

**NEW JERSEY  
DEPARTMENT OF  
TRANSPORTATION**

**SURVEY  
MANUAL**



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# New Jersey DOT Survey Manual

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# Preface

## Purpose

Many State Departments of Transportation have developed a survey manual. The purpose of the manual is to provide uniform guidelines for implementing survey decisions, and to assure quality and continuity in collection of survey data. The use of the survey manual is to assure appropriate execution of projects in conformity with the operational needs of the Department of Transportation, and to assure compliance with State and Federal criteria. The objective of this manual is not to serve as a general purpose text on the practice of surveying but rather as a guide to fit the special needs of the New Jersey Department of Transportation. Basic education and training in surveying require appropriate schooling, seminars and field exercises with appropriate textbook and learning kits. At the end of this manual there is a suggested reference list, including some helpful Web sites.

This manual deals with technical surveying issues. Other issues such as professional conduct and safety procedures should be in accordance with appropriate Federal and State manuals. For example, all the procedures at NJDOT with respect to safety, traffic protection, operation of tools and equipment, vehicle operation and usage, and first aid must be in accordance with the latest edition of NJDOT "safety manual". To avoid duplications and potential conflicts with existing regulations, this survey manual does not include these procedures.

## Content and Format

Survey manuals of other State Department of Transportations follow one of two general conceptual models. Some manuals provide detailed instructions for surveyors, while others take the form of a more general reference guide used by DOT employees and Consultants, who are not necessarily surveyors. The purpose of the first approach is to produce a prescriptive manual to train people in surveying. The danger in such a detailed manual is that it could become easily outdated due to rapid technological developments. Such a manual may require frequent maintenance and revisions to keep it current. The second approach is more technology independent and used to educate its readers about surveying. This education provides proper understanding of surveying and improves the communication among various DOT employees. This manual follows the latter approach. The model used in developing this manual was the Ohio DOT (ODOT) survey manual.

The criteria included in this manual have been developed along the lines of various State's survey manuals, as well as in conformance with applicable Department directives, policies and procedures. The manual assures uniform guidelines for implementing survey decisions, assure quality and continuity in collection of survey data and execution of project support of operations in New Jersey, and assures compliance with Federal criteria. Consideration must also be given to submission standards adopted by city, county, or other local governments when submitting documentation under their jurisdiction.

The manual consists of seven chapters and an appendix. The first chapter deals with general terms and definitions of surveying and surveying related terms. Chapter two describes the various survey systems. Survey systems are, to some extent, technology free concepts that serve as a foundation for different types of surveys. Chapter three deals with survey measurements and the errors associated with them. Chapter four is a continuation of chapter three and focuses on Global Positioning Systems (GPS). GPS is somewhat a different surveying technique served better with its own chapter. Chapter five discusses surveying equipment, its characteristics, and proper usage. Chapter six discusses location surveys and some field procedures. Photogrammetry is discussed in the last chapter. Photogrammetry is another surveying technique that is somewhat different compared with the traditional surveying. The special chapter serves as a means for emphasizing the applicability and the recommended utilization of photogrammetry as an integral part of the surveying tool box.

## **Preparation**

The NJDOT Survey Manual was developed through the cooperation and effort of numerous staff members and the surveying program of the New Jersey Institute of Technology. Errors or omissions should be reported to the Bureau of Civil Engineering, Office of Survey Services, New Jersey Department of Transportation, PO Box 600, Trenton, New Jersey 08625.

## **Revisions**

Updating the manual will be a continuous process and revisions will be issued periodically. Some of the revisions will become necessary as a result of changes in specifications and methodology, while others result from user feedback. All manual users are encouraged to suggest modifications and improvements to this manual, in writing, to the Bureau of Civil Engineering, Office of Survey Services, at the New Jersey Department of Transportation.

Submit Manual orders to the Bureau of Civil Engineering, Office of Survey Services, New Jersey Department of Transportation, or check the Department's web site to download the latest version.

## **Acknowledgment**

This document was prepared under a research partnership between NJDOT and New Jersey Institute of Technology. The author, Dr. Joshua Greenfeld, Surveying Program Coordinator, New Jersey Institute of Technology, wishes to thank Mr. Arthur J. Eisdorfer, Mr. Louis Marchuk, and Mr. J. Eric Kraehenbuehl of NJDOT for their assistance and support for this project. Special thanks are also due to Mr. James K. Crowl and especially Ms. Kelly Jean McEntee of Ohio Department of Transportation for making available a digital copy of the Ohio Survey manual. Their ideas and experience were widely utilized in this manual. Also, the author extends thanks to Ms. Wendy Lathrop, PLS and NJDOT employees for reviewing this manual and offering valuable comments and suggestions.

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# Chapter 1

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# Chapter 1 Introduction

## 1.1 Purposes of Manual

The principal purposes of this Manual are:

- To establish and maintain survey standards.
- To improve the overall efficiency of the NJDOT's survey function.
- To provide a single reference source for surveying policies, procedures, and information.
- To secure an optimum degree of statewide uniformity in surveying.
- To serve as a reference for new employee orientation.
- To provide source material for developing training.
- To help employees in other offices gain a better understanding of surveying and its proper relationship to other NJDOT activities.

This Manual, in general, covers surveying policies, procedures, and appropriate reference material. It is not a textbook or a contract document, nor is it a substitute for surveying knowledge, experience, or judgment. Although portions include textbook material, this Manual does not attempt to completely cover any facet of surveying. General policies and procedures, such as those related to safety, that apply to all NJDOT employees are not reviewed in this manual. They are omitted from the survey manual for two reasons. The first is to avoid inconsistencies and disparity between this manual and other established NJDOT policies and procedures. The second reason for not including them here is to avoid unnecessary revisions of this manual whenever policies and procedures change.

## 1.2 Importance of Surveys

- Surveying is basic to all civil engineering works. In transportation engineering, surveying provides the foundation and continuity for route location, design, land acquisition, and all other preliminary engineering. A survey sets up a basic "framework" of control that contractors and State engineers use in building and inspecting transportation projects.
- Surveying provides a thread of continuity throughout an engineering project. Surveying is the single engineering function that links all the elements of a project: from conception; through design, land acquisition, and construction; to final monumentation.
- To a great degree, the acceptability and cost effectiveness of planning, land acquisition, design, and construction are dependent upon properly performed surveys.

### **1.3 Definition of Surveying**

The traditional definition of surveying is:

*The art of making measurements of the relative positions of natural and man-made features on the earth's surface, and the presentation of this information either graphically or numerically.*

In 1990, the International Federation of Surveyors (FIG) adopted a more contemporary definition of surveying. This definition is more specific about the particular activities involving a surveyor.

According to FIG, a surveyor may be involved in one or more of the following activities that may occur either on, above or below the surface of the land or the sea and may be carried out in association with other professionals:

The determination of the size and shape of the earth, and the measurement of all data needed to define the size, position, shape, and contour of any part of the earth surface.

1. The positioning of objects in space, and the positioning and monitoring of physical features, structures, and engineering work on, above or below the surface of the earth.
2. The determination of the position of boundaries of public and private land, including national and international boundaries, and the registration of those lands with the appropriate authorities.
3. The design, establishment and administration of land and geographic information systems, and the collection, storage, analysis and management of data within those systems.
4. The study of the natural and social environment, the measurement of land and marine resources, and the use of the data in the planning of development in urban, rural, and regional areas.
5. The planning, development, and redevelopment of property, whether urban or rural land.
6. The assessment of value and management of property, whether urban or rural land.
7. The planning, measurement, and management of construction works, including estimate of cost.
8. The production of plans, maps, files, charts, and reports.

This list includes some activities that are not universal to all countries or organizations, because it was prepared by surveyors from different countries. Nevertheless, it is informative to know the extent of the scope of surveying.

In recent years there was a trend to use the term Geomatics instead of surveying. The rationale for Geomatics is that surveying has changed and expanded beyond what people traditionally considered as surveying. Since the adoption of the term Geomatics is not universal, the term will not be used in this edition of the survey manual.

In summary, surveying is performed to determine the relative location or positioning of points on or near the earth's surface. More specifically, surveying is the science of making measurements, relative to known or assumed datum and standards, and applying the principles of mathematics to such measurements to determine existing or future horizontal and vertical position, form, area, magnitude, boundaries, and extent of land parcels and topographical features.

### **1.3.1 Types of Surveying**

There are numerous types of surveying. The classification is based mostly on describing a specific surveying activity such as construction surveys, etc. Sometimes the classification is determined by the methodology used to perform it (i.e., geodetic surveys). The following are some of the types of surveying:

- Geodetic Surveys - Surveys that take into account the true shape of the earth. Used mainly to establish control networks on a mathematical datum that closely approximates the shape of the earth. The introduction of the Global Positioning System (GPS) and Geographic Information System (GIS) made this type of surveying essential in most projects.
- Plane Surveys – Surveys that assume that the earth is flat. This assumption simplifies the procedures and computations of surveying projects. For small, isolated and local projects this assumption may introduce only small and negligible errors.
- Control Surveys – Made to establish the horizontal or vertical positions of arbitrary points to be used as a reference in prior and future surveys.
- Property Surveys - Surveys that include retracement and establishment of property boundaries including highway Right-of-Way. These are also known as land or boundary surveys.
- Topographic Surveys – Made to determine the configuration of the ground.
- Engineering Surveys - Surveys performed for the design and cost estimating of fixed works.
- Route Surveys - Surveys performed for locating, designing, and constructing transportation facilities.
- Construction Surveys - Surveys that establish stakes in the ground, and other like reference points, at known horizontal and vertical positions to define location and size of fixed work contract items, enable inspection of contract items, and serve as a basis of payment for work.
- Hydrographic Surveys – Surveys that determine the configuration of the bottom of a water body.
- Aerial Survey or Photogrammetry - A method of measurement which is applicable to various surveying activities. Normally, it utilizes aerial photographs and specialized office equipment to perform control, engineering, topographic, and other surveys.

### **1.3.2 Related Activities**

Surveying also includes the related activities of:

- Cartography - The design and production of maps compiled from existing data, and the development and maintenance of map information systems.
- Geographic (Land) Information Systems(GIS/LIS) - An organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information

## **1.4 Organization**

### **1.4.1 Survey Sections**

In NJDOT, Survey Sections may be organized either on an area or on a functional basis. In the "area" organization a Survey Operations Manager is responsible for all surveys, of whatever type, in a given area. This area may be a region, specific counties, district, or the entire state. Under the "functional" system, individual field crews are assigned to specific types of surveys; for example, control surveys, planning and design surveys, land surveys, or construction surveys.

### **1.4.2 Survey Functions**

Basically, a Survey Section will perform and provide all surveying services and data required. Surveying functions may include, but not be limited to the following:

- Establish the New Jersey State Plane Coordinate System along transportation corridors by providing a network of horizontal control surveys.
- Establish project control surveys.
- Obtain supplemental data for design and special purposes.
- Perform land surveys for appraisal, deed descriptions, acquisition, relocation, and monumentation.
- Perform Right-of-Way and construction staking, including bridge staking.
- Perpetuate existing survey monuments.
- Establish monumentation.
- Prepare Centerline Survey Plats.
- Maintain files of horizontal and vertical data.
- Furnish horizontal and vertical data to other public agencies and private surveyors.
- Cultivate and maintain proper relations with private citizens, public agencies, private surveyors, and other Departmental branches.
- Monitor survey costs and evaluate efficiency.
- Provide training for Survey personnel.

### **1.4.3 Survey Crew**

The survey crew shall consist of sufficient employees to safely and efficiently complete the proposed work. It shall include a crew chief and survey assistants. Crew size may be increased as required by operational considerations such as: safety, survey type, terrain, survey priority, and weather. In addition, crew size may be reduced if safety of personnel or the public is not jeopardized by the reduction.

#### **1.4.3.1 Survey Crew Daily Report**

A. Reporting - Daily, each crew chief should record his or her crew's operations.

Entries shall be made daily, regardless of whether the report is submitted on a daily or weekly basis. Errors are much more probable when entries are delayed for one or more days and made from memory.

B. Submittal - Submit this report either daily or weekly as directed by the Survey Operations Manager.

C. Information to Report - Include the following minimum information:

- The date(s) the report covers.
- The identification of the project(s) on which the crew worked.
- The names of the survey crew members and the number of hours they worked on each project. If a regular crew member does not work, show the number of hours on leave and the type of leave, such as vacation or sick leave.
- In the narrative portion of the report briefly discuss weather conditions; the location; type of work performed; important conversations with the contractor, engineer, property owners, or others; and any other matters of importance, including damages.

D. Other Information - This report may also be used to record any other information the crew chief desires to make a part of the written record.

E. Precautions - Carefully prepare each Survey Crew Report. Survey Crew Reports should be as neat and accurate as survey notes.

## **1.5 Public Relations**

### **1.5.1 General**

- A. Importance - Public relations is one of the more important duties of the surveyor. This is especially true for surveyors who enter onto private property. The wide variety of situations encountered by the surveyor requires a constant awareness of the rights and needs of others. The ability to adjust to these needs is also required.
- B. Basic rules - Common sense and common courtesy are the best rules in any form of public relations. Be prepared, and try to create a good impression when meeting the public. First impressions, whether good or bad, are often lasting. Maintain a pleasant, professional attitude at all times and be informed about your job. The impression you create thereby will be a credit to you, your profession, and the Department of Transportation.
- A crew chief contacts many individuals: property owners, other surveyors, park rangers, etc. Often it is necessary to leave a telephone number and an address with these people. Crew chiefs may use, when available, business cards to help in fostering good relationships with others. At other times, the business card can simply be a means of introduction or of creating goodwill. All employees should carry their State issued identification cards at all times.
  - The value of developing good public relations cannot be over-emphasized. Time and money are saved, and the work is more pleasant for all concerned. Public contact enables a surveyor to improve his or her ability to meet and deal with people. This increases personal stature and the stature of the surveying profession. In addition, it improves the Department's image.

### **1.5.2 Internal Relations**

- A. Survey Crew - Proper relationships within a survey crew are necessary if individuals are to function as a team.
- Crew chiefs can help maintain good crew relationships by keeping crew members well informed about individual and crew roles and the duties for each job.
  - Crew chiefs and supervisors should be kept informed of important developments. *They should not be put in the embarrassing positions of learning important information from outside sources.*
- B. Region - Good relations among region personnel can be maintained through good communications and a clear understanding of responsibility. When in doubt about the requirements of a survey request, telephone the requester for clarification.
- C. Department - Relations and contacts with other Regions and with Central Office should be courteous and business-like.

### **1.5.3 Reporting Unusual Occurrences**

A vital part of public and internal relations is the prompt reporting of unusual and unexpected occurrences.

A. Types of Occurrences - These are incidents which:

1. Affect public safety.
2. Involve damage to NJDOT facilities.
3. Could lead to litigation.
4. Involve NJDOT and would be considered newsworthy.
5. Involve other governmental agencies on matters of mutual interest that would affect NJDOT.
6. Might have a derogatory effect on the NJDOT.

B. Examples:

1. Traffic accidents.
2. Flood damage, landslides, and earthquakes.
3. Damage to or failure of facilities.
4. Public protests or demonstrations affecting use of facilities.

C. Reporting - All incidents must be reported immediately. A written report of observations may be required. Notify the Regional Survey office and/or immediate supervisor if occurrence is during normal working hours. In addition to the above, minor damage, or damage which does not affect public safety must be reported to the appropriate Regional Maintenance supervisor, or the project engineer if on a construction project. Thefts of State equipment or supplies must be reported to the New Jersey State Police. Additional reporting requirements can be found in Departmental Policy and Procedure directives.

### **1.5.4 Relations With the Public**

- Attitude - Each employee is a representative of the New Jersey Department of Transportation. Each is responsible for developing and maintaining public goodwill. The Department is a public service organization; our behavior reflects on the Department.

- **Conduct** - The outdoor nature of surveying keeps surveyors in the "public eye" much of the time. Work should be accomplished efficiently and with a minimum of idle time. Good-natured relations among crew members helps morale. However, around the public, you must be prudent in oral and sign communications.
- **Direct Contact** - All direct contact with the public should be pleasant, courteous, and businesslike. This includes answering questions, listening to criticism (justified or not), and listening to suggestions.
- **Answering Questions** - In the field, refer questions concerning the work to the crew chief who should answer each appropriate question for which he or she knows the facts. If any doubt exists, the person asking the question should be referred to the crew chief's immediate supervisor. Probabilities, conjectures, or statements which might be misunderstood or misinterpreted should be left unsaid.

### **1.5.5 Relations With Property Owners**

Dealing with property owners is a most vital phase of public relations. Property owners are the ones who could be directly affected by the survey and, possibly, by subsequent construction. They will naturally take a close interest in any intrusion on their property, no matter for what purpose.

Good relations developed by conscientious surveyors carry over in the owner's attitude toward other NJDOT employees.

### **1.5.6 Entry on Private Property**

#### **1.5.6.1 Right of Entry**

NJSA 27.7-21g and NJSA 45:8-44.1 gives the State, acting through its employees, the right to enter private property to make surveys. See Appendix A for further reference.

#### **1.5.6.2 Pre-Entry Contacts**

NJSA 27.7-21g and NJSA 45:8-44.1 gives the State, acting through its employees, the right to enter private property to make surveys. See Appendix A for further reference.

#### **1.5.6.3 Notification**

NJSA 27.7-21g and NJSA 45:8-44.1 gives the State, acting through its employees, the right to enter private property to make surveys. See Appendix A for further reference.

Before a State employee enters a property not in the State's possession as of the time of entry, a written notice, in accord with the standard approved form, shall be sent to the owner of record by certified and regular mail or personally at least three days prior to

entry (three days must be added to this time frame when notice is by mail) the notice shall only be signed and sent by a State employee even though entry is for a contractor or consultant. The notice shall state the purpose of the entry, the approximate date and time during which the entry will last and what specific activities will take place. The approximate anticipated length of the entry shall be included. The owner of record must receive this notice before any entry is actually carried out, even where the property is vacant or not farmed or where no physical disturbance of the property would occur.

#### **1.5.6.4 Objection to Entry**

When a property owner or tenant objects to entry, DO NOT ENTER! If a property owner claims actual or anticipated damage or interference after a survey has begun, immediately leave the property. The Regional Survey Supervisor should be alerted and actions according to DEPARTMENT Policy and Procedure shall be taken to gain right of entry. The actual negotiation will be handled by the Regional Survey Supervisor.

#### **1.5.6.5 Conduct and Property Care**

Conduct operations in a manner that will not create ill feelings in property owners or tenants. This will be accomplished by:

- Survey Methods - Choose the survey method which will have the least effect on the land.
- Stake Location - Place stakes and other markers where there is little likelihood of them being a hazard.
- Property Rehabilitation - As nearly as possible, leave the property in the condition that existed prior to the survey. Repair any damage, fill any holes, and restore the property to its original condition, when possible. If you must temporarily leave a hazard created by your work, protect people and animals by the use of protective devices, such as cones, barricades, and portable fencing.
- Removal of Hazards - Remove all temporary and hazardous survey stakes and other potentially hazardous items from the work area after their usefulness has ended. The crew chief is responsible for determining which items to remove and when to do so. However, each crew member should call the crew chief's attention to possible hazards. Examples of items to be removed are stakes across fields which are to be mowed, stakes in pedestrian areas, back sights and foresights, and photogrammetry ground control materials.
- Concern for Children - Consider hazards to children when setting or leaving survey stakes.
- Litter Removal - DO NOT LITTER. Paper, stake fragments, and other trash shall be placed in litter cans in State vehicles. Litter shall not be left on private or on public property.

## **1.5.7 Private and Public Agencies**

### **1.5.7.1 Utility Companies**

Survey data, new development, and other survey information are freely exchanged between utility companies and public agencies. This practice exists at the federal, state, county and local level and includes both public and private utility companies. To maintain this goodwill and a cooperative attitude, promptly reply to requests from such agencies and companies.

### **1.5.7.2 Private Surveyors**

Land surveyors, photogrammetrists and engineers in private practice have valuable information in their files which we frequently need. Their attitudes and the extent of their cooperation results, largely, from previous contacts. Survey Sections should cultivate good relationships with private firms. Extend full cooperation to them whenever possible (this includes access to our control data and right of way engineering information).

### **1.5.7.3 Railroads**

Property which a railroad owns primarily as a landowner (land which does not carry rails) should be regarded as any other private property.

Land which carries rails is called "operating Right-of-Way". Before entry is made on such property, a notice of entry must be sent. Right of entry permit must be obtained from Railroad Company.

Stay alert at all times, and remember that you are there to survey safely. Railroad operations are not to be disrupted.

### **1.5.7.4 Public Lands**

Public lands should be treated as special types of private property where attention to additional regulations is required. Some of the types of public lands where you might survey are state parks, national parks, local parks, national forest, wilderness areas, state and national monuments, and historical sites.

#### **1.5.7.4.1 Pre-Entry Activity**

Before surveying in agency areas:

- A. Contact the person having responsibility for the public facility. (This contact should be made by the crew chief or the crew chief's immediate supervisor.)
- B. Explain the need for the survey, its anticipated duration, and any probable effects on the facility.
- C. Learn the requirements for working in these areas: permits, fire regulations, brush cutting procedures, and restriction on vehicular operations. In addition, the Park Supervisor (Ranger) might be able to give valuable information, such as the locations of control points and access roads.
- D. Orient each surveyor involved. Tell each about all survey requirements.
- E. Obtain required permits.

Forest and park rangers and supervisors are cooperative and helpful when all rules are obeyed. Consulting them in advance will ensure that regulations will not inadvertently be broken.

#### **1.5.7.4.2 Work Activity**

- A. Survey within all the requirements determined above.
- B. Obtain additional permits when work arises which is not covered by an active permit.
- C. Consult with the ranger or supervisor when additional "non-permit" work arises.
- D. Inform the responsible ranger or official of your daily location.
- E. Notify the responsible official when you leave and when you reenter, when there is a substantial time break in the survey.

#### **1.5.7.4.3 Wilderness Areas**

Surveys in wilderness areas are subject to very stringent regulations. **DO NOT WORK** in these areas prior to receiving approval from U.S. Forest Service. Usually, a permit will be required. Obtain approval for a survey in a wilderness area with the forest supervisor in charge of that area.

#### **1.5.7.4.4 State Parks**

The New Jersey Department of Parks and Recreation requires permits for surveys in State parks. For reconnaissance surveys, the Regional Survey Supervisor or crew chief might be able to arrange for surveying without a permit by having a thorough discussion with the park supervisor.

#### **1.5.7.5 Law Enforcement Agencies**

When a survey requires night work, notify local law enforcement agencies. This enables them to be aware of the source and reason for the appearance of "unusual" lights and activity.

#### **1.5.8 Cemeteries**

General Guidelines - Do not let survey activities interfere with the operation or maintenance of cemeteries. Contact cemetery owners to see if they have any special entry requirements. Pet cemeteries should be handled in the same manner.

Undocumented Sites - Be on the lookout for old cemeteries, large or small, when working in rural areas. In addition to obvious headstones, look for enclosed areas, unusual mounds of grass, and other indications. If evidence indicates a cemetery, the crew chief should promptly report the evidence to the Survey Section so proper approval can be obtained. When a cemetery or individual gravesite is not discovered until the construction phase, many problems can develop.

#### **1.5.9 Archaeological Sites**

Site Recognition - Most potential sites can be recognized only by a trained archaeologist. However, the more obvious evidence can be recognized by a layperson. Watch for such things as mounds of earth, fossil beds, charcoal pits, circular pits, and unusual stones. The archaeology departments of local colleges can furnish information on recognizing potential sites. This Bureau of Environmental Services can furnish information on recognizing potential sites.

Reporting a Site - When a site is located, the archaeologist needs considerable time for exploration. Therefore, promptly notify the archaeological representative.

Site Integrity - Leave the site in its "found" condition. Leave artifacts, undisturbed, at the site.

## **1.6 Safety**

### **1.6.1 “Code of Safe Surveying Practices”**

NJDOT employees survey in many different challenging environments. Rugged terrain, high-speed traffic, tools used, and construction equipment are some of the elements that typify survey hazards.

Most people have one thing in common with many who have experienced an accident: they believe it could not happen to them. A meaningful safety program requires that each Survey employee acknowledge that, "It can happen to me". Each must also ask, "What is my responsibility?", and "What can I do to keep it from happening?"

NJDOT employees should consult and follow the safety codes and procedures as outlined in the most recent “Safety Manual” of the New Jersey Department of Transportation. Each field employee shall have ready access to this manual.

- All field personnel shall have a practical working knowledge of this Manual.
- Each employee is charged by law to do everything reasonably necessary to protect life, safety, and health of everyone and comply with all occupational safety and health regulations which are applicable to his or her job.
- Promptly report injuries and accidents and unsafe conditions, tools, and equipment.
- Report to work each day in a physical condition that will enable functioning with agility and alertness.

Supervisors, crew chiefs and/or Field Supervisors are responsible for:

- Monitoring safety conditions and performance.

### **1.6.2 First Aid**

The crew should be equipped with a First-Aid manual, and an approved first-aid kit.

## **1.7 Communications**

Good communications are essential to efficient and safe survey operations. Survey employees shall strive to communicate as effectively as possible.

Besides the usual verbal and written communications, survey may directly or indirectly use the following communication systems:

- Telephones.
- FCC accepted mobile, hand-held and base station radios, and fax machines.

NJDOT employees should follow the established regulations and proper conduct with regard to using and operating these devices.

# Chapter 2

## Control Surveys and State Plane Coordinate Systems

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# Chapter 2 Control Surveys and State Plane Coordinate Systems

Although most engineering related surveys seem to be made on a plane, they are actually performed on the curved surface of the Earth. To ensure continuity and congruity of statewide projects, it is necessary to register the survey points to a mathematical representation of the topography (actual surface of the earth).

The objective of this chapter is to introduce the key terminology and concepts necessary to represent the actual surface of the earth. The first concept is the mathematical representation of the earth as a curved surface and its approximation as a plane. This concept leads to understanding the New Jersey State Plane Coordinate System (NJ-SPCS) and its relationship to the topography where surveys are performed. A second concept that will be introduced is elevation. Following the introduction of these concepts, methods for performing control surveys will be presented. Finally, the importance of monumentation of survey points will be discussed.

## **2.1 Survey Datums and Coordinate Systems**

### **2.1.1 Introduction**

A datum is any numerical or geographical quantity or set of such quantities, which may serve as a reference or base for other quantities. In surveying (or geodesy), datum is a set of quantities that describe the shape, size, rotation and gravity field parameters of the Earth. A geodetic datum is comprised of two surfaces that approximate the real Earth. The first of these surfaces is an ellipsoid (or spheroid) that mathematically approximates the shape and size of the Earth. The ellipsoid is used as a reference frame for horizontal position computations. The second surface is the geoid that is a mathematically irregular surface of elevation zero. The geoid is used for determining elevations.

In order to design and construct highway projects, all distances (both horizontal and vertical) must be referenced to a recognized datum. It is recommended that all projects be referenced to the horizontal North American Datum of 1983 (NAD 83) and that the vertical component of the project be referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29) or the North American Vertical Datum of 1988 (NAVD 88). The datum used should be clearly noted on the plans.

### **2.1.2 Horizontal Datums**

A horizontal datum is a surface of constant values which forms the basis for the computations of horizontal control surveys in which the curvature of the earth is considered. A reference ellipsoid is used for a horizontal datum. Five parameters are required to define a horizontal datum: two to specify the dimensions of the ellipsoid, two to specify the location of an initial point (origin), and one to specify the orientation (i.e. north) of the coordinate system. Selection of datum parameters depends on the objectives of the datum. Countries, or groups of countries, choose different reference ellipsoids to minimize the deviations between the topography and the ellipsoid in their region (best-fit ellipsoid for their region.). These individual geodetic datums are often referred to as local datums. Since the advent of GPS, the tendency is to adopt a global datum that provides the best fit for the entire Earth. Global datums are also related to the Earth's centermass, the geocenter.

Positions of points (coordinates) on a horizontal datum are expressed in terms of latitude and longitude. Latitude is measured, in degrees of arc, along a north-south direction from the plane of the equator to the location of a point on the ellipsoid. At the equator the latitude is  $0^\circ$  while at the north and south poles the latitude is  $90^\circ\text{N}$  and  $90^\circ\text{S}$  respectively. Longitude is measured, in degrees of arc, in an east-west direction from a reference meridian (customarily Greenwich meridian) to the local meridian. A meridian at any given point (called a local meridian) is an arc on the ellipsoid that connects the north and south poles and passes through that point. In the US, longitudes are measured in degrees of arc from Greenwich in a westerly direction. For example, the longitude at center of New Jersey is approximately  $74.5^\circ\text{W}$ .

Modern positioning equipment, such as GPS, display locations in terms of latitudes and longitudes. USGS topographic maps, as well as many navigation charts, include geodetic latitude and longitude in the form of grid ticks along their margins.

A discussion of the calculations for the determination of position by the use of geodetic or spherical coordinates is rather complex and is not essential to the purpose of this manual.

#### **2.1.2.1 The North American Datum of 1927 (NAD27)**

In 1927 a general adjustment of all the horizontal geodetic surveys was performed. The adjustment utilized the Clarke ellipsoid of 1866 and held fixed the latitude and longitude of station Meades Ranch in Kansas as the initial point, along with an azimuth to a nearby station Waldo. The control points that made up the national geodetic reference system were assigned NAD27 latitudes and longitudes. Many local surveys were based on these control points and their positions were also expressed in terms of NAD27 coordinates. The introduction of highly accurate electronic measurement systems in the late 1950s, and the advent of satellite tracking systems such as Doppler (an earlier satellite positioning system) in the 1960s and GPS in 1970s, unveiled many weaknesses in NAD 27.

Discrepancies between existing control and newly established surveys necessitated the establishment of an entirely new datum, rather than fixing NAD 27.

### **2.1.2.2 The North American Datum Of 1983 (NAD83)**

In 1986 the National Geodetic Survey (NGS) completed a project for the redefinition and adjustment of the existing horizontal reference system. The North American Datum of 1983 (NAD83) represents the single most accurate, and comprehensive geodetic survey datum in the history of the United States. It supersedes the North American Datum of 1927 (NAD 27). The new datum, NAD83, is earth centered, and relies on an ellipsoid (and other constants) of the Geodetic Reference System of 1980 (GRS 80). The primary advantage of GRS 80 is that it facilitates the computation of correct geometric relationships on a global, as well as a continental, scale.

The adjusted latitudes and longitudes of all monuments in NAD83 differ from their NAD27 values. The differences are due to change in datum, as well as due to superior (quantitative and qualitative) measurements and adjustment.

*One should be very careful not to mix latitudes and longitudes between these different datums.*

### **2.1.2.3 HARN and NAD83**

The original NAD 83 geodetic network was computed mostly by using traditional surveying observations and methods. Very few GPS observations were included in the adjustment computation. The design and implementation of this network preceded the developments of the GPS technology and, therefore, the practical usage of these control points for GPS application can be problematic. Some of these problems are:

1. Most of these control points are not "GPSable". In other words, the points are located near objects that obstruct the required clear visibility between the receiver and the satellites.
2. Many of these control points are located on mountain tops and other locations that are not easily accessible. To work efficiently with GPS, one needs to have quick and easy access to control points.
3. Control points of the original NAD 83 network are spaced irregularly. Hence, chances are that there will be insufficient control points in the vicinity of your project.
4. The original NAD 83 network is not accurate enough to serve as control for GPS observations. The most accurate horizontal standard in the original NAD 83 network is 1:100,000 as compared to a 1:100,000,000 accuracy attainable by GPS.

To eliminate or significantly reduce the problems listed above several states (including New Jersey) in conjunction with National Geodetic Survey are developing a High Accuracy Reference Network (HARN). The HARN is designed to establish geodetic control points accessible 24 hours a day by car or light truck within, at most, 30 to 45 minutes from anywhere in the State. Once the HARN is established, a new adjustment must be computed and the points in the network are assigned new coordinates. These coordinates are different from those of the original NAD 83 adjustment. The new coordinate values will be designated as NAD 83(199x), where 'x' indicates the year of the adjustment. For example, a point that was computed in 1994 bears an NAD 83(1994) code value.

NAD 83(199x) is not a new datum. It is just an improvement over the original NAD83 datum. When the HARN project is completed for the entire US, NGS will most probably embark on defining and computing a new datum.

### **2.1.3 Vertical Datums**

Elevations for engineering projects must be referenced to a single vertical datum so various phases of a project, and contiguous projects, will match. This datum can be based on some particular standard, such as sea level, an assumed elevation or the elevation of a local permanent point or natural object. Various organizations, private and public, use datums that best serve their individual needs. This has led to many different datums throughout the State, causing a considerable amount of confusion.

The New Jersey Department of Transportation has adopted the use of the NGVD 29 or NAVD 88 datum as established by the NGS as the vertical datum for highway projects. The datum used must be noted on each benchmark note/description, as the datums are not the same. Exceptions to NGVD 29 or NAVD 88 may be permitted for small, remote, isolated surveys where ties to a recognized vertical datum cannot be economically established.

#### **2.1.3.1 The National Geodetic Vertical Datum (NGVD 29)**

The orthometric heights in NGVD 29 refer to the geoid, and are usually referred to as MSL heights (mean sea level heights). Mean sea level is the average height of the sea surface for all stages of the tides for an 18.6 year period. This period is required because the sun and moon, which affect the tides, repeat the same pattern every 18.6 years. The height of mean sea level is determined from continuous measurements made with automatic tide gauges set in relatively calm water. Gauging stations have been established and are maintained by NGS at regular intervals along the coast and along tidal rivers. NGVD 29 was computed based on twenty-one tidal stations in the US and five in Canada.

These gauges are connected through tidal bench marks to a precise network which covers the 48 contiguous states. When the network was run, the height of mean sea level was found to vary slightly from one tidal station to another. In 1929 the network was adjusted so the elevation of mean sea level at each gauge was zero. This established the 1929 Sea Level Datum (SLD). In 1973 the name of this datum was changed to National Geodetic Vertical Datum of 1929 (NGVD 29).

Similarly to the experiences with the horizontal datum which was discussed earlier, NGVD 29 was found inadequate for modern day surveying. It became necessary to redefine and readjust the entire system of vertical control or bench marks.

### **2.1.3.2 The North American Vertical Datum (NAVD 88)**

In 1991 the National Geodetic Survey completed a general adjustment of the North American Vertical Datum of 1988 (NAVD 88). NAVD 88 supersedes NGVD 29, which was the height reference for the United States. NAVD 88 provides a modern, improved vertical datum for the United States, Canada and Mexico. NAVD 88 heights are a result of a mathematical least squares general adjustment of the vertical control portion of the National Geodetic Reference System (NGRS) and include 80,000 kilometers of new U. S. leveling observations undertaken specifically for this project.

Extreme care must be used to insure that all height values of individual bench marks used within a project are referenced to only one vertical datum. In the State of New Jersey the difference between NGVD 29 heights and NAVD 88 heights varies between 0.18 to 0.4 meters (0.6 to 1.22 feet). Therefore, the mixing of these datums could cause many errors in the vertical portion of a survey.

### **2.1.3.3 Local Vertical Datums**

During the original level surveys through the State, bench marks were established in every city or town. The bench marks were generally located near the courthouse, railroad depot, or other prominent building within the town limits. Most of the towns and cities have extended that control by "benching" fire hydrants or other semipermanent points. Generally, throughout a municipality, the control is fairly consistent. Due to the 1929 adjustment and subsequent refinements of the USC&GS network, most of those local datums do not agree with current network elevations.

In order to maintain a consistent datum throughout highway projects, extreme care should be used to identify which benchmark and which datum were referenced. Benchmarks must be referenced to the NGVD 29, NAVD 88, assumed or local datum. If this information is known, it is then a fairly simple procedure to establish a vertical equation for local systems by leveling between the local and NGVD 29 or NAVD 88 benchmarks.

### 2.1.4 Plane Coordinate Systems (General)

A coordinate system is used to determine the relative position of points within the survey area or, in many cases, with respect to a much larger area. In order to make the coordinate system usable for engineering projects, the horizontal relationships should be defined as two dimensional on one (mapping) plane. To make the coordinate system usable and to simplify linear measurement, the coordinate system should be rectangular so that equal values measured from a datum axis form a parallel line with that axis. Parallel lines to each of the two axes form a "grid" and the intersection of those lines are rectangular "grid coordinates". This type of coordinates are called Cartesian coordinate systems.

The following table summarizes the differences between plane and ellipsoidal coordinates

	<b>Plane</b>	<b>Ellipsoid</b>
North-South Direction	Straight up or parallel to the direction of the North Arrow	Slanted (not uniformly) towards the North Pole. All lines pointing to North converge at the North Pole.
Distances	Straight lines	Curved lines
Sum of angles in a quadrilateral	360°	360° + spherical excess
Even coordinate differences correspond to:	Even (same length) distances.	Uneven distances, i.e. the length of an arc of 2° of longitude near the pole is much shorter than 2° of arc near the equator.

Table 1. Some differences between working on a plane and on an ellipsoid.

In highway work, the north-south axis is designated as the Y-axis and the east-west axis as the X-axis. The horizontal distance from the Y-axis is the "easting" coordinate and the vertical distance from the X-axis is the "northing" coordinate. A statement of the exact position of a point within the system can be expressed as X-Y, or easting-northing value of the point. Stated either way, the point location is being described by rectangular coordinates and the location is a grid location.

Another statement of the exact position of a point (P) within the system can be expressed as a direction and distance from the origin (O, intersection of the Y and X axes). In this case, the location of the point is being described by polar coordinates and the location is the polar location.

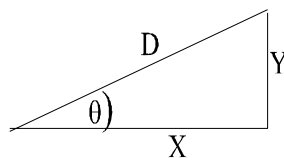


Figure 2-1. Rectangular coordinates (X,Y) vs. Polar coordinates (D,θ)

Due to the rectangular nature of the grid system, the conversion between rectangular and polar coordinates is accomplished by simple right triangle plane trigonometric calculations. The conversion is used throughout the survey. For instance, a traverse is started at a grid location described by the X and Y coordinates. The direction of the first leg of the traverse is established by turning an angle from a known direction to the next traverse point (thus establishing the polar direction); the distance is measured between the points (thus establishing the polar distance). A simple right triangle solution adding the northing and easting of the line to the northing and easting of the beginning point to give the rectangular coordinates of the new traverse point. Conversely, a point with predetermined X,Y coordinates may be established from a pair of known points by calculating the polar relationships between the point occupied and the point to be established. A predetermined angle is turned to the calculated polar direction and the point set at the calculated polar distance. This simple operation, called radial surveys, is extremely useful in setting Right-of-Way markers, slope stakes or other construction control points from project control points.

It is noteworthy to mention here that in order to make volumetric calculations, set grade lines and establish vertical clearances, etc., the third dimension (elevation) is shown on the plane map surface as contour lines (a line depicting equal elevation) or spot elevations. A combination of horizontal position and elevation data makes up a "topographic map". This same data in digital form is called a Digital Elevation Model or (DEM.)

To define a plane coordinate system one has to select an origin for the X-Y coordinates and a direction of the Y-axis or the north. The selection of these coordinate system parameters can be done on a local, state or even on a worldwide basis.

#### **2.1.4.1 Assumed (Local) Plane Coordinate System**

Traditionally, most surveys used an assumed or local plane coordinate system. A point is assigned an arbitrary coordinate, such as X=10,000 and Y=20,000, and a direction from that point to a nearby point is set to be due north. In the case of a closed traverse (which is the most widely used surveying operation) the first point is assigned the arbitrary coordinates and the direction from the first to the second point is fixed as due north. An assumed plane coordinate system has two major drawbacks.

1. It does not accommodate splitting a large project into smaller independent projects. Dividing a project into smaller ones is desirable in circumstances of time and/or budget constraints.
2. The approximation of the surface of the earth to a plane is valid for only a limited extent of an area. Beyond that, the corrections have to be applied to distances and angle to reflect the deviation of the curved earth from a plane.

For small and isolated projects, such as local property surveys or construction surveys, an assumed plane coordinate system can be acceptable. However, for large engineering projects, such as a lengthy highway, this practice must be avoided.

#### **2.1.4.2 State Plane Coordinate System**

It is impossible to map a curved Earth on a flat map using plane coordinates (X,Y or northing, easting) without distorting angles, distances or areas. However, it is possible to design a map projection such that some of these elements are undisturbed or minimally distorted. The State Plane Coordinate System (SPCS) is a map projection system that minimizes angular distortions if only a small portion of the Earth is flattened out. The (X,Y) coordinates are computed by projecting latitudes and longitudes from a mathematical approximation of the earth (i.e. NAD 83) onto a surface that can laid out flat. The three surfaces that are used for this purpose are a plane, a cone or a cylinder. The earth is wrapped with a cone or a cylinder and the earth's features are projected onto it. When the projection is done the cone or the cylinder are cut and opened into a flat surface.

SPCS consists of a set of mathematical relationships that are used to convert northing and eastings into latitude and longitudes and vice versa. It also includes a set of formulas to compute the size and the direction of location displacement (positional error) resulting from the projection process.

In the US there are mainly two projection systems utilized for the state plane coordinate system. The first is the Transverse Mercator (TM) which best serves states (or portions of states) which extend in the north-south direction. The other projection system is the Lambert Conformal Conic (LCC) projection that is best suited for mapping long distances in the east-west directions. The TM projection utilizes a cylinder, resting on its side, for projecting points from an ellipsoid into a plane. Thus, along one meridian (i.e. north-south) there is no distortion at all regardless of the latitude. The LCC projection utilizes a cone so that along a given parallel (i.e. east-west) there is no distortion regardless of the longitude.

#### **2.1.4.3 Benefits and Need for Use of the State Plane**

1. All surveys correlate to a single reference framework. This means that all surveys, old and new, can be combined seamlessly into a consistent and contiguous mapping project. Points from old and new surveys can be used without the need to re-calculate the old measurements. Surveyors having numerous projects in a certain area could, theoretically, “cut and paste” different projects to produce a map without compromising the accuracy of the new product.
2. Large projects can be surveyed in parallel as independent sections. Although during the time of the execution of the project the different sections are not yet connected physically, they are connected computationally because they all share a common

reference framework. As the work progresses, all sections will be connected and the accuracy of the entire project will be maintained throughout.

3. Data sharing among surveyors is simplified if everyone is working on the same reference system. Data is a precious commodity in the GIS/LIS world. Surveyors have an abundance of spatial information. If it is in a useable form (such as SPCS), it has a market value.
4. No point can be considered lost because it can be recovered from its coordinates. For example, if a point has State Plane Coordinates, it can be reestablished by using GPS. There is no need to recover points from ties (which may have also been destroyed), unless there is a legal issue involved.
5. Using SPCS, the earth can be viewed mathematically as a plane. This means that plane geometry and trigonometry mathematics can be used in the computations. One needs only to apply a small, well defined, correction to compensate for the plane approximation. This manual explains what corrections have to be made.
6. Working with SPCS provides an extra external computation check for the surveys. Loop closures, such as a closed traverse, check only the inner consistency of the survey. If, for example, there is a systematic scale error in the traverse, it will not be detected by summing up the latitudes and the departures. Only when the traverse is connected to two or more points with given State Plane Coordinate values can this error be discovered and corrected. A similar argument holds for the orientation of the traverse. To maintain proper orientation of a traverse, it has to be connected to at least two control points with State Plane Coordinates.
7. Use of the system of State Plane Coordinates is vital to accomplishing precision mapping, highway design and location, and cadastral surveying on a statewide basis.
8. By law, the New Jersey State Plane Coordinate System based on NAD 83, is the official survey base for the State of New Jersey (N.J.S.A.51:3-7).
9. Use of SPCS accommodates statewide GIS/LIS activities.

## **2.2 New Jersey State Plane Coordinate System**

The New Jersey State Plane Coordinate System is based on a Transverse Mercator (TM) projection. The reason for using the TM projection is because the shape of New Jersey is elongated in a north-south direction. As mentioned earlier, projection distortions in a TM projection increase as the east-west distance from the central meridian increases, but remain rather constant in the north-south direction. The best projection for a state is the one that introduces the least distortions.

There are two New Jersey state plane coordinate systems. The first is based on NAD 27 and the other is based on NAD 83. The NAD 27 SPCS is the earlier one and should be avoided. According to N.J.S.A. 51:3-7, the official state plane coordinate system for New Jersey is the one based on NAD 83. State plane coordinate values of NAD 83 are different from those of NAD 27 because:

- Change in datum (NAD 83 is based on GRS 80, NAD 27 is based on Clarke 1866)
- Changes as a result of a new adjustment
- New mapping (projection) equations (derived mathematically not empirically) to support 1mm accuracy
- Changes in numerical grid value of the origin of each zone
- Changes in mapping constants in some zones (new standard parallel or meridian)
- Azimuth orientation is due North
- The use of Metric units rather than English units.

The parameters of the New Jersey state plane coordinate systems are:

SPCS	NAD 27	NAD 83
Zone (NGS) Code	2900	2900
Projection	TM	TM
Scale Factor	1:40,000	1:10,000
Origin latitude: $\phi$	38° 50'	38° 50'
Central Meridian: $\lambda$	74° 40'	74° 30'
(X) E at Central Meridian	2,000,000	150,000
(Y) N at origin latitude	0	0
Units	Feet	Meters
Initial Azimuth due	South	North

### **2.2.1 The Surveyor and SPCS**

A surveyor should have a basic understanding of the derivation of this grid system and the relationship of the various components of the Transverse Mercator Projection. In most cases, inverses computed from grid coordinates do not correspond to measured values in the field. The surveyor must understand why the discrepancy exists and properly apply the necessary corrections so that field measurements and coordinate geometry computations are consistent. Thus, it is important to understand the relationship between a point on the topography and its representation on the state plane coordinate system.

### **2.2.2 From Topography (Surface) to State Plane**

In the geodetic reference system, coordinates of points (latitudes and longitudes) and the lengths and azimuths of lines are defined on an ellipsoid. Therefore, surveys that are to be

adjusted to stations of the national control network must first be reduced to the ellipsoid. Since the state plane coordinate systems are developed directly from geodetic values, the use of those systems require the further reduction of the ellipsoid values to grid values. The reduction from ground to the state plane is a simple two-stage process. Reduction from ground to the ellipsoid is called the "elevation factor" and reduction from the ellipsoid to the state plane grid is called the "scale factor". The scale factor in New Jersey is set to 0.9999 at the central meridian and it increases as a function of easterly or westerly distance of the point from the central meridian. The maximum value of the scale factor is 1.0001.

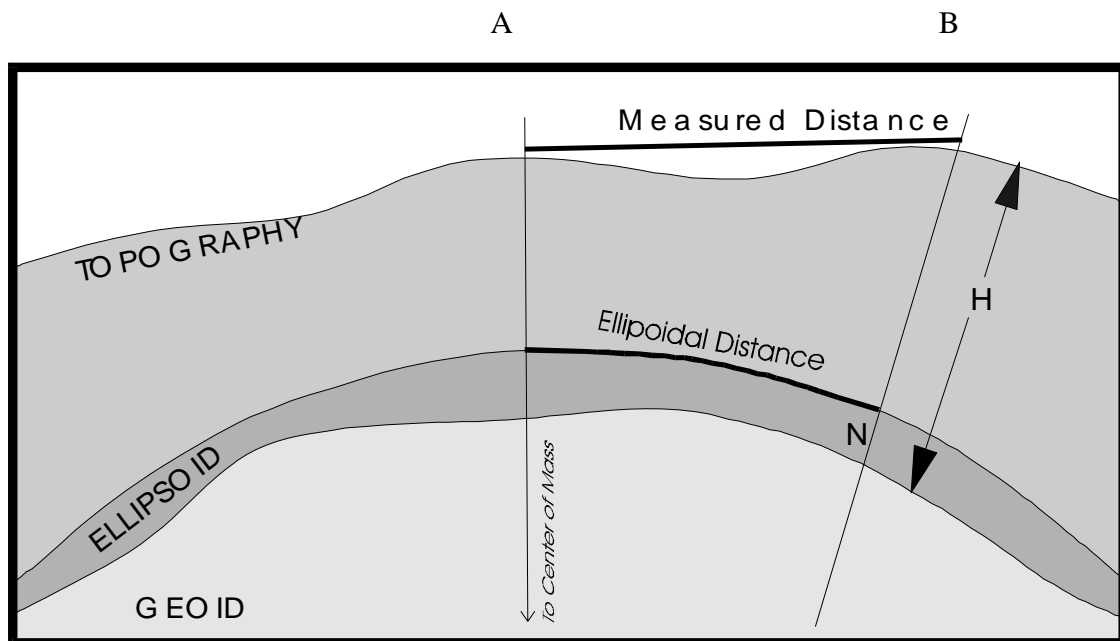


Figure 2-2. The relationship between a measured distance and a distance on the ellipsoid.

The following sections contain the formulas for reducing a distance from the topography to the state plane grid.

### **2.2.2.1 Reduction I. (Grid) Scale Factor $K_{AB}$ for a Line from Point A to Point B**

**Purpose:** To correct for scale distortion due to the projection of the ellipsoid onto a plane.

**Formula:** 
$$K_{AB} = \frac{K_A + 4K_m + K_B}{6}$$

**Where:**

- $K_{AB}$  - Grid scale factor of a line between points A and B.
- $K_A$  - Grid scale factor at point A
- $K_B$  - Grid scale factor at point B
- $K_m$  - Grid scale factor at the line's mid- point.

**Usage:** A reasonable approximation for the above formula is to compute a simple average of  $K_A$  and  $K_B$ . A further approximation is to compute a single  $K$  value for the entire line or for the entire survey area.

For New Jersey, the value of  $K$  can be computed for a point with a given easting,  $E$ , from:

$$K = 0.9999 + (E - 150000)^2 \cdot 1.23 \cdot 10^{-14}$$

### **2.2.2.2 Reduction II. Elevation Factor, Reducing Measured Horizontal Distance to Grid Distance.**

**Purpose:** To reduce a measured horizontal distance to the projection plane. As mentioned earlier, field measurements are carried out on the physical surface of the earth, while office computation are performed on the projection of the earth onto a plane. This reduction is in essence the bridge between field measurements and the computations on the state plane coordinate system.

**Formula:** 
$$S = D \times \left( \frac{R}{R + H + N} \right) \times K_{AB}$$

**Where:**

- $S$  - Grid Distance
- $D$  - Horizontal (Measured) Distance
- $H$  - Mean Elevation (Above Mean Sea Level)
- $N$  - Mean Geoid Height (About -32m or -100ft in NJ)
- $R$  - Mean Radius of the Earth (About 6,372,000m or 20,906,000)
- $K_{AB}$  - Grid Scale factor of the Line.

**Usage:** Obtain the elevations of the terminal points of the line, the Geoid height of the region, and calculate.

Although the above discussion appears complicated, the solution for surface measurements to state plane distances are quite simple to program on programmable calculators or computers.

### **2.2.3 State Plane to Surface Coordinates**

The surveyor's primary concern is with surface measurements and the use of the coordinate relationship between points established, or to be established, on the ground. To compute a distance 'D' between two points on the ground from their state plane coordinates (grid) distance 'S', the above corrections must be applied in a reversed order. The inverse correction is:

$$D = S \times \left( \frac{R + H + N}{R \times K_{AB}} \right)$$

In some situations it is impractical to adjust every surface measurement to determine the state plane coordinates of the point. There are some cases where it may be advantageous to produce engineering mapping on a plane that closely relate to the ground on which that facility is being designed and constructed.

The advantage of having a coordinate system that can be as closely related to the ground as practicable is obvious. The danger is that this data could erroneously be confused with state plane based surveys. Therefore, the coordinate listings should be clearly identifiable so that surface coordinates cannot be confused with state plane grid coordinates. Other criteria for establishing a coordinate system (Project Specific Adjusted State Plane Coordinate) for engineering projects should include:

- a. Adjustment between ellipsoid and actual ground measurement should be minimal.
- b. Coordinate relationship between the surface grid and the reference state plane should be constant and simple to calculate.
- c. The surface coordinate system should extend throughout the project area so that no coordinate equations are required. If practical, the coordinate system should be made compatible with adjacent projects.

In accordance with the above criteria, surface coordinates should be established for the project, which best fit the elevation of the ground. A Project Adjustment Factor (PAF) should be calculated for each project using the average of the combined factors for reducing surface distance to state plane distances. Some NJDOT mapping and engineering calculations are produced on the surface plane and listings indicate surface coordinates.

#### **2.2.4 Universal Transverse Mercator (UTM)**

The Universal Transverse Mercator (UTM) system is another important plane coordinate system. Originally developed by the military for artillery use, it provides worldwide coverage from 80° South latitude to 84° North latitude. Each zone has a width of 6° 00'00", which requires 60 zones to cover the entire earth. The zones are numbered easterly from 180° West longitude. New Jersey is located in zone 18.

Longitudes and latitudes used in UTM calculations are based on Clarke 1866, the same ellipsoid used in NAD 27.

The UTM system is a modified transverse mercator projection. It has recently taken on new importance since UTM coordinates are widely used in GIS/LIS. Current USGS 7 1/2

minute quad sheets, as well as other maps in the national mapping program now show 10,000 meter grid ticks to allow manual plotting in this system.

The central meridian of each zone is assigned an easting of 500,000 meters and a northing of 0 meters is applied to the equator for the northern portion and 10,000,000 meters applied to the equator for the southern portion. The scale factor at the central meridian is set to 0.9996 or a relative accuracy of 1:2500. UTM was not adopted by NGS as the state's plane coordinate system for several reasons. One reason is that a relative accuracy of 1:2500 is too low to make it practical for surveying projects. Another reason is that UTM does not conform to state boundaries, which is a desirable feature for a state plane coordinate system. It is desirable to place the central meridian or the standard parallels in the center of a state to minimize projection distortions. This cannot be done with the rigid structure of the UTM system. Surveyors may encounter UTM when dealing with buildings on the National Historic Register, sewer outfalls, historic sites, etc.

## **2.2.5 Azimuths**

### **2.2.5.1 Definition**

Azimuth is the horizontal direction of a line measured to the right (clockwise) from a reference meridian. In the past (NAD 27), azimuths published by the various government survey branches were measured from the south. Since the development of (NAD 83), new data for all NGS control points are published with zero azimuth pointing to the north.

It is noteworthy to mention here that most calculators and computers use the mathematical convention for reference (zero) azimuth which points towards the east and measures counterclockwise. Angles in computers are also usually expressed in radians. Surveyors must also be alert and realize that some agencies also use grads (1/400 of a circle) for the angular definition. Azimuths in grads should not be confused with those expressed in degrees of arc (360°). These various definitions of azimuths are generally easy to overcome when known, but the surveyor should be alert to recognize the differences and know how to make the appropriate change to the system he or she is using.

NJDOT, local and other state agencies and private surveyors are north oriented. The advantage of north oriented azimuth is that the algebraic signs of trigonometric functions are correct when calculating latitudes and departures (in traverse computation).

There are three basic azimuth systems used in highway surveys:

- A. Astronomic azimuth is the angle between the (instantaneous) true north and a vertical plane through the observed object. Astronomic azimuths are usually measured to maintain proper orientation of long traverses along a highway. Astronomical azimuths are determined from observations to the Sun or to Polaris. The use of GPS has diminished the utilization of astronomic azimuths in route surveys.

- B. Geodetic azimuth is the angle between the meridian of the ellipsoid representing the earth and a plane perpendicular to the ellipsoid through the observed object.
- C. Grid azimuth is the angle in the plane of the projection between grid north and the straight line from the point of observation to the point observed. Grid azimuth is the same as geodetic azimuth only when the point of observation falls on the central meridian.

### **2.2.5.2 Forward and Back Azimuths**

The azimuth for a given line, AB, is usually stated as the azimuth measured at point A towards point B. This is called the forward azimuth. However, each line has a corresponding back azimuth, BA, which is the azimuth at point B towards point A. For grid azimuths, the difference between forward and back azimuths is always exactly 180°. This is not the case with geodetic azimuths. Because of convergence of the meridians, the difference between forward and back geodetic azimuth is 180 degrees plus the difference in the angle of convergence and a small arc-to-chord correction.

### **2.2.5.3 Conversion From Grid Azimuth to Geodetic Azimuth**

It is useful for the surveyor to know the difference between the geodetic and grid azimuths of a survey line for the purpose of obtaining a check on a computed value or to provide a starting azimuth for the survey. It may also be useful to convert grid azimuth to geodetic azimuths of property lines to an azimuth that is independent of the choice of map projection. For this, and other reasons, the issue of convergence angle is important to surveying.

#### **Relationship Between Geodetic and Grid Azimuths**

**Purpose:** To account for the convergence of the north direction towards the pole vs. parallel north direction on a plane.

**Formula:** 
$$AZ_{\text{Grid}} = AZ_{\text{Geodetic}} - \gamma + (t-T)$$

**Where:**

- $AZ_{\text{Grid}}$  - Grid Azimuth
- $AZ_{\text{Geodetic}}$  - Geodetic Azimuth
- $\gamma$  - Meridian Convergence
- $(t-T)$  - Arc-to-chord correction

**Usage:** This formula (except for the t-T correction) is used only when it is necessary to convert grid azimuth to geodetic azimuth, or geodetic azimuth to grid azimuth. Grid

Azimuth can be computed from an inverse between two points with plane coordinates. Geodetic Azimuth is usually provided by NGS or from GPS measurements. It can also be computed from Astronomical observations corrected for the deflection of the vertical (called Laplace Correction).

The value of the meridian convergence at stations of the national control network is listed on their data sheets published by NGS. There are software and interpolation tables to compute this convergence angle. The magnitude of the convergence angle in NAD 83 is illustrated in figure 2-3:

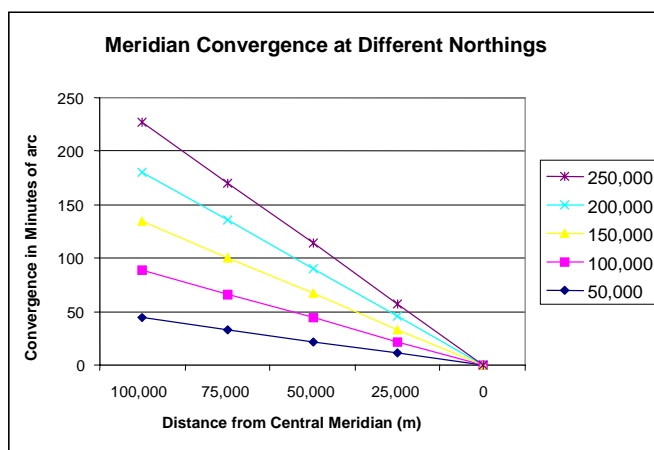


Figure 2-3. The

meridian convergence as a function  
of the distance from the central meridian  
**Arc-to-Chord Correction (t-T) for line 1-2.**

**Purpose:** The (t-T) correction is due to the fact that the measured direction between two points is actually a curved line, on the surface on a body such as an ellipsoid, that passes through these points. When projected onto a plane, the geodetic direction looks like an arc, rather than a straight line. The angle that is computed from field notes is defined by the difference between two measured directions. Thus, the computed angle differs slightly from the plane angle of the state plane coordinate system. This difference is expressed by (t-T).

**Formula:** 
$$(t-T)'' = 25.4 \times \Delta N \times \Delta E \times 10^{-10}$$

**Where:**

- $\Delta N$  =  $N_2 - N_1$
- $\Delta E$  =  $\frac{E_2 - E_1}{2} - E_0$
- (t-T)'' - Arc-to-chord correction in seconds of arc.
- $N_1$  - Northing of point 1
- $N_2$  - Northing of point 2

- $E_1$  - Easting of point 1
- $E_2$  - Easting of point 2

**Usage:** The size of the correction is rather small and can be neglected for most ordinary work (not high accuracy). The sign of the correction is dependent on the direction of the line with respect to the north (Azimuth dependent). The magnitude of the correction in New Jersey is:

	Average Distance of the line from the Central Meridian (m)			
$\Delta N$	150,000	100,000	50,000	0
2 km	0.8"	0.5"	0.3"	0"
5 km	1.9"	1.3"	0.6"	0"
10 km	3.8"	2.5"	1.3"	0"
20 km	7.6"	5.1"	2.5"	0"

Where  $\Delta N$  is the difference in Northing between the end points of the line.

## **2.3 Geodetic Control**

### **2.3.1 Introduction**

The Federal Geodetic Control Committee (FGCC) and subsequently the Federal Geographic Data Committee (FGDC) have developed standards and specifications for establishing horizontal and vertical control. The (NGS) has developed a standard format for geodetic survey data, commonly known as "Bluebook" format. This format must be used if geodetic survey data is to be submitted to the NGS for review and inclusion into the National Network.

It must be noted that the FGCC Standards and Specifications also require a survey control monument to meet certain physical conditions. It is not reasonable to require that a survey meet first-order requirements and submit data to the NGS if the monuments do not meet the same standards. Not every point on every survey project or a subdivision has to be included in the national geodetic network of control points. It may be reasonable to set a few monuments throughout a project area that meets federal monumentation standards. These points are to be submitted as primary control stations. The primary control stations in this example would be "bluebooked" and included in the national network. The remaining points are to be monumented with lower and less expensive standards, and referenced to the primary monuments.

The recommended procedure is to use (GPS) survey methods to establish horizontal control, use spirit leveling methods for establishing vertical control when elevations of highest accuracy are needed, otherwise elevations determined by GPS may be adequate for

most projects. The surveyor should follow FGCC Standards and Specifications for the surveying of all geodetic control. He/she should also "Bluebook" the primary, if not the entire, survey control project and submit it to the NGS for review and inclusion into the national network.

### **2.3.2 Survey Control Network**

To facilitate the creation of GIS/LIS, all spatial objects must be maintained in a common coordinate system. This means that they have to be tied to control points with geodetic or state plane coordinates. Since the primary geodetic control is too sparse, there is a need to densify the survey control network. Arbitrarily setting monuments as needed for the mapping/GIS/LIS control is one pattern that can be used for physically placing survey control throughout the project. Another pattern would be some systematic planning of control points that are easily accessible for a variety of projects.

The survey control network is the framework of the entire project. It will only be as accurate as the control survey upon which it is based. The cost of the survey control network is a small percentage of the overall cost, ranging from 1% to 5% of the total survey cost being invested in the project. Factors affecting cost include:

- A. Setting new monuments or occupying existing monuments (property corners, road centerline monuments, etc.). Being able to incorporate existing monumentation, when available would save not only the cost and time of physically setting a new monument, but would also allow the project to have actual ties to property line and road right-of-way information.
- B. Number of survey control monuments being established for the project. Mobilization for performing the survey can affect the cost in several ways. Fewer monuments will make the cost of mobilization higher per monument, and fewer monuments also means more time is spent traveling between survey control stations, causing higher costs per station for performing the survey. A greater number of monuments will decrease the cost per station for both mobilization and performing the survey.
- C. Terrain and location can affect the cost of performing the survey. Tree cover, urban areas and hilly areas can also make the planning and implementation difficult. Road occupations in busy intersections can incur additional costs for traffic control.
- D. "Bluebooking": Survey control submitted to NGS in their format will have an extra quality check by the federal government at no charge, but there is a cost incurred in the time spent formatting the data to "bluebook" standards.
- E. Time spent to go farther away from the project area to recover needed horizontal and vertical control, if there isn't enough available control in the project area, increases the cost of the survey.

### **2.3.3 Planning**

It is important to plan for the future use of the control points from the beginning stages of developing the project. The geodetic survey control framework is the foundation of the project. If proper consideration is given to the quality and accuracy needed for current and future needs, the project will be much easier to use and to keep updated in the maintenance/update phase. Surveys for new highways and engineering projects, etc., can be readily incorporated into a GIS/LIS if they are accurately referenced to the control network. All personnel involved in geodetic surveys should become familiar with NGS bluebooking procedures before beginning work on a project. See the Regional Survey Services Supervisor for these procedures.

### **2.3.4 Conclusions**

Do not cut costs. The survey is the framework of the entire project and a small percentage of the overall investment. Establish horizontal coordinates on each monument by following "bluebooking" and other specifications. Plan for the use of the survey control in the future, both to be able to accurately update the transportation network and for future requirements for the surveyors to tie into GIS/LIS. This planning includes establishing "station pairs", performing the geodetic control survey to FGCC specifications for second order accuracy, or higher, and setting permanent survey monuments.

## **2.4 Monumentation**

### **2.4.1 Definition**

A monument is a fixed object on the ground, whether natural or artificial, serving as a permanent mark of the survey. The monumentation of control survey points is an important part of a highway project. Hundreds of thousands of dollars in surveying work have been lost because surveys were not properly monumented or the monuments were destroyed. A control survey monument should possess stability, positive identity and protection against destruction. The practice of monumenting control points should be continued even though GPS has made it easier to reestablish the location of points with known coordinates. As long as surveys are performed with equipment other than GPS, monumentation remains indispensable. If the control point is associated with property records, its monumentation is important from the legal boundary recovery perspective.

### **2.4.2 Purpose**

It is apparent that time spent on monumentation serves a three-fold purpose:

- A. The monuments provide a permanent physical object that is readily acceptable by local surveyors as the survey control for the roadway.
- B. The monuments can be incorporated into a city, county or state system to enhance the control network GIS/LIS.
- C. The monuments can be incorporated into the National Geodetic Reference System (NGRS) and referenced to that system.

### **2.4.3 Characteristics of Monuments**

With the increasing use of GPS measurement techniques which rely on relative positioning, it is important that station markers have the properties of permanence and stability. The markers must be stable in all three dimensions.

Factors that may affect the stability of a monument include frost heave action, changes in ground water level, and settlement. When selecting sites for stations of a high precision primary network or for monitoring deformation, it is recommended that soil and geothermal specialists be consulted.

Markers for existing network control should show no historical evidence of significant movement. If an existing network control marker does not adequately exhibit the properties of permanence and stability, it may have to be replaced by a new marker. The decision to replace old markers will depend on their use and purpose in future surveys.

To meet the requirements for permanent and stable monumentation, the markers are usually bronze disks that may be set in rock outcrops or large masses of concrete such as bridge abutments and other structural foundations.

When bedrock or large massive structures are not available, it is more difficult to ensure the monument has the properties of permanence and stability. Traditional concrete monuments, with or without an underground mark, are not recommended as a suitable choice for preserving the three dimensional coordinates. A three dimensional (3D) driven survey monument will provide the necessary stability for most conditions. Reference the NJDOT Minimum Guidelines for Aerial Photogrammetric Mapping Manual page 4-32 for details.

### **2.4.4 Monument Types**

There are several types of monuments in general use. They vary from 3D-driven rod monuments, cast in place concrete monuments and monument assemblies for permanent

monumentation to iron pins with caps for semi-permanent applications. The monument used depends on the type of survey, local conditions and the requirements of the project. In highway engineering there are mainly four types of monuments.

- A. 3D - driven rod monuments. This monument is to be used for points that require maximum stability such as (HARN) stations. Follow NGS specifications for this type of monuments.
- B. Standard tablets set in concrete, rock or existing structures. This type of monument is used mainly for marking primary survey control points, (i.e. GPS, triangulation, trilateration, and primary traverse).
- C. Survey capped iron pins. This monument, if properly referenced and witnessed is probably the best for marking the stations of a supplementary control traverse. Iron pins are also used as right-of-way monuments.
- D. Iron pin with cap set in concrete. Rock outcrops or existing concrete structures, such as bridges or culvert headwalls, may be used for setting permanent marks. Bronze or aluminum tablets firmly implanted in concrete are as permanent as the structure in which they are placed. These monuments can be used for marking any kind of survey control. When properly set in concrete, the standard monument is relatively indestructible.

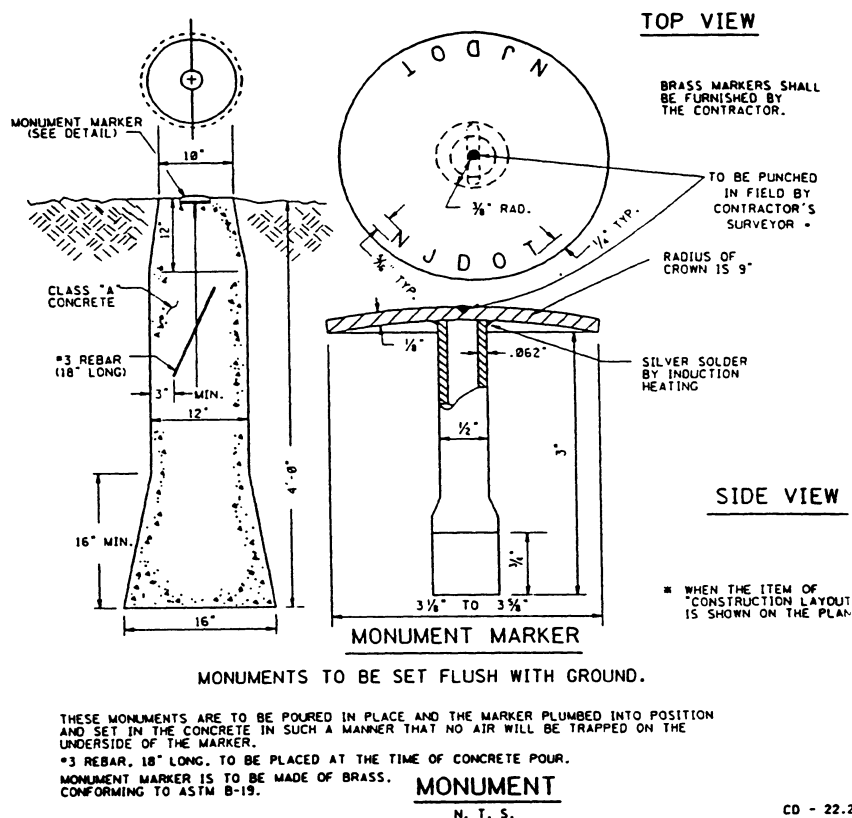


Figure 2-4 New Jersey DOT monument

For detailed construction of these monuments, see Figure 2-4 and the NJDOT standard construction drawings.

#### **2.4.5 Cost**

The cost of monumentation relatively speaking is small compared to the millions of dollars routinely spent on highway projects. The cost involved in monumentation is far outweighed by the benefits derived, and an effort should be made to monument existing highways. Whether the project is a new road or a major renovation every effort should be made to include the cost of monumentation in the plans.

#### **2.4.6 Referencing Monuments**

A written description and a location sketch of each monument should be made in the field. Monuments must be tied to either permanent natural objects or to additional points set nearby, including angular references to visible landmarks.

A steel or fiberglass witness post should be set near each 3D - driven rod monument and existing concrete structures. These posts should be provided with a warning, 'DO NOT DESTROY PROPERTY STATE OF NEW JERSEY,' to serve as a warning to others and make a significant reduction in the number of monuments destroyed.

#### **2.4.7 Right-of-Way**

Right-of-way monumentation is required on all new property acquisitions by NJDOT (see Appendix A). Right-of-way monuments shall be set by NJDOT and NJDOT consultants at the time of staking the bounds of fee parcels and permanent easement parcels acquired by NJDOT, and shall be called for in the legal descriptions. Monuments will be set along NJDOT ROW, or baselines at PC's, PT's, POT's and will be stamped "NJDOT R/W" when set by NJDOT personnel. Monuments set by consultants, will be stamped "NJDOT R/W" and company name in accordance with NJAC 13:40-5.1(d)3. Also, reference section 6.3.3.5.

# Chapter 3

## Surveying Measurements

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# Chapter 3 Surveying Measurements

## 3.1 General

Basic field operations performed by a surveyor involve linear and angular measurements. Through application of mathematics (geometry and trigonometry) and spatial information knowledge, the surveyor converts these measurements to the horizontal and vertical relationships necessary to produce maps, plans of engineering projects, or Geographical Information System/Land Information System (GIS/LIS).

The highway surveyor must be adept at making the required measurements to the degree of accuracy required. Various types of engineering works require various tolerances in the precision of the measurements made and the accuracies achieved by these measurements.

The use of common sense and development of good surveying practice in all phases of a survey cannot be overemphasized. All conditions that may be encountered in the "real world" during the actual field survey cannot be covered in any manual. A manual may specify certain techniques, such as a certain number of repeated operations, to achieve a required accuracy. The surveyor must then often use judgment based on the equipment being used and the field conditions encountered, to modify those techniques. Some field conditions (heat waves or wind for example) may make it impossible to perform some operations to a consistent degree of accuracy.

## 3.2 Accuracy and Precision

### 3.2.1 Accuracy

Accuracy is the degree of conformity with a standard or accepted value. Accuracy relates to the quality of the result. It is distinguished from precision that relates to the quality of the operation used to obtain the result. The standard used to determine accuracy can be:

- A. An exact known value, such as the sum of the three interior angles of a plane triangle is  $180^\circ$ .
- B. A value of a conventional unit as defined by a physical representation thereof, such as the international meter.

- C. A survey or map value determined by superior methods and deemed sufficiently near the ideal or true value to be held constant for the control of dependent operations.

Although they are known to be not exact, higher order NGS control points are deemed of sufficient accuracy to be the control for all other less exact surveys.

### **3.2.2 Precision**

Precision is the degree of refinement in the performance of an operation (procedures and instrumentation) or in the statement of a result. It is a measure of the uniformity or reproducibility of the result.

### **3.2.3 Accuracy Versus Precision**

The accuracy of a field survey depends directly upon the precision of the survey. Although through luck (compensating errors, for example) surveys with high order closures might be attained without high order precision, such accuracies are meaningless. Therefore, all measurements and results should be quoted in terms that are commensurate with the precision used to attain them. Similarly, all surveys must be performed with a precision that ensures that the desired accuracy is attained. However, surveys performed to a precision that excessively exceeds the requirements are costly and should be avoided.

## **3.3 Errors and Classification of Accuracy**

### **3.3.1 General**

Statistically speaking, field observations and the resulting measurement are never exact. Any observation can contain various types of errors. Often some of these errors are known and can be eliminated by applying appropriate corrections. However, even after all known errors are eliminated, a measurement will still be in error by some unknown value. To minimize the effect of errors, the surveyor has to use utmost care in making the observations and utilizing only calibrated equipment. However, a measurement is never exact, regardless of the precision of the observations.

Although this manual contains many guidelines and standards, the ultimate responsibility for providing surveys that meet desired accuracies remains with the field personnel. To fulfill this responsibility, the crew chief and his or her assistants must understand errors, including but not limited to:

- A. The various sources of errors.
- B. The effect of possible errors upon each observation, each measurement, and the entire survey.
- C. Economical procedures which will eliminate or minimize errors and result in surveys of the desired accuracies.

### **3.3.2 Blunders**

Many textbooks on surveying refer to a blunder as a gross error. One can easily make a case for a blunder to be considered an error. However, a blunder is really an unpredictable gross mistake made by the surveying team. It is not a hidden error that will go unnoticed, but usually it becomes apparent that something is wrong with the measurements. Examples of blunders are:

- Transposing two numbers (in field notes or computer input.)
- Misplacing decimal point.
- Incorrect reading (i.e. the foot value on a leveling rod.)
- Inadvertently altering set instrument constants in the middle of a project.
- Placing sighting device or the instrument at a wrong point.
- Misunderstanding verbal instructions or reading announcements (call out).
- Neglecting to level an instrument.
- Using the incorrect coordinates or benchmark values.

Blunders are caused by carelessness, misunderstanding, confusion, or poor judgment. They are, for the most part, avoided by alertness, common sense, and good judgment.

Blunders are detected and eliminated by using proper procedures, such as:

- Checking each recorded and calculated value.
- Making independent and redundant measure check observations and measurements.
- Making redundant measurements that allow closure computation of sections of the entire survey.

Small blunders are more difficult to detect and correct especially if the number of redundant measurements is too small. Therefore, surveys must be carried out with sufficient redundancy to prevent a blunder from going undetected. All blunders must be eliminated prior to correcting and adjusting a survey for errors.

### **3.3.3 Definition of Error**

Error is the difference, after blunders have been eliminated, between a measured or calculated value of a quantity and the true or established value of that quantity.

### **3.3.4 Types of Errors**

Excluding gross errors, which were discussed above, there are two general types of errors, systematic and random.

#### **3.3.4.1 Systematic Errors**

A systematic error is an error that will always have the same magnitude and the same algebraic sign under the same conditions.

In most cases, systematic errors are caused by physical and natural conditions that vary in accordance with known mathematical or physical laws. Systematic errors are caused by:

- Equipment out of calibration
- Use of insufficiently accurate computation equations (too few terms in a series.)
- Failure to apply necessary geometric reductions of measurements.
- Failure to apply necessary reductions of measurements due to weather related conditions.
- Personal biases of the observer.
- Use of incorrect units (feet instead of meters.)

A systematic error of a single kind is cumulative. However, several kinds of systematic errors occurring in any one measurement could compensate for each other. Some examples of systematic errors are:

- EDM that measures 99.95 feet while indicating a measurement of 100.00 feet.
- Refraction in vertical angles.
- Observer's tendency to sight on near or distant sights in a slightly different manner.

Although some systematic errors are difficult to detect, the surveyor must recognize the conditions that cause such errors. Once the conditions are known, the effect of these errors can be minimized as follows:

- Turning angles (with theodolite or total station) in direct and reverse modes.
- Balancing (maintaining similar distances between level and rod) foresights and backsights.
- Calibrating all surveying equipment.
- Calibrating EDM's yearly at a baseline calibration site.

When systematic errors cannot be eliminated by procedural changes, corrections are applied to the measurements. These corrections are documented in the user manuals of the equipment or in surveying textbooks.

Undeterminable systematic errors can also be modeled into the adjustment computation, but surveyors should not rely on this. They must eliminate all the known systematic errors prior to proceeding with any adjustment of the survey data.

#### **3.3.4.2 Random ( Accidental ) Errors**

A random error (or accidental error) is an error produced by irregular causes that are beyond the control of the observer. They do not follow any established rule which can be used to compute the error for a given condition or circumstance of the observation. The occurrence, magnitude, and algebraic sign of a random error is truly random and cannot be predicted. For a single measurement, it is the error remaining in the measurement after all possible systematic and gross errors are eliminated. An important characteristic of the random error is that if we repeat the same measurement many times, the sum of all these errors tends to be zero. This is yet another good reason to make extra measurements beyond the required minimum.

An example of a random error is the personal reading error of any scale. An observer estimates the final reading that can be either high or low in estimation since exactness cannot occur.

Unlike systematic errors, corrections for random errors cannot be computed directly. Random errors must be compensated by adjustments. The adjustment process computes adjusted observations for the actual ones in such a way that the remaining random errors are minimized. An example of such a process is computing an average distance from several measurements. The average represents the adjusted value for the distance for which the random error is minimized.

Random error obey the laws of chance or the random theory of statistics. Therefore, they are analyzed by applying the laws of probability. A complete discussion on the mathematical laws of probability is beyond the scope of this manual. The reference list at the beginning of this manual cites some excellent publications concerning the topic.

#### **3.3.5 Sources of Error**

Errors in measurements stem from three sources: personal, instrumental, and natural.

### **3.3.5.1 Personal Errors**

Personal errors are caused by the physical limitations of the human senses of sight and touch. An example of a personal error is an error in the measured value of a horizontal angle, caused by the inability to hold a range pole perfectly in the direction of the plumb line. Personal errors can be either systematic or random. Personal systematic errors are caused by an observer tendency to react the same way under the same conditions. When there is no such tendency, the personal errors are considered to be random.

Common sense, self-calibration (estimating personal errors by experiments and experience) and attention to proper procedures generally keep such errors to a minimum.

### **3.3.5.2 Instrument Error**

Instrumental errors are caused by imperfections in the design, construction, and adjustment of instruments and other equipment. Instruments can be calibrated to overcome these imperfections. Examples of instrument error are:

- Imperfect linear or angular scales.
- Instrument axes are not perfectly parallel or perpendicular to each other.
- Misalignment of various part of the instrument.
- Optical distortions causing “what you see is not exactly what you are supposed to see”.

Most instrumental errors are eliminated by using proper procedures, such as observing angles in direct and reverse modes, balancing foresights and back sights and repeating measurements. Since not all instrument errors can be eliminated by procedures, instruments must be periodically checked, tested and adjusted (or calibrated.) Instruments must be on a maintenance schedule to prevent inaccurate measurements.

### **3.3.5.3 Natural Errors**

Natural errors result from natural physical conditions such as atmospheric pressure, temperature, humidity, gravity, wind, and atmospheric refraction. Examples of natural errors are:

- A steel tape whose length varies with changes in temperature.
- Sun spots activity and its impact on the ionosphere, hence on GPS surveying.

Natural errors are mostly systematic and should be corrected or modeled in the adjustment. Some natural errors such as the effect of curvature and refraction can be eliminated by a procedure. The leveling procedure to eliminate curvature and refraction corrections is to average foresights and backsights.

### **3.4 Observation vs. Measurement**

An observation is a single, unadjusted determination of a linear or angular value. A single reading of an angle or a single reading of an EDM is an observation. An observed value is a quantity that is obtained by instrumental measurement of the quantity. A direct observation is an observation of the desired quantity while an indirect observation is a quantity computed from direct observations. For example, rod readings in leveling are direct observations and the elevation difference between two points that is computed from these rod readings is an indirect observation.

A measurement is the entire process of obtaining a desired quantity. A measurement entails performing a physical operation that usually consists of several more elementary operations such as preparations (instrument calibration and setup), pointing, matching, and comparing (reading). The result of these physical operations renders a numerical value that is called a “measurement”.

Surveys should be considered as measurements not as observations. With the advent of electronic readouts of linear or angular quantities everyone can make an observation. It requires a surveyor to make a measurement.

### **3.5 Linear Measurement**

This section covers two methods of obtaining linear measurement: taping and EDM. Linear measurements with GPS are discussed in Chapter 4 of this manual.

#### **3.5.1 Taping**

EDM instruments have largely replaced steel tapes in practically all measurements, except lower order work, such as close staking out, building measurements, etc. Wherever feasible, distances over 30 meters (100 feet) should be measured with an electronic measuring device. Accurate distances under 30 meters can be obtained with a calibrated steel tape.

Many surveyors believe that third order accuracy is a natural result of taping a distance. This is not true. Taped measurements will produce a linear accuracy of one part in 7,500 and yield a position closure of one part in 5,000 only if correct procedures are used. Such correct procedures would include standardization of tape, application of temperature correction, application of correct tension (particularly if tape is suspended), correct horizontal and vertical alignment of tape, and careful plumbing procedures.

It is anticipated that taping will not be used in critical measurements and a detailed explanation of taping procedures will not be included in this discussion.

### **3.5.2 Electronic Distance Measuring**

**General** Detailed operating instructions, instrument specifications and field adjustment information are included in the Operation Manual furnished with each instrument. The instrument manual should be kept with the instrument at all times.

**Training** Prior to performing field surveys, each operator should be thoroughly trained in the care and use of the measuring device and the allied equipment used therewith. The operator should be made fully aware of the instrument's limitations, possible causes of measurement errors, and have a thorough knowledge of the various functions performed by the instrument.

**Checking Instrument** When an instrument is received by a crew, whether new or transferred from another crew, the instrument should be checked on a known distance base line with the reflectors to be used with that instrument. All EDMs should be checked periodically, particularly prior to starting an important survey.

NGS calibrated base lines are currently available in different locations within the state. Each calibrated base line has permanent monuments set to test instruments at several distances. A description of the test areas is included in Appendix B. Caution should be exercised to insure use of the most current data. Current data is available through the NJ DOT Geodetic Survey office or the WWW site of NGS "www.ngs.noaa.gov"

**Atmospheric Correction** Atmospheric correction must be calculated and entered according to the instrument manufacturer's directions. Directions are usually supplied in the operator's manual for any instrument.

### **3.5.3 Common Sources of EDM Error**

- A. **Setting Up** The heavier EDM equipment puts an added strain on tripods and instrument stands. The tripods used to support EDM equipment should be sturdy and in good condition. Therefore, hinge and foot screws should be checked for tightness quite regularly.
- B. **Tribrachs** Plumbing errors cannot be eliminated by measuring procedures. Therefore, tribrachs must be checked for adjustment (bubble and optical plummet) frequently. This includes not only the tribrachs used for the EDM instrument, but also those used with the reflectors. If a tribrach is accidentally bumped, dropped, or knocked over, it should be checked before any additional measurements are made.
- C. **Range Pole Mounted Prisms** Range pole mounted prisms will seldom be used for measurements on the control traverse. When such prisms are used for tying in supplemental points and topographic features or staking out, an out of adjustment

pole level can be the source of considerable error. Pole levels should be checked frequently and when in use should be attached securely to the pole in a position that can easily be viewed by the holder.

- D. **Reflections From Extraneous Objects** Under most circumstances, an EDM measurement will be within the accuracy specified for that instrument even if the line of sight passes through leaves, fences, or other obstructions. However, such objects can sometimes reflect or interrupt the light rays and cause erroneous measurements. This occurs usually when the object is relatively close to the instrument. Roadside reflectors, windows, or other reflective objects in the path of or behind the prism can often cause erroneous measurements. When the line of sight cannot be cleared, such conditions should be recorded. Then, if poor closures result, those distances can be isolated and rechecked. When measuring various distances along a straight line, only one reflector should face the instrument. Otherwise, the instrument may be measuring to the wrong reflector.
  
- E. **Light Wave Skip** All EDMs have the inherent capability of false readings due to light wave skips. The skip is generally in increments of 1, 10, 20 or more meters. Generally, the skip is of sufficient magnitude to alert the operator that an erroneous measurement is being made. However, at some distances the skip will be small and difficult to eliminate. Repeat measurements are often successful, but not always.

Quite often the small one meter skip will not be evident until the survey is closed. An analysis of the traverse can sometimes indicate the false measurement.

A routine method of checking for skip is by eccentric measurement. The reflector can be moved two or three feet on line and a check measurement taken. If the check measurement is near the eccentric difference, in all likelihood there is no skip present.

- F. **Improper Prisms or Preset Prism Constants** Most EDM prisms have built in cross lens constants of 30 millimeters (0.098 feet). Each EDM manufacturer provides for their instruments' direct measurements by the combination of an internal adjustment within the instrument, and position of the prism in relation to the vertical axis of the prism.

In the final analysis, extreme caution should be exercised to make sure that the EDM prism constant setting coincides with that of the prisms being used. Be sure to check the EDM operator's manual and the specifications for the type prisms currently being used.

#### **3.5.4 Number of Measurements**

The number of measurements that should be made is a function of the characteristics of the survey. NGS has a set of standards and specifications for control surveys and the

American Congress on Surveying and Mapping/ American Land Title Association (ACSM/ALTA) has another set of specifications for land surveying work. Other organizations developed their own standards and specifications. These standards and specifications outline the number of linear measurements that are to be performed. Under some circumstances, the distance between two points may be determined only on one line and only in one direction. In other words, reciprocal measurements or measurements to eccentric points may not be necessary. A good rule of thumb to follow is that any time an angular direction is measured to a prism pole with a total station, a distance should be measured as well. There is very little extra effort involved in measuring the extra distance while the redundant measurement can provide a valuable check for the quality of the survey.

All base and control measurements should be the average of at least three measurements made in the standard (normal) measurement mode. Measurements made to set construction control stakes or points of equal importance should also be made in the standard mode.

Measurements made for topographic surveys, spot elevations, etc., can be made in the tracking mode. In order for the tracking mode to operate at the speed required, the instrument rounds off the displayed measurement.

## **3.6 Angular Measurement**

### **3.6.1 Purpose**

Points on the ground or on a map are related to each other through a horizontal distance and a horizontal angle (or direction.) Horizontal angular measurements are made between survey lines to determine the angle between the lines. A horizontal angle is the difference between two measured directions. Horizontal angles are measured on a plane perpendicular to the vertical axis (plumb line).

Vertical angular measurements are measured to determine slope of survey lines from the horizontal plane (level line). When the vertical angle is applied to the slope distance, the horizontal and vertical distances may be calculated. Vertical angles are measured on a plane passing through the vertical axis perpendicular to the horizontal plane. In order to facilitate the trigonometric calculations of horizontal and vertical distance, the reference or zero angle is on the vertical axis directly above the instrument, which is termed the zenith angle.

In the United States, the sexagesimal system of angular measurement is used. In the sexagesimal system, there are  $360^\circ$  in the circumference of a circle. The basic unit is the degree ( $^\circ$ ), which is further divided into 60 minutes ( $60'$ ), and the minute is subdivided into 60 seconds ( $60''$ ), and decimals thereof. Other angular unit systems utilize  $400^g$  (grads) or  $2\pi$  Radians per complete circle ( $360^\circ$ ).

### **3.6.2 Terms**

The following terms are defined specifically for angular measurement. Their meanings may differ slightly in other contexts.

- A. A pointing consists of a single sighting and circle reading on a single object.
- B. An angular observation is a single, unadjusted determination of the size of an angle. A single angular observation is derived by subtracting the value of a pointing on a reference object from the value of a pointing on an observed station.
- C. An angular measurement is the final determination of the magnitude of an angle before adjustment. Minimum angular measurement is the mean of at least two observations, one in the direct mode and the other in the reverse mode.
- D. A reference object (RO) is a survey point that is used as an initial sight for orientation when measuring horizontal angles and "directions". The term, RO, will be used interchangeably with backsight (BS) in this manual.
- E. A direction is the value of a clockwise angle between a backsight and any other survey point. The reference direction to the backsight can be either arbitrary or set to a desired value.
- F. Setting a position is the act of setting a specified horizontal circle reading while the telescope is pointed toward a reference object. Generally, either zero degrees or the calculated "back azimuth" is used.
- G. A direct reading is with the telescope in the upright (normal) position. An inverted or reverse reading is with the telescope inverted or plunged.
- H. Turning a position is the act of making one direct and one reverse observation on each survey point to which a direction is required.
- I. A repetition is a single observation (in a series of observations) of a horizontal angle, made with a repeating theodolite. This type of theodolite is rarely used nowadays. Information about repeating theodolites can be found in surveying textbooks.
- J. Indirect measurement of an angle is a computed value of the angle from other data. For example angles of a triangle can be computed from distance measurements of its three sides. Orientation of the triangle is established by selected sides whose directions are known or measured.

### **3.6.3 Errors, Corrections, and Precautions**

Direct measurement of angles and line direction by total station, theodolite, compass, or transit is familiar to all surveyors. However, many surveyors are not completely familiar with specific procedures that will achieve specified results. This section discusses errors involved in angular measurements and outlines procedures that will enable the surveyor to achieve specified results.

As mentioned earlier, errors in a measurement stem from various sources. Generally, angular measurements can be impacted by four classes of errors. These four classes are: instrumental, personal, natural, and miscellaneous errors. In the subsequent sections these factors and how to minimize them are discussed in detail.

#### **3.6.3.1 Instrumental Factors**

- A. **Adjustment** Adjustments should be made at regular intervals and particularly before work on any control survey is started. Such adjustments should be made under the most ideal conditions available, normally in the highway yard or shop. Adjustment should be done in accordance with the user's manual of the specific instrument.
- B. **Servicing** Instruments requiring major adjustments should be serviced at an authorized repair shop as specified by the Survey Operations Manager.
- C. **Level Bubbles and Optical Plummet** Normal measuring procedures do not compensate for maladjustment of either the plate bubble(s) or the optical plummet. These components must be checked more frequently than others.

On base and control traverse projects, the optical plummet should be checked at least once each day. The plate bubbles should be routinely checked on each setup.

- D. **Double Centering** Double centering compensates for lack of adjustment of almost all components of the instrument and should be standard practice for all angles measured (or laid off with a transit). Double centering consists of two repetitions (one direct and one reverse) with a transit.
- E. **Parallax** Parallax occurs when the focal point of the eyepiece does not coincide with the plane of the cross hairs. The condition varies for each observer because the focal length depends in part on the shape of the observer's eyeball. Parallax is also a major concern in the optical plummet.
  - 1. **When to Check** Parallax should be checked by each instrument person when beginning to operate a new instrument or one that has been operated by

someone else. The optical plummet should be checked on every setup, particularly if the instrument height is significantly different from the last setup.

2. **How to Check** Focus the telescope on some well defined distant object. Slowly move the head back and forth, about an inch from the eyepiece, while watching the relationship of the object to the cross hairs. If the object appears to move, parallax exists.
3. **Eliminate** Rotate the knurled eyepiece ring until apparent object movement is no longer present. It may be necessary to refocus the cross hairs.

### **3.6.3.2 Personal Factors**

#### A. Setting up Instrument

1. Be sure the tripod is in good condition and all hardware is snugly fitted.
2. Push the tripod shoes firmly into the ground. Pressure should be parallel to each leg. Keep your foot lightly on foot piece when adjusting leg lengths.
3. Place the legs in a position that will require a minimum of walking around the setup. In windy conditions, additional stability can be achieved if one leg is set downwind.
4. If the ground is soft or muddy, drive long 50 x 100 millimeter (2" x 4") wedges or iron pipes 19 millimeters x 1 meter (3/4" x 36") in the ground to support the tripod legs. Use duck boards to support the instrument man.
5. On warm asphalt pavement set the tripod shoes on stakes that have been nailed to the pavement. Shading tripod feet from direct sun may also be helpful.
6. Be sure that the instrument is exactly over the point.
7. Check the optical plummet after the instrument is set up and just before moving to another point. If the instrument has moved, check the angle just measured.
8. Recheck the instrument level. The bubble should hold one position when the instrument is smoothly turned through one circle.
9. Protect the instrument from direct exposure to the sun. Use a parasol if necessary.

#### B. Setting Sights

1. When tribrach mounted targets are used, take the same precautions as when setting up an instrument. With this equipment, "forced centering" between targets and

theodolite (and vice versa) will greatly decrease the effects of plumbing errors in traverse closures. Forced centering is especially beneficial in short course traverses.

Forced centering is the traverse procedure whereby backsight, instrument point and foresight are "leapfrogged". Once a tribrach is set over a point, it must stay mounted on the tripod over that point for all uses. The instrument and sights are transferred from point to point without disturbing the tribrach setup.

2. Before picking up the instrument or the target, check to see that the tribrach or the sighting device has not moved.
3. When setting a pole sight, plumb it with a precision equal to that required for the total survey. A twenty second error results from a sight that is 0.1 meters (0.32 feet) out of plumb at 1,000 meters (3280.8 feet ) away.
4. If a sight is set near ground level, check the line of sight for obstructions or for excessive heat waves. When excessive heat waves are present, ground level sights are not advisable.

### C. Pointing

1. **Tangent screw use** When moving sighting device onto a target, always make the last turn of the tangent screw clockwise. Clockwise movement increases the tension on the loading springs. A final turn counterclockwise releases tension and the spring can hang up, causing a "backlash" error.
2. **Cross Hair Use**
  - a. **Consistency** Sight each object with the same part of the cross hair, preferably near the center of the field of view. This practice will minimize small residual adjustment errors.
  - b. **Technique** The human eye can estimate the center of a wide object more accurately than it can line up two objects. For this reason, different pointing techniques should be used depending on the type and apparent size of the sight in the telescope.

When pointing on narrow sights, such as the center of a red and white target or distant range pole, straddle the sight with the double cross hairs. When pointing on wide sights, such as a lath or range pole at close range, split the sight with the single cross hair.

### D. Split Bubble Image

A frequent error in zenith angle measurement is failure to adjust the split bubble image into coincidence before reading the angle. If coincidence is not made, the scale is not indexed to the vertical and significant errors can result. Always set the bubble before each reading.

#### E. Measuring Angles

Measure angles as rapidly as comfortably possible with a uniform rhythm. Take the first reading at an object, rather than fidgeting with the tangent screw trying to improve the pointing. Too much pointing time increases the probability of error through instrument settlement or atmospheric changes. Speed should not be cultivated at the expense of good results. Accuracy is more important than speed.

#### F. Reading the Circles and the Micrometer

1. Call Outs Carefully read and call out each reading to the recorder. Call out the entire reading each time so any large blunders will be caught. Have the recorder repeat the reading to the instrument man after it is recorded.
2. When using the old style instruments, always check the ten minute interval. This is done by counting the number of graduations between opposite, corresponding degree marks, after the circle has been brought into coincidence.

#### G. Analyzing Observation Sheets

Many recording errors and inconsistencies can be caught by carefully analyzing observation sheets. The following most important items should be checked in the field by the recorder and then rechecked in the office. They are:

1. Spreads between the seconds of direct and reverse readings should be consistent and in the same direction throughout the set.
2. Ten minute reading errors can frequently be located by examining a set of positions. This is the reason that it is highly recommended that the circle be closed (angle between foresight and backsight observed and recorded) for each observation. If one observation disagrees with all others by ten minutes, it is safe to assume that a reading or recording error was made.
3. When a direct and reverse observation of a position are in different minutes, be sure the average second value is coupled with the correct minutes value.
4. When checking the direction to a station and either the minutes or the seconds value of the backsight mean observation are greater than corresponding values to another station, be sure the subtraction is correct.

5. Using the entire set of averaged angles in the calculation will normally prevent errors in either of the above instances.

### **3.6.3.3 Natural Factors**

- A. **Differential Temperatures** Bright sunlight striking certain parts of the instrument may cause differential expansion of the metal components of the instrument, resulting in small errors. To minimize this error, it is recommended to work under a parasol.
- B. **Heat Waves** Heat waves can cause distortion of lines of sight near a reflecting surface. The use of a tower can reduce the effect of heat waves. Working at night is another alternative available. Otherwise, unless it is urgent, on control surveys the work should be postponed until better conditions exist.
- C. **Phase** If a sight is not evenly lighted on both sides, the instrument man will tend to point toward one side. This phenomenon, called "phase", can be reduced by using a target with a flat surface pointed directly toward the instrument. "Y" shaped targets are useful in reducing phase.
- D. **Diffraction** If a line of sight passes very near a solid object such as a pole, light rays from a distant target may bend or diffract around the object, causing the object to appear in the wrong place. The closer the obstacle is to the instrument, the greater the diffraction. Diffraction can occur in either horizontal or vertical observations.

To detect diffraction, move the focusing knob slowly back and forth while watching the target. If the target appears to move relative to the obstacle and the cross hairs, the obstacle is causing diffraction. Offset the line to correct this condition.

- E. **Refraction** When light waves pass from a medium of one density into a medium of a different density, the rays change in direction (bend). The change in direction is called refraction. Since sight lines are light rays, they are refracted, or bent, by changes in the atmosphere, causing small errors in angular measurement. Normally, the lateral refraction is insignificant in most surveys, but its effects can be further minimized by understanding and avoiding situations that generate the largest refraction of line of sight.
  1. When the sun shines on a barren, dark surface, the surface warms relatively quickly. This warms the air and, if calm, it produces a column of warm, light air rising from the surface.
  2. Other situations include:

- Dark, freshly plowed fields lying between lighter colored areas of growing crops.
  - Clear areas between heavy forests.
  - Large bodies of warm water between land areas.
  - Open valleys bordered by bluffs on either side. If a line must pass over a valley, set the observation points as far back from the edges of the valley as possible.
  - Air tends to layer parallel to the slopes of embankments or the base of foothills.
3. **Minimizing Refraction** When refraction is probable in angles to be measured, or is suspected in angles that have been measured, carefully examine the survey area and plan station locations to avoid problem conditions listed above.

Make your observations when a breeze keeps the air stirred and prevents layering, or on cloudy days or at night. Reobserve lines under different atmospheric conditions, preferably when the wind is from a different direction.

#### **3.6.3.4 Miscellaneous Factors**

- A. **Trigonometric Functions** When trigonometric functions are used in computations, the precision of the computations is affected by the rates of change of the functions (the magnitude of the differences between the functions for a given angular increment). For example, to compute the impact of an angular error on the precision of the 'Sin' function at a particular angle, use the following equation:

$$precision\_of\_sin = \frac{\sin(angle + error) - \sin(angle)}{\sin(angle + error)}$$

Example: The precision of a sin of an angle of 5° with an error of 5" is 1:3610.

$$\text{precision\_of\_sin} = \frac{\sin(5^\circ + 5'') - \sin(5^\circ)}{\sin(5^\circ + 5'')} = 0.000277 \text{ or } 1:3610$$

For a 'Cosine' and 'Tangent' replace the 'sin' in the above equation with the respective trigonometric function. The following table shows the angles at which trigonometric functions have the highest and lowest precision.

	Sin	Cos	Tan
Highest precision	90°	0°	45°
Lowest precision	0°	90°	0° or 90°

The precision of the angular measurements might have to be increased to compensate for the large rates of change in the trigonometric functions.

This problem can be lessened by careful reconnaissance which:

1. Minimizes the use of such angles in the computations.
2. Provides sufficient checks that will ensure that desired accuracy is maintained (for example, cross ties in traverse).

#### B. Relationship Between Angular and Linear Measurement

1. **Consistency** When a survey involves both angular and linear measurements, maintain consistency (if practicable) between the precision of angular measurements and that of the linear measurements. In other words, keep the offsets in line, caused by errors in angular measurements, approximately equal to the errors in linear measurements. For example, if distances are to be measured to a precision of 1/10,000, measure the angles to the nearest 20 seconds. (A 20 second error will result in an error of 0.10 meters (0.32 feet) offset in 1,000 meters (3280.8 feet).)
2. Angular errors and their corresponding linear errors per unit of distance can be computed from:

$$\text{Linear error} = \text{Tan}(\text{angular error}) \times (\text{distance of the line})$$

Example: an angular error of 1" over a distance of 300meters (1000') is 1.5mm (0.005').

3. **Inconsistency** Often it is not practical to maintain the same precision in angular and linear measurements. In this case the accuracy of each measurement should be estimated and properly recorded. During the computation (or adjustment) of this data, each measurement should be weighted in accordance to its precision.

Computation methods that do not accommodate for weighting measurements (such as the Compass Rule) should be avoided in this instance.

### C. Curvature and Vertical Refraction

Zenith angles measured for horizontal and vertical reduction of long lines require curvature and refraction corrections.

The manufacturer's specifications for most total stations indicate that the earth's curvature and atmospheric refraction are internally computed and the corrected horizontal and vertical distances displayed. This correction can be eliminated (or balanced) by taking the mean of two reciprocal measurements. The reciprocal procedure means that a distance and a zenith angle are measured at point A to point B and then from point B back to point A. At longer distances (over 1000 meters (3280.8 feet)), it is better to use this averaging solution than the on board correction factors provided within these total stations, even when they are in perfect adjustment.

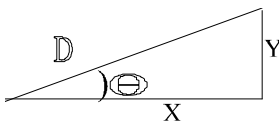
## **3.7 Vertical Measurement**

### **3.7.1 Purpose**

In addition to the horizontal position of points and features as determined by the previously described linear and angular measurement, the complete survey requires vertical measurements. Such vertical measurements establish the elevation of points in relation to a datum that extends through and beyond the project limits. In the coordinate survey, the horizontal position is described by X and Y coordinates and the elevation described by the letter Z (or H.) The complete description of a point being (X,Y,Z).

Vertical angular measurements are also required to reduce slope measured distances to horizontal distances. Most EDM instruments used by the Department are equipped with zenith sensing devices that provide the reduction internally. These instruments display the operator's choice of slope, horizontal or vertical distance.

Some older EDMs that are mounted on top of a theodolite measure the slope distance only. The theodolite is then used to make the angular measurement and the horizontal distance(X) is computed from the zenith angle( $\theta$ ) and slope distance(D). A correction for the earth's curvature and atmosphere must be applied to determine the true horizontal distance and difference in elevation (Y).



### **3.7.2 Importance**

The determination of accurate elevations is an extremely important part of the information required for the design of highway projects. Grade lines, drainage structures and other highway features are designed in relation to existing and final elevations. Volumetric quantities are determined by preliminary (before) and final (as constructed) cross sections. Additionally, accurate elevations are very important in ensuring the reliability of photogrammetric mapping and orthophoto products.

Due to its importance in all other phases of the project development, vertical measurements to establish primary elevation control are made at an early stage of the survey. For example, in traversing, vertical angle elevations are established for all traverse control monuments to aid in the computation process. The control monuments become benchmarks. Subsequent fixed end loops between the control monuments established, again by differential leveling, are used to establish benchmarks for photogrammetric, preliminary, construction or other control networks.

### **3.7.3 Planning**

By the time a project survey is completed from preliminary through the construction phase, each benchmark will have been used many times to provide the base for vertical measurement. Proper planning in anticipation of the future uses of vertical control benchmarks is as essential as that required for the horizontal control. Some considerations in that plan should be:

- A. Location of the primary control (generally on the base traverse monuments).
- B. Permanence (outside of anticipated construction limits), and type of monument set
  - concrete monuments (permanent).
  - Iron pins (semi permanent).
  - wooden hubs (temporary)
- C. Accessibility (on the Right of Way or other accessible lands).
- D. Spacing (generally at 300 meters (1.000 feet) or less).
- E. Visibility.

### **3.7.4 Methods**

Vertical measurements are made directly or indirectly. The choice of the method and its procedures depend on present and future accuracy requirements and the relative cost. Considerations in selecting the method and procedures should include:

- Classification of controlling benchmarks. (The precision of the survey should be compatible with the accuracy of the controlling monuments.)
- Type of equipment available.
- Future survey needs.

### **3.7.5 Direct Vertical Measurement**

This method means "the direct reading of elevations or vertical distances". The two common types of direct elevation determinations are readings from altimeters and from direct elevation rods. Tape (or Laser) measurement of a building height or depth of a mine shaft are also examples of direct measurements.

Elevations obtained by any of the above direct methods are less accurate and their application quite limited in highway surveys.

### **3.7.6 Indirect Vertical Measurement**

Indirect vertical measurements require the use of calculations to determine elevations or vertical distances.

Most vertical measurements made in highway surveys are made by indirect methods, such as spirit level (differential) and trigonometric leveling. There are numerous procedural systems used in both methods to achieve various levels of accuracy versus the expenditure of field and office time. In recent years, vertical measurements are made by GPS as well. It has been proven that careful GPS leveling can yield accurate elevations that are comparable with those of differential or trigonometric leveling. GPS leveling will be discussed in Chapter 4 of this manual.

Prior to the development of the total station, almost all vertical measurements on highway projects were made by differential leveling. By strict adherence to distance limitations and other procedural methods, trigonometric measurements can often be the best option for making vertical measurements.

#### **3.7.6.1 Accuracy**

Tolerances for the various types of control points and other elevation points are a function of the needs of a given project. The general requirements are cited here for reference.

- A. Base traverse and monumented control points:
  - Second order Class II misclosure (mm) is  $8 \times \text{square root of } D$  ( $D = \text{shortest length of section in kilometers}$ ) or
  - Maximum loop misclosure (mm) is  $8 \times \text{square root of } E$  ( $E = \text{perimeter of loop in kilometers}$ ).
- B. Secondary control, such as construction benchmarks, horizontal vertical photo control hubs, etc.:
  - Third order misclosure (mm) is  $12 \times \text{square root of } D$  ( $D = \text{shortest length of section in kilometers}$ ) or
  - Maximum loop misclosure of  $12 \times \text{square root of } E$  ( $E = \text{perimeter of loop in kilometers}$ ).
- C. Vertical only spot elevations, slope stakes, etc.  $\pm 0.015$  meters (0.05 feet).

### **3.7.6.2 Differential Leveling**

#### **3.7.6.2.1 General**

- A. **Equipment** The standard instrument for all differential leveling is the pendulum type (automatic) level.

The Department primarily uses Philadelphia two section, Lenker Rods, and fiberglass leveling rods. Each type of rod has its particular advantage under certain field conditions. Any rod used should be clean, "tight", and have properly indexed scales, Slip joint rods should be checked periodically for index.

- B. **Instrument Setups**

1. Use a hand level in uneven terrain to aid in selecting setup and turning point sites.
2. Do not waste time by deeply imbedding tripod feet. Settlement is usually insignificant. Avoid setups on hot pavement or in spongy or muddy soil.
3. Set turning points so backsights and foresights are approximately equal. This compensates for curvature and refraction and for maladjustment of the instrument.
4. Use sight distances that best fit the terrain and are the most comfortable for the instrument person. Some operators can read the rod at much further distances than others. Sight distances should never exceed 75 meters (250 feet).

5. In steep terrain, place "turns" and instrument setups so they follow parallel paths (not along the same line).
6. Periodically test the level to be certain the pendulum compensator is working. Point on a "natural" sight with the telescope over a foot screw, and turn the screw back and forth, or lightly tap the instrument. If the cross hair dips and returns to its original position, the compensator is working properly.

#### **3.7.6.2.2 Turning Points and Benchmarks**

- A. Establish benchmarks of the same physical quality as the technical quality of the leveling procedures. Set them in a stable, protected location.
- B. Do not use spikes in utility poles. Do not use wooden stakes except as temporary benchmarks.
- C. Make each turn stable and with a definite high point. If a turning point (TP) does not have a prominent point, mark the exact point with keel or paint. Depending on the soil, stakes driven at a slight angle make excellent TP's. A small piece of flagging will make them easily recoverable.

#### **3.7.6.2.3 Rod Reading**

- A. Focus the eyepiece to eliminate parallax before any readings are made.
- B. Do not deliberate over readings. Read and call them out in a moderate rhythm.
- C. Turn through important points, rather than take "side shots". Benchmarks and photogrammetric control points should never be side shots.
- D. Wherever possible, make it standard practice to plumb the rod with a rod bubble. In the absence of a rod bubble, the rodperson should slowly sway the rod at and away from the instrument. The observer reads and records the lowest reading. The rod must be set on a sharp or rounded projection; otherwise the rod will rise as it is rocked and will result in a false reading.
- E. Avoid low, ground-skimming shots where refraction might become pronounced. Also, avoid sighting close to obstructions that might diffract the line of sight; if possible, not closer than 0.3 meters (1 foot) to obstruction.

#### **3.7.6.2.4 Single - Wire Levels**

Single-wire leveling is the most common and widely used method of vertical differential measurement. With proper attention to procedural consistency, and by the use of several variable methods of elevation checks, third-order accuracy may be achieved with single-wire leveling. Some of the various methods will be described in general terms only.

Detailed procedures may be found in the appropriate referenced publications at the beginning of this manual.

**Computations** - Normally, single wire notes are reduced to height of instrument (HI) and turning point (TP) elevations as the survey progresses. To check the elevations of benchmarks (BM's) that are turned through, differences in elevations, delta elevations, are also calculated. Basically, the difference of the sum of the plus rods (backsights) and minus rods (foresights) should equal the difference in elevation between the BM's. All side shots must be eliminated from the calculation.

**Adjustments** Simple, single-wire level runs should be straight line adjusted. The closing error is prorated to each TP between two consecutive, controlling benchmarks.

$$C = E \cdot \frac{n}{N}$$

Where:

C – Correction applied at a TP.

E – Closure error of the leveling loop.

n – Number of turns to a given TP.

N – Total number of TP's in the loop.

#### **3.7.6.2.5 Double Turning Point (TP) Leveling**

This technique uses two parallel, independent foresight and backsight TP's for each HI. It is usually used for third order leveling or very special circumstances. Each pair of TP's is set, if possible, at an appreciable difference in elevation (preferably 0.3 meters or more). They are also set a few feet apart so the level will have to be rotated slightly between the two rod readings.

From each setup, single wire plus shots are read on both backsight TP's; minus shots are read on both foresight TP's. Notes are kept separately for each line of levels.

The adjusted elevations from the two lines of TP's are averaged.

The system has some advantages in that the HI is determined from each of the two lines and misreading or misleveling blunders can be isolated immediately.

The system is time consuming and both lines are run in the same direction, which may not cancel natural systematic errors.

#### **3.7.6.2.6 Double Height of Instrument (HI) Leveling**

This technique is similar to double TP leveling and is used for the same reasons as double TP leveling. A double line of levels is run through a single line of TP's. At each setup site, two HI's are established, at approximately 0.3 meters difference. From each HI the rod is read on the single backsight TP and on the single foresight TP.

The system has approximately the same advantages and disadvantages as for double TP leveling except that the difference in elevation can be immediately checked between the two TP's. If the difference is more than 0.001 meters (0.002 feet), a third HI may be used.

#### **3.7.6.2.7 Three Wire Leveling**

When the distance between control benchmarks exceeds three kilometers, the system of three wire leveling can often be the most efficient method to establish project control benchmark elevations.

With this leveling technique, the cross hair and both stadia hairs are read to the nearest thousandth of a meter. (This system is widely used with an Invar rod and the readings taken to the nearest thousandth of a meter.) Stadia intercepts of plus and minus shots are accumulated. The running totals are constantly monitored so balance can be maintained between totals of foresight and backsight distances. The backsights and foresights should be balanced within 5 meters (20 feet) when setting BM elevations.

This technique is generally preferred over the two previously described methods in that it is faster and, to a large degree, self checking.

Since it is anticipated that this technique will be used most often in project control surveys, special requirements will be discussed in some detail.

#### **A. Equipment**

1. **Instrument** The Department generally uses pendulum levels with either a stadia ratio of 0.3 to 100 or 1.0 to 100. For precise levels, the 0.3 to 100 ratio is preferred because the stadia hairs are nearer the optical center. It also permits a greater elevation difference between the level and the TP while keeping all three cross hairs on the rod.
2. **Rods** If Invar rods are not available, it is recommended that the best Philadelphia rod available be used on these surveys. Even new rods should be checked upon delivery, as some rods have been found to be not calibrated.

#### **B. Procedures**

1. Check the instrument and rod before starting each day's run, test the level for collimation error. Test at or near the first setup of the day and record the process in the field notes. If the error exceeds 0.005 in 200, the instrument should be adjusted. Any time the instrument has a severe jolt or bump, it should be readjusted.

Check the rod in the raised position to ensure there is no index difference above and below the slip joint. The rod should be rechecked each time it is extended.

2. **Setups** Keep all sights within 75 meters (250 feet). When rejected readings average more than two in every ten, shorten the sighting distance.
3. **Turning Points** Railroad spikes, boat nails, wooden stakes or stakes may be used for TP's. If possible, all TP's should be left in place and flagged in case a complete or partial rerun is required. Permanent TP's should be numbered so they can be identified when recovered.
4. **Benchmarks** Establish all benchmarks prior to leveling. Check all found monuments that are to be incorporated in the level line for stability.
5. **Rod Readings** Plumb the rod with an accurate rod level. Start the rod reading with the top stadia wire, and progress to the bottom wire.

Estimate readings to 0.002 meters. Read at moderate speed without deliberations. Do not turn or pick up the instrument until the note keeper has verified the spread. If the spread between top and center wire and bottom and center wire exceeds 0.002 meters (0.0065 feet), reread all three wires. The original readings should be crossed out with a single line and new readings entered on the next line of the Field Book.

6. **Reruns** The highest order of accuracy required will normally be met by a single run of three wire levels. If the run fails to close within the tolerance specified, one of two problems probably exist.
  - a. There may be a discrepancy between the elevations of the beginning and closing benchmarks. This should be the first possibility checked. Be sure that the government elevation data sheet is the last published for the two points. (There is a possibility that one or both of the benchmark elevations have been readjusted.)

If the last information was used, carry the survey to the next benchmark.
  - b. If the above does not account for the discrepancy, the run should be releveled in the opposite direction. Releveling at a different time of day is preferable.

### **3.7.6.3 Trigonometric Vertical Measurement**

Trigonometric vertical measurement is a procedure whereby vertical differences in elevation are computed from slope distance and zenith angle measurements.

The development and continuing refinement of total stations is making rapid changes in the use of trigonometric vertical measurements. These instruments are of varied vertical angle accuracy and certain procedural restrictions must be applied to equal the accuracy of differential leveling. Those restrictions required to meet the various tolerances will be discussed under each of the vertical traversing techniques described herein.

A. **Applicability** Vertical traversing is often the most practical (and economical) method for establishing elevations in rolling to steep terrain. It is useful for many types of surveys. Some of these are:

1. Reconnaissance surveys.
2. Control for aerial photography
3. Check levels for long differential lines.
4. Establishing elevations for datum adjustment.
5. Establishing low order benchmarks by precise vertical traversing. This would be done when accuracy is difficult to attain at reasonable expense by differential leveling.
6. Slope staking.
7. Cross sectioning.

B. **Accuracy Attainable** The accuracy that can be obtained from vertical traverses is sufficient for surveying work. The accuracy attained depends on the individual measurement accuracies of:

1. **Slope distance** With today's EDMs, slope distance accuracies are seldom significant in vertical measurement. For instance, with a zenith angle between 89 and 91 degrees, a slope distance error of one meter would result in a vertical error of less than 0.02 meter.
2. **Zenith Angle** The effect of zenith angle depends on the size of the angle and slope distance. To consistently attain good results, proper procedures must be used. Reciprocal observations minimize zenith angle and refraction errors. An erroneous zenith angle will result if the target and reflector are not properly spaced to provide parallel sight lines.
3. **Height of Instrument (HI) and Height of the Reflector(HR)** The major cause of error in trigonometric vertical measurement is the inaccurate determination of instrument and reflector heights. The net error that results from the two measurements produces a direct error in the difference in elevation. Aligning the height of the instrument and the reflector before making the measurements can reduce the effect of this error.

C. **Calculations** The calculation methods discussed herein provide satisfactory results. The methods are described in principle only, as all such systems require consistent good practices in equipment operation as detailed in other sections of this manual. The equation for computing elevations using trigonometric leveling (without corrections for curvature and refraction) is:

$$H_B = H_A + S (\cos(Z)) + HI - HR$$

Where:

$H_B$  – Elevation of point B (the new elevation to be established).

$H_A$  – Elevation of point A (a point with known elevation on which the instrument is set up).

$Z$  – Zenith angle from A to B.

$S$  – Slope distance from A to B.

The term  $S(\cos(Z))$  is the elevation difference component of the slope distance and it is denoted by DE.

There are three basic methods used in the computations to determine the elevation of a point from one or more points

1. **Difference in elevation without HI or HR.** This method is the most recommended one. It requires that the height of the rod and the height of the instrument are the same. As one can see from the above equation, if  $HI=HR$  then  $HI- HR=0$ . Thus, we do not need either of these heights. Most total stations have a special mark on the reflector as well as on the instrument that facilitates the alignment of these heights.
2. **Difference in elevation with HR only.** – When the instrument is set up at an arbitrary point (not a benchmark) and the reflector is held on a benchmark, HI can be computed adding HR and DE to the height of the benchmark. There is no instrument height measurement involved in this process. Once HI is established, additional points can be leveled ,even if HR is changed.

The advantage of the above method is that the errors due to HI mismeasurement are eliminated. Once visualized, the systems are easy to use for remote wing points and spot elevations. They also allow the instrument to be set up at the best location for sight and distance.

3. **Difference in elevation with HI and HR.** This method requires the recording of the HI and HR for each observation. Calculations are done according to the above equation. While this is the least recommended procedure for trigonometric leveling, topographic and other constraints may dictate using this method.

#### **3.7.6.3.1 Uses of Trigonometric Leveling**

- A. **General** – Elevation traversing, spot elevations, profiles of centerline and cross sections, drainage flow lines, or other required vertical information may be acquired by trigonometric leveling. Such elevations may be taken at identifiable points, such as staked centerline stations, or the horizontal position of said points may be determined during the same process.
- B. **Elevation Traversing** – Trigonometric vertical measurements can be made at the same time that horizontal positions are surveyed or separately for vertical elevations only. Traverse point elevations should always be determined. Obtaining the elevations of traverse points require very little (if any) additional effort. The elevations of the traverse points can be used as a blunder check for more precise

leveling of these points. They are also needed for reducing measurements to the state plane coordinate system,

- C. **Vertical Only Traverse** On many occasions the elevation is required on points where the position is known (bridge ends, profile stations, etc.) or points that can be identified (wing points, etc.). Such elevations may be obtained by any of the three computation methods described previously. The accuracy required and position of the needed point relative to established horizontal and vertical control will generally determine the type of vertical traverse required.
- D. **Centerline Profile** Centerline profiles are normally determined by differential leveling, but there are situations where trigonometric leveling may be the most economical. Much of the economy will depend on the location of control points in relation to the required profiles and the terrain involved. If the terrain is steep or rolling, requiring numerous "turns" with a level, trigonometric leveling may become the most economical method to obtain such elevations.

Any of the same procedures as described for vertical measurement to remote points may be used. If all the spot elevations required are not visible from a nearby control point, the instrument should be set where one or more control points, and all the required spot elevations, are visible. In order to increase the reliability of the elevations, foresights and back sights should not exceed 300 meters (1,000 feet). All DE's should be read at least three times.

- E. **Roadway Cross Sections** The standard method of obtaining field roadway cross section elevations is normally the most efficient. There are situations, however, where trigonometric leveling may be the most economical method. Such conditions may be where cross sections have to be extended beyond efficient taping distance, or where the terrain is steep and level turns are required. In such cases, the most efficient method of trigonometric leveling would be to set up over each cross section station turning right angles and measuring the distances and DE's with the EDM. This may be measured from the profile station, or by measuring the DE from a control point. If a uniform rod height can be used for the entire cross section, the relative elevation can be obtained by sighting another profile station, or a control point. If setting over the centerline station is impractical because of traffic, the same procedures may be used from an offset centerline.
- F. **Borrow Pit or Other Cross Sections** Field cross sectioning or grid elevations of borrow pits, building sights, or odd shaped areas by trigonometric leveling can be fast and economical survey procedures. Several options are available using either trigonometric positioning and leveling, trigonometric positioning and differential leveling, or various combinations of the three techniques. The shape of the area and terrain involved will generally be the factors that would most influence which method would be the most economical.

1. Grids by Coordinates (Radial) The trigonometric positioning and leveling technique can be used from a single setup for which the coordinate position and elevation are known, or specifically established for the survey.

Coordinates for each grid point can be prefigured and the azimuth and distance from the instrument tabulated for positioning the rod person at each grid point. Differences in elevations (DE's) would be read at each point and an accurate grid elevation computed. Total station tracking mode speeds up the operation.

The primary advantage of this system is that very few stakes or flags are required and much of the control work can be prefigured at the office.

If the grid area is quite large, additional setup points may be required.

2. Grid by Double Base Lines The trigonometric positioning and leveling technique is advantageous where the shape and topography of the area provides good visibility for the rod person. Two rows of grid lath are placed along one side and one end of the area. The rod person can "eyeball" grid points for either trigonometric or differential leveling on the unstaked points.

This system requires some time to set up the control lath, but speeds up the location of grid points for the remainder of the survey.

3. Cross Sectioning from Base Line(s) Cross sectioning requires the establishment of one or more baselines. Normally, the instrument would be set up at each station and distances and DE's taken at each break along the cross sectional profile. Proper positioning of the base line(s) for good coverage and sights is the most critical part of this type of survey.

This system is most advantageous where the terrain is rough and grids would not reflect the true topography.

4. Contouring Other possible uses of trigonometric leveling, such as contouring by random spot elevations, could also be considered for each survey. The point in all of the above being that trigonometric leveling gives the surveyor many options to do the work efficiently and effectively.

# Chapter 4

## GPS Surveys

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# Chapter 4 GPS Surveys

## 4.1 General

GPS, as utilized for surveying, can be classified as a linear measurement technique that determines vectors between points, instead of just a direct distance. A vector has a magnitude and a direction (orientation) in space, whereas, a direct distance is only the magnitude component of a vector. Thus, a GPS vector contains a horizontal and vertical angle, and a distance between two points.

This chapter is a continuation of chapter 3, except that it is devoted to GPS. The reason why a separate chapter is dedicated to GPS is because of its prominence in contemporary and future surveys. GPS is becoming the first choice surveying technique for all types of surveys. In the near future, all surveys will be done with GPS, except in those circumstances where it cannot be utilized due to obstructions or other restricting factors.

In this chapter, GPS will be discussed with the same approach that other surveying techniques were discussed in chapter 3. The discussion will include a short introduction to GPS, error issues, and field procedures.

Disclaimer: *The specifications included in this chapter are general recommendations. Contractors should follow their specific contractual agreement with NJDOT.*

## 4.2 Introduction to GPS

### 4.2.1 What Is GPS?

The Navigation Satellite Timing And Range Global Positioning System, or NAVSTAR GPS, is a satellite based radio navigation system that is capable of providing extremely accurate, worldwide, 24 hour, 3 dimensional locational data (latitude, longitude, and elevation). The system was designed and is maintained by the US Department of Defense (DOD) as an accurate, all weather, navigation system. Though designed as a military system, it is freely available with certain restrictions to civilians for positioning. The system is now fully operational, which means that the system has a complete set of at least 24 satellites orbiting the earth in a carefully designed pattern.

### **4.2.2 The Fundamental Components of GPS**

The NAVSTAR GPS has three basic segments: space, control, and user.

- The space segment consists of the orbiting satellites making up the constellation. This constellation is comprised of 24 satellites, each orbiting at an altitude of approximately 20,200 Km above the earth, in one of six orbital planes. Each satellite broadcasts a unique "bar code", known as Pseudo Random Noise (PRN) code, that enables GPS receivers to identify the satellites from where the signals came, and makes positioning possible.
- The control segment, under DOD's direction, oversees the building, launching, orbital positioning, monitoring, and providing GPS positioning services. A master control station updates the information (message) component of the GPS signal with satellite ephemeris data and other announcements to the users. This information is then decoded by the receiver and used in the positioning process.

There are two classes of GPS service; the Precise Positioning Service (PPS) which is available only to users authorized by the military, and the Standard Positioning Service (SPS), which is available for civilian use.

- The user segment is the most important segment of the system and is comprised of all users making observations with GPS receivers. The civilian GPS user community has increased dramatically in recent years, due to the emergence of low cost, portable GPS receivers and the ever-expanding areas of applications in which GPS has been found to be very useful. Some of these applications are: surveying, mapping, navigation and vehicle tracking.

### **4.2.3 GPS Limitations**

Though GPS can provide worldwide, 3D positions, 24 hours a day, in any type of weather, the system does have some limitations. First, there must be a (relatively) clear "line of sight" between the receiver's antenna and several orbiting satellites. Buildings, trees, overpasses, and other obstructions that block the line of sight between the satellite and the observer (GPS antenna), make it impossible to work with GPS. Anything shielding the antenna from a satellite can potentially weaken the satellite's signal to such a degree that it becomes too difficult to make reliable positioning. As a rule of thumb, an obstruction that can block sunlight can effectively block GPS signals.

Bouncing of the signal off nearby objects may present another problem, that of distinguishing between the signal coming directly from the satellite and the "echo" signal that reaches the receiver indirectly. In areas that possess these types of characteristics, traditional surveying techniques must be used instead of GPS positioning or to complement GPS positioning.

The receiver must receive signals from at least four satellites to be able to make reliable position measurements. In addition, these satellites must be in a favorable geometrical arrangement. The four satellites used by the receiver for positioning must be fairly spread apart. In areas with a relatively open view of the sky, this will almost always be the case because of the way these satellites were placed in orbit.

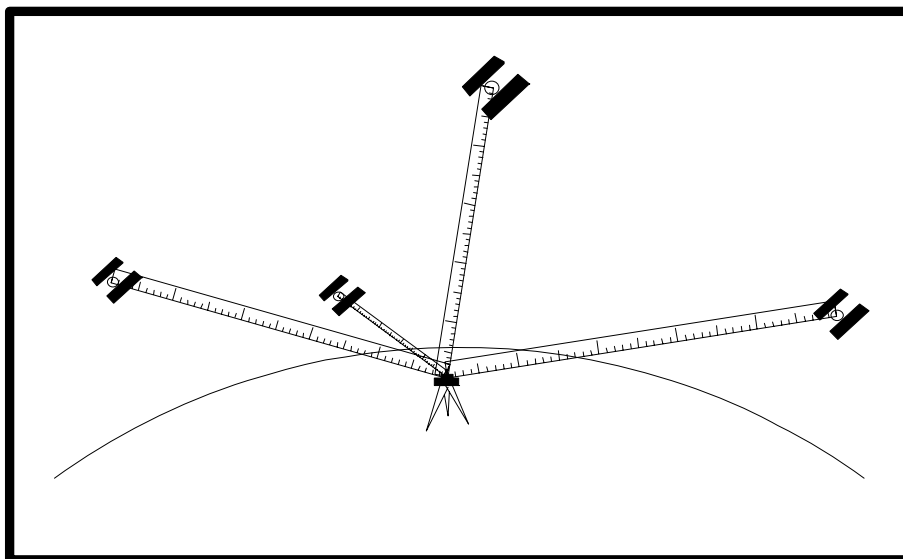


Figure 4.1. Position Determination by Measuring Distances to Satellites

#### **4.2.4 How Does A GPS Receiver Determine Positions?**

The position of a point is determined by measure distances or pseudo ranges from the receiver to at least four satellites (see figure 4.1). The GPS receiver "knows" where each of the satellites is at the instant in which the distance was measured. These distances will intersect only at one point, the position of the GPS receiver (antenna). The receiver "knows" the position of the satellites, because this information comes from the broadcast ephemeris that is downloaded when the GPS receiver is turned on. The GPS receiver performs the necessary mathematical calculations, then displays and/or stores the position, along with any other descriptive information entered by the operator from the keyboard.

The way in which a GPS receiver determines distances (called pseudo ranges) to the satellites depends on the type of GPS receiver. Basically, there are two broad classes: carrier phase based and code based.

##### **4.2.4.1 Carrier Phase Receivers**

Carrier phase receivers, mainly used in surveying, are capable of millimeter (mm) accuracy or better. These receivers measure distances or pseudo ranges to visible satellites by determining the number (N) of whole wavelengths ( $\lambda$ ) and measuring the partial (phase) signal wavelength ( $\Phi$ ) between the satellites and the receiver's antenna. Once the number (N) of wavelengths is known, a pseudo range may be calculated by multiplying 'N' by the wavelength of the carrier signal (L1 and/or L2, 19cm and 24.4cm respectively) plus the partial wavelength. Figure 4.2 illustrates this ranging method. It is then a straight forward (albeit complex) task to compute a baseline distance and azimuth between any pair of receivers operating simultaneously. With one receiver placed on a point with precisely known latitude, longitude, and elevation, and with the calculated baseline (distance between 2 points), the coordinate for the unknown point may be determined.

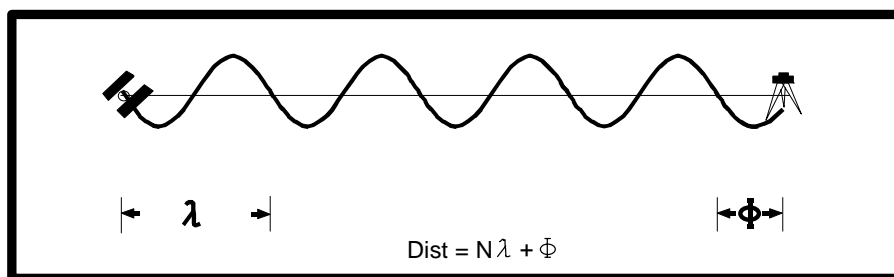


Figure 4.2. Carrier Phase Based Ranging

Carrier phase receivers come in two models: single frequency (using L1 only) and dual frequency (using both, L1 and L2). Dual frequency receivers are more efficient and accurate than the single frequency receivers, but are more expensive. Some type of control surveys must be done only with dual frequency receivers. NJDOT utilizes only dual frequency receivers.

#### **4.2.4.2 Code Based Receivers**

Code based receivers use the speed of light and the time interval that it takes for the signal to travel from the satellite to the receiver to compute the distance to the satellites (see figure 4.3). The time interval ( $\Delta t$ ) is determined by comparing the time in which a specific part of the "bar code" left the satellite with the time it arrived at the antenna. The pseudo range is computed by multiplying the time interval by the speed of light constant ( $c=299,792 \text{ Km/second}$ ). Pseudo ranges from at least four satellites are needed in order for a receiver to perform essentially a triangulation and produce a position fix. Position fixes are made by the receiver roughly every second, and the more advanced receivers enable the user to store the position fixes in a file that can be downloaded to a computer for post processing.

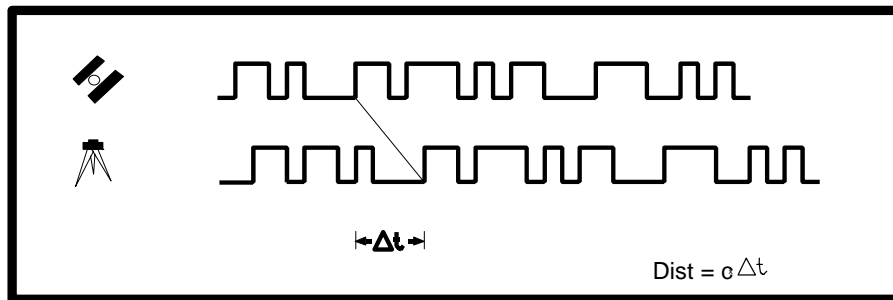


Figure 4.3. Code Based Pseudo Ranging

#### **4.2.5 Advantages of GPS**

Probably the most advantageous aspects of GPS are its accuracy and efficiency, particularly in survey tasks that span a large area. Activities that would have normally taken months to complete, now take only a few days utilizing GPS. Real time applications of GPS enable surveyors to perform quick data collection and construction stakeout activities. In fact, a complete construction design plan can be loaded into a receiver and staked out by following the guidance of the receiver.

Another advantage of GPS is in densification of the control network. The need to maintain a dense network of monumented control points can somewhat be alleviated because establishing new control with GPS is much easier and less expensive than it used to be. The Geodetic Survey Section of NJDOT is using GPS to develop a geodetic control network for New Jersey which will be utilized for GPS activities.

GPS is a positioning system that can also be used as a real world digitizer for mapping point and line features, such as roads or wetland boundaries. However, for large volume data collection which includes measuring many points, mapping, contouring, etc., one should consider photogrammetry as a more efficient data collection tool.

### **4.3 Sources of Errors**

GPS has inherited errors that are unique to this technology. GPS, as a surveying tool, has many standard (traditional) surveying errors as well. For example, an instrument setup error applies across the board to all surveying measurements regardless of the instrument or technique used. It does not make a difference what instrument is used, if a GPS receiver, a total station or a range pole is on the wrong point, the survey is erroneous. There are two major categories of error sources in GPS surveys. The first is system errors and the other is operational errors.

### **4.3.1 System Errors**

System errors are those errors that will affect every positioning activity regardless of the specific location of a particular receiver. System errors originate from inaccuracies in the positions of the satellites, the GPS signal and the propagation of the signal through the earth's atmosphere. Most of these errors can be eliminated if GPS positioning is performed in a relative mode and with dual frequency receivers. GPS surveys are always made relative to a known control point, thus, many systems errors cancel out. NJDOT has only dual frequency receivers, which assures that system errors are held at minimum. System errors include:

- **Ephemerides Errors** – To compute a position with GPS, it is necessary to know the exact position of each observed satellite. The positions of the satellites derived from the broadcast navigation message, are predictions of where the satellites are expected to be. These predictions could have an error of a few meters. For most practical purposes these errors are insignificant in a relative (differential) positioning mode.
- **Satellite Clock** – Precise GPS positioning depends on precise timing devices since one of the GPS observables is time. The double differencing data processing technique (processing observation data from 2 satellites and 2 receivers simultaneously) can eliminate the impact of this error. In GPS surveying, the standard positioning computation is double differencing.
- **Selective Availability** – The Department of Defense introduces a clock “dithering” error to degrade the attainable positioning accuracy by unauthorized users. This error has a similar effect to a satellite clock error and is eliminated by differential or double differencing computation techniques.
- **Ionospheric Delay** – An error introduced by the outer region of the atmosphere, which causes the GPS signal to disperse and change its traveling speed. The magnitude of the impact of the Ionosphere on the GPS signal depends on the intensity of the sun spot activity or the solar radiation. Solar activity has an 11 year cycle which will peak around the year 2001. At that time, accurate positioning with GPS will become more difficult. Dual frequency receivers are more useful in handling this error because they can compute it and apply the necessary corrections. Single frequency receivers must rely on an external correction model to overcome this error and may produce poor results at the peak of the solar activity.
- **Tropospheric Delay** – An error caused at the lower part of the atmosphere and is a function of the atmospheric conditions, such as: barometric pressure, temperature, and humidity. Reasonably established models for the index of refraction and other atmospheric models can correct this error.

### **4.3.2 Receiver Dependent Errors**

- **Receiver Clock Error** – As mentioned earlier, precise timing is essential for GPS positioning. High quality clocks are very expensive and even they are subject to errors. Receiver clock errors can be eliminated by utilizing the double differencing computation method.
- **Receiver Noise** – GPS receivers are not perfect devices. Some level of noise always contaminates the observations and produces positioning errors. The “carrier to noise power density ratio  $C/N_0$ ” value determines how well the tracking loops in the receiver can track the signal and, hence, the precision of the observation. Nominal GPS receiver  $C/N_0$  values are in the 40 50 dB-Hz range.
- **Antenna Phase Center** – The cross hair of a GPS receiver is the antenna phase center. The position that is determined with GPS is the position of the antenna phase center. Every antenna is calibrated by the vendor to determine the offset between the center of the physical center of the antenna (used to place the antenna directly above a point) and the phase center. Each antenna has a setup orientation mechanism to enable the user to orient all antennas used in a given session to the same (usually north) direction. If this is done and the same type of antenna is used in the session, the antenna phase error can be eliminated. This is one of the reasons why it is not recommended to mix antennas from different manufacturers in a given session, unless this error is known and corrected for.
- **Tribrach Misalignment** – This is the same error that can be committed when setting up a total station or a theodolite over a point. The GPS antenna is mounted on a tribrach and, in turn, the tribrach is used to place the antenna directly above a point on the ground. If the tribrach is misaligned, the position determined by GPS is not exactly the one of the intended point, but has a small offset which depends on the misalignment error. This error is usually larger than in the case of total station misalignment because GPS antennas are mounted higher than total stations to avoid low obstructions.

### **4.3.3 Errors Due to Point Selection**

The selection of points to be measured with GPS is not a trivial matter. The rules of point selection in traditional surveying, mainly maintaining line of sight, do not apply in GPS surveys. Since the direct line of sight has to be with the satellites, points have to be selected in such a way that the clearest signal is received at that point. The following are errors that can impact the results of GPS surveys:

- **Multipath** – A signal can arrive at a receiver directly from the satellite, but also from a nearby reflective surface. The reflected signal travels a longer path than the direct one, which results in an observation error. The point to be GPS occupied must be selected in such a way that it is not adjacent to a reflective surface. For this reason, the vehicle used during the survey should not be parked near the GPS antenna, or the antenna should be mounted higher than the vehicle.
- **Obstructions** – There are two types of obstructions that may interfere with GPS signals. The first is a solid obstruction that completely blocks the antenna from the incoming signal. This will cause fewer actual observations to fewer satellites than planned and a weaker positioning solution. Every point to be GPS surveyed must be inspected for such obstructions and the obstructions must be properly mapped. The observation planning software should be updated with these obstructions to provide better session planning and, eventually, better results.

The second type of obstructions are those that do not completely block the signal, such as tree canopy. If the location of the point cannot be altered, longer observation sessions are required to assure quality results.

- **Interference** – Electromagnetic signal interference can cause lower C/N<sub>0</sub> values and less reliable observations. Areas with very high wireless communication traffic or nearby high voltage power lines should be avoided. Longer sessions could overcome some of the effect of the interference.

#### **4.3.4 Operation Errors**

- **Satellite Geometry** – The location or the geometry of the satellites in space at the time of observations is an important factor of GPS positioning accuracy. The best geometry is when the satellites are evenly distributed around the horizon and at least one satellite is at the zenith. The worst geometry is when all the satellites are bunched together in a small region of the sky.

Dilution of Precision (DOP) is a number that indicates the error in position determination as a function of the relative satellite geometry. GPS can be used for determining four parameters: position  $X, Y, Z$  and time  $t$ . The DOP for all four parameters is called Geometric DOP (GDOP.) The DOP for position  $X, Y, Z$  is called PDOP, for horizontal position  $X, Y$ , HDOP and for vertical position  $Z$ , VDOP. For surveys, it is recommended to use GDOP as the indicator for favorable observation geometry. Observations should be done at times when the GDOP is less than 4. One should never perform GPS surveys when GDOP is more than 8.

GDOP information is computed by an observation planning software. It is based on the predicted location of the satellites relative to the observer. One should be aware of two factors which may change the actual value of GDOP at the time of observation. These factors are obstructions blocking the satellite signals and

unanticipated operational problem of satellites. If obstructions are not mapped properly, the software assumes that all the satellites are visible and the computed GDOP may not reflect the actual situation. Similarly, if the observation sessions are planned in advance and one of the satellites has since stopped operating properly (or temporarily turned off), the actual GDOP at the time of observation may not be the same as predicted. Always check the actual GDOP, as indicated on the receiver, to ensure quality observations.

- **Length of Session** – The length of a session is the maximum time interval at which data is collected from all the receivers simultaneously. This means that it is not enough to collect data at a point, but this data collection must be coordinated with other receivers. Longer sessions can provide better results, but are more expensive. The length of a particular session depends on the type of receivers used, the length of the measured baseline, project specifications etc. One should consult the user's manual of the receiver for determining the optimal length of an observation session.
- **Instrument Setup** – The GPS antenna must be placed directly above the point on the ground with the same thoroughness as in any other survey. A setup error translates directly into a position error. See the total station setup procedure in this manual for details on how to minimize setup errors.
- **Antenna Height** – One of the most common errors in GPS surveys is the incorrect reading or recording of the height of the antenna. Antenna height error affects all three position parameters  $X, Y, Z$ , but is more critical for elevation surveys. The height of the antenna should be measured for every setup at least twice, once before the first observation and immediately after the last observation. It is recommended to measure the height of the antenna in feet and in meters so that potential blunders can easily be detected.

#### **4.3.5 Data Processing Errors**

Data processing errors are those errors which can be identified only when the field work has been completed. During the processing of the field data certain “poor” observations have to be filtered while others can be corrected with the software.

- **Loop Closures** – Closed loops of baselines are used for the quality control of the measurements in a similar way as used in traversing and leveling. The acceptable closure for a given survey task should be specified at its planning stage. Survey tasks that require higher accuracies will have more stringent acceptable closures and vice versa.
- **Ambiguity Resolution Error** – The ambiguity in GPS surveys is an integer number of full carrier wave cycles between the receiver and the satellite. An

inaccurate ambiguity determination results in a position error because the computed distance between the receiver and the satellite is incorrect. This value cannot be measured directly, but must be computed (resolved) using sophisticated algorithms. Longer sessions and low GDOP values will reduce the potential for ambiguity resolution errors.

- **Cycle Slip** – A cycle slip is a discontinuity in GPS carrier phase observations caused by signal loss, usually due to obstructions. If a GPS receiver loses a signal temporarily, when the signal is reacquired there may be a jump in integer number of full carrier phase cycles (ambiguity). This jump must be identified and corrected; otherwise the position determination may be in error. Most GPS software have a cycle slip repair tool to overcome short cycle slips. If the cycle slip cannot be repaired, some of the observations may have to be discarded.
- **Station Coordinate and Transformation Errors** – Since GPS surveys are made relative to known control points, an error in the coordinate values of these control points will translate into errors in the newly determined points. The same applies to elevations and benchmarks. This error can be detected if a GPS survey is tied into several control points. Erroneous coordinate or elevation values will result in an inconsistent fit between the survey and the control points.

## **4.4 GPS Surveys**

### **4.4.1 Network Design and Connections**

- A. The location of the new control points depend on the optimum layout to carry out the required needs of the survey.
- B. Checks shall be made to ensure that no existing network control points have been moved or disturbed. If any are doubtful, additional existing points shall be tied into the network.
- C. Horizontal networks shall be connected to a minimum of three National Geodetic Survey (NGS) first order stations, or four stations if any NGS second order stations are used. At least one benchmark shall be used (held fixed) if only a horizontal survey is being done. The use of eccentric horizontal stations is not permitted.
- D. Vertical networks shall be connected to three or more NGS elevation marks of first or second order accuracy. In areas of sparse NGS vertical control, contact the Geodetic Survey unit of NJDOT for alternative benchmarks. The use of eccentric vertical stations is permitted provided they are located within 100 meters of the original mark and three wire leveling is used to determine the elevation of the eccentric point.

- E. The existing control, both horizontal and vertical, used to control a network shall lie in a minimum of three quadrants using the geographic center of the project as the reference point.
- F. Depending on the project requirements, azimuth marks can be established by GPS procedures. Station pairs (station and reference station) to provide azimuths shall be established at intervals no greater than 10 kilometers along the project length. Station pairs shall be intervisible at normal tripod heights and spaced not less than 500 meters apart.

#### **4.4.2 Reconnaissance**

A key to a successful GPS survey is a thorough reconnaissance. Reconnaissance consists of station selection, identification of existing stations, monumentation or marking of new stations, estimation of travel time between stations and scheduling. A thorough reconnaissance could save a lot of money, as well as make the field and office operation much more fluent and efficient. A good reconnaissance plan includes the following procedures:

1. Inventory existing control and their relationship to the survey task.
2. Organize and plot possible tie marks before leaving the office. This will help the field crew to identify the points easily.
3. Recover control before using it and mark them discretely.
4. Obtain permission to enter property. Do not offend land owners, private, public, or unknown.
5. Check the stations for GPS suitability. If necessary make an obstruction diagram that will be used in the session planning software. Eccentric points should be established for stations that have insufficient open skies.
6. Avoid selecting locations for new stations which are close to:
  - power sources; microwave or TV transmitters etc.
  - Reflective environment.
  - Impossible tripod setups.
7. If a station is at a busy location determine the best time to occupy the station.
8. Determine accessibility to the station.
  - Determine the best way to get to the station and write clear and concise directions to the station. If possible, provide alternative routes to the station. Remember that the schedule of the observations sessions must be strictly kept strictly otherwise, some observation session may become useless.

- Draw maps/sketches to help observers to identify the station.
- Supply contacts for site access, keys, etc.
- Determine if there are special setup requirements.

### **4.4.3 Field Procedures**

#### **4.4.3.1 General**

As discussed in the previous section of this manual, the precision of the GPS vector baseline results depends (among other) on the following:

- The number of satellites visible simultaneously from each station during an observing session.
- The geometric relationships between the satellites and the receiver (GDOP.)
- The duration of the period when the desired number of satellites can be observed simultaneously.
- The uncorrected effects of ionospheric and tropospheric refraction.
- The length of line.

The number of possible observing sessions per day is a function of the required survey accuracy, satellite availability, survey method utilized, and project logistical considerations, such as travel and set up time required between observing sessions.

The specifications for field procedures depend on the survey methods utilized. In general, there are six different GPS survey methods: static, rapid static, stop and go, reoccupation, kinematic and real time kinematic. Regardless of the particular observation method selected, the following specifications must be met:

- A minimum of five satellites shall be observed simultaneously. At no time during the observing session shall the Geometric Dilution of Precision (GDOP) be greater than 8. The Position Dilution of Precision (PDOP) shall not be greater than 5.
- Satellite signals shall be observed from a minimum of two quadrants that are diagonally opposite each other.
- Obstructions that are 20° or more above the horizon should be noted on an obstruction diagram. The effect of obstructions should be minimized by proper reconnaissance prior to observations.
- Satellite data below an elevation mask of 15° shall not be used in baseline measurements.

Each one of these methods has advantages and disadvantages for different types of surveys. Next, these field procedures will be discussed in detail.

### **4.4.3.2 Observation Methods**

#### **4.4.3.2.1 Static Observations**

This is the classical GPS survey method for long lines and high accuracy. Points are occupied for long sessions and are re-observed in different sessions according to a predetermined observation scheme.

- Static observations are required for all baselines over 20 kilometers in length. Static observations may be required for lines less than 20 kilometers depending on particular project requirements.
- A minimum of three receivers shall be used simultaneously during all static GPS sessions.
- A minimum of five satellites shall be observed simultaneously for a minimum of 30 minutes, plus one minute per kilometer of base line length per session. Remember, sessions that are a bit longer than this minimum will provide worthwhile redundancy that could make data processing more robust and improve project results.
- Data sampling shall have an epoch time interval of 15 seconds or less.

#### **4.4.3.2.2 Rapid (Fast) Static Observations**

Short observation time for shorter lines. It can be done with a classical network design or as radial surveys. This is the most common GPS survey method.

##### Specifications:

- Rapid static procedures may be used on baselines up to 20 kilometers in length.
- A minimum of three receivers shall be used simultaneously during all rapid static GPS sessions.
- A minimum of 5 satellites shall be observed simultaneously for a minimum of 5 minutes, plus one minute per kilometer of base line length per session. Sessions that are slightly longer than this minimum could prove rewarding during data processing stage.
- Data sampling shall have an epoch time interval of 5 seconds or less.

#### **4.4.3.2.3 Stop and Go Observations (For Baselines < 5 km)**

A temporary reference station is tracking constantly. The roving receivers are initialized to establish an accurate relative position between them and the reference station. Following the initialization each new point is occupied for only a short period of time. Lock on the satellites must be maintained at all times or a new initialization must be performed.

Specifications:

- A minimum of three receivers shall be used simultaneously during all stop and go GPS sessions. Two receivers shall occupy reference stations and one receiver will be the rover. This procedure shall be limited to baselines of 5 kilometers or less.
- A minimum of 5 satellites shall be observed simultaneously for a minimum of 5 epochs.
- Initialization of the roving receiver can be accomplished by occupying a known point for a minimum of 5 epochs or making a rapid static observation of at least 5 minutes on the first point and then moving to other points to be surveyed.
- Data sampling shall have an epoch time interval of 5 seconds or less. A minimum of 5 epochs must be recorded for each point located.

#### **4.4.3.2.4 Reoccupation Observations**

Same as rapid static, except that the length of each session is short. Each point is re-visited after at least an hour, when the geometry of the satellites becomes significantly different.

Specifications:

- A minimum of three receivers shall be used simultaneously during all Reoccupation GPS sessions.
- Minimum of 5 satellites shall be observed simultaneously for a minimum of 5 minutes plus one minute per kilometer of base line length per session. All points surveyed shall be re-occupied after at least one hour has elapsed to allow for a different alignment of the satellites. This method is not recommended unless the satellite configuration or site conditions do not permit rapid static procedures.
- Data sampling shall have an epoch time interval of 5 seconds or less.

#### **4.4.3.2.5 Kinematic Observations**

The reference receiver and rovers are initialized as in stop and go. After initialization the rover is constantly moving and measuring positions. Lock on the satellites must be maintained at all times or a new initialization must be performed.

Specifications:

- A minimum of three receivers shall be used simultaneously during all kinematic GPS sessions. Two receivers shall occupy reference stations and one receiver shall be the rover.
- Initialization of the roving receiver can be accomplished by occupying a known point for a minimum of 5 epochs or making a rapid static observation on the first point and then moving to other points to be surveyed.
- Data sampling shall have an epoch time interval of 2 seconds or less.

**4.4.3.2.6 Real Time Kinematic Observations (Baselines < 3 km)**

This is the same as kinematics, except that instead of making measurements that have to be post processed, the positions are available in real time. To achieve real time positioning, a radio link between the reference receiver and the rovers must be established. The observations and/or the computed positions are transmitted from the reference station to the rover.

Specifications:

- A minimum of 2 receivers shall be used simultaneously during all real time kinematic GPS sessions. One receiver (master) shall occupy a reference point and one or more receivers shall be used as rovers.
- Initialization of the roving receiver can be accomplished by occupying a known point for a minimum of 5 epochs or making a rapid static observation on the first point and then moving to other unknown points. Lock on the satellites must be maintained at all times.
- Data sampling shall have an epoch time interval of 2 seconds or less. Real time coordinates must be recorded. The raw data shall be recorded for post processing.

**4.4.3.3 Independent Reoccupation of Stations.**

GPS surveys require redundancy of observations which are used to detect blunders and to obtain statistically sound results. Redundancy is achieved by reoccupying some points in different sessions with different geometric combinations. The following criteria pertains to static, rapid static and reoccupation procedures for network adjustments:

- Ten percent of all stations shall be occupied three times or more.

- Thirty percent of new stations shall be occupied two or more times.
- All vertical control stations shall be occupied two or more times.
- Twenty five percent of horizontal control stations shall be occupied two or more times.
- All "station pairs" for azimuth control shall be occupied simultaneously two or more times.
- One hundred percent of new vertical stations shall be occupied two or more times.
- When a station is occupied during back to back sessions, the antenna/tripod must be reset between the sessions to be classified as an independent occupation.

#### **4.4.3.4 Making the Observations**

A. Every day, before leaving the office, the following equipment must be checked for inventory, as well as for proper functioning:

- Receiver
- Antenna and cables
- Batteries and power cables
- Cigarette lighter adapter cable
- Tripods, tribrachs and adapters
- Tape measures
- Flashlights
- Radios
- Vehicles
- Station log sheets
- Writing utensils (pens)
- Station descriptions
- Observing schedule and station lists
- Special equipment required
- Traffic cones, safety equipment
- Maps, keys, lock combinations.

B. Antenna set up.

- Check that tripod is stable.
- Check that antenna/tribrach is level.
- Keep signal path clear; heads, trucks, etc.
- Check for reflective objects (your car!).
- Orient the phase center offset.
- Follow the manufacturer's recommended procedure for determining the antenna height.
- Make at least two antenna height measurements per session.
- Verify the height at the end of station occupation.

- Measure the antenna height in meters and preferably in feet as well.
- C. Operate the receiver following the instructions of its manufacturer. Initialize the session according to the requirements of the survey method utilized. Key in all necessary station and session related information. Coordinate the length of the session with other stations. If other stations are not ready, you may start observing early. Extra data cannot hurt.
- D. Check receiver and antenna frequently during observations. Check for power loss, tripod movement, etc.
- E. Record weather data and note any drastic changes during sessions.
- F. Monitor data logs and note unusual occurrences during sessions.

#### **4.4.3.5 Monumentation**

- Permanent type monuments shall be placed at all "station pairs". Monuments shall meet NJDOT specifications. All permanently monumented stations shall be fully described with "how" descriptions and local connections.
- All new stations shall be described using sketches and local connections.

#### **4.4.4 Office Procedures**

##### **4.4.4.1 General**

- Software used for processing the raw data must be capable of producing results that meet the accuracy standards specified for the survey.
- The software must be able to produce, from the raw data, relative position coordinates and corresponding variance covariance statistics, which, in turn, can be used as input to three dimensional network adjustment programs.
- The 1996 or later version of the Geoid Model shall be used for elevation determinations.
- A three dimensional least squares adjustment shall be made to provide final adjusted coordinates of the GPS network control stations. All NGS control stations are to be held in the adjustment, unless it is proven that the station does not meet the required accuracy.

##### **4.4.4.2 Loop Closure Analysis**

The following list of occupation rates shall be used for static and rapid static procedures for network adjusting:

- Baselines in the loop shall be from a minimum of two independent observation sessions.
- Baselines in the loop shall not total more than ten.
- Loop length shall not exceed 100 kilometers.
- Percentage of base lines not meeting criteria for inclusion in any loop shall be less than 30% of all independent base lines.
- In any component (XYZ) maximum misclosure shall not exceed 30 cm.
- In any component (XYZ) maximum misclosure in terms of loop length shall not exceed 20 ppm.
- In any component (XYZ) the average misclosure in terms of loop length shall not exceed 16 ppm.

#### **4.4.4.3 Repeat Baseline Difference**

- Baseline length shall not exceed 50 kilometers.
- In any component (XYZ) maximum difference shall not exceed 20 ppm.

#### **4.4.4.4 Project Documentation**

The following information should be documented and filed upon completion of the horizontal and vertical control work:

- Original GPS raw data in digital form of either the receiver's proprietary or RINEX format.
- Listings of loop closure analyses.
- Listing of geographic coordinates, ellipsoidal heights, and geoid separations for all stations.
- Listings of final State Plane Coordinates shall be in meters or U.S. Survey Feet, depending on project requirements, and shall be referenced to North American Datum of 1983. The elevations of all stations shall be referenced to the National Geodetic Vertical Datum of 1988.
- Map showing all measured baselines.
- A report of the minimally constrained three dimensional adjustment holding the latitude and longitude of one NGRS station and the ellipsoidal height of an existing bench mark. This will be used to analyze the internal quality of the field work.
- A report of the constrained 3D adjustment holding the latitude and longitude of all NGRS horizontal stations and all benchmarks. This will be used to analyze how well this project fits within the NGRS from a three dimensional mapping standpoint.
- A written report including obstruction charts and events logs.

## **4.5 GPS Specifications for Photogrammetric Control**

### **4.5.1 Introduction**

These specifications set forth the minimum requirements for utilizing GPS techniques to establish horizontal and vertical control used in photogrammetric mapping projects. The objective of this section is to provide specifications for photogrammetric consultants performing mapping for NJDOT projects.

### **4.5.2 Location Mapping (1:2500)**

Only static and rapid static procedures, as outlined in Section 4.43 of this manual, shall be used to obtain the horizontal and vertical positions of aerial survey control points. All coordinates shall be established using the North American Datum of 1983 for the horizontal datum and the National American Vertical Datum of 1988 for the vertical reference datum unless the project has special requirements. The latest version available for the geoid model shall be used in determining the orthometric heights for the control points established for a photogrammetric project.

### **4.5.3 Design Mapping (1:300)**

Static and rapid static procedures shall be used, as outlined in Section 4.43 of this manual, to establish the horizontal control positions for the aerial points. Vertical control can be established by GPS procedures provided 95% of all tested points meet or exceed the accuracy of 30 mm. Elevations of a minimum of 10% of the vertical control points shall be determined by conventional means to be used as a quality control measure.

### **4.5.4 Network Design**

All points must be surveyed to allow loop closures to be calculated, using data from a minimum of two sessions, to form a loop. If control is required to be brought in to the project, a static or rapid static survey should be done to establish project base control. These base stations then are to be used to establish the project control points. A Least Squares adjustment is required to be completed for all control points established for a photogrammetric project.

### **4.5.5 Criteria for Establishing Project Control Points**

#### **4.5.5.1 Procedure 1: Project Framework Control**

Control points should be established to create a framework around the project. This framework is used to control the project targets.

Specifications:

1. A framework point can be a NGS horizontal station, a NGS vertical station or another monumented station with confirmed coordinate values. If framework points do not already exist, then a network must be established to bring control into the project area to establish the required points.
2. Framework points shall have X, Y, and Z values. If the X, Y, and Z do not already exist, they should be established using a GPS network.
3. Framework points can be located from 1.6 km (1mile) to 5 km (3 miles) from the main line of the project. Spacing along the project can be up to 8 km (5 miles) apart.
4. Every fourth target (or photo identified point) must have at least one tie to a framework point.
5. A measurement must be made between consecutive targets to provide consistency checks.
6. If vertical control is going to be established for the targets (or photo identified points) using GPS, then all targets (or photo identified point) must be occupied at least twice.
7. All work within the area bounded by framework points can be done by rapid static procedures.
8. There should be enough redundancy in the measurements to be able to eliminate a few of them (up to 10%) and still compute the job without returning to the field.
9. At approximately 8 km spacing along the alignment, a tie should be made to two framework points.
10. All office procedures, in Section 4.442 "Loop Closure Analysis", must be met when using this procedure for photo control.

**4.5.5.2 Procedure 2: Horizontal Targets Along Center of Corridor.**

All horizontal targets (or photo identified points) shall be spaced along the centerline of a given corridor or centerline.

Specifications:

1. If first order NGS control lies within 30 km of the ends of the project, a traverse, like GPS survey, can be run between two first order NGS stations. If the monumentation does not meet the 30 km restrictions, a network must be established to bring control to the project site. Follow the procedures, as outlined in Section 4.42 of this manual, to do a network.
2. All distances between traverse stations shall be measured twice.
3. Two known benchmarks (preferably NGS) shall be occupied near the ends of the project.
4. It is recommended that wing points be set away from the main traverse line at 8 km (5 miles) spacing along the project corridor to help strengthen the horizontal coordinates.
5. If a measurement between two traverse stations proves to be in error during final analysis, it shall be remeasured and incorporated into the final adjustment before proceeding with the photogrammetric mapping.
6. All office procedures, in Section 4.442 "Loop Closure Analysis", shall be met when using this procedure for photo control.

#### **4.5.5.3 Procedure 3: Full Control of Photo Wing Points**

Horizontal and vertical information for photo control shall be placed along the outer edges of the aerial photography.

##### Specifications:

1. Any targets placed along the centerline of the mapping corridor shall be used as quality control points during the mapping process or set to establish horizontal control for other project purposes.
2. If first order NGS control lies within 30 km of the ends of the project, a GPS traverse can be run between two first order NGS stations. If the monumentation does not meet the 30 km restrictions, a network shall be established to bring control to the project site. Follow the procedures, as outlined in Section 4.42 of this manual, to do a network.
3. All distances between traverse (target) stations shall be measured twice.
4. Two known benchmarks (preferably NGS) shall be occupied near the ends of the project. If the horizontal stations do not have vertical information, then benchmarks shall be occupied.

5. It is recommended that wing points be set away from the main traverse line at 8 km (5 miles) spacing along the project corridor to help strengthen the horizontal coordinates.
6. All office procedures, in Section 4.443 "Loop Closure Analysis", shall be met when using this procedure for photo control.

#### **4.5.6 Project Documentation**

See Section 4.4.4.4 of this manual, on project documentation, for GPS surveys.

## **4.6 GPS Specifications for Topographic Surveys**

### **4.6.1 Introduction**

These specifications set forth the minimum requirements for utilizing GPS techniques to establish horizontal and vertical control and the topographic data points for a NJDOT planning or design survey.

### **4.6.2 Network Design**

If known control does not already exist within 30 km of the ends of a project, a static or a rapid static survey shall be done to establish second order control at the project site to be used for the topographic survey. All points must be surveyed to allow loop closures to be calculated using data from a minimum of two sessions to form a loop. These base stations then are to be used to establish the project data points. A Least Squares adjustment is required to be completed for all control points established when performing a static or rapid static survey.

### **4.6.3 Criteria for Establishing Project Control Points**

1. If first order NGS control lies within 30 km of the ends of the project, a GPS traverse can be run between two first order NGS stations. If the monumentation does not meet the 30 km restrictions, a network must be established to bring control to the project site. Follow the procedures, as outlined in Section 4.42 of this manual, to do a network.
2. All distances between traverse stations must be measured twice.
3. Two known benchmarks (preferably NGS) must be occupied near the ends of the project. If the horizontal stations do not have vertical information, then benchmarks must be occupied.
4. It is recommended that wing points be set away from the main traverse line at 8 km (5 miles) spacing along the project corridor to help strengthen the horizontal coordinates.
5. All office procedures, in Section 4.443 "Loop Closure Analysis", must be met when using this procedure for base control.

### **4.6.4 Topographic Design and Mapping Data Collection**

The GPS method of Stop and Go is the most efficient one to use in collecting topographic data for mapping and design purposes. Stop and Go procedures shall be used, as outlined in Section 4.42 of this manual, to establish the horizontal and vertical positions for the topo points. When collecting topo data, the roving receiver shall return to a known point, after every 50 data points, to perform a check on the system.

#### **4.6.5 Project Documentation**

See Section 4.4.4.4 of this manual, on project documentation, for GPS surveys.

# Chapter 5

## Surveying Equipment

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# Chapter 5 Surveying Equipment

## **5.1 General**

Surveying equipment is being used under most stressful conditions. The equipment is exposed to extreme weather conditions, used in dusty construction areas and is subject to bumpy transportation. Proper care in the methods by which equipment is used, stored, transported, and adjusted is a major factor in the successful completion of the survey. Lack of good maintenance practices not only causes unjustified replacement costs, but also can seriously jeopardize the efficiency and accuracy of the entire survey.

The crew leader is responsible for training all crew members in the use of equipment for its intended purpose and the maintenance of all surveying instruments, equipment, tools, and supplies. Should there be a need for additional assistance or training to deal with problems that arise during the course of the survey, a supervisor should be notified about it.

## **5.2 Care and Maintenance of Surveying Equipment and Tools**

### **5.2.1 General**

Surveying instruments, which include theodolites, levels, total stations, electronic measuring devices, and GPS receivers, are designed and constructed to provide years of reliable use. The shafts, spindles, pendulums, and electronics of precision instruments, although constructed for rugged field conditions, can be damaged by one careless act, or continued inattention to prescribed procedures for use, care, and adjustment of the instrument.

Each new instrument is furnished with an operator's manual. The manual contains a description of the instrument, specifications of its various components and capabilities, and applications. The manual also contains basic instructions for use of the instrument and describes recommended servicing and adjusting methods. The operator's manual should be kept with the instrument at all times. Each operator should thoroughly study the manual prior to use of the instrument, particularly whenever prescribed field

adjustments are to be made. If the manual is lost, stolen, or damaged beyond use, a replacement copy should be obtained as soon as practicable.

The following general principles of care and servicing should be applied as a routine matter for all survey equipment and supplies:

- A. All equipment and tools should be kept as clean and dry as practicable, particularly if they are to be transported or stored for any length of time.
- B. Wooden surfaces should be wiped clean of caked mud or moisture prior to returning the equipment to the vehicle. The original painted or varnished surfaces should be repaired as often as needed to keep moisture from entering the wood.
- C. Metal surfaces should be cleaned and wiped as dry as practicable. A coat of light oil should be applied to tapes and the metal parts of tools to prevent rusting during storage. Excess oil should be wiped off.

### **5.2.2 Routine Care of Surveying Instruments**

Before making the first set up of the day, visually inspect the instrument for cracks, bumps, and dents. Check the machined surfaces and the polished faces of the lenses and mirrors. Try the clamps and motions for smooth operation (absence of binding or gritty sound).

- A. Frequently clean the instrument externally. Any accumulation of dirt and dust can scratch the machined or polished surfaces and cause friction or sticking in the motions.
- B. Dirt and dust should be removed only with a clean soft cloth or with a camel hair brush.
- C. Non-optical parts may be cleaned with a soft cloth or clean chamois.
- D. Clean the external surfaces of lenses with a fine lens brush and, if necessary, use a dry lens tissue. Do not use silicone treated tissues, as they can damage the coated optics. It is permissible to breathe on the lens before wiping it, but liquids, such as oil, benzene, water, etc., should never be used for cleaning purposes. DO NOT loosen or attempt to clean the internal surfaces of any lens.

- E. Cover an instrument whenever it is uncased and not being used for any length of time, particularly if there is dust or moisture in the air.
- F. After an instrument has been used in damp or extremely cold situations, special precautions must be taken to prevent condensation of moisture inside of the instrument. When working with the instrument in cold weather, it should be left in the carrying case in the vehicle overnight. If stored in a heated room overnight, the instrument must be removed from the carrying case. If the instrument is wet or frost covered, remove it from its case, and leave it at room temperature to dry out.

### **5.2.3 Transporting**

#### **5.2.3.1 Vehicular Transport**

The major portion of damage to equipment and tools occurs when they are being placed into or taken out of the survey vehicle. Other damage occurs during transport, when equipment is jostled against other tools or equipment. Compartments (lined with carpeting, when possible) should be provided to keep equipment and supplies separated. This not only keeps the equipment from being damaged, it facilitates finding such items more rapidly. Heavier items should be carried in the lower parts of vehicles and they should never be in direct contact with other tools or equipment below them.

- A. The care, organization, and general housekeeping of a vehicle are good indications of the attitude of the entire survey crew. Keep passenger compartments free of unnecessary clutter and equipment. Any equipment or material carried in the passenger compartment should be firmly secured.
- B. Transport and store instruments in positions that are consistent with the carrying case design. Many instrument cases indicate the position in which they should be transported. Treat optical targets, prisms, and staffs with the same consideration.
- C. Transport the instruments in their carrying cases placed in a compartment cushioned with firm polyfoam or similar material to protect them from jolting or excessive vibrations.
- D. Remember, loose equipment, out of place tools, and general clutter not only contribute to damage of the items, they also waste crew time in locating them and are a safety hazard.

### **5.2.3.2 Casing and Uncasing**

Before removing an instrument, study the way it is placed and secured in the case. The instrument must be replaced in the same position when returned to the case.

In removing the instrument from the case, carefully grip it with both hands, but do not grip the vertical circle standard or where pressure will be exerted on tubular or circular level vials.

### **5.2.3.3 Field Transport of Surveying Instruments**

Do not "shoulder" or carry a tripod mounted theodolite or electronic distance measuring equipment (EDM). These instruments should always be removed from the tripod and secured in their carrying cases when moved.

These precautions are necessary because the center spindle (center spigot or standing axis) of a theodolite is hollow and relatively short. When carried horizontally while on the tripod, the alidade's weight is an excessive load for the hollow centerpiece to bear. Instrument damage can result if the above precautions are ignored. Also, the instrument fastener can break, causing the theodolite to fall.

### **5.2.4 Care During Instrument Setups**

Whenever possible, select instrument stations where operation is not dangerous to the instrument operator, the crew, or the instrument. Select stable ground for the tripod feet. Do not set an instrument closely in front of, or behind, a vehicle or equipment which is likely to move. Take a safe route to all setups.

- A. At the site, firmly plant the tripod with its legs widespread. Push along the legs, not vertically, downward. On smooth surfaces, use some type of tripod leg restrainer to keep the legs from sliding outward.
- B. Always have the tripod firmly set over the point before removing the instrument from its carrying case. Immediately secure the instrument to the tripod with the instrument fastener.
- C. Never leave an instrument or its tribrach on the tripod without securing either to the tripod. Moderate pressure on the fastener screw is sufficient. Excessive tightening

causes undue pressure on the foot screws and on the tribrach spring plate. Make sure the tribrach clamp is in the lock position.

## **5.2.5 Adjustments of Surveying Instruments**

### **5.2.5.1 Field Adjustments**

The crew leader should develop a set of test procedures to be used frequently for elimination of gross errors. Such tests should include a check of items such as the levels, optical plummet, and tripod. In the field, adjustments should only be made when the instrument results are poor or require excessive manipulation.

Normally, each instrument should be periodically checked at a facility where the best conditions for testing are possible. Only the adjustments described in the manual for the instrument should be made in the field or shop. Do not "field strip" (dismantle) instruments.

### **5.2.5.2 Major Adjustments**

When an instrument has been damaged or otherwise requires major adjustments, it will need to be sent to an authorized repair shop. The instrument should be accompanied by a written statement indicating the types of repairs needed. In the case of electronic devices, the request should describe conditions under which the instrument does not function properly, i.e., coldness, dampness, etc. If a "loaner" is needed, this should also be indicated.

Wherever possible, the instrument should be "double cased" for shipping, with its case packed inside a cardboard container.

## **5.2.6 Care of Tools**

Improperly maintained tools can be a source of annoyance, as well as being a safety hazard. Each employee is responsible for keeping his or her tools and equipment in good condition. To prevent loss of small equipment and tools, avoid laying them on the ground, on vehicles, or on equipment which might be moved. When not in use, carry them in scabbards and pouches.

- A. Repair or replace any driving tool that is burred or fractured on any part of the striking or driving face. Many surveyors have been injured by the "shrapnel" effect

from gads and sledges which had ragged edges. The same is true for "bull points" or other tools which are driven.

- B. Crooked or warped handles can cause injury as well as mishitting and damage to the tool. Promptly replace such handles and those that are cracked or broken. Handles should be firmly secured in all cutting and driving tools.

## **5.3 Angular Measurement Instruments**

### **5.3.1 General**

Theodolites and mainly total stations are today's primary angle measuring instruments, particularly on all baseline and control surveys. Angular measurements by a theodolite or a total station are done essentially following the same procedure. The main difference between them is that a total station has battery operated electronic devices to display the measured angles, measure distances and perform on board computation. In general, they are also similarly built with many common features which are necessary to assure accurate and reliable operation.

Due to its low accuracy and inefficiency, the transit is not being used in today's survey work. Only theodolites and total stations will be discussed in this section.

### **5.3.2 Care of Theodolites and Total Stations**

Although the instruments are ruggedly built, careless or rough use and unnecessary exposure to the elements can seriously damage them. If handled reasonably, they will provide consistently good results with a minimum of downtime for repair or adjustment. Some general guidelines for the care of instruments are:

- A. Lifting - Instruments should be removed from the case with both hands, gripping the micrometer knob standard and base on the older instruments. Newer instruments are equipped with a carrying handle; the other hand should support the base. One hand should continually support the instrument until the tribrach lock is engaged and the tripod fixing screw secured.
- B. Carrying a Tripod - In most cases, the instrument should be removed and re-cased for transportation to a new point. If the point is nearby, the instrument should be carried in the vertical position (tripod legs pointing straight down). An instrument should never be "shouldered" or carried horizontally.
- C. Adjusting Collimation - The collimation error of theodolites and total stations is determined by following the procedure outlined in the users manual. If the collimation error is found to be consistently in excess of ten seconds on the horizontal

and twenty seconds on the vertical, the instrument should be adjusted. The collimation adjustment should be made in the field only by a specially trained individual. Otherwise, the instrument should be returned to an authorized repair shop.

## **5.4 Distance Measurement Instruments**

### **5.4.1 General**

Virtually all distance measurements are made today with an electronic instrument such as an EDM or GPS. Tapes are used only when very short distances have to be measured (i.e. on a construction site).

### **5.4.2 Total Stations and EDM's**

Most electronic distance measuring instruments (EDM's) are used in combination with a total station. The EDM is either integrated into a total station or mounted on top of it. Some theodolites have special brackets for mounting an EDM on top of them as well.

Each EDM should be checked on a calibration baseline at least once every year, with results documented and filed at the State Bureau of Weights and Measures in Avenel, NJ. Most EDM's have approximately the same distance measuring accuracy when operated in accordance with the manufacturer's instructions, with the proper reflector systems. Every instrument, whether radio or light beam measuring, has an inherent plus or minus error in every measurement, plus a small error based on parts per million of the distance measured. These errors are generally insignificant in the overall survey, but the surveyor should be aware that they are present and that there is no such thing as an exact measurement.

#### **5.4.2.1 Care of EDM's**

- A. EDM's are designed, constructed, and tested to withstand normal field conditions. They are, however, precision instruments and should be handled with the same degree of care required for other types of precision survey equipment.
- B. Secure EDM's in vehicles in padded compartments with substantial tie downs so movement and jarring are minimized. Cushion with firm polyfoam or similar material. Do not use soft foam rubber. The instruments should be stored and transported in the position indicated on the case.

- C. Required maintenance of most EDM's is minimal. However, protection from the elements and routine external cleaning is necessary.
- D. NEVER point an EDM directly at the sun. The focused rays of the sun can damage sensitive internal parts.
- E. Protect EDM's from excessive heat. Heat can cause erratic readings and deterioration of components. Do not leave instruments in closed vehicles that are parked in the sun. Avoid rapid changes in temperature, particularly from extreme cold to warm, which can cause condensation in the internal parts of the instruments. Condensation can normally be avoided by leaving the instrument in its carrying case for at least 10 minutes and then opening the case to allow any trapped moisture to evaporate. An instrument taken from a warm office or vehicle to an extremely cold operating environment may require some time to adjust itself. The same type of precautions should be taken to let the instrument cool off slowly.
- F. Although EDM instruments are water resistant and well shielded, keep them as dry as practicable. The case should be opened and the instrument allowed to dry in a warm dry room when not in use.
- G. Frequent partial discharge and charge of batteries could cause the battery to lose its ability to hold power. Periodically, batteries should be discharged completely and then recharged overnight, or for the specified charge time. Effective usage of batteries will also decrease at low temperatures. An EDM in the tracking mode position will discharge the battery quite rapidly, so it is important to be able to charge batteries to their maximum capacity. In general, one should follow the user's manual instructions on how to maintain the batteries for top performance. If the batteries still fail to hold power, they should be re-celled or replaced.

### **5.4.3 Tapes**

Surveyor's tapes are available in various lengths, of different materials, and with many methods of graduations. Although EDM's have replaced tapes for longer measurement, every crew should have both metallic and non-metallic tapes available. Tape reels for metallic or fiberglass tapes save time and help prevent damage to the tape, particularly if used in construction or heavy traffic areas.

#### **5.4.3.1 Care of Tapes**

Routine care extends tape life. The following are basic guidelines for the care of tapes:

- A. Do not place a tape where it can be stepped on or run over, unless the tape is flat, taut, and fully supported on a smooth surface. Keep the tape straight when in use. When pulling a slack tape, a loop can develop into a kink and easily break the tape. Avoid

pulling a tape around poles or other objects, as a hard pull can stretch or break the tape.

- B. Do not wind tapes overly tight on their reels, as it can cause unwanted stresses and lead to stretching of the tape.
- C. After the day's work, clean tapes that are soiled. In wet weather, dry before storing. Clean rusty tapes with fine steel wool and cleaning solvent or kerosene. Use soap and water when tape is dirty or muddy. To prevent rust after cleaning, oil lightly and then dry the tape.
- D. Avoid storing in damp places.

## **5.5 Accessories for Angular and Distance Measurement Instruments**

### **5.5.1 Tribrachs**

A tribrach is the detachable base of all theodolites, total stations, forced centering targets, and most EDM's. Tribrachs are equipped with a bulls eye bubble for leveling and optical plummets for setting up precisely on a survey mark. The discussion on tribrachs is conducted in a separate section because they are being used with a wide variety of surveying equipment

#### **5.5.1.1 Use of Tribrachs**

The ability to "leapfrog" backsight, instrument point and foresight by using interchangeable tribrachs increases the speed, efficiency and accuracy of the traverse survey. Whenever possible, the tribrach should be detached from the instruments and placed on the tripods for either theodolite or EDM setups. This procedure speeds up the setting up process and protects the instrument from accidents. In some cases, the same tribrach can be used to perform angular and/or distance measurements, as well as GPS observations from the same survey point.

#### **5.5.1.2 Care of Tribrachs**

Tribrachs are an integral part of the precision equipment and should be handled accordingly. They should be transported in separate compartments or other containers to prevent damage to the base surfaces, bulls eye level, and optical plummet eye piece. Over tightening of the tripod fastener screw can put undue pressure on the leveling plate.

Although the leveling screws are covered, dirt or dust can work into the threads and cause wear. The tribrach should be carefully disassembled, cleaned, and lubricated with light instrument oil whenever the threads appear to be binding. Such repairs should be done in the shop by someone experienced in such work.

### **5.5.1.3 Adjustments of Tribrachs**

An out of adjustment tribrach can cause small random errors and each tribrach should be routinely checked for centering. Careful adjustment with a plumb bob is quite fast and should provide a centering accuracy within 1 millimeter. A more accurate method is to rotate the tribrach 120 degrees over a smooth markable surface. For the first sighting, a soft pencil line is drawn on the tripod head around the tribrach base. The tribrach is carefully leveled and the sighting point marked. The tribrach is then rotated 120 degrees, carefully set in the pencil marks, re-leveled, and a new sighting point marked. Repeat this procedure. If the tribrach is slightly out of adjustment, the three rotational marks should form a triangle. The plummet should be sighted to the center of the triangle and the optical plummet adjusted to that setting. The test should be repeated to verify the adjustment.

## **5.5.2 Tripods**

Tripods provide a fixed base for all types of surveying instruments and sighting equipment.

### **5.5.2.1 Types of Tripods**

In the past, different equipment required different tripods. However, due to standardization by instrument manufacturers, most of today's equipment utilize the same tripod. The same tripod can be used for total station, levels, and GPS. Tripods are made of either metal or wood. Wooden tripods are recommended for precision surveys to minimize errors because of expansion and contraction due to heat and cold.

### **5.5.2.2 Care of Tripods**

A stable tripod is required for precision in measuring angles. A tripod should not have any loose joints or parts which might cause instability. Some suggestions for proper tripod care are:

- A. Maintain firm snugness in all metal fittings, but never tighten them to the point where they will unduly compress or injure the wood, strip threads or twist off bolts or screws.

- B. Tighten leg hinges only enough for each leg to just sustain its own weight when legs are spread out in their normal working position.
- C. Keep metal tripod shoes tight and free of dirt.
- D. Keep wooden parts of tripods well painted or varnished to reduce moisture absorption and swelling or drying out and shrinking.
- E. Replace top caps on tripods when not in use.

The most damage occurs to tripods when being placed in or taken out of survey vehicles. The life and usefulness of tripods can be significantly extended if compartments are constructed so that the tripods are not riding on or against other equipment.

### **5.5.3 Sighting Equipment**

Surveyors use a wide range of sights for a variety of survey operations. The main purpose of a sight is to provide a reference that is visible to the instrument operator for either referencing from a survey point or establishing a survey point. In this context, sights may be required for line, distance, or a combination of line and distance.

#### **5.5.3.1 Plumb Bob**

The plumb bob string with Gammon reel is the old standard short distance sighting method, particularly for establishing temporary points. Steadiness of the holder can be enhanced by the use of braces or any type of framework. Various types of inexpensive string line targets are also available.

#### **5.5.3.2 Range Poles**

Range poles are the most common sight used by NJDOT and are made in several cross sectional shapes, of various materials and in different lengths or combinations thereof. Some are solid, some tubular, and others laminated. Most poles are approximately 25 millimeters (1 inch) in diameter. Smaller diameter "lining poles" may be made from small diameter pipe or rod. Electrical conduit suitably tipped and painted makes a good light weight sighting pole.

The use of a bulls eye rod level is an essential option when any type of range pole is "hand held" or guyed.

#### **5.5.3.3 Forced Centering Targets**

The tribrach mounted traverse target sets are recommended for all baseline traverse surveys, and other control surveys, when they are available. The tribrach contained optical plummet and target configuration provide the most positive daytime sight available. Several illumination kits, consisting of a light bulb case and battery case, are available for nighttime surveys.

#### **5.5.3.4 EDM Prisms**

Each manufacturer of EDM's supplies special prisms and prism holders that are compatible with its equipment. The single lens, tiltable holder with provisions for direct connection on the top of a sectional or telescoping plumbing pole is the most common type used in most survey work. Such prism holders are generally equipped with a sighting target mounted above or below the prism to provide parallel sight between the sighting and measuring beams. The maintenance of parallel sight becomes more significant in the accuracy of measurements as the distance is decreased. The use of the tiltable holder, with properly mounted target, maintains the parallel sight relationship, particularly in rough terrain. The surveyor should understand the necessity for parallel sights and know what the telescope aiming point is for the type of EDM being used. The various EDM's have different methods of transmitting, receiving and computing the light beam. Some light beams may be transmitted and returned to the instrument on the same path, while others travel to one side of the prism and return from the other side in a rectangular pattern. The pattern determines from which part of the prism the beam will be measured and, thus, affects the prism constant relationship between the EDM and prism being used. The position of the prism relative to the vertical axis of the sight also affects the prism constant. It is important that the proper prism constant is used; otherwise a systematic error will be introduced in all the measurements made between a particular EDM and prism. The best way to verify that true measurements will be made is to test the EDM and prism on a baseline of a previously established distance.

- A. For longer measurements, cluster holders are available to provide an enhanced light return to the EDM. The clusters are generally arranged in groups of three prisms per holder with facilities to stack up to nine or more prisms on a common sighting plane. The sighting point for such distances is not critical. The surveyor should use his or her best judgment as to where the vertical sighting point should be. Most cluster holders are equipped for mounting on a tribrach by means of a standard tribrach adapter.

#### **5.5.3.5 Care of Sighting Equipment**

As with any survey equipment, proper care will extend the useful life of sighting equipment.

- A. Range or sighting poles should be kept straight and well painted. Whenever possible, poles should be sheathed or carried in a separate compartment when being transported. Never use range poles for vaulting or spears.

- B. Bull's eye rod levels should be checked periodically, or whenever there is any indication that they may be out of adjustment. A quick check against a pre-checked door jamb will indicate if the level is out of adjustment.
- C. Forced centering target sets should be treated as any other precision equipment. They should be transported in their carrying case in the proper compartments. They should never be put away wet or dirty. The tribrachs should be kept in the same adjusted condition as theodolite or EDM tribrachs.
- D. When not in use, keep prisms in their proper containers with face covers in place. They should be kept clean and moisture free to ensure maximum light return. Clean the reflective surface with a camel hair brush or soft lens tissue.

## **5.6 Leveling Instruments**

### **5.6.1 Hand Levels**

Most surveyors maintain a hand level as part of their personal equipment. Hand levels are useful in level "runs" for quick location of turn and instrument points and to determine differences in elevation when chaining. They are also quite useful for rough elevation checks during grading operations. As with any other level, the level bubble can become out of adjustment and should be checked periodically. A quick check can be made against a good carpenter's level and adjusted similar to a regular level instrument.

### **5.6.2 Automatic Levels**

Although the Department inventory shows dumpy and wye level instruments still in existence, pendulum type automatic levels are the standard leveling instruments used on Department surveys. The principal of operation is essentially the same in all makes. The line of sight is maintained perpendicular to the direction of gravity through a system of prisms, called a compensator. Pendulum levels are fast, accurate and easy to maintain. Proper care and service is required to ensure continuous service and required precision. Do not disassemble instruments in the field. Only attempt those adjustments set forth in the instrument manual.

#### **5.6.2.1 Care of Levels**

Review the previously stated guidelines for the care of instruments. These guidelines are also generally true for the proper care of pendulum levels. Additional guidelines are:

- A. Do not spin or bounce pendulum levels, as such movement can damage the compensator.
- B. Protect the level from dust. Dust or foreign matter inside the scope can cause the compensator's damping device to hang up.
- C. Frequently check the adjustment of the bull's eye bubble. Adjust the bull's eye to the center, not almost to the center. Make certain it is adjusted along the line of sight and transversely as well. Proper adjustment reduces the possibility of compensator hang up.
- D. To check for compensator hang up, slightly tap the telescope with a pencil or operate the fine movement screw jerkily to and fro. If the instrument has a push button release, use it. If the compensator is malfunctioning, send the instrument to an approved repair service for servicing. Do not attempt compensator repair in the field.

### **5.6.3 Leveling Rods**

Leveling rods are made of wood, metal, or fiberglass and are graduated in feet or in meters. The foot rod can be read directly to 0.01 feet, whereas, the metric rod is usually read to 0.01 m. More precise reading can be made with add-on accessories such as a vernier or an optical micrometer. Since leveling rod graduations come in a wide variety of patterns, the crew must become familiar with the specific rod used. Digital levels use a special leveling rod that has a bar code, instead of a numerical scale, for reading the elevation.

Leveling rods come in one, two or three sections. The multi-section rods can be extended to their full length in different ways. Some have hinges that accommodate folding of the sections, some have sliding sections that can be locked at the proper length, while others are folded telescopically and can be pulled open. The sole of the rod is a metal plate that will withstand the constant wear and tear of the leveling activities.

For very precise work, a one-section Invar rod is used. Invar rods are precision rods, which have been calibrated and are to be used in control surveys, deformation surveys, precise surveys and resetting or referencing surveys for benchmarks.

#### **5.6.3.1 Care of Leveling Rods**

Leveling rods should be maintained and checked as any other precision equipment. Accurate leveling is as dependent on the condition of the rods as on the condition of the levels. Reserve an old rod for rough work, such as measuring sewer inverts, mud levels, etc. The care requirements common to all types of rods are:

- A. Protect from moisture, dirt, dust and abrasion.

- B. Clean graduated faces with a damp cloth and wipe dry. Touch graduated faces only when necessary and avoid laying the rod where the graduated face will come into contact with other tools, objects, matter, or materials where damage might result.
- C. Do not abuse a rod by placing it where it might fall, throwing, dropping, dragging, or using it as a vaulting pole.
- D. Keep the metal shoe clean and avoid using it to scrape foreign matter off a bench or other survey points.
- E. If possible, leave a wet rod uncovered, unclosed, and extended until it is thoroughly dry.
- F. Store rods, either vertically (not leaning) or horizontally with at least three point support, in a dry place and in their protective cases.
- G. Periodically check all screws and hardware for snugness and operation.
- H. Periodically check accuracy by extending the rod to its full length and checking its scale with an accurate tape. This should be done at the beginning of control level surveys. If the rod indicates a tendency to be "off", it should be checked each time it is extended.

#### **5.6.4 Bull's Eye Rod and Pole Levels**

The bull's eye level is used for maintaining both level rods and sighting poles in a vertical position. An out of adjustment bull's eye level can cause accumulative error in level lines. Although the sighting pole is infrequently used for traversing, an out of adjustment bull's eye level used on sighting poles can cause errors in both angle and distance measurements.

##### **5.6.4.1 Adjustment**

A simple method for checking for gross error in bull's eye level adjustment is to check it against a previously checked door jamb or other permanent building part.

Other, more elaborate, checking procedures can be developed using plumb lines or other devices.

## **5.7 Miscellaneous Accessories**

### **5.7.1 Hand Held Radios**

Modern survey equipment and techniques have made the hand held radio an essential part of a survey crew's equipment. The statewide mobile radio system may be used to keep the crew in contact with the office and relatively short range hand held radios are used to maintain contact between members of the survey crew. Although units are generally ruggedly constructed, they require special care and maintenance.

Batteries are the primary source of problems with hand held radios. The care and maintenance of batteries is discussed under "Care and Servicing of Other Equipment".

#### **5.7.1.1 Care and Use of Radios**

- A. Radios should be kept in the carrying case at all times. Avoid laying radios in precarious places where they could be blown off or knocked to the ground.
- B. When one radio is being used for most of the transmission, battery life can be extended by switching radios during the day. Transmission causes considerably larger discharge than reception only. Battery life of the receiving radio can be extended by simply pressing the transmission button to acknowledge receipt of a message.
- C. All messages should be as short and to the point as possible.
- D. It has been found that radio transmission can affect measurements of EDM's. No transmission should take place near the instrument while measurements are being made.

### **5.7.2 Batteries**

Hand held radios and EDM's operate on rechargeable NiCad batteries. Battery failure is the cause of most problems with the operation of radios and such failures can completely disrupt the crew's effectiveness. Some EDM's are provided with alligator connections for temporary use of the vehicle battery.

- A. The need to retain a vehicle at the instrument point can often disrupt the crew's normal procedures. Therefore, the care and maintenance of batteries is an important part of the crew operation and one member of the crew should be assigned that responsibility.

- B. NiCad batteries have a tendency to develop false "bottoms" when they are only partially discharged between charging cycles. Periodically, the radio (or instrument) should be left "on" to discharge the battery to almost bottom. Over discharging could cause a reversal in polarity.

# Chapter 6

## Survey Procedures

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# Chapter 6 Survey Procedures

## **6.1 Notekeeping**

### **6.1.1 General**

Field survey notes are the record of work done in the field. They contain the complete graphic, tabular or written (or combination thereof) survey records which depict each step of the survey. Field survey notes should be recorded on suitable forms, special notebooks or in digital format. They should enable knowledgeable persons to interpret and use the survey and its results, and to retrace the footsteps of the surveyor.

Field notes are not an accessory to the survey; they are an integral part of the survey. A survey is never completed until field notes are submitted, checked, and filed. Field notes are important because:

1. Field notes perpetuate a survey even when stakes have rotted and monuments are obliterated. Good field notes make it possible to re-establish lost monuments or other measured data. Conversely, incomplete, illegible or incorrect field notes cause the time and money invested in the survey to have been wasted.
2. Field notes of boundary or right-of-way surveys, together with diaries and survey crew reports, are important documentation in court cases arising between the Department and landowners or contractors.
3. Field notes are the means of communication between field and office personnel. The office personnel should be able to understand and process the data without needing additional explanations.

In view of the importance of the field notes, the duties of notekeeping should always be assigned to a knowledgeable member of the crew. The notekeeper should have a thorough understanding of the purpose of the survey and the operations.

### **6.1.2 Types of Notes**

There are four basic types of notes currently used: sketch, tabular, modular, and electronic. A given survey may be recorded by a single type or combination of these four types.

1. **Sketch and/or Description Notes** - The main purpose of sketch notes is to clarify information shown in other types of notes, as described below in #3 and #4, and to prevent misinterpretation thereof. Sketches increase the efficiency with which notes are taken and subsequently interpreted in the office. Description notes are a written narration of the survey procedure and of the measurement to clarify information shown in other types of notes, as described below in #3 and #4. Whenever the field crew observes a noteworthy circumstance, it should also be recorded in writing.
2. **Tabular Notes** - Tabular notes are records of measurements referenced to survey stations or topographic features. Tabular notes may or may not require the use of a sketch, but one should make an effort to include one. The advantage of this type of note taking is that it does not depend on electronic devices. That is also the main disadvantage in that the transportability of data is limited.
3. **Modular Notes (Preprinted Forms)** - Modular notes are those in which original raw values are entered on special forms. The forms are generally designed as a "trade off" between ease in recording notes in the field and computer input needs. In some cases, computer operators are trained to input into the computer directly from the modular form. In other cases, the field information is transferred manually to special forms.

The advantages of modular notes are:

- Notes are neater and easier to interpret because entries are made in predetermined places and in predetermined order.
- Field data is generally more complete because spaces are provided for recording each required raw value. If a space remains empty, it may indicate that data is missing.
- The problem of arrangement and balancing a variety of information on a given page is eliminated.
- It is easier to train members of the crew to become competent notekeepers.

The disadvantages of modular notes are:

- Modular notes are usually in a loose leaf unbound format. This presents two problems. The first is that it is more difficult to organize, store, and preserve single forms. The second is a legal issue of the opportunity to alter and replace an original page with another one.

4. **Electronic Notes (Data Collection)** - A data collector is a device on which traditional survey data may be recorded electronically. This data is usually horizontal angle, zenith angle, slope distance and descriptive survey data such as feature identification or comments.

A system of codes needs to be developed that will identify topographic and terrain features, such as a road, stream, tree, power pole, etc. Codes are also needed for

computer drafting instructions, such as the start of a linear feature and the placement of topographic feature. Note sheets with point number, feature code, specific description and an occasional sketch, for unusually hard to define situations, could save a return trip to the field.

A systematic method of data collection should be established so that the surface can be adequately covered. The collection method should also have built in checks to prevent features from not being accounted for or unintentionally measured again.

The editing of the original electronic file should be avoided. If the collection system does not automatically preserve the raw data file, a copy should be made so that edits and revisions are made on the copy.

The advantages of electronic notes are:

- No reading or recording mistakes. Measurement data is transferred automatically from the instrument to the data collector.
- No computer input (typing) errors because there is no need to convert field notes into digital form.
- Data can be processed in significantly less time, and therefore, at less cost.

The disadvantages of electronic notes are:

- Data could be accidentally erased due to hardware problems or carelessness.
- Most data collectors do not allow sketch and diagram input. Sketches have to be made separately and must be associated with the data.
- The legal status of electronic notes as original unedited notes is yet to be determined by the court. This is critical, especially in right-of-way and other boundary surveys.

It is worthwhile noting that electronic notes are subject to code and description input errors.

### **6.1.3 Arrangement of Notes**

#### **6.1.3.1 Title Page**

A title page is the orientation, index, table of contents, and summary information for a set of field notes. It should include information that will aid someone searching for specific survey information. By the time a survey project is completed, there may be numerous books and forms filed. Digging through the survey records can be time consuming and expensive, particularly with those not involved with the actual survey. The title page should facilitate the information recovery process.

### **6.1.3.2 Header Information**

The header information serves as an identifier that associates the notes with a survey project. It is usually entered at the top of the note page and should be completely filled in for each page. The header information shall include project name and appropriate designation, location of the survey, date, time, weather conditions, instrument (type and number), crew members and their individual duties.

### **6.1.3.3 Record Information**

Record information is survey-related information that is not measured in the field, but retrieved from files, usually at the survey planning stage. For example, coordinates, control stations, curve data, point descriptions, computed bearings, etc. are all record information. Record information comes from such sources as control survey maps, filed survey notes, construction plans, government data sheets, etc.

Most of the record information should be assembled prior to the field survey. Where practical, the source or authority should be cited for the acceptance and use of any found point.

Record information includes calculated data results from mathematical manipulation of record or measured values. Whenever a calculated value is shown, also show the record or measured values which are the basis of the calculation.

### **6.1.3.4 Observations and Measurements**

On most modular note forms, measurements are the only required field entries, except for perimeter information and point names. These values represent the heart of the survey. Record each required field value in its proper place.

Explanatory notes, such as unusual weather conditions, problems with equipment, etc., aid in the interpretation and analysis of the reliability of portions of a survey.

Those entries which are recorded at the time observations are made, are original entries. Entries which are transcribed to the formal note form from memory or from any other written source are not original entries. Field notes with original entries will stand up in court and will assure maximum accuracy. After-the-fact entries are suspect and more likely to be erroneous.

Some guidelines to follow when recording measurements are:

1. Always record the full raw value as called out by the instrument operator. Do not set the instrument to compute reduced measurements. Do not record only the

- sums or the differences or the mean of a series of raw values. Also, do not record only "corrected" sums, differences or means.
2. Record significant figures only and clearly indicate the decimal portion of a measured value.
  3. Do not erase any observation. If a blunder is made in recording a "call out", or if an observation is rejected, draw a slash through the entry without destroying the legibility of the erroneous entry. Erasures diminish, and often destroy, the credibility of field notes.
  4. Do not discard a page with erroneous records. To void a page, draw a diagonal across the page and write the word "VOID" in large letters.
  5. Write clear and legible notes. A professional looking set of notes is likely to be of professional quality.

#### **6.1.3.5 Descriptions**

A survey point description is a (written, sketched, or written and sketched) recording of the general and exact horizontal (and vertical) location, datum, and the particular physical characteristics of a point which enable its recovery and the differentiation of that point from any other point.

There are several basic elements which, when included in the description, will aid in its identification. These elements are:

- Name of point.
- Physical description of monument, including size, appearance, materials, specific marks, and condition.
- Angles and/or distances to, and descriptions of, reference marks.
- General location and directions to its immediate vicinity.
- Citation of document or filed original field notes which first described point.

#### **6.1.3.6 Suggestions for Recording Notes**

- Make notes dark enough to be reproducible.
- Use standard abbreviations and symbols.
- Be consistent in style and lettering. Write tabulated figures inside and off column rulings. Align decimal points and digits vertically.
- Do not crowd information to a point where numbers or letters are hard to distinguish or some information is covered. Do not try to economize on paper. Do not write in margins of notes.

- Use drafting aids to produce neat drawing.
- Draw sketches to approximate scale. Exaggerate details on a separate diagram if clarity is thereby improved.
- Orient sketches and entries according to standard mapping procedure.
- Draw framework of sketch before measurements begin.

## **6.2 Preliminary Surveys**

Surveying activities for an engineering project consist of research, reconnaissance, control, and mapping of the project area. A preliminary survey consists of all survey activity connected with the gathering of data and establishment of survey control systems through the reconnaissance and design phases of a project development.

The results of the preliminary survey are the basis for the design, detailed plans, and cost estimate of the project. Since every engineering facility can be located and designed with different variations, the preliminary survey usually covers a larger area than necessary for the particular facility.

### **6.2.1 Research**

The primary source of information is the county recorder's office. These records, generally in easy form to follow, are based strictly on land transfer documents. Additional valuable information can be obtained from the county or municipal engineer's office, clerk of courts, New Jersey Department of Transportation, New Jersey Department of Environmental Protection, etc.

Quite often, contracts for deeds, surface rights, leases, and other documents of a temporary nature are not filed, and occupation or use of the land may not be reflected in the county records. In such cases, an actual interview with whoever is occupying the land or person listed as agent for the owner should be conducted.

Determining land use and ownership along roads under the jurisdiction of a County or Municipality, within the state, is generally not required unless, the Department will be acquiring the Right-of-Way on behalf of the County or Municipality.

If entry to private property is required, a letter should be prepared for each landowner as described in section 1.56 of this manual. Where absentee ownership is involved, the letters should be sent out well in advance of actual survey operations.

### **6.2.2 Reconnaissance and Gathering Data**

As soon as practical after approval of the project, notification to landowner, and receipt of authority to proceed, the representative surveyor should visit the job site and determine the type of control that is needed and, in general, how the survey will be conducted.

**Data Required** - Pertinent information and data on the area involved should be gathered and compiled to aid in some of the decisions to be made. Such information could include:

- 7 ½ minute quadrangle maps, and County maps.
- NJDOT information, including previous construction plans, listings of highway control, etc.
- Utility permit listings.
- Benchmark control maps and listings (and their sources).
- Horizontal control (and their sources).
- Photo mosaics.

**Available Information** - The most important objective of the reconnaissance is to determine what control is available, its suitability for the survey and what additional control will be required. Some of the questions to be asked are:

- How was the existing control established and to what accuracy?
- Is the existing control in the proper location?
- Will it suit all of the survey needs for the project, i.e. construction control, etc.?
- Is it properly monumented?
- Will a new control network be required?

### **6.2.3 Horizontal Control**

All projects shall be based on an approved coordinate system. Wherever practical, that system should be the New Jersey State Plane Coordinate System. Local (arbitrary) grids may be used on small, isolated projects where it is impractical to tie to the established control network. With the availability of GPS technology, there is little justification for local grids, since control can be extended to virtually anywhere.

Control points in preliminary surveys are defined as permanently monumented points from which additional control can be established. Therefore, the establishment of control monuments through the project area is an extremely critical step. All subsequent phases of the project development, as well as future projects, will rely on these control points. Inaccurate or inadequate control can cause unnecessary and costly delays in the project.

