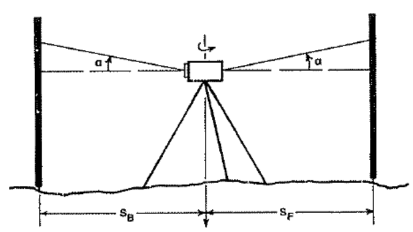

**Figure 3-4.**—Consistent collimation error cancels in a balanced setup since $s_B = s_F$.

- Requirements for lines of Sight and balance.

| Lines of sight | First Order Class 1 | First Order Class II | Second Order Class I | Second Order Class II | Third Order |
|---|---|---|---|---|---|
| Maximum sighting distance | 160 Ft | 195 Ft | 195 Ft | 230 Ft | 295 Ft |
| Maximum imbalance | | | | | |
| Per Setup | ±6Ft | ±15Ft | ±15Ft | ±33Ft | ±33Ft |
| Per Section | ±13Ft | ±33Ft | ±33Ft | ±33Ft | ±33Ft |

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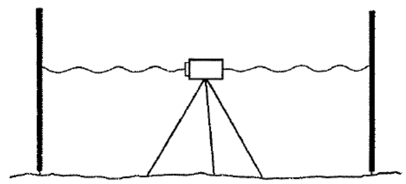
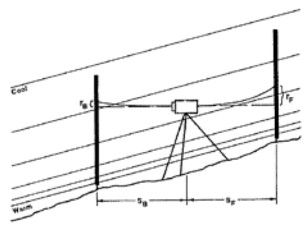
# Leveling Field Procedures

- Heat Shimmer Usually Cancels in a Balanced Setup.



Shimmer.

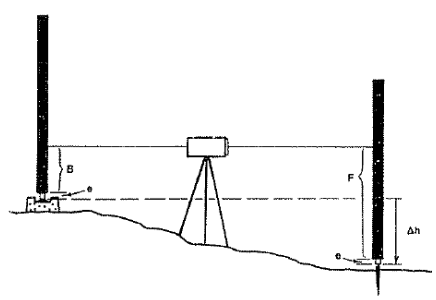
- Refraction does not Cancel even with Balanced Setups. "No readings less Than 1.5 ft"



Refraction error, $r$, does not cancel on sloping terrain since $r_B \neq r_F$, even if $s_B = s_F$.

# Leveling Field Procedures

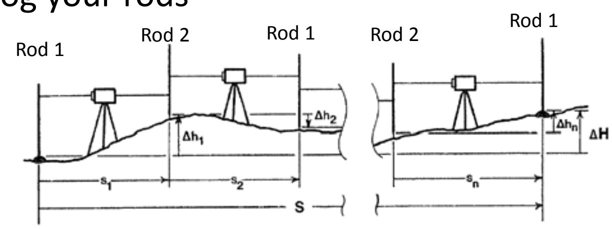
- Using a Plug "Errors Cancel"



When using spacers the height, $e$, of each spacer cancels when the elevation difference, $\Delta h$, is computed: $\Delta h = (B+e) - (F+e) = B - F$.

# 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: