SURVEYING AND MAPPING MANUAL

pennsylvania
DEPARTMENT OF TRANSPORTATION
www.penndot.pa.gov

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CHAPTER 1 - GENERAL REQUIREMENTS

This chapter outlines the specific products, services, standards, and procedures available for use when requesting and using surveys, lidar, aerial photography, Unmanned Aerial Systems (UAS), and photogrammetry. The products and services described have specific uses during preliminary and final design, and construction phases. The District Chief of Surveys is the accountable party for determining appropriate data collection and processing methods for your project.

1.0 ROLES AND RESPONSIBILITIES

The Importance of early and continuous coordination between the Survey Unit and Design Unit cannot be overstated.

DISTRICT PROJECT MANAGER (PM)

The District Project Manager (PM) or designated District project development lead is responsible for requesting an existing conditions model to support project development. The PM will obtain a request form from the District Chief of Surveys. This form may be found in Appendix C.1.2.1. PMs initiate survey requests and communicate intended uses of survey products and timelines for final deliverables to the District Chief of Surveys. Requests will be issued at a minimum of six months in advance of a preliminary survey's due date, except in emergency situations. The intended uses of survey products and schedule constraints will help the District Chief of Surveys to determine appropriate data collection technologies and approaches.

DISTRICT CHIEF OF SURVEYS (DCS)

The District Chief of Surveys (DCS) is responsible for determining survey accuracy requirements, along with data collection technologies and methods, production-hour/cost estimates, and schedules for the delivery of the survey products. It is important for the DCS to be involved early in the project development process to carefully plan resources and coordinate data collection and post-processing activities. Existing conditions digital models serve as foundations for design models, so the DCS understanding specific project needs is important. The DCS is also responsible for coordinating with the Photogrammetry and Surveys Section. The importance of early and continuous coordination between the Survey Unit and Design Unit cannot be overstated.

PHOTOGRAMMETRY AND SURVEYS SECTION (PSS)

The Photogrammetry and Surveys Section (PSS) is responsible for providing production-hour/cost estimates, project schedules, and recommendations about products to be considered for mapping projects, including geodetic surveys, aerial photography, UAS, photogrammetric mapping, aerial, mobile and advanced lidar, among others. All requests start at the Districts and must be coordinated with their DCS. PSS will also provide UAS support to the Districts. Even if photogrammetric mapping is not required for a project, project managers may want to consider contacting the DCS to obtain aerial photography for displays, public meetings, and project planning.

1.1 EXISTING CONDITION SURVEY CHARACTERISTICS

An existing conditions survey is required for most design projects and will often employ several technologies resulting in an integrated survey compiled from different data sets.

> **Designing a survey is a balance between achieving accuracy, precision, data density, and controlling cost and effort.**

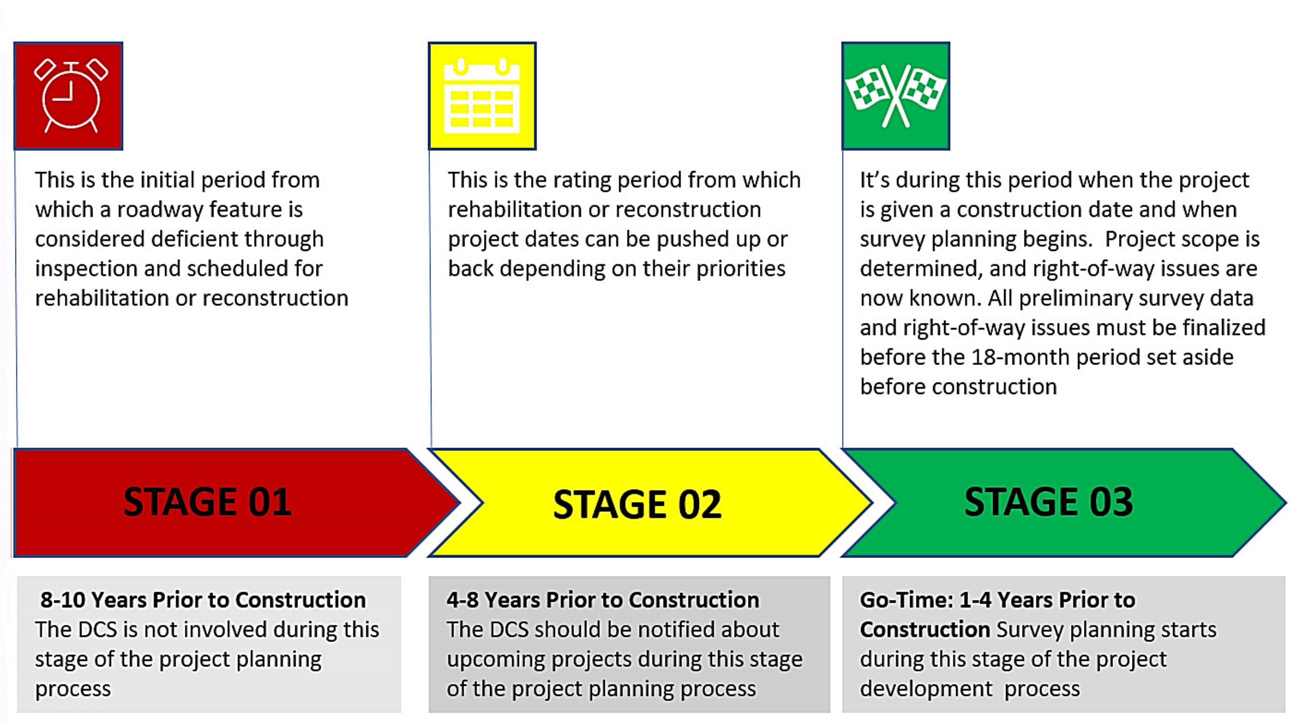
Designing a survey is a balance between achieving accuracy, precision, data density, and controlling cost and effort. Many factors affect the selection of survey requirements for a project. Field survey characteristics should be reviewed to meet the project requirements. Careful evaluation of project requirements with respect to the selection of survey procedures and methods should be undertaken by all interested parties during the scoping process.

The following factors should be considered in the evaluation and decision-making process:

- Location/Complexity- All project locations requiring survey will need accurate horizontal and vertical monumentation to be established and protected during the project's timeline. This horizontal and vertical monumentation is utilized to facilitate the reestablishment of alignment(s) and elevation(s) throughout design, construction operations, final plans (as-builts), and future location operations. Complex projects involving interchanges, intersecting side roads, and large bridges also require an abundant amount of accurate monumentation while projects involving simpler designs and construction activities require less monumentation and may not require stringent vertical control or horizontal alignment.
- Database- The availability of data for performing a project survey has a direct bearing on the requirements. As an example, a project on a new location with photogrammetric mapping will require relatively precise horizontal and vertical control surveying to ensure that measurements, computations, monumentation, and staking meet required accuracies. Another example would be a project on a new location without photogrammetric mapping. Such a project requires the same precision for monumentation of horizontal and vertical alignment control, but also requires additional precise, control traversing to tie the projects' datum to the geodetic reference system.
- Project Variability- Individual projects may necessitate several classifications of surveys in response to a combination of design and construction requirements. As an example, a reconstruction project at an existing location with mainline resurfacing and with widening at an intersection would require alignment staking and horizontal resurfacing of the mainline with additional vertical control and resurfacing in the area of the widening. Survey requirements must fit project needs.
- Methods- The methods by which survey data are collected can be directly proportional to existing data availability. Direct consultation with the DCS may yield substantial time and cost savings due to the knowledge of previous or on-going survey activities in or around the project location. As an example, a proposed survey for a large bridge reconstruction project in an area where Photogrammetry was done a year earlier for roadway betterment. In these cases, utilizing Photogrammetry data and infusing new terrestrial data will yield a decrease in survey time as well as cost. Ultimately it is up to both the Project Manager and DCS to determine project needs, the viability of using existing data, required accuracies and densities needed to manage construction risk, as well as best methods of collection.

1.2 SURVEY PROJECT REQUESTS

IT'S GO TIME… It's during this period when the project is given a construction date and when survey planning begins. Project scope is determined, and right-of-way issues are now known.



Project Timeline for Survey Requests

Figure 1.2.1

A. DISTRICT SURVEY REQUEST

The PM reviews this form with the DCS to establish the scope and schedule of the project, along with the type of survey to be performed. A standard version of this form can be found in Appendix C.1.2.1 or see the DCS for a District specific survey request form.

This form indicates the who, what, where, when, and why, as well as any other pertinent project specifics. Any special or crucial information to be attained from the survey must be specified on this form. The PM should review this form along with the DCS to substantiate the scope of the project, schedule, and the type of survey to be performed.

Survey requests are submitted to the DCS and include the following information:

- Project number

- Project description
- Type of Project (Betterment, Right-of-Way (R/W), Milling, Culvert Replacement, among others)
- Location and mapping limits delineated on a map
- Desired deliverables (existing condition survey, bridge survey, Right-of-Way survey, 3D model)
- Output file type needed
- Project schedule and status (including existing R/W plans, Deeds, among others)
- The need for any additional survey resources such as photogrammetry, UAS, or lidar can be determined during this consultation and the DCS can consider the following requests.

B. PHOTOGRAMMETRY REQUEST

When submitting the form to the PSS, the DCS or District Photogrammetry Coordinator shall review the request with the Photogrammetry Manager, or if absent, the Chief of Surveys in Photogrammetry. A standard version of this from can be found in Appendix C.1.2.2. Forms may be sent to the resource account, PD, Photogrammetry and Surveys Requests (PSSrequest@pa.gov) or directly to the Chief of Surveys in Photogrammetry.

C. STATIC (TERRESTRIAL) LIDAR MONITOR REQUEST

Many Districts have Static lidar capability, however, when assistance is needed, the DCS may submit this form to the PSS. The DCS or PM shall review the request with the Chief of Surveys in Photogrammetry. A standard version of this from can be found in Appendix C.1.2.3.

D. MOBILE LIDAR REQUEST

The need for mobile lidar on a project is usually determined by the DCS or the PSS. It is mainly used to acquire roadway corridor surfaces and is similar in accuracy to ground survey. Also, overhead features are collected more accurately and efficiently. Lastly, the safety issues and lane closures associated with ground surveys are alleviated when using this data collection method. If it is determined that mobile lidar may benefit a project, designate this special need in the Photogrammetry Request Form.

E. UAS REQUEST

UAS flights may be requested by the DCS or PSS. UAS aerial capture can be used for many applications within the Department. Mapping applications can include both aerial and lidar collection of project sites to densify terrain data and create aerial mapping deliverables. UAS requests are initiated with the Photogrammetry Request Form.

Project Timeline for Survey Requests

Figure 1.2.1

1.3 PRODUCT DELIVERABLES

A. FIELD SURVEY SERVICES AND DELIVERABLES

PennDOT requires all survey service requests to be reviewed by the DCS.

There are several types of surveys:

- Preliminary Surveys are performed to obtain accurate topography utilizing a variety of advanced survey equipment to reach the desired accuracy required for design. Below is a list of some project types that would require topography data that preliminary survey provides.
  - Bridge replacement or reconstruction
  - Roadway improvements
  - Traffic Signal improvements
  - Streetscape improvements
- Right-of-Way & Retracements Surveys are performed to delineate the Department’s interest in right-of-way or state-owned property whether it be by fee title or easement.
  - Vacation
  - Disposition
  - Acquisition
  - Right-of-Way re-establishment
  - State property boundary retracements
- Construction Layout is the process of placing stakes or other markings in or on the ground to delineate position from a plan or other reference. This survey provides a real time reference for checking horizontal and vertical measurements against the design requirements.
- As-built Surveys are similar to preliminary surveys; however, the survey is performed after the project is completed to compare the built environment against the design requirements. These surveys also provide detailed locations to finalize the 3D model and aid in Asset Management.

B. AERIAL SURVEY AND ADVANCED LIDAR SERVICES AND DELIVERABLES

All discussions regarding the services described in this section should start with your DCS or Photogrammetry Coordinator.

- Aerial Surveys

An aerial survey is a method in which imagery is collected by using airplanes and UAS platforms. The imagery is used for mapping highway projects and is developed using a variety of techniques. Flights may be conducted year-round; however, mapping projects resulting from winter or summer photography could be lower quality and have large areas obscured by vegetation or snow.

Products developed from an aerial survey may include:

  - Vertical aerial photos are taken from a near vertical orientation or with the axis of the camera pointed straight toward the ground. For crewed aerial missions, this can result in pixels as small as 1.0 inch and covering several thousand feet in each direction per photograph up to much lower resolution (larger pixels), but covering several miles in each direction per photograph. Traditional staffed aerial vertical imagery can be more cost effective on larger project sites. For UAS, resolution is much higher (much smaller pixels, as small as a 0.05 inch). but covering less area per photograph. UAS missions can generally be mobilized much more easily and can capture a large number of images in a small amount of time. All vertical aerial imagery should be planned so that it may be used to produce mapping should that become necessary.

- Oblique photos are any non-vertical images taken with the camera axis tilted from the vertical plane. High oblique images capture the horizon in their limits, while low oblique images are tilted more toward the vertical axis and do not include the horizon within their limits. It may be possible to use oblique imagery in automated photogrammetric modelling programs. Oblique imagery is particularly useful for construction monitoring and final project documentation.

- Ortho-corrected imagery are images that have photogrammetric corrections along with relief displacement applied so that the imagery becomes 'true scale,' and each pixel of the imagery is in its proper geo-graphic location. Ortho-corrected imagery will line up with other survey and design data produced to the same accuracy and on the same datum. Ortho-corrected images are a part of every mapping project and will be produced to the same accuracy, scale, and datum as the mapping. However, lower accuracy ortho-corrected imagery can be produced independently.

- Photogrammetric mapping is most useful as a base map upon which other surveys are added, or where high accuracies are not needed. Photogrammetry offers the benefits of dense and intelligently collected data, but individual data points are low accuracy, achieving 2" RMSE on hard surfaces. The data density contributes to an overall accurate DTM. Photogrammetric mapping includes these components:

  - Planimetric mapping depicts the horizontal position of features on the Earth's surface, including natural and cultural physical features. These elements also include ground cover, such as wooded areas, brush or cultivation and bodies of water, like streams, rivers, or lakes.

  - Digital Terrain Models (DTMs) are used in the generation of contours, profiles, and cross-sections. DTMs consist of breaklines (a line depicting a major change in contour direction) mass points (random spot elevations) and spot elevations (high and low points in the terrain). DTMs can also be used to compute volumetric quantities.

  - Automated reality modelling is a process where photogrammetric corrections are applied to imagery and each pixel is placed on its actual horizontal and vertical position. This creates a point cloud of data from which terrain definition can be extracted. This process can be completed very rapidly; however, vegetation, vehicles, snow, and other obstructions will be a part of the DTM, not bare earth only.

- Advanced Lidar

Advanced lidar is a remote sensing technology that allows for rapid and accurate data collection for mapping highway projects. Lidar may be collected from different platforms:

- Mobile lidar is a complex lidar technology where lidar data is collected from any moving terrestrial vehicle. Mobile lidar, when properly controlled and executed, reaches ground survey accuracies. It is typically used within the Department to provide high accuracy shoulder-to-shoulder mapping for roadways and is usually integrated into photogrammetric mapping. It is most useful on digital delivery projects that are over one-half mile in length. Shorter digital delivery projects, such as intersection improvements would benefit more from static lidar which is when the lidar data is collected from a static location. The portable static lidar instrument is typically mounted on a tripod and utilizes imagery and a laser-based measurement system.

- Aerial lidar is similar to mobile but captured from a crewed airplane or UAS. From a crewed airplane, extremely fast lidar units lead to dense ground sampling and can reach accuracies higher than photogrammetry, but generally lower than mobile lidar. However, new techniques and equipment are reaching mobile lidar accuracies and may be an alternative for higher pavement accuracies. The dense sampling and multiple returns can also measure bare earth through vegetation where other remote sensing can't. UAS based lidar is not as fast but may be useful for smaller sites or specialized applications.

1.4 SURVEY RECORDS AND ARCHIVES

Survey Records and Archives contain valuable data that pertains to the history of how a survey was performed and any control set or recovered. This valuable data can help retrace the footsteps of the previous surveyor to determine if there was an error or re-establish previous control for a new project. Survey archives, including field books, will be maintained for the current statute of limitations of 12 years. Field Books containing data used to establish right-of-way baselines, property lines and corners, or other high-order control data should be archived as historic record.

A. SURVEY FIELD BOOKS

- All surveys shall have a field book record and/or a survey report provided for each survey at the discretion of the DCS for the division performing or requesting said survey.
- The field book record shall be required and may be in book form (Form D-428) and/or in electronic form at the discretion of the DCS for the division performing or requesting said survey.
- Survey notes are original records, and care will be exercised to guard against the loss of and/or the damage to any field books. Each survey party chief or other person using a field book will be charged with its safe custody and will be responsible for returning it in good condition to the District or to their immediate superior. Dated receipts will be issued for the exchange of field books from one person to another. Pages will not be removed from a field book for any reason. All notes that are obsolete will be marked accordingly. All recorded notes and sketches will be clean and legible.

> Survey notes are original records, and care will be exercised to guard against the loss of and/or the damage to any field books.

Survey Supervisor Check-off List for Form D-428 (Survey Field Book)

Project:
Date:

1. Inside front cover must be completely filled in (See Figure 1.4.1).
2. Dates must be entered on all pages containing entries.
3. Weather conditions and air temperature must be entered on all pages containing entries.
4. Field book entries must be formatted in accordance with this publication.
5. Note Pennsylvania Coordinate Zone, Horizontal Datum, Vertical Datum, how it was established, and project Combined Scale Factor.
6. Note the right-of-way source, existing plan, or road docket established in the field.
7. Traverse, angles, and distances measured to accuracy standards according to this publication.
8. Enter traverse sketch(es) into field book.
9. Enter a note if traverse is adjusted, not adjusted, adjustment method, and unadjusted and adjusted coordinates.
10. Enter 3D survey notes into a separate field book.
11. Enter bridge structure sketch(s).
12. Enter benchmark description tied to Segment and Offset.

13. Enter a list of point numbers for all property corners located on project.
14. All entries must be checked by and initialed on notes and calculations on each page containing entries.
15. When applicable, complete a survey report.

D-428 (5-18)

IF FOUND PLEASE RETURN TO
PENNSYLVANIA DEPARTMENT OF TRANSPORTATION

District Executive: ____________________
Address: ____________________
____
Start Date: __________ End Date: __________
SR: __________ Section No: __________
Municipality: __________ County: __________
District/Consultant: ____________________

Crew | Title

Survey Type: Preliminary, Construction, Final, Bridge, R/W,
Other: ____________________

Contents | Page

Pennsylvania Coordinate System
Zone: ____________________
Combined Factor: ____________________
Horizontal Datum: ____________________
Established by: ____________________
Vertical Datum: ____________________
Established by: ____________________
Right of Way Source: ____________________
Existing Plan No.: ____________________
Road Docket No.: ____________________
Misc. Project Notes: ____________________

Inside Cover D-428 Survey Field Book

Figure 1.4.1

B. RECORD OF CONTROL DATASHEET

See Chapter 4.4. Datasheets are used to provide an easily accessible record of control established and/or recovered by PennDOT, NGS, and Consultants. These Datasheets inform interested parties of how the Horizontal or Vertical mark was established, what and where specific marks are, who established specific marks, and the last time marks were recovered. All newly established and historical PennDOT Datasheets can be found at www.surveycontrol.penndot.pa.gov (Pennsylvania Department of Transportation Photogrammetry Asset Management System). Note that the DCS may have other local information that may be pertinent that is not contained in the PennDOT database.

C. PHOTOGRAMMETRY ARCHIVES

The Photogrammetry and Surveys Section stores copies of all photogrammetry projects, including, but not limited to, project imagery and survey control. Project imagery and survey are kept permanently. Survey control is stored according to its geographic location and records are available on the Sections website www.PenndotPAMS.org. Aerial photography is too large to be made available on the website, however, meta-data is stored geographically, and is available by request. Data will be transmitted online or by portable data drive. Mapping CADD files are available, but changing formats and project media make older mapping obsolete.