#### **6.2.3.1 Base Control**

After thorough research of all control information, the extent of horizontal control required will be determined. If sufficient government or NJDOT established control is found within the project area, there should be no need for a new control network survey. If any of the found points to be used as base control were established by other surveys, their validity should be checked thoroughly. If, after such review, they are determined to be of questionable positional accuracy, they should be reconnected to the government control or a new control survey considered.

The base control should be established by GPS techniques. Traversing can also be used for setting control points when GPS is unavailable or for short ties between GPS points. The use of traversing for base control should be discouraged.

The distance between control points should be limited to no more than one half kilometer (one quarter mile). This limitation arises from the control requirements of subsequent activities, such as photogrammetry, supplemental topography surveys, and construction staking.

### **6.2.3.2 Supplemental Control**

Accurate positional determination of such items as property corners, right-of-way markers, bridge ends, headwalls or other identifiable fixed objects can serve many purposes. For example:

- Such points can serve as supplemental control points for the data gathering process.
- The coordinate location of such objects establishes their positional relationship with all elements of the existing highway facility including centerlines.
- Such points are aids in correlation of old and new surveys.

### **6.2.4 Vertical Control**

A consistent elevation datum is required through the project area. Unless authorized and documented otherwise, that datum will be the NGVD 29 or NAVD 88, and so specified on the plan as described in section 2.13 of this manual. The normal procedure is to establish the control monuments as the primary bench line for the project. Supplementary vertical control, such as construction benchmarks, right-of-way markers or other monumented points to be used during the course of the project, would then be set from the primary bench line.

#### **6.2.4.1 Base Control**

The primary level line should be of second order accuracy, unless specified otherwise.

A three wire circuit between (NGS) benchmarks is the most efficient method of establishing vertical control on project control points. Satisfactory results may also be obtained by double turning points or double height of instrument circuits (see section 3.7.6.2.6).

In some areas, discrepancies in the (NGS) benchmarks may be found. The level line should be extended to other (NGS) benchmarks until tolerances are met, or return level runs to the original benchmark. The former is the preferred method because it provides an extra check on the elevations.

#### **6.2.4.2 Supplemental Control**

The supplemental vertical control provides easy to reach benchmarks through the project area and, therefore, it should be established as accurately and efficiently as possible. Level circuits between control monuments should be used to establish the elevation of such benchmarks. Tolerance in closure should be third order. Carefully run single wire levels should meet this prescribed tolerance (see section 3.7624). If a different tolerance is specified, Federal Geodetic Control Committee (FGCC) standards and specifications should be followed to meet this requirement.

### **6.2.5 Alignment**

#### **6.2.5.1 Computing Existing Alignment**

Most projects involve construction along or over existing alignment. In order to accurately locate the right-of-way, centerline and other features of the existing facility, right-of-way markers, bridge ends and other identifiable points should be accurately tied to the control network. These points should be surveyed from the control points with the same accuracy as prescribed for supplemental control, for, in essence, such points may become supplemental control monumentation.

After coordinate positions of the points surveyed have been computed, the existing centerline and right-of-way can be computed. As a result of the new measurements and design, new centerline stationing and curve data will be required. Generally, it is not practical to compute equations between the old and new stationing and the old stationing should only be used to identify the monumented points.

#### **6.2.5.2 Establish Centerline**

If required, the new computed tangents and curve points may be set from control points. In some cases, it may be more practical to stake a computed reference line or reference points for the points on tangent (POT), points of curve (PC) and points of tangency (PT).

If field cross sections are to be taken, it may be necessary to establish the centerline on the ground. Points which fall on roadways, cultivated fields, or other lands subject to disturbance should be referenced with at least 3 well placed ties.

### **6.2.5.3 Profiles**

Profile elevations are taken on baseline stations to aid the engineer in establishing a grade line to fit field conditions. The profile and preliminary grade line also serve as reference elevations for cross sections and the soils profiles.

Profiles should be taken by differential leveling circuits beginning and ending on the previously established benchmarks. Heights of instruments and turning point elevations should be carried to the nearest 0.005 meter (0.016 foot). Profile elevations should be recorded to the nearest 0.01 meter (0.03 foot), unless they are on pavement, curbs, structures or other fixed objects that would require less tolerance in determination of the final grade line.

Profiles of grade line controlling features, such as crossroads, drainage, utility lines, irrigation works, railroads or other grade influencing features should be taken far enough on either side of the centerline to clearly define the grade lines of those features.

### **6.2.5.4 Cross Sections**

Cross sectioning should not be started until the preliminary alignment and profiles have been approved.

The photogrammetric process may be used to obtain terrain cross sections. There are some occasions, however, that will require field checking of photogrammetric sections, such as, if the terrain extends outside of covered areas or if the ground is not visible due to obstructions.

In most projects, cross sections at all 20 meter stations should be sufficient. Closer spacing may be required for street sections, uneven terrain or in areas where there are special drainage problems. The general criteria for taking extra cross sections should be determined prior to commencement of the work.

Cross sections should be taken far enough on either side of the centerline to assure that all of the proposed construction zone will be included.

In general, skewed sections for drainage pipes or other special sections not required for earthwork computation should be recorded separately or clearly marked as not for use in earthwork computations.

## **6.2.6 Topographic Data**

Topography for the preliminary survey is defined as all man-made or physical objects in or adjacent to the highway corridor that would normally be shown on plans. The survey should include such items as existing fencing, roads, buildings, power lines, land features, waterways, railroads, pipes, utilities, etc. If the plan sheets are to be made from aerial photography, much of the information listed below can be identified and located by annotation of enlarged aerial photos. When the plans are to be developed solely from field notes and electronic data collection, the following is a list of minimum requirements for location and identification of topographic features.

### **1. FENCES**

Include the fence type and location of existing gates.

### **2. UTILITIES**

#### **A. Gas and Petroleum Pipelines**

- Identify the location of the centerline crossing by station or surveyed coordinates at both rights-of-way.
- Location of vents (if cased).
- Location of bends.
- Location of meter vaults and valve pits.
- Depth of the line.

#### **B. Water and Sewer Lines**

- Identify the location of the centerline crossing or, in case of parallel lines, the actual distance from the centerline.
- Location of manholes, valve boxes, meter pits, crosses and tees and bends.
- Elevation on top of the waterline, sewer invert elevation, and manhole ring elevations.
- Location of fire hydrants and curb stops.

#### **C. Power Lines**

- Location of supporting structures on each side of the centerline with the elevation of the neutral or lowest conductor at the centerline crossing point.
- Location of each pole and pole lines, including their alignment on either side of the corridor.
- Location of poles on parallel lines that may require relocation, location of guys, stubs and anchors for overhead lines.
- In cases of buried power, location of cables, pull boxes, transformer pads and notation of whether direct burial or conduit.
- Identification of the type and owner of the power utility.

#### **D. Telephone Lines**

- Denote direct burial or conduit run (number of conduits).
- Location of pedestal loop boxes.
- Location of manhole and sizes.
- Location of each pole and pole lines, including elevation, centerline crossing station and distance from centerline.
- Identification of the type and owner of the telephone utility.

### **3. BUILDINGS**

All buildings should be shown with dimensions and type of construction, as well as appurtenances.

### **4. DRAINAGE COURSES**

Show irrigation ditches, rivers, creeks, canals, and streams, giving the direction of flow.

### **5. DRAINAGE STRUCTURES**

Describe bridges, pipes, inlets, manholes, and culverts in place on the existing roads, indicating their dimensions, type of facility and general condition.

### **6. RAILROADS**

- Mainline station and milepost at survey centerline crossing.
- Existing right-of-way.
- Rail profile 60 meters (200 feet) each side of the centerline crossing point.
- Switch points within 60 meters (200 feet) of the centerline crossing point.
- Signal and communication line locations.
- Any structures or other features relevant to the railroad.

#### **6.2.7 Right-of-Way**

Wherever new right-of-way may be acquired, it is necessary to tie property corners to either the centerline or control points. Sufficient land ties must be made to accurately define the centerline with respect to property ownership or other boundaries, such as corporate limits, subdivisions, or county lines. For detailed specifics of the required fieldwork, it will be necessary to reference the NJDOT Procedure Manual, section 9.2, Preparation of ROW Documents.

## **6.3 Construction Surveys**

Construction surveys provide the horizontal and vertical layout for every key component of a construction project. They involve horizontal and vertical control and the placement of stakes to establish a framework for the construction site. From this control, lines and grades are established by means of stakes and strings. The contractor uses these stakes and strings to place supplemental stakes that may be necessary to guide the construction activities. In summary, construction surveying is the process of drawing the design plans on the actual construction site at the designated location and at a scale of 1:1.

Construction surveying techniques are also used for verifying the location and quantities of completed work (as-built).

Traditionally a "station/offset" method was used for establishing construction control. The introduction of computers, total stations and GPS in surveying have revolutionized the way construction surveys are done now. Construction surveys are now based on the three dimensional (X,Y,Z) coordinate system with which the design was made. From the three dimensional coordinates, angles and distances are computed to facilitate radial stakeout. Radial stakeout data can be downloaded into many total stations or electronic data collectors. This data guides the surveyor to the location of the points to be staked out. Three dimensional coordinates of the construction plan can also be downloaded into a GPS receiver and used in a real time kinematics mode to stake out the site.

### **6.3.1 Horizontal Control**

The construction phase of most projects requires a relatively dense network of horizontal control monuments. The horizontal control network will normally consist of basic control monuments that were established during a preliminary survey and of additional control monuments established specifically for construction control.

Project control, consisting of centerline or centerline references, may be set by GPS or by traditional traversing.

#### **6.3.1.1 Traverse Style Base Control**

A traverse style control system is a control scheme that traverses between two terminal points. In construction surveys of highways, this type of control is set in the immediate vicinity along the construction site. The traverse points can be surveyed either by GPS or by a total station. Traverse style control monumentation may be the preferred control system for several reasons:

1. Points can be set where they will not be disturbed by construction activities.

2. Monuments can be used for both horizontal and vertical control, which makes use of total station capabilities.
3. Monuments can be set at optimum spacing for the staking accuracies required and the type of equipment being used.
4. The same monument would be used for setting all phases of the construction, including restoration of stakes obliterated during construction.
5. Distance, direction and elevation calculations can be made from any control point to any desired construction stake. This calculation can be done in the office, before leaving for the field, or by calculating inverses in the field with hand-held calculators.

### **6.3.1.2 Supplemental Control Monuments**

Supplemental control is the establishment of extendible control monuments from the base (traverse) control at locations that will aid either the data gathering process or the construction staking. With proper planning, much of the supplemental control may have been included in the base control or the control completed for the preliminary survey operations. A thorough review of construction plans and staking requirements will generally indicate where additional control may be required. Interchanges, structures or other complex facilities will generally require monuments in unforeseen locations. Some basic suggestions for establishing additional supplemental control monuments are:

1. Set monuments by closed traverse between the highest order base control economically available. Never use previously set, unchecked points to set other control or construction stakes.
2. Set points where they can be used for setting all phases of construction staking.
3. Set points where they are accessible by vehicle, if possible. A vehicle can often be used to protect the instrument person from wind, and hand carrying equipment to inaccessible points is time consuming.
4. Generally, try to pick point locations where the instrument is above all stages of the work. This is particularly advantageous for structures.
5. Flag and protect points so they are easy to find and will not be disturbed by equipment.
6. Generally, space control points on both sides of the road to assure that any required staking point will be within approximately 200 meters (650 feet) from a control point.

## **Staking from Supplemental Control**

There are two basic staking methods used from supplemental control points; namely, "direct" or "traverse". The direct method is the most common and advantageous with modern surveying equipment.

**Direct staking** from supplemental control is called "radial" staking. This system involves the use of inverse calculations that yield azimuth and distance and, where required, transfer elevation from the control monument to a construction stake. If several stakes are being set from one control point, the back sight setting should be rechecked.

**Traverse staking** is accomplished by running a line through the points to be staked, and setting the points as the line is run. Control points on the traverse line are established from the supplemental control point by direct ties. It is often advantageous to set PC's, PT's, and PI's from control points and then traverse the centerline or offset line before setting station marks.

### **6.3.1.3 Secondary Control**

Secondary control, such as right-of-way, centerline references and pipe or structure reference points, can be set from supplemental control by either direct or traverse staking.

### **6.3.1.4 Centerline Control**

This type of control uses the centerline (or a similar construction layout line) as the principal control line for a project. Since centerline stakes are usually destroyed by construction, strategic points must be referenced outside the construction limits. The reference points provide the horizontal control during the construction period.

Some advantages of the centerline method are:

1. Straightforward and easily understood.
2. Familiar to construction personnel.
3. Provides actual on-the-ground checks of the centerline. Also provides easy on-the-ground checks for critical clearance points.
4. Requires less computations.

Some disadvantages of the centerline method are:

1. The principal control line (centerline) is usually destroyed by construction work.

2. Intermediate steps of establishing each centerline station point must be set and occupied to set each construction control stake.
3. Adapts poorly to steep terrain and often requires more brush cutting.
4. The Survey is never "closed", unless the ends of the project are tied to base control stations. Positional accuracy is difficult to determine.

#### **6.3.1.5 Alignment Control**

The new alignment should be reset from the strongest ties or reference monuments available. When a base traverse is used for development of the project, all critical alignment points should be set directly from the base traverse monuments. In any event, those alignment control points should be set only from control monuments that were originally installed in accordance with criteria for extendible points. Also, each alignment control point should be set using the same criteria. Tacked hubs, nails and shiners or other types of semi-permanent station markers appropriate for the soil or type of surface should be used.

#### **6.3.1.6 Reference Points**

The cost and time required for resetting stakes, or for setting new lines of construction control stakes can be reduced if easy to use reference markers are set before construction is started. The prime considerations for reference points are that they too will not be destroyed and that they can be used without special survey equipment to accurately place the required control stakes.

Whenever feasible, reference points should be set on the right-of-way line because they have the best likelihood of remaining undisturbed. If the road or other terrain features will interfere with the line of sight between reference points, additional sight only references may be required.

#### **6.3.1.7 Control Stakeout Methods**

Once the alignment control is set, several optional methods for setting the intermediate station points are available. The option selected by the surveyor should be based on personnel, available equipment, terrain and safety.

**Traverse Method** - The traditional system of instrument setups at control points and sighting on line or turning appropriate angles to set station points. The main advantage of this method is that it provides on-the-ground and visual checks of the centerline. However, it is more time consuming and less accurate than using the supplemental control method.

**Supplemental Control Method** - (Centerline Stations) The setting of intermediate station points from strategically placed extendible control monuments. Some of the advantages of this method are:

1. Any section of the project can be set at any time.
2. Once methods are developed, it is generally faster and can be done with as few as two people. Three crew members are generally the most efficient, as rod people can move ahead while the new angle is being turned and the other rod person is painting or completing installation of the set station mark.
3. Generally provides the best setup and sighting conditions.
4. Points can be accurately re-established to their original position at any stage of the construction.
5. Coordinate calculations for curves can be pre-figured in the office and tabulated for simple reference in the field.

The main disadvantage is the lower level of accuracy obtained as compared to the higher levels obtained using GPS.

**Real Time GPS Method** - Recent developments in GPS surveying provides the most efficient method for setting the centerline and additional reference points. A base GPS receiver and a (one or several) roving receiver are used for this purpose. Numerical and graphical instructions displayed on the roving receiver direct the surveyor to the desired point. The real time kinematics GPS method is based on the following procedure:

- The three dimensional coordinates of all the points to be staked out are stored in the roving receiver.
- A base station is set up on a known point.
- The rover and the base station receivers are initialized to establish a relative position between them.
- The rover and the base receivers communicate measurements via a radio (usually FM) frequency.
- Since the coordinates of the rover are measured and updated continuously, it is relatively easy to compute the direction and distance to the construction stake to be staked out. This information is then displayed and made available to the surveyor.

The main advantages of the real time GPS method are:

1. One base receiver can serve many rovers simultaneously. This makes this method very efficient.

2. Less control is needed for the project because line-of-sight does not have to be maintained. The only limitation is the range of the radio communication between the rover and the base.
3. It is very easy to reset any destroyed point.

A disadvantage of this method is the present relatively high cost of equipment.

### **6.3.2 Vertical Control**

Vertical control is an important part of all projects. A relatively dense network of vertical control (benchmarks) must be established for most projects prior to construction staking operations. Such vertical control is seldom accomplished in one survey, but is a culmination of several vertical surveys beginning with the base vertical survey to establish the vertical datum on all major control monuments. The most important aspect of the various stages of vertical control is that the same datum be used from preliminary surveys through design and final construction control.

Ideally, most of the project control benchmarks have been established during the preliminary stage of the project development or the preliminary survey. This existing network is then densified by closed loop vertical surveys throughout the preliminary and construction period. Prior to beginning establishment of construction control benchmarks, several steps should be taken.

1. **Check monuments** - If there has been a long delay between the time the base vertical survey was conducted and the completion of the design plans, the condition of the base monuments should be field checked. Each monument should be checked for possible disturbance or settlement, and whether it is in satisfactory condition. Benchmarks that are to be used in the project should also be reflagged for easy location.
2. **Plan benchmark locations** - Design plans should be thoroughly reviewed and a set of plans marked up with the approximate location of existing benchmarks and locations where construction control benchmarks will be required. Such planning can save considerable field time and assure that required benchmarks will be established at their optimum location on a timely basis.
3. **Plan BM establishment** - The planning process should determine which benchlines should be established for the initial grade staking (normally earthwork on mainlines and service roads), final grade staking, structure staking and vertical control monumentation. Each benchline should be planned to reduce the difficulty and length of level runs required to establish the subsequent benchmarks.

### **6.3.2.1 Bench Mark Spacing**

The required density of benchmarks will depend on terrain, vegetation and type of construction. They should be of sufficient density to decrease survey time for subsequent leveling requirements. The advantage of density must be weighed against the greater initial cost for establishing extra benchmarks. The following are suggested spacing for benchmarks on a typical construction project:

1. A secondary line of semi-permanent benchmarks along one right-of-way line spaced at 300 meters (or approximately 1,000 feet) or less horizontal distance, the primary line being the permanent base control monuments. In heavy construction or rough terrain, a benchline may be required on both right-of-way lines.
2. Successive benchmarks should not be separated (vertically) by more than two "turns" or 7 meters (or approximately 24 feet) in elevation. Relative elevation and ease of access to bench marks is more important than the horizontal distance between them.
3. Bridge sites and major drainage sites should have at least two benchmarks placed outside the area to be disturbed.
4. At interchanges, at least one benchmark should be established for each quadrant in addition to those required for the structure(s).

### **6.3.2.2 Bench Mark Location**

Benchmarks should be placed in locations suitable for the intended purpose and permanence. Utility poles, ornamental trees, or fire hydrants should be avoided.

**Permanent benchmarks** - Benchmarks that are to remain as reliable elevation references over a period of years, or even for extended construction duration, such as major structures, should generally meet the following criteria:

1. Place in stable, undisturbed original ground.
2. Establish on abutments or wing walls of older existing structures that have become stabilized.
3. Locate near "join" lines of cross streets, intersection of sidewalks and existing facilities outside of the construction area.
4. Select locations with locally level terrain. A benchmark on top of a high slope is not as desirable as one lower on the slope, provided all other criteria can be met. Quite often, the positions of horizontal (traverse) points are not compatible with project use of benchmarks, but are compatible with other considerations. In such

instances, benchmarks in more usable locations should be established from the traverse control.

**Temporary Benchmarks** - Less permanent benchmarks may be required for a limited use period for a specific survey operation, i.e., slope staking. Such stakes are called temporary benchmarks and they are not perpetuated after construction. Temporary benchmarks are usually marked with wooden stakes.

### **6.3.2.3 Marking Bench Marks**

The density of benchmarks in the project area can be a source of confusion and possible error through misidentification. It is important that each be uniquely identifiable by name, number, or location and marked with the appropriate identification code. During periods of use, a flagged or painted lath can aid the rod person in the speedy location of the benchmark. Care should be used not to deface private property or structures that will remain after construction.

### **6.3.2.4 Leveling Accuracies**

The elevation of all permanent benchmarks should be determined to third order accuracy in accordance with methods outlined in section 3.7 of this manual.

Temporary benchmark accuracy should be consistent with the type of construction for which they will be used.

## **6.3.3 Earthwork Staking**

### **6.3.3.1 Cross Sections and Slope Staking (Grading)**

Design quantities are calculated from field cross sections, from cross sections derived through the photogrammetric process, or from electronically collected data. Normally the staked location and elevation should agree fairly closely with the plotted location and elevation. Discrepancies of up to 0.3 meters (1 foot) in distance or less than 0.1 meters (0.3 feet) in elevation would not be a reason for complete reacquisition of cross sections. If the plotted and staked locations disagree, the staked position, as reflected in the staking notes, would be used for final quantities.

Some surveyors have found it advantageous to add at least one line of grade control stakes as the roadway sections near completion. A control line of centerline, median ditch, or roadway shoulder stakes is run and grade stakes set to aid the contractor in the final stages of the earthwork prior to staking for finished grades. This not only works toward a better end product, but also expedites the finish grading.

## Marking Slope Stakes

It is extremely important that the information shown on construction stakes is concise, legible and clearly understood by the contractor. Since a contractor may have projects in any part of the State, consistency among the various survey crews is a great aid to the contractor's understanding of the information being conveyed. The required information should be neatly written on a stake that has been painted and set.

## Slope Staking with a Total Station

The use of a three dimensional coordinate system for the design makes staking with total station instruments a valuable option for slope staking, particularly in rough terrain.

The first requirement for "radial" slope staking is that two control points be available for all slope staking. A second requirement is that the instrument be within 300 meters (1,000 feet) of the furthest slope stake to be set and the control point ("back azimuth").

In order to establish the horizontal position of each slope stake, the instrument should be set over a control point, back sighting another with the calculated "back azimuth" set on the horizontal circle. Turn the calculated "forward azimuth" to the slope stake being set. Alternatively, the slope stake may be set by setting the back sight to zero degrees and turning the angle calculated from the difference in azimuths between the back sight and the slope stake. The rod person should be directed on the line-of-sight to the calculated distance of the slope stake.

### Determination of the ground elevation of the staking point.

One of the following methods can be used for determining the ground elevation of the staking point:

**Relative elevation without HI or HR** - Determination of relative elevation (DE) where the height of the rod or the prism (HR) is set to be equal to the height of the instrument (HI). In this case, the elevation differences or the vertical component of the slope distance is due only to the elevation changes in the topography. Or

$$DE = \text{the vertical component of the slope distance}$$

**Relative elevation with HI and HR** - When the height of the rod must be changed for visibility or other reasons, the height of the rod and the height of the instrument have to be recorded. In this case:

$$DE = \text{the vertical component of the slope distance} + HR - HI.$$

### 6.3.3.2 Borrow Areas

Determination of volumes removed from borrow areas involves a comparison of "before" and "after" elevations. For large or extremely rough borrow areas, or in areas that may require more than one stage or type of removed material, photogrammetric methods are generally the most efficient methods. Field cross sectioning, especially the real time kinematics GPS method, can be also be used for this purpose.

**Photogrammetric Borrow** - Stereo photos taken at various stages of material removal provide positive proof of the quantities of material removed. Reliable quantity determination by aerial photography requires that the area is photographed prior to any material being removed and after each stage for which quantities will be computed. It is also important that the "model" control be targeted for each photographic flight. If the elevation of a targeted point was changed between flights, a new ground elevation will be required for that point.

Pit layouts and special needs should be reviewed with the photogrammetry and survey representatives prior to setting up the survey.

**Field Cross-Sections** - A total station can be used to establish the baseline, turn the right angles from the established station points, measure offset distance and determine elevations by trigonometric calculations. Ground elevations may be calculated by any of the recommended methods.

Additionally, total station instruments with electronic data collectors are capable of computing coordinate and elevation information of any target point. When baselines are tangent (straight) lines, it is possible to orient the total station relative to the baseline for stationing and offset. The stationing at the total station defines the northerly coordinate value, while the offset at the total station is the easterly coordinate value. An orientation of 0 degrees on the horizontal circle should be set parallel to the baseline in the ascending stationing direction of the baseline. Station and offset values of the target point should be then computed and displayed directly on the total station. By determining the height of the instrument and subtracting the target (rod) height, the ground elevation should be displayed.

The instrument operator can direct the rod person to stay on the cross section. Offset distances and elevations of topographic features are read directly. The ground point station, offset, and elevation may be either manually recorded in traditional cross section type notes, on forms or recorded digitally in an electronic data collector. Some advanced total stations come with programs or processes that can automatically determine the instrument's random setup location from measurements to control in both the horizontal and vertical components automatically. These methods can greatly increase the productivity of field crews in severely sloping terrain or even in areas when offsets exceed 30 meters (100 feet) or taping offsets are difficult due to elevation differences, between the instrument and the rod person.

Salient points and ground slope break line data may be recorded in total station data collectors, downloaded into computers and processed into digital terrain models from

which cross sections may be interpolated and plotted. Very accurate volumes may be calculated by comparing grid files of the original ground with that of the excavation or fill.

**Real Time GPS** - GPS in real time kinematics mode is the fastest ground based method for determining volumes of borrow areas. In a similar manner to that outlined earlier in section 6.317 of this manual, a grid of X,Y coordinate values can be downloaded into a roving receiver to direct its operator to measurement points. Additional salient points or break line data can also be recorded. One base station can serve many rovers, which makes this method very efficient.

### **6.3.3.3 Structure Staking**

#### **Major Structure Staking**

Stakes set to control the location and elevation of structures serve several purposes:

- They ensure that the contractor has the information needed to construct a structure to the lines and grades shown in the plans and are compatible with the adjacent roadway.
- They provide the contractor with accessible and understandable reference points and working lines to line up with, or measure from, without the use of sophisticated surveying equipment.

**Field Notes** - Separate field notes should be set up for each major structure and maintained on a daily basis when work is being done on the structure. Information for setting up staking diagrams and sketches should be obtained from the detail sheets in the plans. Separate pages should be used to show the overall staking system and detail drawings of the various structural components. Do not try to crowd too much information onto one page.

**Coordinate Control** - Most major highway projects are presently designed using a horizontal and vertical coordinate control system. The structure design may or may not have been laid out under the same coordinate system. If not, the structural layout should be converted to the roadway coordinate system for staking purposes. Such conversion is a comparatively simple office procedure using two common coordinate positions from each of the two systems. Use of the roadway coordinate system will ensure that the roadway and structural components will fit in the completed facility. It also simplifies on the job calculations and provides a more exact method of establishing or restoring control references.

**Reference Markers** - All reference markers should be iron pins or tacked hubs set to line and grade as accurately as practicable. Although certain tolerances do exist between the various components of a structure, those tolerances should be preserved, as much as practicable, for subsequent measurements.

In general, all major working lines for abutments, footings, columns and centerline should be referenced with two intersecting lines of stakes. At least the two stakes nearest the component should be on line with, and at a set distance from, the component. Outer stakes may be set for line only. All reference markers should be double guarded and lathed on line where required for "eyeball" sight in. Each guard stake should be marked to identify the station and/or offset from the component. If the stake controls elevation, the cut, fill or flow line information should be included.

Where many stakes or much information is required, a stake numbering system can be used and each marker identified on the guard stake by number only. A listing of each marker would then be furnished to the contractor.

**Special Items** - Separate pages in the structure field notes should be maintained for such pay items as excavation, back fill material, rip rap, wire mesh, etc., in order to compute and document quantities.

### **Minor Structure Staking**

Minor structures consist of reinforced concrete boxes, reinforced concrete pipe and corrugated metal or plastic pipe installations. The same general procedures for staking and documentation of the various pay items apply as described previously for major structures.

**Staking Notes** - Staking notes are generally set up in the office from the plans as amended by the revised pipe list.

**Excavation and Backfill** - Most pipe or box installations require several types of excavation and backfill. During the staking processes, cross sections of sufficient width on either side of the installation should be taken to establish natural ground. The cross sections should be taken at sufficient distance beyond each end of the pipe to encompass the excavation anticipated.

**Reference Markers** - Reference markers may be either iron pins or tacked hubs. Except on approach pipe or other small installations, the ends of the installation should be referenced both on centerline and by fixture end offsets. The offset markers should be set 3 meters (5 to 10 feet) or more from centerline. Elevations should be taken on each marker and the offset distance, cut to flow line, type, size of pipe and designation of flared end, if applicable, are marked on the guard stakes.

A centerline marker should be set at 1 to 3 meters (3 to 10 feet) out from each pipe end with additional centerline markers set a sufficient measured distance to provide line of sight and distance reference in any area that will not be disturbed by construction. The terrain may dictate other reference marker layout. Information on the guard stake for the nearest to pipe reference marker should include station and offset distance on the

backside and on the front side, size of pipe (if flared end is required), length of pipe, cut or fill to flow line, and grade per foot.

#### **6.3.3.4 Centerline Monument Staking**

Centerline monument assemblies and/or centerline reference monuments shall be set according to the construction plans and must be set under the direct supervision of a licensed professional surveyor. Following the completion of the centerline monuments, their locations should be checked. The monuments must check within a tolerance of the smaller of an error ratio of 1:10,000 for distance and alignment or a maximum positional error of 2 centimeters (0.06 feet). Failure to meet the tolerance will require the contractor to reset the monument assembly properly.

#### **6.3.3.5 Right-of-Way Markers and Property Boundary Monuments**

Right-of-way markers are monuments placed at points of curvature, points of tangency, points of compound curvatures along the necessary baselines. These are always mentioned in the right-of-way description. Right-of-way markers constitute the monumentation of the highway property. As such, they are used by others to make legal ties to the highway. If shown on the right-of-way plans, right-of-way monuments will be set prior to the start of construction activities under the direct supervision of a professional surveyor licensed in the State of New Jersey. The locations of these and other property boundary monuments of record shown on the construction plans, shall be referenced to the project control and checked prior to the start of clearing, excavation or grading activities. The contractor shall be responsible for replacing any right-of-way markers or property boundary monuments disturbed or destroyed during or by the construction activities. All markers or monuments replaced must be set under the direct supervision of a professional surveyor licensed in the State of New Jersey.

Private surveyors have the obligation to either accept the monumentation as a legal boundary or to reject it and re-establish the described boundary in accordance with their findings. Therefore, it is extremely important that right-of-way markers be staked to the closest tolerance practicable and that markers conform to the positions described by the highway description. If, for any reason, the disturbed or destroyed right-of-way markers or property boundary monuments cannot be reset in their original horizontal location, then the contractor's surveyor shall notify the Department's project supervisor. A witness monument or monuments may have to be set to replace the old one. The witness monument shall clearly show its relative position to the record marker or monument, and to the right-of-way or property boundary line it was identifying.

#### **6.3.3.6 Right-of-Way Fence Staking**

Right-of-way fence is normally constructed approximately 0.3 - 0.6 meters (1 to 2 feet) inside the established right-of-way. Normally, the centerline offsets, survey for right-of-way markers and other control surveys have basically established the fence line location. Some additional staking may be required, such as gate, end panel and brace panel locations.

Fence should be measured as construction progresses and gate, cattle guard, brace panel, and end panel installations documented in relation to the project stationing.

Construction area fencing should be staked prior to any construction activity in the area.

#### **6.3.3.7 Curb and Gutter Staking**

Tacked hubs should be set for radius points and as offsets from back of curb. The offset is normally 0.6 meters (2 feet) or a distance dictated by the contractor's operation. Offset stakes set outside the right-of-way must be approved in writing by the adjacent property owner. Guard stakes should show the station on the back side and offset distance and cut or fill to top of curb on the road side. Again, depending on the contractor's equipment and operation, the distance between offset stakes may vary from 5 to 30 meters (16 to 100 feet).

# Chapter 7

## Photogrammetric Surveys

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# Chapter 7 Photogrammetric Surveys

*This chapter does not supersede the NJDOT Aerial Mapping (Photogrammetry) Manual, but provides general overview. For more complete information on the subject, please consult the NJDOT Aerial Mapping (Photogrammetry) Manual.*

## **7.1 General**

Photogrammetry is a surveying and mapping method that has many applications in the Department of Transportation. Applications of photogrammetry in surveying practice include topographic mapping, site planning, earthwork volume estimation for proposed roads, compilation of digital elevation models (DEM), and image base mapping (orthophotography).

The term “photogrammetry” is composed of the words “photo” and “meter” meaning measurements from photographs. The classical definition of photogrammetry is:

*The art, science and technology of obtaining reliable information about physical objects and the environment, through processes of recording, measuring, and interpreting images on photographs.*

Photogrammetry is an art, because obtaining reliable measurements requires certain skills, techniques and judgments to be made by an individual. It is a science and a technology because it takes an image and transforms it, via technology, into meaningful results. Modern photogrammetry includes image sources and image forms other than photographs, such as radar images.

The photogrammetric process consists of project planning, image acquisition, image processing, control data for image orientation, data compilation and presentation of an end product. The end product of the photogrammetric process can be coordinate values of individual points, a graphic representation of the ground surface (topographic map), or a rectified image of the ground surface with map-like characteristics (orthophoto.)

Images used for photogrammetry can originate from a special (metric) camera, an ordinary camera or from digital sensors. The image can be recorded from a device mounted on a satellite, on an airplane (including helicopters), or on a tripod (terrestrial photogrammetry) which is set up on the ground. In this Manual, only applications that are based on aerial photographs recorded with a metric camera will be discussed.

### **7.1.1 Advantages and Disadvantages.**

Some advantages of photogrammetry over conventional surveying and mapping methods are:

- It provides a permanent photographic record of conditions that existed at the time the aerial photographs were taken. Since this record has metric characteristics, it is not only a pictorial record but also an accurate measurable record.
- If information has to be re-surveyed or re-evaluated, it is not necessary to perform expensive field work. The same photographs can be measured again and new information can be compiled in a very timely fashion. Missing information, such as inadequate offsets for cross sections, can be remedied easily.
- It can provide a large mapped area so alternate line studies can be made with the same data source can be performed more efficiently and economically than other conventional methods.
- It provides a broad view of the project area, identifying both topographic and cultural features.
- It can be used in locations that are difficult, unsafe, or impossible to access. Photogrammetry is an ideal surveying method for toxic areas where field work may compromise the safety of the surveying crew.
- An extremely important advantage of photogrammetry is that road surveys can be done without closing lanes, disturbing traffic or endangering the field crew. Once a road is photographed, measurement of road features, including elevation data, is done in the office, not in the field.
- Intervisibility between points and unnecessary surveys to extend control to a remote area of a project are not required. The coordinates of every point in the mapping area can be determined with no extra effort or cost.
- The aerial photographs can be used to convey or describe information to the public, State and Federal agencies, and other divisions within the Department of Transportation.

Some disadvantages are:

- Weather conditions (winds, clouds, haze etc.) affect the aerial photography process and the quality of the images.
- Seasonal conditions affect the aerial photographs, i.e., snow cover will obliterate the targets and give a false ground impression. Therefore, there is only a short time normally November through March, that is ideal for general purpose aerial photography. A cleared construction site or a highway that is not obstructed by trees, is less subjected to this restriction. These types of projects can be flown and photographed during most of the year.
- Hidden grounds caused by man-made objects, such as an overpass and a roof, cannot be mapped with photogrammetry. Hidden ground problems can be caused by tree canopy, dense vegetation, or by rugged terrain with sharp slopes. The information hidden from the camera must be mapped with other surveying methods.

- The accuracy of the mapping contours and cross sections depends on flight height and the accuracy of the field survey.

## **7.2 Components of Photogrammetry**

In general, photogrammetry has three major components. These components are image acquisition, image control and product compilation.

1. Image acquisition includes planning the over flight, selecting an appropriate camera system, photo taking film processing, film inspection and annotation, printing of paper prints and diapositives, and image scanning (if necessary.)
2. The control component includes selecting locations for ground control and targeting, field surveying control points and aerial triangulation. In the future, this component could be eliminated when advanced GPS methodology will be able to solve the photo orientation problem without needing ground control.
3. The product compilation component of photogrammetry varies and depends on the nature of the product. Topographic maps, orthophotos, or monoscopic updates are all photogrammetric products which are compiled in different ways as discussed later. Each of these components requires the utilization of different equipment, different measurement techniques, and different data processing.

A successful photogrammetric survey project depends on a thorough understanding of these components and on careful planning and execution of the project specifications.

### **7.2.1 Image Acquisition**

#### **7.2.1.1 Flight Mission Planning**

A flight plan generally consists of two items:

1. A flight map which shows where the photos are to be taken. A flight map consists of flight lines, usually marked on a medium scale topographic map, showing the starting and ending points of each line. It is used by the pilot for navigation and by the photographer for taking the pictures. Usually, there are enough topographical features in the flight area to assist the pilot in flying the designated flight lines. Otherwise, a large arrow on the ground at the beginning and end of each flight strip is necessary to aid the pilot and photographer. The number of flight lines, their location, the spacing between them, and their orientation depends on the characteristics of the project to be mapped and on the specifications of the flight mission.

2. Specifications which outline how to take the photos, including camera and film requirements, scale, flying heights, end lap, side lap, tilt and crab tolerances, etc.

### **7.2.1.2 Aerial Cameras**

Aerial mapping cameras are perhaps the most important photogrammetric instruments, since they record the image on which the photogrammetric principles will be applied. Aerial cameras must be able to produce very sharp images, almost distortion free, in rapid succession under the adverse conditions of a moving aircraft. Any error, distortion, or compromise in the clarity of the image will result in mapping and positioning errors.

### **7.2.1.3 Aerial Films**

Aerial films are fine grained, high speed photographic emulsion on a stable polyester film base. The fine grain is necessary for identifying features as small as 1 micron on the negative. High speed film permits short exposure time which is necessary to prevent image smearing and displacement that may result from the movement of the aircraft. The image must be recorded on a stable film to prevent it from irregular shrinkage or expansion. Any change in the dimension of the film results in a measurement error and less accurate product. Aerial films come in a roll of about 200 exposures of 9x9 inches (23x23 cm) each.

To insure dimensional stability, the film should not be stretched or deformed in any way. It should not be subjected to extreme changes in humidity and temperature. The film should be sealed in its container and stored at a temperature recommended by the manufacturer at all times, except when in actual use during the flight mission or when being processed.

### **7.2.1.4 Image Scanning**

Until recently, photogrammetric products were developed from diapositives or paper prints. With the emergence of digital photogrammetry, photographs are now scanned into a digital format that is compatible with digital image processing software. Scanners for digital photogrammetry are precision devices that maintain the radiometric and geometric integrity of the scanned image

## **7.2.2 Control for Photogrammetry**

### **7.2.2.1 General**

The second element of the photogrammetric process is control, which is used to establish the position and orientation of the camera at the instant of exposure. The necessity,

accuracy and the rigor of photogrammetric control depends on the particular product sought. Photo mosaics used for annotation, cultural studies, public meetings, and other varied purposes may not require any control. Rectified aerial photographs, used mainly for photo plan sheets, may require partial control in the form of measured distances. Field measured distances are scaled down to match corresponding distances on the photograph. However, most common photogrammetric products, such as mapping and orthophotography, require full control information. The minimum full control to establish a stereo model is two points with known horizontal positions (for scaling) and three points with known elevations (for orientation). Using this bare minimum is unacceptable; therefore, additional control is required for a processing a stereo model.

Photographs can be controlled using three different methods:

1. Ground control points that were surveyed on the ground using ordinary surveying techniques.
2. Bridging control through aerial triangulation. Bridging is accomplished by measuring on the photographs common points that appear in three consecutive photographs or in two adjacent strips and computing their 3 D coordinate values.
3. Aerial photography control through kinematic GPS technique in which the position and the attitude of the camera are computed without ground control.

In most photogrammetric projects, a combination of all or some of these methods are utilized.

### **7.2.2.2 Ground Control**

Ground control can be classified as targeted and photo-identifiable (picked) control points, and can also be classified as horizontal control, vertical only control, or as 3-D control. Horizontal and vertical controls require different configurations to make them serve their intended purposes. The use of only ground control is now limited to small projects, such as bridge sites, borrow areas and where only one or two models are needed. Photo identifiable control points are rarely needed. The surveyor needs to know what type of control is called for when he or she attempts to pick or photo-identify the point. Accessibility for surveying should also be considered when selecting the locations for control points.

### **7.2.2.3 Targeting**

Targeting operations are an essential part of photogrammetric mapping to be considered prior to establishing a control survey. Preflight targeting is performed to make ground locations of control points visible on the photographs. Easy identification and clear image of the control points on the photograph increases the accuracy and efficiency of the

photogrammetric process. Highway design mapping often requires careful preflight planning for optimal target placement. To reduce the possibility of pre-marked points being moved or lost prior to the aerial mission, it is important to either paint them on a hard surface or schedule the field paneling operation as close as possible to the anticipated flight. Targets should be located where shadows will not adversely affect the visibility of the panel.

Photographic targets should be of symmetrical shape, adequate size, and appropriate photographic contrast and resolution. (See Figure 7.1).

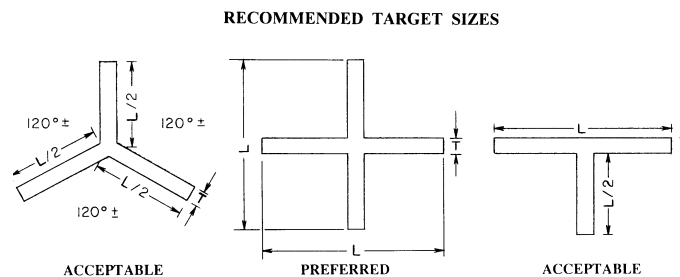


Figure 7.1 Photogrammetric ground control targets

Photo. Scale	Thickness of Leg (T)	Length of Legs (L)
1:1800	6 Inches(150mm)	3 Feet(0.9m)
1:2400	6 Inches(150mm)	3 Feet(0.9m)
1:3000	6 Inches(150mm)	4 Feet(1.2m)
1:3600	6 Inches(150mm)	4 Feet(1.2m)
1:4200	6 Inches(150mm)	5 Feet(1.5m)
1:4800	8 Inches(200mm)	6 Feet(1.8m)
1:6000	8 Inches(200mm)	6 Feet(1.8m)
1:8400	12 Inches(300mm)	7 Feet(2.1m)
1:9600	15 Inches(375mm)	8 Feet(2.4m)
1:12000	18 Inches(400mm)	10 Feet(3.0m)
1:19200	24 Inches(600mm)	15 Feet(4.5m)
1:24000	30 Inches(750mm)	20 Feet(6.0m)

Table 7.1. Recommended target dimensions as a function of photo scale.

#### **7.2.2.4 Field Survey of Photogrammetric Control**

Field surveys for photogrammetric control should be treated as ordinary surveys. The methods and procedures that are described in this manual must be applied to photogrammetric control field work. The key issue here is to select suitable survey procedures that address the project requirements.

Photogrammetric control points are usually spaced widely around the project area. For large projects, this spacing could be extensive enough to require a significant surveying effort. Therefore, GPS is the better suited surveying method for most large photogrammetric projects.

Ground control that is to be used in successive photogrammetric projects or field surveys should be monumented accordingly.

#### **7.2.2.5 Aerial Triangulation**

Aerial triangulation, or aerotriangulation, is the process of determining X, Y, and Z ground coordinates of individual points based on measurements from photographs. Aerial triangulation is used extensively for many purposes. One of the principal applications is densifying ground control through strips or a block of photos to be used in subsequent photogrammetric operations. When used for this purpose it is often called bridging, because it allows the computation of necessary control points between those measured in the field. In a large project, with dozens of photographs, the effort and cost of providing the needed control using field surveys is prohibitive. Aerial triangulation is used to provide the necessary control for each stereo model with only a limited number of field surveyed control point. Other advantages of aerial triangulation are:

- The control densification is done in the office, thus minimizing delays and hardships due to adverse weather conditions.
- Field surveys in difficult or unsafe areas are minimized.
- Access to much of the (private or public) property within a project area is not required.
- The aerial triangulation process provides accuracy and consistency checks for the field surveyed control points.

#### **7.2.2.6 GPS as Control for Photogrammetry**

In recent years, GPS has been demonstrated to be able to replace, partially or entirely, the need for ground control. The basic concept of GPS controlled photogrammetry is to use GPS equipment to determine the position and orientation of the camera at the instant of exposure. Remember that the only reason for using ground control in photogrammetry is to recover the position and orient a photograph in space at the time that the photograph was taken. If the values of these parameters can be resolved at the time of photography with GPS and/or additional instruments, there is no need for ground control to compute them. Even if GPS controlled photography is not yet at a level of maturity to be able to completely replace the need for ground control, it does reduce the number of field surveyed control points in a given project.

## 7.2.3 Product Compilation

### 7.2.3.1 Photogrammetric Plotters

The most commonly used photogrammetric instrument is the stereo plotter. A stereo plotter is used to reconstruct the actual orientation and geometric integrity of an image at the instant of exposure and to collect three dimensional (3 D) data. Data collection with a stereo plotter is a two stage process. The first stage is orientation, which consists of:

1. **Inner orientation** – Orient each photograph with respect to the geometry of the camera.
2. **Relative orientation** – Orient two photographs with respect to each other to form a stereo model.
3. **Absolute orientation** – Orient and scale the stereo model to the ground. In some instruments the relative and absolute orientation are performed simultaneously. The simultaneous solution of these orientations is called **exterior orientation**.

In the second stage, the operator views the image of the ground in 3 D. Data collection is performed by placing a floating mark on the images of the feature that is surveyed and record its X,Y,Z coordinates. Line features, such as roads or contours, can be digitized, point by point, or traced and recorded continuously.

There are different types of stereo plotters, analog, analytical, and digital (softcopy.) Each of these types of plotters are classified according to their accuracy characteristics as first, second, or third order stereo plotters. Another classification of stereo plotters is as precision, topographic, or simple plotters. Figure 7.2 summarizes the differences between the various types of photogrammetric stereo plotters.

	<b>Stereo Plotter</b>		
Characteristics	Analog	Analytic	Digital
Image	Film	Film	Pixels
Plotter	Analog	Analytical	Computer
Model Construc.	Mechanical	mechanic/computer	Computer
Stereo Viewing	Optical	Optical	Varies
Output	Mech./CAD	Mech./CAD	CAD
Aerotriangulation	Very limited	On/Off Line	Semi-automatic*
Orthophoto	Very limited	Unavailable	Automatic**
Limitations	Focal length Film format	Film Format	None
Accuracy	Average up to $\pm 15$ $\mu\text{m}$ (microns)	Very high up to $\pm 3 \mu\text{m}$	Same as scanning accuracy
Cost	Very high	Very high	Reasonable to high

\*Some operator assistance is needed.

\*\*If DEM is available

**Figure 7.2.** Characteristics of photogrammetric stereo plotters.

Two additional photogrammetric instruments that are used in aerial triangulation are the point transfer device and the comparator. The point transfer device is used to drill a hole into the diapositive to mark a pass or a tie point. The point transfer process is as follows. The operator views a pair of photographs stereoscopically. A pass or tie point is selected by placing the left and right floating marks on the same image on the corresponding photographs. A drilling device is then activated to pierce a tiny hole on the diapositives exactly at the location of the floating marks.

Comparators are precise digitizers, many of them with a one micrometer least count, with which image coordinates of pass, tie and ground control points are measured. Mono comparators measure one photograph at a time in monoscopic mode while stereo comparators measure the points in stereo mode. If a mono comparator is used, pass points must be marked on each photograph. However, if a stereo comparator is used, the pass points are marked only on one photograph. The marked photograph is the one on which the pass points appear along a vertical line at the center of the photograph.

### **7.2.3.2 Data Collection and Mapping**

Photogrammetry can be used to collect a variety of data, presented in the following formats:

**Planimetric maps** – Planimetric maps are maps that represents only the horizontal features of the mapped area. Planimetric maps display features such as roads, sidewalks, buildings, river banks, shore lines, manholes, trees etc. No elevation information appears on planimetric maps.

**Topographic maps** – Topographic maps are maps on which both horizontal and vertical features of the mapped are represented. In addition to the above mentioned planimetric features, a topographic map depicts elevation information as contours and/or as spot elevations.

**DEM's** – Digital Elevation Model (DEM) or Digital Terrain Model (DTM) are dense networks of spot elevations represented by X,Y,Z coordinates. The DEM points are collected in a regular grid with break points which depict the characteristics of the topography. DEM's are used to draw contours and are an essential ingredient for the production of orthophotos.

In highway applications, DEMS can be used for producing cross sections, road profiles, and earth work computations. The advantage of using DEM's for volume computations is that the computation and the generation of the associated plots are almost automatic if the design was made under the same coordinate system. This is another good reason to use state plane coordinates and a unique elevation datum in all NJDOT work. One should be aware that an appropriate photo scale must be used to obtain centimeter level elevations.

**Special purpose maps** – Special purpose maps are maps that are designed to meet special needs or depict a special theme. The rule is that if you can see it on the aerial photograph, you can map it with photogrammetry. For example, a right-of-way map can be produced if all property corners are either targeted or can be identified on the photographs. Another example is a wetland map showing the delineation of wetland areas.

### **7.2.3.3 Monoscopic Mapping and Updates**

Aerial photographs can be used to produce photomaps mainly for indexing, referencing and general studies. Photomaps can be composed of a single photograph or of several photo parts mosaiced together. This is not an accurate metric product, but serves as a valuable means to present spatial information.

Monoscopic based photogrammetry is also used for minor updates of maps. The update that results from this process is of a lesser accuracy and is intended more for maintaining feature inventory at an approximate spatial location. Map updates are accomplished by locally rubbersheeting (superimposing) the photographic image and the map. A few common features are identified on the map and on the photograph. The photograph is then scaled and/or tilted to locally match the corresponding features. A special device called the “zoom transferscope” is commonly used for this purpose.

### **7.2.3.4 Orthophotos**

Orthophotos are covered in section 7.5 of this manual

## **7.3 Accuracy and Errors**

The attainable accuracy of a photogrammetric product depends on two main factors. The first is the scale of the photographs from which the product is derived and the second is related to errors in the photogrammetric process.

The scale of the photograph determines the ground resolution. If the smallest identifiable ground feature on the photograph is a  $0.1 \text{ m}^2$  ( $1 \text{ ft}^2$ ) object, then the mapping accuracy from this photograph, assuming perfect data compilation, is limited to no better than  $0.3 \text{ m}$  ( $\pm 1 \text{ ft}$ ). Selecting the appropriate photo scale for a particular product depends on product specifications. For example, the photo scale for topographic mapping is a function of the required map scale, the contour interval, and the quality of the photogrammetric plotter. A required accuracy can be met by either using smaller scale photographs and high quality equipment or larger scale photos with less accurate photogrammetric equipment. The photo scale is always smaller than the map scale but the ratio between these two scales should never be larger than eight.

