



## Development of GPS Survey Data Management Protocols/Policy



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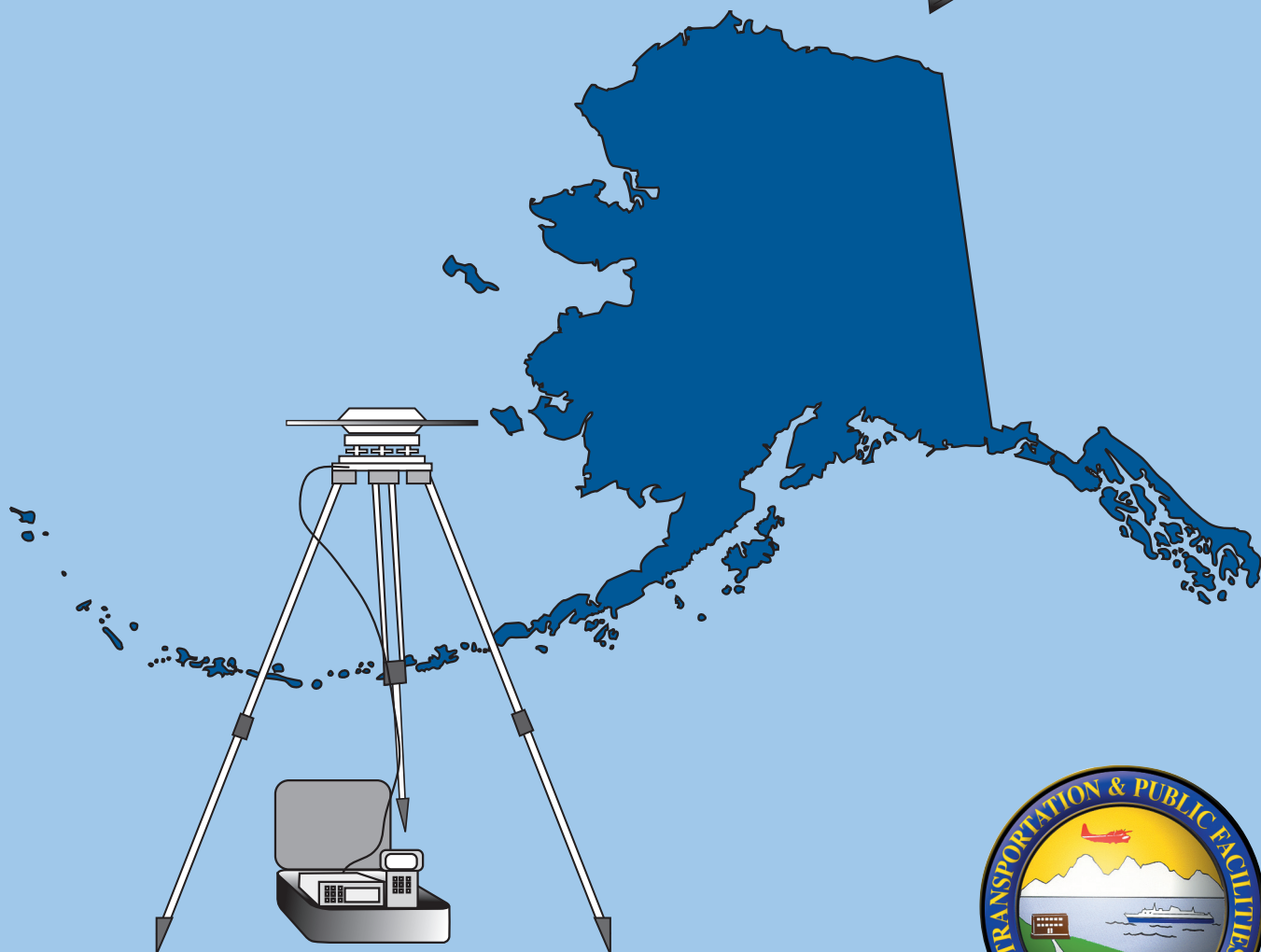
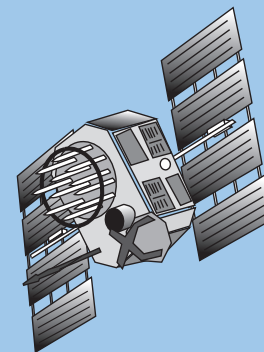
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	645.2	square millimeters	mm <sup>2</sup>
ft <sup>2</sup>	square feet	0.093	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yard	0.836	square meters	m <sup>2</sup>
ac	acres	0.405	hectares	ha
mi <sup>2</sup>	square miles	2.59	square kilometers	km <sup>2</sup>
<b>VOLUME</b>				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft <sup>3</sup>	cubic feet	0.028	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.765	cubic meters	m <sup>3</sup>
NOTE: volumes greater than 1000 L shall be shown in m <sup>3</sup>				
<b>MASS</b>				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
<b>TEMPERATURE (exact degrees)</b>				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
<b>ILLUMINATION</b>				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m <sup>2</sup>	cd/m <sup>2</sup>
<b>FORCE and PRESSURE or STRESS</b>				
lbf	poundforce	4.45	newtons	N
lbf/in <sup>2</sup>	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
<b>AREA</b>				
mm <sup>2</sup>	square millimeters	0.0016	square inches	in <sup>2</sup>
m <sup>2</sup>	square meters	10.764	square feet	ft <sup>2</sup>
m <sup>2</sup>	square meters	1.195	square yards	yd <sup>2</sup>
ha	hectares	2.47	acres	ac
km <sup>2</sup>	square kilometers	0.386	square miles	mi <sup>2</sup>
<b>VOLUME</b>				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m <sup>3</sup>	cubic meters	35.314	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meters	1.307	cubic yards	yd <sup>3</sup>
<b>MASS</b>				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
<b>TEMPERATURE (exact degrees)</b>				
°C	Celsius	1.8C+32	Fahrenheit	°F
<b>ILLUMINATION</b>				
lx	lux	0.0929	foot-candles	fc
cd/m <sup>2</sup>	candela/m <sup>2</sup>	0.2919	foot-Lamberts	fl
<b>FORCE and PRESSURE or STRESS</b>				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in <sup>2</sup>

\*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

# Alaska Survey Manual

## GPS Surveys

2010



**Alaska Department of Transportation and Public Facilities**

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And the Colorado DOT and its Survey Manual, which was the main basis for this document.

—R. S. Sexton, P.L.S.

## **DOT Survey Manual Acronyms**

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**ADOT:** Alaska Department of Transportation and Public Facilities  
**CBN:** Cooperative Base Networks  
**CORS:** Continually Operating Reference Stations (National Geodetic Survey)  
**DOP:** dilution of precision  
**FBN:** Federal Base Networks  
**FGCC:** Federal Geodetic Control Committee  
**FGDC:** Federal Geographic Data Committee  
**FHWA:** Federal Highway Administration  
**GGASS:** Geometric Geodetic Accuracy Standards and Specifications  
**GLONASS:** Global Navigation Satellite System, Russian-based “GPS.”  
**GPS:** global positioning system  
**GNSS:** Global Navigation Satellite Systems  
**HARN:** High Accuracy Reference Network  
**ITRF00:** International Terrestrial Reference Frame of 2000  
**NAD:** North American Datum  
**NAVD 88:** North American Vertical Datum of 1988  
**NGVD 29:** National Geodetic Vertical Datum of 1929  
**NSRS:** National Spatial Reference System  
**NGS:** National Geodetic Survey  
**NOAA:** National Oceanic and Atmospheric Administration  
**NOS:** National Ocean Service  
**NSRS:** National Spatial Reference System  
**OPUS:** On-line Positioning User Service (National Geodetic Survey)  
**PDOP:** positional dilution of precision  
**PLS:** professional land surveyor  
**PLSS:** public land survey system  
**PPK:** Post-Processed Kinematic  
**RINEX:** GPS generic data exchange format.  
**RTK:** Real-Time Kinematic  
**UDN:** User Densification Networks  
**USCGS:** U.S. Coast and Geodetic Survey  
**USGS:** U.S. Geological Survey



## Preface

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This manual delineates the survey specifications and procedures for State of Alaska Department of Transportation and Public Facilities survey services.

### General Requirements

All survey services shall be conducted by, or under, the direct supervision of a professional land surveyor (PLS) holding current registration in the State of Alaska. This land surveyor shall be an active, on-site field supervisor of the survey crew and be directly involved in the preparation of the base maps, right-of-way maps, and parcel plats. The field books, horizontal and vertical control summaries, survey control diagram, adjusted coordinates, TIN certification, survey control sheet(s), final centerline control, and all final maps and plats shall be sealed, signed, and certified by the PLS responsible for the accuracy and completeness of the services.

The contractor shall furnish hardbound field books for recording survey information. The books shall become the property of the contracting agency after the survey information has been entered and the contract completed. Each book shall be labeled with the project name and an appropriate title, e.g., “Horizontal Control,” “Vertical Control,” etc., and shall have an index and comments page. The index page shall reference the contents by page number. A readable PDF copy of the field books is acceptable.

Field notes shall be kept in a neat and orderly fashion. All pages shall be consecutively numbered, showing date, weather, and crew names. All abbreviations used shall be described on the comments page. Sketches are to be used frequently and shall be detailed enough to assist in following the progression of the services. Notes and sketches shall be adequately detailed to convey their intent to a person who is not familiar with the project.

Descriptions of all monuments or other points, recovered or set, are to include the data stamped on the monument and the condition of the monument. Handheld GPS coordinates should be included with each description. Two digital photos are required of each point found or set. The first is a close up of the cap, and the second is a general location picture, with some sort of reference like a tripod over the point. A list of all corners searched for, but not recovered shall be included in the field notes. The *DOT&PF Construction Surveying Requirements* details the general note-keeping procedures.

### Content Overview

**Chapter 1** addresses GPS survey methods, procedures, and specifications.

**Chapter 2** addresses preliminary surveys, horizontal and vertical control, types of surveys, and drafting.

**Addenda** address construction requirements, reports, and guidelines.



# Table of Contents

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<b>Acknowledgements</b> . . . . .	<b>3</b>
<b>DOT Survey Manual Acronyms</b> . . . . .	<b>4</b>
<b>Preface</b> . . . . .	<b>5</b>
General Requirements . . . . .	5
Content Overview . . . . .	5
<b>Chapter 1: Global Positioning System Surveys</b> . . . . .	<b>11</b>
1.1 GPS Survey Specifications . . . . .	11
1.1.1 <i>General</i> . . . . .	11
1.1.2 <i>GPS Methods</i> . . . . .	11
1.1.3 <i>Specifications</i> . . . . .	11
1.1.4 <i>Specification Types</i> . . . . .	11
1.1.5 <i>Alaska High Accuracy Reference Network (HARN)</i> . . . . .	11
1.1.6 <i>GPS Equipment</i> . . . . .	12
1.1.7 <i>GPS Control Monument Database</i> . . . . .	12
1.2 Error Sources in GPS . . . . .	12
1.2.1 <i>General</i> . . . . .	12
1.2.2 <i>Multipath</i> . . . . .	12
1.2.3 <i>Ionosphere</i> . . . . .	13
1.2.4 <i>Dilution of Precision</i> . . . . .	13
1.2.5 <i>Equipment Error</i> . . . . .	13
1.2.6 <i>Precise Ephemeris</i> . . . . .	13
1.2.7 <i>Human Error</i> . . . . .	13
1.3 GPS Equipment Checking and Calibration . . . . .	13
1.3.1 <i>General</i> . . . . .	13
1.3.2 <i>Checking and Calibration</i> . . . . .	14
1.3.3 <i>Equipment Maintenance</i> . . . . .	14
1.3.4 <i>Federal Published Calibrated Baseline Check</i> . . . . .	14
1.3.5 <i>Existing ADOT Primary Control Check</i> . . . . .	15
1.3.6 <i>Zero Baseline Check</i> . . . . .	16
1.4 GPS Survey Methods . . . . .	16
1.4.1 <i>23 CFR 630.402—Geodetic</i> . . . . .	16
1.4.2 <i>HARN Densification Surveys (HARND)</i> . . . . .	16
1.4.3 <i>Static GPS Surveys</i> . . . . .	19
1.4.4 <i>Fast Static GPS Surveys</i> . . . . .	19
1.4.5 <i>RTK GPS Surveys</i> . . . . .	20
1.4.6 <i>RTK Site Calibrations</i> . . . . .	21
1.4.7 <i>PPK GPS Surveys</i> . . . . .	22
1.4.8 <i>GPS for GIS Mapping Grade Surveys</i> . . . . .	23
1.4.9 <i>Survey Class Definitions</i> . . . . .	23
1.5 Static and Fast Static Network Design . . . . .	23
1.5.1 <i>Required Existing Control Monumentation</i> . . . . .	23
1.5.2 <i>Network Geometry</i> . . . . .	23
1.5.3 <i>Redundancy of Networks</i> . . . . .	24
1.5.4 <i>Independent (Nontrivial) Baselines</i> . . . . .	24

1.5.5 Network Loops . . . . .	24
1.5.6 Twenty Percent Rule . . . . .	24
1.5.7 Network Adjustment . . . . .	24
1.6 GPS Planning . . . . .	24
1.6.1 Control Monumentation Site Selection . . . . .	24
1.6.2 Ephemeris . . . . .	26
1.6.3 Satellite Geometry . . . . .	26
1.6.4 Elevation Mask . . . . .	26
1.6.5 Weather Conditions . . . . .	26
1.6.6 GPS Calendar . . . . .	27
1.7 GPS Vertical Procedures . . . . .	27
1.7.1 Antenna Height Measurement . . . . .	27
1.7.2 GPS-Derived Orthometric Heights (Elevations) . . . . .	28
1.7.3 ADOT Class A Primary Vertical Surveys . . . . .	30
1.7.4 ADOT Class B Secondary Vertical Surveys . . . . .	30
1.7.5 ADOT Class C Topo Modeling Survey System Vertical Surveys . . . . .	31
1.8 GPS Horizontal Procedures . . . . .	31
1.8.1 Minimum Horizontal Accuracy Tolerance Table . . . . .	31
1.8.2 ADOT Class A Primary Horizontal Surveys . . . . .	31
1.8.3 ADOT Class B Secondary Horizontal Surveys . . . . .	31
1.8.4 ADOT Class C TMOSS . . . . .	31
1.8.5 Process for State Plane Coordinate Reduction . . . . .	31
1.8.6 Low Distortion Projection . . . . .	32
1.9 Survey Control Diagrams and Project Reports . . . . .	33
1.9.1 Primary Control Diagram . . . . .	33
1.9.2 Secondary (Project) Control Diagram . . . . .	33
1.9.3 Project Reports . . . . .	33
1.10 Continually Operating Reference Stations (CORS) . . . . .	35
1.10.1 General . . . . .	35
1.10.2 CORS Stations Used for Static, Fast Static, RTK, or PPK Surveys . . . . .	35
1.11 On-line Positioning User Service (OPUS) . . . . .	35
1.11.1 General . . . . .	35
1.11.2 OPUS use for Static, Fast Static, RTK, or PPK Surveys . . . . .	36
<b>Chapter Two: Preliminary Surveys . . . . .</b>	<b>37</b>
2.1 Presurvey Conference, Preliminary Survey . . . . .	37
2.2 Minimum Horizontal Accuracy Tolerance . . . . .	37
2.2.1 Minimum Horizontal Accuracy Tolerances at 95% Confidence . . . . .	37
2.2.2 Minimum Horizontal Accuracy Tolerance Table . . . . .	38
2.3 Control Survey . . . . .	39
2.3.1 General . . . . .	39
2.3.2 Performed by Professional Land Surveyor . . . . .	39
2.3.3 Types of Control Surveys . . . . .	39
2.3.4 Types of Control Survey Monuments . . . . .	39
2.3.5 Primary Control Monumentation . . . . .	39
2.3.6 Setting of Primary Control Monumentation . . . . .	40
2.3.7 Secondary Control Monumentation . . . . .	40
2.3.8 Setting Secondary Control Monumentation . . . . .	41

2.3.9	Setting Secondary Control Monuments for Construction Staking	41
2.3.10	Monument Material	41
2.4	Horizontal Control Survey	41
2.4.1	Types of Horizontal Control Surveys	41
2.4.2	Primary Horizontal Control Survey	41
2.4.3	GPS Primary Horizontal Control Survey Methods	42
2.4.4	Conventional Primary Horizontal Control Survey Methods	42
2.4.5	Secondary Horizontal Control Surveys	42
2.4.6	GPS Secondary Horizontal Control Survey Methods	42
2.4.7	Conventional Secondary Horizontal Control Survey Methods	42
2.5	Vertical Control Survey	43
2.5.1	General	43
2.5.2	North American Vertical Datum of 1988 (NAVD 88)	43
2.5.3	Benchmarks	44
2.5.4	Setting Primary Control Benchmarks	44
2.5.5	Setting of Secondary Control Benchmarks	44
2.5.6	Vertical Accuracy Tolerance	44
2.6	Differential Leveling	45
2.6.1	General	45
2.6.2	Leveling Definitions	45
2.6.3	Curvature and Refraction	45
2.6.4	Equipment Types	46
2.6.5	Methods	46
2.6.6	Single Wire	46
2.6.7	Direct Reading Rod (Lenker Rod)	46
2.6.8	Double Rod	46
2.6.9	Profile Leveling	46
2.6.10	Reducing Errors	46
2.6.11	Field Notes	48
2.6.12	Two-Peg Test Method for Levels	48
2.7	Project Control Drafting Standards	48
2.7.1	General	48
2.7.2	Minimum Standards	48
2.7.3	Minimum Notes and Surveyor's Certification	49
2.8	Right-of-Way Survey	50
2.8.1	General	50
2.8.2	Performed by Professional Land Surveyor	50
2.8.3	Preliminary or Base Mapping Phase	50
2.8.4	Accuracy Tolerance	50
2.8.5	GPS Survey Methods	50
2.8.6	Conventional Survey Methods	51
2.8.7	Right-of-Way Monuments Defined	51
2.8.8	Final or Post-Construction Record of Survey Phase (Right-of-Way Monuments)	51
2.8.9	PLSS Aliquot Monuments	52
2.9	Land Survey Control Drafting Standards	52
2.9.1	General	52
2.9.2	Minimum Standards	52
2.9.3	Minimum Notes and Surveyor's Certification	53

2.10 Boundary Analysis . . . . .	53
2.10.1 General . . . . .	53
2.11 TMOSS/PICS . . . . .	53
2.11.1 TMOSS Special Requirements . . . . .	53
2.12 Topographic Survey (TMOSS) . . . . .	54
2.12.1 General . . . . .	54
2.12.2 Types of Topographic Surveys . . . . .	54
2.12.3 Horizontal Accuracy Tolerance . . . . .	55
2.12.4 Vertical Accuracy Tolerance . . . . .	55
2.12.5 Method of Verifying Accuracy Tolerance . . . . .	55
2.12.6 Conventional Survey Methods . . . . .	56
2.12.7 GPS Survey Methods . . . . .	56
2.12.8 Aerial Photogrammetry Methods . . . . .	56
2.12.9 Remote Sensing Methods . . . . .	56
2.13 Drainage Survey . . . . .	56
2.13.1 General . . . . .	56
2.13.2 Horizontal Accuracy Tolerance . . . . .	57
2.13.3 Vertical Accuracy Tolerance . . . . .	57
2.13.4 Method of Verifying Accuracy Tolerance . . . . .	57
2.13.5 Conventional Survey Methods . . . . .	57
2.13.6 GPS Survey Methods . . . . .	57
2.13.7 Aerial Photogrammetry Methods . . . . .	57
2.13.8 Photographs . . . . .	58
2.13.9 Guidelines . . . . .	58
<b>References . . . . .</b>	<b>59</b>

# Chapter 1: Global Positioning System Surveys

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## 1.1 GPS Survey Specifications

### 1.1.1 General

The purpose of this chapter is to define the specifications that shall be followed while performing GPS surveys for the Alaska Department of Transportation. As GPS technology improves and better accuracy is more easily attained, ADOT will develop new specifications and sections of this chapter will be revised to stay current with those advances.

GPS is used in a generic sense and is meant to encompass all global navigation satellite system (GNSS) usage. See chapter 2 for additional policies, procedures and specifications. Any variation from the specifications must have the prior approval of the region location survey manager or their designated representative.

### 1.1.2 GPS Methods

ADOT accepts a wide variety of GPS survey methods. These methods vary in the type of equipment used, length of observation times, and the accuracy that is attained. GPS survey methods most commonly used within ADOT include but are not limited to:

1. Static
2. Fast static
3. Real Time Kinematic (RTK)
4. Post Processed Kinematic (PPK)

### 1.1.3 Specifications

The specifications included in this chapter are based on the Geometric Geodetic Accuracy Standards and Specifications (GGASS) as published by the Federal Geodetic Control Committee (FGCC) and the Geospatial Positioning Accuracy Standards as published by the Federal Geographic Data Committee (FGDC).