1.5 SURVEY CODES, ATTRIBUTES, AND FEATURE LIBRARIES

A list of survey codes including attributes and feature codes can be found in Appendix C.1.5.1.

1.6 PHOTOGRAMMETRY MAPPING STANDARDS

Photogrammetry and lidar mapping standards can be found in the document "Features and Standards" found in Appendix C.1.6.1.

1.7 CADD STANDARDS

CADD Resources can be found at:

https://www.penndot.pa.gov/ProjectAndPrograms/RoadDesignEnvironment/RoadDesign/Pages/CADD-Resources.aspx

CADD standards can be found in the draft Modeling Standards Manual.

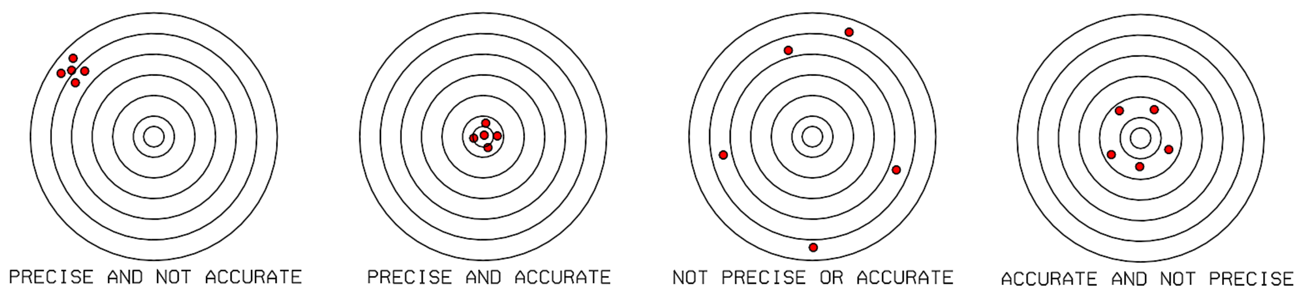
CHAPTER 2 – CLASSIFICATION OF ACCURACY STANDARDS

2.0 DEFINITIONS

This chapter focuses on the development and classification of topographic mapping and Existing Ground models (EG), along with the definitions and characteristics of existing technologies. Included is a table to aid in combining the various tools available to create an EG that is sufficiently accurate and dense to cost effectively satisfy project requirements.

Accuracy is defined as the closeness of a measured value to the "true" value. Note that "true" value is never actually known as all measurements have some level of error. Thus, accuracy standards are described within a specific level of confidence. For example, when a particular data set is said to be accurate to +/- 0.10 feet, it is difficult for the recipient of that information to understand how often this is true. However, when the accuracy of a data set is described as +/- 0.10 feet at 95% confidence level, there is an expectation that only 5% of the points within such data set can fall outside of the stated threshold. The 95% confidence level is determined from Root Mean Square Error (RMSE). It is also important to note whether the accuracy is being described as absolute (the level of accuracy that can be achieved in a global coordinate system) versus relative to the National Spatial Reference System (see Chapter 3). (NCHRP Report 748).

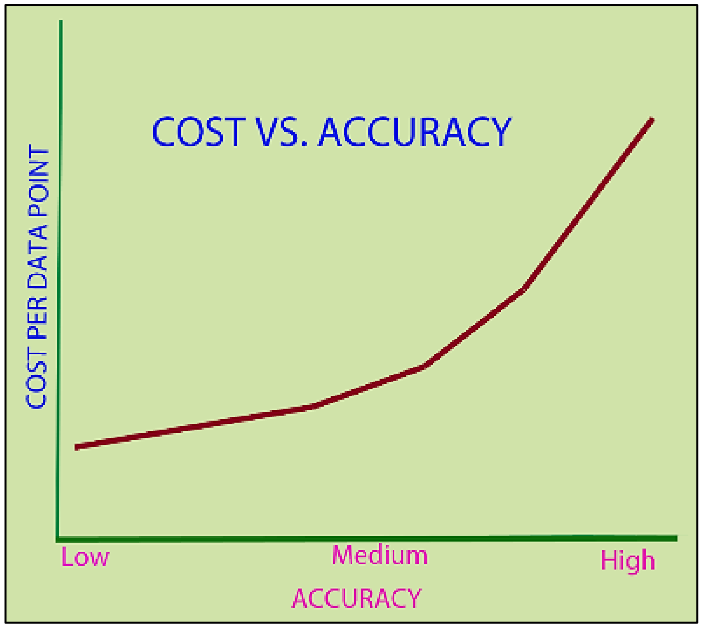
Accuracy is often confused with precision. **Precision** is the closeness of all measured values to each other. The four targets in Figure 2.0.1 demonstrate the correlation between accuracy and precision.



Precision v. Accuracy

Figure 2.0.1

There are several survey techniques and technologies available for data collection. Some allow for data to be collected more quickly and provide higher accuracy and density of points. Density is defined as the number of points per unit area. For example, conventional survey techniques such as traverse and leveling usually result in the highest levels of accuracy in individual points, but the data set has the least density compared to other data collection methods. Conventional survey techniques are the standard upon which other technologies are measured. Remote sensing technologies such as lidar and photogrammetry provide very dense point fields, but lower accuracy in the individual points. Lastly, the cost of data collection and mapping is directly proportional to the required certified accuracies. As accuracy increases, so does cost.



Increasing Accuracy Increases Costs

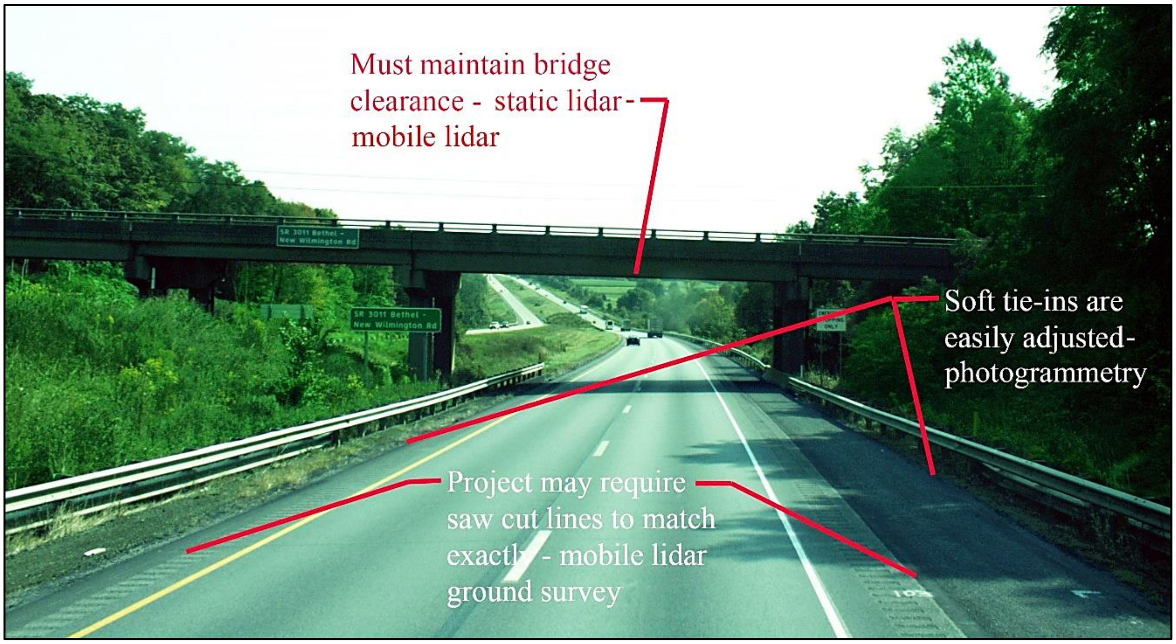
Figure 2.0.2

It is important to note that there is always a balance between project accuracy and density requirements, cost of data acquisition and schedule, and managing the risk of construction uncertainties.

2.1 ACCURACY CLASSIFICATIONS

Most digital delivery projects will benefit from a combination of multiple survey sources and technologies. Geospatial data fusion may be as simple as various conventional survey data sets such as right-of-way surveys, hydrology cross sections, and alignment traverses consumed into a design project. It may be as complex as all these conventional surveys along with photogrammetry, aerial lidar, and mobile lidar. All these data sets have different accuracy classes and must be carefully defined.

> **Most digital delivery projects will benefit from a combination of multiple survey sources and technologies.**



Potential high-risk project example

Figure 2.1.1

EG models control the accuracy of how the final design model will tie into the existing ground during construction, and the accuracy of the estimated earthwork quantities. It is important for the designer to understand the quality of the EG both in terms of accuracy and density. Density of data is defined by how many data points are collected. Higher density data has less space between data points.

This information allows the designer to manage the risk of uncertainty when communicating design intent. The less certainty of existing conditions, the higher the risk. Risk is managed by increasing the requirements for accuracy and density of points for areas of high-risk situations. High-risk areas are those in which the design is determined by immovable physical features (e.g., bridge abutment, existing hard surfaces, bridge clearance, and tie-ins to existing drainage structures). Models for these kinds of features need to be depicted with high accuracy. These high-risk situations may have significant impacts to the project budget, timeline, or both. It is also important to note that there are different acceptable accuracy thresholds for soft surfaces, sensitive features like wetlands, and hard tie-ins like pavements. For pavement reconstruction projects, the accuracy of the EG will also affect the accuracy of the material quantities and any slope correction designs. (Figure 2.1.1).

Density of points is also a consideration for managing risk. Traditional survey methods support cross-section design models, which are only accurate at the interval shown in the plans (e.g., 50-ft cross-sections). The point density of a EG model determines the amount of interpolation, which contributes to the level of uncertainty of the quantities and success of final design. Higher density EG models are needed to deliver a model as a legal document that sufficiently reduces the associated risk with the uncertainty of interpolation.

Communication with the survey team is critical when making decisions regarding accuracy needs and appropriate data collection methods, to manage those areas and situations with the most risk. The designer shall communicate the needs of the project, so the surveyor can determine the best data collection methods. The surveyor shall evaluate the data collection methods and recommend a data fusion approach to manage the cost of data collection.

The technologies and accuracy classifications table below, Table 2.1.1, has been developed by PennDOT to express standards of the 3-dimensional DTM data being acquired.

Source	Data point absolute accuracy (estimated)	Data Density	Advantages	Disadvantages	Typical uses
Ground Survey	0.02 feet RMSE* 0.04 feet At 95%	- Varies - Intelligent Collection**	-The most accurate methods available -Coded planimetrics*** - descriptive - Intelligently collected- Surface defined by breaks, high and low points in the terrain - quick mobilization, District forces and consultants	-Labor intensive -Usually sparse data -Not for large area topographic maps -Safety -Lane closures	-Ground survey is required on every project - first option -Some features can't be collected remotely – must be surveyed -Provides control for all remote sensing
Photogrammetry	0.16 feet RMSE* 0.31 feet At 95%	- 25 feet or less - Intelligent Collection**	-Inexpensive -Large area, base map -Coded planimetric***- descriptive - Intelligently collected**- Surface defined by breaks, high and low points in the terrain -Safety – remote sensing -Ortho-photo bi-product	-Low individual point accuracy -Dense vegetation obscures ground -Must be scheduled, slow mobilization	-Base map for other sources – tie-ins -Large projects where high accuracy not needed -QA for other remote sensing -Used for final design in combination with ground survey
Static Lidar	0.03 feet RMSE* 0.06 feet At 95%	- Very Dense - not intelligent**	-Safety – remote sensing -Overhead features -Difficult to collect areas – structures, slopes -Very dense data – detail	-Not for large areas -Coded planimetrics*** labor intensive	-Specialty needs, bridges -Clearances -Add in high accuracy to base maps where needed
Mobile Lidar	0.05 feet RMSE* 0.10 feet At 95%	- Very Dense - not intelligent**	-Safety – remote sensing -Overhead features collected effectively -Very dense data detail -Very accurate pavement	-Must be verified -Expensive -Requires dense ground control	-Ground survey accuracies on pavement, safe, no lane closure -Best used shoulder to shoulder -Overhead (bridge clearance, etc.)
Aerial Lidar	0.10 feet RMSE* 0.20 feet AT 95%	- 6” or less - not intelligent**	-Accurate elevation data -May collect under vegetation -Option for pavement – may replace mobile -Less expensive than mobile	-Must be verified -Best used in conjunction with photogrammetry -Not for small areas	-When higher accuracy surface needed – dense data -Best remote sensing in vegetation
UAS – DSM	Varies	- Very Dense - not intelligent**	-Small projects – volumes -easy to deploy, inexpensive	-Vegetation obscures -Not for large areas	-Specialty apps -Small – fast turn-around

UAS - Lidar	Varies	- 6" or less - not intelligent**	-Small projects -difficult to collect areas	-Not for large areas -Not as easy to deploy	-Specialty apps -Small areas

*RMSE – Root Mean Square Error

**Intelligent collection – An operator is directly involved with strategic placement of data points, identification of features and examination for blunders and extraneous data points

***Coded planimetrics – Vectorized and structured CADD data including all manufactured and natural features.

Table 2.1.1

Determining project requirements and selecting the appropriate survey approach, may be guided by Table 2.1.1. Each technology offers advantages and particular benefits and carry certain disadvantages. Please see the following Figures 2.1.2 through 2.1.5 for some examples and more information.

Figure 2.1.2 represents a small rural project that could be done very effectively with ground survey only. The low Average Daily Traffic (ADT) makes roadway collection safe. In the "High Density" area, care must be taken to collect data at a spacing that defines every break and change in the surface. In the "supplemental" area, it may be appropriate to collect less dense data. In all areas, features such as pipe inverts, pole numbers, and house numbers may be collected. Other surveys may include hydrology or right-of-way.

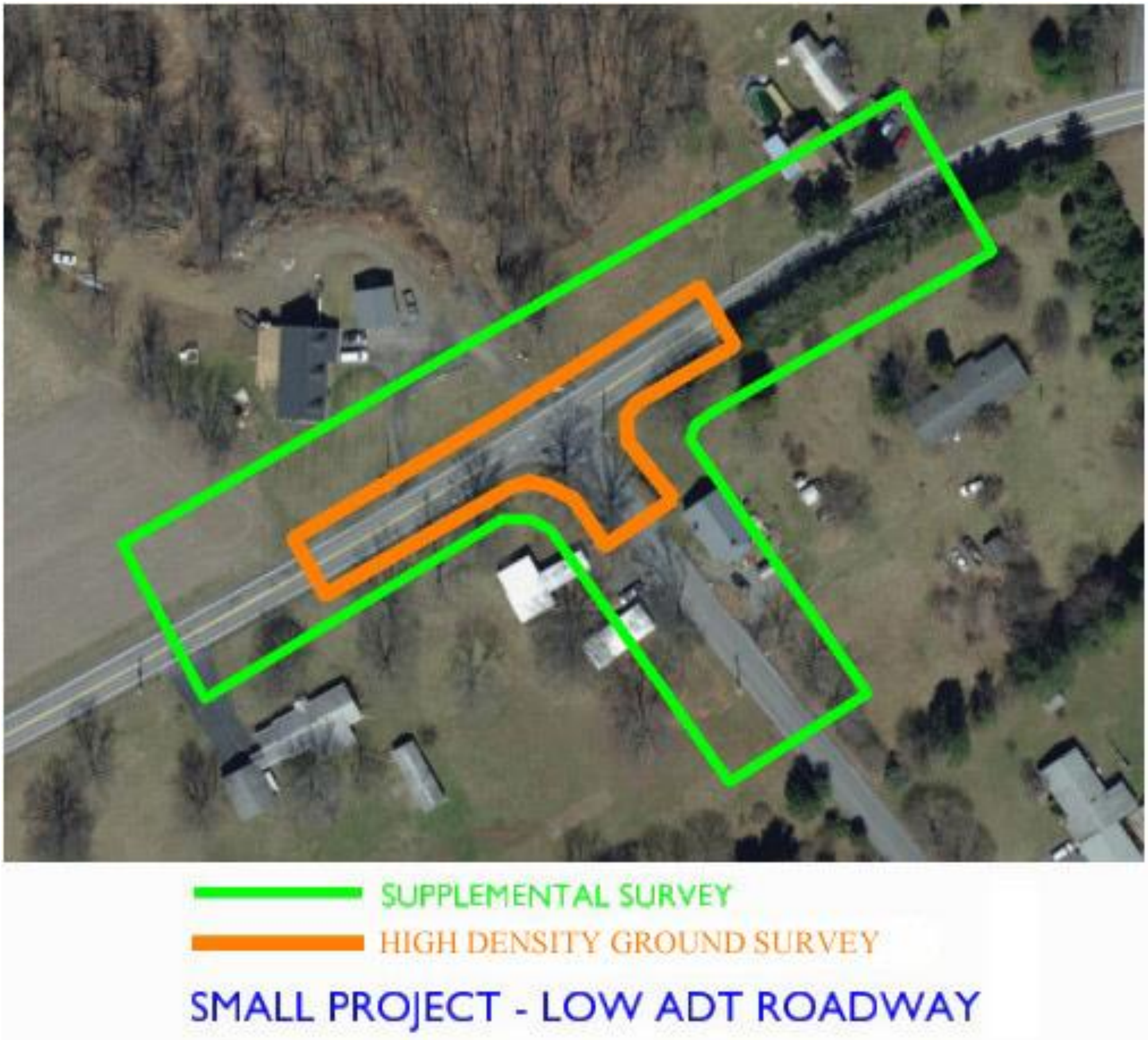


Figure 2.1.2

Figure 2.1.3 represents a small but high traffic project. Here, to reduce or eliminate the need for lane closures, static lidar may be the best approach. Wires, traffic control, and other overhead features will be located along with a very dense roadway surface. Significant office time is required to get coded planimetrics, meaning linework with level symbology in CADD. That office time is also needed to refine and check the surface. Supplemental ground survey is likely also required as outlined in Figure 2.1.2.

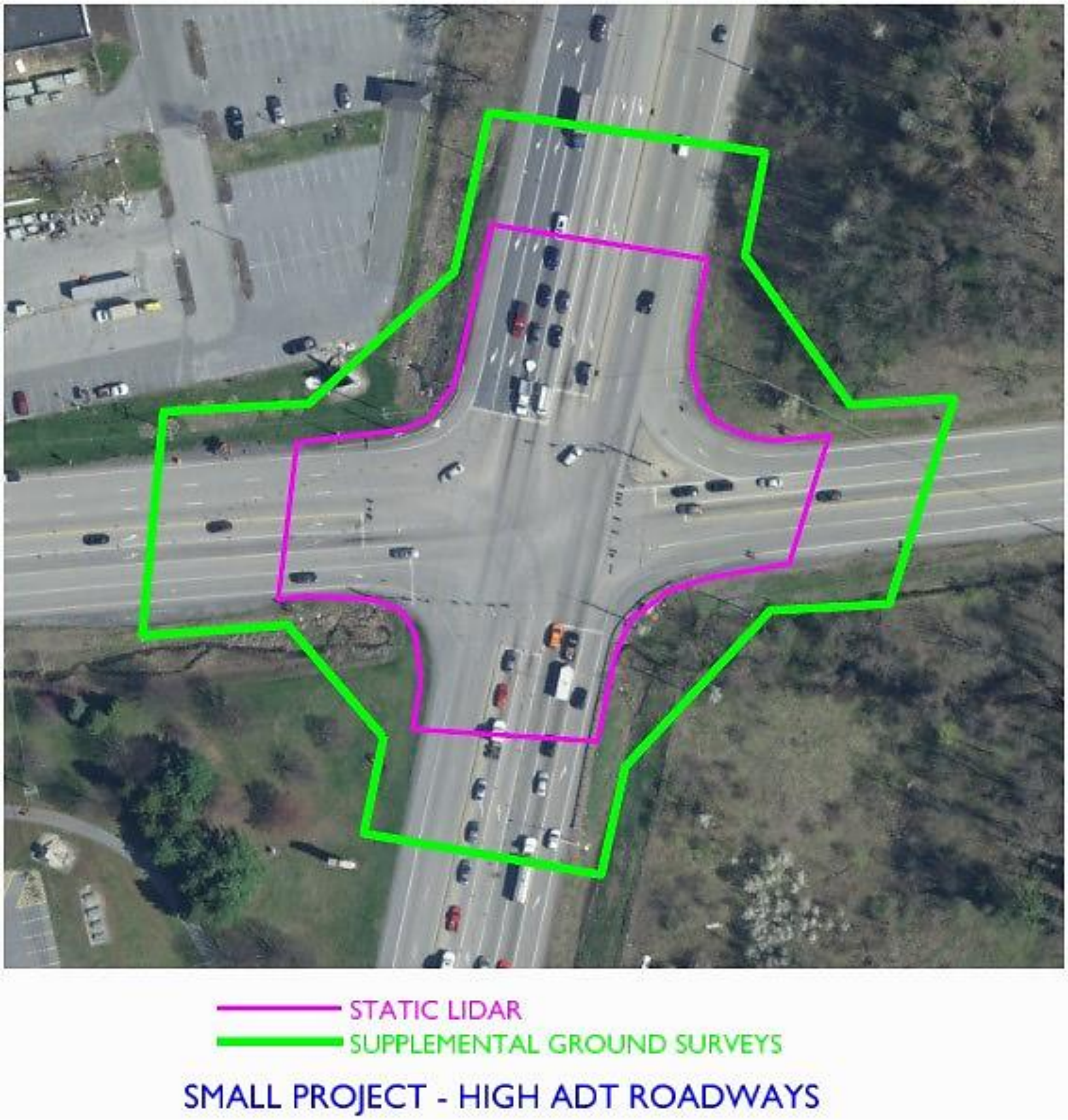


Figure 2.1.3

Figure 2.1.4 represents a long corridor project. Photogrammetry may become appropriate for projects over one-half mile depending on requirements. On the example here, photogrammetry is collected for 250' left and right of, and including the corridor. The relative accuracy is sufficient for this project; however, high density ground surveys are added where the project ties into old pavement. High density ground surveys are also added near the mid-point where a new retaining wall is scoped. This will field verify the photogrammetry and add data as needed. Finally, supplemental ground surveys as outlined in Figure 2.1.2 are needed throughout.

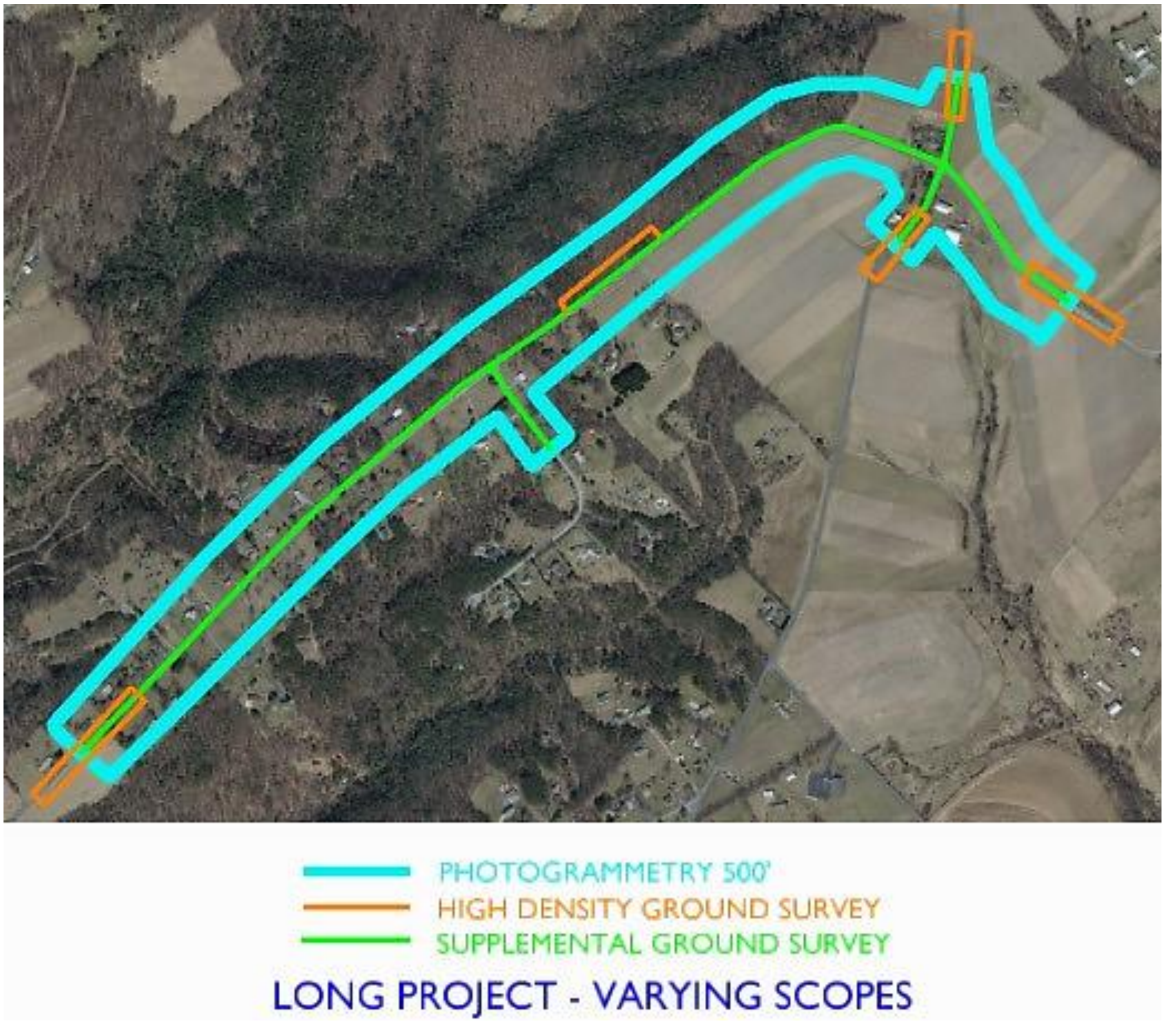


Figure 2.1.4

Figure 2.1.5 represents a complex project. The photogrammetry is the base map upon which the other data is added. Because very accurate pavement mapping is needed along the main corridor, mobile lidar is driven. This may also be replaced by aerial lidar depending on requirements. Mobile lidar will collect overhead features including clearances on two bridges. On the intersecting corridor, mobile is not required, so static lidar is used to get accurate clearances at two additional bridges. Finally, supplemental ground surveys are required throughout as outlined in Figure 2.1.2.

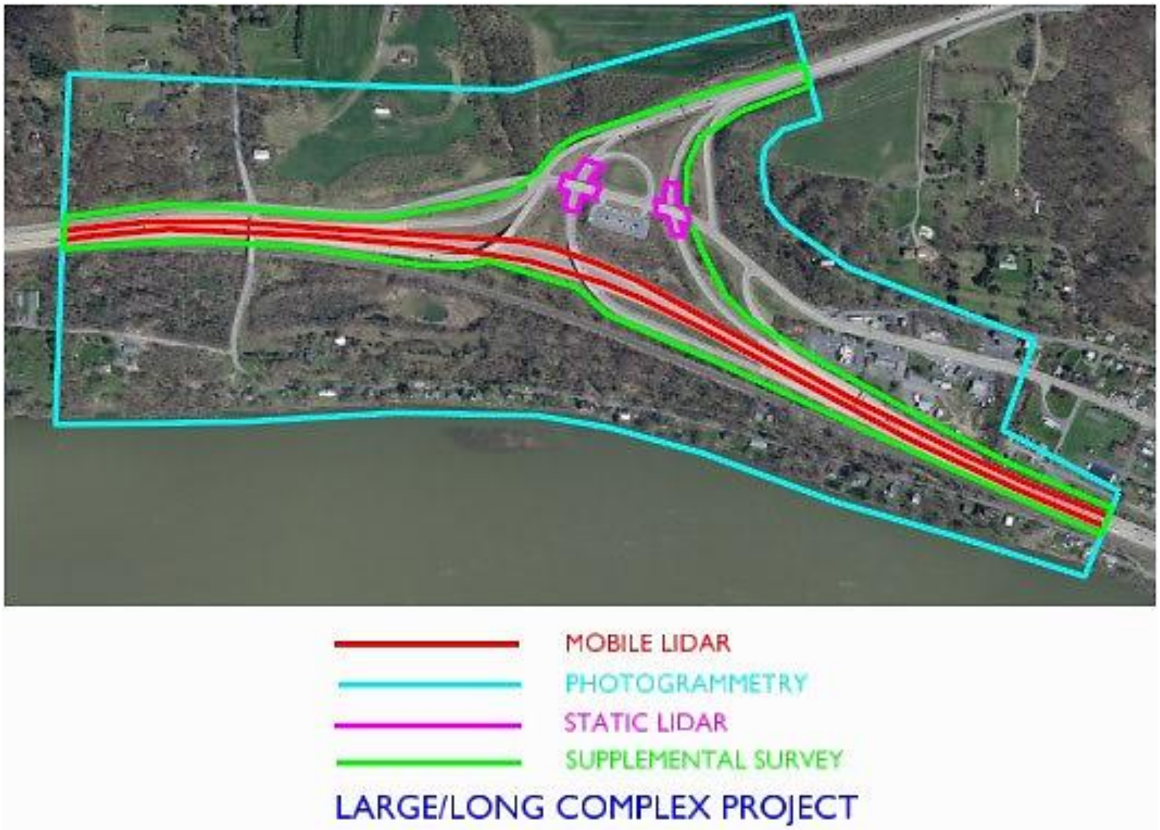


Figure 2.1.5

2.2 EXISTING GROUND CONFIDENCE LEVEL

For Department digital delivery projects employing a 3D model as a Legal Document, Existing Ground Confidence Level (EGCL) will be determined on every project using map testing techniques, until sufficient historic data is collected to establish acceptable standards. This is common practice for recent technologies or processes. The Department has significant testing data for photogrammetry and mobile lidar. However, more robust testing as outlined below will be performed for these and all data sets until consistent results are achieved and recorded. Proper map testing will establish expectations not only for the technologies but for the best practices being employed.

Existing Ground Confidence Level (EGCL) will be determined on every project using map testing techniques, until sufficient historic data is collected to establish acceptable standards.

EGCL techniques are described below.

A. Selecting Map Test Points - Testing any data set is done with a series of 3D points that fall within the EG data set. When possible, identifiable points should be chosen such as corner of drop inlets or corners of sidewalks. Although the focus of this testing is on the vertical component, identifiable features like those outlined above will also help define the horizontal accuracy. Selection of identifiable points is not always possible and should not limit the even distribution of points. Therefore, random vertical only points may also be selected. They must include a coordinate or some other method of finding the point within the EG data set. One example is to define a start point on a painted line and a series of vertical points spaced at 25’ along said line. Vertical only points must have some method for locating the same point in the EG data set.

B. Ground Survey of Map Test Points - The position of selected map test points must be established with ground survey techniques capable of accuracies twice greater than the expected accuracy of the data being tested. For the horizontal coordinates this may require either Robotic total station or GNSS RTN techniques. For vertical elevations, this may require GNSS RTN or differential leveling from existing project control. Map test control must be twice as accurate as the expected map accuracy.

C. Number of Points – In order to calculate a true RMSE, a minimum of 30 points are required. Multiple RMSE numbers may need to be established for various areas in the EG model. It may be appropriate to calculate a vegetated RMSE and a non-vegetated RMSE. It may also be appropriate to establish an RMSE for each data set merged into the EG model (i.e., lidar and ground survey). For larger projects, more than 30 points may be useful. As a rule, EG models more than 10 miles in length should have a minimum of 5 additional points per every 10 additional miles.

D. Spacing – It is critical for the map test points to be evenly distributed within the EG data set. It is acceptable for 5 or fewer points to be grouped together, but those groups should be distributed as well. You might group points together in the example of points along a painted line described in Chapter 2.2.A above.

E. Blind Testing - The locations of the points should not be made known to the individuals compiling the EG model. This facilitates a “blind” test which is considered a better determination of RMSE accuracy. Test point locations should be determined before any other evaluation has occurred. Observed value coordinates to be tested should be measured from the final edited EG model.

Errors are determined by subtracting the test point coordinates and elevations (true value) from the values extracted from the EG model (observed value). These error residuals are then used to calculate the RMSE.

See Appendix C.2.2.1 for an Existing Ground Confidence Level Verification Form used to calculate RMSE and provide a narrative of how the model was produced. The example in this form has a narrative describing a base map from photogrammetry, hard surfaces collected with mobile lidar and ground survey throughout. Two RMSE numbers may be calculated, one for the base map and one using hard surface lidar, using this spreadsheet.

The results of the map test will be reported in the Existing Ground Terrain Report as found in Appendix E.

CHAPTER 3 – SURVEY DATUMS AND COORDINATE SYSTEMS

3.0 DATUMS

The Department requires that all surveys be delivered in the most current Horizontal and Vertical Datums with the corresponding Geoid as accepted by PennDOT. These Datums are defined and managed by NOAA's National Geodetic Survey (NGS) and referred to as the National Spatial Reference System (NSRS). Further information about Pennsylvania Datums can be found in Appendix F-1 - Pennsylvania Coordinate System Law.

If a project is an extension of an existing project and requires use of an older datum, or if there is a locally accepted regional datum, consult the District Chief of Surveys (DCS) prior to use.

If a project is an extension of an existing project and requires use of an older datum, or if there is a locally accepted regional datum, consult the District Chief of Surveys (DCS) prior to use. If the older or regional datum is required and accepted by the DCS, ties must be made from the chosen datum to the most recent NSRS Datum. These ties must be of an acceptable method to be able to recreate the chosen datum from the most recent published NSRS Datum. The ties and conversions must be listed on the right-of-way and construction plans.

Assumed coordinate systems are only to be used when no other option is available and with the written authorization of the DCS. The actual coordinates used must be truncated to a point not to be mistaken for state plane coordinates. Assumed coordinate origins are recommended to be Northing 50,000.00 and Easting 75,000.00. The horizontal and vertical datum used, along with the Geoid and Combined Scale Factor, must be noted in all field books and plans.

For horizontal datums, list the Pennsylvania State Plane Coordinate System Zone, North American Datum, Year of realization, and by what method it was obtained. For vertical datums, list the North American Vertical Datum and by what method it was obtained. For the Geoid, list the Geoid that used to convert ellipsoidal heights to orthometric heights. For the Combined Scale Factor, list the computed project scale factor. See Chapter 3.3 for examples.

Note: NGS will be retiring the US Survey Foot definition (1 foot = 0.30480061 meter) or (1200/3937) effective December 31, 2022, and fully implement the International Survey Foot definition (1 foot = 0.3048 meter) in all future conversion computations. Also, NGS will be instituting new horizontal and vertical datums in the future. The current proper names are listed below, and they will be accepted and required to be used by the Department at a future date to be determined.

- New Horizontal Datum: North American Terrestrial Reference Frame of 2022 (NATRF2022)
- New Vertical Datum: North American-Pacific Geopotential Datum of 2022 (NAPGD2022) with new geoid model (GEOID2022)

The NGS Coordinate Conversion and Transformation Tool (NCAT), an on-line tool available from NGS, converts and translates coordinates between new and old datums.

https://geodesy.noaa.gov/NCAT/

3.1 COORDINATE SYSTEMS AND PROJECTIONS

A. Geodetic Positions are based upon locations on a regular mathematical surface (ellipsoid) formed by the rotation about the minor axis (earth's polar axis). Locations east and west are expressed in the sexagesimal numeral system of degrees (°), minutes (‘), and seconds (“- to 5 decimal places) of geodetic longitude, and locations north and south are expressed in the sexagesimal numeral system of degrees (°), minutes (‘), and seconds (“- to 5 decimal places) of geodetic latitude. Ellipsoid Height is the third parameter, which is a significant element in the computations. NGS has compiled all horizontal control data for the NSRS in meters and converted all points to the Pennsylvania State Plane Coordinate System in units of U.S. survey feet and/or International Feet.

B. State Plane Coordinate System (SPCS) Positions are based upon converting geodetic positions of a portion of the earth's surface to a plane rectangular surface. Points are projected mathematically to an imaginary surface, which can be developed (unrolled or laid out), without distortion of shape or size. A rectangular grid is superimposed on the developed surface and the position of the points is referenced to the grid axis. Pennsylvania is recognized by current law to have two coordinate zones, the North, and the South zones. See Appendix F-1 - Pennsylvania Coordinate System Law for the definition of the PA North and PA South Zones. All coordinates provided on the SPCS must be shown on plan sheets and field book notes to 4 decimal places for computational purposes only and will not imply a precision beyond two (2) decimal places.

> All coordinates provided on the SPCS must be shown on plan sheets and field book notes to 4 decimal places for computational purposes only and will not imply a precision beyond two (2) decimal places.

C. The Geoid is the equipotential surface of the Earth’s gravity field which best fits, in a least squares sense, global mean sea level.

D. Along with the NGS release of the 2022 Datums, there will be new Pennsylvania State Plane Coordinate Zones (SPCS 2022) defined. The new PA zones will include a single PA zone and four PA sub-zones in the West, Central, Northeast, and Southeast. See Appendix F-2 thru F-10 to utilize the new Pennsylvania Zone maps to determine which zones apply to which PennDOT Engineering Districts and Counties.

3.2 NATIONAL SPATIAL REFERENCE SYSTEM (NSRS)

“The National Geodetic Survey (NGS) defines and manages the National Spatial Reference System (NSRS) - a consistent coordinate system that defines latitude, longitude, height, scale, gravity, and orientation throughout the United States. In addition to a network of continuously operating reference stations (CORS) supporting three-dimensional positioning activities, the NSRS includes a network of permanently marked points; a consistent, accurate, and up-to-date national shoreline; and a set of accurate models describing dynamic, geophysical processes that affect spatial measurements.”

> The NSRS integrates the NCN, PCN, RTN, and Passive Control Marks into one homogenous reference system.

The NSRS integrates the NCN, PCN, RTN and Passive Control Marks into one homogenous reference system.

Source : (https://oceanservice.noaa.gov/facts/nsrs.html).

3.2.1 NOAA CORS NETWORK (NCN)

“The NOAA Continuously Operating Reference Stations (CORS) Network (NCN), managed by the National Geodetic Survey, provide Global Navigation Satellite System (GNSS) data, supporting three-dimensional positioning, meteorology, space weather, and geophysical applications throughout the United States.

Surveyors, GIS users, engineers, scientists, and other people who collect GNSS data can use NCN data, acquired at fiducial geodetic control stations, to improve the precision of their positions, and align their work within the National Spatial Reference System (NSRS). NCN enhanced post-processed coordinate accuracies can approach a few centimeters, both horizontally and vertically.

The NCN is a multi-purpose, multi-agency cooperative endeavor, combining the efforts of hundreds of governmental, academic, and private organizations. The stations are independently owned and operated. Each agency shares their GNSS carrier phase and code range measurements and station metadata with NGS, which are analyzed and distributed free of charge."

Source : (https://geodesy.noaa.gov/CORS/)

Acceptable uses of the NGS CORS Network for Department projects are the Online Positioning User Service (OPUS), which processes GPS data in static and real-time kinematic (RTK) forms via uploading data to its website and receiving an emailed report in return with computed geodetic and state plane coordinates and their statistical results.

The following forms of OPUS can be used for Department projects:

- OPUS-DB: Processes, computes, and publishes GPS data from 2 to 48 hours in length for a single position (Classic Static Observations)
- OPUS-RS: Processes and computes GPS data from 15 minutes to 2 hours in length for a single position (Rapid Static / Fast Static Observations)
- OPUS-Projects: Processes, computes, adjusts, and publishes GPS data of varying time lengths for multiple positions (Static, Rapid Static, Real-Time Kinematic (RTK) Observations)

3.2.2 PENNDOT CORS NETWORK (PCN)

PennDOT has developed and maintains a well distributed network of continuously operating reference stations (CORS) throughout the commonwealth. These CORS are managed by the Photogrammetry and Surveys Section of the Bureau of Construction and Materials. Some of the CORS established have been accepted by NGS and are part of the NCN. All PennDOT CORS are shared within a statewide privately run real-time network to offer the state a highly reliable RTN based solution for real-time surveys. The PennDOT CORS Network is also a fully functioning single base solution for real-time surveying. The real-time network operation is currently only available to users that have access to the PennDOT IT network. http://rtn.penndot.pa.gov

3.2.3 REAL-TIME NETWORKS (RTN)

"Real-Time Network (RTN) surveying is similar in concept to Real-Time Kinematic (RTK) surveying in that corrections sent from a base station improve rover positional accuracy in real time. The primary difference is that unlike RTK surveying, where the reference station is physically located at a permanent or semi-permanent location, RTN surveying uses a computed, or "virtual" reference station."

"With RTN surveying, a permanent network of reference stations is required. Spacing of the reference stations can be from 10-50 miles and can cover a local, regional, or statewide area. The reference station network continuously streams data (using LAN, Internet, or radio links) to a central location (computer server). The computer server then performs several functions including storage of RINEX data, performance of quality assurance checks on the raw GNSS data, network modeling and estimation of systematic errors, calculation of and conversion of position correction data to a user format (RTCM format or CMR+), and communication of the data to the users. The user then receives the corrections (using LAN, Internet, radio links, or a cellular modem) in the field, in real time."

Source : (https://water.usgs.gov/osw/gps/real-time_network.html)

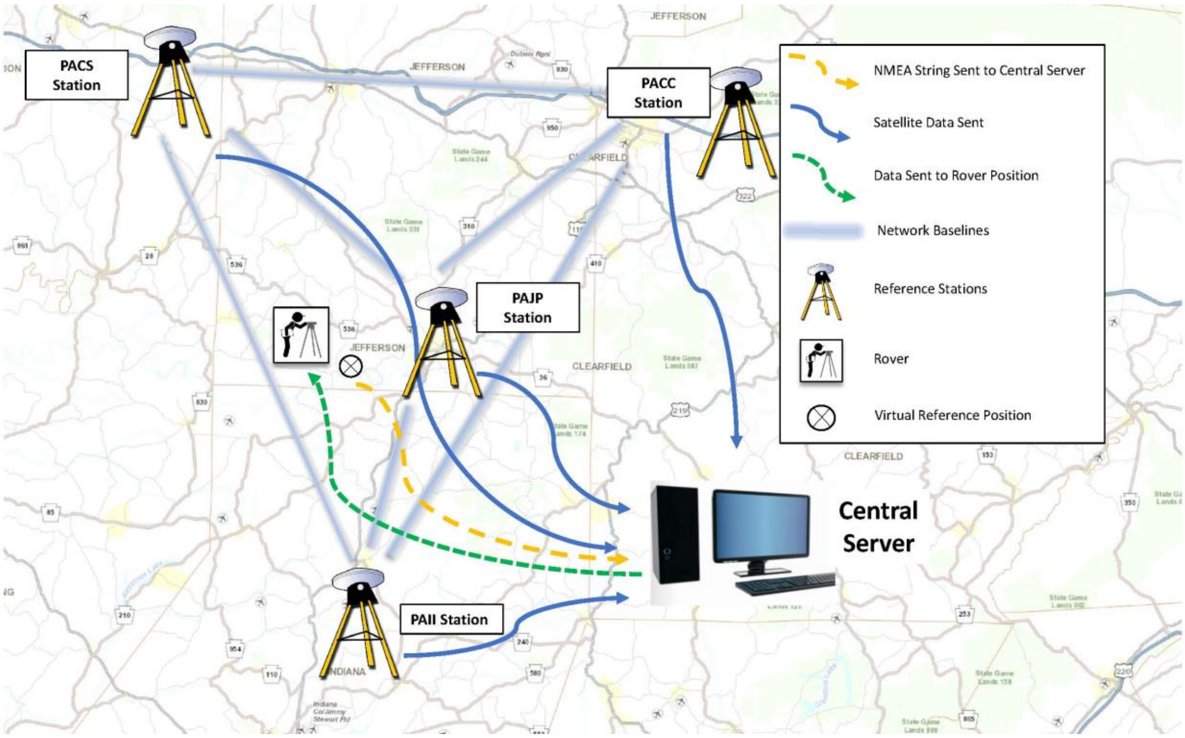


Figure 3.2.3.1

Examples of RTN's that are currently used and accepted by the Department are:

- PennDOT RTN: A state government owned, internal use only RTN
- KeyNetGPS: A Trimble based, privately owned, subscription service RTN
- Trimble RTX: A Trimble based, privately owned, subscription service RTN
- TopNetLive: A Topcon based, privately owned, subscription service RTN
- SmartNet: A Leica based, privately owned, subscription service RTN

For the Department to accept surveys performed utilizing an RTN, the RTN must meet the following criteria:

- All reference stations in the RTN with permanently mounted GNSS antennas shall be calibrated and approved by NGS and be survey grade GNSS receivers.
- The coordinate system shall be derived by network ties to existing NCN Stations tied to the NSRS.
- Be able to provide real-time corrections in the current NSRS horizontal & vertical datums.
- Be able to show measurement ties to existing passive control marks' coordinates in a project area to within the tolerances set forth in Chapter 4 – Survey Control Specifications.
- Be able to receive remote field internet connectivity with speed, reliability, and consistency.

3.2.4 PASSIVE CONTROL MARKS

Passive Control is the traditional method of referencing positions to physical control marks that have known horizontal and/or vertical locations. Examples of passive control marks are brass disks embedded in concrete survey monuments, bridge walls, boulders, buildings, and other permanent structural placements. They can also include chiseled square cuts in concrete structures, RR spikes in utility poles, iron rebar pins or bolts, and more innovative physically stable items. Online resources to find, view, and update these types of survey control marks are listed below:

National Geodetic Survey (NGS):

- NGS Data Explorer
  - https://geodesy.noaa.gov/NGSDataExplorer/
- NGS Datasheets
  - https://geodesy.noaa.gov/datasheets/index.shtml
- NGS OPUS
  - https://geodesy.noaa.gov/OPUS/view.jsp

PennDOT PAMS (PennDOT Photogrammetry Asset Management System):

- PennDOT, NGS, USGS Survey Control Datasheets
  - https://www.penndotpams.org/home.html (legacy web address)
  - https://www.surveycontrol.penndot.pa.gov (planned web address 2023)

3.3 COMPUTING THE PROJECT COMBINED SCALE FACTOR FROM STATE PLANE COORDINATES

> The combined scale factor is to be rounded to 8 decimal places and included in the general notes of the plan.

A project combined scale factor will be required to be computed and used on all Department projects. For PennDOT projects, a single project combined scale factor can be computed from the approximate center of the project and used to reduce all measured ground distances to grid distances for the project. The combined scale factor is to be rounded to 8 decimal places and included in the general notes of the plan.

A combined scale factor is used to convert grid distances (distances derived from state plane coordinates and as noted on plan sheets) to actual ground distances (distances that are scaled from grid distances to reflect actual measurements of distances in the field and are not on a mathematical flat plane surface). Ground distances are derived by dividing the grid distance by the combined scale factor (product of scale [grid] factor and elevation factor) in state plane coordinate systems. See Figure 3.3.1.

- *Combined Scale Factor = Elevation Factor * Scale Factor*
- *Ground Distance = Grid Distance / Combined Scale Factor*
- *Grid Distance = Ground Distance * Combined Scale Factor*

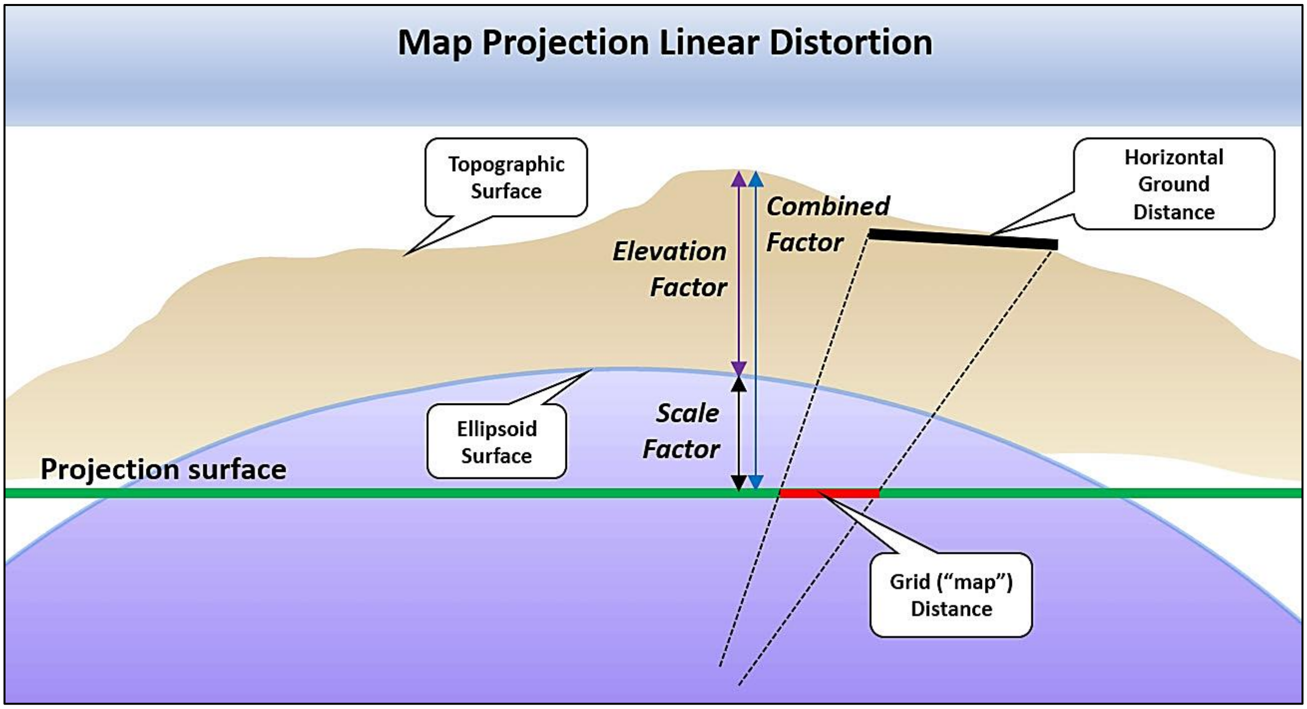


Figure 3.3.1

With the future release of the 2022 datums, State Plane Coordinate grids will have the projection surface at the topographic surface. This will minimize the linear distortion between the ground and grid distances and reduce the combined scale factors dramatically. The resulting State Plane coordinates will be computed on this projected plane. See Figure 3.3.2.

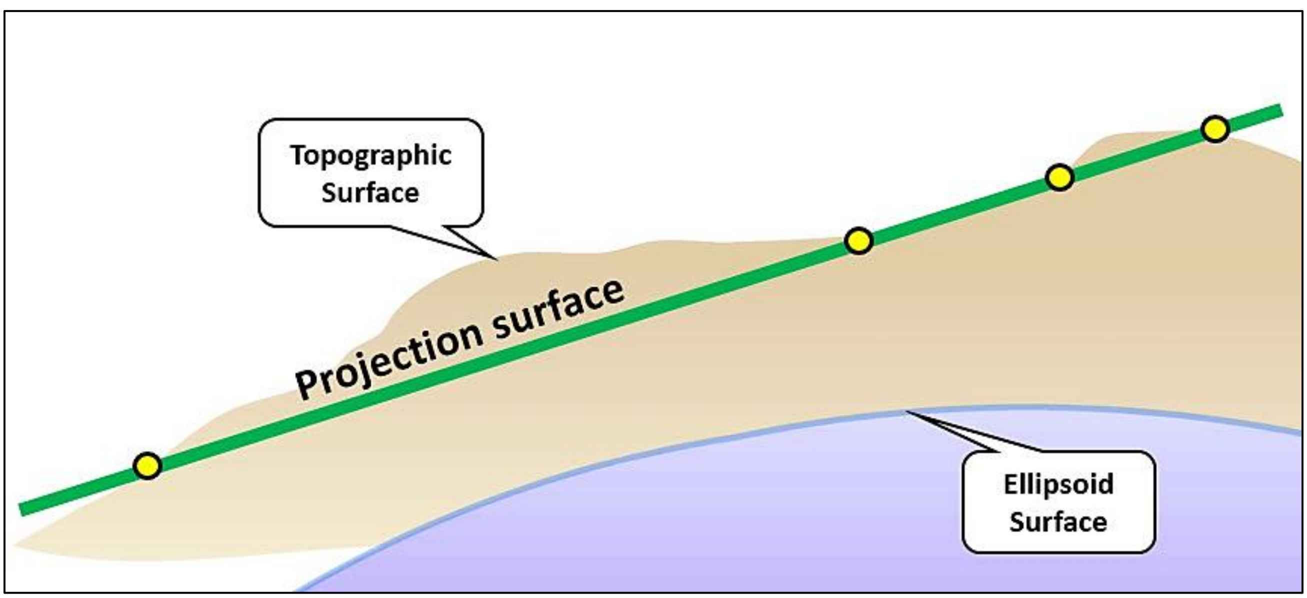
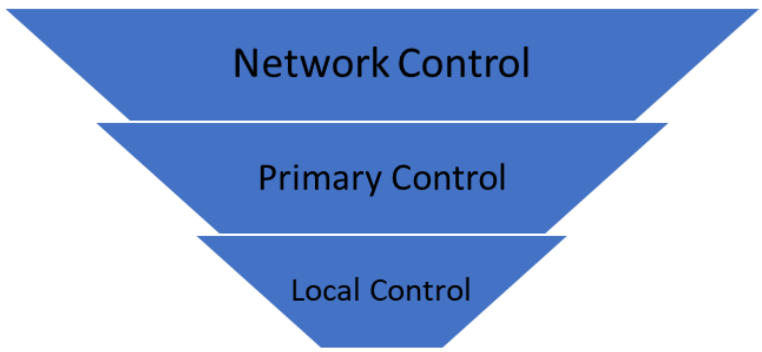


Figure 3.3.2

CHAPTER 4 – SURVEY CONTROL SPECIFICATIONS

4.0 SURVEY CONTROL REQUIREMENTS

The utilization of survey control requirements is an integral part of establishing and maintaining the accuracy and consistency of any survey control network structure. Network Control Surveys in a geographic region ensure the continuity of primary project control of multiple adjacent projects throughout that region. Primary Control Surveys are utilized to create all other Local Control Surveys and Benchmarks that are used on specific projects. Only the District Chief of Surveys (DCS) has the authority to approve any deviations from the requirements and the specifications set forth in this chapter. Survey reports stating the accuracy and methodology of establishing these monuments are submitted to, and approved by, the District Chief of Surveys before all subsequent activities commence.



A. The NOAA CORS Network (NCN) and PennDOT CORS Network (PCN) establish the highest order of network stations in the National Spatial Reference System (NSRS). This network of Continually Operating Reference Stations (CORS) will be used to establish Network Control Monumentation.

B. Network Control Surveys (NCS) utilize the NCN and PCN to establish geodetic control stations that provide continuity amongst survey control established in a large geographic region. Network Control Surveys will establish one centimeter (0.03 feet) horizontal network accuracies and two centimeter (0.07 feet) vertical network accuracies. All network control monumentation shall be established at five (5) mile monument spacing using Global Navigation Satellite Systems (GNSS) Static surveying methods. When higher order elevation accuracy is required, Network Leveling Specifications are required with differential leveling techniques as laid out in Chapter 5. Network control monuments are located in secure areas with open sky and accessibility. All Department network control monuments shall be catalogued in the Photogrammetry Assets Management System.

C. Primary Control Surveys (PCS) utilize monuments derived from and tied to Network Control Surveys and define a project's horizontal and vertical datums. PCS must be tied both horizontally to a minimum of four (4) horizontal network control monuments and vertically to a minimum of five (5) vertical network control monuments. NCN and PCN stations may be used to supplement the NCS control as well as CORS in privately operated Real-time Networks (RTN). Primary Control Surveys will establish two centimeter (0.07 feet) horizontal network accuracies and three centimeter (0.10 feet) vertical network accuracies using GNSS Static, Fast Static, and RTN surveying methods. All Primary Control Monumentation must consist of an intervisible pair of control stations and be established at two (2) mile monument spacing. When higher order elevation accuracy is required, Primary Leveling Specifications will be required with differential leveling techniques. Primary control monumentation will be located in an area not to be disturbed during the entirety of the project lifecycle. All primary control Monuments shall be catalogued in the Photogrammetry Assets Management System.

D. Local Control Surveys (LCS) utilize the monuments derived from, and tied to, Primary Control Surveys to create the LCS horizontal and vertical control points. LCS are the stations and benchmarks to control all preliminary surveys and layout for construction projects. All local control monumentation shall be established by total station traverse methods with acceptable closures as laid out in Chapter 6 or GNSS Real-time Kinematic positioning (RTK) methods achieving two centimeter (0.07 feet) local horizontal and vertical accuracies. The concentration and accuracy of this type of control is dependent upon the type of preliminary survey and construction project requirements, such as automated machine grading (AMG), which is governed in Publication 408, Section 686.

E. Benchmarks that are established from any of the above categories of control must follow the acceptable procedures and closures as established in Chapter 5 of this manual.

4.1 CORS AND MONUMENTATION

The PennDOT CORS Network (PCN) is part of the highest order of network stations in the NSRS.

4.1.1 PENNDOT CORS NETWORK

The PennDOT CORS Network (PCN) is part of the highest order of network stations in the NSRS. This network of Continually Operating Reference Stations (CORS) will be used to perform Network Control and Primary Control Surveys, as well as augment Local Project Control.

4.1.1.1 SHALLOW-BRACED CORS

Shallow-braced CORS is a remotely placed reference station that can be placed almost anywhere by using a cellular modem for communications, with the possibility of utilizing a solar array for power. These setups promote a long station life span due to the potential versatility of placement. If the district or consultant is installing a Shallow-braced CORS, please consult the DCS for monument specifications. The link below provides examples of various shallow-braced CORS.

Shallow Drilled Braced Monument Overview (unavco.org)

Figure 4.1.1.1

4.1.1.2 BUILDING-MOUNTED STATIONS

A Building-mounted CORS is an antenna mounted on a building with a cable running to the actual GNSS receiver inside the building. The ability to access power, internet, and open sky are the three major needs for this kind of set-up. However, building maintenance and or settling can often lead to poor station life spans.

Figure 4.1.1.2

The above Figure 4.1.1.2 shows a building-mounted PennDOT CORS currently installed at the Materials Testing Lab in Harrisburg.

4.1.2 NETWORK CONTROL SURVEYS

4.1.2.1 CONCRETE MONUMENTS

The minimum requirements for monumentation to be used in network control surveys are concrete monuments that are 3.0 feet deep by 1.0 foot at the top and belled toward the bottom to a diameter of 1.5 feet. A steel reinforcing rod of 2.0 feet in length must be placed inside the concrete monument. A properly stamped bronze disk is to be placed on top of the concrete with the two tongues on the bottom of the disk slightly widened. Refer to Figure 4.1.2.1 below.