The second factor controlling the accuracy of a photogrammetric product is the total amount of errors accumulated during its derivation. In photogrammetry, as in any other surveying and mapping procedures, there are systematic errors and random errors, assuming all blunders have been removed.

## **7.4 The Photogrammetric Procedure**

The photogrammetric procedure will be outlined below:

### **7.4.1 Project Planning**

Project planning is comprised of the following steps:

1. Convert project requirements to specifications in terms of area to be mapped, desired map scale and contour interval. The determination of these specifications depends on the required accuracy of the final map and on cost constraints. More accurate maps are more costly and take longer to compile.
2. Determine photogrammetric specifications in terms of flight height, the number of photographs needed, the number of strips needed, flight lines, approximate location for exposure stations, and equipment to be used. Specifications should also be developed for ground control, aerial triangulation, and compilation methodology.
3. Develop a schedule for aerial photography, field work, and map compilation. The schedule should be coordinated among the various groups involved in the project. A critical coordination is between the field crew placing the targets and the aerial photography crew. Targets should be placed as close as possible to the time of photography. A project timetable with completion dates for different tasks and the approximate cost associated with them should be developed as well.
4. Define the expected deliverables, including details on what features are to be mapped and their graphic representation.

### **7.4.2 Aerial Photography**

The aerial photography process consists of the following:

1. Verify that the weather conditions are suitable for flying. Flying under conditions of low visibility or potential strong turbulence should be avoided. Bad weather conditions could not only produce unacceptable photographic results, but also risk the flying crew.

2. Mount the aerial camera according to the established procedure. Test the camera to ensure that it functions properly.
3. Fly the designed routes and take the photographs according to plans.
4. Process the film according to specification to ensure radiometrically and geometrically quality images.
5. If necessary, print on the negatives the missing photo information (titles), such as serial number, date, project information, etc.
6. Prepare contact prints from the negatives. If necessary, prepare enlargements to be used later, according to the project requirements.
7. Inspect the photographs for image quality and for coverage completeness. Verify that all the photographs have enough end laps to assure stereoscopic coverage of the entire project area. A similar inspection should be made to verify complete side lap coverage. Incomplete end and side lap coverage or coverage gaps could void the entire aerial photography and require re-planning or re-flying.

Another inspection that has to be made is identifying the preset targets. Target inspection includes checking whether they are visible, appear in a stereo coverage and whether there are enough of them to ensure reliable results. If some targets are missing, or the entire project was not targeted, points that can be identified and surveyed on the ground should be selected and marked on paper prints. A copy of the prints and a description of the points selected should then be submitted to the surveying crew for field measurements.

8. Select photographs that will be used for data compilation and develop diapositives for them.

### **7.4.3 Ground Control**

1. Research project region for existing control. Existing control that can be targeted can save time and money by avoiding unnecessary field surveys. Sometimes it is more cost efficient to expand the aerial photography slightly beyond the project area to include existing control than to establish new control.
2. Place targets according to the discussion in section 7.2.2.3 of this manual.
3. Perform field surveys as discussed in Sections 7.2.2.2, and 7.2.2.4 of this manual. Field surveys of picked points could be necessary after the aerial photography is completed.

4. Compute and adjust the field data and establish coordinate values for the control points.
5. Prepare a report on the surveys and on the results. An accuracy analysis of the results should be included in the report. The analysis should indicate the methodology used to determine that the results are in agreement with the project specifications.

#### **7.4.4 Aerial Triangulation**

1. Order the photographs as a continuous strip, or a block if the project encompasses more than one strip.
2. Select and mark pass and tie points. Pass and tie points should be clearly marked and numbered on the paper prints. Establish a point numbering system that will make it easy to associate these points with the project and with individual photos. The selection criteria are described in Section 7.2.2.5 of this manual.
3. Mark artificial pass and tie points on the diapositives with a point transfer device. Points that are marked in stereo (tie points) should be executed with utmost care. A marking error in the latter causes a measurement error that is equivalent to observing an incorrect point.
4. Measure and record pass and tie points with a photogrammetric plotter (including digital workstations) or a comparator. At least an inner orientation must be performed prior to measuring pass and tie points so that image coordinates of these points can be obtained. If the operator encounters difficulties in measuring some points, these difficulties should be documented. The operator may want to record supplemental points in areas where there are no well defined features or suitable image texture to be used for pass or tie point selection.

Measure and record ground control points. Ground control points are measured with the same stereo model setup or photograph measurements as for the pass and tie points.

5. Compute and adjust the aerial triangulation measurements. Check the results for possible measurement, marking, identification and control errors. If necessary, repeat some measurements and computations until the adjustments consist of only small random errors.
6. Prepare a report on the aerial triangulation results. The report should include the photogrammetric block layout and a diagram showing the location and names of all the points that participated in the adjustment. Erroneous points that were removed from the computation or had to be measured again should be listed. The results of the computations and an accuracy analysis of final adjustment with respect to the project specifications are to be documented as well.

### **7.4.5 Stereo Compilation**

The use of mostly CAD based digital mapping software have simplified the manuscript preparation, editing and error checking of the stereo compilation process. The stereo compilation process is as follows:

1. Select models to be used for mapping. The selection should include a layout of what areas are to be mapped from which stereo model. Mapping from the fringes of the stereo model is usually less accurate than at the center. Therefore, the operator should be instructed on the limits of stereo model that should be used for mapping.
2. Set up the stereo models by performing interior and exterior orientations.
3. Compile the planimetric features according to the project specifications. The specifications should be clear in terms of what features are to be mapped and their graphic representation in terms of color, shape, symbol, and other attributes.
4. Compile elevation features as contours or spot elevation. Contours should be compiled according to the specified contour interval. Nowadays, contouring is performed by interpolating a DEM, instead of plotting them directly from a stereo model. DEM must be comprised of spot elevations (regularly or irregularly spaced) and breaklines. A DEM that does not include breaklines will probably produce unacceptable contouring accuracy.
5. Inspect the map for completeness, consistency and accuracy. The purpose of inspecting the map for completeness is to verify that all the required features have been mapped. Modern photogrammetric plotters have a capability of superimposing the map on the photographic image so that both of them can be viewed simultaneously with correct spatial registration. This superimposition makes it very easy to perform the completeness inspection. The stereo model is visually checked for required features and the features can be immediately verified.

Consistency and accuracy inspection is performed to verify that the features are mapped in the correct location with the correct attribute. For example, a line representing a sidewalk should correspond to an actual sidewalk and it should spatially coincide with the image of the sidewalk in the stereo model. This inspection is important, especially for features that are mapped from more than one stereo model since, for example, a road can span over several stereo models. One has to make sure that features are mapped continuously and accurately.

6. Edit the map and make the necessary corrections.

### **7.4.6 Field Completion**

Photogrammetry can be used for mapping only what is visible on the photographs. Thus, if important features are obscured by trees, man-made structures or steep topography, they cannot be mapped. Therefore, a field completion activity has to take place to map the missing features. The field completion phase of the project should be used for accuracy testing of the map.

### **7.4.7 Drafting**

Drafting of photogrammetrically derived maps is performed with CAD software. It consists of the following:

- Sheet Layout
- Sheet Format
- Scale Change
- Edit and Final Corrections

All of these parameters should be part of the project specifications and should be performed accordingly.

### **7.4.8 Quality Control**

A final report on the quality and accuracy of the maps should accompany the submission of the final product. The report should review the accuracy of the control, as described in sections 7.4.3 and 7.4.4. The procedure used to determine the map's spatial and content accuracy should be documented as well. A statement, such as "this map meets the National Map Accuracy Standards" or "this map meets the project requirements", is unacceptable. Any claim of accuracy or standard must be substantiated by an actual test and analysis. The testing methodology used and the findings of its implementation should be documented in a final report.

## **7.5 Orthophotos**

### **7.5.1 General**

An orthophoto is an aerial image that has been rectified so that it possesses characteristics of a line map. The rectification process is performed by combining photogrammetric principles with digital elevation model (DEM) data. Orthophotos have been used for many years by a diverse group of users. Recently, orthophotos have been re-discovered by GIS/LIS users and are rapidly becoming a leading form of base maps.

### **7.5.2 Aerial Photograph vs. Orthophoto**

An aerial photograph does not have a constant scale throughout the entire image; therefore, it cannot be used as a map. The scale of an aerial photograph is defined as the ratio between the focal length of the camera and the height of the camera above the surface (topography). This scale is correct only for one point in the entire image (usually somewhere around the center of the photograph). All other points (or features) have different scales caused by the perspective nature of the image, by the tilt of the camera at the instance of exposure and by changes in elevation. A feature, such as a tall building, will also have shape distortion because the top of the feature will have a larger scale than the bottom of it. In addition, the sides of the building, which are not supposed to be mapped, will show on a photograph.

An orthophoto is a picture of the ground prepared in such a manner that all of these scale and shape distortions have been removed. In the past, orthophotos were produced with a specially outfitted photogrammetric stereo plotter. With the advent of digital photogrammetric methods, an orthophoto can now be produced, even on a desktop PC, provided that appropriate software and data are available. An orthophoto is produced by computing the scale and position distortions of each pixel of the aerial photograph, re-scaling and re-positioning the pixels in a new computer generated image. This process is called *differential rectification*. Orthophotos that are produced from, and saved as, digital images are sometimes called *digital orthophotos*.

### **7.5.3 Advantages of Orthophotos**

Orthophotos have several advantages over a typical planimetric map:

1. An orthophoto has map-like characteristics, while preserving the pictorial image. A major drawback of a map is that it shows only what the mapper decided to include. For example, if the client was not interested in trees they will not be shown on the map, except for those that the surveyors or the photogrammetrist decided to include. If a hut was left out during data collection, it will not appear on the map. However, if the map is a picture, this problem does not exist. Whatever exists on the ground and is large enough to be recorded on the image, will automatically be mapped. One does not have to decide in advance (usually a budget constrained decision) what features should be mapped. Everything is mapped by default for the same price.
2. Speed of production, which becomes more evident when maps have to be revised or updated.
3. Cost. They are less expensive, especially when a DEM for the project area is available.
4. Hard and soft copy products.

5. GIS compatible. Almost all GIS software can integrate digital orthophotos into a project.
6. Cartographic overlay can be added to enhance interpretability.
7. Ability to perform change analysis by comparing images from before and after.
8. Use of wider sensing spectrum, such as infrared for special studies.
9. Mapping inaccessible areas, such as contaminated areas.

#### **7.5.4 Disadvantages of Orthophoto**

Orthophotos have several disadvantages as well:

1. In order to produce a very accurate orthophoto one needs to know not only the elevation of the surface (topography) but also the height of every feature (buildings, trees etc.) above that surface. Otherwise, these features will be positioned incorrectly on the orthophoto.
2. Missing images of obstructed features. Let us assume that the elevation of every pixel on a building is known and that the building was rectified correctly (the pixels were relocated to their proper locations). The problem is how to map the area that was obscured by the building (i.e. the street segment behind the building), which has now no available images. One needs to search for additional information and somehow blend it into the orthophoto.
3. While the pictorial images present all the existing features on the ground, their interpretation and classification could be difficult at times. A map with a clear legend is more easily understood and interpreted than a picture. Thus, an added cost of a cartographic enhancement becomes imperative.

#### **7.5.5 Digital Orthophoto Production**

The production of digital orthophotos has many steps in common with photogrammetric mapping. These steps are:

1. Project and flight mission planning.
2. Image acquisition with precise aerial cameras.
3. Film processing, annotation etc.
4. Image scanning.

## 5. Control points and aerial triangulation.

Details on these operations have been discussed earlier in this chapter. Procedures that are specific for orthophotos are:

### 1. Image rectification

In order to correct scale distortions resulting from the perspective projection of an image, the elevation of each pixel must be known. The pixel elevation is interpolated from a Digital Elevation Model (DEM). There are several sources for DEM data. They vary mainly by cost and accuracy of data compilation. The most accurate source for elevation is from field surveys. But the cost associated with developing a DEM (even for a small project) from field surveys is prohibitive to most users. A more common source for DEM is photogrammetry. One should note that the same photographs that are used for the aerial triangulation could also be used for developing the DEM. Other methods for deriving DEM's are kinematic GPS or digitizing contours from topographic maps. DEM data for small scale applications is also available from USGS. The decision on which DEM to use depends on the scale of the orthophoto. Small scale orthophotos can use less accurate DEM (i.e. USGS data), while large scale orthophotos require a more accurate DEM (i.e. photogrammetry). One should note that DEM data has a much longer "shelf life" than planimetric data. Thus, a good DEM could be reused for several cycles of orthophoto production.

When all the data (image, orientation and DEM) is available, each (digital) photograph, or part of it, is rectified individually using a special software. A single rectified photograph usually covers only a small portion of the entire orthophoto project. Thus, a mosaicing process becomes necessary. Mosaicing is the process of piecing together multiple image patches into a seamless and continuous orthophoto. Some of the technical difficulties of this matching process are:

### 2. Mosaicing and Image Enhancement

**Spatial continuity or edge matching** – Features that appear on more than a single image patch must be continuous. For example, a road must form a continuous line and show no jumps at the original photo edges where the images are connected.

**Radiometric consistency** – Different photographs may have different contrast and brightness resulting from lack of uniform conditions during the photographic processing, image scanning or from changes in illumination conditions. For example, a lake could appear as white in one image, because of the reflection of the sun, and black on another image, where there is no reflection. This must be corrected during the mosaicing process.

### 3. Quality Control

The quality control involves inspecting the orthophoto for incorrect rectification, image matching problems, and missing images due to hidden ground problems.

### 4. Output Design and Cartographic Enhancement.

Output design and cartographic enhancement consists of formatting the image and enhancing it by adding:

- line information that either appears fuzzy or does not exist on the image (for example, parcel boundaries)
- area (polygon) information (for example shading a park area)
- a contour layer to show hypsography (relief features)
- coordinate graticules and North arrow
- annotation (text and symbols)
- legend, product information etc.

## **7.5.6 Accuracy and Quality Issues**

The elements that contribute errors to an orthophoto product are:

1. Camera (characteristics and calibration)
2. Scanner (characteristics calibration and resolution or image scale)
3. Ground control (accuracy, distribution, and abundance)
4. Aerial triangulation (design, measurement, and computation)
5. Digital Elevation Modeling(DEM)-(method of compilation; quality of the source material; characteristics of the terrain; sampling spacing, with or without breaklines; type of breaklines used; method of interpolation into pixel grid and availability of height information on or above surface features, such as buildings.)
6. Rectification process (method and software). When all of these errors are propagated and summed up following a valid error theory methodology, one can assess the spatial accuracy of the final product.

Image quality issues of orthophotos are:

1. Pictorial defects caused by orthophoto production:
  - Contrast and brightness differences resulting mainly from the mosaicing process.
  - Dirt and scratching marks that appear on the image resulting from inappropriate handling of the film during the lab processing or during the scanning process.

2. Image defects caused by inaccurate DEM:

- Missing images
- Image blurring
- Double image
- Discontinuities of features

The ground resolution of each pixel and the added impact of the above errors define the spatial accuracy of the orthophoto. To assess that accuracy, one should test it with the same procedure used for line maps.

**Additional reading and information on orthophoto on the Web:**

<http://www.esri.com/base/common/userconf/proc95/to150/p124.html>

<http://www.sgi.ursus.maine.edu/gisweb/spatdb/gis-lis/gi94093.html>

<http://www-nmd.usgs.gov/metadata/doq.html>

## **APPENDIX A**

### **New Jersey Statutory and Administrative Laws on Surveying**

**13:9A - 1. Legislative intent; inventory and mapping of tidal wetlands; filing in office of county recording officer**

a. The Legislature hereby finds and declares that one of the most vital and productive areas of our natural world is the so-called "estuarine zone," that area between the sea and the land; that this area protects the land from the force of the sea, moderates our weather, provides a home for water fowl and for 2/3 of all our fish and shellfish, and assists in absorbing sewage discharge by the rivers of the land; and that in order to promote the public safety, health and welfare, and to protect public and private property, wildlife, marine fisheries and the natural environment, it is necessary to preserve the ecological balance of this area and prevent its further deterioration and destruction by regulating the dredging, filling, removing or otherwise altering or polluting thereof, all to the extent and in the manner provided herein.

b. The Commissioner of Environmental Protection shall, within 2 years of the effective date of this act, make an inventory and maps of all tidal wetlands within the State. The boundaries of such wetlands shall generally define the areas that are at or below high water and shall be shown on suitable maps, which may be reproductions or aerial photographs. Each such map shall be filed in the office of the county recording officer of the county or counties in which the wetlands indicated thereon are located. Each wetland map shall bear a certificate of the commissioner to the effect that it is made and filed pursuant to this act. To be entitled to filing no wetlands map need meet the requirements of R.S. 47:1-6.

L.1970, c. 272, § 1, eff. Nov. 5, 1970.

**Historical Note**

**Title of Act:**

An Act concerning the protection of natural resources in coastal wetlands, providing for the designation by the Commissioner of Environmental Protection of

certain coastal wetlands after public hearing, and requiring from the commissioner prior to the dredging, removing, filling or otherwise altering or polluting coastal wetlands. L.1970, c. 272.

ARTICLE 3D. ENTRY UPON EASEMENTS AND RIGHTS OF WAY

**48:3-17.9. Definitions**

As used herein:

- (a) "Public utility" means any public utility defined in 48:2-13;
- (b) "Right-of-way" means the area devoted to passing over, on, through or under lands with utility plant facilities as part of a way for such purpose;
- (c) "Easement" means privileges essential or appurtenant to the enjoyment of a right-of-way; and
- (d) "Emergency" means any time a public utility service is interrupted or in immediate danger of being interrupted by the elements or by any other cause or when the condition of the equipment of the public utility is in need of immediate repair to prevent injury to persons, or damage to property.

L.1969, c. 182. § 1.

**48:3-17.10. Notice to landowner before entry**

It shall be unlawful for any public utility to enter upon any lands in which it has acquired an easement or right-of-way, for the purpose of erecting, installing, moving, removing, altering or maintaining any structures or fixtures thereon, other than structures or fixtures owned by the public utility, or for the purpose of maintaining such easement or right-of-way by cleaning moving, cutting or destroying any trees, shrubs, plants or other growth thereon unless and until not less than 5 days' notice of such entry shall be given to the owner of the lands subject to such easement or right-of-way personally or by certified or registered mail addressed to the owner at his address as shown by the assessment records of the municipality in

which the land is situate, but nothing herein shall prohibit entry without notice in any case

- (a) Of an emergency, or
  - (b) Where such notice is waived by the owner, or
  - (c) Where the easement or right-of-way contains an express provision permitting entry without notice or upon notice of a lesser period of time, which is complied with,
- or
- (d) Where the owner consents to the entry of the public utility for such purposes, or
  - (e) Where the structure, fixture, tree, shrub, plant or other growth, or portion thereof, to be dealt with as aforesaid, is located over, on, through or under any public street, road, highway or other public thoroughfare.

L1969, c. 182, § 2.

## **27:7-21. Additional powers of commissioner**

In addition to, and not in limitation of, his general powers, the commissioner may:

- a. Determine and adopt rules, regulations and specifications and enter into contracts covering all matters and things incident to the acquisition, improvement, betterment, construction, reconstruction, maintenance and repair of State highways;
- b. Execute and perform as an independent contractor or through contracts made in the name of the State, all work incident to the maintenance and repair of State highways;
- c. Establish and maintain as an independent contractor or employer a patrol repair system for the proper and efficient maintenance and repair of State highways;
- d. Employ and discharge, subject to the provisions of the Civil Service law, all foremen and laborers, prescribe their qualifications and furnish all equipment, tools and material necessary for such patrol repair system;
- e. Widen, straighten and regrade State highways;
- f. Vacate any State highway or part thereof;
- g. The commissioner and his authorized agents and employees may enter upon any lands, waters and premises in the State, after giving written notice to the recorded owner at least three days prior thereto, for the purpose of making surveys, soundings, drillings, borings and examinations as he may deem necessary or convenient for the purposes of this Title, and such entry shall not be deemed a trespass; nor shall such entry be deemed an entry under any condemnation proceedings which may be then pending. The commissioner shall make reimbursement for any actual damages resulting to such lands, waters and premises as a result of such activities;
- h. Enter into cooperative agreements with any State department, agency or authority or any county or municipality enabling the State to negotiate for and condemn lands and also provide relocation services and payments deemed necessary for the effectuation of State or federally financed State Aid Transportation and related Programs;
- i. Enter into agreements with the New Jersey Turnpike Authority with respect to the funding of the resurfacing, restoring, rehabilitation and reconstructing of the I-95 Extension of the New Jersey Turnpike through the allocation of monies apportioned by the United States Department of Transportation pursuant to 23 U.S.C. s.119 or a successor program. Any such agreement shall be subject to the continued eligibility of the I-95 Extension for federal aid, the availability of funds appropriated by Congress and the appropriation of funds by the Legislature for that purpose. No such agreement shall constitute or create a debt or liability of the State within the meaning of any constitutional or statutory limitation nor shall any such agreement constitute a pledge of either the faith and credit or the taxing power of the State; and
- j. Do whatever may be necessary or desirable to effectuate the purposes of this Title.

Amended 1967,c.174; 1972,c.56; 1991,c.183,s.2.

**Assembly Higher Education and Regulated Professions Committee Statement**  
**Assembly, No. 5048-L. 1989. c. 276**

The Assembly Higher Education and Regulated Professions Committee favorably report Assembly Bill No. 5048 with amendments.

As amended by committee, this bill changes certain of the provisions regarding the practice of engineering by expanding and revising the definition of professional engineering. The bill also expands the definition of "responsible charge" and permits the State Board of Professional Engineers and Land Surveyors to issue certificates of authorization to certain corporations for the provision of engineering and land surveying services. The certificate of authorization shall designate a New Jersey licensee or licensees who are in responsible charge of the engineering or land surveying activities and decisions of the corporation. All final drawings, papers or documents involving the practice of engineering or the practice of land surveying, when issued by the corporation or filed for public record, shall be signed and sealed by the New Jersey licensee who is in responsible charge of the work.

The bill also provides for review of complaints to the Joint Committee of Architects and Engineers, which is to be established by a companion bill the "Building Design Services Act," of 1989. Under the provisions of that bill, the board:

(1) May refer any complaint, question or controversy involving the application of that act to the joint committee.

(2) Shall take no disciplinary action against any licensed architect alleged to have engaged in a violation of that act or the unlicensed practice of engineering.

(3) Shall refer a request for a disciplinary ruling to the joint committee.

(4) Shall provide any and all documents in its possession regarding any matter referred to the joint committee.

(5) Shall, when necessary and appropriate, exercise the investigation or enforcement powers conferred by law to aid and assist the joint committee in its functions.

(6) Shall discipline any unlicensed individual who, or unauthorized business association which, designs an engineering work in violation of that act. Such a violation shall be deemed the unlicensed practice of engineering. Any other violation of that act by an unlicensed individual or business association shall be disciplined by the New Jersey State Board of Architects. Such a violation shall be deemed the unlicensed practice of architecture.

The bill also repeals section 18 of P.L.1938, c. 342 (C. 45:8-44) which provided that all licensed land surveyors must maintain a place of business with a conspicuous sign including his name, address and the designation "Licensed Land Surveyor."

The committee amended the bill to delete a partnership of certified landscape architects as one of the groups eligible to offer engineering services under the bill's provisions. The committee also made a variety of technical amendments to the bill.

**Historical and Statutory Notes**

**1989 Legislation**

Section 13 of L.1989, c. 276, approved Jan. 9, 1990, provides:

"This act shall take effect immediately but shall remain inoperative until 120 days following the enactment into law of P.L.1989, c. 275 (C.....) and P.L.1989, c. 277 (C. 45:4B-1 et seq.). [Both approved Jan. 8, 1990]"

**Administrative Code References**

Board of professional engineer-, and land surveyors, see N.J.A.C. 13:40-1.1 et seq.

Contract requirement, see N.J.A.C. 13:40- 1 0. 1.

**Notes of Decisions**

**2. Obligation to obtain license**

Licenses to practice professional engineering or professional land surveying are required as a matter of public policy of state. Hyland v. Ponzio, 159 N.J.Super. 233, 387 A.2d 1206 (A.D.1978).

#### **45:8-28. Definitions**

2. (a) The term "professional engineer" within the meaning and intent of this chapter shall mean a person who by reason of his special knowledge of the mathematical and physical sciences and the principles and methods of engineering analysis and design, acquired by professional education and practical experience, is qualified to practice engineering as hereinafter defined as attested by his license as a professional engineer.

(b) The terms "practice of engineering" or "professional engineering" within the meaning and intent of this chapter shall mean any service or creative work the adequate performance of which requires engineering education, training, and experience and the application of special knowledge of the mathematical, physical and engineering sciences to such services or creative work as consultation, investigation, evaluation, planning and design of engineering works and systems, planning the use of land and water, engineering studies, and the administration of construction for the purpose of determining compliance with drawings and specifications; any of which embraces such services or work, either public or private, in connection with any engineering project including: utilities, structures, buildings, machines, equipment, processes, work systems, projects, telecommunications, or equipment of a mechanical, electrical, hydraulic, pneumatic or thermal nature, insofar as they involve safeguarding life, health or property, and including such other professional services as may be necessary to the planning, progress and completion of any engineering services. The design of buildings by professional engineers shall be consistent with section 7 of the "Building Design Services Act," P.L.1989, c.277 (C.45:4B-7).

The practice of professional engineering shall not include the work ordinarily performed by persons who operate or maintain machinery or equipment. The provisions of this chapter shall not be construed to prevent or affect the employment of architects in connection with engineering projects within the scope of the act to regulate the practice of architecture and all the amendments and supplements thereto.

A person shall be construed to practice or offer to practice engineering, within the meaning and intent of this chapter, who practices any branch of the profession of engineering; or who, by verbal claim, sign, advertisement, letterhead, card, or in any other way represents himself to be a professional engineer, or through the use of some other title utilizing or including the word engineer, implies that he is a professional engineer; or who represents himself as able to perform, or who does perform any engineering service or work or any other professional service recognized by the board as professional engineering.

Nothing herein shall prohibit licensed architects from providing or offering services consistent with the "Building Design Services Act," P.L.1989, c.277 (C.45:4B-1 et seq.).

(c) The term "engineer-in-training" as used in this chapter shall mean a person who is a potential candidate for license as a professional engineer who is a graduate in an approved engineering curriculum of four years or more from a school or college accredited by the board as of satisfactory standing, and who, in addition, has successfully passed an examination in the fundamental engineering subjects, as defined elsewhere herein.

(d) The term "land surveyor" as used in this chapter shall mean a person who is a professional specialist in the technique of measuring land, educated in the principles of mathematics, the related physical and applied sciences, and the relevant requirements of law, all requisite to the practice of land surveying as attested by his license as a land surveyor.

(e) The term "practice of land surveying" within the meaning and intent of this chapter shall mean any service or work the adequate performance of which involves the application of special knowledge of the principles of mathematics, the related physical and applied sciences and the relevant requirements of law to the act of measuring and locating distances, directions, elevations, natural and man-made topographical features in the air, on the surface of the earth, within underground workings, and on beds of bodies of water for the purpose of determining areas and volumes, and for the establishing of horizontal and vertical control as it relates to construction stake-out, for the monumentation of property boundaries and for the platting and layout of lands and subdivisions thereof and for the preparation and perpetuation of maps, record plats, field notes, records and property descriptions in manual and computer coded form that represent these surveys. The practice of land surveying shall include the establishment and maintenance of the base mapping and related control for land information systems that are developed from the above referenced definition of the practice of land surveying.

For purposes of this subsection, "land information systems" means any computer coded spatial database designed for multi-purpose public use developed from or based on property boundaries.

A person who engages in the practice of land surveying; or who, by verbal claim, sign, advertisement, letterhead, card or in any other way represents himself to be a land surveyor or professional surveyor; or who represents himself as able to perform any land surveying service or work or any service which is recognized as within the practice of land surveying shall be deemed to practice or offer to practice land surveying.

Nothing in this chapter shall preclude a person licensed by the board as a professional engineer from performing those measurements necessary for the design, construction stake-out, construction and post-construction records of an engineering project, provided that these measurements are not related to property lines, lot lines, easement lines, or right-of-way lines, the establishment of which are required to be made by a land surveyor.

(f) The term "board" as used in this chapter shall mean the State Board of Professional Engineers and Land Surveyors.

(g) The term "responsible charge" as used in this chapter shall mean the rendering of regular and effective supervision by a competent professional engineer or land surveyor to those individuals performing services which directly and materially affect the quality and competence of the professional services rendered by the licensee. A licensee engaged in any of the following acts or practices shall be deemed not to have rendered regular and effective supervision:

(1) The regular and continuous absence from principal office premises from which professional services are rendered, except for performance of field work or presence in a field office maintained exclusively for a specific project;

(2) The failure to personally inspect or review the work of subordinates where necessary and appropriate;

(3) The rendering of a limited, cursory or perfunctory review of plans or projects in lieu of an appropriate detailed review;

(4) The failure to personally be available on a reasonable basis or with adequate advance notice for consultation and inspection where circumstances require personal availability.

(h) The term "certificate of authorization" shall mean a certificate issued by the board pursuant to this amendatory and supplementary act.

(i) The term "joint committee" shall mean the Joint Committee of Architects and Engineers established pursuant to the "Building Design Services Act," P.L.1989, c.277 (C.45:4B-1 et seq.).

(j) The term "closely allied professional" as used in this chapter shall mean and is limited to licensed architects, professional engineers, land surveyors, and professional planners.

(k) The term "telecommunications" as used in this chapter, shall mean, as it is applied to the practice of engineering, subjects which deal with the generation, transmission, receiving, and processing of information bearing signals for the purpose of fulfilling a particular communication need. The most

common forms of signals are those encountered in voice, image and data transmission. Subjects relevant to telecommunications include but are not limited to: analog and digital circuits, propagation of electromagnetic energy through guided media such as a transmission line, fibers, wave guides, and unguided media such as free space as in broadcast and mobile communication systems, communication theory, including modulation, noise interference, and the interface with computers.

(l) The term "surveyor-in-training" as used in this chapter shall mean a person who is a potential candidate for licensure as a land surveyor, who is a graduate in an approved surveying curriculum of four years or more from a school or college accredited by the board as of satisfactory standing, and who, in addition, has successfully passed an examination in the fundamental surveying subjects, approved by the board pursuant to section 9 of P.L. 1938, c.342 (C.45:8-35).

L.1938,c.342,s.2; amended 1950,c.149,s.2; 1970,c.177,s.2; 1977,c.340,s.1; 1989,c.276,s.2; 1992,c.64,s.1.

#### **45:8-39. Practice without license and other violations; penalties; actions for penalties**

13. a. Any person who, hereafter, is not legally authorized to practice professional engineering or land surveying in this State according to the provisions of this act, who shall so practice or offer so to practice in this State, except as provided in section 14 of this act, or any person presenting or attempting to file as his own the certificate of license of another, or who shall give false or forged evidence of any kind to the board, or to any member or representative thereof, in obtaining a certificate of license, or who shall falsely impersonate another licensed practitioner of like or different name, or who shall use or attempt to use an expired certificate of license, an unexpired and revoked certificate of license, or a certificate of license which is on a retired status list, or who shall use either the title "Engineer-in-Training" or "Surveyor-in-Training" without holding a valid certificate of registration issued by the board, or who shall otherwise violate any of the provisions of this act, shall be subject to a penalty of not more than \$200.00 for the first offense and not more than \$500.00 for each and every subsequent offense. The penalties provided for by this section shall be sued for and recovered in civil actions by the State Board of Professional

Engineers and Land Surveyors.

b. Pursuant to the provisions of the "Building Design Services Act," P.L.1989, c.277 (C.45:4B-1 et seq.) the board:

(1) May refer any complaint, question or controversy involving the application of that act to the joint committee.

(2) Shall take no disciplinary action against any licensed architect alleged to have engaged in a violation of that act or the unlicensed practice of engineering.

(3) Shall refer a request for a declaratory ruling to the joint committee.

(4) Shall provide any and all documents in its possession regarding any matter referred to the joint committee.

(5) Shall, when necessary and appropriate, exercise the investigation or enforcement powers conferred by law to aid and assist the joint committee in its functions.

(6) Shall, consistent with that act, discipline any professional engineer who, or business association authorized to offer engineering services which, violates that act. Such a violation shall be deemed professional misconduct. Any violation of that act by an unlicensed individual or unauthorized business association shall be disciplined by the New Jersey State Board of Architects pursuant to the provisions of P.L.1978, c.73 (C.45:1-14 et seq.). Such a violation shall be deemed the unlicensed practice of architecture. However, the design of an engineering work by an unlicensed individual or unauthorized business association shall be disciplined by the State Board of Professional Engineers and Land Surveyors pursuant to the provisions of P.L.1978, c.73 (C.45:1-14 et seq.). Such a violation shall be deemed the unlicensed practice of engineering.

c. No person, firm, partnership, association or corporation shall bring or maintain any action in the courts of this State for the collection of compensation for services constituting the practice of engineering or land surveying without alleging and proving that he was duly licensed in accordance with this chapter at the time the alleged cause of action arose.

d. The Superior Court shall have jurisdiction of actions for penalties under this act.

L.1938,c.342,s.13; amended 1947,c.60,s.2; 1950,c.149,s.13; 1952,c.129; 1953,c.43,s.38; 1970,c.177,s.3; 1989,c.276,s.4; 1992,c.64,s.4; 1995,c.36,s.2.

#### **45:8-40. Persons exempt**

The following shall be exempted from the provisions of this chapter:

(1) A person not a resident of and having no established place of business in this State, practicing or offering to practice herein professional engineering or land surveying within the meaning and intent of this chapter, when such practice does not exceed in the aggregate 30 consecutive days in any calendar year; provided, such person is legally qualified by license to practice said professional engineering or land surveying in any State or country in which the requirements and qualifications for a certificate of license are at least comparable to those specified in this chapter.

However, no final plans or reports may be submitted under this provision.

(2) A person not a resident of and having no established place of business in this State, or who has recently become a resident thereof, practicing or offering to practice herein for more than 30 days in any calendar year professional engineering or land surveying, if he shall have filed with the board an application for a certificate of license and shall have paid the fee required by this chapter; provided, that such a person is legally qualified to practice said professional engineering or land surveying in any State or country in which the requirements and qualifications for obtaining a license are at least comparable to those specified in this chapter. Such exemption shall continue only for such time as the board requires for the consideration of the application for license certificate.

(3) An employee or a subordinate of a person holding a license under this chapter or an employee of a person exempted from license by subsections (1) and (2) of this section; provided, this practice does not include responsible charge of design or supervision.

(4) Officers and employees of the Government of the United States while engaged within this State in the practice of professional engineering or land surveying, for said government.

(5) The practice of engineering or land surveying solely as an officer or employee of a corporation engaged in interstate commerce as defined in an act of Congress entitled "Act to regulate commerce," approved February 4, 1887, and as amended, unless the same affects public safety or health.

L.1938, c. 342, p. 866, s. 14. Amended by L.1950, c. 149, p. 327, s. 14; L.1977, c. 340, s. 5, eff. Jan. 25, 1978.

**45:8-41. Licensed engineers and surveyors on public contracts or works required**

Hereafter no county, city, town, township, village, borough or other municipal corporations or other Political subdivisions in the State shall engage in the design, construction or maintenance of any public work involving professional engineering for which plans, specifications and estimates have not been made by and the construction and maintenance supervised by a licensed professional engineer or a registered architect, nor shall any county, city, town, township, village, borough or other municipal corporation or other political subdivision in the State employ any person to perform work involving land surveying except a licensed land surveyor.

**45:8-43. Filing of name of engineer engaged by governmental departments; employment of engineers and land surveyors**

The clerk of such department, institution, commission, board or body of the State Government or of any political subdivision thereof shall file with the secretary-director of the State Board of Professional Engineers and Land Surveyors the name of any engineer designated, appointed or employed, within 30 days after appointment. Where professional engineers or land surveyors are employed, subject to the provisions of the civil service law, the appointment of any such person shall be understood to mean and include appointment after such person has been certified as having satisfactorily passed a civil service examination. No person, firm, association or corporation engaged in engineering or land surveying, shall employ an engineer or land surveyor, in responsible charge of any work, within the meaning and intent of this act, other than a duly qualified professional engineer or land surveyor, who has been licensed pursuant to the provisions of this chapter, prior to such employment by the person, firm, association or corporation so engaged in engineering or land surveying; provided, however, that nothing in this chapter shall apply to any public utility as defined in chapter 2 of Title 48 of the Revised Statutes, or any employee thereof or to any improvement or proposed improvement made by any such public utility or by any employee of or any contractor or agent for said public utility.

Nothing in this chapter shall apply to a corporation or any of its affiliated companies any of which are in the field of telecommunications or any employee thereof where either said corporation or any of its affiliated companies is subject to the jurisdiction of the State Board of Public Utilities or the Federal Communications Commission.

Nothing in this chapter shall apply to a corporation in the field of telecommunications, or to its affiliates, or any employees thereof in which the primary business is research and technical development manufacturing or product design.

L.1938, c.342, s.17; amended 1950,c.149,s.17; 1989,c.276,s.6.

**Historical and Statutory Notes**

**1989 Legislation**

L-1989. c. 276 operative 120 days after Jan. 8, 1990. see Historical and Statutory Notes under § 45:8-27.

**Statement:** Committee statement to Assembly, No. 5048-L.1989. c. 276, see 1 45:8.27.

**45:8-44. Repealed by L.1989, c. 276, § 12, eff. Jan. 8, 1990**

**Historical and Statutory Notes  
1989 Legislation**

L.1989. c. 276 operative 120 days after Jan. 8, 1990,  
see Historical and Statutory Notes under § 45:8-27.

**Statement:** Committee statement to Assembly,  
No. 5048-L.1999, c. 276, see § 45:8-27.

**45:8-44.1. Authority of land surveyors to go on, over and upon lands of others during reasonable hours**

A person licensed to practice land surveying as provided in P.L.1938. c. 342 (C. 45:8-27 et seq.) and any of his agents, servants or employees under his direction who are necessary to make a land survey shall have the authority to go on, over and upon lands of others during reasonable hours when necessary to make land surveys if:

a. The licensed professional land surveyor has made a reasonable attempt, as defined in this section, to notify the owner of the land and, in the case of a lease, the lessee thereof, of his desire to enter on, over and upon the owner's or lessee's land to make a land survey and, the attempt having failed, the licensed professional land surveyor has given written notice, seven days prior to the proposed entry, to the municipal police department of the municipality in which the land is located of his intention to enter, containing the names, addresses, and telephone numbers of those who propose to enter the land and the date, time, duration, and location of the proposed entry; and

b. The land or any part thereof, to which entry is sought, is not enclosed by a constructed or natural barrier which is at least 6 feet in height or is not posted with signs or notices which prohibit trespassing and contain the name and address of the owner or lessee of the land;

c. As used in this section a "reasonable attempt" to notify an owner or lessee means: an attempt to seek acknowledgment of the owner of the land and, in the case of a lease, the lessee thereof, by certified mail, return receipt requested, the attempt to be made a second time if unsuccessful the first time and a third time if unsuccessful the second time, each attempt to be made on a separate business day.

L.1983, c. 460, § 1, eff. Jan. 12, 1984.

**Historical and Statutory Notes**

**Title of Act:**

An Act authorizing licensed professional land surveyors to enter lands of third parties under certain circumstances. L.1983, c. 460.

**45:8-45 Certificate and seal of licensed engineer, surveyor or architect on plans and specifications on public work**

No department, institution, commission, board or body of the State Government, or any political subdivision thereof, being the depository or having the custody of any plan or specification involving professional engineering, shall receive or file any such plan or specification unless there is affixed thereto the seal of a professional engineer licensed pursuant to the provisions of this chapter, or the seal of a registered architect thereon nor receive or, file any plan involving land surveying unless there is affixed thereto the seal of a land surveyor licensed pursuant to this chapter.

L.1938, c. 342, p. 869, § 19. Amended by L.1950, c. 149, p. 330, § 18.

**Historical Note**

The 1950 amendment omitted the words "involving professional engineering" following the words "plan or specification", substituted "unless there is affixed thereto the seal" for "unless there shall be attached there to the

certificate and seal", and omitted the words "or specification" following the words "file any plan" and preceding the words "involving land surveying".

**46:23-9.14. Prerequisites to filing**

The county recording officer shall not accept for filing any map unless it has endorsed thereon a certificate signed and sealed with the municipal seal by the municipal.. clerk or secretary of the planning board as the case may be, stating that the proper authority has approved the map or stating its exemption from approval which certificate shall state that said map complies with the provisions of this law and shall designate the day on or before which said map is required to be filed by the provisions of the applicable law and provided that said map is filed on or before said designated day.

**47:1-6. Maps; requirements prerequisite to filing In certain offices**

No map, plat, plan or char-t of lands, required or that may be required by law to be filed, or that may be presented to the clerk of the County Court, register of deeds and mortgages or surrogate in any county of this State, shall be received for filing unless the same shall be made upon translucent tracing cloth, with fast colored, waterproof ink and be accompanied by a cloth print duplicate.

Amended by L1953, c. 45, p. 828, § 2, eff. March 19, 1953.

**Historical Note**

Source: L1914, c. 12, § 1, p. 25 [1924 Suppl. § 44-98d].

The 1953 amendment substituted " county court" for "court of common pleas."

#### **46:23-9.15. Filing and indexing of maps, fee**

The county recording officer of each county shall, when received by him for that purpose in accordance with the provisions of this law file in folios, slides, cabinets or other receptacles, maps of land lying in whole or in part in the county where the same are offered to be filed; provided that he shall retain the original tracing on translucent tracing cloth or its equivalent unmounted in an appropriate file or container, for preservation and use for reproduction purposes only, prints of which may be made available to the public at a reasonable cost. He shall endorse on the tracing and cloth print duplicate the date of the filing thereof in his office, and he shall provide and keep a proper index of all maps on file in his office. The county recording officer shall, for filing and indexing each map receive such fee as may be provided by law, except that when any map shall be presented for filing by the State of New Jersey, or any of its agencies no fee shall be charged for the filing thereof.

L.1960, c. 141, p. 669, § 7, eff. Jan. 1, 1961.

#### **Historical Note**

**Prior Laws:** C. 46:23-9.6 (L.1953, c. 358, p. 1941, § 6).  
R.S. 46:23-9.

L.1910, c. 83, § 1. p. 122 (C.S. p. 1574, § 118). L.1927, c. 54, § 1, p. 107.

## CHAPTER 218

### An Act concerning the official survey base of the State and amending R.S.51:3-7 and R.S.51:3-8.

BE IT ENACTED *by the Senate and General Assembly of the State of New Jersey*:

1. R.S.51:3-7 is amended to read as follows:

Official survey base established; plane co-ordinates.

51:3-7. The official survey base for New Jersey shall be a system of plane co-ordinates to be known as the New Jersey system of plane co-ordinates, said system being defined as a transverse Mercator projection of the Geodetic Reference System of 1980, having a control meridian 74° 30' west from Greenwich on which meridian the scale is set at one part in 10,000 too small. All co-ordinates of the system are expressed in meters, the x co-ordinate being measured easterly along the grid and the y co-ordinate being measured northerly along the grid, the origin of the co-ordinates being on the meridian 74° 30' west from Greenwich at the intersection of the parallel 38° 50' north latitude, such origin being given the co-ordinates x = 150,000 meters; y=0 meters. The precise position of said system shall be as marked on the ground by triangulation or traverse stations established in conformity with the standards adopted by the National Geodetic Survey, formerly the United States Coast and Geodetic Survey for first and second-order work whose geodetic positions have been rigidly adjusted on the North American Datum of 1983 or the most recently published adjustment by the National Geodetic Survey, and whose plane co-ordinates have been computed on the system defined. The New Jersey co-ordinate system defined by the North American Datum of 1927 may be used concurrently with or in lieu of the system defined by the North American Datum of 1983 for a period of 36 months after the effective date of this amendatory act, P.L.1989, c.218.

Standard conversions from meters to feet shall be the adopted standards of the National Oceanic and Atmospheric Administration.

2. R.S.51:3-8 is amended to read as follows:

#### **Connecting property surveys with system of co-ordinate".**

51:3-8. Any triangulation or traverse station established as described in section 51:3-7 of this title shall be used in establishing a connection between a property survey and the above-mentioned system of rectangular co-ordinates.

3. This act shall take effect immediately.

Approved December 29, 1989.

### **51:3-9. Indorsement of surveys**

No survey of lands hereinafter made shall have endorsed thereon any legend or other statement indicating that it is based upon the New Jersey system of plane co-ordinates unless the co-ordinates have been established on that system as herein defined.

#### **Historical Note**

Source: I 1935, c. 116 § 3 p. 300.

### **51:3-10. Reliance wholly on system not required**

Nothing in this article contained shall be interpreted as requiring any purchaser or mortgagee to rely on a description based wholly upon the aforesaid system.

## **CHAPTER 118**

An Act concerning geodetic markers and information, supplementing P. L. 1966, c. 301 (C. 27:1-A-1 et seq.) and repealing P. L. 1938, c. 225 (C. 51:3-11 et seq.).

BE IT ENACTED *by the Senate and General Assembly of the State of New Jersey* :

#### **C. 27:1A-5.5 Transportation Department responsibility,**

1. The Commissioner of Transportation shall: a. receive, preserve and make available to engineers, surveyors and others all records related to bench marks, plane coordinate monuments and triangulation stations provided for by R. S. 51:3-7 to R. S. 51:3-10, inclusive; b. inspect periodically all these marks, monuments and stations, replacing any which may have been destroyed or establishing new ones in lieu thereof; and c. erect new marks, monuments and stations wherever he considers it to be in the public interest to do so.

The commissioner shall establish a schedule of fees to be charged for supplying copies of maps, diagrams and reports and for providing elevations of bench marks, positions of plane coordinate monuments or other geodetic data.

2. All files, books, papers and records of the Department of Environmental Protection relating to the functions, powers and duties assigned to that department by sections 1 and 2 of P. L. 1938, c. 225 (C. 51:3-11 and C. 51:3-12) shall, upon the effective date of this act, be transferred to the Department of Transportation.

Repealer.

3. P. L. 1938, c. 225 (C. 51:3-11 et seq.) is repealed.

4. This act shall take effect immediately.

Approved October 8, 1986.

**Senate State Government, Federal and Interstate Relations and Veterans'  
Affairs Committee Statement**

Assembly, No. 21-L.1989, c. 218

The Senate State Government, Federal and Interstate Relations and Veterans' Affairs Committee reports favorably and with committee amendments Assembly, No. 21.

This bill changes the system of plane coordinates which comprises the official survey base for the State. The plane coordinates system currently in use is a transverse Mercator projection of Clarke's spheroid of 1866, with a central meridian located 74° 40' west from Greenwich. Under the bill, the system will be a transverse Mercator projection of the Geodetic Reference System of 1980, with a central meridian located 74° 30' west from Greenwich. The bill also provides for the use of the North American Datum of 1983 or the most recently published adjustment by the National Geodetic Survey.

All coordinates of the system shall be expressed in meters rather than in feet. The bill revises the scale of the coordinate system from 1:40,000 (expressed in feet) to 1:10,000 (expressed in meters). It also provides that standard conversions from meters to feet shall be the adopted standards of the National Oceanic and Atmospheric Administration.

#### COMMITTEE AMENDMENTS

The committee amended the bill to correct the reference to the Geodetic Reference System of 1980 and to provide that the New Jersey coordinate system defined by the North American Datum of 1927 may be used concurrently with or in lieu of the system defined by the North American Datum of 1983 for a period of 36 months after the effective date of this act.

**46:23-9.9.** Short title

**This act shall be known and may be cited as "the map filing law."**

L.1960, c. 141, p. 662, s. 1, eff. Jan. 1, 1961.

**46:23-9.10 Definitions.**

2. Definitions. As used in this act:

a. "Map" means a map, plat, condominium plan, right of way parcel maps of the State, county or municipality, chart, or survey of lands presented for approval to the proper authority as hereinafter defined or presented for filing in accordance with the provisions of this act, but does not mean a map, plat or sketch required to be filed or recorded under the provisions of P.L.1957, c.130 (C.48:3-17.2).

b. "Municipal Engineer" means the official licensed professional engineer appointed by the proper authority of the municipality wherein the territory shown on a map is situate.

c. The term "Professional Engineer" within the intent of this act shall mean a person, who is qualified to practice professional engineering and as attested by his license as a professional engineer as provided by subsection a. of section 2 of P.L.1938, c.342 (C.45:8-28).

d. The term "Land Surveyor" as used in this act shall mean a person who is qualified to practice land surveying, and as attested by his license as a land surveyor as provided by subsection d. of section 2 of P.L.1938, c.342 (C.45:8-28).

e. "Proper authority" means the chief legislative body of a municipality or any other agencies to whom the authority for the approval of maps may be duly designated by ordinance.

f. "Right of way parcel map" means any right of way property parcel map of the State, county or municipality which shows highways, roads or street takings and any associated easements.

g. "Entire tract" means all of the property that is being subdivided including lands remaining after subdivision.

h. "Condominium plan" means a survey of the condominium property in sufficient detail to show and identify common elements, each unit and their respective locations and appropriate dimensions, which shall be filed in accordance with the requirements of section 3 of P.L.1960, c.141 (C.46:23-9.11). A condominium plan shall bear a certification by a land surveyor, professional engineer or architect authorized and qualified to practice in this State setting forth that the plan constitutes a correct representation of the improvements described.

L.1960,c.141,s.2; amended 1997, c.211, s.1.

**46:23-9.11 Requirements for approval.**

3. Requirements for Approval.

All subdivision plats, both major and where required minor, right of way parcel maps of the State, county or municipality, shall be filed in accordance with the provisions of P.L.1960, c.141 (C.46:23-9.9 et seq.). Right of way parcel maps shall meet the requirements of subsections a. through d., subsections f. through i., subsection m. and paragraph 12 of subsection r. of this section. Minor subdivision maps shall meet the requirements of subsections a. through i., and k. through q., and subsection j. except for the outside tract line monuments, and paragraph 13 of subsection r. of this section.

A condominium plan shall be filed in accordance with the requirements of subsections a. through c., subsections f. through i., and subsection m. of this section.