These standards and specifications have been modified to best suit the needs of ADOT.

### 1.1.4 Specification Types

There are two types of specifications that shall be followed while performing GPS surveys for ADOT:

1. FGDC/FGCC Standards and Specifications: for surveys that are submitted for inspection and acceptance into the National Spatial Reference System (NSRS) database by federal approval (see 23 CFR 630.402—Geodetic, for additional information).
2. ADOT Specifications: for surveys that are not to be submitted for inspection and acceptance into the national database by federal approval.

### 1.1.5 Alaska High Accuracy Reference Network (HARN)

All GPS surveys for ADOT shall be referenced and tied into the Alaska High Accuracy Reference Network (HARN) as defined by the National Geodetic Survey (NGS) National Spatial Reference System (NSRS). Order of surveys are defined by the NGS Geometric Relative Positioning Accuracy Standards as published in the Geometric Geodetic Accuracy Standards and Specifications for using GPS Relative Positioning Techniques by the Federal Geodetic Control Committee, printed May 11, 1989, reprinted with corrections August 1, 1989. If no HARN sites are within 10 miles of the project limits, then a minimum of two primary monuments will be tied to the NGS Continually Operating Reference Stations (CORS) sites. The preferred method is to use NGS On-line Positioning User Service (OPUS) techniques (see section 1.11). Exception: It is possible that only one CORS site will be held to establish the CORS value at a given location. In rare instances, the remoteness of possible work locations throughout the state make holding only the nearest CORS site a viable option, in which case the contractor will have to do their own processing.

The U.S. Department of Commerce National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), National Geodetic Survey (NGS) provides geodetic control throughout the United States. Although known by other agency names in the past, the National Geodetic Survey (NGS) is the primary source for geodetic data in Alaska.

NGS defines and manages the National Spatial Reference System (NSRS)—the framework for latitude, longitude, height, scale, gravity, and orientation throughout the United States. NSRS provides the



foundation for transportation, communication, and defense systems; boundary and property surveys; land records systems; mapping and charting; and a multitude of scientific and engineering applications. NGS also conducts research to improve the collection, distribution, and use of spatial data.

The NSRS is a system of permanently monumented survey marks and their corresponding geodetic data referenced to the North American Datum of 1983 (NAD 83). The NSRS is made up of Federal Base Networks (FBN), Cooperative Base Networks (CBN), and User Densification Networks (UDN), all of which are known as Alaska's High Accuracy Reference Network (HARN), and Alaska's HARN Densification surveys as defined by ADOT in cooperation with NGS.

### **NGS/NOAA Datasheets**

<http://www.ngs.noaa.gov/datasheet.html> allows searching and downloading of datasheets for HARN stations.

Any type of survey performed for ADOT that will be submitted for acceptance into the NSRS national database by inspection and approval of the federal government shall be performed under the correct and current federal government agency standards and specifications.

#### **1.1.6 GPS Equipment**

Survey grade dual frequency GPS receivers shall be used. For static surveys these shall be set up on adjustable leg tripods at a minimum. Fast or rapid static GPS surveys require a bipod at a minimum. RTK or PPK surveys may use fixed or adjustable poles, secure lashings to vehicles etc.

#### **1.1.7 GPS Control Monument Database**

The GPS Control Monument Database is a statewide database designed to integrate ADOT GPS Primary Control Monument data.

The GPS control monument data must have been determined by a GPS primary control survey performed by ADOT or by consultant surveyors in accordance with this manual. The control data will be documented on a Record of Survey plat and recorded in the appropriate recording district. Each region shall be responsible for ensuring that this recorded document is

included in the State of Alaska Department of Natural Resources online geographic information system database. The November 2002 earthquake will require that all HARN and HARN densification monuments be reobserved. This will dictate that a new database of control monuments will be required. This will be a work in progress.

## **1.2 Error Sources in GPS**

### **1.2.1 General**

Although measurement errors in GPS can never be completely eliminated, through proper planning, procedures, redundant checks, and repeat measurements, errors can be identified and kept to a minimum.

### **1.2.2 Multipath**

Multipath results from the interference of a GPS signal that has reached the receiver's antenna by two or more different paths, usually caused by one path being bounced or reflected off of a surface. The effects of multipath occur at all GPS receivers used to perform the survey (e.g., base and rovers). While performing any GPS survey, multipath must be kept to a minimum at all receivers.

Sources of multipath include but are not limited to the following:

1. mountains
2. towers
3. buildings
4. bodies of water
5. chain link fences
6. vehicles
7. signs
8. snow
9. ground surface
10. overhead utility lines
11. airport antenna array systems

The effects of multipath can be reduced by the following methods:

1. Be aware of your surroundings; do not set GPS points in areas with multipath.
2. Collect data for longer periods of time.
3. Collect data with multiple sessions with substantially different GPS constellations (i.e.,



substantially different times of the day, since the satellite constellation geometry repeats itself every 12 hours).

4. Move the base to a different primary control monument for RTK or PPK sessions.
5. Use an antenna ground plane.
6. Raise the elevation mask to get above the surface that is causing the multipath (most GPS processing software allows for the elevation mask to be raised while processing, but not lowered).

### **1.2.3 Ionosphere**

The ionosphere is a layer of the atmosphere filled with charged particles. Satellite signals passing through this layer of atmosphere are subject to ionospheric refraction, resulting in a change in the speed of the GPS signal as it passes through the ionosphere. The effects of the ionosphere for baseline lengths under 10 kilometers are almost equal to each other at both receivers; therefore, ionospheric modeling is not necessary for processing of these baselines. For baseline lengths over 10 kilometers, the ionosphere is not equal to each other at both receivers, so ionospheric modeling is necessary. Ionospheric modeling is accomplished by multichannel tracking, dual-frequency receivers.

ADOT requires multichannel tracking, dual-frequency receivers for all GPS surveys.

### **1.2.4 Dilution of Precision**

Satellite geometry quality is a numerical expression known as the dilution of precision (DOP) and is caused solely by the geometry of the satellites in relation to the observer of those satellites. There are several types of DOP, including geographic dilution of precision (GDOP), positional dilution of precision (PDOP), vertical dilution of precision (VDOP), and time dilution of precision (TDOP). Proper satellite geometry is critical for accurate GPS measurements, so plan GPS surveys to be performed during times of optimum satellite geometry.

### **1.2.5 Equipment Error**

Poorly maintained GPS equipment can introduce errors. Although not all error in GPS equipment can be completely eliminated, the error caused by GPS equipment shall be kept to a minimum by doing

scheduled maintenance, checking, and calibration of GPS equipment on a continual basis.

### **1.2.6 Precise Ephemeris**

The satellite's orbit (navigation files) sent by the satellite's clock may be off by a few milliseconds, and its position could be off by as much as 20 meters. A precise orbit is calculated after the fact by several analysis centers around the world and is good to 7 centimeters. The precise ephemeris is typically available seven days after the observations are completed.

For the final processing of ADOT Class A—Primary surveys, a precise ephemeris should be used. The following links provide information on obtaining a precise ephemeris:

#### **U.S. Coast Guard Navigation Center**

<http://www.navcen.uscg.gov/gps/precise/default.htm>

#### **National Geodetic Survey Precise GPS Orbits**

<http://www.ngs.noaa.gov/CORS/metadata2/>

### **1.2.7 Human Error**

The greatest contributor to error in GPS measurement is human error. Care must be taken while performing any GPS survey to keep human error to a minimum by proper procedures, redundant checks, repeat measurements, and GPS observation log reports.

The following are some examples of human error:

1. Misreading antenna height measurements
2. Transposing numbers entered electronically and/or on the GPS observation log
3. Rushing observations
4. Poor centering and leveling over points
5. Observing the wrong survey point (for example, observing a reference mark instead of the actual mark itself)
6. Incorrect equipment configuration settings

## **1.3 GPS Equipment Checking and Calibration**

### **1.3.1 General**

It is essential to check and calibrate all types of survey equipment to obtain and maintain the tolerances required in this chapter. At the beginning of any survey, all survey equipment needed to perform the

survey shall be checked and calibrated by the professional land surveyor in charge of the survey under their direct supervision. All survey equipment shall be checked and calibrated once every six months thereafter and as needed during the course of the survey, whichever comes first.

Errors due to poorly maintained or malfunctioning equipment will not be accepted. If any equipment errors are found to exist they must be reported to the contracting agency before the start of the survey. These errors will need to be verified and eliminated before performing any survey. For surveys lasting longer than six months, the checking and calibration of equipment shall be repeated to show that the equipment is staying within acceptable tolerances as required in this manual.

### **1.3.2 Checking and Calibration**

Following types of checking and calibration of equipment are accepted by ADOT:

1. equipment maintenance
2. federal published calibration baseline check
3. existing ADOT project control check
4. Zero baseline check

An authorized equipment vendor or manufacturers service department shall perform calibration of GPS survey equipment.

### **1.3.3 Equipment Maintenance**

At the beginning of any survey and once every six months thereafter, all necessary survey equipment needed to perform the survey shall be checked and adjusted by the professional land surveyor in charge of the survey under their direct supervision. All equipment shall be checked once every six months and as needed during the course of the survey, whichever comes first.

Checks and adjustments shall include but are not limited to those outlined in Calibration and Checking above and the following:

1. Tripods: nuts and bolts are tight, no loose or broken legs, tripod head is tight, flat, and not damaged.
2. Fixed height tripods: level bubbles are in adjustment, rod is not bent or damaged, height

of rod is correct as reportedly measured, legs are secure.

3. Rods: level bubbles are in adjustment, rod is not bent or damaged, height of rod is correct as reportedly measured, and adjustable rod height clamps are secure.
4. Tribrachs: optical plummets are in adjustment, level bubble is in adjustment, no loose legs, no loose or missing screws, bottom head is flat and not damaged.
5. Collimators: level bubble is in adjustment, top and bottom heads are both flat with no damage.
6. Cables: no cuts, breaks, pinch marks, or damage.
7. Receivers: no cracks or visible signs of damage.
8. Receiver antennas: if equipped with a ground plane, it is not bent or warped, no cracks or visible signs of damage.
9. Ground planes should produce a plane that when leveled varies no more than  $\pm 0.003$  meters when measured at three notches approximately 120 degrees apart. Ground planes that are warped more than  $\pm 0.003$  meters shall not be used for any ADOT GPS surveys.

### **1.3.4 Federal Published Calibrated Baseline Check**

The NGS conducts a cooperative program that provides surveyors with a means for calibrating and checking of errors in electronic distance measuring instruments. Publications are available through NGS on the procedures for checking of electronic distance measuring instruments against a federal calibrated baseline. The same procedures used for checking of electronic distance measuring instruments are adopted and used for checking GPS equipment for static, fast static, RTK, and PPK methods. The observed unadjusted baseline lengths shall meet or exceed the manufacturer's ratings for the equipment used when checked against a calibrated baseline both horizontally and vertically.

<http://www.ngs.noaa.gov/CBLINES/calibration.html> provides information and downloads of federal published calibrated baselines from NGS/NOAA.

The basic procedure for a calibrated baseline check of GPS equipment in either static or fast static mode is as follows:

1. A minimum of two receivers are set up on any two calibrated baseline marks.
2. Either a static or fast static survey is performed with simultaneous observations collected at each mark with the same equipment configurations (i.e., elevation mask, epochs, sync time, maximum DOP, satellite tracking, session duration, etc.) and methods that will be used for performing the survey.
3. After the first session is completed, the receivers are moved and set up on each calibrated baseline mark so that each published baseline length is observed at least twice.
4. This procedure is repeated as many times as needed until all equipment that will be used for the survey has collected simultaneous data observations at each calibrated baseline mark.
5. The data is downloaded and processed using GPS processing software with the same procedures and settings that will be used for the survey.
6. The unadjusted baseline lengths and vertical differences are calculated and compared to the published calibrated baseline lengths and vertical differences.
7. For the equipment to be considered in adjustment, the final unadjusted baseline lengths and vertical differences shall meet or exceed the manufacturer's ratings for the equipment.

The basic procedure for a calibrated baseline check of GPS equipment in RTK mode is as follows:

1. A base receiver is set up on any one of the calibrated baseline marks.
2. A rover receiver collects data at each calibrated baseline mark with the same equipment configuration (i.e., elevation mask, epochs, sync time, maximum DOP, satellite tracking, session duration, etc.) and methods that will be used for performing the survey.
3. After the rover has collected data at each calibrated baseline mark, the base receiver is moved and set up on each calibrated baseline mark and the rover again collects data at each calibrated mark.
4. This procedure is repeated as many times as needed until both a base and a rover receiver have occupied all calibrated baseline marks and

data has been collected at all calibrated baseline marks.

5. The data is downloaded into the GPS processing software with the same procedures and settings that will be used for the survey.
6. The unadjusted baseline lengths and vertical differences are calculated and compared to the published calibrated baseline lengths and vertical differences.
7. For the equipment to be considered in adjustment, the final unadjusted baseline lengths and vertical differences shall meet or exceed the manufacturer's ratings for the equipment.

### **1.3.5 Existing ADOT Primary Control Check**

While collecting data in either RTK or PPK mode, existing ADOT primary control monuments shall be checked to ensure that the data being collected meets or exceeds the minimum horizontal and vertical accuracy tolerances as required for the survey. This is intended as a quality control check during the survey and is not to be used instead of a calibrated baseline check. A primary control check report shall be submitted for all existing primary control checks (see 1.9, GPS Reports, for additional information). Primary control checks should be performed

1. immediately after each initialization,
2. during roving while initialized, and
3. before ending the initialization session.

Primary control monument checks shall be performed as follows:

1. The RTK rover shall be placed on a primary control monument mark and leveled.
2. RTK data shall be collected with the same equipment configuration (i.e., elevation mask, epochs, sync time, maximum DOP, satellite tracking, session duration, etc.) and methods that will be used for performing the survey.
3. The horizontal and vertical difference between the record primary control data and the collected RTK data shall be verified by either inverting the two locations or by use of a RTK stakeout mode that calculates and reports the difference within the data collector.
4. The horizontal and vertical difference shall be stored for inclusion in the primary control check report.

5. The horizontal and vertical differences should meet or exceed the minimum horizontal and vertical accuracy tolerances required for the survey or the RTK setup will be checked for errors and the process repeated.

### 1.3.6 Zero Baseline Check

The zero baseline check is an optional equipment check. This check is performed to check the antenna phase center of GPS antennas and for noise carried through the GPS antennas and cables. All receivers, antennas, and cables that will be used while performing the survey should be checked. Publications on the procedures for this type of check are available from various manufacturers such as Trimble and Leica.

The basic procedure for performing a zero baseline check is:

1. Multiple receivers are connected to a single receiver antenna using a splitter cable.
2. Either a static or fast static session is performed.
3. When the first session is completed, each receiver, receiver antenna, and cable that will be used during the survey is rotated through the next session until all equipment has been used in conjunction with each other.
4. The data is downloaded and processed with the use of GPS processing software and the unadjusted baselines are calculated.
5. For the equipment to be considered in adjustment, the final unadjusted baseline lengths should not exceed 0.002 meters.

## 1.4 GPS Survey Methods

### 1.4.1 23 CFR 630.402—Geodetic

- a. Geodetic surveys along federal-aid highway routes may be programmed as federal-aid highway projects.
- b. All geodetic survey work performed as a federal-aid highway project will conform to National Ocean Survey (NOS) specifications. NOS will, as the representative of Federal Highway Administration (FHWA), be responsible for the inspection and verification of the work to ascertain that the specifications for the work have been met. Final project acceptance by FHWA will be predicated on a finding of acceptability by NOS.

### 1.4.2 HARN Densification Surveys (HARN D)

The HARN D standards and guidelines are available at the following web sites:

NGS/NOAA:

<http://www.ngs.noaa.gov/> provides information on NGS/NOAA.

NGS Index of FGDC Accuracy Standards:

<http://www.fgdc.gov/standards/documents/standards/accuracy/> provides downloads of the following FGDC accuracy standards:

- Part 1: Reporting Methodology
- Part 2: Standards for Geodetic Networks
- Part 3: National Standard for Spatial Data Accuracy
- Part 4: Standards for Architecture, Engineering, Construction (A/E/C) Management
- Policy of the National Ocean service regarding the incorporation of geodetic data of other organizations into the National Geodetic Survey database: [http://www.ngs.noaa.gov/INFO/incorp\\_data.html](http://www.ngs.noaa.gov/INFO/incorp_data.html) provides information on the format, accuracy, monumentation etc. that is acceptable to NGS for inclusion into the national database.

### NGS Draft GPS Survey Manual:

<http://www.ngs.noaa.gov/PROJECTS/GPSmanual/index.htm> provides a NGS draft manual for the following three areas of “bluebooking” surveys:

1. Equipment
  - a. equipment specifications, calibration, and care
  - b. troubleshooting guide
  - c. equipment check list
2. Observations
  - a. Planning
  - b. Procedures
  - c. Observer check list
3. Data
  - a. Forms
  - b. Download, reformatting, and shipping instructions
  - c. Processing



### **Input Formats and Specifications of the National Geodetic Survey Database, the NGS Bluebook:**

<http://www.ngs.noaa.gov/FGCS/BlueBook> provides information on NGS “bluebooking” procedures and standards:

1. Volume I—Horizontal Control
2. Volume II—Vertical Control
3. Volume III—Gravity Control
4. Annexes

### **NGS Mark Recovery Entry:**

[http://www.ngs.noaa.gov/FORMS\\_PROCESSING/cgi-bin/recvy\\_entry\\_www.prl](http://www.ngs.noaa.gov/FORMS_PROCESSING/cgi-bin/recvy_entry_www.prl)

The above link provides for entry of NGS mark recoveries.

### **D-File Processing Handbook:**

[http://www.ngs.noaa.gov/PC\\_PROD/DDPROC4.XX/dformat.htm](http://www.ngs.noaa.gov/PC_PROD/DDPROC4.XX/dformat.htm)

The above link provides information on the D-File format for submitting mark descriptions by WDDPROC.

### **WDDPROC:**

[http://www.ngs.noaa.gov/PC\\_PROD/DDPROC4.XX/ddproc.menu.html](http://www.ngs.noaa.gov/PC_PROD/DDPROC4.XX/ddproc.menu.html)

The above link provides information for the NGS WDDPROC description program.

### **NGS PC Software:**

[http://www.ngs.noaa.gov/PC\\_PROD/pc\\_prod.shtml](http://www.ngs.noaa.gov/PC_PROD/pc_prod.shtml)

The above link provides information on NGS software such as the Adjust Package, Adjust Utilities, CALIBRAT, CORPSCON, etc.

### **NGS PAGE-NT:**

Download from the NGS anonymous ftp server:

ftp: <ftp://ftp.ngs.noaa.gov>

login: anonymous

password: your complete email address

PAGE-NT is a menu-driven suite of programs used to process GPS data and is suitable for projects requiring the highest accuracy. A User’s Manual, the software, and sample data set can be downloaded. Once logged on, go to the /pub/ngs22/data1 directory and download

all the files using binary transfer mode. The input 1 and results 1 directory contain the sample data sets. Follow the setup instructions in the PAGE-NT User’s Manual.

### **Trimble GPS Data Resources:**

<http://www.trimble.com/gpsdataresources.html>

The above link provides information on obtaining a current ephemeris almanac.

### **US Coast Guard Navigation Center:**

<http://www.navcen.uscg.gov/gps/precise/default.htm>

The above link provides information on obtaining a precise ephemeris.

### **National Geodetic Survey Precise GPS Orbits:**

<http://www.ngs.noaa.gov/CORS/metadata2/>

The above link provides information on obtaining a precise ephemeris, typically available seven days after observations.

Or contact NGS directly at:

National Geodetic Survey

1315 East-West Highway

Silver Springs, Maryland 20910-3282

Phone 301-713-3194

Before starting any ADOT HARND survey, the region right-of-way engineering supervisor or their designated representative and the National Geodetic Survey/National Oceanic Atmosphere Administration (NGS/NOAA) shall be contacted and a general plan for the survey shall be submitted for approval. The general plan shall be in conformance with the FGDC/FGCC standards as outlined by the region right-of-way engineering supervisor or their designated representative and NGS/NOAA.

Once the general plan has been submitted and approved, reconnaissance work may begin. All existing HARN or HARND marks and federal NAVD 1988 benchmarks, including but not limited to NGS and U.S. Geological Survey (USGS) benchmarks, shall be recovered within and surrounding the project area as outlined in the general plan. All existing marks used to reference or “tie in” the survey shall be of the same or higher accuracy as required for the survey. The surveyor must have Permission to Enter Property Forms completed for any existing marks located on private land or that require crossing private land for access to

the mark. For each mark searched for and either found or determined to be lost, a Mark Recovery Form shall be completed and entered into NGS/NOAA mark recovery database. For each found mark, draw a station visibility diagram and photograph the mark.