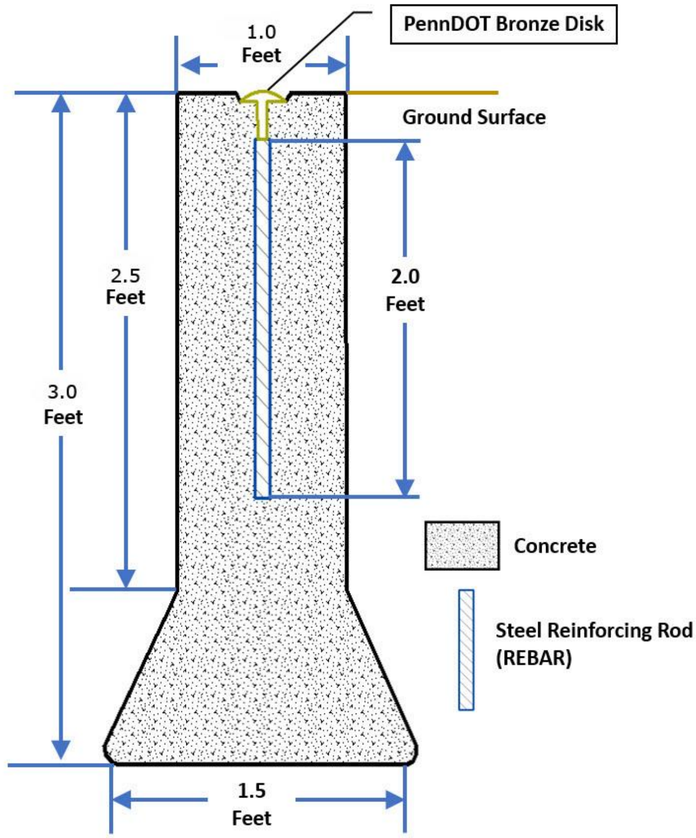


Figure 4.1.2.1

PA ONE CALL is to be contacted to assure underground utilities will not be damaged when placing these concrete monuments.

4.1.3 PRIMARY CONTROL SURVEYS

4.1.3.1 CONCRETE MONUMENTS

The minimum requirements for monumentation to be used in primary control surveys are the same as noted above for network control surveys, with the additional requirement that each monument set will have a minimum of one azimuth mark, set at a minimum distance of 1320 ft from the primary control monument. The azimuth mark will be the adjacent inter-visible primary control station. Refer to Figure 4.1.2.1 above.

PA ONE CALL is to be contacted to assure underground utilities will not be damaged when placing monuments.

4.1.3.2 EXISTING PERMANENT STRUCTURES

Monuments may be placed using existing permanent structures. Such monumentation may be survey disks, drill holes, or nails embedded in existing concrete structures.

4.1.4 LOCAL PROJECT CONTROL

A. 24” No. 5 Rebar with Cap

B. MAG/PK Nails in pavement or concrete
C. RR Spikes with center punch mark in pavement

4.1.5 VERTICAL BENCHMARKS

A. Benchmarks are to be placed on permanent structures (i.e., bridge abutments, inlet headwalls, traffic signal bases) as chiseled squares, embedded survey disks and nails, or constructed as permanent concrete monuments as outlined above.
B. Where possible, benchmarks are to be located where a survey bipod can be easily set on the mark.

4.2 TYPES OF ERRORS

Understanding types of errors and what causes them may lead to improved survey procedures that eliminate or minimize errors.

A. Systematic errors, otherwise known as cumulative errors, are repetitive and can be introduced from a variety of factors. Some of these factors are incorrect prism constant, incorrectly measured height of instrument, or an incorrectly adjusted total station. These factors can be avoided by diligently following strict instrument operating protocols, and by employing thorough operational knowledge of the equipment.
B. Blunders are significant gross errors and are caused by human error such as a number transposition or occupying the wrong control point with a total station.
C. Random error is the error that remains after all systematic errors and blunders have been accounted for. This error is often associated misclosure. Least Squares Adjustments help to estimate this error by computing the most probable value associated with the measurement.

4.3 LEAST SQUARES ADJUSTMENT

Least Squares Adjustments make it possible to detect unseen blunders as well as random errors. However, this adjustment assumes that all systematic errors have been resolved. The Department utilizes this method of adjustment in four stages.

The first stage is referred to as a “free” adjustment. The free adjustment utilizes only the network measurements and is not weighted or constrained by any type of control. This stage of the adjustment is used to detect blunders in the data.

The second stage of the adjustment is a “weighted” adjustment using weights computed from the standard deviation in the measurements. At this stage, very precise measurements are weighted more, and less precise measurements weighted less to yield a better network solution.

The third stage is referred to as “Minimally Constrained” or “Horizontally Constrained.” This is when the Network is constrained to one known horizontal control point. This adjustment shifts the network to the chosen horizontal datum and helps to identify random errors in the data associated with the standardized residuals bell curve.

The fourth and final stage is referred to as “Fully Constrained” or “Horizontally and Vertically Constrained.” This adjustment holds selected known published values in the horizontal and vertical dimensions, thus transforming the network and adjusting to the specified datum.

4.4 SURVEY REPORTING

All Deliverables must be reviewed and accepted by the DCS. If any work is found to be unsatisfactory by the DCS review, the responsible party will confer with the DCS to formulate a plan to resolve any issues.

All Deliverables must be reviewed and accepted by the DCS. If any work is found to be unsatisfactory by the DCS review, the responsible party will confer with the DCS to formulate a plan to resolve any issues.

A Survey Control Report includes these components:

- Narrative description of the project, which summarizes the project, conditions, objectives, methodologies, and conclusions.
- Discussion of the observation plan, equipment used, satellite constellation status, and observable recorded.
- Description of data processing performed. Note software used, version number, techniques employed including integer bias resolution, if applicable, and error modeling.
- Provide a summary and detailed analysis of the minimally constrained and fully constrained least squares adjustments performed. List observations and parameters that are included in the adjustment. List absolute and standardized residuals, variance of unit weight, and relative confidence for the coordinate differences at the 95% confidence level.
- Identify any data or solutions excluded from the network with an explanation as to why it was rejected.
- Prepare and input Department "Record of Control Sheets" into PennDOT PAMS (Pennsylvania Department of Transportation Photogrammetry Asset Management System). For a sample sheet output from PennDOT PAMS, see Appendix C.4.4.1.
- Include the following:
  - A diagram of the project stations and control at an appropriate scale on an overall site map in a compatible format approved by the Department.
  - CAD and DTM files compatible with Department used drafting programs
  - Raw data and solution files compatible with Department used software
  - Original Form D-428 field books

CHAPTER 5 – DIFFERENTIAL LEVELING SPECIFICATIONS

5.0 GENERAL SPECIFICATIONS

Differential leveling is the most common method for accurately determining orthometric heights from previously established benchmarks. Differential leveling must be used to establish elevation on high-order network monuments, project control, and other benchmarks. Differential leveling may also be performed to establish elevations of traverse, temporary control, and as needed on the project site.

- Benchmarks established should be:
  - In accessible areas
  - Outside construction limits
  - Stable and permanent in placement and material
- All level data, written or electronic, must be submitted with all the deliverables the specific project requires. A note should be included stating if the level has been adjusted and which adjustment method was used.

5.1 DIFFERENTIAL LEVELING EQUIPMENT

- **Automatic Levels.** Automatic levels include a self-leveling feature, which reduces the set-up time of the operation. Most automatic levels must be leveled using a three-screwed leveling head to center a bull's-eye bubble. Once this has been accomplished, a compensator will then fine-tune the instrument and establish a level line of sight.
- **Digital Levels.** Digital levels use electronic image processors to determine heights, distances, and record data automatically. Digital levels with one-piece barcoded rods are highly recommended for Network Control Leveling Specifications.
- **Level Rods.** An English rod graduated in 0.01-feet intervals, or a barcoded rod will be required for use with vertical measurement procedures. These English rods can be read and interpolated to the nearest 0.005-feet. Third Order leveling requires a geodetic level and a wooden, invar, fiberglass bar coded or calibrated fiberglass rod for differential leveling. The rods must not be more than 12 feet in length. If utilizing two level rods in the same loop, the rod on a foresight measurement should be held at that location for the subsequent backsight measurement while the second rod sets up on the next foresight/backsight location creating a leapfrog effect. When utilizing this method, ensure both rods are equal length, otherwise errors will be introduced. Attempts should also be made to equalize the backsight and foresight distance, as this will minimize any instrument error.

5.2 ORDER AND ACCURACY REQUIREMENTS

Table 5.2.1 below contains the required specifications for each level of control for a survey. Any variation from the set specifications for differential leveling must be approved by the DCS.

Specifications	Network	Primary/local	Benchmark Transfer
Max Sight Length	230 feet	300 feet	100 feet
Single Set-up Differences	15 feet	33 feet	10 feet
Cumulative Distance	33 feet	100 feet	33 feet
Peg Test Interval	Before and after use	Before use	Before and after use
Loop Misclosure	0.025 feet x SQRT(D)	0.035 feet x SQRT(D)	Not to exceed 0.01 feet

D is distance in miles

Table 5.2.1

Any level line not meeting the above criteria will be analyzed for failure by the Survey Crew Chief and DCS and run again by the survey crew. Project level lines will be adjusted either outside of the network adjustment or as part of the final network adjustment.

5.3 EQUIPMENT CARE REQUIREMENTS

Manufacturers' guidelines will always be followed when utilizing leveling equipment as well as any requirements set forth by the Department.

Survey measurement equipment is expensive and extra care must be used by those handling and using precision instruments to secure satisfactory service and avoid excessive repairs and adjustments. Careless use and handling of survey measurement equipment will impair the accuracy of work performed. Manufacturers' guidelines will always be followed when utilizing leveling equipment as well as any requirements set forth by the Department. All leveling equipment will be checked at a frequency set mentioned in the Table above or every 6 months, whichever comes first. All levels will be calibrated by a certified repair business at a minimum of once every two years or whatever frequency is set by the manufacturer.

Any adjustment of survey measurement instruments must be done by experienced personnel or under the direct supervision of qualified personnel. Extreme caution will be utilized in all tests and adjustments of surveying instruments to attain the highest degree of accuracy. Complications will arise if a faulty test shows a need to adjust an instrument that stands already in good adjustment. Therefore, it is wise to test an instrument twice before attempting any adjustment.

5.4 BENCHMARK REQUIREMENTS

High-order Benchmarks are to be drilled and epoxied in rock outcrop or on permanent structures (i.e., bridge abutments, inlet headwalls, traffic signal bases) as embedded survey disks or constructed as permanent concrete monuments as outlined in Chapter 4.1.2.1. Steel rods driven to refusal will also be accepted. When High-order benchmarks are required, detailed survey notes and record of control datasheet must be prepared and submitted to DCS. See Chapter 4.4 and Appendix E.

Project Benchmarks are to be placed on permanent structures (i.e., bridge abutments, inlet headwalls, traffic signal bases) as chiseled squares or embedded nails. In areas where permanent structures are limited, Railroad Spikes in poles or steel pins and caps will be acceptable. Minimum spacing for project benchmarks will not exceed 1,000 feet. Detailed benchmark descriptions must be included in the survey notes to include RMS segment and offset or plan station and offset. Project benchmarks are to last beyond the completion of the project lifecycle and be clearly marked on all right-of-way and Construction plans.

Benchmark transfers are required when a currently monumented and published benchmark in the Photogrammetry Asset Management System, NGS, or USGS database will be disturbed or destroyed in construction. Newly established benchmarks on constructed bridges and structures will be placed in abutment or wing walls, where the benchmark disk can be occupied by a survey bipod. These benchmark transfers are to be under the direct supervision of a registered Professional Land Surveyor.

5.5 DELIVERABLES

Following is a list of the deliverables that must be included with the survey control report.

- A description of the level loop shall be included in the Narrative
- Any Digital Raw Data Files
- Reduced Level Run including closure report
- Record of control datasheets used and created by the project and submitted to the DCS

CHAPTER 6 – TOTAL STATION SYSTEM SPECIFICATIONS

6.0 GENERAL SPECIFICATIONS AND CARE

All manufacturer's specifications and procedures will be followed when servicing or calibrating these delicate instruments.

A total station instrument combines a digital electronic theodolite, an electronic distance meter (EDM) device, and a built-in microprocessor (or computer) into a single device. Total station devices can automatically measure both horizontal and vertical distances and determine both station coordinates and elevations. All pertinent information, distance, and angular measurements are recorded in the instrument's microprocessor or external data collector. This information can then be transferred to an office computer and be manipulated as required. Total stations are critical versatile parts of every surveying operation, requiring appropriate maintenance. A proper maintenance schedule can help alleviate systematic errors.

6.1 MAINTENANCE

All manufacturer's specifications and procedures will be followed when servicing or calibrating these delicate instruments. The following is a maintenance and care schedule that is required by the Department and completed by a professional.

- Every 3 Months:
  - Clean and inspect optics, electrical contacts, instrument body, and instrument case
  - Check and adjust level vials
  - Check and adjust vertical plummet
  - Check horizontal and vertical circle collimation and adjust as needed
- Every 6 Months:
  - Check calibration of EDM on a calibration baseline and adjust as needed
    - NGS Baseline Locations can be found at https://www.ngs.noaa.gov/CBLINES/BASELINES/pa
    - Baselines established by a business certified by the manufacturer may also be used
- Yearly
  - Clean and calibrate by a certified Manufacturer
  - EDM baselines shall be utilized yearly to calibrate the EDM's horizontal measurement

Note all equipment that assists in the operation of total station devices will be checked every 3 months for wear and tear and plumbness, for example Prism Pole Plumbness and Prism damage.

EDM Baseline Procedures:

All EDMs will be carefully adjusted and precisely calibrated to obtain the required accuracies. However, it should be noted that these instruments will still exhibit a small, but constant, instrumental error and an error that is proportional to the distance measured. These two pieces of information are compiled and are presented as the specification for the instrument. A typical instrument specification is:

$$\pm \pm (0.02\ \text{feet} + 5\ \text{ppm})$$

The first number, 0.02 feet, is an indication of the precision of the instrument (constant instrumental error). This specification implies that the distances measured will be within 0.02 feet from the mean of a group of measurements. The second number, 5 ppm, is an indication of the attainable accuracy levels. This specification implies that the distances measured will be within 5 parts per million of the true distance. Accuracy adjustments to an EDM device will require a test range as specified in the information compiled and published by the National Oceanic and Atmospheric Administration (NOAA), National Geodetic Survey (NGS). Prior to making any adjustments at the test range, all optical plummets should be checked. All offset changes should be made in accordance with the manufacturers' manual. In addition, all prisms that will be used on a daily basis with the EDM should be used when calibrating the instrument. The following are the accuracy adjustment procedures required when calibrating an EDM:

- Place and level the EDM over the "0" monument of the calibrated baseline.
- Place the prism over the first monument of the calibrated baseline range. Be certain that the prism offset established in the EDM is the same as that of the prism located at the first monument.
- Apply all correction factors, as specified by the manufacturer, to the EDM to account for various atmospheric conditions (such as atmospheric pressure, temperature, and humidity).
- Measure and record 10 to 15 measurements. Compare the mean reading with the true value from the calibrated baseline information sheet provided by the National Geodetic Survey. Care should be exercised to ensure that the measured distances have been reduced to their horizontal equivalents.
- If the mean reading and the true value are not the same, then the EDM must be adjusted. Fine adjustment procedures to the prism offset are available with the specific dealer of the instrument.
- Once the EDM has been adjusted, move the prism to another identified monument and measure and record 10 to 15 measurements. Compare these results with the calibrated baseline information and verify that the manufacturer's specifications are exceeded.

Unlike accuracy adjustment procedures, precision determination can be accomplished without the use of a calibrated baseline test range. The following are recommended precision determination procedures:

- Place the EDM on a sturdy tripod.
- Place a prism 300' away on a prism pole, and measure and record 10 to 15 measurements. Discard the first measurement taken after the EDM has been turned on.

Compare the mean reading value with each measurement. If the difference between the two values exceeds the manufacturer's specifications, then the instrument will need to be serviced.

- Horizontal (Length) Measurement Accuracy - Horizontal distances must be measured and expressed to 0.01 feet.
- Vertical (Elevation) Measurement Accuracy - Vertical elevations must be measured and expressed to 0.01 feet.
- Angular Measurement Accuracy - Angular measurements must be recorded and expressed to 'dd' Degrees- 'mm' Minutes – 'ss' seconds.

The Table 6.1.1 below shows required manufacturer's stated equipment accuracies.

Total Station Accuracy Requirements

		Control Type	
Specifications		Primary	Local
Directions	Number of positions or sets	4	2
	Standard Deviation of Mean not to exceed	1.2"	2.0"
	Rejection Limit from the Mean	5"	5"
Angular Misclosure	Average not to Exceed	3.0"	5.0"
Distance	Minimum Distance Precision	1:25000	1:15000

Table 6.1.1

CHAPTER 7 – GNSS SPECIFICATIONS

7.0 GLOBAL NAVIGATION SATELLITE SYSTEM

The Global Navigation Satellite System (GNSS) is a term that refers to the system of satellite constellations that provides positioning, navigation, and timing services on a global scale.

An understanding of measurements and computations is an essential aspect of the surveying profession especially when operating equipment utilizing Global Navigation Satellite System (GNSS). The Global Navigation Satellite System (GNSS) is a term that refers to the system of satellite constellations that provides positioning, navigation, and timing services on a global scale. This Chapter outlines various applications, procedures, and specifications for the use of equipment that utilizes the GNSS. All work performed using GNSS equipment should be documented and included with Survey Reports.

The Table 7.0.1 below shows estimated accuracies of the types of GNSS survey observation types.

GNSS Survey Accuracy Estimation				
GNSS SURVEY TYPES	Observation Time	Estimated Accuracy		Max. Range Between Observation Stations
STATIC GNSS	1 to 2.5 hours	Horizontal	0.02 - 0.05 ft.	50 Miles
		Vertical	0.10 - 0.15 ft.	
Fast Static GNSS	8 to 20 minutes	Horizontal	0.05 - 0.09 ft.	6 Miles
		Vertical	0.10 - 0.15 ft.	
RTK GNSS	5 to 300 seconds	Horizontal	0.05 - 0.07 ft.	6 Miles
		Vertical	0.05 - 0.07 ft.	
RTN GNSS	5 to 300 seconds	Horizontal	0.05 -0.07 ft.	Optimal within 35 Miles of a Network Station
		Vertical	0.05 -0.20 ft.	

Table 7.0.1

This estimation chart does not represent the redundancy measurements needed to accurately establish Control Stations.

7.1 GNSS EQUIPMENT

A GNSS network survey includes multiple sets of receivers, antennae, fixed-height tripods, etc. Identical equipment should be used whenever possible to minimize the effect of equipment biases. The compatibility of mixing different instrument models or brands should be demonstrated by performing a validation survey. Survey equipment, like all scientific instrumentation, should be handled with care, maintained according to manufacturing specifications, and calibrated on a regular basis. An equipment calibration should be performed at the start and end of a project, before and after any maintenance, and at sufficient intervals to maintain data integrity. Data not bracketed by successful calibrations are suspect. To prevent the invalidation of good data, frequent calibrations are recommended. The entire system of GNSS equipment, personnel, and processing procedures should be proven with a validation survey as a final check to ensure all components interact properly. Following are descriptions of GNSS-related equipment:

- **Receiver Specifications:** The receivers used for network surveys should record the full wavelength carrier phase and signal strength of both the L1 and L2 frequencies and track at least eight satellites simultaneously on parallel channels. Dual frequency instruments are required for all baselines. Receivers should have completed instrument testing by the Federal Geodetic Control Subcommittee (FGCS). Receivers should have sufficient memory and battery power to record 6-hours of data at 15 second epochs. Receiver at Hub Stations should have sufficient memory and power to record 72 continuous hours of 30-second epochs.
- **Receiver Calibration and Care:** Ensure that your receiver contains the latest manufacturer’s firmware upgrades. A zero-baseline test can measure receiver internal noise if the performance is suspect. Consult your user’s manual for additional specifications.
- **Antenna Specifications:** Antennae should have stable phase centers and choke rings, or large ground planes (greater than 16 cm) to minimize multipath interference, and a common orientation indicator (e.g., an arrow) to point north during observations.
- **Antenna Calibration and Care:** All antenna models used shall have completed Antenna Calibration by the National Geodetic Survey (NGS). Consult your user’s manual for other specifications.
- **Tripod Specifications:** The tripods used must facilitate precise offset measurements between the mark datum point and the Antenna Reference Point (ARP). Fixed height tripods are preferable, due to the decreased potential for antenna centering and height measurement errors.
- **Tripod Calibration and Care:** All tripods shall be examined for stability with each use. Ensure that hinges, clamps, and feet are secure and in good condition. Fixed-height tripods shall be assessed for stability, plumb alignment, and height verification at the start and end of each project.
- **Tribrach Specifications:** Tribrach used shall be of suitable quality and condition for high-accuracy surveys. Consult with the Department’s DCS for details.
- **Tribrach Calibration and Care:** The optical plummet alignment shall be assessed at the start and end of each project.
- **Personnel Specifications:** All field personnel should be trained in the avoidance of systematic errors and blunders during field operations. Field personnel often work alone and must be prepared to make wise, on the spot decisions regarding mark identification and stability, equipment use and troubleshooting, and antenna setup. Office personnel should be familiar with geodetic concepts and least-squares adjustments. Personnel should participate in any available training and achieve the recommended certifications.