No map requiring approval by law or that is to be approved for filing with a county recording officer, shall be approved by the proper authority unless it shall conform to the following requirements:

a. It shall be clearly and legibly drawn, and where required endorsed and presented either as an original drawing in black ink on translucent tracing cloth, translucent mylars at least 4 mils thick or its equivalent, of good quality, with signatures in ink, or as an equivalent reproduction on photographic fixed line mylar 4 mils thick with signatures in black ink or its equivalent and shall be accompanied by a cloth print or photographic fixed line mylar 4 mils thick duplicate thereof.

b. It shall be one of six standard sizes namely, 8 1/2" x 13", 30" x 42", 24" x 36", 11" x 17", 18" x 24" or 15" x 21" as measured from cutting edges. If one sheet is not of sufficient size to contain the entire territory, the map may be divided into sections to be shown on separate sheets of equal sizes, with references on each sheet to the adjoining sheets.

c. It shall show the scale, which shall be inches to feet and be large enough to contain legibly written data on the dimensions, bearings and all other details of the boundaries, and it shall also show the graphic scale.

d. It shall show the dimensions, square footage of each lot to the nearest square foot or nearest one hundredth of an acre, bearings and curve data to include the radius, delta angle, length of arc, chord distance and chord bearing sufficient to enable the definite location of all lines and boundaries shown thereon, including public easements and areas dedicated for public use. Non-tangent curves and non-radial lines shall be labeled. Right of way parcel maps shall show bearings, distances and curve data for the right of way or the center line or base line and ties to right of way lines if from a base line.

e. Where lots are shown thereon, those in each block shall be numbered consecutively. In municipalities where tax maps exist, block and lot designations shall conform therewith, if the

municipal regulations so require. In counties which have adopted or shall adopt the local or block system of indices pursuant to sections 46:24-1 to 46:24-22 of the Revised Statutes, it shall have delineated and shown thereon the block boundary or boundaries and designations established by the board of commissioners of land records of such counties respecting the territory intended to be shown on such map.

f. The reference meridian used for bearings on the map shall be shown graphically. The coordinate base, either assumed or based on the New Jersey Plane Coordinate System, shall be shown on the plat. A minimum of three corners distributed around the tract shall indicate the coordinate values.

g. All municipal boundary lines crossing or adjacent to the territory intended to be shown shall be shown and designated.

h. All natural and artificial watercourses, streams, shorelines and water boundaries and encroachment lines shall be shown. On right of way parcel maps all easements that affect the right of way shall be shown and dimensioned, including but not limited to slope easements and drainage.

i. All permanent easements shall be shown and dimensioned including but not limited to sight right easements and utility easements.

j. The map shall clearly show all monumentation as required by this act, including monuments found, monuments set, and monuments to be set. An indication shall be made where monumentation found has been reset. The outside tract line monuments of the original tract prior to any sectionalizing shall be set prior to the filing of the map and a certification added pursuant to subsection n. of this section. For purposes of this subsection "found corners" shall be considered monuments.

k. It shall conform to such other technical design controls as may be required by the provisions of local ordinances, including but not limited to minimum street widths, minimum lot areas and minimum yard dimensions and should be shown as a chart on the plat.

l. The name of the subdivision, name of the last property owner or owners, municipality and county shall be shown.

m. The date of the survey shall be shown and the map shall be in accordance with the minimum survey detail requirements as promulgated by the State Board of Professional Engineers and Land Surveyors.

n. There shall be endorsed thereon a certificate of a land surveyor, as follows:

I hereby certify that to the best of my knowledge and belief this map and land survey dated ..... meets the minimum survey detail requirements as promulgated by the State Board of Professional Engineers and Land Surveyors and has been made under my

supervision, and complies with the provisions of "the map filing law" and that the outbound monuments as shown have been found or set.

(Include the following, if applicable)

I do further certify that the monuments as designated and shown hereon have been set.

.....

Licensed Professional Land Surveyor and No.

(Affix Seal)

If the land surveyor who prepares the map is different than the land surveyor who prepared the outbound survey, the following two certificates shall be added in lieu of the certificate above.

I hereby certify to the best of my knowledge information and belief that this land survey dated has been made under my supervision and meets the minimum survey detail requirements, promulgated by the State Board of Professional Engineers and Land Surveyors and that the outbound monuments as shown have been found or set.

.....

Licensed Professional Land Surveyor and No.

(Affix seal)

I hereby certify that this map has been made under my supervision and complies with the provisions of the "map filing law."

(Including the following if applicable)

I do further certify that the monuments as designated and shown hereon have been set.

.....

Licensed Professional Land Surveyor and No.

( Affix seal)

If interior monuments are to be set at a later date, the following requirements and endorsement shall be shown on the map.

The interior monuments shown on this map shall be set within an appropriate time limit as provided for in the "Municipal Land Use Law," P.L.1975, c.291 (C.40:55D-1 et seq.) or local ordinance.

I certify that a bond has been given to the municipality, guaranteeing the future setting of the monuments shown on this map and so designated.

.....

Municipal Clerk

If the map is a right of way parcel map the project surveyor need only to certify that the monuments have been set or will be set.

o. There shall be endorsed thereon a certificate of the municipal engineer as follows:

I have carefully examined this map and to the best of my knowledge and belief find it conforms with the provisions of "the map filing law" resolution of approval and the municipal ordinances and requirements applicable thereto.

.....

Municipal Engineer

(Affix Seal)

p. There shall be submitted to the proper authority an affidavit setting forth the names and addresses of all the record title owners of the lands subdivided by said map and the consent in writing of all such owners to the approval of such map shall be required.

q. If the map shows streets, avenues, roads, lanes or alleys, there shall be endorsed thereon a certificate by the municipal clerk that the municipal body has approved such streets, avenues, roads, lanes or alleys, except where such map is prepared and presented for filing by the State of New Jersey or any of its agencies. The map shall show all of the street names as approved by the municipality.

r. Monuments are required on one side of the right of way only and shall be of metal detectable durable material at least 30 inches long. The top and bottom shall be a minimum of 4 inches square; if concrete, however it may be made of other durable metal detectable material specifically designed to be permanent, as approved by the State Board of Professional Engineers and Land Surveyors. All monuments shall include the identification of the professional land surveyor or firm. They shall be firmly set in the ground so as to be visible at the following control points; provided that in lieu of installation of the interior monuments, the municipality may accept bond with sufficient surety in form and amount to be determined by the governing

body, conditioned upon the proper installation of said monuments upon the completion of the grading of the streets and roads shown on the map.

(1) At each intersection of the outside boundary of the whole tract, with the right-of-way line of any side of an existing street.

(2) At the intersection of the outside boundary of the whole tract with the right-of-way line on one side of a street being established by the map under consideration.

(3) At one corner formed by the intersection of the right-of-way lines of any 2 streets at a T-type intersection.

(4) At any two corners formed by the right-of-way lines of any two streets in an "X" or "Y" type intersection.

(5) If the right-of-way lines of two streets are connected by a curve at an intersection, monuments shall be as stipulated in (3) and (4) of this subsection at one of the following control points:

(a) The point of intersection of the prolongation of said lines.

(b) The point of curvature of the connecting curve or,

(c) The point of tangency of the connecting curve.

(6) At the beginning and ending of all tangents on 1 side of any street.

(7) At the point of compound curvature or point of reversed curvature where either curve has a radius equal to or greater than 100 feet. Complete curve data as indicated in subsection d. of this section shall be shown on both sides.

(8) At intermediate points in the sidelines of a street between 2 adjacent street intersections in cases where the street deflects from a straight line or the line of sight between the adjacent intersections is obscured by a summit or other obstructions which are impractical to remove. This requirement may necessitate the setting of additional monuments at points not mentioned above. Bearings and distances between the monuments or coordinate values shall be indicated.

(9) In cases where it is impossible to set a monument at any of the above designated points, a nearby reference monument shall be set and its relation to the designated point shall be clearly designated on the map; or the plate on the reference monument shall be stamped with the word "offset" and its relation to the monument shown on the filed map.

(10) In areas where permanency of monuments may be better insured by off-setting the monuments from the property line, the municipal engineer may authorize such procedure;

provided, that proper instrument sights may be obtained and complete off-set data is recorded on the map.

(11) By the filing of a map in accordance with the provisions of "the map filing law," reasonable survey access to the monuments is granted, which shall not restrict in any way the use of the property by the landowner.

(12) On right of way parcel maps, the monuments shall be set at the points of curvature, points of tangency, points of reverse curvature and points of compound curvature or the control base line or center line, if used, and be intervisible with a second monument.

(13) On minor subdivisions a monument shall be set at each intersection of an outside boundary of the newly created lot(s) with the right of way line of any side of an existing street.

L.1960,c.141,s.3; amended 1997, c.211, s.2.

#### **46:23-9.12. Time for approval**

The proper authority shall approve or disapprove such map within 45 days from the receipt thereof.

L.1960, c. 141, p. 667, s. 4.

#### **46:23-9.13. Approval of map by municipality not acceptance of roads, streets or highways**

The approval of any map under this law by the proper authority shall in no way be construed as acceptance of any road, street or highway indicated thereon; nor shall any such approval in any way obligate the State of New Jersey or any county or municipality therein, to maintain or exercise jurisdiction over such roads, streets or highways.

L.1960, c. 131, p. 667, s. 5.

#### **46:23-9.14. Prerequisites to filing**

The county recording officer shall not accept for filing any map unless it has endorsed thereon a certificate signed and sealed with the municipal seal by the municipal clerk or secretary of the planning board as the case may be, stating that the proper authority has approved the map or stating its exemption from approval which certificate shall state that said map complies with the provisions of this law and shall designate the day on or before which said map is required to be filed by the provisions of the applicable law and provided that said map is filed on or before said designated day.

Said map shall also comply with the provisions of section 3, paragraphs a. and b. of this act in order to be accepted for filing.

L.1960, c. 141, p. 667, s. 6.

#### **46:23-9.15. Filing and indexing of maps, fee**

The county recording officer of each county shall, when received by him for that purpose in accordance with the provisions of this law file in folios, slides, cabinets or other receptacles, maps of land lying in whole or in part in the county where the same are offered to be filed; provided that he shall retain the original tracing on translucent tracing cloth or its equivalent unmounted in an appropriate file or container, for preservation and use for reproduction purposes only, prints of which may be made available to the public at a reasonable cost. He shall endorse on the tracing and cloth print duplicate the date of the filing thereof in his office, and he shall provide and keep a proper index of all maps on file in his office. The county recording officer shall, for filing and indexing each map receive such fee as may be provided by law, except that when any map shall be presented for filing by the State of New Jersey, or any of its agencies no fee shall be charged for the filing thereof.

L.1960, c. 141, p. 669, s. 7.

#### **46:23-9.16. Repeals**

Sections 1 to 6, both inclusive, of chapter 358 of the laws of 1953 entitled "An act concerning the approval and filing of maps, supplementing chapter 23 of Title 46, and repealing sections 46:23-1, 46:23-2, 46:23-3, 46:23-4, 46:23-5, 46:23-6, 46:23-7, 46:23-8 and 46:23-9, of the Revised Statutes" (approved August 10, 1953, P.L.1953, c. 358) are hereby repealed.

L.1960, c. 141, p. 669, s. 8.

#### **46:23-10. Duplicates of maps in cities having atlases or block maps filed with recording officer and transmitted to proper city officer**

Whenever any map of lands situate in any city of this state that has or may have an atlas, or block map, upon which shall be plotted the lots or subdivision of lots of lands, is filed in the office of the county recording officer, or other officer, whose duty it is to record and file such maps, the person filing the same shall file a duplicate thereof, and the officer receiving such map shall indorse on such duplicate the time of recording and filing the original and deliver such duplicate to the officer of such city having charge of such city atlas or block map.

This section shall have no application to maps filed by commissioners appointed to assess benefits derived from the construction of sewers, drains or other municipal improvements.

**46:23-11. Approval and filing of duplicates of maps identical with maps already filed except as to style or title thereof; effect**

Whenever there has been or may be duly filed in the office of the county recording officer in any county maps of lands, and there have been made duplicate copies thereof, which copies have been delineated identically with the maps so filed, except for the style or title thereof, and such duplicate maps have not been filed in the office of such county recording officer, and there have been made conveyances of lands, or interests therein, and other instruments of similar nature, under which the lands intended to be conveyed or liened, have been described by reference to such unfiled map, the governing body of any municipality within this state and located in any such county may provide for the filing of a duplicate of such map delineated identically with the filed map, even though the title or style of the map may be in different form from the filed map approved by such municipality in the manner prescribed by law; but any such approval and filing shall not constitute a dedication of the streets or lot locations as therein delineated; and any such approval and filing of any such map shall be merely for the identification of the lands therefore conveyed or liened, which approval shall be stated in the resolution adopted by the governing body approving such maps.

This above Law has been recently modified per P.L. 1999, Chapter 258, approved October 15, 1999, Assembly, No. 3025 .

To insure the most recent materials are referenced it is directed that all users of this material research the most recent Law at [www.state.nj.us](http://www.state.nj.us), and reference the DOT web site at [www.state.nj.us/transportation](http://www.state.nj.us/transportation).

## **APPENDIX B**

### **NJDOT FEATURE CODE LIST FOR ELECTRONIC DATA COLLECTION**

## Preference Table

### Alignments

- 100 Bench Mark
- 101 Bench Mark-Temporary
- 102 Monument-NJDOT
- 103 Monument-USCGS
- 104 Point-Angle
- 105 Point-Control
- 106 Point-Traverse
- 107 Point-Misc.

### Topo (Natural)

- 200 Bush-Shrub
- 201 Cultivated Field
- 202 Grass
- 203 Orchard
- 204 Hedge-Line
- 205 Tree-Conifer
- 206 Tree-Deciduous
- 207 Wood/Tree Line
- 208 Dirt
- 209 Gravel/Stone

### Topo (Bridge)

- 300 Crib Wall-Bottom
- 301 Crib Wall-Top
- 302 Joint Longitudinal
- 303 Joint Transverse
- 304 Parapet
- 305 Pier-Column
- 306 Pier-Corner
- 307 Retaining Wall-Bottom
- 308 Retaining Wall-Top
- 309 Scupper
- 310 Sound Wall-Bottom
- 311 Structure-Bottom
- 312 Structure-Top

### Topo (Roadway)

- 325 Attenuator-Impact
- 326 BenchMark -Topo
- 327 Benchmark-Temp-Topo
- 328 Boring
- 329 Curb-Depressed-Drive
- 330 Curb-Depressed-Handicap
- 331 Driveway-Bituminuous
- 332 Driveway-Concrete
- 333 Driveway-Dirt

- 334 Driveway-Gravel
- 335 Drive-Stone
- 336 Fence-Chain Link
- 337 Fence-Gate
- 338 Fence-Wire
- 339 Fence-Wood
- 340 Guide Rail-Anchor
- 341 Guide Rail-BCT
- 342 Guide Rail-Left
- 343 Guide Rail-Right
- 344 Guide Rail-Wire Rope
- 345 Island Concrete
- 346 Monument-Box
- 347 Monument-NJDOT-Topo
- 348 Monument-USCGS-Topo
- 349 Sidewalk-Bituminuous
- 350 Sidewalk-Concrete
- 351 Sign
- 352 Sign-Bridge
- 353 Sign-Cantilever
- 354 Sign-Delineator
- 355 Sign-MileMark
- 356 Silt Fence
- 357 Slab-Approach
- 358 Slab-Concrete
- 359 Slab-Transition

### Topo (Other)

- 375 Billboard
- 376 Cesspool Cover
- 377 Corner-Building
- 378 Corner-Porch
- 379 Corner-Steps
- 380 Disposal Bed
- 381 Pool
- 382 Septic Tank
- 383 Flag-Pole
- 384 Gas Valve
- 385 Gas-Pump
- 386 Mail-Box
- 387 Parking Meter
- 388 Railroad Ties
- 389 Well
- 390 Wood/Metal Post
- 391 Vent-Pipes
- 392 Oil Filler Valve

### **Drainage**

- 400 Culvert-Corner-Bottom
- 401 Culvert-Corner-Top
- 402 Flume
- 403 Riprap
- 404 Flared End Section
- 405 HeadWall (Max 900mm Pipe)
- 406 HeadWall w/Apron (Max 900mm Pipe)
- 407 HeadWall-Bottom (Max 900mm Pipe)
- 408 HeadWall-Top (Max 900mm Pipe)
- 409 Headwall-RCES
- 410 Inlet-Type "A"
- 411 Inlet-Type "B"
- 412 Inlet-Type "D1"
- 413 Inlet-Type "D2"
- 414 Inlet-Type "E"
- 415 Inlet-Type-"Unknown"
- 416 Manhole-NJDOT-Storm
- 417 Manhole-Other-Storm
- 418 Pipe (Note Size & Type)
- 419 Pipe-Centerline-Top
- 420 Pipe-Invert
- 421 Roof-Drain
- 422 Slotted-Drain
- 423 Under Ground Vault-Drainage

### **Right of Way**

- 700 Corner-Iron Pipe
- 701 Easement
- 702 Monument-Property
- 703 Property-Line
- 704 ROW Line-Access
- 705 ROW Line-NoAccess
- 347 Monument-NJDOT
- 348 Monument-USCGS

### **Traffic Stripe**

- 750 Gore Stripe
- 751 100mm Dashed
- 752 100mm Solid White
- 753 100mm Solid Yellow
- 754 Double Yellow
- 755 200mm Solid White
- 756 200mm Solid Yellow

### **Utilities**

- 500 Booth-Telephone
- 501 Box-Fire
- 502 Box Police
- 503 Cabinet-Meter
- 504 Hydrant

- 505 Junction Box
- 506 Junction Box w/Light
- 507 Loop Detector
- 508 Manhole-NJDOT-Electric
- 509 Manhole-Other-Electric
- 510 Manhole-Sanitary
- 511 Manhole-Telephone
- 512 Manhole-Unknown
- 513 Pavement Marking-Electric
- 514 Pavement Marking-Gas
- 515 Pavement Marking-Telephone
- 516 Pavement Marking-Water
- 517 Pole-Guy Wire
- 518 Pole-Light
- 519 Pole-Utility
- 520 Pole-Utility w/Light
- 521 Signal-Railroad
- 522 Signal-Traffic
- 523 Test Pit
- 524 Traffic Control Box
- 525 Under Ground Vault-Cable
- 526 Under Ground Vault-Elect.
- 527 Under Ground Vault-Gas
- 528 Under Ground Vault-Sani
- 529 Under Ground Vault-Tele.
- 530 Under Ground Vault-Water
- 531 Utility Marker
- 532 Valve-Gas
- 533 Valve-Water
- 534 Vent-Gas
- 535 Vent-Other
- 536 Vent-Sewer
- 537 Fiber Optic J.B.
- 538 Pavement Marking-Cable T.V.
- 539 Valve-Unknown

### **Breaklines**

- 600 Barrier Curb-Gutter
- 601 Barrier Curb-Reveal
- 602 Barrier Curb-Top
- 603 Breakline
- 604 Curb-Bituminuous-Top
- 605 Curb-Concrete-Top
- 606 Curb-Gutter-Left
- 607 Curb-Gutter-Right
- 608 Bituminuous Pavement
- 609 Concrete Pavement
- 610 Bulkhead
- 611 Joint
- 612 Lane
- 613 Shoulder

- 614 Railroad-Top of Rail
- 615 Rock-Bottom
- 616 Rock-Top
- 617 Rock-Intermediate
- 618 Slope-Bottom
- 619 Slope-Top
- 620 Slope-Misc.
- 621 Swale-Bottom
- 622 Swale-Top
- 623 Swale-Misc.
- 624 Swamp-Edge
- 625 Swamp-Misc.
- 626 Water-Bottom of Bank
- 627 Water-Top of Bank
- 628 Water-Surface
- 629 Water-Bed

**999 Unknown Feature**

## **APPENDIX C**

### **Miscellaneous Check Lists**

## SURVEY NOTES CHECKLIST

Yes    No    Not  
                 Appl.

Is a TITLE SHEET attached and properly filled out?  
Does IT include an AREA SKETCH showing location of survey?  
Are HORIZONTAL DIRECTION MODULES attached?  
Are EDM MODULES attached?  
Are TAPING MODULES attached?  
Are all BLANKS filled?  
Have NEW OBSERVATIONS been entered for all rejects?

Does each page show all required PERIMETER INFORMATION?

- a. Date and page number.
- b. Personnel and their duties.
- c. Location and cost accounting information.
- d. Weather (temperature, pressure, etc.) and equipment used.

Is ORIENTATION DATA adequate? (N Arrow, Topo, Bearings, Coords., Datums, Line Labels, etc.)

Have POINTS ACCEPTED AS RECORD been verified by descriptions, RP's, other witness?

Is this shown on the notes?

Have UNWITNESSED RECORD POINTS been RP'd and so recorded?

Have major SET POINTS been RP'd and so recorded?

Have thorough DESCRIPTIONS been written?

Do the descriptions of record points cite REFERENCES?

Are page CROSS REFERENCES shown?

Are notes -

ACCURATE?

VALID? (recorded precision = measuring precision, raw values)

ORIGINAL? (entries made at the time raw values are called out)

NEAT?

LEGIBLE?

SELF CHECKING? (adequate control points, closures, basis of calcs.)

INTERPRETABLE?

COMPLETE? (all required elements)

Is PRECISION of angular measurements equal to precision of distance measurements?

**NEW JERSEY DEPARTMENT OF TRANSPORTATION**  
**BASE PLAN SURVEY REQUEST CHECKLIST**

ROUTE \_\_\_\_\_ SECTION \_\_\_\_\_

ITEMS NOT CHECKED WILL BE CONSIDERED NOT REQUIRED

Person filling out this checklist \_\_\_\_\_ Date \_\_\_\_\_

Total number of attachments to this checklist \_\_\_\_\_.

\_\_\_\_\_ Establish horizontal control  
\_\_\_\_\_ True coordinates required or  
\_\_\_\_\_ Assumed coordinates satisfactory.

\_\_\_\_\_ Establish vertical control  
\_\_\_\_\_ True elevations required or  
\_\_\_\_\_ Assumed elevations satisfactory.

\_\_\_\_\_ Tie existing base line to horizontal control.

\_\_\_\_\_ Locate existing topo within the project limits (for survey purposes) of  
\_\_\_\_\_ Station \_\_\_\_\_ To station \_\_\_\_\_ and from  
\_\_\_\_\_ left to the base line to \_\_\_\_\_ right of the base line or  
\_\_\_\_\_ Plan or sketch of survey limits required attached.

\_\_\_\_\_ Locate buildings  
\_\_\_\_\_ Only within project limits.  
\_\_\_\_\_ On entire adjacent parcels.  
\_\_\_\_\_ Other (provide attachment).  
\_\_\_\_\_ Show building fronts only.  
\_\_\_\_\_ Show complete building footprint.

\_\_\_\_\_ Locate all driveways  
\_\_\_\_\_ To project limits.  
\_\_\_\_\_ To R.O.W. line only.  
\_\_\_\_\_ Show parking lots and site circulation.  
\_\_\_\_\_ Show driveway openings only.  
\_\_\_\_\_ Include profile of driveway center line  
\_\_\_\_\_ Every \_\_\_\_\_ for a distance of \_\_\_\_\_.

\_\_\_\_\_ Locate visible utilities (includes poles, gas & water valves, san. & telephone manholes, etc.)

- \_\_\_\_\_ Existing pavement mark outs.
- \_\_\_\_\_ Overhead wires
- \_\_\_\_\_ Locate all drainage consisting of:
  - \_\_\_\_\_ Surface structures only (inlets, manholes, head walls, etc.)
  - \_\_\_\_\_ Surface structures plus under ground pipes including
    - \_\_\_\_\_ Pipe sizes
    - \_\_\_\_\_ Inverts
    - \_\_\_\_\_ Direction
  
- \_\_\_\_\_ Locate existing traffic stripes.
  - \_\_\_\_\_ All traffic stripes within project.
  - \_\_\_\_\_ Just those within the area shown on the attached plan.
  - \_\_\_\_\_ Just within \_\_\_\_\_ of any intersection.
  - \_\_\_\_\_ Just gore area.
  
- \_\_\_\_\_ Locate all side streets.
  - \_\_\_\_\_ Establish center line & tie to main base line.
  - \_\_\_\_\_ Center line not required.
  - \_\_\_\_\_ Provide cross sections every \_\_\_\_\_
    - \_\_\_\_\_ To project limit.
    - \_\_\_\_\_ For a distance of \_\_\_\_\_.
  - \_\_\_\_\_ No profile or cross sections required.
  
- \_\_\_\_\_ Cross sections will be required at \_\_\_\_\_ intervals.
  
- \_\_\_\_\_ This project requires new ROW
  - \_\_\_\_\_ Deed searches required for \_\_\_\_\_ parcels.
  - \_\_\_\_\_ Location of new ROW within project (provide attachment).
  
- \_\_\_\_\_ Bridge survey (provide attachment showing specific requirements)
- \_\_\_\_\_ Stream survey (provide attachment showing specific requirements).
- \_\_\_\_\_ Other (provide attachment showing specific requirements).
  
- \_\_\_\_\_ Please provide the survey of the project site in the following order.  
 (List order in which each area or topic is preferred)
  1. \_\_\_\_\_
  2. \_\_\_\_\_
  3. \_\_\_\_\_

## **APPENDIX D**

### **Metrication Issues**

## Basic Metric Information

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### BACKGROUND

The modern metric system (Système International or SI system) has been the international standard of measurement since it was adopted by the 11th General Conference on Weights and Measures in 1960.

The Metric Usage Act of 1975, as amended by the Omnibus Trade and Competitiveness Act of 1988, requires that the metric system be used in all federal procurement, grants, and business-related activities to the extent feasible by September 30, 1992. The intent of the law is to make the United States more competitive in international trade by bringing its measurement system into line with that of the rest of the world. Executive Order 12770 of July 1991, Metric Usage in Government Programs, requires federal agencies to develop specific timetables and milestones for the transition to the metric system. Federal agencies involved in construction generally agreed to institute the use of metric measures in the design of all federal construction by January 1994.

The United States is the only industrialized country on earth that does not use the metric system.

The metric system is more than just the International System of Units (SI). In international trade, the metric system refers to the use of product standards and preferred sizes that are accepted by industries throughout the world. It is, therefore, essential that goods manufactured in the United States be built to metric specifications to be competitive in the international marketplace.

### WHAT ARE SOME OF THE BASIC SI UNITS

Some of the fundamental items are:

**Meter (m):** The basic unit for the measurement of length in the metric system is the meter. It is slightly longer than a yard (39.37 Inches) and generally used for measuring short distances. The length of a football field is approximately 91 m.

**Kilometer (km):** The metric unit used to denote longer distances is the kilometer. The kilometer is equal to 1000 meters and is slightly longer than half of a mile.

**Millimeter (mm):** Applied to the measurement of small distances or thicknesses is the millimeter. The millimeter is equal to one thousandth of a meter, or 0.001 meter. An inch is approximately 25 mm.

**Square meter (m<sup>2</sup>):** The unit commonly used for the measurement of area is the square meter. A square meter is approximately 20% larger in area than a square yard. A room ten feet long and ten feet wide has a floor area of approximately 9 m<sup>2</sup>.

**Hectare (ha):** To express the area of land or bodies of water use the hectare. A hectare is equal to 10 000 m<sup>2</sup>, which is approximately 2.5 acres.

**Cubic Meter (m<sup>3</sup>):** The unit of volume in the metric system is the cubic meter. The cubic meter has approximately 30% more volume than a cubic yard.

**Liter (L):** The unit that is used for the measurement of liquids or gasses is the liter. A liter is slightly more than a quart. Ever purchased a soft drink in a 2 L bottle?

**Kilogram (kg):** The basic unit that is used to express the mass of large items is the kilogram. A kilogram is a little more than two pounds.

**Gram (g):** The unit used to express the mass of small items is the gram. A gram is equivalent to one thousandth of a kilogram (0.001 kg). The mass of a penny is about 3g.

**Metric ton (t):** Used to express the mass of very large items or quantities, the metric ton. The metric ton is equivalent to 1000 kg, or approximately 2200 pounds.

**Second (s):** The second is the fundamental unit of time and is the same unit as currently used in everyday terminology.

**Temperature (C):** Widely used in the measurement of temperature is the degree Celsius (C°). On a hot summer day when the temperature is 95 F (Fahrenheit scale), the metric equivalent would be 35 C°.

**Velocity (km/h):** Velocity, or speed, is expressed in kilometers per hour (km/h). A residential speed limit of 25 miles per hour (mph) is approximately 40 km/h.

## **SOFT METRIC CONVERSION VERSUS HARD METRIC CONVERSION**

Soft conversion is the result of a mathematical conversion of inch-pounds to SI equivalents. ASTM defines soft conversion as the "process of changing the description of an existing measurement to acceptable metric units without a significant change in size or magnitude." Hard conversion, on the other hand, is the "process of changing the description of an existing measurement to acceptable metric units, but with a change in the size of an existing quantity to obtain standard, convenient, rounded or rationalized metric dimensions."

Simple mathematical dimensional conversions should be avoided when at all possible. If "soft conversions" are made a "rational equivalent" would be more appropriate. For example, 12 inches (exactly 304.8 mm) is not a clean, rational number. It should be rounded to 300 mm to facilitate the cleanest construction possible.

Other common measurements would be rounded to a rational equivalent. Consider the following:

- 1" = 25 mm

- 4" = 100 mm
- 6" = 150 mm
- 12" = 300 mm
- 16" = 400 mm
- 24" = 600 mm (a normal building planning grid)

Once conversions have been made many architects, engineers and contractors alike find the metric system easier, simpler and more efficient to use since it is a decimal based system. The steps necessary to compute the area of a floor 27' 8-5/8" wide x 32' 6-7/16" long versus one that is 8.45 m wide x 9.92 m long, demonstrates the complexity of our current system of measurement. The metric system also simplifies building design by using only one unit for each physical property. For example, our current system of measurement uses psi, psf, tons/SF, inches of water, inches of mercury, and kips/SF to measure pressure. The metric system greatly simplifies this measurement by establishing one unit of measurement for pressure, the Pascal (Pa). Depending upon how large the measurement, kilopascals (x 1000), kPa, or megapascals (x 1000000), MPa, can be used.

### Conversion Factors\*

Quantity	From English Units	To Metric Units	Multiply By
Length	mile	Km	<u>1.609 344</u>
	yard	m	<u>0.914 4</u>
	foot	m	<u>0.304 8</u>
	foot	mm	<u>304.8</u>
	inch	mm	<u>25.4</u>
Area square mile	acre	km <sup>2</sup>	2.590
	square yard	ha (10 000 m <sup>2</sup> )	0.404 685 6
	square foot	m <sup>2</sup>	<u>0.836 127 36</u>
	square inch	m <sup>2</sup>	<u>0.092 903 04</u>
Volume	cubic yard	mm <sup>2</sup>	<u>645.16</u>
	cubic foot	m <sup>3</sup>	0.764 555
	cubic foot	m <sup>3</sup>	0.028 316 8
	gallon	L (1000 cm <sup>3</sup> )	28.316 85
	cubic inch	L (1000 cm <sup>3</sup> )	3.785 41
Mass	lb	mm <sup>3</sup>	<u>16 387.064</u>
	ton (2000 lb)	Kg	0.453 592
Force	lb	metric ton (1000 kg)	0.907 184
Pressure, stress	psi	N	4.448 22
Torque	in-lb	kPa	6.894 76
	ft-lb	N·m	0.112 98
		N·m	1.355 82

**NOTE: Underline denotes exact number**

\*(From the homepage of Montana Department of Transportation)

### METRIC CONVERSION PITFALLS

One might think that metric conversion is as simple as a mathematical "soft" conversion. However as one soon discovers, metric conversion, unlike the "hard" metric design that some are

accustomed to is full of pitfalls. The following are the general rules and guidelines to be used when converting existing designs, specifications and calculations from English units to SI units.

- Know which is the correct conversion factor, especially when converting weight, or mass, and force. The SI system has specific values for both.
- Be careful not to introduce accuracy into a value which did not have it to begin with, when converting from the English system to the SI system.
- Use common sense when rounding, and strive for consistency.
- When necessary, perform a soft metric conversion, however, wherever possible, make all conversions hard. Hard conversion will accelerate the learning process and acceptability of the metric system.
- Again, be careful not to introduce accuracy into a value which did not have it to begin with. This is probably the most common mistake when making metric conversions. Review what the original intent of the value was, before making the conversion. If possible, try to make hard metric conversions.

In almost every case, the products and material strengths are not changing, however the nomenclature used to specify these particular products is changing. This constantly changing criteria and nomenclature can turn even the simplest metric conversion project into a difficult one. Common sense and good engineering judgement must be used!

## CONVERSION AND ROUNDING

- ◆ Always establish intended precision as a guide to how many digits to retain after conversion. The number 1.1875 may be a very accurate decimalization of a number that could have been expressed as 1.19. The value 2 may mean "about 2," or it may be a very accurate value of 2, expressed as "2.0000".
- ◆ The converted dimension should be rounded to a minimum number of significant digits so the unit of the last place is equal to or smaller than its conversion.

**Example:** Precision of a 6 inch stirring rod is estimated at about 1/2 in ( $\pm 1/4$  in) or, converted, 12.7 mm. The converted dimension, 152.4 mm, should be rounded to the nearest 10 mm and shown as 150 mm.

- ◆ Converted values should be rounded to the minimum number of significant digits in order to maintain the required accuracy.

**Example:** A length of 125 ft converts exactly to 38.1 m. But if the 125 ft length was obtained by rounding to the nearest 5 ft, the conversion should be given as 38 m; if it had been obtained by rounding to the nearest 25 ft, the result should be rounded to 40 m.

- ◆ A stated limit such as "not more than" must be handled so the limit is not violated. "At least 3 inches wide" requires a width of at least 76.2 mm, or at least 77 mm.
- ◆ When converting, multiply a value by a more accurate factor than required, then round appropriately afterward. Rounding before multiplying will reduce accuracy.

**Example:** When converting 3 feet 2 9/16 inches to meters (9/16" = 0.5625"):

$$(3 \times 0.3048) + (2.5625 \times 0.0254) = 0.979\ 487\ 5\ \text{m, rounds to } 0.979\ \text{m}$$

### Significant Digits

- ◆ When converting integral values of units, consider the implied or required precision of the integral value to be converted.

**Example:** The value *4 in.* may represent 4, 4.0, 4.00, 4.000 or 4.0000 in.

- ◆ Any digit necessary to define the specific value or quantity is significant.

**Example:** Measured to the nearest 1 m, a recorded distance of 157 m would have three significant digits. Measured to the nearest 0.1 m, a distance of 157.4 m would have four significant digits.

- ◆ Zeros may indicate either a specific value or an order of magnitude. As an example, the population of the United States in 1970, rounded to thousands, was 203 185 000. The six left-hand digits are significant, each measuring a value. The three right hand zeros indicate that the number has been rounded to the nearest thousand.
- ◆ Identifying significant digits is only possible by knowing the circumstances by which they were originally arrived at. For example, if the number 1000 is rounded from 965, only one zero is significant. If it is rounded from 999.7, all three zeros are significant.
- ◆ When adding or subtracting, the answer must contain no significant digits to the right of the least precise number.

**Example:** For the problem: Round the numbers one significant digit to the right of the least precise number and take the sum as follows:

163 000 000	163 000 000
217 885 000	217 900 000
<u>96 432 768</u>	<u>96 400 000</u>
477 317 768	477 300 000

(Round the total to 477 000 000 as called for by the rule)

- ◆ When multiplying or dividing, the product or quotient must contain no more significant digits than the fewest significant digits used in the multiplication or division.

**Example:**  $113.2 \times 1.43 = 161.876$  – round to 162 because 1.43 has three significant digits  
 $113.2 \div 1.43 = 79.160\ 8$  – round to 79.2 for same reason.

### Rounding Values

When the first digit discarded is less than 5, the last digit retained is not changed.

**Example:** 3.463 25, rounded to four digits would be 3.463; if rounded to three digits, 3.46.

- ◆ When the first digit discarded is greater than 5 or is a 5 followed by at least one digit other than 0, add 1 to the last digit retained.

**Example:** 8.376 52, rounded to four digits would be 8.377; if rounded to three digits 8.38.

- ◆ When the first digit discarded is exactly 5 followed only by zeros, the last digit retained should be rounded upward if it is odd. No adjustment is made if it is an even number.

**Example:** 4.365, rounded to three digits becomes 4.36. The number 4.355 would round to the same value, 4.36, if rounded to three digits.

### HOW WILL THIS EFFECT ENGINEERING?

Drawing units will change from feet and inches to millimeters for all building dimensions and to meters for large site plans and civil engineering drawings; meters are always carried to one, two or three decimal places depending on the accuracy required. Drawing scales will change from  $1_{\text{inch}} = x_{\text{feet}} - y_{\text{inch}}$  (1"=1'-8") to true ratios (1:20). Drawing sizes will be changed to the standard ISO metric drawing sizes. Drawings should be presented with only metric units. Typically, all dimensions are shown in millimeters, however, the suffix mm is not used, nor needed. Currently, most products that go into concrete work can be accomplished with either soft or hard metric conversions. At this time, reinforcing steel is still specified using the bar number, however, bar diameters in millimeters may eventually be used. Metric design guides for concrete design are available through the American Concrete Institute. Most products associated with steel construction have undergone soft metric conversions. Metric steel shape tables and design guides are available through the American Institute of Steel Construction.

One obvious advantage to the metric system is that metric dimensions can easily be checked with a calculator. By eliminating the cumbersome feet and inches, addition and conversion errors can be reduced significantly. The use of dual dimensions is discouraged since dual dimensioning takes time, double the change for errors, makes drawings more confusing and impedes the learning process. Plans are usually presented in meters with sections and details presented in millimeters. Specifications will require either soft or hard metric conversions. Units of measure from feet and inches should be converted to millimeters for linear dimensions, from square feet to square meters for area, and from cubic yards to cubic meters for volume (except use liters for fluid volumes). Again, dual units are discouraged except when the use of an inch-pound unit of measure serves to clarify an otherwise unfamiliar metric measure, then place the inch-pound unit in parentheses after the metric unit. Calculations should be performed solely in metric units. This will eliminate the possibility of conversion errors. Many technical manuals and codes are currently available in their metric equivalents. Cost estimates should also be prepared in metric units. Many cost estimating guides are now being prepared in both English and metric units of measure.

## **WHAT EFFECT WILL THIS HAVE ON CONSTRUCTION?**

Recent construction awards indicate that there is no detectable cost premium for using metric units. Construction contractors find that the use of metric units eliminates most dimensional construction errors since it is easier to use. By substituting metric measuring tapes, some contractors have found that very little effort and training was required to make the conversion from English to metric units.

## **HOW WILL THIS EFFECT THE GENERAL PUBLIC?**

Most people today purchase metric packaged products and don't even know it. Almost all soft drinks are sold in liter containers, and have been for several years. Items purchased in grocery stores have displayed a dual system of volume and weights measurements for nearly 10 years. School children are now being taught both systems of measurement in the public school system and will be the first to readily accept either form of measurement. Car speedometers have been provided in both miles per hour and kilometers per hour for several years. The metric system of measurements have been introduced in our daily lives without our even realizing it. Once a conscious effort is made to convert to the metric system of measurements, the more widely accepted the metric system will become. Many Americans each year travel abroad and are immersed not only in a foreign culture, but the metric system of measurements. Speed limits are given in kilometers per hour and weights are given in kilograms. Although it may take some getting used to, many of these travelers eventually feel that a system based on a simple decimal system is easier to understand and is easier to use. To visualize metric equivalents, visualize the following:

- 1 mm (millimeters) is the approximate thickness of a dime
- 10 mm is the approximate diameter of a ball point pen
- 30 mm is the approximate length of a standard paper clip
- 150 mm is the length of a dollar bill
- 2 m (meters) is the average height of a door
- 90 m is the length of a football field

## **WHAT'S NEXT?**

One of the largest obstacles to overcome is the inherent dislike for anything different. Most practicing engineers and architects have a real dislike for metric units because they lose their intuition and don't have a "feel" for what a value means in another system of measurements. For example, many structural and civil engineers know, and have a good physical sense of what 100 psf or 4000 psi means. However, convert 4000 psi to 27.5 MPa, and engineers and architects are confronted with a system of measurement that is completely foreign to them. Education and practice is required in order for engineers and architects to feel comfortable with metric units and regain their sense of "feel" for what is right. One of the biggest pitfalls in metric conversion will be to rely on soft conversions and not hard conversions. The faster one can use metric units from beginning to end, the sooner one will achieve the confidence needed to work with metric units.

Much effort is needed in the area of education for engineers and architects. The federal government has made a concerted effort to bring metrication to fabrication and construction. However, if engineers and architects are unwilling or unable to perform the necessary calculations and contract drawings in metric units, it will take years before the metrication process can be completed. Metrication is important for our future economic survivability in an ever shrinking global economy. Engineers have been called upon time and time again to solve problems, this is not one that they should shy away from.

#### **REFERENCES:**

1. American Society of Civil Engineers. <http://www.pilot.infi.net/~cstone/comindex.htm>
2. ASCE Metric References. [http://www.pilot.infi.net/~cstone/com\\_i\\_1.htm](http://www.pilot.infi.net/~cstone/com_i_1.htm)
3. Metric Conversion Pitfalls. <http://www.pilot.infi.net/~cstone/asceref7.htm>
4. Metrication - Who, What, When, Where and Why!.  
<http://www.pilot.infi.net/~cstone/asceref0.htm>
5. Metrics Facts and Figures. <http://www.pilot.infi.net/~cstone/mfacts2.htm>
6. Montana Metrics. <http://www.mdt.mt.gov/metric/mtmetric.htm>
7. U.S. Metric Association (USMA). <http://lamar.ColoState.EDU/~hillger/>
8. The 1-Step metric conversion calculator. <http://www.shaban.com/>

## **APPENDIX E**

### **Surveying and Transportation INTERNET Resources.**

## Surveying and transportation related INTERNET Resources

### Surveying

<a href="http://cesgi1.city.ac.uk/weblists/">http://cesgi1.city.ac.uk/weblists/</a>	Web servers for Photogrammetry, Remote Sensing, & Land Surveying
<a href="http://gdim.geod.emr.ca/~craymer/#tcg">http://gdim.geod.emr.ca/~craymer/#tcg</a>	Mike Craymer's Home Page
<a href="http://homepage.interaccess.com/~maynard/">http://homepage.interaccess.com/~maynard/</a>	Land Surveying and Geomatics: On-Line Resources
<a href="http://homepage.interaccess.com/~maynard/groups.htm">http://homepage.interaccess.com/~maynard/groups.htm</a>	NewsGroups and FAQs
<a href="http://megahertz.njit.edu/~survey/">http://megahertz.njit.edu/~survey/</a>	NJIT's Surveying Program
<a href="http://www.anzlic.org.au/icsm/sp1/contents.htm">http://www.anzlic.org.au/icsm/sp1/contents.htm</a>	Recommended practices for surveying
<a href="http://www.auslig.gov.au/welcome.htm">http://www.auslig.gov.au/welcome.htm</a>	Australian surveying and LI group
<a href="http://www.cenews.com/">http://www.cenews.com/</a>	CE News
<a href="http://www.geocan.NRCan.gc.ca/geomatics/">http://www.geocan.NRCan.gc.ca/geomatics/</a>	GIS & GPS Technology page
<a href="http://www.isaust.org.au/">http://www.isaust.org.au/</a>	The Institution of Surveyors, Australia
<a href="http://www.landsurveyor.com/">http://www.landsurveyor.com/</a>	Land Surveyors Online
<a href="http://www.leica.com/surv-sys/index.asp">http://www.leica.com/surv-sys/index.asp</a>	Leica Surveying Group Homepage
<a href="http://www.lsrp.com/">http://www.lsrp.com/</a>	Land Surveyor Reference Page
<a href="http://www.vfmeyer.com/frames.htm">http://www.vfmeyer.com/frames.htm</a>	Land Surveying Info

### Photogrammetry

<a href="ftp://www.fgdc.gov/pub/standards/">ftp://www.fgdc.gov/pub/standards/</a>	Directory of /pub/standards
<a href="http://nsdi.usgs.gov/nsdi/products/doq.html">http://nsdi.usgs.gov/nsdi/products/doq.html</a>	USGS NSDI Clearinghouse DOQ
<a href="http://tresc.dot.ca.gov/Engineering_Technology/GeometronicsBranch/PHOTOGRAMMETRY.html">http://tresc.dot.ca.gov/Engineering_Technology/GeometronicsBranch/PHOTOGRAMMETRY.html</a>	California DOT Photogrammetry
<a href="http://www.asprs.org/asprs/resources/standards/daps/daps.html">http://www.asprs.org/asprs/resources/standards/daps/daps.html</a>	ASPRS Draft Aerial Photography Standard
<a href="http://www.c3.lanl.gov/~bradley/mrsid/bay_area/">http://www.c3.lanl.gov/~bradley/mrsid/bay_area/</a>	USGS Bay Area Digital Orthophoto
<a href="http://www.dot.state.oh.us/Aerial/index.htm">http://www.dot.state.oh.us/Aerial/index.htm</a>	Office of Aerial Engineering
<a href="http://www.esri.com/base/common/userconf/proc95/to150/p124.html">http://www.esri.com/base/common/userconf/proc95/to150/p124.html</a>	Digital Orthophotography and GIS
<a href="http://www-nmd.usgs.gov/metadata/doq.html">http://www-nmd.usgs.gov/metadata/doq.html</a>	USGS 3.75 Minute, 1:12,000 DOQ
<a href="http://wwwsgi.ursus.maine.edu/gisweb/spatdb/gis-lis/gi94093.html">http://wwwsgi.ursus.maine.edu/gisweb/spatdb/gis-lis/gi94093.html</a>	A national digital orthophoto program

### GPS - General

<a href="http://galaxy.einet.net/editors/john-beadles/introgps.htm">http://galaxy.einet.net/editors/john-beadles/introgps.htm</a>	Introduction to GPS Applications
<a href="http://gauss.gge.unb.ca/gps.guidelines.html">http://gauss.gge.unb.ca/gps.guidelines.html</a>	GPS Guidelines (Maritime Canada)
<a href="http://www.aero.org/publications/GPSPRIMER/GPSPRMR.html">http://www.aero.org/publications/GPSPRIMER/GPSPRMR.html</a>	The Global Positioning System

<a href="http://www.ashtech.com/">http://www.ashtech.com/</a>	Welcome to Ashtech
<a href="http://www.ashtech.com/pages/gps/glossary.html">http://www.ashtech.com/pages/gps/glossary.html</a>	Ashtech GPS/GIS/LIS Glossary Of Terms
<a href="http://www.env.gov.bc.ca/~srmb/gps_ad.htm">http://www.env.gov.bc.ca/~srmb/gps_ad.htm</a>	GPS Specs and guidelines, BC
<a href="http://www.gpsworld.com/">http://www.gpsworld.com/</a>	GPS World Home Page
<a href="http://www.gsys.com/gpsnet/index.html">http://www.gsys.com/gpsnet/index.html</a>	GPS for Land Surveyors
<a href="http://www.inmet.com/~pwt/gps_gen.html">http://www.inmet.com/~pwt/gps_gen.html</a>	GPS General Information Sites
<a href="http://www.navcen.uscg.mil/GPS/reports/sigspec/sigspec.htm">http://www.navcen.uscg.mil/GPS/reports/sigspec/sigspec.htm</a>	GPS Signal Specifications
<a href="http://www.navcen.uscg.mil/navcen.htm">http://www.navcen.uscg.mil/navcen.htm</a>	US Coast Guard Navigation Center GPS, DGPS, LORAN, OMEGA, LNM
<a href="http://www.questsystems.com/qs005.htm">http://www.questsystems.com/qs005.htm</a>	GPS Information Links on the WWW
<a href="http://www.technologyplus.com/gps/">http://www.technologyplus.com/gps/</a>	The GPS Home Page
<a href="http://www.tmpo.dma.gov:8001/">http://www.tmpo.dma.gov:8001/</a>	Terrain Modeling Project Office
<a href="http://www.trimble.com/">http://www.trimble.com/</a>	Trimble Navigation: The GPS Solution
<a href="http://www.trimble.com/gps/nfsections/howworks/aa_hw1.htm">http://www.trimble.com/gps/nfsections/howworks/aa_hw1.htm</a>	Trimble – How GPS works
<a href="http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html">http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html</a>	GPS notes at uTexas
<a href="http://www.volpe.dot.gov/gps/">http://www.volpe.dot.gov/gps/</a>	GPS – at DOT

#### GPS – Geodesy

<a href="http://www.ngs.noaa.gov/">http://www.ngs.noaa.gov/</a>	National Geodetic Survey
<a href="http://www.olld.nos.noaa.gov/bench.html">http://www.olld.nos.noaa.gov/bench.html</a>	NOAA Published Benchmark Sheets
<a href="http://164.214.2.59/index.html">http://164.214.2.59/index.html</a>	National Imagery and Mapping Agency (formerly DMA)
<a href="http://164.214.2.59/geospatial/products/GandG/geology/toc.htm">http://164.214.2.59/geospatial/products/GandG/geology/toc.htm</a>	Glossary of Geodetic Terms from DMA
<a href="http://www.tec.army.mil/TD/software.html">http://www.tec.army.mil/TD/software.html</a>	US Army Tech Center
<a href="http://www.nrc.ca/inms/cnmse.html">http://www.nrc.ca/inms/cnmse.html</a>	Canada NRC
<a href="http://www.spatial.maine.edu/~leick/alpha.htm">http://www.spatial.maine.edu/~leick/alpha.htm</a>	Leick GPS Home Page
<a href="http://lupus.gsfc.nasa.gov/vlbi.html">http://lupus.gsfc.nasa.gov/vlbi.html</a>	VLBI

#### GPS – Time and ITRF

<a href="ftp://maia.usno.navy.mil/ser7/ser7.dat">ftp://maia.usno.navy.mil/ser7/ser7.dat</a>	ITRF and related data
<a href="http://riemann.usno.navy.mil/AA/data/online.html">http://riemann.usno.navy.mil/AA/data/online.html</a>	Data Online
<a href="http://tycho.usno.navy.mil/?rwin=UTC">http://tycho.usno.navy.mil/?rwin=UTC</a>	Directorate of Time
<a href="http://tycho.usno.navy.mil/leapsec.html">http://tycho.usno.navy.mil/leapsec.html</a>	Leap Seconds