After all existing marks have been recovered, you may begin site selection for establishing new marks. The network shall be made of existing and/or new network marks monumented on the ground in a six-mile grid for borough-wide areas, or at six-mile intervals along the highway corridors and city roads. When feasible, new marks should be located on public land with access to the mark by public access. If you select a new mark site located on private land or that requires one to cross private land for access to the mark, you must complete a Permission to Enter Property Form and acquire an easement for access, installation, and maintenance of the mark in ADOT's name for the benefit of the public for the purpose of performing a land survey. While selecting a site, it is critical to keep in mind that the overall objective of the HARND network is to provide a highly accurate network with stable monuments that will stand for a substantial duration of time and be of value not only to the highway project itself but for all surveying activity within the area, either government or private.

When setting new network marks, give priority to the location that has an unobstructed sky and the best chance of a stable monument (see 1.6.1, Control Monumentation Site Selection, for additional information). See Table 1.1.

The region right-of-way engineering supervisor or their designated representative and NGS/NOAA shall concur with the location, stability rating, and monumentation of new network marks before they are established in the field. Mark all underground utility locations on the ground surrounding the new mark before installing the mark. If underground utilities conflict with the establishment of the new mark, make a new site selection. After the mark has been established, complete a station visibility diagram and WDDPROC description in D-file format for acceptance by NGS/NOAA into the NGS database.

Once all existing and new network marks have been recovered and/or established, the GPS field survey may begin following the outline as approved by the region right-of-way engineering supervisor or their

designated representative and NGS/NOAA. The basic procedures for the survey are as follows:

1. Design a GPS network in accordance with ADOT specifications, FGDC/FGCC standards, and approved by the region right-of-way engineering supervisor or their designated representative and NGS/NOAA.
2. Design a GPS schedule for coordinating receivers, operators, observation times, satellite availability, the logistics of the project. The design must be approved by the region right-of-way engineering supervisor or their designated representative and NGS/NOAA. A current almanac shall be used for planning the survey.
3. The GPS project surveyor responsible will hold a presurvey densification meeting with all receiver operators to review the project, methods, and procedures. Each operator shall be provided with all the necessary mark recovery information, schedule, and forms for their marks. The GPS survey coordinator will ensure that operators are trained in operating their receiver, collecting data, setting up, taking down, and moving to and from each mark.
4. Check all GPS receivers and equipment for errors and/or defects in accordance with ADOT procedures as approved by NGS/NOAA (see 1.3.2, Equipment Calibration and Checking for additional information).
5. Receivers must be capable of recording data for post processing. Multichannel tracking dual frequency receivers are required. Receivers and post-processing software must be specified by the manufacturer to be suitable for high accuracy static surveys.
6. Simultaneous observations shall be collected for a duration of at least 2 ½ hours for each GPS session with the same receiver configuration such as elevation mask (typically set at 15 degrees), epochs, sync time (typically set at 15 seconds), maximum DOP (typically set at 6) and satellite tracking for each receiver.
7. Each receiver antenna should have a ground plane in place.
8. Each antenna tripod shall be either an adjustable leg or a fixed-height tripod with sand bags or weights attached to the tripod legs and hubs

driven solidly into the ground for support and to minimize movement of the tripod.

9. Whenever feasible all antennas should be of the same make and model.

Once the field survey has been completed, download the data and process it with GPS post-processing software using a precise ephemeris (see 1.2.6, Precise Ephemeris, for additional information) in accordance with the accuracy standards as outlined and modified by ADOT and NGS/NOAA for HARND. See Table 1.2.

The GPS network shall be “bluebooked” using NGS Adjust and other software programs to include all GPS reports as required for inspection by NGS/NOAA. (See Appendix NGS Bluebook Submission Checklist for additional information).

The NGS Adjust program performs a least squares adjustment on horizontal, vertical angle, and/or GPS observations. The program comprises six data checking programs in addition to the adjustment software. This software package has numerous options, such as choice of ellipsoid, and includes sample input data.

Once a HARND mark has been “bluebooked” and accepted by NGS/NOAA into the national database, the mark is classified on the NGS datasheet as having a horizontal first order classification with a precision of 1:100,000. This is because the NGS horizontal accuracies have been modified by ADOT and NGS does not have an Order B Class 2 classification.

**Table 1.1. NGS/NOAA defines the stability of marks as follows:**

<i>Vertical Stability Code</i>	<i>Definition</i>
A	Monuments of the most reliable nature which are expected to hold their position/elevation well
B	Monuments which probably hold their positions/elevations well
C	Monuments which may hold their positions/elevations well, but which are commonly subject to surface ground movements
D	Monuments of questionable or unknown reliability

**Table 1.2. The survey shall be checked for errors and be verified to meet or exceed the following accuracy requirements:**

<i>ADOT/NGS Order B Class 2</i>	
PPM:	+/- 2
Line-Length Dependent Error	1:500,000
Precision at 95% confidence level	0.004 meters

### 1.4.3 Static GPS Surveys

Use static survey methods for either HARN densification surveys or as an option for ADOT project control surveys when the required minimum horizontal accuracy tolerance is for a ADOT Class A Primary or ADOT Class B Secondary survey. Static surveys allows systematic errors to be resolved when high accuracy positions are required by collecting simultaneous data between stationary receivers for an extended period of time, during which time the satellite geometry changes. Static survey methods require creating a GPS network and a schedule for coordinating receivers, operators, observation times, and the logistics of the project.

Receivers must be capable of recording data for processing. Multichannel tracking dual-frequency receivers are required. Receivers and processing software must be specified by the manufacturer to be suitable for high accuracy static surveys. The static horizontal and vertical accuracy tolerances specified by the manufacturer must meet or exceed the ADOT minimum horizontal and vertical accuracy tolerances as required for the survey.

Static equipment requirements include:

1. Use only extended leg tripods or fixed height tripods for static surveys.
2. Whenever feasible, all antennas for the survey should be of the same make and model.
3. As a guideline ADOT recommends an epoch setting of 5 seconds and a sync time setting of 1 second for all static surveys.

### 1.4.4 Fast Static GPS Surveys

Use fast static survey methods for ADOT project control as an option to static survey methods when the required minimum horizontal accuracy tolerance is for a ADOT Class A Primary or ADOT Class B

Secondary survey. Fast static surveys allow systematic errors to be resolved when very accuracy positions are required by collecting simultaneous data between stationary receivers for a shorter period of time than that of static surveys. For fast static surveys, observation times are typically 8 to 20 minutes and are determined at the time of the field survey by the number of satellites available. Fast static survey methods allow the creation of a GPS network in a “leap frog” pattern. Each baseline between adjacent **intervisible** control monuments along a transportation corridor must be observed at least twice. The maximum fast static baseline length should not exceed 10 kilometers (6 miles).

Receivers must be capable of recording data for processing. Multichannel tracking dual frequency receivers are required. Receivers and processing software must be specified by the manufacturer to be suitable for high-accuracy fast static surveys. The fast static horizontal and vertical accuracy tolerances specified by the manufacturer must meet or exceed the ADOT minimum horizontal and vertical tolerances required for the survey. See Table 1.3.

Fast static equipment requirements:

1. Use only adjustable leg tripods or fixed height tripods for fast static survey.
2. Whenever feasible, all antennas for the survey should be of the same make and model.
3. Antennas should have a ground plane in place for fast static surveys.
4. As a guideline ADOT recommends an epoch setting of 5 seconds and a sync time setting of 1 second for all fast static surveys.

**Table 1.3. Typical ADOT fast static time duration settings**

<i>Fast Static Observations</i>	
Minutes of simultaneous observations	Minimum number of satellites (SV)
15 minutes	6 SV
20 minutes	5 SV
20 minutes	4 SV (not recommended)

### 1.4.5 RTK GPS Surveys

Don't use RTK survey methods for any survey project requiring ADOT minimum horizontal accuracy tolerances for a ADOT Class A Primary survey or ADOT Class B Secondary survey.

Post-processed kinematic (PPK) or real-time kinematic (RTK) GPS procedures are only allowed for topography if the contractor submits an observation plan for quality control to the department's region location survey manager or their designee, and the plan is approved by the department for use on this project.

RTK surveys are a radial type survey that uses two or more receivers with at least one receiver remaining stationary over a known (reference or base station) project control monument. Other receivers (rovers) are moved from point to point, collecting data in a short amount of time. Reference stations must be of the same or higher accuracy than is required for the RTK survey and networked into project control using static or rapid static techniques. RTK surveys measure the baselines from the reference station to the roving receiver's point. A radio at the reference station broadcasts the position of the reference point to the rovers, and the system processes the baselines in real time, allowing project coordinate information to be gathered and analyzed during the actual field survey.

Receivers must be capable of being connected to a radio at the reference station for broadcasting and to a radio at the rover for receiving the reference station broadcast. Multichannel tracking dual-frequency receivers are required. Receivers must be specified by the manufacturer to be suitable for RTK surveys. The RTK horizontal and vertical accuracy tolerances specified by the manufacture must meet or exceed the ADOT minimum horizontal and vertical accuracy tolerances required for the survey.

Ensure that the RTK calibration, base station, and project control points have been set up correctly so that the RTK data being collected will meet or exceed the ADOT minimum horizontal and vertical accuracy tolerances as required for the survey. No RTK baseline should exceed 5 kilometers (3 miles) in length. (See 1.3.5, Existing ADOT Primary Control Checks and 1.9, GPS Reports, for additional information).

Keep multipath (at the reference station and at the rovers), re-initializations, and loss of radio link to a minimum by project scheduling and planning for the best



practice for the logistics of the survey project. Keep in mind that RTK surveys are just another tool to complete a survey project and should only be used when the ADOT minimum horizontal and vertical accuracy tolerances for the survey can be met or exceeded.

As a guideline ADOT recommends an epoch setting of 1 second.

Before collecting any survey data, initialize the RTK rover for a minimum of two minutes or until the ambiguities are resolved, whichever is longer. Before any data is collected, after initialization, and an average of once every two hours thereafter, verify a control point. At the end of the session, verify one control point. You can verify interim control points by using temporary control points or by reoccupying a data point in the current survey (i.e., while collecting TMOSS cross-section data on station 1, occupy the centerline, acquire cross-section data to the right, do a temporary control check on centerline, and acquire cross-section data to the left). If loss of lock or the number of satellite vehicles (SVs) drops below five on either L1 or L2 or the 3D position, or quality drops below 5 cm (0.16 ft.), then the rover needs to be reinitialized for a minimum of two minutes or until the ambiguities are resolved, and a control verification needs to be obtained as soon as practical. (See 1.1.5, Existing ADOT Primary Control Check.)

#### **1.4.6 RTK Site Calibrations**

RTK site calibration establishes the relationship between the latitude, longitude, and ellipsoid height (NAD 83 GRS 80 positions) observed with GPS and the final adjusted local project control northing, easting, and differential leveled elevation for each point. The relationship between these coordinate systems is defined by a series of mathematical parameters. Conversions are applied during the calibration through a process of least squares that allows for future NAD 83 GRS 80 positions determined by GPS observations to be converted to local project coordinates.

Site calibrations shall only be used when necessary to match established project coordinates. Site calibrations, other than typical construction and machine control applications, shall be approved by the region right-of-way engineering supervisor or their designated representative.

The site calibration is performed to obtain the parameters that allow conversion from NAD 83 GRS 80 coordinates to local project control coordinates and back again within the data collector in real time. The local project control coordinate values of the control points are used in the calibration to generate residuals of the GPS-derived observations. The GPS-derived coordinates will not be used because known local project control values already exist for the control points and remain fixed.

A minimum of five horizontal control points are required for a site calibration of a site measuring about one square mile, such as most airports. Each of these horizontal control points must have NAD 83 GRS 80 positions that were observed by either a GPS static or fast static network, as well as having final adjusted project control coordinate values. For a vertical calibration, at least five vertical control points are required. The vertical calibration makes the GPS-derived orthometric heights (GPS-derived elevations) match as closely as possible with the control differential elevations. Vertical control will be set using conventional leveling techniques and spirit levels. (See 1.7.2, GPS-Derived Orthometric Elevations, for additional information).

To perform a site calibration on strip routes such as roadways, you need a minimum of six horizontal control points every six miles. Each of these horizontal control points must have NAD 83 GRS 80 positions that were observed by either a GPS static or fast static network, as well as having final adjusted project control coordinate values. For a vertical calibration, a minimum of 18 vertical control points are required, and 66% of the vertical control points must be perpendicular to the centerline alignment with a minimum offset of 150 meters (500 ft.). Set vertical control along the main alignment using conventional leveling techniques and spirit levels. You can obtain wing or perpendicular points using trig levels. No site calibration will extend beyond six miles. If the project extends beyond six miles, you must perform a new site calibration for the additional distance. Each successive site calibration shall have a half-mile overlap and contain a minimum of two horizontal and six vertical control points in common.

Both horizontal and vertical control points used in a site calibration should be evenly distributed throughout the site, including the central portion as well as

the extents in both the parallel and perpendicular directions. A minimum of 60% of the control points need to encompass the extents of the project.

The site calibrations consist of the following horizontal conversion parameters:

1. Rotation: All of the horizontal points in the calibration are used to calculate the centroid (geographic center) about which all horizontal GPS points are rotated by the same angular amount.
2. Translation: All of the horizontal points in the calibration have their NAD 83 GRS 80 positions moved in the same direction and the same distance so they will match closer to the final local project control coordinates.
3. Scale: A scale factor is calculated using a ratio of the true distances between the local project control coordinates and the distances calculated between the GPS-derived NAD 83 GRS 80 positions for the same points. This ratio is the scale factor.

Once you have determined the above conversion parameters and calculated a best fit of the observed GPS-derived NAD 83 GRS 80 positions with the local project control coordinates, there will still be minor discrepancies between the GPS-derived NAD 83 GRS 80 positions and the local project control coordinates. These discrepancies are called the “residuals” and should be relatively small. The residuals are very helpful in deciding whether the site calibration is satisfactory or not. AKDOT recommends that these residuals be no larger than the accuracy tolerance of the static or fast static control survey that was performed for the control points, and they must not exceed the accuracy tolerance for the RTK survey being performed. RTK site calibrations require a calibration narrative. See 1.9.3, Project Reports.

#### **1.4.7 PPK GPS Surveys**

Do not use PPK survey methods for any survey project requiring ADOT minimum horizontal accuracy tolerances for ADOT Class A primary or ADOT Class B secondary surveys. PPK surveys are a “radial” type survey similar to an RTK survey; however, there is no radio at either the reference station or the rover to broadcast, and the system does not process the baselines in real time. PPK uses two or more re-

ceivers, with at least one receiver remaining stationary over a known (reference or base station) project control monument. Other receivers (rovers) are moved from point to point, collecting data in a short amount of time. Reference stations must be the same or higher accuracy than required for the PPK survey. PPK surveys measure the baselines from the reference station to the roving receivers. Data is collected at both the reference station and at the rover receivers. The data is downloaded into a GPS processing software program to process the baselines. No PPK baseline should exceed 5 kilometers (3 miles) in length. Airborne GPS with an inertial measuring unit could be an exception to this.

Receivers must be capable of collecting data at the reference station and at the rover for downloading into a GPS processing program. Multi-channel tracking dual-frequency receivers are required. Receivers must be specified by the manufacture to be suitable for PPK surveys. The PPK horizontal and vertical accuracy tolerances specified by the manufacturer shall meet or exceed the ADOT minimum horizontal and vertical accuracy tolerances required for the survey.

Take care in the field to ensure that the PPK calibration, base station, and project control points have been set up correctly so that the PPK data being collected meets or exceeds the ADOT minimum horizontal and vertical accuracy tolerances required for the survey. (See 1.3.5, Existing ADOT Primary Control Checks, and 1.9.3, Project Reports, for additional information).

Keep multipath to a minimum at the reference station and at the rovers through project scheduling and using the best survey method for the logistics of the project. Keep in mind that PPK surveys are just another tool to complete a survey project and should be used only when the ADOT minimum horizontal and vertical accuracy tolerances required for the survey can be met or exceeded.

Before collecting any survey data, initialize the PPK rover for a minimum of two minutes or until the ambiguities are resolved. Before any data is collected, after initialization, and an average of once every two hours thereafter, verify a control point. At the end of the session, verify one control point. You can verify interim control points using temporary control points or by reoccupying a data point in the current survey (for example, while collecting TMOSS cross section data on station 1, occupy the centerline, ac-

quire cross-section data to the right, do a temporary control check on the centerline, and acquire cross-section data to the left). If loss of lock or the number of SV's drops below five on either L1 or L2, then the rover needs to be reinitialized for a minimum of two minutes or until the ambiguities are resolved and a control verification needs to be obtained as soon as practical. (See 1.1.5, Existing ADOT Primary Control Check.)

As a guideline, ADOT recommends an epoch setting of one second and a sync time setting of one second for all PPK surveys.

#### **1.4.8 GPS for GIS Mapping Grade Surveys**

GIS mapping grade receivers shall not be used to meet any ADOT horizontal or vertical accuracy tolerance. A GIS mapping grade receiver is defined as one that is unable to produce a post-processed result within a horizontal accuracy tolerance of 0.050 meters at a 95% confidence level.

#### **1.4.9 Survey Class Definitions**

ADOT Class A primary surveys include HARN densification and primary project control networked into the HARN and/or using the NGS CORS data or OPUS utility.

ADOT Class B secondary surveys include project control densification networked into the primary control. This would apply to most road and airport control surveys.

ADOT Class C TMOSS or topographic modeling surveys include planimetric and DTM data acquisition for design studies.

See section 2.2.2 for accuracy tolerance table.

### **1.5 Static and Fast Static Network Design**

#### **1.5.1 Required Existing Control Monumentation**

As stated earlier, GPS surveys for all ADOT projects shall be referenced and tied into the federal base network using the CORS sites, preferably using OPUS.

Use a minimum of three OPUS horizontal control monuments to reference the survey: two for primary control and one for a redundancy check. These horizontal control monuments should be located outside

the survey project area, set to encompass the entire project, and provide for good network geometry throughout the network project area.

Use a minimum of one existing North American Vertical Datum of 1988 control monument to reference the survey; four are recommended for redundancy. If feasible, the existing vertical control monuments should be located in all four quadrants of the survey and encompass the entire project. If no NAVD 1988 vertical control exists within 10 miles of the project, then the relevant Geoid model and Epoch will be referenced as vertical control and transferred to one control point. Conventional spirit levels, using this point as a basis of vertical, will then be transferred to other points in order to create a local Geoid Model correction for the project.

Type and density of monumentation shall conform to each region's specifications and specific project requirements.

#### **1.5.2 Network Geometry**

A network consists of a set of baselines between network points. Networks have one of the following network designs:

1. Good network geometry: A network design that has computed loop closures around small closed figures. If the loop misclosure is high, it indicates that there is a problem with at least one of the baselines in the loop. Good network geometry allows other loop closures to be done that identify and isolate problematic baselines so they can be easily removed.
2. Poor network geometry: A network design that allows loop closures to be computed that will show a problem exists within the network but that does not allow the problematic baselines to be identified, isolated, and removed.
3. Bad network geometry: A network design that allows coordinates to be computed for the unknown points but that does not identify any errors that may exist in the network. This will result in baseline errors going undetected and propagating through the rest of the network. All GPS networks shall be designed with good network geometry. A draft network design showing the proposed geometric configuration should be confirmed by the ADOT ROW Survey Section in conjunction with project

engineer or project manager before commencing survey work.

For highway corridor control networks that are geometrically long and narrow, we recommend that control network points be established outside of the highway corridor on monuments such as Public Land Survey System (PLSS) monuments to strengthen the overall network geometry. Complete right of entry forms if required. Once these control network points have been incorporated into the control network survey, they can be used during RTK calibrations to strengthen the RTK calibration without the need to reoccupy the monument.

### **1.5.3 Redundancy of Networks**

Redundancy allows quality control checks of a network and also provides for the desired confidence in the results of the survey. Design each network to have enough redundancy built in to detect and isolate errors.

Redundancy of a network is achieved by:

1. Establishing a minimum of four horizontal and vertical primary control monuments for each project, encompassing the entire project.
2. Build in good network geometry throughout the entire network
3. Establish a minimum of two independent baselines between each control monument.
4. Have interconnecting closed loops.
5. Repeat baselines measurement.

### **1.5.4 Independent (Nontrivial) Baselines**

Design static and fast static networks to process at a minimum two independent (nontrivial) baselines (vectors) between at least 67% of adjacent control monuments. All points in a network shall have a minimum of three baselines (vectors) either terminating or originating at that point. For each session of simultaneous observations, there is one less independent baseline than there are receivers.

Figure 1.1 gives an example for a control network consisting of four control monuments observed with three receivers. There must be five sessions to allow two independent baselines to be measured between each control monument. Notice that for each session the receivers are moved to a different control monument. This allows additional redundancy in the network.

Two or more independent occupations for each station are recommended.

### **1.5.5 Network Loops**

Networks should contain only closed loops. A closed loop is a series of at least three independent connecting baselines that start and end on the same point, with each loop having at least one baseline in common with another closed loop to prevent a break in the network. Single radial (spur) lines or sideshots to a point are not acceptable. Closed loops shall include observed baselines from at least two observation sessions.