7.2 STANDARDS AND ADJUSTMENTS TO GNSS CONTROL NETWORKS

All control surveys will be based upon, and referenced to, National Spatial Reference System (NSRS).

- The Federal Geodetic Control Subcommittee (FGCS) publishes standards and specifications for geodetic control surveys in the United States. The document pertaining to conventional geodetic control surveying (traverse, triangulation, and differential leveling) is entitled "Standards and Specifications for Geodetic Control Networks." Corresponding documents for GNSS surveys ("Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques,” and “Geospatial Positioning Accuracy Standards, Part 2: Standards for Geodetic Networks”) are to be used by the Department and its consultants when finalized and deemed necessary. These Accuracy Standards can be found at https://www.fgdc.gov/standards/projects/accuracy/part2/chapter2

- For a GNSS network, the propagated relative error will be computed using a least squares adjustment for all three dimensions (X, Y, and Z or N, E, and U) with 95 percent (two-sigma) confidence criteria. Accuracy classification of a GNSS relative positioning survey may be determined in one of two ways, dependent upon the project classification:
  - A "geometric “classification may be made where the confidence tests are imposed upon a minimally constrained (free) least squares adjustment independent of the local geodetic reference system external control. Geometric classifications are applicable to project specific control systems such as those developed for specialized design surveys and monitoring networks.
  - The second method for classifying GNSS relative positioning surveys is a National Spatial Reference System (NSRS) classification determined from a least squares adjustment constrained to the local geodetic reference system, holding the external control fixed. This method is a good measure of the accuracy of a network when the local geodetic reference system is of higher accuracy than the new observations (i.e., when a statewide High Accuracy Reference Network (HARN) is used). Advances in GNSS technology have provided new systems to be used in addition to traditional NSRS concrete monuments. NSRS permanently mounted GPS or GNSS antennae, such as continuously operating reference stations (CORS) and Real Time Network (RTN – a network of CORS with real-time kinematic capability), are used to augment for and with traditional monumentation.

7.3 NETWORK AND PRIMARY CONTROL CRITERIA

Network Requirements

	Control Type & Method Utilized			
	Network Static	Primary Static	Primary RTN	Local
Project length (P)	P > 5 Miles	P < 5 Miles	P < 5 Miles	Within Primary Control Area
Minimum Number of CORS Ties	3	1	1	**
Minimum Number of Horizontal Control Ties	1 Passive Mark	4 Network Control Survey Marks	4 Network Control Survey Marks	4 Primary Control Marks
Minimum Number of Vertical Control Ties	3 Passive Marks	5 Network Control Survey Marks	5 Network Control Survey Marks	2 Primary Control Marks
Minimum Number of Occupations	2	2	2	**
Occupation Time	2.5 hr.	1 hr.	5 min	**
Time Between Observations	3 hrs.	1 hr.	4 hrs.	N/A
Percentage of Repeat Baselines	40%	20%	20%	N/A
Type of Ephemeris Required	Precise	Rapid or Precise	Broadcast	N/A

Table 7.3.1

** Established from Primary Control

- Note, all observations will have a 15 degree masking angle.
- All GNSS observations set ups need to be broken down and set up again to be considered a NEW observation.

A. NETWORK CONTROL

When a project is greater than 5 miles:

- Static data from a minimum of 3 CORS during occupation times must be used in the positional solution.
- Minimum of 3 vertical passive monuments and 1 horizontal passive monument must be utilized:
  - 2 Static observations per monument and a duration of occupation of 2.5 hours with a span of 3 hours between observations or 1 Static observation of 5 hours per monument.
  - A Minimally constrained and a Fully Constrained Network adjustment must be performed to find any blunders and adjust to previously established NGS & PennDOT Geodetic control along with NGS & PennDOT CORS.
- All Primary control will be based off these network control points to promote continuity between projects and maintain absolute accuracies.

B. PRIMARY CONTROL

When a project is less than 5 miles:

- Static GNSS:
  - Minimum of 1 CORS horizontal positional data must be used in the project's positional solution.
  - Minimum of 4 horizontal and 5 vertical ties to the Network Control Monumentation.
- RTN GNSS:
  - Minimum of 1 CORS horizontal positional data must be used in the project's positional solution.
  - Minimum of 4 horizontal and 5 vertical ties to the Network Control Monumentation.
  - 2 separate occupations are required, 4 hrs. between occupations:
    - 1 occupation equates to a 5-minute observation then rotating the rod 180 degrees and then another 5-minute observation.
  - All Local control will be based off the primary control points to promote continuity throughout the project's timeline.

C. LOCAL CONTROL

Within Project's Primary Control Limits:

- All Local Control shall be established from Primary Control:
  - Horizontal Control can be established through Total Station traverse methods. Achieving accuracies established in Chapter 6.
  - Vertical Control established by differential leveling from the Primary Vertical Control.
  - Any horizontal or vertical local control established by RTK methods. Achieving accuracies established in Chapter 4.

Be sure to accurately describe and document the method and results of how all control was established. Please contact the DCS if there is a need to alter the above conditions.

7.4 SITE CALIBRATION REQUIREMENTS

Real Time Kinematic GNSS and Real Time Network GNSS are both differential GNSS techniques. These techniques utilize known coordinates of a base station or CORS to derive a highly accurate position. The Table below delineates the acceptable estimated error of a site calibration.

	Maximum Site Calibration Estimated Error
Horizontal	0.04 feet
Vertical	0.08 feet

Table 7.4.1

Site Calibration Requirements:

- Minimum of 4 known horizontal points
- Minimum of 5 known vertical points
- Every effort should be made to get the entirety of the project inside of the GNSS site calibration.
- Document the estimated error of the calibration in Survey Reports.
- DCS should be contacted if the site requirements cannot be met to discuss if there are acceptable alternatives.

7.5 GNSS SURVEY DELIVERABLES

Following is a list of the deliverables that must be included with the survey control report when GNSS survey methods are used:

- Narrative description of the project, which summarizes the project, conditions, objectives, methodologies, and conclusions.
- Document the observation plan, equipment used, satellite constellation status, and observable recorded.
- Provide a description of data processing performed. Note software used, version number, techniques employed including integer bias resolution, if applicable, and error modeling.
- Provide a summary and detailed analysis of the minimally constrained and fully constrained least squares adjustments performed. List observations and parameters that are included in the adjustment. List absolute and standardized residuals, variance of unit weight, and relative confidence for the coordinate differences at the 95% confidence level.
- Identify any data or solutions excluded from the network with an explanation as to why it was rejected.
- Submit Department "Record of Control Sheets" to be reviewed by the DCS for submission to PennDOT PAMS. See Chapter 4.4.
- Include a diagram of the project stations and control at an appropriate scale (an overall site map in Bentley OpenRoads or another compatible format approved by the Department).
- Raw data and solution files in a manufactures' native format and RINEX.

CHAPTER 8 – DATA ACQUISITION SPECIFICATIONS - AERIAL PHOTOGRAPHY, LIDAR SYSTEMS, AND UAS

8.0 INTRODUCTION

Aerial photography and lidar are the primary remote sensing data sources used to create 3D models. Traditional aerial photography, Unmanned Aircraft Systems (UAS), as well as mobile, terrestrial (static), and aerial lidar specifications for equipment and collection are outlined in this chapter.

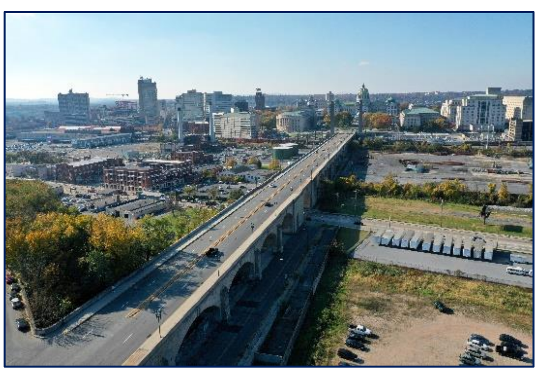
8.1 TRADITIONAL AERIAL PHOTOGRAPHY

This section outlines the requirements for piloted aerial photography flown for PennDOT, however, these requirements are recommended for unmanned aerial photography as well.

Traditional aerial photography refers to aerial photography from a piloted aircraft with specialized, high resolution aerial cameras. Traditional aerial photography may be more cost effective for larger areas or where traditional vectorized base mapping is desired. This section outlines the requirements for piloted aerial photography flown for PennDOT, however, these requirements are recommended for unmanned aerial photography as well.

A. OBLIQUE AERIAL PHOTOGRAPHY

Oblique aerial photography is captured at an angle away from vertical, towards the horizon. High obliques include the horizon in the image, see Figure 8.1.1. Low obliques do not include the horizon in the image, see Figure 8.1.2.



High Oblique Aerial Image
Figure 8.1.1

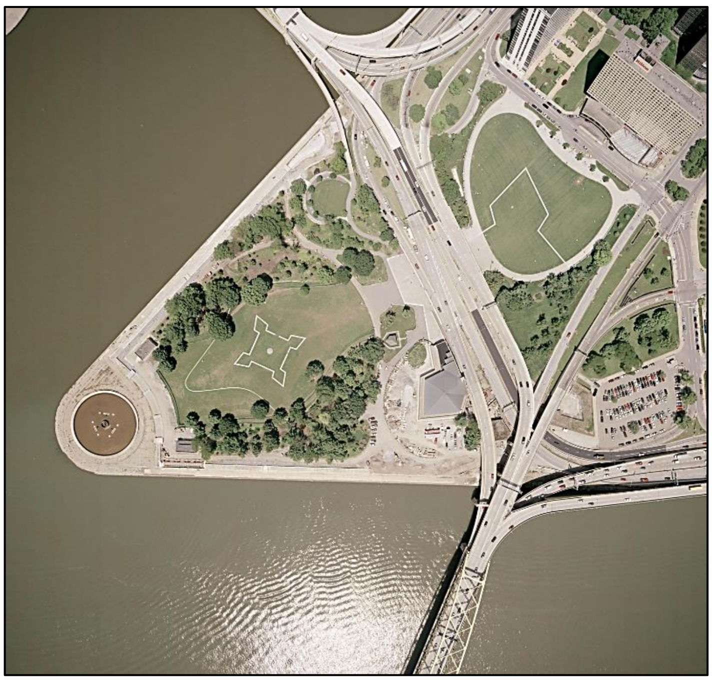
Low Oblique Aerial Image
Figure 8.1.2

Oblique aerial photography may be captured with mounted, or handheld cameras. The resolution of the camera shall be at least 15 million pixels. Images should be captured from a minimum of four positions surrounding the area of interest. Imagery shall be captured during the same time-of-day requirements as found in Chapter 8.1.D, but care should also be used to avoid hazy conditions.

Minimum requirements are listed here and should be followed unless directed otherwise by the Department:

- Image collections shall consist of 80% low obliques and 20% high obliques.
- At least 20 images surrounding the area of interest.
- Images shall be captured from the four cardinal directions or from 4 directions giving the best definition of the area of interest.
- Images are to be captured from a maximum of 3000 feet above terrain.
- Specifications for oblique imagery for the purpose of mapping will be directed by the Department.

B. VERTICAL AERIAL PHOTOGRAPHY



Vertical Aerial Image
Figure 8.1.3

Vertical aerial photography shall be flown with a digital camera meeting the specifications throughout Chapter 8.1. If the purpose of the vertical photography is to produce mapping, the guidelines found in Table 8.1.4 shall also be followed.

Map Accuracy	Ground Sample Distance		Maximum Flight Altitude
	Inches	Centimeters	Above Mean Ground (AMG)
Final Design Mapping	1.6	4	2200 feet
Intermediate	3.5	9	4500 feet
Preliminary Design Mapping	7	18	9000 feet

Flight GSD/Altitude
Table 8.1.4

C. EQUIPMENT SPECIFICATION

Digital cameras are required and must have a manufacturer's certificate of calibration or equivalent.

Flight planning is normally provided by the Department. It shall be done with a planning software that pre-plans photo centers on a DTM, taking into consideration the effects of the DTM on end-lap and side-lap.

Aircraft used for photography will be maintained and operated in accordance with regulations of the Federal Aviation Administration (FAA) and the Civil Aeronautics Board. Aircraft will have a service ceiling with an operating load (crew, camera, film, oxygen, and other required equipment) of not less than 18,000 feet (5,500 m) above mean sea level. Aircraft will have performance capabilities for safe flight at the lowest altitudes permissible within FAA regulations while still maintaining a ground speed slow enough to expose photography free of detectable image motion. Aircraft will also contain the appropriate avionic equipment to operate in positive control areas.

Digital cameras are required and must have a manufacturer's certificate of calibration or equivalent. Digital cameras shall have a minimum resolution of 70 million pixels, a minimum 0.25 base to height ratio and capable of capturing 4 cm GSD photography at 60% end-lap.

D. PHOTOGRAPHY SPECIFICATIONS

All deviations in flight height will be within 5% of the specified values of flight planning provided by the Department. If flight planning is not provided by the Department, or a different camera must be deployed, aerial photography shall meet the specifications found in Figure 8.1.4. In such cases, contractors shall ensure that planned footprints or mapping limits, as well as planned ground control locations are covered. Any such planning by contractors shall be approved by the Department.

Each flight line will track the alignment plotted on the flight map within a ground distance that is no more than 10% of the flight height above mean ground elevation.

Each flight strip will be photographed so that the principal points of the first two and last two exposures fall outside the boundaries of the specified photography coverage area. If project requirements dictate a single stereo pair with the photo center positions predetermined, then the additional two photos at each end will not be required.

Time of Photography - Photography will be recorded only when light and atmospheric conditions are satisfactory for producing images that will meet specifications. Photography for mapping will normally be taken mid-day when the solar angle is equal to or greater than 30 degrees. However, under certain conditions and types of terrain, acceptable photography can be obtained when the solar angle is less than 30 degrees. Areas with predominately steep, wooded slopes facing West, Northwest, North, Northeast, or East will be photographed at the time of day when the sun's angle provides the optimum illumination of the project area. Photography for mapping will be taken when the ground is clear of snow and trees are foliage-free, unless otherwise directed by the Department.

Forward Overlap – The forward overlap for each flight line will average 60% +/- 2%. Overlap of any two consecutive exposures of less than 55%, or more than 65%, may be cause for rejecting that flight line in total. In some instances, because of terrain or other special factors, the average overlap may not meet the specific requirements established. If so, this information will be recorded on the project flight map.

Side Lap - The side lap of parallel lines of vertical aerial photography will average 25% +/- 10%. Any exposure not meeting this criterion may be cause for rejecting that flight line.

Crab - The crab of all photographs for a flight line will not exceed an average of 3 degrees. Crab of two or more consecutive photographs exceeding 5 degrees may be cause for rejecting that flight line in total.

Tilt - Care should be taken to minimize tilt. A gyro-stabilized mount shall be utilized. The tilt of all photographs for a flight line will not exceed an average of 1 degree. The tilt of any single photograph exceeding 3 degrees may be cause for rejecting that flight line in total.

Image Motion - Care must be taken to eliminate image motion. Cameras used shall incorporate Forward Motion Compensation (FMC) and gyro-stabilized mountings to eliminate image motion. Projects displaying image motion may be rejected by the Department.

Metadata - All photography must contain metadata, including, at a minimum, a calibration report for the camera used and a flight report including date, time, and conditions.

E. FLIGHT LINE AND PHOTO NUMBERING

Numbering of flight strips and exposures will originate at the western or southern end of the project.

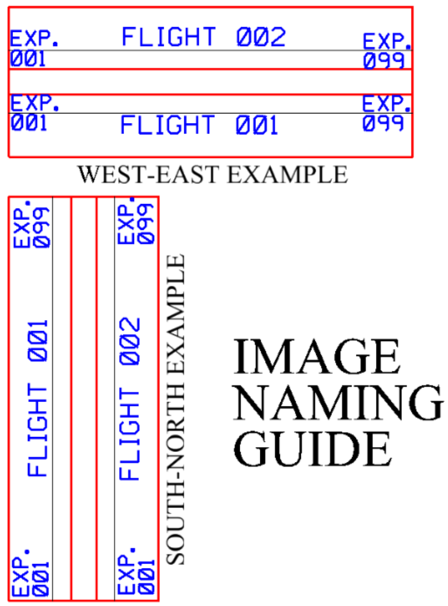
The flight strip numbers will be numbered in a continuous sequence, but photo numbers will start at 001 for each new flight strip. Each individual flight strip will be identified with a flight number. The first flight strip will be labeled as "Flight 001". All flight strips following "Flight 001" will be labeled numerically in ascending order. Therefore, the last flight number is the same as the total number of flights covering the project area. Photographs will be numbered in a sequence beginning anew for each flight strip with "Exposure 001". For example, flight strip identification would be as follows:

Flight 001, Exposures 001 through 012

Flight 002, Exposures 001 through 015

Flight 003, Exposures 001 through 010, etc.

Numbering of flight strips and exposures will originate at the western or southern end of the project. If the project has a predominately north-south orientation, exposure numbering will start in the south and flight line numbering in the west, if it has a predominately east-west orientation, exposure numbering will start in the west and flight line numbering in the south. See Figure 8.1.5.



Flight Line and Exposure Numbering Convention
Figure 8.1.5

Flight planning is normally provided by the Department and will include the proper numbering plan.

F. DELIVERABLES

Aerial photography will be delivered at a minimum 8 bits, radiometrically adjusted, 4 band (RGBI) TIFF format in native resolution with jpeg compression at Q40. Delivery can be made on any media sent to our office. Delivery may also be made by FTP or other Internet-based transfer mechanism provided that the transfer speed is sufficient to complete the transfer in less than 4 hours. A complete aerial photography submittal includes these components:

- 1 set imagery at full resolution and jpeg Q40
- 1 set imagery at 10% resolution and jpeg Q40
- A flight report including date, time, and conditions during the mission
- Camera calibration report
- Raw airborne GPS/IMU data
- A flight index

8.2 TERRESTRIAL (STATIC) LIDAR

This technology is excellent for surveying bridges, walls, heavily traveled highway surfaces, busy intersections, and rock faces/slopes.

Terrestrial Lidar Scanners provide surveyors a tool to accurately measure complex objects quickly, efficiently and from a safe location. The object to be surveyed does not have to be physically occupied during data collection. This technology is excellent for surveying bridges, walls, heavily traveled highway surfaces, busy intersections, and rock faces/slopes.

Terrestrial Laser Scanning (TLS) saves field time especially on complex, hard to access projects. However, data extraction and production of usable CADD-Digital Terrain Model (DTM) products usually take considerable office processing time. Great care must be taken to create final deliverables that satisfy the end user and accurately represent the surface.

A. INSTRUMENT CALIBRATION AND CARE

The instrument shall be maintained according to manufacturer recommendations including proper storage, lens and unit cleaning, and periodic calibration and maintenance. Firmware will be kept up-to-date.

After any incident involving the instrument such as a fall or impact, the equipment should be sent for maintenance and calibration.

B. INSTRUMENT SELECTION AND SCAN PROJECT CONSIDERATIONS

There are several models and types of terrestrial scanners which have specific uses, functionality, and overall advantages or disadvantages. It is therefore critical to understand client requests in order to select the type of scanner that will meet project requirements.