### GIS General

<a href="http://deathstar.rutgers.edu/projects/smac/resource.html">Http://deathstar.rutgers.edu/projects/smac/resource.html</a>	New Jersey GIS Resource Guide
<a href="http://everest.hunter.cuny.edu/mp/">Http://everest.hunter.cuny.edu/mp/</a>	Map Projection Home Page
<a href="http://geog.gmu.edu/gess/jwc/cart2.html">http://geog.gmu.edu/gess/jwc/cart2.html</a>	Cartography Resources on the Web
<a href="http://head-smashed-in.ccm.emr.ca/naismap/naismap.html">Http://head-smashed-in.ccm.emr.ca/naismap/naismap.html</a>	NAISMap Home Page
<a href="http://kaos.erin.gov.au/gis/gis_gloss.html">http://kaos.erin.gov.au/gis/gis_gloss.html</a>	GIS and Metadata Glossary
<a href="http://ogis.org/">http://ogis.org/</a>	OpenGIS
<a href="http://www.census.gov/geo/www/faq-index.html">http://www.census.gov/geo/www/faq-index.html</a>	GIS FAQ
<a href="http://www.csn.net/gis/ores/gis/index.html">http://www.csn.net/gis/ores/gis/index.html</a>	Online Resources for Earth Scientists
<a href="http://www.esri.com/">http://www.esri.com/</a>	ESRI = The Leading GIS Software
<a href="Http://www.fgdc.gov/">Http://www.fgdc.gov/</a>	Federal Geographic Data Committee
<a href="http://www.hdm.com/gis3.htm">http://www.hdm.com/gis3.htm</a>	Great GIS Net Sites!
<a href="Http://www.specsci.com/gis_resource/geolinks.html">Http://www.specsci.com/gis_resource/geolinks.html</a>	Great GIS-Related Resources
<a href="http://www.urisa.org/glossary/">http://www.urisa.org/glossary/</a>	Glossary of Terms
<a href="Http://www.usgs.gov/">Http://www.usgs.gov/</a>	US Geological Survey
<a href="Http://www.wessex.com/">Http://www.wessex.com/</a>	Wessex Inc.
<a href="http://www-nmd.usgs.gov/www/ti/DEM/standards_dem.html">http://www-nmd.usgs.gov/www/ti/DEM/standards_dem.html</a>	Standards for DEM

### GIS – Data

<a href="http://164.214.2.59/nimahome.html">http://164.214.2.59/nimahome.html</a>	NIMA Public Home Page (Image Data)
<a href="http://mercury.census.gov:80/about.html">http://mercury.census.gov:80/about.html</a>	TMS About Tiger Data
<a href="http://nsdi.usgs.gov/nsdi/wais/maps/dlg24.html">http://nsdi.usgs.gov/nsdi/wais/maps/dlg24.html</a>	1:24,000-scale Digital Line Graphs
<a href="http://www.census.gov/ftp/pub/geo/www/tiger/">http://www.census.gov/ftp/pub/geo/www/tiger/</a>	The TIGER Page
<a href="http://www.usps.gov/ncsc/lookups/lookup_ctystzip.html">http://www.usps.gov/ncsc/lookups/lookup_ctystzip.html</a>	Post office zip codes

### GIS - Transportation

<a href="http://www.bts.gov/gis/">http://www.bts.gov/gis/</a>	BTS Geographic Information Services
<a href="http://www.bts.gov/gis/reference/apts.html">http://www.bts.gov/gis/reference/apts.html</a>	APTS Map Database User Requirements Specification
<a href="http://www.upa.pdx.edu/CUS/contents.html">http://www.upa.pdx.edu/CUS/contents.html</a>	Papers Portland St. University on GIS-T

## GIS – Education

<a href="http://www.cfm.ohio-state.edu/homepage.html">http://www.cfm.ohio-state.edu/homepage.html</a>	OSU Center for Mapping home page
<a href="http://www.ncgia.ucsb.edu/pubs/pubs_list.html">http://www.ncgia.ucsb.edu/pubs/pubs_list.html</a>	NCGIA Publications List
<a href="http://www.swt.edu/~bb09002/class/gis.html">http://www.swt.edu/~bb09002/class/gis.html</a>	SWT GIS Class Notes
<a href="http://www.utexas.edu/depts/grg/gcraft/contents.html">http://www.utexas.edu/depts/grg/gcraft/contents.html</a>	The Geographer's Craft Project
<a href="http://www.utexas.edu/depts/grg/gcraft/notes/notes.html">http://www.utexas.edu/depts/grg/gcraft/notes/notes.html</a>	Notes for GIS and The Geographer's Craft

## Maps

<a href="http://city.net/indexes/top_maps.html">http://city.net/indexes/top_maps.html</a>	Excite City.Net Top Maps
<a href="http://mapweb.parc.xerox.com/map/">http://mapweb.parc.xerox.com/map/</a>	Xerox PARC Map Viewer
<a href="http://www.cedar.buffalo.edu/AdServ/maps.html">http://www.cedar.buffalo.edu/AdServ/maps.html</a>	Street Maps on the Net
<a href="http://www.mapquest.com/">http://www.mapquest.com/</a>	MapQuest! Welcome!
<a href="http://www.vicinity.com/yahoo/">http://www.vicinity.com/yahoo/</a>	Yahoo! Maps

## DOTs

<a href="http://www.dot.gov/internet/usadots.html">http://www.dot.gov/internet/usadots.html</a>	US State DOT Web Sites
<a href="http://www.state.nj.us/transportation/framed/njdot.htm">http://www.state.nj.us/transportation/framed/njdot.htm</a>	NJ-DOT

## Transportation – General

<a href="http://al.al.autometric.com/main/">http://al.al.autometric.com/main/</a>	AASHTO Homepage
<a href="http://ota.fhwa.dot.gov/pubs/index.html">http://ota.fhwa.dot.gov/pubs/index.html</a>	FHWA Publications on the Web
<a href="http://www.dot.gov/">http://www.dot.gov/</a>	US DOT
<a href="http://www.fhwa.dot.gov/">http://www.fhwa.dot.gov/</a>	FHWA Home Page
<a href="http://www.nas.edu/trb/">http://www.nas.edu/trb/</a>	TRB Home Page
<a href="http://www.tfrc.gov/">http://www.tfrc.gov/</a>	Turner Fairbank Highway Research Center Web Site

## Metrication Issues

<a href="http://lamar.ColoState.EDU/~hillger/">http://lamar.ColoState.EDU/~hillger/</a>	U.S. Metric Association (USMA)
<a href="http://www.dot.state.ak.us/external/state_wide/dnc/eos.d/online.html">http://www.dot.state.ak.us/external/state_wide/dnc/eos.d/online.html</a>	Downloads of Metric Manuals
<a href="http://www.mdt.mt.gov/metric/mtmetric.htm">http://www.mdt.mt.gov/metric/mtmetric.htm</a>	Montana State Metrics
<a href="http://www.pilot.infi.net/~cstone/asceref0.htm">http://www.pilot.infi.net/~cstone/asceref0.htm</a>	Metrication - Who, What, When, Where

	and Why!
<a href="http://www.pilot.infi.net/~cstone/asceref7.htm">Http://www.pilot.infi.net/~cstone/asceref7.htm</a>	Metric Conversion Pitfalls
<a href="http://www.pilot.infi.net/~cstone/com_i_1.htm">Http://www.pilot.infi.net/~cstone/com_i_1.htm</a>	ASCE Metric References
<a href="http://www.pilot.infi.net/~cstone/mfacts2.htm">Http://www.pilot.infi.net/~cstone/mfacts2.htm</a>	Metrics Facts and Figures
<a href="http://www.shaban.com/">http://www.shaban.com/</a>	The 1-Step metric conversion calculator
<a href="http://www.wsdot.wa.gov/metrics/">http://www.wsdot.wa.gov/metrics/</a>	WSDOT Metrics Page
<a href="http://www.wsdot.wa.gov/Metrics/factors.htm">http://www.wsdot.wa.gov/Metrics/factors.htm</a>	Metrics factors

#### New Jersey State sites

<a href="http://www.nasire.org/">http://www.nasire.org/</a>	State Info Resources Web Site
<a href="http://www.state.nj.us/">http://www.state.nj.us/</a>	New Jersey Home Page
<a href="http://www.state.nj.us/transportation/framed/njdot.htm">http://www.state.nj.us/transportation/framed/njdot.htm</a>	njdot
<a href="http://www.njleg.state.nj.us/folio.cgi/statutes.NFO?">http://www.njleg.state.nj.us/folio.cgi/statutes.NFO?</a>	New Jersey Permanent Statutes Database
<a href="http://www.njleg.state.nj.us/html/njleg.htm">http://www.njleg.state.nj.us/html/njleg.htm</a>	New Jersey State Legislature
<a href="http://www.yahoo.com/Regional/U_S_States/New_Jersey/">http://www.yahoo.com/Regional/U_S_States/New_Jersey/</a>	Yahoo! - Regional:U.S. States:New Jersey

#### Learn more about the Internet

<a href="http://uu-gna.mit.edu:8001/uu-gna/text/internet/notes/index.html">Http://uu-gna.mit.edu:8001/uu-gna/text/internet/notes/index.html</a>	The Internet Text Project
<a href="http://world.std.com/~walthowe/ilrntree.html">http://world.std.com/~walthowe/ilrntree.html</a>	Walt Howe's Internet Learning Center
<a href="http://www.anonymizer.com/">http://www.anonymizer.com/</a>	Conceal your computer while browsing
<a href="http://www.cookiecentral.com/demomain.htm">http://www.cookiecentral.com/demomain.htm</a>	More Information On Cookies
<a href="http://www.cybergate.net/noframes/noframe_understanding.html">http://www.cybergate.net/noframes/noframe_understanding.html</a>	Understanding the Internet
<a href="http://www.davesite.com/webstation/html/">Http://www.davesite.com/webstation/html/</a>	HTML: Interactive Tutorial for Beginners
<a href="http://www.delphi.com/navnet/">Http://www.delphi.com/navnet/</a>	Navigating the Net
<a href="http://www.delphi.com/navnet/privacy.html">Http://www.delphi.com/navnet/privacy.html</a>	Privacy: Information about you on the net
<a href="http://www.dreamscape.com/frankvad/internet.html">http://www.dreamscape.com/frankvad/internet.html</a>	Virtual Internet Guide
<a href="http://www.ed.gov/pubs/parents/internet/">Http://www.ed.gov/pubs/parents/internet/</a>	Parents Guide to the Internet
<a href="http://www.hamline.edu/library/bush/handouts/comparisons.html">http://www.hamline.edu/library/bush/handouts/comparisons.html</a>	Understanding and comparing search engines
<a href="http://www.lib.berkeley.edu/TeachingLib/Guides/Internet/FindInfo.html">http://www.lib.berkeley.edu/TeachingLib/Guides/Internet/FindInfo.html</a>	Finding Information on the Internet: A TUTORIAL
<a href="http://www.massnetworks.org/~nicoley/tutorial/tutorial.html">Http://www.massnetworks.org/~nicoley/tutorial/tutorial.html</a>	Tutorial: Introduction to the Internet for Teachers
<a href="http://www.pbs.org/uti/begin.html">Http://www.pbs.org/uti/begin.html</a>	Using and Understanding the Internet
<a href="http://www.screen.com/start/guide/default.html">http://www.screen.com/start/guide/default.html</a>	Life on the Internet: Exploring the

	Internet
<a href="http://www.ttu.edu/newslist/newsgroups.html">Http://www.ttu.edu/newslist/newsgroups.html</a>	Newsgroups available
<a href="http://www2.famvid.com/i101/internet101.html">Http://www2.famvid.com/i101/internet101.html</a>	Internet 101: Welcome!
<a href="http://www-spires.slac.stanford.edu/FIND/internet.html">Http://www-spires.slac.stanford.edu/FIND/internet.html</a>	Introduction to the Internet

#### Miscellaneous Interests

<a href="http://www.phys.virginia.edu/education/teaching/HowThingsWork/">http://www.phys.virginia.edu/education/teaching/HowThingsWork/</a>	How Things Work
<a href="http://www.cnet.com/Content/Features/Howto/?st.cn.gp.tb.fe">http://www.cnet.com/Content/Features/Howto/?st.cn.gp.tb.fe</a>	CNET Features - How To

For more information

Searching for information on the Internet can produce peculiar results. Some searches will end up with no information on the key words that you submit to the search engine, while other will come up with a long list of sites that are not relevant to the information you are looking for. In addition, the using the same key words for a search with different search engines such as Yahoo, Excite, Infoseek, Lycos, Alta Vista, etc. each one of them will produce different results. Therefore, it is advantageous to use multi engine search tools that will submit your search to several different search engines. Usually, the results of such a search produce better results and more useful information.

Examples of Multi-Engine Search Tools:

<http://www.dogpile.com/>  
<http://www.highway61.com/>  
<http://www.metacrawler.com/home.html>  
<http://www.albany.net/allinone/>  
<http://www.searchinsider.com/sites.html>  
<http://www.cs.colostate.edu/~dreiling/smartform.html>  
<http://www.cnde.iastate.edu/search.html>

## **APPENDIX F**

### **Surveying Terms and Glossary**

## **Glossary** (Edited from <http://www.auslig.gov.au/corpinfo/info/glossary.htm>)

**AMI** Active Microwave Instrument - active sensing system on-board ERS-1 and ERS-2 satellites which consists of two separate radars, operating at a frequency of 5.3ghz (c-band) with three modes of operation - a Synthetic Aperture Radar (SAR) for image and wave mode and a three antenna Wind Scatterometer.

**AOS** - Acquisition of Signal.

**ARC/INFO** - GIS Software.

**Array Sensor** - an imaging device employing an array of electronically sampled detectors in the focal plane.

**Ascending node** - the point on a satellite's orbit when a satellite crosses the Earth's Equatorial plane from South to North.

**Atmospheric correction** - image processing procedure that compensates for the effects of scattered and absorbed radiation by the atmosphere.

**Attribute accuracy** - component of data quality describing the likelihood of an attribute of a spatial feature being erroneous.

**AUTOCAD** - Drafting Software.

**Automated cartography** - the preparation and presentation of maps using machines controlled by computers.

**AVHRR** Advanced Very High Resolution Radiometer - sensor on-board the NOAA series of satellites.

**Azimuth** - geographic orientation of a line given as an angle measurement in degrees clockwise from north.

**Azimuth range** - for radar images this term represents the distance measured along a line between the limits of the radar beam in the direction of the satellite or aircraft.

**Band** - a selection of a wavelength interval in the electromagnetic spectrum.

**Band-pass filter** - a wave filter that has a single transmission band extending from a lower cutoff frequency greater than zero to a finite upper cutoff frequency.

**Bandwidth** - the number of cycles per second between the limits of a frequency band. usually associated with topographic mapping covering country or region at different scales.

**Bathymetric surveying** - is the measure of the depth and shape of the ocean floor. Usually associated with the mapping of the resources of the sea bed.

**BMP** - an abbreviation for Windows Bitmap. BMP is a common raster data format supported by many Microsoft Windows products and applications.

**Brightness** - the attribute of visual perception in accordance with which an area appears to emit more or less light.

**Cadastral survey** - a survey of the boundaries of land parcels.

**Cadastre** - a public register usually recording the quantity, value and ownership of land parcels in a country or jurisdiction.

**Calibration** - the act or process of comparing certain specific measurements in an instrument with a standard.

**Cartography** - the art and science of producing maps, charts and other representations to spatial relationships.

**CCD** Charged Coupled Device - a device in which electrons are stored at the surface of a semiconductor.

**CCRS** Canadian Centre for Remote Sensing

**Cell** - an area on the ground from which electromagnetic radiation is emitted or reflected.

**CEOS** Committee on Earth Observation Satellites

**Change detection** - sensing of environmental changes.

**Characteristic curve** - a curve showing the relationship between exposure and resulting density in a photograph image, usually plotted as density (D) against the logarithm of the exposure (log E) in candela-meter-seconds. It is also called the H and D curve, the sensitometric curve, and the D log E.

**Chemical fog** - density produced on photographic paper or films by chemical means, such as too energetic or contaminated developer.

**CNES** Centre National d'Etudes Spatiales (French Space Agency)

**Completeness** - component of data quality describing the completeness of coverage within a data set(s).

**Contour** - an imaginary line drawn on a map joining all the points on the earth that are the same height above sea level.

**Control** - a system of points which are used as fixed references for positioning other surveyed features.

**Control, ground** - control obtained by ground surveys as distinguished from control obtained by photogrammetric methods; may be for horizontal or vertical control, or both. Ground (in-situ) observations to aid in the interpretation of remote sensing data.

**Control point** - any station in a horizontal and/or vertical control system that is identified on a photograph and used for correlating the data shown on that photograph.

**Coordinates** - linear or angular quantities which designate the position of a point in a given reference or grid system.

**Coordinate, geographic** - a system of spherical coordinates for describing the positions of points on the earth. The declinations and polar bearings in this system are the latitudes and longitudes respectively.

**Coordinates, grid** - a plane-rectangular coordinate system based on and mathematically adjusted to a map projection in order that geographic positions (latitudes and longitudes)

may be readily transformed into plane coordinates and the computations relating to them made by the ordinary methods of plane surveying.

**COPYFILE** - shareware software owned and copyright by Informatix Inc, USA. Used by GEODATA RASTER-250K to reformat the raster data.

**CP** Centering Point or Control Point

**CSA** Canadian Space Agency

**DCX** - a raster image format, and is a variation of PCX file. DCX is used by many MS-DOS fax boards.

**DEM Digital Elevation Model** - a geographic grid of an area where the contents of each grid cell represents the height of the terrain in that cell. Consists of X, Y and Z coordinates.

**Descending node** - point on the orbit of a satellite when a satellite crosses the Earth's equatorial plane while moving from north to south. Using two GPS satellite receivers with one at a known position it is possible to increase the accuracy from a roving receiver by applying corrections derived from the fixed receiver.

**DIGEST** Digital Geographic Information Exchange Standard: a system for compiling spatial data directly in digital form.

**Distortion** - any shift in the position of an image on a photograph which alters the perspective characteristics of the photograph. Compression or expansion of the scale of the imagery in the azimuth direction. Change in scale from one part of the imagery to another.

**DMA** Defense Mapping Agency - United States of America

**Downlink** - a communication link between a satellite and a ground station.

**DORIS** Doplar Orbitography and Radiopositioning Integrated by Satellite

**DPI** - dots per inch.

**Dynamic range** - the ratio of maximum measurable signal to minimum detectable signal.

**EDM** Electronic Distance Measurement - measurement of distance by means of electromagnetic transmissions, including radio, visible high, laser and infrared light.

**Elevation** - the angle above the horizon, measured from the horizontal plane.

**EMR** Electromagnetic Radiation - energy propagated through space or through material media in the form of an advancing interaction between electric and magnetic fields.

**Engineering surveying** - surveying associated with the setting out and monitoring of engineering or construction works.

**Enhancement, image** - the process of altering the appearance of an image to extract additional information. It may be accomplished by digital or photographic (optical) methods.

**ERC** Earth Rotation Correction

**ERS** European Remote Sensing Satellite - ERS-1 was launched 17 July 1991 and operates in a near circular sun synchronous orbit with a period of 100 minutes. The satellite altitude is 785km. The repeat coverage cycle varies, depending on mission requirements, and includes 3, 35 and 168 day cycles. ERS-2 was launched 20 April 1995 and has the same orbit parameters as ERS-1.

**ESA** European Space Agency

**FIG** Federation Internationale des Geometres or International Federation of Surveyors

**Frequency** - the number of oscillations per unit time or number of wavelengths that pass a point per time.

**Geocentric Datum****Error! Reference source not found.** - a datum based on the Earth's centre of mass (or geocentre); as distinct from a regional datum, such as the AGD, whose origin does not coincide with the Earth's centre of mass.

**GEODATA products** - comprise map information converted into digital format. Used in conjunction with geographic information systems GEODATA products assist applications such as resource management, environmental assessment, mineral prospecting, communications and transportation planning.

**Geodesy** - the study of the size and shape of the Earth's surface, the measurement of the position and motion of points on the surface and the configuration and area of large portions of its surface.

**Geodetic control****Error! Reference source not found.** - a network of sites for which precise positions and/or heights are known and for which the shape and size of the Earth are taken into account.

**Geodetic surveying** - surveying which takes into account the shape and size of the earth. The result of a geodetic survey is a continuous series of accurately marked points on the ground, to which topographic, land and engineering surveys can be related to provide additional coordinated points for mapping and other purposes.

**Geographical Grid** - grid derived from geographical coordinates (commonly referred to as longitude and latitude).

**Geometric correction** - the removal of sensor, platform, or scene induced geometric errors such that the data conforms to a desired projection. This involves the creation of a new digital image by resampling the input digital image.

**GEOREFERENCED** - digital spatial data (and non-digital map features) for which the coordinates or location can be determined.

**GICS** Geocoded Image Correction System - an image processing system employed at ACRES.

**GIF** Graphics Interchange Format - the image file format originally developed by CompuServe as a machine-independent image file format. GIF files are a popular way of storing 8 bit, scanned or digitised images, and the compression ratios achieved are commonly better than other 8 bit formats. This format is commonly used in Internet applications.

**GIS** Geographic Information System - a computer-based system used to capture, create, maintain, display and analyze spatially-related information.

**GPS Global Positioning System**~~Error! Reference source not found.~~ - is a satellite based navigation system developed by the United States Department of Defense and widely used for civilian navigation and positioning.

**Grey scale** - a monochrome strip of tones ranging from white to black with intermediate shades of gray. The scale is placed in a setup for a color photograph and serves as a means of balancing the separation negatives and color dye images.

**Ground Station** - a facility capable of receiving signals from earth observation satellites such as LANDSAT, SPOT, ERS, JERS and MOS.

**Ground Resolution Cell** - the area on the ground that is covered by the **IFOV** of a detector.

**GRS** Grille de Reference SPOT - the system of using a path and row combination to identify nominal scene positioning for data from the SPOT satellites.

**HDDT** High Density Digital Tape - one inch magnetic tape containing data from a remote sensing satellite and recorded in a compressed format.

**HRV** Haute Resolution dans le Visible - the name given to the multispectral radiometer designed for SPOT spacecraft and offering high resolution in the visible and near-infrared. The first three SPOT spacecraft (SPOT-1,-2,-3) carry two identical HRVs designed for operation in a number of viewing configurations and in different spectral modes.

**HRVIR** Haute Resolution Visible Infra Rouge (proposed SPOT4).

**Hydrographic surveying** - the measurement and description of the physical features offshore and adjoining coastal areas with special reference to their use for the purpose of navigation.

**Hypsometric tints** - colors on a map depicting variations in the height of the earth's surface above sea level.

**IFOV** Instantaneous Field Of View - is the pixel dimensions of the bulk (Level 1) product not the pixel dimensions of the resampled product.

**IGAE** Intergovernmental Agreement on the Environment

**IMAGINE** - software owned and copyright to ERDAS, USA. Used to update RASTER-250K map images.

**IR** Infra-Red

**LANDSAT** - earth resources satellites operated by NOAA, United States. LANDSAT 5 was launched 1 March 1994 and operates in a near polar sun synchronous orbit at an altitude of 705km. Repeat cycle is 16 days.

**Legal cadastre** - a cadastre compiled so that the jurisdiction may have a record of ownership of all land parcels.

**Lineage** - component of data quality describing the history or origin of features within the described data set.

**LIS** Land Information System - synonymous with GIS although more often associated with cadastral based systems.

**Look angle (radar)** - the direction of the look, or direction, in which the antenna is pointing when transmitting and receiving from a particular cell.

**LOS** Loss of Signal

**LUT** Look-Up Table

**LZW compression** - a compression routine for raster data, patented and owned by Unisys Corporation of the United States of America.

**Map** - a representation of the earth's surface. A cadastral map is one showing the land subdivided into units of ownership; a topographic map is one showing the physical and superficial features as they appear on the ground; a thematic map displays a particular theme, such as vegetation or population density.

**Mbps** Megabits per second - the rate of transfer of binary information in millions of bits per second and commonly referred to in data transmission rates from satellites to ground stations.

**Metadata** - summary information describing the content of a dataset.

**Mining surveying** - associated with the construction, monitoring and mapping of mines and associated works.

**MLA** Multispectral Linear Array

**MMOFE** Mission Management Organization Front End - NASDA's mission management computer.

**MOS** Marine Observation Satellite (Japan)

**Mosaicing** - the assembling of photographs or other images whose edges are cut and matched to form a continuous photographic representation of a portion of the earth's surface.

**MOSS** Modelling of Surface Systems

**MQS** Microimage Quicklook System - image cataloguing system employed at ACRES.

**MSS** Multi-spectral Scanning System - a scanner on board LANDSAT 4 and 5 that records four bands of digital data.

**Multipurpose cadastre** - a cadastre containing a variety of parcel-based information considered necessary for good land administration.

**Multispectral** - generally used for acquisition of remote sensing data in two or more spectral bands.

**MW** Microwave

**Nadir** - that point on the ground vertically beneath the perspective centre of the camera lens.

**NASA** National Aeronautics and Space Administration

**NIR** Near Infra-Red

**NOAA** National Oceanic and Atmospheric Administration

**Number of looks (radar)** - this term refers to the successive observations of the same area as the antenna moves along its designated path. Many observations may be required in order to characterize the backscatter properties of a surface.

**Orbit** - path of a satellite around the earth.

**Orbital elements** - a set of parameters defining the orbit of a satellite. Also called orbital parameters.

**Orbital period** - the time taken by a satellite to make one revolution around the earth. Also referred to as the anomalous or nodal period.

**Orthographic projection** - the projection by parallel rays onto a plane at right angles to the rays.

**Orthophotomaps** - aerial maps, true to scale.

**Path** - the number of the north/south track of the satellite in its specific satellite grid. LANDSAT uses the WRS and SPOT the GRS. For LANDSAT, in the visibility circle for the Alice Springs receiving station, the path range is 84 to 117, from east to west.

**PC** - IBM or compatible personal computer.

**PCX** - raster data format originally developed by Zsoft and extensively used in IBM PC computer applications.

**Photogrammetry** - the science and art of obtaining measurements from photographs.

**PHOTOSHOP** - software owned and copyright to ADOBE, USA. Used to edit and enhance GEODATA RASTER-250K map images.

**Pixel** - a contraction of the words 'picture element'. A data element having both spatial and spectral aspects. The spatial variable defines the size of the resolution cell (i.e. the area on the ground represented by the data values), and the spectral variable defines the intensity of the spectral response for that cell in a particular channel.

**PLA** Panchromatic Linear Array - the single band sensor onboard the SPOT 1, 2, and 3 spacecraft.

**Polarisation** - the direction of vibration of the electrical field vector of **electromagnetic radiation**.

**Positional Accuracy** - component of data quality describing the planimetric accuracy of features

**PSMA** Public Sector Mapping Agencies

**Quantization** - the process of converting from continuous values of information to a finite number of discrete values.

**RADARSAT** - the earth observation satellite launched 4 November 1995 and operated by the Canadian Space Agency (CSA). RADARSAT is equipped with a C-band SAR which can be operated in a variety of modes with swath widths ranging from 35 kilometers to 500 kilometers and with resolutions from 10 meters to 100 meters respectively.

**Radiance** - a measure of the energy radiated by an object together with the frequency distribution of that radiation.

**Raster Data** - a picture or image composed of rows and columns of data cells (pixels). Satellite data and GEODATA RASTER-250K are examples of raster data.

**Raster Image** - a cellular data structure composed of rows and columns. Each cell has a value which represents an attribute value for the feature represented by that group of cells.

**Relief Displacement** - a shift in position of the optical image of an object caused by the height of the object above or depth below a datum plane.

**Remote sensing** - the acquisition of information about an object without physical contact. Usually associated with the acquisition of information about the Earth's surface by electronic and/or optical instruments from satellites, airborne platforms or ground observation.

**Repeat Cycle** - cycle time for a satellite to pass over a given point on the earth.

**Row** - the number of the east/west grid line in the specific satellite grid. LANDSAT uses the WRS and SPOT the GRS. For LANDSAT, in the visibility circle for the Alice Springs receiving station, the row range is 61 to 91, from north to south.

**SAR Synthetic Aperture Radar** - type of instrument on recently launched satellites which can "see" through clouds and make it possible to acquire satellite imagery day and night.

**SATOPS** Satellite Operations Section (ACRES) - the primary responsibilities include the management of all client future acquisition requests and also long and short term acquisition planning for the ACRES archive program.

**Scale** - the indication given on a map, either as a linear scale or representative fraction, of the ratio between a given distance on the map and the corresponding distance on the earth's surface.

**SDTS** Spatial Data Transfer Standard

**Sensor** - any device which gathers EMR or other energy and presents it in a form suitable for obtaining information about the environment.

**Slant Range** - for radar images this term represents the distance measured along a line between the antenna and the target.

**SLR Satellite Laser Ranging** - the measurement of the distance to a satellite fitted with retro-reflectors, by measuring the time taken for a laser beam to travel to the satellite and

back. These measurements are used to determine satellite orbits and to monitor the movement of the earth.

**Spectral band** - an interval in the electromagnetic spectrum defined by two wavelengths, frequencies, or wave numbers.

**SPOT** Satellite Pour L'Observation de la Terre - the SPOT series of earth observation satellites are operated by CNES, France. SPOT 1 was launched 22 February 1986, SPOT 2 was launched 21 January 1990 and is currently operational and SPOT 3 was launched 26 September 1993 and is currently fully operational. SPOT satellites are operated in a sun synchronous near polar orbit. Satellite altitude is 830km and the repeat cycle is 26 days. SPOT 4 is proposed for launch in December 1997.

**Stereoscopic pair** - two images of the same area taken from different camera stations so as to afford stereoscopic vision; frequently called stereopair.

**Stereoscopic plotting instrument** - an instrument for plotting a map or obtaining spatial solutions by observation of stereoscopic models formed by stereopairs of images.

**Sun synchronous** - earth satellite orbit in which the orbital plane is near polar and the satellite passes over points on the earth at the same latitude at the same local sun time.

**Surveying** - measurement of dimensions (contour, position, boundaries, area, height etc.) of any part of the earth's surface (land or water) or any cultural feature. Depending on the type of survey undertaken and the degree of accuracy required, "surveys" may involve the application of the theory, principles and techniques of geodesy, photogrammetry and cartography.

**SWIR** Short Wave Infra-Red

**Telemetry** - radio signals transmitted between satellites and ground stations.

**TIFF** Tagged Information File Format - raster image format created by Aldus and Microsoft Corporations and designed to be a universal format. It is used extensively in desktop publishing packages. TIFF can be compressed using a wide range of compression routines. The most common of these is LZW.

**Title** - the evidence of a person's right to land.

**TM** Thematic Mapper - a scanner on-board the LANDSAT 4 and 5 satellites that records seven bands of digital data.

**Topographic surveying** - involves establishing the contour level and interval of the earth's surface above and below sea level based on a particular control survey system. These surveys may be done by aerial, photogrammetric and ground survey and involves recording of natural features such as hills, streams, valleys and cultural features, such as roads, bridges, railways, etc. These surveys are used to produce topographic maps.

**Topography** - description or representation on a map of the physical and cultural surface features.

**UV** Ultra-Violet

**Vector data** - spatial data in which the location of features is defined by points and straight lines (vectors). A road network would be described by vector data.

**VLBI Very Long Baseline Interferometry**

**Wavelength** - the least distance between particles moving in the same phase of oscillation in a wave disturbance. For electromagnetic waves wavelength is influenced by the environment in which the waves are propagating (e.g. air versus a vacuum).

**WGS84** World Geodetic System 1984 Geocentric datum used by GPS systems.

**WRS** World Reference System - the system of using a path and row combination to identify nominal scene positioning for data from the MSS and TM sensors on the LANDSAT satellite.

## GPS/GIS/LIS Glossary of Terms

FROM ASHTECH <http://www.ashtech.com/pages/gps/glossary.html>

**Aerotriangulation (phototriangulation)** - a complex process vital to aerial photogrammetry that involves extending vertical and/or horizontal control so that the measurements of angles and/or distances on overlapping photographs are related to a spatial solution using the perspective principles of the photographs. Aerotriangulation consists of mathematically extending the vectors/angles of a triangular pattern of known reference points on or near the designated photo-block terrain upward through a rectangle representing the area of the photo-block (as seen by the camera's optical center) in such a way that the three-point terrain triangle and the camera's eye three-point triangle (within the photographic frame) are analogous.

**Almanac** - a set of parameters used by a GPS receiver to predict the approximate locations of a GPS satellite and the expected satellite clock offset. Each GPS satellite contains and transmits the almanac data for all GPS satellites. (See ephemeris **Error! Reference source not found.**).

**Ambiguity** - the initial bias in a carrier-phase observation of an arbitrary number of cycles; the uncertainty of the number of cycles a receiver is attempting to count. If wavelength is known, the distance to a satellite can be computed once the number of cycles is established via carrier-phase processing.

**Antenna** - a variety of GPS antennas ranging from simpler microstrip devices to complex choke ring antennas that mitigate the effects of multipath scattering.

**Anti-Spoofing (AS)** - the process of encrypting the P-Code modulation sequence so that the code cannot be replicated by hostile forces. When encrypted, the P-Code is referred to as the Y-Code (see Y-Code & Spoofing). **Error! Reference source not found.**

**Atomic clock** - a clock whose frequency is maintained using electromagnetic waves that are emitted or absorbed in the transition of atomic particles between energy states. The frequency of an atomic transition is very precise, resulting in very stable clocks. A cesium clock has an error of about one second in one million years. For redundancy purposes, GPS satellites carry multiple atomic clocks. GPS satellites have used rubidium clocks as well as cesium clocks. The GPS Master Control Station uses cesium clocks and a hydrogen maser clock.

**Baseline** - the measured distance between two receivers or two antennas.

**Bipolar biphasic shift key (BPSK)** - the modulation technique used on GPS satellites. In this method, a binary bit transition results in a 180-degree shift of the carrier.

**Cadastral survey** - a survey that defines boundaries, property lines, etc., and pertains to cadastre, an official register of ownership, the extent and value of real property. Cadastral surveys usually determine taxation.

**Carrier frequency** - the basic frequency of an unmodulated radio signal. GPS satellite navigation signals are broadcast on two L-band frequencies, L1 and L2. L1 is at 1575.42 Mhz, and L2 is at 1227.6 Mhz.

**Carrier phase** - the fraction of a cycle, often expressed in degrees, where 360 degrees equals a complete cycle. Carrier phase can also mean the number of complete cycles plus a fractional cycle. In a survey-grade GPS receiver, the receiver can lock on to a satellite and, keeping track of the number of whole cycles of the carrier, creates a cumulative phase of the signal which is often referred to as integrated Doppler.

**C/A (clear acquisition) Code** - consists of a sequence of 1023 bits (0 or 1) that repeats every millisecond. Each satellite broadcasts a unique 1023-bit sequence that allows a receiver to distinguish between various satellites. The C/A-Code modulates only the L1 carrier frequency on GPS satellites. The C/A-Code allows a receiver to quickly lock on to a satellite.

**Carrier phase** - the cumulative phase of either the L1 or L2 carrier of a GPS signal, measured by a receiver while locked-on to the signal (also known as integrated Doppler).

**Channel** - refers to the hardware in a receiver that allows the receiver to detect, lock-on and continuously track the signal from a single satellite. The more receiver channels available, the greater number of satellite signals a receiver can simultaneously lock-on and track.

**Circular Error Probable (CEP)** - the radius of a circle, centered at the true location, within which 50% of position solutions fall. CEP is used for horizontal accuracy (see SEP).

**Constellation** - refers to the collection of orbiting GPS satellites. The GPS constellation consists of 24 satellites in 12-hour circular orbits at an altitude of 20,200 kilometers. In the nominal constellation, four satellites are spaced in each of six orbital planes. The constellation was selected to provoke a very high probability of satellite coverage even in the event of satellite outages.

**Conventional Terrestrial System (CTS)** - a standardized reference system, originating at the planet's center of mass, that is designed to allow uniformity in geodetic measurements and computations.

**Cycle slip** - a loss of count of carrier cycles as they are being measured by a GPS receiver. Loss of signal, ionospheric interference and other forms of interference cause cycle slips to occur (see carrier phase).

**Differential GPS (DGPS)** - a technique whereby data from a receiver at a known location is used to correct the data from a receiver at an unknown location. Differential corrections can be applied in either real-time (see RTCM SC-104 format **Error! Reference source not found.**) or by post-processing. Since most of the errors in GPS are common to users in a wide area, the DGPS-corrected solution is significantly more accurate than a normal SPS solution.

**Dilution of Precision (DOP)** - a measure of the receiver-satellite(s) geometry. DOP relates the statistical accuracy of the GPS measurements to the statistical accuracy of the solution. Geometric Dilution of Precision (GDOP) is composed of Time Dilution of Precision (TDOP) & Position Dilution of Precision (PDOP), which are composed of Horizontal Dilution of Precision (HDOP) & Vertical Dilution of Precision (VDOP).

**Doppler shift** - a shift similar to that experienced by audio phenomena, except occurring in the electromagnetic spectrum, where an apparent change in signal frequency occurs as the transmitter and receiver move toward or away from one another.

**Double difference** - (see single difference **Error! Reference source not found.**) the arithmetic differencing of carrier phases measured simultaneously by a pair of receivers tracking the same pair of satellites. Single differences are obtained by each receiver from each satellite; these differences are then differenced in turn, which essentially deletes all satellite and receiver clock errors.

**Earth Centered, Earth Fixed (ECEF)** - a Cartesian coordinate system centered at the earth's center of mass. The Z-axis is aligned with the earth's mean spin axis. The X-axis is aligned with the zero meridian. The Y-axis is 90 degrees west of the X-axis, forming a right-handed coordinate system.

**Elevation mask** - an adjustable feature of GPS receivers that specifies that a satellite must be at least a specified number of degrees above the horizon before the signals from the satellite are to be used. Satellites at low elevation angles (five degrees or less) have lower signal strengths and are more prone to loss of lock thus causing noisy solutions.

**Ellipsoid of revolution (often referred to simply as ellipsoid)** - a mathematical representation of the earth that is an ellipse that is rotated about its minor axis. An ellipsoid is an equipotential surface of a rotating, homogeneous body. Various ellipsoid models have been determined to approximate the geoid in local areas and in a global sense. GPS uses the WGS84 earth model which is based on the GRS80 ellipsoid.

**Ephemeris (plural: ephemerides)** - a set of parameters used by a GPS receiver to predict the location of a GPS satellite and its clock behavior. Each GPS satellite contains and transmits ephemeris data its own orbit and clock. Ephemeris data is more accurate than the almanac data but is applicable over a short time frame (four to six hours). Ephemeris data is transmitted by the satellite, every 30 seconds. (See almanac **Error! Reference source not found.**)

**Firmware** - the electronic heart of a receiver, where coded instructions relating to receiver function, and (sometimes) data processing algorithms, are embedded as integral portions of the internal circuitry.

**Frequency** - the number of times that a periodic event occurs per unit of time. For GPS, frequency usually refers to the radio frequency, in Hz, of either of two basic carriers transmitted by each satellite (see L1 & L2 **Error! Reference source not found.**).

**Geodetic coordinates** - a coordinate system whose elements are latitude, longitude and geodetic height. The latitude is an angle based on the perpendicular to the ellipsoid. Longitude is the angle measured in the XY plane (see ECEF **Error! Reference source not found.**).

**Geodetic datum (horizontal datum)** - a specifically oriented ellipsoid typically defined by eight parameters which establish its dimensions, define its center with respect to Earth's center of mass and specify its orientation in relation to the Earth's average spin axis and Greenwich reference meridian.

**Geodetic height (ellipsoidal height)** - the height of a point above an ellipsoidal surface. The difference between a point's geodetic height and its orthometric height equals the geoidal height.

**Geoid** - the equipotential surface of the Earth's gravity field which best fits mean sea level. Geoids currently in use are GEOID84 and GEOID90.

**Geoidal height (geoidal separation; undulation)** - the height of a point on the geoid above the ellipsoid measured along a perpendicular to the ellipsoid.

**Global Orbiting Navigation Satellite System (GLONASS)** - the Russian version of GPS.

**GPS week** - GPS time started at Saturday/Sunday midnight, January 6, 1980. The GPS week is the number of whole weeks since GPS time zero.

**Gravity** - a force that is the vector sum of gravitational attraction of the various masses within the planet (gravitation) plus the centrifugal force caused by the rotation of the Earth. Unit of measurement: the gal = 1 cm per m/sec<sup>2</sup>.

**Hydrographic and bathymetric surveying** - surveying or mapping of harbors, inlets or deep water locations. Hydrography is the study of the physical characteristics of oceans, lakes and rivers as well as the elements affecting safe navigation. Bathymetry is the measurement and study of water depths.

**Ionosphere** - refers to the layers of ionized air in the atmosphere extending from 70 kilometers to 700 kilometers and higher. Depending on frequency, the ionosphere can either block radio signals completely or change the propagation speed. GPS signals penetrate the ionosphere but are delayed. The ionospheric delays can be either predicted using models, though with relatively poor accuracy, or measured using two frequency receivers.

**Julian date** - the number of days that have elapsed since 1 January 4713 B.C. in the Julian calendar. GPS time zero is defined to be midnight UTC, Saturday/Sunday, 6 January 1980 at Greenwich. The Julian date for GPS time zero is 2,444,244.5.

**Kinematic surveying** - a method which initially solves wavelength ambiguities and retains the resulting measurements by maintaining a lock on a specific number of satellites throughout the entire surveying period.

**L1 & L2** - designations of the two basic carrier frequencies transmitted by GPS satellites that contain the navigation signals. L1 is 1,575.42 Mhz and L2 is 1,227.60 Mhz.

**L-band** - a nominal portion of the microwave electromagnetic spectrum ranging from 1 to 2 Ghz.

**Multipath** - the reception of a signal both along a direct path and along one or more reflected paths. The resulting signal results in an incorrect pseudorange measurement. The classical example of multipath is the "ghosting" that appears on television when an airplane passes overhead.

**Multiplexing** - a technique used in some GPS receivers to sequence the signals of two or more satellites through a single hardware channel. Multiplexing allows a receiver to track

more satellites than the number of hardware channels at the cost of lower effective signal strength.

**Navigation messages** - data modulated onto the satellite's signals. The navigation data is transmitted at 50 bits per second and contains ephemeris and clock data for that particular satellite, other data required by a receiver to compute position velocity and time and almanac data for all NAVSTAR satellites. The data is transmitted in 1500 bit frames, each requiring 30 seconds to transmit. A complete set of data to include all almanacs, timing information, ionospheric information and other data requires 12-1/2 minutes to transmit.

**NAVigation Satellite for Timing And Ranging (NAVSTAR)** - Another term for GPS or sometimes used in conjunction with GPS as in "NAVSTAR GPS."

**On-the-Fly (OTF)** - a term used to describe the technique of resolving differential carrier-phase integer ambiguities without requiring a GPS receiver to remain stationary.

**Orbit** - the path a satellite takes in space.

**Orthometric height (orthometric elevation)** - the height of a point above the geoid.

**P-Code** - "precise" or "protected" code which is bi-phase shift modulated on both the L1 and L2 carrier frequencies. P-code has a 10.23MHz bit rate and, as implemented in GPS, has a period of one week. Each satellite has a unique P-code that is used to distinguish the satellite from all other GPS satellites.

**Photogrammetry** - an aerial remote sensing technique whose latest innovations employ a high-resolution aerial camera with forward motion compensation and uses GPS technology for pilot guidance over the designated photo block(s). Photogrammetry forms the baseline of many Geographic Information Systems (GIS) and Land Information System (LIS) studies and endeavors.

**Post-processing** - the reduction and processing of GPS data after the data was actually collected in the field. Post-processing is usually accomplished on a computer in an office environment where appropriate software is employed to achieve optimum position solutions.

**Precise Positioning System (PPS)** - the more accurate GPS capability that is restricted to authorized, typically military, users.

**Pseudo-kinematic surveying** - a variation of the kinematic method where roughly five-minute site occupations are repeated at a minimum of once each hour.

**Pseudorandom noise (PRN)** - the P(Y) and C/A codes are pseudo-random noise sequences which modulate the navigation signals. The modulation appears to be random noise but is, in fact, predictable hence the term "pseudo"random. Use of this technique allows the use of a single frequency by all GPS satellites and also permits the satellites to broadcast a low power signal.

**Pseudorange** - the measured distance between the GPS receiver antenna and the GPS satellite. The pseudorange is approximately the geometric range biased by the offset of the receiver clock from the satellite clock. The receiver actually measures a time difference which is related to distance (range) by the speed of propagation.

**Quartz oscillator** - the timing device within a receiver that synchronizes the receiver's operation and maintains time for the receiver.

**Ratio** - a measure of the precision of observations that takes into account the resolution of ambiguities and arrives at an RMS value during the processing computations.

**Real-time** - refers to immediate, "on the spot," GPS data collection, processing and position determination (usually) within a receiver's firmware, rather than post-processing "after the fact" via a computer in an office environment.

**Real-time kinematic (RTK)** - a DGPS process where carrier-phase corrections are transmitted in real-time from a reference receiver at a known location to one or more remote "rover" receiver(s).

**Reference Network** - a series of monuments or reference points with accurately measured mutual vectors/distances that is used as a reference basis for cadastral and other types of survey.

**Reference Station** - a point (site) where crustal stability, or tidal current constants, have been determined through accurate observations, and which is then used as a standard for the comparison of simultaneous observations at one or more subordinate stations. Certain of these are known as Continuous Operating Reference Stations (CORS), and transmit reference data on a 24-hour basis.

**RINEX** - the Receiver-INdependent EXchange format for GPS data, which includes provisions for pseudorange, carrier-phase, and Doppler observations.

**Root mean squared (RMS)** - a statistical measure of the scatter of computed positions about a "best fit" position solution. RMS can be applied to any random variable.

**RTCM SC-104 format** - a standard format used in the transmission of differential corrections.

**Satellite Image Mapping (SIM)** - a product of remote sensing where discrete blocks of orbital photography are "mosaicked" into a comprehensive whole, then "geocoded" or computer-linked to specific Mercator, Lambert Conformal, or other types of projections that include a scale factor and reference geoid, with each pixel related to a specific latitude and longitude.

**Selective Availability (SA)** - the process whereby DoD "dithers" the satellite clock and/or broadcasts erroneous orbital ephemeris data to create a pseudorange error (see Standard Positioning System **Error! Reference source not found.**).

**Spherical Error Probable (SEP)** - a navigational measure of accuracy equaling the radius of a sphere, centered on the true location, inside which 50% of the computed solutions lie. (See CEP.)

**Sidereal Time** - is defined by the hour angle of the vernal equinox. Taking the mean equinox as the reference yields true or apparent Sidereal Time. Neither Solar nor Sidereal Time are constant, since angular velocity vary due to fluctuations caused by the Earth's polar moment of inertia as exerted through tidal deformation and other mass transports.

**Single difference** - the arithmetic "differencing" of carrier phases simultaneously measured by a pair of receivers tracking the same satellite (between-receivers and satellite), or by a single receiver tracking two satellites (between-satellite and receivers); the former essentially deletes all satellite clock errors, while the latter essentially deletes all receiver errors.

**Software** - usually refers to a set of advanced modules, such as Ashtech's PRISM II Package, that allows the user to plan efficient surveys, organize and acquire GPS data, verify and download GPS data into a computer, process and analyze the measurements, perform a network adjustment, and report/archive the final results.

**Spoofing** - the process of replicating the GPS code in such a way that the user computes incorrect position solutions.

**Standard Positioning System** - the less accurate GPS capability which is available to all. (See Anti-Spoofing and Selective Availability **Error! Reference source not found.** **Error! Reference source not found.**).

**Static observations** - a GPS survey technique that requires roughly one hour of observation, with two or more receivers observing simultaneously, and results in high accuracies and vector measurements.

**Triple difference** - the arithmetic difference of sequential, doubly-differenced carrier-phase observations that are free of integer ambiguities, and therefore useful for determining initial, approximate coordinates of a site in relative GPS positioning, and for detecting cycle slips in carrier-phase data. (See single difference & double difference **Error! Reference source not found.**)

**Universal Time Coordinated (UTC)** - time as maintained by the U.S. Naval Observatory. Because of variations in the Earth's rotation, UTC is sometimes adjusted by an integer second. The accumulation of these adjustments compared to GPS time, which runs continuously, has resulted in an 11 second offset between GPS time and UTC at the start of 1996. After accounting for leap seconds and using adjustments contained in the navigation message, GPS time can be related to UTC within 20 nanoseconds or better.

**World Geodetic System 1984 (WGS 84)** - a set of U.S. Defense Mapping Agency parameters for determining global geometric and physical geodetic relationships. Parameters include a geocentric reference ellipsoid; a coordinate system; and a gravity field model. GPS satellite orbital information in the navigation message is referenced to WGS 84.

**Y-Code** - the designation for the end result of P-Code during Anti-Spoofing (AS) activation by DoD.

**Y-Code tracking, civilian** - several methods of obtaining valid data from encrypted Y-code are available:

1. Signal squaring (now obsolete) multiplies the signal by itself, thus deleting the carrier's code information and making distance measurement (ranging) impossible. Carrier phase measurements can still be accomplished, although doubling the carrier frequency halves

the wavelength, further weakening an already weak signal. This method required collecting data over a much longer period.

2. Cross correlation, where no local (receiver) code is generated to match the L1 & L2 encrypted Y-codes. The ionosphere "slows" the L2 Y-code slightly in respect to the L1 Y-code, hence the difference between these distances can be measured and, once known, matched and multiplied to remove the codes and leave pure carrier frequencies for measurement. This does away with the half-wavelength problem, but again results in a weakened signal that necessitates longer observation periods.

3. Code correlation & squaring. Here, the L1 & L2 Y-Codes are compared against a locally generated P-Code; the difference (the encrypting Y-code signal) is thus revealed, measured and squared so that pure carrier frequencies can be measured. Squaring once again weakens the resulting half-wavelengths of both carrier frequencies, and once again requires longer observation periods.

4. Ashtech's "Z-Technique" (see Z-Tracking™).

**Z count** - a 29-bit binary number consisting of the fundamental GPS time unit. The (10) most significant bits carry the GPS week number, and the (19) least significant bits give the time of week (TOW) count in units of 1.5 seconds.