### **1.5.6 Twenty Percent Rule**

For any two control monuments where the distance between the two control monuments is less than 20% of the total distance as measured along a series of closed connected loops to connect the two control monuments, there should be at least two independent baselines measured between the two control monuments. See Figure 1.2.

### **1.5.7 Network Adjustment**

All networks shall be adjusted using the appropriate least squares technique constrained to a minimum of two primary control monuments such as the OPUS or NGS control points. Design static and fast static networks so this control monumentation encompasses the majority of control points.

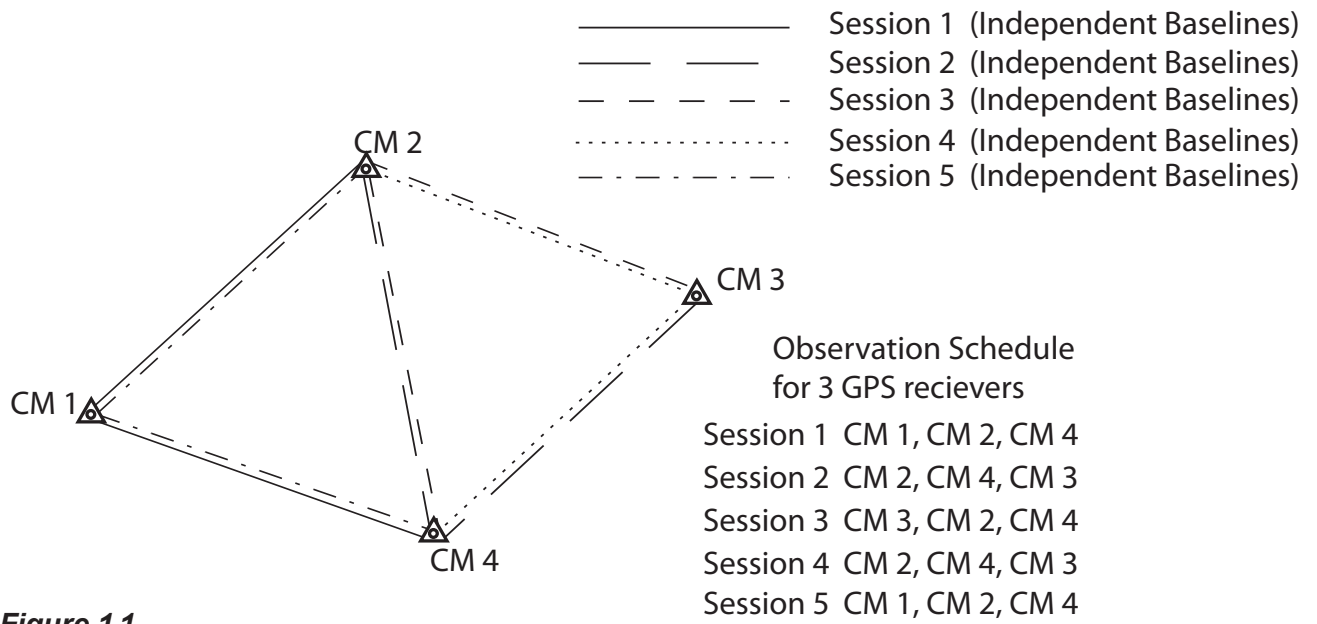
Primary survey control networks shall use an appropriately constrained and weighted least squares adjustment of over-determined and statistically independent observations. If any statistically dependent observations are included, their affect on the estimated accuracy must be accounted for and documented.

## **1.6 GPS Planning**

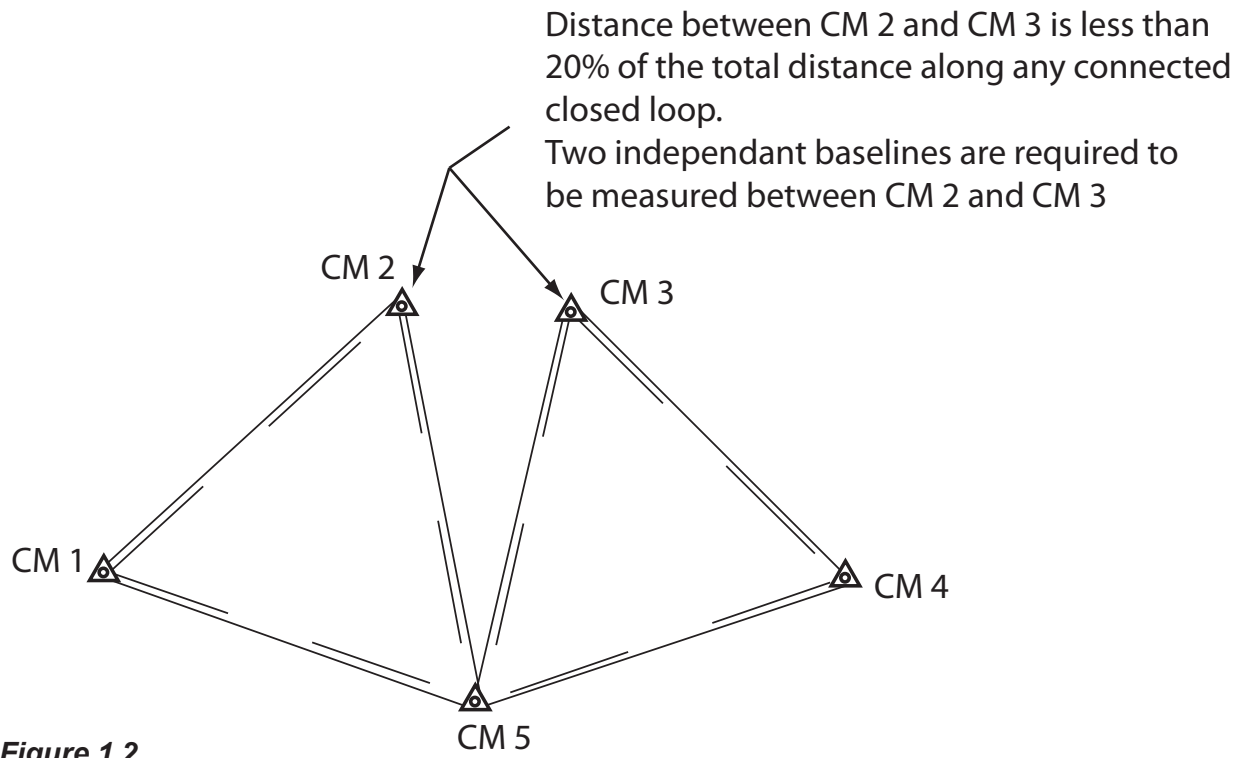
### **1.6.1 Control Monumentation Site Selection**

Before you set any control monumentation, identify the project needs. This is typically done through the initial scoping of the project to determine the project's limits, factors, and requirements. After the scoping has been completed, the project surveyor will identify areas to install ADOT Type 1 control monuments. Take the following into account when choosing a site for installing control monumentation:





**Figure 1.1**



**Figure 1.2**

1. Sites should be free of vertical obstructions blocking the horizon such as buildings, overhangs, terrain, trees, fences, utility poles, overhead lines, or any other visible obstructions. Unobstructed skies 15 degrees above the horizon are best.
2. Sites located close to radio transmitters, including cellular phone equipment, may disrupt satellite signal reception.
3. Sites close to large flat surfaces such as signs, fences, glass, or utility boxes should be avoided.
4. Intervisible sites must have more than 0.2 mile (1,000 feet) between adjacent control monuments.
5. Set intervisible sites at a minimum of every 5 miles with a single site set at the midway point (2.5 miles).
6. Establish a minimum of three primary control monuments for each project.
7. If feasible, sites should not be disturbed by future construction activities and should be outside the design toe of slopes and top of cuts for the project.
8. Sites should be located within the existing highway right-of-way or as close as practical.
9. If a site is located outside the existing highway right-of-way, a right of entry form must be completed and an easement for access, installation, and maintenance of the control monument must be acquired in ADOT's name for the benefit of the public for the purpose of performing a land survey.

### **1.6.2 Ephemeris**

A GPS ephemeris is the prediction of current satellite positions. You can only have accurate GPS planning when you use a current ephemeris.

Current ephemeris can be obtained by:

1. downloading the ephemeris from the internet, or
2. observing the satellites for a minimum of 15 minutes and downloading from the receiver.

### **1.6.3 Satellite Geometry**

A minimum of five satellites are required to survey with GPS. A minimum of six satellites is recommended. The configuration of the visible satellites that the

receiver is able to track in relation to each other will make a significant difference in the data that are collected. Satellite geometry is expressed as a numeric value known as dilution of precision (DOP). Good satellite geometry will have small DOP values while poor satellite geometry will have large DOP values. As a guideline, DOP values of six or lower are recommended for ADOT GPS surveys. A DOP of greater than 8 is unacceptable. The ideal satellite geometry is one that has the visible satellites distributed throughout the sky. Good satellite geometry yields a higher precision.

Satellite geometry factors that must be considered when planning a GPS survey are:

1. number of satellites available,
2. minimum elevation angle above the horizon (elevation mask),
3. obstructions limiting satellite visibility,
4. position dilution of precision (PDOP),
5. vertical dilution of precision (VDOP),
6. horizontal dilution of precision (HDOP), and
7. geographic dilution of precision (GDOP).

The website <http://www.navcen.uscg.gov> provides satellite information and important messages from the United States Coast Guard, Navigation Center, or you can call 1-703-313-5907 for a 24-hour recorded message.

### **1.6.4 Elevation Mask**

An elevation mask is the lowest elevation above the observer's horizon that a satellite's data is recorded. Most obstructions below a set elevation mask can be ignored; however, multipath can still be produced from a surface below the set elevation mask. Elevation mask also help to minimize the atmospheric noise in the data. Satellites that are high in the sky will have less atmospheric noise than satellites low in the sky and very close to the observer's horizon. Having an elevation mask set keeps the noise in the GPS satellite signals to a minimum. Most GPS processing software allows for the elevation mask to be raised while processing, but not lowered.

As a guideline ADOT recommends an elevation mask setting of 15 degrees for all GPS surveys. The minimum elevation mask is 10 degrees.

### 1.6.5 Weather Conditions

Generally, weather conditions do not affect GPS surveying; however, the following conditions must be considered when planning a GPS survey:

1. GPS observations should never be conducted during an electrical storm.
2. Significant changes in weather or unusual weather conditions should be noted either in the field notes, data collector, or receiver.
3. Horizontal and vertical GPS observations can at times be affected by severe snow, hail, and rain storms. Highly accurate GPS surveys should not be conducted during these periods.
4. Sunspots or magnetic storms can affect GPS observations, so care needs to be taken to avoid GPS surveying during these periods.

### NOAA Space Weather Now

<http://sec.noaa.gov/SWN/>

The above link provides information for space weather activities and warnings.

### Sun Spots and Geomagnetic Storm Warnings

[http://members.tripod.com/~Post\\_119\\_Gulfport\\_MS/space.html](http://members.tripod.com/~Post_119_Gulfport_MS/space.html)

The above link provides information of space weather activities and warnings.

### Geomagnetic data and Products ONLINE at NOAA

<http://www.swpc.noaa.gov>

The above link provides geomagnetic data, in particular the daily Fredericksburg, College, and Planetary A&K indices. Search for Geomagnetic Kp index. This is ADOT's preferred solar weather report.

### 1.6.6 GPS Calendar

<http://www.ngs.noaa.gov/CORS/instructions3/>

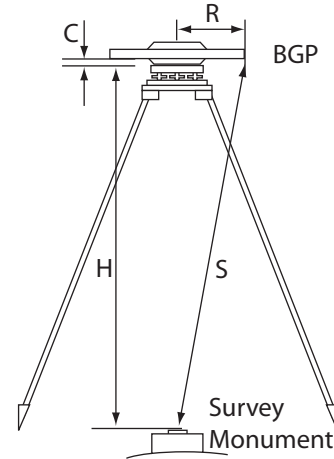
The above link provides information along with current and past GPS calendars.

## 1.7 GPS Vertical Procedures

### 1.7.1 Antenna Height Measurement

Blunders in antenna height measurements are a common source of error in GPS surveys. All GPS surveys

are three-dimensional, whether the vertical component will be used or not, so be diligent when measuring the antenna height. Antenna height measurements determine the height from the survey monument mark to the phase center of the GPS antenna.



H = True height of fixed height tripod rod

S = Slant height field measurement

C = Distance for addition of ground plane

R = Radius from antenna phase center to edge of ground plane

BGP = Bottom of ground plane (or antenna)

### Figure 1.3

There are three types of antenna height measurements done for ADOT GPS surveys:

1. Fixed height tripod rods: To be used for static, fast static, RTK, and PPK surveys. Preferred over adjustable height tripods for static and fast static surveys.
2. Adjustable height tripods: To be used for static, fast static, RTK, and PPK surveys.
3. Adjustable height rods: To be used only for RTK and PPK surveys (see Figure 1.3).

### Fixed height tripod rod antenna height measurement procedures

Verify the length of fixed height tripod rods each day before beginning any observation sessions (see “H,” Figure 1.3).

1. Be careful to correctly enter the antenna type, antenna height measurement type, and antenna height measurements into the data collector.

2. The following is recorded on the observation log sheet for each observation setup:
  - a. Antenna type
  - b. Antenna height measurement type
  - c. Antenna height measurement in both meters and feet
3. When downloading the data into a GPS processing software program for each observation session, verify the following:
  - a. antenna type,
  - b. antenna height measurement type, and
  - c. antenna height measurement in both meters and feet
5. For each observation station, verify the following when downloading the data into GPS post-processing software:
  - a. antenna type
  - b. antenna height
  - c. mean antenna height measurement is within  $\pm 0.006$  meters of the measurement recorded on the observation log sheet in meters.

To measure the height of an adjustable height tripod antenna:

1. Set up the tripod over the survey monument mark and level it using a precision level before the observation session.
2. Use the appropriate measurement as per the manufacturer's recommendation or supplied measuring device. This measurement should be taken once at the beginning of the session and again at setup breakdown.
3. Be careful to enter the correct antenna type, antenna height measurement type, and the mean antenna height measurement into the data collector.
4. Record the following on the observation log sheet for each observation setup:

At the beginning of the observation:

- a. station name
- b. antenna type
- c. observation start time
- d. antenna height
- e. appropriate DOP for instrument used (GDOP or PDOP)
- f. satellites observed

Just before breakdown:

- g. satellites observed
- h. appropriate DOP for instrument used (GDOP or PDOP)
- i. antenna height
- j. observation end time

Measurement procedures for adjustable height rods:

1. The length of adjustable height rods, including the distance for the addition of the antenna (see "C" in Figure 1.3), should be verified each day before beginning any observation sessions.
2. For adjustable height rods that are graduated either in meters, feet, or both, verify that the height reading of the rod includes the correct distance for the addition of the antenna.
3. Check adjustable height rods continually for loose height clamps and tighten them as necessary to prevent the rod height from slipping during the duration of the survey (see 1.3.3, Equipment Maintenance, for additional information).
4. Ensure that any changes in the height of the adjustable height rod are entered into the data collector and that the correct antenna type, antenna height measurement type, and antenna height measurement are correctly entered into the data collector and on a log sheet or in a field book.
5. When downloading the data from a PPK survey into GPS post processing software, verify the following for each observation session:
  - a. antenna type
  - b. antenna height measurement in both meters and feet

When a station is occupied during two or more back-to-back observation sessions without the equipment moving to another point, the entire antenna tripod setup must be taken down, set up again, and leveled for each new observation session.

For stations that are occupied during two or more observation sessions with the tripod remaining stationary for the point but with new equipment being used for the observation session (such as antennas and



receivers), the legs of the tripod shall be broken down and the setup leveled for an antenna height substantially different than that of the previous antenna height for each new observation session.

### 1.7.2 GPS-Derived Orthometric Heights (Elevations)

GPS is a three-dimensional system, and so errors in the vertical component of GPS measurements will effect the horizontal positions. Therefore, all GPS surveys for any type of ADOT survey must measure the vertical component, even if the vertical is not a requirement for the survey. GPS-derived orthometric elevations are compiled from ellipsoid heights as determined by GPS observations and modeled geoid heights using the most current geoid model available.

In order to convert elevations from GPS into ground elevations, it is necessary to apply geoid height corrections as depicted by the latest geoid model for the area of interest. The National Geodetic Survey is the primary source for defining and maintaining geoid models. NGS updates geoid models on a three-year cycle (e.g., GEOID 93, GEOID 96, GEOID 99).

#### The NGS geoid page is

<http://www.ngs.noaa.gov/GEOID/>.

This link provides downloads for the latest NGS/NOAA-approved geoid models.

#### The NGS geodetic tool kit is at

<http://www.ngs.noaa.gov/TOOLS/>.

This link also provides downloads for the latest NGS/NOAA-approved geoid models.

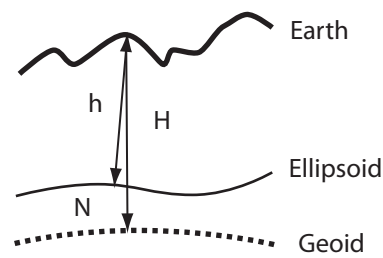
#### The Trimble geoid files are at

[http://www.trimble.com/geomaticsoffice\\_ts.asp?Nav=Collection-71](http://www.trimble.com/geomaticsoffice_ts.asp?Nav=Collection-71).

This link provides downloads for the latest geoid models for Trimble products.

#### NOAA Technical Memorandum:

The link [http://www.ngs.noaa.gov/PUBS\\_LIB/NGS-58.html](http://www.ngs.noaa.gov/PUBS_LIB/NGS-58.html) contains a NOAA technical memorandum that provides information and guidelines for establishing GPS-derived ellipsoid heights.



GPS - Derived Orthometric Heights - (elevations)

$$h = N + H$$

h = Ellipsoid height  
 N = Geoid height (negative in Colorado)  
 H = Orthometric height (elevation)

Figure 1.4

Because of distortions in vertical control networks, lack of high accuracy benchmarks, and errors in the geoid height models, GPS-derived heights can be difficult to validate. GPS-derived heights will generally be plus or minus three times worse than the horizontal (see Figure 1.4).

Because highway corridors have GPS control networks established on the ground with GPS control monuments every mile with latitudes, longitudes, ellipsoid heights, and differential leveled elevations, you don't have to import a geoid model into an RTK systems data collector to obtain GPS-derived orthometric heights if you are performing an RTK survey inside a control network; however, it is recommended (see 1.4.6, GPS Reports RTK Site Calibration, for additional information). If no geoid model is used, the undulation of the geoid with respect to the ellipsoid is resolved to produce a simple planar geoid model for the project area. If you use the latest geoid model available the GPS-derived heights will be related to the geoid, resulting in elevations that will better fit the Earth's surface.

The geoid 09 model for the State of Alaska has not been confirmed accurate in all areas of the state. The long-range wavelengths are fairly consistent but the geoid separation may be incorrect. This indicates that the model needs local project-wide corrections to make it fit the existing true orthometric heights. This requires differential levels distributed about the project in order to correct for errors in the modeling.

Each quadrant of the network should be included in the vertical distribution, and the control should be located outside the project limits. In areas where first-order benchmarks are available, these should be used to correct the geoid. In areas where the level network has not reached, the geoid model should be used with reference to the model used and epoch date. The NGS software HDTP, used to convert data to the same epoch date, currently does not work in Alaska.

If accurate elevations are needed outside the control network, a differential level loop should be run to provide control and checks of the vertical component.

### **1.7.3 ADOT Class A Primary Vertical Surveys**

Don't use GPS-derived heights for elevation on any ADOT Class A primary vertical survey or primary control monument that requires accurate elevations, unless otherwise approved by the region right-of-way engineering supervisor or their designated representative.

All ADOT Class A primary vertical surveys performed with GPS must use the methods and procedures as required in this chapter, either for a static or fast static survey meeting the minimum vertical accuracy tolerance for for a ADOT Class A primary survey (see Chapter 2, Preliminary Surveys, for additional information).

For any ADOT Class A primary vertical survey or any primary control monument that requires accurate elevations beyond the GPS equipment manufacturer's stated vertical accuracy tolerance, use differential leveling to obtain North American Vertical Datum 1988 elevations by the methods, procedures, and minimum vertical accuracy tolerance as required in Chapter 2, Preliminary Surveys, in this manual.

For processing of any ADOT Class A Primary vertical survey or any static or fast static survey, complete a minimal constrained adjustment by holding fixed only one three-dimensional control mark having a published latitude, longitude, ellipsoid height and a North American Vertical Datum 1988 elevation of either the same or higher accuracy than that of the survey being performed. The minimal constrained adjustment shall verify that the vertical component for the ellipsoid

heights are within an acceptable tolerance for the survey at the 95% confidence level, or the survey data shall be checked for errors and corrected.