Coordinate System and Units of Measure – Care must be taken to ensure that scanning software is configured for the correct coordinates system and units of measure, as well as being consistent with project control.

Point Density and Scan Distance – As the distance from the scanner increases, point densities and point accuracies decrease. Scan positions must be planned to provide consistent scan distances and point densities throughout the project.

Data Voids – Scan positions should be planned to eliminate voids or shadows in the scan data.

C. SCAN REGISTRATION

If requested by the Department, control for lidar scan projects will be within the PA State Plane Coordinate System. Ground control targets will not be positioned, or be so large, that they obscure important details of the subject. Targets mounted to the surface of the subject must be fixed in a manner that does not damage the surface.

The ground control survey must be performed to support the project accuracies requested. This may require differential leveling to support the highest possible vertical accuracies. The project's combined scale factor may need to be applied, particularly on bridge scans.

Most projects will require multiple scan locations. Ground control should be placed at no more than 500 feet on corridor projects and 500-foot grids on non-corridor projects. Ground control should not be placed in lines, but should be staggered throughout the site.

Various methods exist for registration of lidar scans to each other and to the coordinate datum. Any method is acceptable so long as final project accuracy specifications can be verified by the map testing procedure outlined in Chapter 2.2.

D. WEATHER AND TRAFFIC

Scanning and image capture may not be performed in adverse weather conditions where the quality of observed data would be affected. Rain or snow may cause data voids due to erroneous data points caused by returns from precipitation or erroneous range measurement due to refraction of the measurement beam. Wet surfaces tend to have lower reflectivity and will affect scan density.

Scanning in heavy traffic will obscure the road surface. Mitigation procedures such as additional scans from multiple points of view, increased scan densities or scanning during the lowest traffic volumes should be applied.

E. DELIVERABLES

Deliverables include the following information, required in digital format, unless otherwise requested in the project scope of work:

- Project metadata, including weather conditions and site sketches.
- Scan metadata, including scan density, camera settings, scan target area, and ground control measured for each set-up location.
- Raw scan data in its original format.
- Ground control information included in a survey report as described in Chapter 4.4.
- Registration information for relative (cloud to cloud) and Georeferencing registration.
- Any imagery captured.
- Registered scan data in LAS format classified to the latest LAS classification standard.
- Any other scan data format as requested such as Bentley format (.pod) with classifications.
- CADD data produced such as linework and terrain surfaces. Terrain surfaces should be created directly from classified scan data or from data subsampled to no more than 2 feet grid spacing.

8.3 AIRBORNE LIDAR SYSTEMS

Airborne lidar may be used for many different purposes within the Department. Some of these uses include supplementing digital terrain model data for existing surface models, mapping bare earth under difficult vegetation canopies, change detection, and flood event modeling.

Airborne lidar techniques have improved and are currently capable of reaching very high accuracies on hard surfaces. Processes, equipment, flight heights, and ground control surveys must all be carefully specified to reach high accuracies.

Because of the broad types of use cases for airborne lidar, specifications will not be defined here. If these services and products are required, specifications will be customized to the project and outlined in the contract documents.

If you need help in procuring airborne lidar services, see your DCS. The DCS may contact the PSS to procure the service.

8.4 MOBILE LIDAR SYSTEMS

Mobile lidar is typically used by the Department to acquire very accurate data on road surfaces and is usually combined with other data sets such as photogrammetry or ground survey.

Mobile lidar is typically used by the Department to acquire very accurate data on road surfaces and is usually combined with other data sets such as photogrammetry or ground survey. Mobile lidar is very dense and also measures overhead features such as structures and wires. Mobile lidar can be driven at near highway speeds. Mobile lidar can help improve safety and reduce or eliminate the need for lane closures.

A. EQUIPMENT SPECIFICATIONS

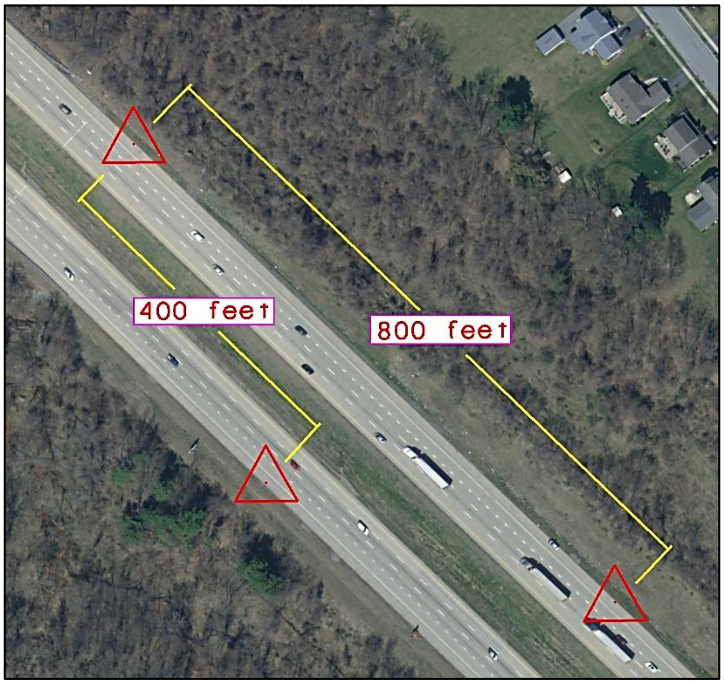
Mobile lidar systems vary greatly according to the purpose for which they are needed. The Department must pre-approve the equipment prior to any project.

B. DATA CAPTURE

Typically, mission planning will begin at the Department level including control layout, target painting, and ground survey strategies. Data collection planning will continue with the consultant or Department personnel performing the field data collection. The data collection mission shall be planned to adhere to sensor or system manufacturers' specifications. All manufacturers' specifications regarding sensor/system calibration shall also be performed. This includes the appropriate sensor alignment (bore sighting) procedures prior to data collection.

The typical application as described above is for the highest possible accuracy pavement mapping. To achieve this, data is collected from all travel lanes so that at least 25% overlap is achieved. This overlap will then be used to enhance quality assurance.

Control will be painted as directed in Chapter 8.6. Control will be spaced every 800 feet along each planned lidar collection path. Multiple lanes in the same travel direction will only count as a single path for the purpose of control planning. In the case of interstates or other corridors where travel lanes are separated by a median or other natural features, the control should be placed at 800 feet spacing along both directions of travel and be staggered as seen in Figure 8.4.1.

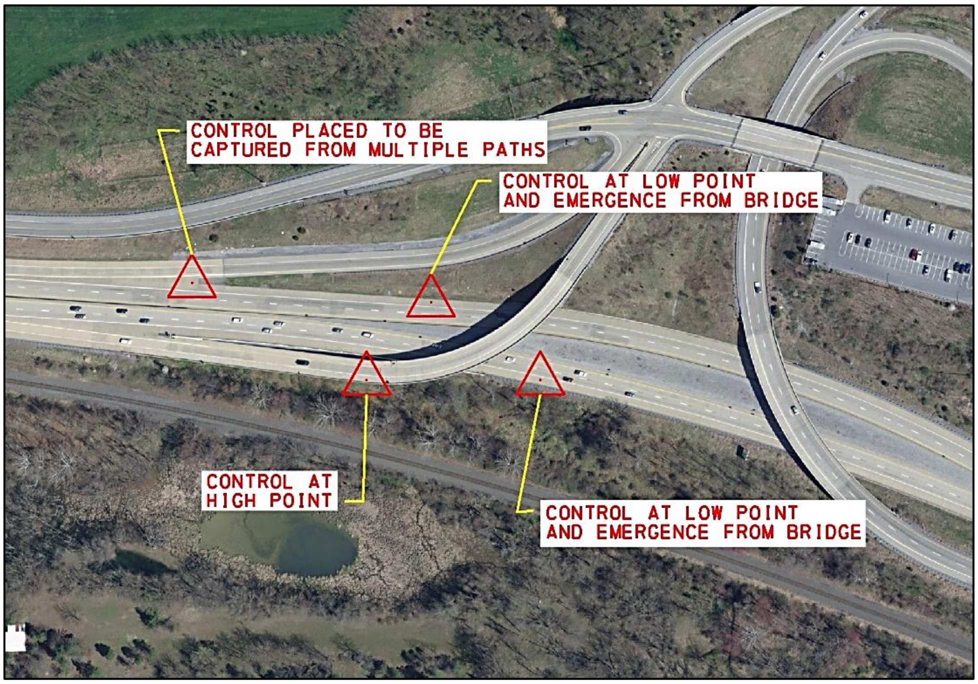


Mobile Lidar Control Placement
Figure 8.4.1

When a planned lidar path passes under a bridge or tunnel, a control point should be placed no more than 200 feet from where the path re-emerges.

At interchanges or other areas where lidar will be collected on roadways passing over each other, control should be placed near the highest and lowest points in the interchange.

Control may be extended to 1,200 feet spacing where there are curves if necessary. Control should also be planned when practical so that a single control point may be seen from multiple lidar paths. See Figure 8.4.2.



Mobile Lidar Control Placement

Figure 8.4.2

C. DATA PROCESSING

Raw lidar data will be post-processed to reach the highest possible accuracy with the control provided by the Department. The resulting vectorized CADD mapping data must map test to an accuracy of 0.05 feet RMSE.

D. DELIVERABLES

Mobile lidar data will primarily be used to enhance the accuracy of existing condition 3D models and are usually combined with photogrammetric mapping for areas off pavement or where higher accuracy is not needed.

Photogrammetry should also be used to enhance feature identification and horizontal definition. In some cases, the horizontal location of features such as drop inlets or manholes can be better defined horizontally from a combination of lidar and photogrammetry; however, the elevation should always be determined from the lidar cloud.

See Chapter 9 for more information on the requirements for CADD mapping deliverables. Lidar data should also be delivered as follows:

- Point clouds will be cut into manageably sized tiles.
- Point clouds will be delivered in LAS format and classified according to the latest American Society for Photogrammetry and Remote Sensing (ASPRS) Standards.
- Imagery and related GPS position data
- An index showing the point cloud tile layout

8.5 UNMANNED AIRCRAFT SYSTEMS

The designated UAS pilot must be certified under FAA Part 107

Unmanned Aircraft Systems (UAS) have a multitude of uses through the Department. This section will focus on the various requirements a UAS pilot must meet in order to fly for the Department and on UAS capture for mapping purposes.

A. POLICIES, REGULATIONS, AND LAWS

Prior to conducting any UAS flight on a PennDOT project, an employee or provider must be aware of, and in compliance with:

- Federal Aviation Administration (FAA) Part 107 Rules (see Appendix F-11)
- PennDOT Publication 832 – PennDOT UAS Policy
- Title 18 of the Pennsylvania Consolidated Statutes 3505 (see Appendix F-12)

Among the many requirements found in the items above, the provider must be especially aware of the following:

- The designated UAS pilot must be certified under FAA Part 107.
- The designated UAS pilot must pass the Bureau of Aviation's (BOA) certification.
- Prior to any mission, a BOA form AV-14 (risk assessment) must be completed and approved by the designated 'UAS Coordinator'. Please contact the Department for a current list of UAS Coordinators by region.
- For use during construction, see PennDOT Publication 408, Chapter 108.05(c)7, "Unmanned Aircraft Systems (UAS).".
- Based upon project requirements, sending Notice of Intent to Enter Letters (NOITEs) for UAS operations near privately owned property may be necessary.

B. EQUIPMENT AND DATA PROCESSING

There can be great benefit to the Department for many different purposes in flying simple photo capture missions. For these photo capture only missions, the number of acceptable equipment configurations is too large to list here.

However, if the captured photos are intended to be used to produce Digital Surface Models (DSM) or other mapping products, the following should be considered. These considerations may not be necessary for low accuracy applications.

- A UAS with high grade GNSS capabilities and Real Time Kinetic (RTK) functionality
- Post processing to a known base GNSS receiver
- Ground control spaced at least 1 for each 5 photos and well distributed throughout the site

Project-by-project direction will come from the Department for other remote sensing projects using UAS. Lidar, multi- and hyper-spectral collection, and other remote sensing technologies may offer many useful advantages to the Department and specific direction will come as these projects develop.

C. DELIVERABLES

The following are some possible deliverables from UAS projects:

- Photos in JPEG format (Q-50 or better)
- Associated exposure GNSS positions
- Post processed RTK exposure positions
- DSMs in a format that can be opened or referenced into Bentley CADD
- Common point cloud formats such as LAS or POD
- Vectorized CADD data collected from the Stereo UAS imagery (Bentley CADD formats)

8.6 CONTROL SPECIFICATIONS AND TARGETING

> …ground control must be twice as accurate as the required mapping accuracy.

This section gives details on targeting requirements for the various technologies described in this chapter. Target planning is frequently done by the Department. When target planning is not done by the Department, direction should come from this manual or project specific requirements.

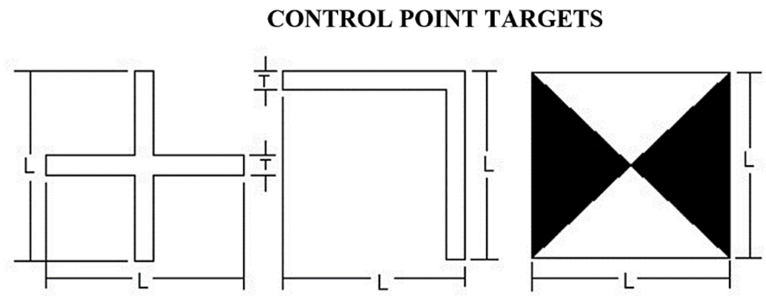
ASPRS has updated its recommendations for ground control requirements. The Department will follow the ASPRS recommendations as follows. For all photogrammetric and lidar mapping products, ground control must be twice as accurate as the required mapping accuracy. In addition, as outlined in Chapter 2.2, map testing points must also be twice as accurate as the expected dataset accuracy.

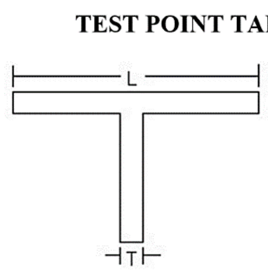
A. TARGET SPECIFICATIONS

> A close-up photo, a second photo showing the point and its surrounding landscape, and a rough GPS position should be collected when control is placed.

Figure 8.6.1 below illustrates the requirements for several types of targeting. With the exception of static and mobile lidar where vertical panels may be useful, horizontally placed targets should be placed on flat and stable ground. Panels should be located away from trees and other obstructions wherever possible. When obstructions cannot be avoided, GNSS signal and exposure positions (position from which the panel will be imaged or lidar collected) must be carefully considered during placement. Areas where vehicles may park and obstruct panels should be avoided.

A close-up photo, a second photo showing the point and its surrounding landscape, and a rough GPS position should be collected when control is placed.





	Length (L)	Thickness (T)	Special Notes
High Accuracy Photogrammetry (UAS/Helicopter)	12 inches	3.0 inches	High contrast and definition important
Final Design Photogrammetry	36 inches	6 inches	Painted or plastic panels are acceptable Photo identifiable points preferred when possible
Intermediate Photogrammetry	60 inches	6 inches	Painted or plastic panels are acceptable Photo identifiable points preferred when possible
Preliminary Design Photogrammetry	120 inches	12 inches	Painted or plastic panels are acceptable Photo identifiable points preferred when possible
Mobile Lidar	12 inches	2 inches	'V' shape preferred but other shapes acceptable Maximum contrast and high definition are critical to mobile lidar
Static Lidar	varies	varies	Requirements vary based on project needs
Aerial Lidar	36 inches	3 inches	Requirements vary based on project needs

Targeting Specifications
Figure 8.6.1

B. PHOTO IDENTIFIABLE POINTS

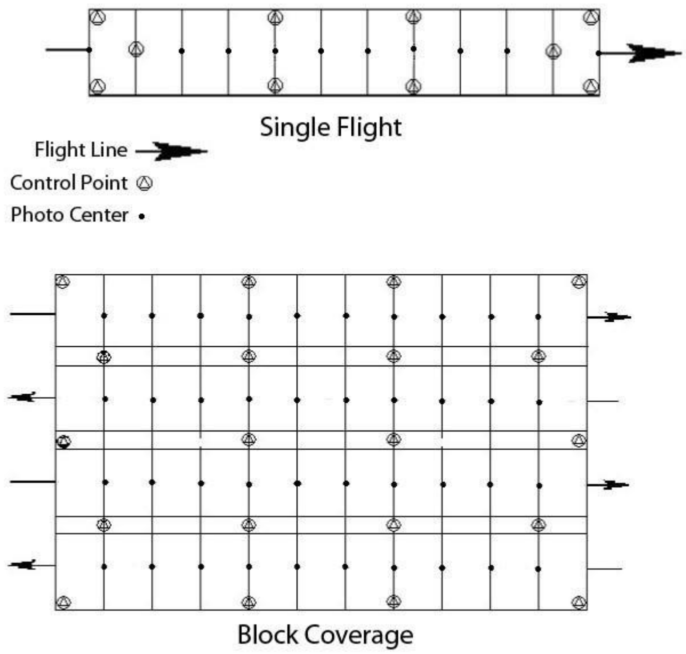
Photo identifiable points are existing features that are imaged on photography or collected as part of a lidar project and are suitable to be used as control points. Below is a list of qualities that are necessary when selecting photo identifiable points.

- Points should be well defined in the X, Y, and Z planes. In some cases where this is not possible, a vertical only point where the Z plane can be fixed is acceptable.
- Points should be unobstructed by trees or other features if possible. When obstructions cannot be avoided, GNSS signal and exposure positions (position from which the ID will be imaged or lidar collected) must be carefully considered during placement.
- Points should be on flat areas.
- Areas where vehicles may park and obscure the point should be avoided.
- Private property should be avoided where possible.

A close-up photo, a second photo showing the point and its surrounding landscape, and a rough GNSS position should be collected when photo identifiable points are selected.

C. CONTROL LAYOUT

Figure 8.6.2 below illustrates a typical layout for manned aerial photogrammetry. It assumes full width mapping; however, if mapping limits are delineated, the mapping limits should be controlled rather than the full width photos. This involves moving control in towards the centers of the photos where mapping limits allow, but always ensuring control surrounds the map limits. Three-exposure spacing is the standard to support analytical aerial triangulation in areas with significant topographic relief. In very flat areas, this spacing may at times be increased to five exposures. Spacing for UAS flights must be customized for each project, but this general configuration should be followed.



Photogrammetry Control Layout
Figure 8.6.2

Any questions or issues regarding control layout can be directed to the Photogrammetry unit at the Photogrammetry and Surveys Section (PSS).

CHAPTER 9 – MAPPING STANDARDS: (PHOTOGRAMMETRY, LIDAR, AND REMOTE SENSING DATA REDUCTION AND PROCESSING)

9.0 INTRODUCTION

> Existing Ground (EG) mapping products are data sets that serve to interpret, classify, and reduce raw geo-spatial data into products that are more easily consumed by end-users.

This chapter outlines specifications for geo-spatial mapping products or Existing Ground (EG) models produced from aerial photography, lidar, and other remote sensing data sets. EG mapping products are data sets that serve to interpret, classify, and reduce raw geo-spatial data into products that are more easily consumed by end-users.

CADD (vectorized) Mapping: Any of a number of manual or semi-automatic processes in which a geospatial professional analyzes raw geospatial data such as ground survey, stereo-photos or lidar, and collects CADD linework to model and describe the area to be mapped. These result in Digital Terrain Models (DTM), which are produced manually with features identified and placed with proper CADD coding.

DTM is used throughout this publication to refer to any digital topographic model of a project site. However, DTMs may also be distinguished by the definition in the paragraph above, while DEM and DSM refer to less complex and less detailed models.

Classified Point Clouds and Digital Elevation Models (DEM): Any of a number of automatic or semi-automatic processes for classifying and deriving bare-earth models from raw geospatial data. DEMs typically do not include breaklines or identified CADD features.

Digital Surface Models (DSM): Fully automatic processes for quickly creating models that are typically not bare earth but include vegetation and human-made features.