Once the minimal constrained adjustment is at an acceptable accuracy tolerance level as required for the survey, import a current corrected geoid model into the software and calculate the geoid separations. Then perform a fully constrained adjustment by incorporating and holding fixed only one additional differential leveled vertical control mark at a time. For each vertical control mark that is added and held fixed, readjust the entire network and verify it to be within an acceptable vertical tolerance level for the survey by comparing the GPS-derived orthometric heights to the differential leveled elevations. Repeat this process as many times as needed until all differential leveled vertical control marks have been incorporated into the survey and are held fixed.

### **1.7.4 ADOT Class B Secondary Vertical Surveys**

No ADOT Class B Primary vertical survey or primary control monument that requires accurate elevations will have elevations established by GPS-derived heights, unless approved otherwise by the region right-of-way engineering supervisor or their designated representative.

All ADOT Class B Secondary vertical surveys using GPS must use the methods and procedures in this chapter either for a static, fast static, RTK, or PPK survey meeting the minimum vertical accuracy tolerance for a ADOT Class B Secondary survey (see Chapter 2, Preliminary Surveys, for additional information).

For survey monuments that require accurate elevations beyond the GPS equipment manufacturer's stated vertical accuracy tolerance, 100% of all GPS-derived elevations must be verified or supplemented with elevations by a more accurate survey method as follows:

1. Differential leveled elevations using the methods and procedures as required in Chapter 2, Preliminary Surveys.
2. Trigonometric elevations by conventional survey methods such as a total station in accordance with the methods and procedures as required in Chapter 2, Preliminary Surveys.

### **1.7.5 ADOT Class C Topo Modeling Survey System Vertical Surveys**

All ADOT Class C TMOSS (Topo Modeling Survey System) vertical surveys performed with GPS must use the methods and procedures as required in this chapter either for a static, fast static, RTK or PPK survey meeting the minimum vertical accuracy tolerance for a ADOT Class C TMOSS survey (see Chapter 2, Preliminary Surveys, for additional information).

For TMOSS locations that require accurate elevations beyond the GPS equipment manufacturer's stated vertical accuracy tolerance, verify 100% of all GPS-derived elevations or supplement them with elevations by a more accurate survey method as follows:

1. Trigonometric elevations by conventional survey methods such as a total station in accordance with the methods and procedures as required in Chapter 2, Preliminary Surveys.
2. Differential leveled elevations in accordance with the methods and procedures as required in Chapter 2, Preliminary Surveys.

## **1.8 GPS Horizontal Procedures**

### **1.8.1 Minimum Horizontal Accuracy Tolerance Table**

All GPS surveys for ADOT must meet the minimum horizontal accuracy tolerance table as shown in Chapter 2, Preliminary Surveys, for either a ADOT Class A Primary, Class B Secondary, or Class C TMOSS.

### **1.8.2 ADOT Class A Primary Horizontal Surveys**

All ADOT Class A Primary horizontal surveys using GPS must use the methods and procedures in this chapter for either a static or fast static survey meeting the minimum horizontal accuracy tolerance for a ADOT Class A Primary survey (see Chapter 2, Preliminary Surveys, for additional information).

Do not use RTK or PPK surveys for any ADOT Class A Primary survey.

For the final processing, adjacent intervisible control monuments should be verified to be within the minimum horizontal accuracy tolerance for a ADOT Class A Primary survey by conventional survey methods such as a total station with an electronic distance

meter. (See see 1.9.3, Project Reports, and 1.6.1, Site Selection, for additional information.)

### **1.8.3 ADOT Class B Secondary Horizontal Surveys**

All ADOT Class B Secondary horizontal surveys performed with GPS shall use the methods and procedures in this chapter either for a static or fast static survey, meeting the minimum horizontal accuracy tolerance for a ADOT Class B Secondary survey (see Chapter 2, Preliminary Surveys, for additional information).

Do not use RTK or PPK survey for any ADOT Class B Primary survey.

### **1.8.4 ADOT Class C TMOSS**

All ADOT Class C TMOSS horizontal surveys performed with GPS must use the methods and procedures for either a static, fast static, RTK or PPK survey meeting the minimum horizontal accuracy tolerance for a ADOT Class C TMOSS survey for the feature being located. Any critical elevation element requires a static, rapid static or spirit levels. Confirm at the pre-survey conference if RTK and PPK methods will suffice for hard shots such as manhole covers, curb and gutter, bridge decks, etc. (see Chapter 2, Preliminary Surveys, for additional information).

### **1.8.5 Process for State Plane Coordinate Reduction**

At the pre-survey meeting, determine if the state plane coordinates are required and the method for determining the scaling parameters and project coordinates. If ADOT has supplied these coordinates and scaling parameters, then these must be used for the project coordinates. If project coordinates need to be developed then proceed as follows.

For ADOT Class A Primary surveys, once the final adjusted state plane northing and easting coordinates have been calculated, reduce the state plane coordinates to modified project northing and easting coordinates in the following order:

NAD 83 state plane coordinates shall be in meters (see Alaska Statute 38.20, the Alaska Coordinate System, for more information).

1. Select three base control points: one at the beginning of the project, one at the end of the

project, and one at the center of the project. These will be used to determine the Alaska state plane zone for the project. If a project encompasses more than one zone, choose the zone containing the majority or primary aspect of the project. Then use the three control points to determine the elevation factor, the scale factor, and the combined factor using a modified Simpson's rule (i.e., 1 times the combined factor for the beginning point, 1 times the combined factor for the end point, and 4 times the combined factor for the central point, summed and divided by 6). This will determine the combined factor for the project.

An alternative method would be to determine the average combined factor for all control points in the project. Then use this averaged factor as the project combined factor. You must consider network geometry and evenly distributed control points and confirm them with the ADOT region right-of-way engineering supervisor or their designated representative before using this approach.

2. Convert final adjusted state plane coordinates in meters to modified ground coordinates in meters using the above calculated factors. This is the inverse of the normal scale and sea level combined factors.
3. Then convert the above modified ground coordinates to U.S. Survey feet with the central control point as the basis of coordinates. This will have the effect of establishing the central control point as the only state plane coordinate for the project, and it will be listed on the control drawing with all three sets of coordinates, that is, latitude and longitude, state plane coordinates in meters, and state plane coordinates in U.S. Survey Feet. Regional standards may require these coordinates to be truncated, translated, or both.

### **1.8.6 Low Distortion Projection**

A low distortion projection (LDP) is a standard transverse Mercator or single parallel Lambert conformal mapping projection optimized for a project area in order to minimize the error budget for the mapping and elevation scaling requirements. An LDP essentially creates the map projection at or near the ground elevation. LDPs are used in lieu of the

standard state plane mapping projections. Properly defined LDPs allow both GPS and optical survey techniques to use the same projection coordinate system without scaling requirements.

LDPs shall be geo-referenced and tied into the National Spatial Reference Frame, either by ties to existing monumentation or through the use of CORS sites or the National Geodetic Survey's OPUS utility.

Control surveys performed to establish geodetic control for LDPs shall be based on an appropriately constrained and weighted least-squares adjustment of over-determined and statistically independent observations. If statistically dependent observations are included, their affect on the estimated accuracy must be accounted for and documented. Stations or marks used for creating LDPs shall be well distributed and representative of the project area.

The statistical characteristics of the minimally constrained and the fully constrained adjustments must be substantially the same. Local point accuracy estimates determined from the control network shall be based on the fully constrained post-adjustment variance-covariance matrix for each point. Results shall include the horizontal error ellipse axis dimensions scaled to 95% confidence using the bivariate scalar and the linear vertical error scaled to 95% using the univariate scalar.

Define the project area and choose a representative ellipsoid height ( $h_0$ ). Place the central meridian near the centroid of the project area for transverse Mercator projections or the standard parallel for Lambert conformal projections. Scale the centroid element ( $k_0$ ) of the projection to the representative ground height ( $h_0$ ).

LDP parameters shall be defined as follows.

- $h_0$  chosen to the nearest 10 feet.
- $k_0$  defined to no more than **six** decimal places exact.
- Latitude and longitude of grid origins to the nearest arc-minute.
- Grid origins using large whole values with as few digits as possible.

Explicitly define linear units and geodetic datum.

All LDPs must be approved by the department's location survey manager or their designated representative. A request containing the above parameters and a point



distortion report distributed throughout the project area shall be submitted for approval. Upon acceptance the LDP shall become the property of the department for use on current and future projects in the area.

## **1.9 Survey Control Diagrams and Project Reports**

### **1.9.1 Primary Control Diagram**

Complete a a survey control diagram for all ADOT Class A Primary surveys performed by GPS methods and file it with the region right-of-way engineering supervisor or their designated representative in accordance with Chapter 2, Preliminary Surveys. Show prominent topographic features on this diagram. This survey control diagram will be recorded in the proper recording district.

Control diagrams must conform to the standards of each region.

### **1.9.2 Secondary (Project) Control Diagram**

Complete a a survey control diagram for all ADOT Class B Secondary surveys and file it with the region right-of-way engineering supervisor or their designated representative in accordance with Chapter 2, Preliminary Surveys. Show prominent topographic features on this diagram. This survey control diagram will be recorded in the proper recording district.

Control diagrams must conform to the standards of each region.

Aerial surveys are excluded from this requirement. Other exceptions shall be discussed at the prework meeting.

Primary and secondary control diagrams may be combined if approved or required by the region right-of-way engineering supervisor or their designated representative.

### **1.9.3 Project Reports**

Submit all project, alignment, monumentation, control, or calibration reports generated from any survey to the region right-of-way engineering supervisor or their designated representative, in electronic and hardcopy format, for review. They will be filed in the region survey office records for the project. All reports must bear the signature and seal of the professional land surveyor in charge and contain a statement

that the report was prepared under their direct supervision and checking. In addition to the above reports, submit TMOSS and construction staking reports to the resident project engineer or contract manager.

Static and fast static survey reports must include the following:

1. project report (narrative summary)
2. names of individuals and their duties
3. project sketch or map showing project location and project network
4. station descriptions
5. station photographs
6. station obstruction diagrams
7. observation logs
8. equipment logs stating manufacturer, model, and calibration report.
9. raw observations in RINEX2 format
10. baseline processing results
11. dilution of precision (DOP) report
12. loop closures
13. repeat baseline analysis
14. least square minimum constrained adjustment results
15. least square full constrained adjustment results
16. elevation report of GPS-derived elevations compared with differential leveled elevations
17. primary control geodetic coordinate report in electronic spreadsheet format, including but not limited to the following:
  - a. point name
  - b. latitude and longitude
  - c. state plane coordinates in North American Datum of 1983(92)
  - d. ellipsoid height
  - e. differential leveled North American Vertical Datum 1988 elevation
  - f. mapping angle (convergence)
  - g. scale factor, sea level factor, combined factor.
  - h. point description
  - j. statement of processing software and version, geoid model, ellipsoid, project sea level factors, project scale factors, project combined factors, metric to English conversion factors

- k. OPUS report with Epoch time and date when applicable
  - l. space weather report
18. project coordinate report, including but not limited to the following for each point:
- a. point name
  - b. modified state plane northing
  - c. modified state plane easting
  - d. differential leveled North American Vertical Datum 1988 elevation
  - e. point description
  - f. descriptor key
  - g. for ADOT Class A Primary surveys, a primary control coordinate comparison report of the final adjusted control coordinates and ground distances between 68% of all directly connected intervisible adjacent control monuments should be verified to be within the minimum horizontal accuracy tolerance for a ADOT Class A Primary survey by conventional survey methods such as a total station with an electronic distance meter. (See ADOT Class A Primary Surveys, for additional information.)

RTK and PPK survey reports must include the following:

1. Project report (narrative summary)
2. Names of individuals and their duties
3. Project sketch or map showing project location
4. Equipment logs stating manufacture, model, serial numbers and equipment settings
5. RTK calibration narrative required elements:
  - a. The basis of project control elements, both horizontal and vertical, is required in the report. Supporting control drawings, traverse closure information, or static GPS network adjustment reports are required.
  - b. Identification of the points used to calibrate the RTK GPS points to the project coordinates and descriptions of where they are located in relation to the entire project. These points should be randomly located and encompass the limits of the project. The correlation information explaining that “project control point x” is the same as “RTK calibration point y” is required.

- c. The confidence region should be included in the report along with the residuals or RMS information for each point used in the calibration; preferably both.
  - d. There should be a statement indicating the largest and average error, either by sorting the residuals or RMS data or indicated in the report proper.
  - e. The report should contain the latitude and longitude, the state plane coordinates, and the project coordinates for each point used in the calibration and indicate the zone, geoid model, and datum associated with the data. These would normally be NAD 83, NAVD 88, and Geoid 09 at the present time.
  - f. The report should indicate the units and conversion used to change the NAD 83 metric state plane coordinates to the usual U.S. survey feet project coordinates.
  - g. The report should be clear, concise, and easy to understand by nonsurvey professionals.
  - h. Supporting documents and reports from the relevant software should be attached. These would include the software calibration, localization, transformation, align local coordinates, localization points, and any other relevant documentation necessary to support the calibration.
6. Calibration report for all points used in the calibration, rotation, scale factor, horizontal and vertical residuals, geoid model. The site calibration itself, at a minimum, will contain the RTK coordinate values, the project control coordinate values, and the discrepancies (residuals or RMS) in northing, easting, and orthometric height for each point used in the calibration, in spreadsheet format. (See 1.4.6, RTK Site Calibrations for additional information.)
  7. Primary control checks immediately after first initialization, during roving while initialized, and before ending the initialization session
  8. Post-processed report for any points located with PPK
  9. Space weather report
  10. Project coordinate report, including but not limited to the following for each point:
    - a. point name

- b. modified state plane northing (project coordinates)
- c. modified state plane easting (project coordinates)
- d. North American Vertical Datum 1988 elevation (see 1.7.2, GPS-Derived Orthometric Heights (Elevations), for additional information)
- e. point descriptors
- f. descriptor key

Unless approved otherwise by the region right-of-way engineering supervisor or their designated representative, all GPS photo control monuments (center and wing points) shall be observed only by static or fast static survey methods and procedures in accordance with this chapter.

Conventional survey reports shall include the following.

1. project report (narrative summary)
2. names of individuals and their duties
3. project sketch or map showing project location
4. equipment logs stating manufacture, model.
5. project coordinate report including but not limited to the following for each point:
  - a. point name
  - b. modified state plane northing (project coordinates)
  - c. modified state plane easting (project coordinates)
  - d. North American Vertical Datum 1988 elevation (See GPS-derived Orthometric Heights (Elevations), for additional information.)
  - e. point descriptors
  - f. descriptor key

Submit any reports for GPS surveys needing federal approval to the correct federal agency for review and approval according to the agency's standards and procedures and to the region right-of-way engineering supervisor or their designated representative for review and filing in the region survey office records for the project.

Bind and index all documents, including reports, computer printouts, half-size survey control diagrams or sheets, in a three-ring binder with the job name listed on the spine and cover. No loose-leaf papers will be accepted. All control diagrams must conform to the standards of each region as applicable.

## **1.10 Continually Operating Reference Stations (CORS)**

### **1.10.1 General**

The National Geodetic Survey coordinates a network of Continuously Operating Reference Stations (CORS) that provide GPS carrier phase and code range measurements that can be applied directly to GPS surveys in support of three-dimensional positioning. The CORS system enables positioning accuracies that approach a few centimeters (approximately six centimeters horizontally) relative to the National Spatial Reference System. In March 2002, NGS upgraded NAD 83 positions and velocities for all CORS sites so they equal the transformed values of recently computed International Terrestrial Reference Frame of 2000 (ITRF00) positions and velocities. NGS will continually update all CORS positions to be relative to the ITRF00 annually each year.

All ADOT GPS surveys are referenced and tied into HARN as defined by the NGS National Spatial Reference System (NSRS). Positions obtained by GPS surveys referencing CORS sites may not be relative to the HARN as monumented on the ground. The surveyor will need to take a close look at whether using a CORS station in conjunction with HARN or HARND marks will help to strengthen the GPS survey or degrade it. Also, ellipsoid heights obtained from CORS may not agree with the HARN or HARND.

### **1.10.2 CORS Stations Used for Static, Fast Static, RTK, or PPK Surveys**

Since the November 2002 earthquake, CORS sites are the preferred method of determining coordinates tied to the NSRS. The preferred method is to use OPUS in order to determine a minimum of two primary control points for any project. (See section 1.11.)

The CORS website at <http://www.ngs.noaa.gov/CORS/> provides information and downloads of CORS station files.

## **1.11 On-line Positioning User Service (OPUS)**

### **1.11.1 General**

The National Geodetic Survey operates OPUS to provide GPS users with easier access to the NSRS. OPUS allows users to submit their GPS data files

in RINEX format to NGS, where the data will be processed to determine a position using NGS computers and software. Each RINEX file that is submitted will be processed with respect to three CORS sites. The sites selected may not be the nearest to your site but are selected by distance, number of observations, site stability, etc. The position for your data will be reported back to you via e-mail in both ITRF and NAD83 coordinates as well as UTM and state plane coordinates northing and easting.

### **1.11.2 OPUS use for Static, Fast Static, RTK, or PPK Surveys**

OPUS is the preferred method for establishing control coordinates for all ADOT projects. The precise ephemeris will be used for all OPUS established coordinates.

The NOAA website at [www.ngs.noaa.gov/OPUS/](http://www.ngs.noaa.gov/OPUS/) provides information and downloads of OPUS data.



## Chapter Two: Preliminary Surveys

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### 2.1 Presurvey Conference, Preliminary Survey

Before beginning any survey activities, a presurvey conference will be held. Submit a narrative detailing survey control and use before the presurvey conference. This narrative should include proposed control to be used, GPS calibration parameters and subsequent calibration checks, the basis of coordinates, the basis of vertical, and the basis of stationing and other relevant details on the methodology and project approach. With the approval of the region right-of-way engineering supervisor or their designated representative or designee, and under extenuating circumstances, this narrative may take the place of the presurvey conference.

Any known error or oversight on the plans or specifications will be discussed at the presurvey conference. The project manager will notify all parties at least two weeks before the presurvey conference. The following individuals should attend the presurvey conference for preliminary surveys, as appropriate:

1. the region right-of-way engineering supervisor or their designated representative or designee
2. region right-of-way plans coordinator or designee
3. design engineer or designee
4. project manager or assistant project manager
5. hydraulic engineer or designee
6. bridge engineer or designee
7. environmental manager or designee
8. resident engineer or designee
9. survey crew chief
10. any appropriate subcontractor personnel

If the preliminary survey work will be performed by a contract consultant, either as a prime or subcontractor, the professional land surveyor who will be responsible for the survey work performed must attend the presurvey conference. If the contract includes design processes, the contract consultant should be strongly urged to send the design engineer who will be responsible for that portion of the work. The presurvey conference at a minimum shall include a presurvey conference preliminary survey form and ADOT Standard Specifications for Road and Bridge

Construction, Highway Standard Specifications Section 642, and/or Aviation Standard Specifications Section G 135 Survey Monumentation. The presurvey conference should be held at the site of the proposed project or a tour of the area to be surveyed should be scheduled in a timely manner that is convenient for all attendees. All those attending the presurvey conference should sign the presurvey conference agenda and indicate whether or not they toured the site of the proposed work.

The surveyor in responsible charge for the survey work shall have the following reference materials, if applicable, at the presurvey conference for preliminary surveys:

1. project plans if available (e.g., project control diagram if supplied by ADOT)
2. preliminary survey scope
3. contract and statement of services
3. ADOT Standard Specifications for Road and Bridge Construction
4. ADOT standard plans
5. ADOT Survey Manual
6. ADOT right-of-way manual if right-of-way is required
7. Manual of Uniform Traffic Control Devices (MUTCD)

One of the primary purposes of the presurvey conference is to delineate the requirements and limits of the upcoming survey. While precise horizontal and vertical control may not be necessary for a simple pavement overlay, it may not be obvious that this control may be required for the design and construction of structures. The presurvey conference provides an opportunity to determine the type and amount of survey activities to be done and will prevent over-surveying as well as under-surveying of the project.

### 2.2 Minimum Horizontal Accuracy Tolerance

#### 2.2.1 Minimum Horizontal Accuracy Tolerances at 95% Confidence

The minimum horizontal accuracy tolerance is the computed horizontal ground distance between different datasets for the same point by multiple

observations, either by GPS, conventional methods, or a combination of both. Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to the horizontal ground position that is equal to or smaller than the required accuracy. It is not observation closures itself within a survey that must meet the 95% confidence level, but the ability of that survey to duplicate horizontal values.

### **ADOT Class A Primary**

Accuracy of a primary point is a value that represents the uncertainty of a point at the 95% confidence level with respect to all other points in the primary survey and referenced to the geodetic datum. The geodetic datum referenced is considered to be error free. Once the data for the primary survey has been adjusted, accepted, and finalized, the primary survey shall be considered to be error free and any secondary surveys referenced to the primary survey shall not include the accuracy error of the primary survey.

All primary control monuments either set or re-established as part of the ADOT approved primary control survey must meet the minimum horizontal accuracy tolerance for a ADOT Class A Primary Survey at the 95% confidence level.

### **ADOT Class B Secondary**

Accuracy of a secondary point is a value that represents the uncertainty of a secondary point at the 95% confidence level with respect to all other directly connected points within the secondary survey. The primary survey is considered to be error free and is not to be included in the secondary survey.

Accuracy of a secondary survey for locating or setting any secondary points by conventional methods is analyzed by independent locations of the survey instrument setup and the reference instrument backsight for a particular group of secondary points. Verify the accuracy for that particular group of points within itself. Once the survey instrument is moved to a different point and/or a new backsight is referenced, a new group of points is being collected that is independent from the previous group of points. Verify a new accuracy for the new group of points independently from that of the previous group. (See 2.8, Right-of-Way Survey, for additional information)

All secondary monuments either set or re-established as part of the ADOT approved secondary survey must meet the minimum horizontal accuracy tolerance for a ADOT Class B Secondary Survey at the 95% confidence level.

### **ADOT Class C Topographic Modeling Surveys**

The accuracy of a TMOSS point is a value that represents the uncertainty of the TMOSS point at the 95% confidence level with respect to the survey being performed for a particular group of TMOSS points.

Accuracy of a TMOSS survey performed by RTK or PPK methods is analyzed by independent locations of the base receiver and the initialization for a particular group of TMOSS points. Verify the accuracy for that particular group of points within itself. Once the base receiver is moved to a different point and/or a new initialization is gained, a new group of points is being collected that is independent from the previous group of points. Verify a new accuracy for the new group of points independently from that of the previous group. (See Chapter 1, GPS Surveys, for additional information.)

Accuracy of a TMOSS survey performed by conventional methods is analyzed by independent locations of the survey instrument setup and the reference instrument backsight for a particular group of TMOSS points. Verify the accuracy for that particular group of points within itself. Once the survey instrument is moved to a different point and/or a new backsight is referenced, a new group of points is being collected that is independent from the previous group of points. Verify a new accuracy for the new group of points independently from that of the previous group. (See 2.12, Topography Survey, for additional information.)

All Class C TMOSS points collected as part of the ADOT-approved TMOSS survey shall meet the minimum horizontal accuracy tolerance for a ADOT Class C TMOSS survey at the 95% confidence level.

### **2.2.2 Minimum Horizontal Accuracy Tolerance Table**

The following minimum horizontal accuracy tolerance table is based on the Geospatial Positioning Accuracy Standards, Part 2, Standards for Geodetic Networks FGDC-STD-007.2-1998 as published by the Federal Geodetic Control Subcommittee (FGCS) of the Federal Geographic Data Committee (FGDC).

These accuracy tolerances have been modified to best suit the needs of surveying for ADOT. minimum horizontal accuracy tolerance. See Sections 1.4 and 1.5 for more information and quality control procedures.

## 2.3 Control Survey

### 2.3.1 General

The purpose of a control survey is to establish a network of physically monumented coordinate points in and along a highway corridor or airport property that provide a common horizontal and vertical datum for the entire project. Normally there are many survey points in a control survey that are not intended as control points. These points are, by their nature, peripheral to a control point. Examples of peripheral points are unoccupied reference and azimuth marks.

The control survey provides a way to tie all of the geographic features and design elements of a project to one common horizontal and vertical coordinate system for aerial, environmental, design, right-of-way, property management, and maintenance.

### 2.3.2 Performed by Professional Land Surveyor

The State of Alaska Board of Registration for Architects, Engineers, and Land Surveyors requires that an Alaska professional land surveyor must direct

any control surveys from which the right-of-way or any land boundary will be calculated, described, or monumented.

### 2.3.3 Types of Control Surveys

The following types of control surveys are performed for ADOT: horizontal and vertical.

### 2.3.4 Types of Control Survey Monuments

ADOT has two distinct control monumentation categories: primary and secondary. It is important for the surveyor to have an understanding of the difference between these two categories and the purpose for which they serve.

### 2.3.5 Primary Control Monumentation

Primary control monuments consist of the horizontal and vertical control monuments established on the ground as the framework for the primary control survey network. This includes the existing control monuments used as reference for establishing the primary control network.

Examples of primary control monuments include but are not limited to the following:

1. Existing High Accuracy Reference Network (HARN) monuments and CORS sites included in the National Geodetic Survey's NSRS as

**Table 2.1**

<i>Typical Classification Type</i>	<i>Horizontal Accuracy Tolerance: 95% Confidence</i>
<b>ADOT Class A Primary</b> Primary control points	0.020 meters or 0.07 feet
<b>ADOT Class B Secondary</b> Secondary control points Aerial survey photo control points (center & wing) Public Land Survey System points Right-of-way points Boundary points Easement points Survey alignment points, etc.	0.031 meters or 0.10 feet
<b>ADOT Class C TMOSS</b> Concrete and asphalt surfaces Roadway striping Bridge structures Drainage structures Earth terrain Tops and toes of slopes Staking for appraisal, etc.	0.031 meters or 0.10 feet

approved by the region right-of-way engineering supervisor or their designated representative for establishing an ADOT control network. (See Chapter 1, GPS Surveys, for additional information on HARN.)

2. Existing monuments referenced to the North American Vertical Datum of 1988 (NAVD 88) such as NGS, U.S. Coast and Geodetic Survey (USCGS), and U.S. Geological Survey (USGS) as approved by the region right-of-way engineering supervisor or their designated representative for use to establish a ADOT control network.
3. Any other existing monumentation as approved by the region right-of-way engineering supervisor or their designated representative for establishing an ADOT control network.
4. Any existing and/or set ADOT monuments as approved by the region right-of-way engineering supervisor or their designated representative to establish an ADOT control network.

ADOT primary control monuments and the monuments used as reference for the establishment of the primary control monuments are considered primary control. Any additional control set from these primary control monuments shall be considered secondary control. See Chapter 1, GPS Surveys, for additional information.

### **2.3.6 Setting of Primary Control Monumentation**

It is critical that the project needs are identified before setting any primary control monumentation. This is typically done through the initial scoping of the project to determine the project limits, factors, and requirements. After the scoping has been completed, the project surveyor will identify areas to install ADOT Type 1 control monuments. The following considerations must be taken into account when identifying a site for installing primary control monumentation:

1. Global positioning sites should be free of vertical obstructions blocking the horizon, such as buildings, overhangs, terrain, trees, fences, utility poles, overhead lines, or any other visible obstructions. Nonobstructed skies 15 degrees above the horizon is best (see Chapter 1, GPS Surveys, for additional information).

2. Radio transmitters, including cellular phone equipment, too close to global positioning sites may disrupt satellite signal reception.
3. Sites close to large flat surfaces such as signs, fences, glass, or utility boxes should be avoided.
4. Sites must have more than 0.2 mile (1,000 feet) between adjacent intervisible control monuments.
5. Establish a minimum of three primary control monuments for each project.
6. If feasible, sites should not be disturbed by future construction activities and should be outside the design toe of slopes and top of cuts for the project.
7. Sites shall be located within the existing highway right-of-way or as near as practical.
8. If a site is located outside the existing highway right-of-way, complete a right of entry form, if necessary, and an easement for access, installation, and maintenance of the control monument will be acquired in ADOT's name for the benefit of the public for the purpose of performing a land survey.

Primary control monuments must have a witness post installed within two feet and facing the control monument, or as approved by the region right-of-way engineering supervisor or their designated representative. ADOT typically uses orange fiberglass witness posts.

All ADOT primary control monuments must be established within the minimum horizontal and vertical accuracy tolerance as required in this chapter for a ADOT Class A Primary monument. See Chapter 1, GPS Surveys, for additional information.

### **2.3.7 Secondary Control Monumentation**

Secondary control monuments are monuments set from the approved primary control monumentation. These secondary control monuments are typically established as survey work points in areas that require additional control be set at a lesser accuracy than that of the primary control network. Establish these work points with the concurrence of the region right-of-way engineering supervisor or their designated representative only for the following areas that can be difficult to survey:

1. area of obstructions of line of sight for conventional surveying,



2. areas of obstructions of the sky for global positioning system surveys, and
3. areas requiring additional control for construction staking.

Examples of secondary control monuments include but are not limited to work points established to obtain data to perform topographic surveys, drainage surveys, utility surveys, appraisal staking, and construction staking.

Work points are established to obtain data for the following types of monumentation and features: Public Land Survey System (PLSS), right-of-way, property boundary, easement, and topography and terrain.

### **2.3.8 Setting Secondary Control Monumentation**

ADOT control monument caps or disks shall be set for any secondary control monument point. All secondary control monuments shall be set solidly into the ground and must consist of a material that will hold the required minimum horizontal and vertical accuracy tolerance for a ADOT Class B Secondary monument for the entire time the point is needed for the project. Set these monuments in locations not to be confused as being property boundary monuments. If a cap is placed on the secondary control monument, it should be stamped “control point,” “traverse point,” “GPS point,” or similar along with its identifying point number and be punch marked with a point not larger than 3 mm.

All ADOT secondary control monuments must be established within the minimum horizontal and vertical accuracy tolerance as required in this chapter for a ADOT Class B Secondary monument. See Chapter 1, GPS Specifications, for additional information.

### **2.3.9 Setting Secondary Control Monuments for Construction Staking**

For setting of secondary control monuments for construction staking, see AKDOT Construction Survey Requirements for the minimum horizontal and vertical accuracy tolerance for the item being staked.

### **2.3.10 Monument Material**

**Primary Monument:** The primary monument, at a minimum, must be made from 2-inch diameter non-ferrous pipe at least 30 inches long, with a minimum

4-inch flange at the bottom and with magnets attached at the top and bottom. A minimum 2 <sup>3</sup>/<sub>8</sub> inch diameter nonferrous metal cap must be permanently attached to the top. Monuments of higher quality or establishment standards, such as driven rods and airport “PACS and “SACS” may also be utilized for primary monuments. Mark the cap around the outside edge with the words “STATE OF ALASKA DOT&PF.” Permanently stamp every monument with the surveyor’s registration number, the year set, and the point/corner identification. Orient the cap so that the data may be read when the reader is facing north, except for centerline monuments that will be oriented to be read facing up-station.

**Secondary Monument:** Secondary monuments must be made from a minimum <sup>5</sup>/<sub>8</sub> inch x 30 inch rebar with a 2-inch aluminum cap attached to the top. Mark the cap around the outside edge with the words “STATE OF ALASKA DOT&PF.” Permanently stamp every secondary monument with the surveyor’s registration number, the point/corner identification, and the year set.

## **2.4 Horizontal Control Survey**

### **2.4.1 Types of Horizontal Control Surveys**

The following types of horizontal control surveys are typically performed for ADOT: (1) GPS surveys (static and fast static), and (2) conventional survey methods (traverse angles and distances). See Chapter 1, GPS Surveys, for additional information.

### **2.4.2 Primary Horizontal Control Survey**

All primary horizontal control surveys must be referenced to and tied into the HARN as defined by the NGS National Spatial Reference System if within 50 road miles of that system. Otherwise the primary horizontal control will be referenced and tied into the CORS sites.

NGS defines and manages the NSRS, which is the framework for latitude, longitude, height, scale, gravity, and orientation throughout the United States. NSRS provides the foundation for transportation, communication, and defense systems; boundary and property surveys; land records systems; mapping and charting; and a multitude of scientific and engineering applications. NGS also conducts research to improve the collection, distribution, and use of spatial data.

The NSRS is a system of permanently monumented survey marks and their corresponding geodetic data references to the North American Datum of 1983 (NAD 83). The NSRS is made of federal base networks, cooperative base networks, and user densification networks, all of which are known as Alaska's High Accuracy Reference Network, and Alaska's HARN densification surveys (HARND) as defined by ADOT in cooperation with NGS. See Chapter 1, GPS Surveys, for additional information on HARN.

### **2.4.3 GPS Primary Horizontal Control Survey Methods**

All primary horizontal control surveys using GPS methods must be performed in accordance with Chapter 1, GPS Surveys, and must meet the minimum horizontal accuracy tolerance for a ADOT Class A Primary survey.

### **2.4.4 Conventional Primary Horizontal Control Survey Methods**

All primary horizontal control surveys performed by conventional methods must be closed traverse or closed loop surveys in accordance with this chapter and must meet the minimum horizontal accuracy tolerance for a ADOT Class A Primary survey.

Each item of conventional survey data collected must have a minimum of four sets of observations. Distances will be measured in both direct and reverse positions (face 1 and face 2) of the telescope, with a minimum of two sets from each terminus for a total of four sets. Angles will be repeated, observing direct and reverse positions (face 1 and face 2) of the telescope (i.e., one set), either by accumulating angles or closing the horizon. Angular closure is not to exceed  $15'' \sqrt{N}$ , where N = the number of stations.

The raw unadjusted data is to be analyzed statistically to assure the minimum specified accuracy level is achieved. Any observation more than 0.02 feet from the mean distance and 6 seconds of arc from the mean angle must be rejected. Closed traverse linear closure shall meet or exceed 1:50,000.

### **2.4.5 Secondary Horizontal Control Surveys**

All secondary horizontal control surveys must be referenced to and tied into an approved ADOT primary horizontal control survey.

### **2.4.6 GPS Secondary Horizontal Control Survey Methods**

All secondary horizontal control surveys using GPS methods must be performed in accordance with Chapter 1, GPS Surveys, and must meet the minimum horizontal accuracy tolerance for a ADOT Class B Secondary survey.

### **2.4.7 Conventional Secondary Horizontal Control Survey Methods**

All secondary horizontal control surveys using conventional methods shall consist of closed traverse or closed loop surveys in accordance with this chapter and shall meet the minimum horizontal accuracy tolerance for a ADOT Class B Secondary Survey.

Each item of conventional survey data collected must have a minimum of two sets of observations. Measure distances in both direct and reverse positions (face 1 and face 2) of the telescope, with a minimum of one set from each terminus for a total of two sets. Angles will be repeated, observing direct and reverse positions (face 1 and face 2) of the telescope (i.e., one set), either by accumulating angles or closing the horizon. Angular closure not to exceed  $15'' \sqrt{N}$ , where N = the number of stations.

All horizontal control survey measurements shall be recorded in field books. The books shall also be used to record all measurements and references to back-site checkshots, control points found or set, section monuments, centerline monuments, and all found property corners. Electronic data collection can be used to record control data but is not acceptable as the sole data source for survey measurements, because this data needs to be recorded in field books for control surveys. Distances shall be measured and recorded in both feet (nearest 0.01 foot) and meters (nearest 0.001 meter) unless electronic data collection is used. In the case of electronic data collection, distances should be measured in the project units and manually recorded and also electronically recorded on the data collector. Record distances in both the direct and reversed positions.

Recorded angle sets, at a minimum, will contain a direct and reverse pointing of both the forward angle right and the horizon closure angle. When the difference between a direct and reverse pointing of an angle pair exceeds six seconds (ten seconds for distances of

150 feet or less), then that angle pair shall be rejected and remeasured. When the sum of the mean angle right and the mean horizon closure angle differs from 360 degrees by more than ten seconds, that angle set shall be rejected and remeasured. The adjusted angle right (the mean angle right corrected by one half of the difference between the sum of the means and 360 degrees) shall be used for all computations. All foresights and backsights shall be of the fixed leg type.

Auxiliary control points and/or monuments may be side-tied, providing that (a) the point is tied from two traverse points or tied with two different backsight points that are closed traverse points or (b) the point is tied from one traverse point with only one backsight, provided there is a three-dimensional backsight check recorded in the field book. When there is more than one value, the raw coordinate values for these side ties (calculated from the adjusted traverse coordinates) shall be within 0.10 feet. The final coordinate values for side-tied points shall be the mean of the two raw coordinate values or proportionally weighted based on the strength of the observations. Auxiliary control points shall never be more than one point away from the closed traverse points and shall only be used to tie existing monumentation where inverse distances from similar monumentation can be used to confirm the location. Auxiliary control points shall be, at minimum, a PK nail (mag nail preferred) in paved areas or a six-inch spike in unpaved areas.

The raw unadjusted data is to be analyzed statistically to assure the minimum specified accuracy level. Any observation more than 0.03 feet from the mean distance or 10 seconds of arc from the mean angle must be rejected. Secondary horizontal control surveys must be tied to the primary control survey by closed traverse methods, beginning and ending on two different primary control monuments, and linear closure shall meet or exceed 1:10,000.

## **2.5 Vertical Control Survey**

### **2.5.1 General**

You must be able to obtain accurate elevations to maintain effective vertical control. Differential leveling is the ADOT-approved process for determining and establishing elevations of primary control monuments and differences in elevations between points and controlling grades in construction surveys.

There are many different types of leveling, such as differential, stadia, reciprocal, profile, trigonometric, and barometric. While differential leveling is discussed in this manual, the theory and application of all other leveling methods will not be discussed. Information on these types of leveling can be found in most surveying textbooks.

Only use trigonometric leveling when it is approved in advance by the region right-of-way engineering supervisor or their designated representative. (See addendums for California-NGS Interim Trigonometric Leveling draft specifications.)

### **2.5.2 North American Vertical Datum of 1988 (NAVD 88)**

Elevations for all vertical control surveys shall be established from existing national benchmarks, referenced and tied to the North American Vertical Datum of 1988 (NAVD 88). The following are some examples of these types of benchmarks:

1. National Oceanic and Atmospheric Administration
2. National Geodetic Survey
3. United States Coast & Geodetic Survey
4. United States Geological Survey
5. National Geodetic Survey CORS data for remote areas.

If there is a choice between a first order benchmark and any lower order benchmark, the higher order benchmark will be used. The past practice of referencing to a fictitious elevation datum such as an assumed elevation at the top of fire hydrant has been discontinued. Don't use existing municipal datum unless approved in advance by the region right-of-way engineering supervisor or their designated representative.

When directed by the region right-of-way engineering supervisor or their designated representative, existing vertical datums, currently established for given areas and multiple projects, shall be utilized. These datums will be defined with an existing network of benchmarks. Examples of these datums are the Anchorage Bowl GAAB72 datum and tidal datums established by the National Ocean Service.

A complete description of the benchmark used and the date on the datasheet that states the elevation must be included in the survey project file.

### **2.5.3 Benchmarks**

A complete and accurate network of vertical control monuments (benchmarks) must be established for preliminary and construction surveying. Benchmarks for ADOT project control consist of the primary control monuments and their corresponding elevation data shown on the project control diagram.

### **2.5.4 Setting Primary Control Benchmarks**

Set primary control benchmarks in accordance with this manual, and set them in locations that will not be disturbed by or conflict with the project, construction, or maintenance activities. The primary control benchmark spacing must not be more than 1.0 mile (5,000 feet) from other benchmarks. Primary control benchmarks must have a witness post installed within 2 feet and facing the benchmark, or as approved by the location survey manager.

Differential leveling is the ADOT-approved process for determining and establishing elevations of any primary control benchmark. Only closed-level circuits will be allowed for primary elevation control. The primary control benchmark spacing requirement is based on the limitations of leveling equipment. The spacing requirement may be varied only if the leveling procedure, such as differential leveling, trigonometric leveling, or GPS-established elevations, produces acceptable results in tolerance and is approved by the region right-of-way engineering supervisor or their designated representative. Proof of required tolerance must be documented in the field notes. Primary control benchmarks shall meet the minimum vertical accuracy tolerance in accordance with this chapter.

### **2.5.5 Setting Secondary Control Benchmarks**

Set secondary control benchmarks in accordance with this manual in locations that will not be disturbed by or conflict with the project, construction, or maintenance activities. Secondary control benchmark spacing must not be greater than 0.5 mile (2,640 feet) from other benchmarks. Secondary control benchmarks must be set solidly into the ground and consist of a material that will hold the required minimum vertical accuracy tolerance as required in this manual for the entire time of the survey. Differential leveling is the ADOT-approved process for determining and establishing elevations of any secondary control bench-

mark. Only closed-level circuits will be allowed for secondary elevation control. Electronic trigonometric leveling methods may only be used when approved in advance by the region right-of-way engineering supervisor or their designated representative.

The secondary control benchmark spacing requirement is based on the limitations of leveling equipment. The spacing requirement may be varied only if the leveling procedure, such as differential leveling, trigonometric leveling, or GPS-established elevations, produces acceptable results in tolerance and is approved by the region right-of-way engineering supervisor or their designated representative. Proof of required tolerance must be documented in the field notes.

Secondary control benchmarks shall meet the vertical accuracy tolerance in accordance with this chapter.

In all cases, use suitable objects for benchmarks, such as monument caps grouted into bridge abutments or boulders, rods driven to refusal, or other such stable objects. Secondary benchmarks can be spikes in larger trees and other material. Objects such as primary monuments on 30-inch pipes, driven rebar, or spikes in manmade objects such as power poles subject to frost effects should not be used as benchmarks.

### **2.5.6 Vertical Accuracy Tolerance**

The following vertical accuracy tolerance (Table 2.2) shall apply to all ADOT Class A primary control benchmarks and surveys and all ADOT Class B secondary control benchmarks and surveys, including aerial photo control surveys (center and wing points): Total maximum error allowed for each loop shall be computed using the following formula, 0.035 feet times the square root of the loop distance in miles for Class A and 0.05 feet times the square root of the loop distance in miles for Class B.

$$0.035\text{ft}\sqrt{d} \text{ miles Class A}$$

$$0.050\text{ft}\sqrt{d} \text{ miles Class B}$$

The results of this evaluation shall be recorded in the field book for each differential level loop. At least two established benchmarks on the same or mathematically related datum shall be used to verify that the starting mark has not been disturbed. No adjustments of the data used for this evaluation will be allowed.



**Table 2.2**

<i>Classification Type</i>	<i>Vertical Accuracy Tolerance</i>
ADOT Class A Primary	0.035ft√d miles
NGS 1 <sup>st</sup> Order BM Reset or Preservation	
ADOT Class B Secondary	0.050ft√d miles
Secondary Control points Aerial Survey Photo Control points Project Bench Marks and Project Temporary Bench Marks, Hard Shots such as Manholes, Curb and Gutter, Bridge Decks	
ADOT Class C TMOSS	
Earth terrain Tops and toes of slopes Slope Stakes Staking for Appraisal Etc. Trig Level auxiliary control	(see construction requirements for specifics on objects being located)

## 2.6 Differential Leveling

### 2.6.1 General

Differential leveling is the most common and economical method for a proficient crew. Differential leveling theory and application can be expressed by two equations as follows:

Elev. A + BS (backsight) = HI (height of instrument)

HI – FS (foresight) = Elev. B.

### 2.6.2 Leveling Definitions

Benchmark (BM): A permanent point of elevation.

Temporary Benchmark (TBM): A semipermanent point of elevation.

Leveling Point (LP): A point temporarily used to transfer an elevation.

Backsight (BS): A rod reading taken on a point of known elevation in order to establish the elevation of the instrument line of sight.

Height of Instrument (HI): The elevation of the line of sight through the level.

Foresight (FS): A rod reading taken on a turning point, benchmark, or temporary benchmark in order to determine its elevation.

Intermediate Foresight (IS): A rod reading taken at any other point in order to determine its elevation.

### 2.6.3 Curvature and Refraction

The line of sight through a well-maintained and adjusted level is in fact almost a horizontal line perpendicular (or plumb) to the pull of gravity at the level's particular location. All rod readings taken with the level will contain errors over a distance known as curvature and refraction. Curvature is the result of the curvature of the Earth, and refraction is the result of light bending as it passes through one medium into another. Although the effect of curvature is quite small (about 0.024 feet over a 1,000 foot distance), the combined effect of curvature and refraction has a significant effect on leveling as shown in the table below:

Use the following leveling techniques to minimize the effects of curvature and refraction:

1. Site distances must average 250 feet in length (500 feet for trig levels).
2. Site distances between turning points shall not exceed 500 feet maximum (750 feet for trig levels).
3. differences in the height of the instruments should be minimized to minimize the temperature differences due to air temperature graduations.
4. The line of sight must clear obstacles by a minimum of 1.5 feet to avoid effects of adverse refraction.
5. Set up the level midway between the backsight and foresight turning points, keeping the sights balanced.

### 2.6.4 Equipment Types

The dumpy level is the basic leveling instrument. At one time it was used extensively on all engineering projects. Today it has been replaced by more sophisticated level instruments: automatic optical levels and automatic digital levels.

The digital level is the preferred instrument for ADOT primary and/or secondary control level work. The digital level has electronic recording of data as opposed to handwritten field notes and it can electronically perform calculations for balancing sites, distances, elevation differences, and level circuit closures. A digital bar code level rod is required to take readings with a digital level; however, most digital levels are also capable of being used as an optical level as well.

When optical levels are used, use the Philadelphia rod to obtain rod readings. Do not use fiberglass or other types of so called “sewer rods” or telescoping rods for any primary or secondary control level work. Hand levels can be used as an aid to prevent the instrument from being set up too high or too low.

### 2.6.5 Methods

There are four methods commonly used for differential leveling:

1. single wire
2. direct-reading rod (Lenker rod)
3. double rod
4. three wire

Three-wire leveling is used in conjunction with an invar rod to obtain higher accuracy for work such as relocating NGS, USGS, or other such benchmarks. Leveling is generally run in two directions, the original run and the return run.

### 2.6.6 Single Wire

Single-wire leveling is the most common method of leveling and is used extensively throughout preliminary and construction surveying.

### 2.6.7 Direct Reading Rod (Lenker Rod)

Do not use the direct-reading rod, also known as the Lenker rod, in place of a Philadelphia rod for running primary or secondary control level circuits.

### 2.6.8 Double Rod

Double-rod leveling is the most reliable method for eliminating errors. It is also the most time-consuming, and should not be used except when a very high degree of precision is required. If you do use this method, use extreme care to prevent errors in recording.

In double-rod leveling, plus and minus sights are taken from two rods (on separate lines) for each setup of the instrument. These are carried in separate columns of the field notes. From these rod readings, two heights of instruments will be computed. Any considerable discrepancy between the two instrument heights for one setup will indicate that a mistake has been made, and the readings must be retaken.

### 2.6.9 Profile Leveling

Profile leveling notes record the elevation and description of points along the centerline or control line that have previously been surveyed or staked. The arrangement is much the same as that of level notes. The station numbers are entered in the first column, and for clarity, the profile elevations are shown in a column separate from the turning point. Keep the descriptions of the elevation points on the right-hand page brief. Obtaining profile elevations directly from a direct-reading rod saves considerable time. Profile leveling is generally used if the cross-sections are going to be taken by transit or theodolite methods.

### 2.6.10 Reducing Errors

Use the following precautions and techniques in order to eliminate or reduce the effect of errors:

1. Limit the length of sights to a distance that permits you to read the rod rapidly and distinctly without eyestrain. For average conditions, this would be approximately 250 feet. For

**Table 2.3. Effects of Curvature and Refraction**

Distance (m)	30	60	100	120	150	300	1 km
(c + r)m	0.0001	0.0002	0.0007	0.001	0.002	0.006	0.068
Distance (ft)	100	200	300	400	500	1000	1 mile
(c + r)ft	0.000	0.001	0.002	0.003	0.005	0.021	0.574

consistent results, the length must be shortened as observing conditions change. Backsights and foresights from any one setup must be practically equal. This will minimize the effect of curvature, refraction, and imperfection in the instrument. Paced distances are usually close enough. The distance between turning points should never be more than 500 feet.

2. Height observation should be such that the difference in refraction of backsights and foresights is negligible. Refraction varies with the difference in temperature between the ground and the air above it. Usually, reading the rod one foot or higher above ground level will be satisfactory. Early morning and late afternoon are the most critical times of day.
3. The speed of reading the backsights and foresights from any given setup has as much effect on accuracy as any leveling operation. It is essential that all observations from any one instrument height be rapidly completed. The greater the time interval between backsights and foresights, the greater the change in conditions affecting the stability of the instruments. Hesitation in reading the rod will increase eyestrain and fatigue, possibly detracting from the reading's accuracy. The instrument should be set up on firm, stable ground whenever possible, to help prevent settling of the tripod legs.
4. Make sure the wind velocity does not cause a noticeable disturbance in the stability of the level and rod positions. This is particularly true on sloping terrain. Wind has the effect of mixing the air and thus reducing differential refraction.
5. To ensure a more accurate reading, the rod person should lean the rod slowly toward and then away from the level, passing through vertical each time. This is known as tilting the rod. The lowest reading on the rod is the correct value and the same as if the rod were held perfectly plumb. For less accurate work, the rod person can balance the rod between their fingers. When available, rod levels can also be used, and this offers a great advantage over tilting the rod.
6. Don't use targets except for reciprocal leveling. Their use in differential leveling wastes time, and reading precision is frequently less than by direct reading.
7. Use one place on the cross hair for telescope observations. This will eliminate errors due to inclined horizontal cross hairs. A good place is just right or left of the vertical cross hair.
8. The bubble must be in the same position for both the backsights and foresights. In dumpy levels, the level vials are usually graduated in 2 mm intervals. The angular value per graduation for most engineering levels used is 20 or 30 seconds. One division of a 30-second vial at 150 feet could cause an error of 0.015 foot. The instrument person must be in the habit of always checking the bubble just before and just after taking a reading.
9. Double turns can be used to prevent the common one foot bust. Double turns consist of setting an extra turning hub at approximately one foot difference in elevation from the regular turning hub. Thus, one foot errors can readily be caught.
10. If you must rerun portions of the leveling work because of errors or blunders, use longer sights and fewer setups to detect large mistakes.
11. Instruments should be checked for adjustment before running a bench line. Two pegging the level is a good check. The field notes for this test must be recorded and maintained as a portion of the instrument calibration requirements. (See 2.6.12, Two Peg Test for Levels, for additional information.)
12. All turning points and benchmarks must be firm and definite to the extent that the shoe or foot of the rod will make contact at only one point. When the point is on a rock or on a paved surface, it should be circled with keel or paint. On single-wire leveling, as many turning points as necessary should be semipermanent but identified so they may be recovered to close the circuit.
13. Benchmarks must be objects that can be easily described and positively identified. Set benchmarks at locations least likely to be disturbed. In areas subject to freezing, the base of the support must extend well below the freezing zone so that frost action will not cause heaving. Benchmarks should not be placed in poles because frequently poles are moved, they may settle, or the spike may cause personal injury. In areas where a pole would be the most

desirable location, the benchmark should be placed in the ground a safe distance from the pole and referenced to the pole.

14. The finished gradeline should always be considered in setting a benchmark. Space the benchmarks so that any finished grade point will be within instrument sight of an established benchmark. There are situations where this is impractical. In any case, the distance between benchmarks should not exceed 500 feet. It is just as easy to set a benchmark as it is to set a turning point when you are in a place where it may be useful during construction.

### **2.6.11 Field Notes**

Field notes for level work must contain enough information to follow in the footsteps of the surveyor who performed the level work. Field notes for level work require but are not limited to the following:

1. benchmark monument descriptions (including all monument stamping)
2. benchmark establishing authority (i.e., NGS, USCGS, USGS, ADOT)
3. benchmark monument locations (such as highway, milepost, cross streets, to reach descriptions)
4. benchmark record elevation and datum (include any benchmark datasheets into the survey project records)
5. description of all set or found temporary benchmark and/or turning points (TP) used as part of the level circuit
6. all backsight and foresight rod readings
7. all calculated instrument height
8. minimum vertical accuracy tolerance calculations and checks
9. all adjustments made to the level data
10. all final benchmark, temporary benchmark, and TP elevations.

### **2.6.12 Two-Peg Test Method for Levels**

Before the start of any level circuit, check the level by the two-peg test method. The two-peg test method for levels checks that the line of sight through the level's optical telescope is horizontal when the instrument is plumb (i.e., perpendicular to the pull of gravity at the level's particular location).

To perform the test, drive two stakes firmly into the ground on a relatively level surface at a distance of 250 to 300 feet apart. Then set up the level midway between the two stakes and take rod readings at both locations. If the line of sight through the level is out of adjustment (therefore is not horizontal), the error of the rods' readings will be identical at both rods because the level is halfway between the two stakes. Therefore, the calculated difference in elevation between the two stakes will be the true difference in elevation.

Then move the level to either one of the two stakes within the minimum manufacturer's sight distance of the instrument. Again, take readings on both rods, calculate the elevation difference, and compare it to the first elevation difference calculated from when the level was set midway between the stakes.

If the two sets of elevation differences exceed the instrument manufacturer's stated accuracy, the level is out of adjustment. Either perform a collimation correction if the level is capable of doing so, or take the level to the manufacturer's shop for repair.

## **2.7 Project Control Drafting Standards**

### **2.7.1 General**

The purpose of the survey control diagram is to graphically show how the survey was performed in the field. The project control diagram shows primary control monumentation and the control survey used to obtain the horizontal and vertical data for the project control monuments, meeting the minimum horizontal and vertical accuracy tolerance for a ADOT Class A Primary survey as required in this chapter. This diagram is either for a large-scale corridor control survey, a small-scale control survey, or a reobservation of already existing primary control monuments to obtain new and updated data. Whenever a primary control monument is established in the ground, a control survey is performed, and this diagram shows all primary control monuments and the final survey data for the monuments. Aliquot, right-of-way, property, land, or any other property boundary monuments do not have to be shown on this diagram. This diagram will be filed with the region right-of-way engineering supervisor or their designated representative and will be recorded at the appropriate recording office. See 2.9, Land Survey Control Diagram, for additional information.



### 2.7.2 Minimum Standards

The project control diagram at a minimum must:

1. be prepared on 22 by 34 inch mylar, with two half-sized copies on 11 by 17 inch paper. All sets must be signed and sealed with the appropriate certificates and signatures. Certificates will be required only on the title sheet but seals are required on all sheets.
2. have the following in the title block:
  - a. project control diagram
  - b. ADOT project name
  - c. ADOT project number
  - d. ADOT PROJECT CODE number
  - e. creation date
  - f. last modified date
  - g. total number of sheets
3. be prepared at a readable scale using as many sheets as required to readily identify the location of primary control monuments. Refer to design drafting standards for font size, line types, etc.
4. show prominent topographic features with names labeled, such as highways, roads, streets, mileposts, fences, lakes, rivers, streams, tunnels, and buildings, to readily identify the location of primary control monuments.
5. show all found and set primary horizontal and vertical control monument locations with an appropriate symbol. Include a symbol legend.
6. show descriptions of all found and set primary horizontal and vertical control monument material and cap markings, including any point numbers or names and milepost. State if the monument was found or set.
7. contain a HARND geodetic coordinate summary table showing all existing HARND primary control monuments used to reference and tie in the survey, and their record geodetic control data, including
  - a. point's designation
  - b. latitude
  - c. longitude
  - d. ellipsoid height
  - e. orthometric height (NAVD 88 elevation)
  - f. state plane coordinate northing
  - g. state plane coordinate easting
  - h. point description
8. Contain a geodetic coordinate summary table showing the following primary control monument final adjusted geodetic control data including.
  - a. point's four-digit number
  - b. latitude
  - c. longitude
  - d. ellipsoid height
  - e. orthometric height (NAVD 88 elevation)
  - f. state plane coordinate northing
  - g. state plane coordinate easting
  - h. point description (including, highway, milepost, and monument type, e.g., Type 2)
9. Contain a project coordinate summary table, showing the following primary control monument final adjusted geodetic control data.
  - a. point's four digit number
  - b. northing
  - c. easting
  - d. orthometric height
  3. point description (including, highway, milepost, and monument type, e.g., Type 2)
10. Show section, township, range, and meridian designations.
11. Have a bar scale and a statement of scale
12. Have a north arrow

### 2.7.3 Minimum Notes and Surveyor's Certification

The project control diagram must, at a minimum, contain the following notes and certifications:

1. Surveyor's certification by the Alaska professional land surveyor in responsible charge of the fieldwork certifying that the survey was performed under their direct supervision and checking and meets or exceeds a ADOT Class A Primary survey.
2. Basis of bearing stating the bearing between two primary control monuments, along with a description of the monuments and the datum referenced.
3. Basis of elevation, describing at least one existing primary control monument with a orthometric elevation of record, along with a

description of the monument, its location, and the datum referenced.

4. Basis of stationing describing abutting projects by name and federal number.
5. Coordinate datum stating how to convert from state plane coordinates to project coordinates. The statement shall include the following:
  - a. project elevation
  - b. state plane coordinate zone
  - c. project combined factor
  - d. meters to feet conversion (U.S. survey foot = 3,937/1,200)
  - e. northing and easting
  - f. a detailed statement of how to convert from state plane coordinates to project coordinates.
  - g. epoch date
6. "Title commitment, or title research, is not a part of this survey, therefore easements, rights, and restrictions of record were not researched and are not shown on this diagram."
7. "NOTE: This survey does not constitute a subdivision as defined by Alaska Statute 40.15.900(5)."
8. all notes required for recording the document at the proper recording district.
9. the diagram must comply with the region-specific requirements for survey control diagrams.

See section 1.9 for more details.

## **2.8 Right-of-Way Survey**

### **2.8.1 General**

There are two phases of the right-of-way survey: (1) preliminary or base mapping survey, and (2) final or post-construction record of survey. The preliminary right-of-way phase gathers data on the existing physical evidence found in the field in order to determine the existing right-of-way boundary. The final right-of-way phase is to design the new right-of-way boundary and to monument that boundary in the field by setting right-of-way monuments as required per project. The following specifications apply to both the preliminary and final right-of-way phases, from the gathering of preliminary field data to setting of the final right-of-way monuments in the field.

### **2.8.2 Performed by Professional Land Surveyor**

The State Board of Architects, Engineers, and Land Surveyors requires that right-of-way surveys and boundary monumentation be performed under the direction and control of a Alaska professional land surveyor. This land surveyor must be an active, on-site field supervisor of the survey crew and be directly involved in the preparation of the base maps, right-of-way maps, and parcel plats.

### **2.8.3 Preliminary or Base Mapping Phase**

The preliminary phase of the right-of-way survey consists of locating all existing monuments in the field, such as:

1. public land survey system (PLSS) aliquot monuments
2. right-of-way monuments
3. property boundary monuments
4. easement monuments
5. survey alignment monuments
6. any other monuments identified in the preliminary survey scope

After both the office research and the preliminary phase are complete, perform a boundary analysis to determine the right-of-way geometry and boundary limits. This analysis may include other types of surveys such as topographic surveys.

**Under no circumstances shall any PLSS, right-of-way, easement, or property boundary monument used for the boundary analysis be located by topography survey accuracy tolerances or methods.**

### **2.8.4 Accuracy Tolerance**

All right-of-way surveys (preliminary and final) must be tied to the ADOT-approved primary control survey referencing the primary control monument data shown on the project control diagram and must meet the minimum horizontal accuracy tolerance for a ADOT Class B Secondary survey as required in this chapter.

### **2.8.5 GPS Survey Methods**

All right-of-way surveys (preliminary and final) performed by GPS methods must be performed in accordance with Chapter 1, GPS Specifications, meeting the



minimum horizontal accuracy tolerance for a ADOT Class B Secondary survey as required in this chapter.

### **2.8.6 Conventional Survey Methods**

All right-of-way surveys (preliminary and final) performed by conventional survey methods shall meet the minimum horizontal accuracy tolerance for a ADOT Class B Secondary survey as required in this chapter by using one or more of the following methods as approved by the region right-of-way engineering supervisor or their designated representative:

1. The monuments (either found or set) shall be tied to the primary control survey by closed traverse methods consisting of direct and reverse (face 1 and face 2) instrument readings, beginning and ending on two different primary control monuments. The unadjusted closed traverse shall meet the minimum horizontal accuracy tolerance for a ADOT Class B Secondary survey as required in this chapter. Apply a least squares adjustment. The region right-of-way engineering supervisor or their designated representative can waive the adjustment requirement.
2. The monuments (found or set) shall be tied to the primary control survey by double side shots consisting of direct and reverse (face 1 and face 2) instrument readings from one primary control monument, with the backsight referencing another primary control monument. Then take a second set of direct and reverse readings from a different primary control monument or backsight. The difference of these observations must meet the minimum horizontal accuracy tolerance for a ADOT Class B Secondary survey as required in this chapter. No adjustment of the data will be permitted without the consent of region right-of-way engineering supervisor or their designated representative. The final coordinate data for the right-of-way monument shall be the average of the sets of double side shots.
3. Open-ended traverse or single side shots will not be accepted for any preliminary or final right-of-way survey.

### **2.8.7 Right-of-Way Monuments Defined**

Right-of-way monuments are markers used to define the Alaska state transportation boundaries in the field. These markers are not to be confused with aliquot corners or corners that define the intersecting property lines with the highway boundary. Furthermore, boundary surveys of adjacent properties are not completed by ADOT, and any discrepancies observed are not adjusted or resolved. Right-of-way monuments are NOT set to delineate the property boundary lines of adjacent landowners, except as related to right-of-way.

### **2.8.8 Final or Post-Construction Record of Survey Phase (Right-of-Way Monuments)**

Right-of-way monuments shall be set at their corresponding coordinates as shown on the monumentation sheet of the right-of-way plans. When monumenting the right-of-way, it is the surveyor's responsibility to verify that the latest set of right-of-way plans are being used.

Establish all right-of-way monuments within the minimum horizontal accuracy tolerance as required in this chapter for an ADOT Class B Secondary Survey.

ADOT recommends that "line of sight" monuments mathematically tied to right-of-way be set along the corridor. The region right-of-way engineering supervisor or their designated representative can modify the location and density of the right-of-way monuments based on project requirements.

Any other points can be approved by the region right-of-way engineering supervisor or their designated representative due to field conditions encountered during setting of the right-of-way monuments.

Right-of-way monuments will have a witness post installed within 2 feet and facing the monument, or as approved by the region right-of-way engineering supervisor or their designated representative. For setting easement monuments, the witness post requirement may be waived by the region right-of-way engineering supervisor or their designated representative.

ADOT uses the orange fiberglass type of witness post typically used throughout Alaska.

All right-of-way monument caps set in the field must be stamped with the year the monument was set and the Alaska professional land surveyor number of the person setting the monument.

### 2.8.9 PLSS Aliquot Monuments

The Alaska professional land surveyor in charge shall make a diligent search for any required aliquot monuments, and shall restore, rehabilitate, upgrade, and file monument records for any aliquot monuments used as boundary control or as required in the preliminary survey scope, within the survey project limits in accordance with Alaska Revised Statutes and the Alaska Society of Professional Land Surveyors (ASPLS) Standards of Practice. The procedures used shall be as specified by Alaska Revised Statutes and the current *BLM Manual of Survey Instructions of the Public Lands of the United States*.

The Alaska professional land surveyor in charge will file monument records. Send a signed and sealed monument record to the region surveyor coordinator. The Alaska professional land surveyor who is certifying the monument record shall be the same professional land surveyor whose number is stamped on the monument in the field.

Send photographs of all aliquot monuments restored, rehabilitated, or upgraded to the region right-of-way engineering supervisor or their designated representative. The photographs at a minimum must show:

1. a closeup of the existing found monument showing the cap markings,
2. each cardinal direction with the monument and the horizon in view, and
3. a closeup of the restored, rehabilitated, or upgraded monument.

Setting of any aliquot monument shall meet the minimum horizontal accuracy tolerance for an ADOT Class B secondary survey as required in this chapter.

## 2.9 Land Survey Control Drafting Standards

### 2.9.1 General

The purpose of the land survey control diagram is to graphically show how the survey was performed in the field and present evidence found in the field. The land survey control diagram shows land property boundary monumentation and the land survey performed to obtain the horizontal and vertical data for the land property boundary monumentation, meeting the minimum horizontal and vertical accuracy

tolerance for a ADOT Class B Secondary survey as required in this chapter.

This diagram shows all aliquot, right-of-way, property, land, easement, and any other property boundary monuments along with the final data obtained for these monuments.

No determination is made as to whether these found monuments are in their proper position and if they are in fact at the corners they are intended to monument. Additional monuments and the final data obtained for these monuments may be shown as determined necessary by the region right-of-way engineering supervisor or their designated representative (e.g., control monuments).

File this diagram with the region right-of-way engineering supervisor or their designated representative. This will be recorded in the proper recording district within 12 months of final approval.

### 2.9.2 Minimum Standards

The land survey control diagram at a minimum will:

1. be prepared on 22 by 34 inch mylar, with two half-sized copies on 11 by 17 inch paper. All sets will be signed and sealed with the appropriate certificates and signatures. Certificates will be required only on the title sheet but seals are required on all sheets.
2. have the following in the title block:
  - a. land survey control diagram
  - b. ADOT project name
  - c. ADOT project number
  - d. ADOT project code number
  - e. creation date
  - f. last modified date
  - g. total number of sheets
3. be prepared at a readable scale, using as many sheets as required to readily identify the location of evidence found in the field. Refer to design drafting standards for font size, line types, etc.
4. show prominent topographic features with names labeled, such as highways, roads, streets, milepost, fences, lakes, rivers, streams, tunnels, and buildings, to readily identify the location evidence found in the field.

5. show all found boundary monument locations with relevant symbols. Show all found aliquot monuments locations with relevant symbols.
6. show descriptions of all found boundary monument materials and cap markings.
7. show all aliquot monument upgrades describing the upgrade monument materials set and cap markings
8. contain found monument coordinate tables titled as follows:
  - a. found aliquot monument coordinate table
  - b. found right-of-way monument coordinate table
  - c. found boundary monument coordinate table
  - d. found easement monument coordinate table
 Each of the above found monument coordinate tables shall show the following monument project data:
  - i. point's number
  - ii. northing
  - iii. easting
  - iv. NAVD elevation (only if required)
  - v. point description (including, monument material and cap markings)
9. show section, township, range, and principal meridian designations
10. have a bar scale and a statement of scale
11. have a north arrow

### **2.9.3 Minimum Notes and Surveyor's Certification**

The land survey control diagram must at a minimum contain the following notes and certifications, titled as follows:

1. Surveyor's certification by the Alaska professional land surveyor in charge of the fieldwork, certifying that the survey was performed under their direct supervision and checking and meets or exceeds a ADOT Class B Secondary survey.
2. Basis of bearing, stating the bearing between two primary control monuments along with a description of the monuments and the datum referenced. (This must be the same basis of bearings used for the project control diagram.)

3. Basis of elevation, describing at least one existing primary control monument with a NAVD 88 elevation of record, along with a description of the monument, it's location and the datum referenced. (Shall be the same basis of elevation as for the Project Control Diagram.)
4. Coordinate datum shall make reference to the project control diagram that the land survey control diagram coordinates are tied into.
5. "NOTE: This land survey control diagram is prepared for ADOT purposes only. It is not a boundary survey, land survey plat, or right-of-way plat. No determination has been made to determine if the found monuments as shown are in their proper position or if they are at the corners they are intended to monument."
6. "NOTE: All monuments are located from existing ADOT primary control monuments. The primary control survey was performed at a higher degree of accuracy than the secondary control survey shown on this diagram."

## **2.10 Boundary Analysis**

### **2.10.1 General**

After the office research, field search, and preliminary right-of-way survey are complete, the office information is merged with the field evidence located and a boundary analysis is performed to determine the right-of-way boundaries. This analysis may include other types of surveys such as a topographic survey. Generally, the analysis should result in a reconstruction of the original survey by following in the footsteps of the original surveyor. The final boundary analysis shall be made by the Alaska professional land surveyor in responsible charge of the right-of-way plans.

**Under no circumstances shall any PLSS, right-of-way, easement, or property boundary monument used for the boundary analysis be located by topography survey accuracy tolerances or methods.**

## **2.11 TMOSS/PICS**

### **2.11.1 TMOSS Special Requirements**

Include the following information along with descriptive notes and field sketches as necessary to provide additional information not contained in the code:

- Primary and secondary control monuments, including boundary monuments, must include a detailed description of the physical monument material and cap markings.
- Advertising signs should show dimensions, whether lighted or unlighted, and owner. Tie down to show skew, placement, etc.
- Bridges and multiplate culverts: the minimum information that should be collected on all major structures is the feature carried, feature crossed, structure number, and structure type. Then collect sufficient information to establish the curb-to-curb width, curb or sidewalk widths, number of spans, span lengths, wing wall lengths, and angles, skew of abutments and piers, and the utilities present.
- Special cases will arise in the form of structures to be widened or rehabilitated, and in these instances Bridge Design or the structure consultant will submit any special requirements at the presurvey conference. Check to see if there is a set of as-constructed plans available. These could be of great value in showing what parts are being tied and/or measured.
- Buildings, foundations or basements: show dimensions and type of construction. Collect shots at all possible corners to show skew.
- Miscellaneous codes: all shots coded as being a miscellaneous feature will have a description of the feature included in the note field associated with that code.
- Overhead power and telephone lines: show pole and direction of lines as well as overhead wire elevations when appropriate (observations should be taken at proposed centerline, the edge of traveled surface, or painted lane lines).
- Sanitary and storm sewer lines: show size, type, and manhole locations. Include invert and rim elevations and indicate direction of flow. Observations should be connected to each manhole and inlet on the line.
- Underground power and telephone lines: show locations and direction of lines. Show name of owner.
- Water and gas lines: show size, type of pipe, and location of valves. Show name of owner.
- Wells.

- Other structures and improvements as deemed necessary to complete the topography mapping.

## 2.12 Topographic Survey (TMOSS)

### 2.12.1 General

The purpose of a topographic survey (TMOSS) is to gather field data to determine the configuration (relief) of the surface of the earth (ground) and the location of natural and artificial objects on it. ADOT uses the data from topography surveys for construction design, hydrology, right-of-way design, environmental compliance, maintenance, and property management.

### 2.12.2 Types of Topographic Surveys

The actual collecting of topographic data can be accomplished in a variety of ways, each with their own unique accuracies, cost, and production times. A few examples of the methods for collecting topographic data are:

1. Survey methods
  - a. conventional methods
  - b. global positioning system methods
2. Aerial photogrammetry survey methods
  - a. Supplemental Survey
3. Remote sensing methods
  - a. Light Detection and Ranging (LIDAR)
  - b. 3D laser scanning
  - c. satellite imagery

It is critical to identify the project needs before selecting the topographic survey method. This is typically done through the initial scoping of the project to determine the project's limits, factors, and requirements. After the scoping has been completed, the region right-of-way engineering supervisor or their designated representative will identify the appropriate topographic survey method.

Right-of-way surveys are not included as part of the topography surveys because the accuracy tolerance and survey methods for right-of-way surveys are more stringent than for topography surveys. If any boundary monuments are located during the topographic survey, they will be located by the methods and accuracy tolerances of a ADOT Class B Secondary survey as required in this chapter.



**Under no circumstances shall any PLSS, right-of-way, easement, or property boundary monument used for the boundary analysis be located by topography survey accuracy tolerances or methods.**

### **2.12.3 Horizontal Accuracy Tolerance**

All topographic surveys shall be tied to the ADOT-approved primary control network referencing the primary control monument data shown on the project control diagram and shall meet the minimum horizontal accuracy tolerance for a ADOT Class C TMOSS survey as required in this chapter.

### **2.12.4 Vertical Accuracy Tolerance**

ADOT Class C TMOSS surveys within the existing constructed transportation corridor template shall have a minimum of 95% of all elevations collected within  $\pm$  one 0.10 foot of the true elevation at 95% confidence level in relation to the primary control monuments.

ADOT Class C TMOSS surveys outside the existing constructed transportation corridor template will have a minimum of 95% of the elevations collected by topographic survey. The data must have an accuracy with respect to true elevation of  $\pm$  one half the contour interval or better at the 95% confidence level in relation to the primary control monuments. The remaining 5% shall have an accuracy with respect to true elevation of  $\pm$  one contour interval or better at the 95% confidence level in relation to the primary control monuments. ADOT recommends a 1-foot contour interval for all Class D mapping. The contour interval can be adjusted by the region right-of-way engineering supervisor or their designated representative as necessary.

No elevations determined by any topographic survey shall deviate from the true elevations by more than one contour interval in relation to the primary control monuments.

### **2.12.5 Method of Verifying Accuracy Tolerance**

Accuracy tolerance requirements are evaluated by comparing a cross-section string, a series of random points taken in the field with the same cross-section location, or a series of random point locations extracted from a terrain triangulated irregular network

(TIN) model produced from the original topographic survey data. The field cross-section string is collected by conventional topographic survey methods and is held as the true representation of what exists in the field in relation to the primary control monuments. Take the interval between observations on the cross-section at a minimum of 30 feet and do not exceed the interval of the topographic survey at the particular cross-section.

The field cross-section string or random points are then processed and compared to the TIN model cross-section or random points. The difference between the sections is evaluated to determine if the delivered product is within the minimum horizontal and vertical tolerances for either a ADOT Class C or D TMOSS survey as applicable to the cross section being evaluated.

Total the number of observations that exceed the minimum tolerances and divide by the number sampled to calculate a percent failing. One hundred minus the percent failing yields the percent passing.

No payment will be made for TMOSS/PICS topographic survey data (paper or electronic) until the data has been verified to be within the required minimum horizontal and vertical accuracy tolerances. Any areas determined not within the required tolerances will be rejected, reworked by the consultant, reverified (by cross section or random point locations) to be within required tolerances, and resubmitted at no additional cost to ADOT.

### **2.12.6 Conventional Survey Methods**

All topographic surveys performed by conventional survey methods shall meet the Minimum Horizontal and Vertical Accuracy Tolerance for a ADOT Class C or D TMOSS survey as required in this chapter.

**Due to the effects of curvature and refraction (see 2.6, Differential Leveling, Curvature and Refraction Table, for additional information), no ADOT Class C TMOSS conventional topographic observation will be more than 750 feet from the instrument setup.**

Conventional topographic survey methods, when performed in accordance with this manual, are considered to be the most accurate method of collecting field TMOSS data for ADOT's use.

### **2.12.7 GPS Survey Methods**

Perform all topographic surveys using GPS methods in accordance with Chapter 1, GPS Surveys, and meet the minimum horizontal and vertical accuracy tolerance for a ADOT Class C or D TMOSS survey as required in this chapter.

GPS topographic survey methods, when performed in accordance with this manual, are considered to be the second most accurate method of collecting field TMOSS data for ADOT's use.

### **2.12.8 Aerial Photogrammetry Methods**

An aerial photogrammetry survey method uses photographic, electronic, digital, or other data obtained from an airplane or helicopter. The advantage of obtaining topographic data by aerial survey methods is the efficiency with which large areas of the Earth can be mapped and large volumes of topographic and planimetric data can be obtained. The disadvantage of aerial mapping is that it requires more advanced planning and lead time than conventional or GPS survey methods. Aerial surveys are typically much less accurate than conventional or GPS survey methods, particularly when there is heavy vegetation or areas of drastic changes in elevation such as mountainous terrain.

Topography surveys are performed to supplement aerial surveys. The purpose of the supplemental survey is to locate features that require a higher level of accuracy than the aerial survey, to locate features that cannot be located by the aerial survey, and to collect information not apparent to the photogrammetrist from the aerial survey.

### **2.12.9 Remote Sensing Methods**

Remote sensing methods includes technology such as Light Detection and Ranging (LIDAR), 3D laser scanning, and satellite imagery. ADOT surveyors should stay current on advances made in remote sensing technology through education, training, seminars, and dealer demonstrations. It is important for ADOT surveyors to take it upon themselves to improve their knowledge and understanding of the appropriate use of such technology. Pilot projects should use such technology when it is cost effective and appropriate to do so.

Some of the possible benefits that should be considered are:

1. Savings in survey crew hours, cost, and time.
2. Increased safety by remotely collecting data, removing survey crews from dangerous situations such as traffic.
3. Increase in the number of points collected, providing more overall coverage. As advances in remote sensing technology are made in hardware and processing software that prove the required accuracy tolerance is more easily attained and more cost-effective, new specifications for ADOT will be developed and sections of this chapter will be revised to stay current with those advances.

## **2.13 Drainage Survey**

### **2.13.1 General**

The purpose of a drainage survey is to ensure that the information needed for hydraulic design will be included in the topographic survey. Use the Preliminary Survey Scope Form 1217a, which will include all drainage structure requirements of the survey. This form will be supplemented or confirmed through direct contact with the hydraulic engineer. The project manager should contact the hydraulic engineer at least two weeks before the presurvey conference. After the survey requirements have been determined and included on the survey scope, a transmittal of the requirements will be submitted to the region right-of-way engineering supervisor or their designated representative. Following these guidelines will provide the hydraulic engineer with an adequate drainage survey.

If there are any questions about the needed information, contact the hydraulics engineer before starting the survey. The hydraulics engineer will be able to supply predicted design flows, special survey requirements, and potential use of upstream area for detention ponding.

All drainage surveys performed by ADOT or contract consultants shall be performed using ADOT's Topography MOdeling Survey System (TMOSS) coding with file formats accepted for use by ADOT's Project Item Coding System (PICS) software. (See 2.11, TMOSS/PICS, for additional information.)



Good drainage surveys are necessary for complete hydraulic designs. Channel locations and changes, bridge skew, water stage, and structure relocations are all determined from the drainage survey.

### **2.13.2 Horizontal Accuracy Tolerance**

All drainage surveys shall be tied to the ADOT-approved primary control network referencing the primary control monument data shown on the project control diagram and must meet the minimum horizontal accuracy tolerance for a ADOT Class C TMOSS.

### **2.13.3 Vertical Accuracy Tolerance**

ADOT Class C TMOSS surveys within the existing constructed transportation corridor template must have a minimum of 95% of all elevations collected within  $\pm$  one 0.10 foot of the true elevation at a 95% confidence level in relation to the primary control monuments.

No elevations determined for any drainage survey may deviate from the true elevations by more than one contour interval in relation to the primary control monuments.

### **2.13.4 Method of Verifying Accuracy Tolerance**

Accuracy tolerance requirements for drainage structures are evaluated by comparing an independent field location collected in the field with a point extracted from a terrain TIN model produced from the original topographic survey data. The field location is collected by conventional topographic survey methods and is held as the true representation of what exists in the field in relation to the primary control monuments.

The field location is then compared to the TIN model. The difference between the field location and the TIN model is evaluated to determine if the drainage structure is within the minimum horizontal and vertical accuracy tolerances for a ADOT Class survey.

No payment will be made for TMOSS/PICS drainage survey data (paper or electronic) until the data has been verified to be within the required minimum horizontal and vertical accuracy tolerances. Any data not within the required tolerances will be rejected, reworked by the consultant, reverified to be within required tolerances, and resubmitted at no additional cost to ADOT.

### **2.13.5 Conventional Survey Methods**

All drainage surveys performed by conventional survey methods shall meet the minimum horizontal and vertical accuracy tolerance for a ADOT Class C or D TMOSS survey as required in this chapter.

**Due to the effects of curvature and refraction (see Differential Leveling, Curvature and Refraction Table for additional information) no ADOT Class C TMOSS conventional drainage observation will be farther than 750 feet from the instrument setup.**

Conventional drainage survey methods, when performed in accordance with this manual, are considered to be the most accurate method of collecting field TMOSS data for ADOT's use.

### **2.13.6 GPS Survey Methods**

All drainage surveys performed by GPS methods will be performed in accordance with Chapter 1, GPS Surveys, and shall meet the minimum horizontal and vertical accuracy tolerance for a ADOT Class C survey as required in this chapter.

GPS drainage survey methods when performed in accordance with this manual are considered to be the second most accurate method of collecting field TMOSS data for ADOT's use.

### **2.13.7 Aerial Photogrammetry Methods**

An aerial photogrammetry survey method uses photographic, electronic, digital or other data obtained from an airplane or helicopter. The advantage of obtaining topographic data by aerial survey methods is the efficiency with which large areas of the Earth can be mapped and large volumes of topographic and planimetric data can be obtained. The disadvantage of aerial mapping is that it requires more advanced planning and lead time than conventional or GPS survey methods. The accuracy of aerial surveys are typically much less than conventional or GPS survey methods, particularly when there is heavy vegetation or areas of drastic changes in elevation such as mountainous terrain.

Drainage surveys are performed to supplement aerial surveys. The purpose of the supplemental survey is to locate features that require a higher level of accuracy than the aerial survey, to locate features that cannot be located by the aerial survey, and to collect information not apparent to the photogrammetrist from the aerial survey.

### **2.13.8 Photographs**

If the hydraulic engineer thinks photographs are necessary, he or she will request them in the drainage survey requirements transmittal. If requested, photographs should show existing inlet and outlet configurations, areas of erosion, structures that experience distress during floods, and natural features of the drainage basin. Photographs must be labeled with the project number, date of photo, description of photo, orientation of the camera, and the photographer's name.

### **2.13.9 Guidelines**

Guidelines for the extent of a drainage survey upstream and downstream are as follows:

1. Large Bridges (design flows greater than 20,000 cfs or spans greater than 250 feet)
  - a. Consult with the hydraulics engineer before scoping the survey. Requirements will be discussed at the presurvey conference.
  - b. Aerial surveys should be considered for these sites.
2. Large Culverts/Medium Bridges (design flows of 2,000 to 20,000 cfs or 20 feet x 10 feet concrete box culvert to 250 feet total span bridge)
  - a. The survey shall extend 1,200 feet upstream and 1,200 feet downstream from the existing roadway centerline.
  - b. Additional survey data must be taken near the upstream and downstream edges of the existing structure, including the abutments.
  - c. The elevations of the existing structure's lowest girders or clearance must be included.
3. Medium to Large Culverts (design flows of 200 to 2,000 cfs or 72 inch pipe to 20 feet x 10 feet concrete box culverts with openings of 28 sq. ft. to 200 sq. ft.)
  - a. The survey shall extend 500 ft. upstream and 500 ft. downstream from the roadway centerline.
  - b. Additional survey data must be taken near the upstream and downstream end of the existing structure.
  - c. The width of the survey will be determined by the hydraulic engineer.
  - d. Survey requirements will be discussed at the presurvey conference.
4. Small Culverts (design flows less than 200 cfs or pipes smaller than 72 inch with less than 28 sq. ft. openings)
  - a. Extend the survey 100 feet upstream and 100 feet downstream from the roadway centerline.
  - b. Also take survey data at each end of the culvert to determine the structure centerline, the depth of silt, headwall dimensions or type of end section, condition of the present structure, type of flow, vegetation, and soil type of banks and bottom.
  - c. Discuss further needs at the presurvey conference.
5. Storm Drains
  - a. Locate all utilities. Indicate the type, size, and depth of the utilities.
  - b. The width of the survey will be determined by the hydraulic engineer.
  - c. Survey requirements will be discussed at the presurvey conference.
6. Storm Drains
  - a. Locate all utilities. Indicate the type, size, and depth of the utilities.

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