For ground control and targeting requirements, see Chapter 8.6.

9.1 ANALYTICAL AERIAL TRIANGULATION

> AAT provides coordinates to supplement MCP networks.

The Analytical Aero-Triangulation (AAT) process is used to apply photogrammetric orientations to raw imagery including real-world coordinates. Manual AAT is used to create stereo models from which operators can manually collect 3D CADD data. Fully automatic AAT are processes that are used to create DSMs. The specifications outlined here may apply to both processes, but are intended mainly for the manual processes. While the fully automatic processes have few opportunities for interaction, the user should make every effort to review results and ensure that these standards are met.

AAT provides coordinates to supplement MCP networks. MCP and benchmarks are appropriately placed throughout the project. In each stereoscopic model, AAT is used to produce ground (X, Y, and Z) coordinates to supplement MCP. These supplemental points are used for precision orientation of the stereo model for map compilation of a highway project.

For minimum control layout required for AAT, see Chapter 8.6.C. Points produced by AAT may not be used in lieu of required MCP as discussed in Chapter 8.6.C.

A. Measuring for AAT. Precision of the photogrammetric equipment and software contributes to the overall accuracy of AAT. These measurements are used to locate X, Y, and Z coordinates of image reference marks and MCP, photographic images, and aero-triangulated points. Accuracies achieved must satisfy established X, Y, and Z coordinate tolerance levels for each point identified. Softcopy processes are required.

B. Accuracy. As determined by AAT bundle adjustment, the horizontal position (X and Y) and elevation (Z) coordinates of all MCP measured in the solution must meet the accuracies established in Table 9.1.1.

Error Tolerances for Analytical Aero-triangulation Absolute Error as a Fraction of Ground Sample Distance (GSD)

Bundle Adjustment Results	Horizontal (X)	Horizontal (Y)	Vertical (Z)
Maximum Error (single Point)	RMSE x 3	RMSE x 3	RMSE x 3
Root Mean Square Error* (RMSE)	GSD x 1	GSD x 1	GSD x 1.2

Table 9.1.1

*RMSE – Expression for accuracy of a single observation, defined as the square root of the quantity – sum of the squares of the errors divided by the number of errors. All three accuracy requirements must be fully met: maximum, average, and root mean square.

C. Supplemental Control. Soft Copy: Supplemental control points (pass points) may be measured manually or by automatic correlation. Identifiable points are not necessary, but careful quality review must be done to ensure that points are well distributed and measured in at least three photographs at each Von Gruber Point. For automatic correlation, care must also be taken to ensure that measurements are parallax free.

D. Interval of Supplemental Control Spacing on Aerial Photography. A minimum of six horizontal/vertical control points will be selected for each stereoscopic model required in subsequent measuring and mapping operations. Each control point will be on or near a line that passes through or near the principal point and is perpendicular to the flight line. Control points will be located in positions on the photograph in order to provide a strong geometric configuration for leveling stereo models and to fully encompass areas to be mapped.

E. Interior Orientation. In any aero-triangulation solution, an accurate camera calibration must be part of the bundle adjustment. For any flights over 400 feet Above Mean Terrain (AMT), atmospheric refraction must also be corrected for in the adjustment.

F. Photography Strip Ties. Wherever separate strips of photographs side lap or cross, they must be tied together by AAT for accomplishing the subsequently required measuring and mapping. Whenever possible, these points should be transferred across flight strips stereoscopically. For this purpose, ground points are selected that provide appropriate stereoscopically corresponding images on the adjacent side lapping, or crossing strip, or strips of photographs. Wherever possible, targeted points and other ground identifiable image points are selected for determining supplemental control in line of flight. Otherwise, additional, and suitable image points are selected stereoscopically to adequately tie the strips together. A minimum of one tie point per model is required.

G. Software and Process. AAT software to be used in the procedure must be capable of executing a simultaneous adjustment (Bundle) on all strips and photographs necessary to cover the work area. It must be capable of solving for a minimum of 48 strips or 500 photographs in one pass. If the project involves more than 48 strips or 500 photographs, then the solution may be split, but distribution of horizontal and vertical control points must be appropriately designated so as to support two or more computations.

When splitting the computation into two or more sectors is necessary, sufficient coverage overlap between the sectors is required. For example, if there are 10 strips covering the area to be mapped, then the first solution should include strips one through six, the second solution should include strips four through ten. Tie points between strips four and five should be held as control points to ensure a proper tie between solutions. If stereo compilation must be started as soon as possible, then only strips one through four should be released for that purpose.

AAT software should offer opportunities for isolation of blunders, error detection and diagnosis, and analysis of results in progressive computational steps. If horizontal and/or vertical control points have been obtained in sufficient numbers (as to exceed distribution, location, and frequency recommended in Chapter 8.6.2), then isolated points may be removed from the control point data file. These isolated points would otherwise have provided for a solution that exceeds misclosure requirements, thereby degrading quality and accuracy of the general solution. In such an event, discarded points will be noted and a description of the problem and magnitude of misclosure will be made for the record and future reference.

Fully automatic AAT software must be approved by the Department prior to use on any Department projects. If a software package does not have the necessary interactivity to meet the requirements of this section, extra care must be taken during quality review. A map test should also be performed according to the specifications in Chapter 2.2 so that a statement of accuracy class may be applied to the final product.

H. Reports and Records. After AAT procedures have been completed, prepare a report consisting of a brief summary of results, computations, accuracies, list of control points not used in the solution, reasons for their removal, and all other pertinent information. Reports will also include printouts of final analytic passes, from original field surveyed control point lists, through all major computational steps, to final analytically generated control point value lists.

9.2 DIGITAL MAP COMPILATION

Stereo compilation is most common on photogrammetric data but can also be performed on lidar clouds.

Digital map compilation is the process of creating final deliverables from raw geospatial data. In most cases, this involves vectorizing features into a CADD file with lines, text, and symbols. In some cases, it may simply be creating a DTM from the raw data, which includes thinning and reviewing the data for quality.

Any map compilation process requires trained and experienced technicians who can properly identify features from raw data, accurately vectorize CADD files from the raw data, and develop and perform quality assurance on DTM data.

A. Stereo compilation is most common on photogrammetric data, but can also be performed on lidar clouds. Stereo compilers must be skilled at feature identification and DTM collection.

Lidar compilation involves collecting data in a virtual 3D environment, but viewed on a 2D monitor. Lidar compilation requires skills and experience with lidar registration, lidar classification, and collecting accurate vectors and measurements in a virtual 3D environment.

DTMs are a required part of compiled data. DTMs may be produced from compiled vector data or from processed lidar data. If produced from vectorized data, a feature list to be used as breaklines and regular points can be found in the Section's Mapping Features and Standards document. Proper definition of terrain features and sufficient density of data is necessary to meet the desired final map accuracy.

All mapping products must be delivered in the latest CADD system being used by the Department. The current Department CADD resource files such as cell libraries, font libraries, and seed files, etc., must be used. Contact the Department’s CADD support unit for the latest resource environment.

All CADD files produced should follow the naming formats in PennDOT Publication 14M, Design Manual, Part 3 (DM3) and should be followed by a “_PHOT” for photogrammetry and “_SURV” for survey files.

B. Planimetry - As visible on and identifiable from the aerial photography or lidar, the following (Table 9.2.1) natural and artificial features will be shown on the mapping for preliminary design and other lower accuracy or large area applications:

Airports & Runways	Ditches (prominent)	Orchards & Nurseries	Substations	Ruins
Aqueducts	Driveways (over 200 ft.)	Parking Areas (prominent)	Powerlines / Towers (x-country)	Sewer Plants
Bridges	Fences (prominent)	Parks	Radio Towers	Smokestacks (prominent)
Buildings (excluding small out-buildings)	Falls	Piers and Wharfs	Railroads (centerlines)	Wetlands
Canals	Golf Courses	Piles (prominent)	Reservoirs	Tanks
Cemeteries	Greenhouses	Pipelines (x-country)	Retaining Walls (large)	Tunnels / Portals
Culverts (prominent)	Lakes and Ponds	Pools (over 50 ft.)	Rivers and Creeks	Walls / Fences (prominent)
Dams	Mapping Control	Power Generation Stations	Roads	Wooded Areas

Preliminary Design Mapping Features

Table 9.2.1

As visible on, and identifiable from, the aerial photography or lidar, the following (Table 9.2.2) natural and artificial features are shown on the mapping for final design engineering and other higher accuracy applications. This list is not intended to be comprehensive, and all features identifiable from the raw data should be vectorized:

Airports & Runways	Conveyors	Fords	Parking Areas	Radio Towers	Sewer Plants	Tunnels
Athletic Fields	Culverts	Fuel Pumps	Parks	Railroad (Both Rails)	Sidewalks	Utility Poles
Aqueducts	Curbs	Golf Courses	Patios	Rapids	Silos	Walls
Billboards	Dams	Greenhouses	Piers & Wharfs	Reservoirs	Signs	Wells
Boulders	Ditches	Guide Rails	Piles	Retaining Walls	Smokestacks	Wooded Areas
Bridges	Driveways	Hedges	Pipelines	Rivers & Creeks	Steps	
Buildings	Fences	Lamp Posts	Platforms & Ramps	Roads	Wetlands	
Bushes	Falls	Lakes & Ponds	Swimming Pools	Rock Outcrops	Tanks	
Catch Basins & Drop inlets	Fire Hydrants	Light Poles	Power Stations	Ruins	Trails	
Canals	Field Roads	Mapping Control	Substations	Shoulders	Traffic Lights	
Cemeteries	Flag Poles	Orchards & Nurseries	Powerlines & Towers	Shrubs	Trees	

Final Design Mapping Features
Table 9.2.2

C. DTMs and Topography - Maps will contain all topographic features visible or identifiable on the aerial photography. All topographic data will be compiled using DTM methods. Breaklines indicating where the slope of terrain changes will be digitized directly into the digital files, along with mass points to properly define the surface to be mapped. Mass points (random points) will be collected on a grid spacing as outlined in Table 9.2.3. DTM data will not be generated from contour data. DTM data will be of sufficient density to correctly portray all drainage, creeks, rivers and tributary streams, springs, falls and rapids, ponds, lakes, swamps, marshes, bogs, flood plains, rock cliffs, and other essential topographic features.

Map Type	Random/Mass point spacing	Examples
Preliminary Design	75 foot grid	Photogrammetry at GSD above 10cm
Intermediate Design	45 foot grid	Photogrammetry at GSD above 6cm
Final Design	25 foot grid	Photogrammetry at GSD below 4cm
High Accuracy Applications	2 foot grid (roads)	LiDAR and some UAV data sets

Random/Mass Point Spacing
Table 9.2.3

All well-defined natural drainage courses will be shown in accordance with DM3. For preliminary design scale mapping, drainage lines will be stopped at a distance of 100 feet from the ridge lines and drainage lines under 200 feet in length need not be shown. At 1” = 50’ scale mapping, drainage lines will be stopped at a distance of 50 feet from the ridge lines and drainage lines under 100 feet in length need not be shown.

D. Obscure Areas (with data). Where terrain is visible but obscured by vegetation, shadows, or other limiting factors, an effort should be made to define the surface as accurately as possible. The area should then be outlined with a line on level 451 and labeled as obscured. A text file will be delivered with every project with a description that indicates that obscured areas may not meet map accuracy standards.

E. Obscure Areas (without data). Terrain completely obscured due to dense vegetation, dark shadows, or other limiting factors will be outlined on level 450 and labeled as “Obscure Area.” No elevation data will be compiled. It is recommended that field surveys be performed to complete missing elevation data.

F. The following title block information (Figure 9.2.4) should be included on every CADD file. The title block includes an American Society for Photogrammetry and Remote Sensing (ASPRS) accuracy statement, a description of the methods used to produce the topographic map along with a description of the limits for those methods, and finally a description of how the survey was tied to the intended datum. If the model was map tested the statement should read “Tested and meets….” If the processes used are well established, the statement “Produced to meet…” may be used.

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION

ALLEGHENY COUNTY

S.R.0079-A53

I376 TO SR60

PHOTOGRAPHY SCALE: DIGITAL 4.2cm
PHOTOGRAPHY DATED: DECEMBER 20, 2021
GRAPHICS SCALE 1"=50'

50 0 50 100 150

THIS DATA SET WAS PRODUCED TO MEET ASPRS POSITIONAL ACCURACY STANDARDS FOR DIGITAL GEOSPATIAL DATA (2014) FOR A 1.0 (IN.) RMSEx RMSEy HORIZONTAL ACCURACY CLASS WHICH EQUATES TO POSITIONAL HORIZONTAL ACCURACY =+/-2.0 (IN.) AT A 95% CONFIDENCE LEVEL, AND A 0.5 (IN.) RMSEz VERTICAL ACCURACY CLASS EQUATING TO NON-VEGETATED ACCURACY =+/- 1.0 (IN.) AT A 95% CONFIDENCE LEVEL FOR ALL AREAS COLLECTED BY MOBILE LIDAR INCLUDING ALL PAVED SURFACES SHOULDER TO SHOULDER FOR THE SR 79 CORRIDOR.

THIS DATA SET WAS PRODUCED TO MEET ASPRS POSITIONAL ACCURACY STANDARDS FOR DIGITAL GEOSPATIAL DATA (2014) FOR A 3.0 (IN.) RMSEx RMSEy HORIZONTAL ACCURACY CLASS WHICH EQUATES TO POSITIONAL HORIZONTAL ACCURACY =+/-6.0 (IN.) AT A 95% CONFIDENCE LEVEL, AND A 2.0 (IN.) RMSEz VERTICAL ACCURACY CLASS EQUATING TO NON-VEGETATED ACCURACY =+/- 4.0 (IN.) AT A 95% CONFIDENCE LEVEL FOR ALL AREAS COLLECTED BY PHOTOGRAMMETRY OUTSIDE OF THE SR 79 CORRIDOR.

DATUMS:
SURVEY BASED ON THE NATIONAL SPATIAL REFERENCE SYSTEM (NSRS)
VERTICAL BASED ON NORTH AMERICAN VERTICAL DATUM-1988 (NAVD88)
HORIZONTAL BASED ON NORTH AMERICAN DATUM-1983 (NAD83)(2011)
PENNSYLVANIA COORDINATE SYSTEM SOUTH ZONE

BENCHMARK ELEVATIONS ARE BASED ON NAVD88 AS PUBLISHED BY THE NATIONAL GEODETIC SURVEY (NGS) & PENNDOT: ALL PROJECT ELEVATIONS WERE ESTABLISHED BY GNSS & DIFFERENTIAL LEVEL OBSERVATIONS. AN ADJUSTMENT WAS PREFORMED HOLDING THE PUBLISHED ELEVATION OF NGS BENCHMARK "A 252 RESET" PID: KY3575 FIXED IN THE FINAL NETWORK ADJUSTMENT AS ESTABLISHED BY THE SURVEY REPORT.

Title Block Information

Figure 9.2.1

9.3 ORTHOPHOTOGRAPHY

> Orthophotography can generally be produced with minimal additional effort when an aerial triangulation solution and a project DTM are available.

Digital Orthophotography is imagery (usually aerial imagery) photogrammetrically corrected so that all image displacement is removed, and all pixels are projected to a project's map projection. An aerial triangulation solution and a project DTM are required. The orthophotography is produced to the same map accuracies as required for the project and will line up with any mapping data produced. Orthophotography can generally be produced with minimal additional effort when an aerial triangulation solution and a project DTM are available. Orthophotography is a two-dimensional product.

- Aerial Photography. Aerial photography specifications will be as described in Chapter 8.1.
- Ground Control. Placement of ground control is to be in accordance with Chapter 8.6.
- Aero-Triangulation Solution. The AAT solution used to produce orthophotography must meet specifications as described in Chapter 9.1.

- Final Resolution and Image Scanning. Digital orthophotographic images must be produced from digital imagery of equal or finer pixel ground resolution than the final ground pixel size required for the orthophotography. Pixel size for final orthophotography is as follows on Figure 9.3.1:

Mapping Type	Pixel Size
Final Design Scale	0.2 ft.
Intermediate Scale	0.5 ft.
Preliminary Design Scale	1.0 ft.

Orthophotography Resolution

Table 9.3.1

9.4 DIGITAL SURFACE MODELS (DSM)

Digital Surface Models (DSMs) are similar to orthophotography in that it is photogrammetrically corrected imagery (usually aerial imagery). However, a DTM is not required because the DSM provides the elevation data since every pixel is reprojected in the X, Y and Z axes. DSMs are similar to point clouds produced from lidar since each pixel has a three-dimensional coordinate.

Any DSM for use by the Department must have a title block including an accuracy statement as outlined in Chapter 9.2.F.

9.5 DATA SET INTEGRATION

Ground survey, photogrammetry, lidar, and digital surface models may all be integrated to produce a single EG model. This is sometimes referred to as data fusion.

Great care must be taken to properly define any EG model produced from multiple data sources. Any such EG model for use by the Department must have a title block including an accuracy statement as outlined in 9.2.F. A detailed description of such data sets must include:

- The types of data sets included in the model
- If necessary, more details on the process used
- A “Tested and meets…” or “Produced to meet…” statement
- A thorough description of the geographic limits of each integrated data set

Care should be taken where various data sets meet or tie together to ensure a seamless transition in the DTM.

9.6 FINAL DELIVERABLES

EG models should include the following:

- A bare earth CADD file and DTM
- Bridge deck CADD files and DTM (bridge decks carrying the subject corridor)
- Ortho-corrected imagery
- Aerial-Triangulation adjustments
- Uncorrected imagery
- Lidar point clouds
- Ground survey data including a survey report

CHAPTER 10 – PRELIMINARY SURVEYS

10.0 ELEMENTS OF A PRELIMINARY SURVEY

Appropriate decisions, such as defining sufficient scheduling time in the initial survey request, can help delineate and streamline the timeline of all Preliminary Survey activities

Preliminary surveys are performed for all types of design and construction projects. Such projects include resurfacing, restoration, and rehabilitation projects as well as realignment, widening, relocating, and reconstruction projects. Preliminary Surveys can be complex and involve multiple objectives. The potential use of several categories of advanced surveying equipment such as lidar scanners, photogrammetry, UAS, and GNSS units in Preliminary Surveys makes initial survey requests and survey planning important. Appropriate decisions, such as defining sufficient scheduling time in the initial survey request, can help delineate and streamline the timeline of all Preliminary Survey activities. This helps survey crews obtain any and all data needed for design at the time of the original survey and reduces the chance of survey crews needing to be redeployed to acquire more data because it was omitted in the original request.

Preliminary surveys are an investigation of a project site. Many times, a preliminary survey will uncover unknowns such as archeological ruins, mine voids, old utilities, and other items that could affect the design. The best practice to follow when performing preliminary surveys is to note and/or locate something that is discovered during the course of the survey, even if there is uncertainty as to the object or structure's function and/or origin. Other appropriate agencies or Department units may need to be involved.

Several other pre-survey activities need to be addressed prior to the start of field work. Surveying activities beyond an existing legal right-of-way require sending letters of intent to enter 10 days prior to the start of work. Current procedures and format requirements are outlined in Pub 378, Right-of-Way Manual. Surveyors are Department representatives, so surveys on private property must be conducted in a courteous, professional manner.

All physical features that affect the proposed design will be recorded. Detailed descriptions include utility names and pole ID numbers, signs (type and description), guide rail (types and end treatment), drainage (size and types), existing property corners and physical lines of property possession, permanent buildings (including type of structure), all permanent improvements constructed by the occupier of the property, and traffic line patterns. Also see Appendix D for Quality Assurance/Quality Control Checklist for Right-of-Way and Construction Plans. The District Chief of Surveys (DCS)will review and discuss any survey request with the appropriate requestee well in advance of the preliminary survey to help develop, schedule, and execute field procedures to best fit each project.

10.1 PRELIMINARY SURVEY CONTROL AND METHODS

A. Project Control and Alignments

a. Establishing and documenting a project's Horizontal and Vertical control is a crucial aspect in the design and construction processes. Horizontal control reference data, benchmark locations and elevations, pre-existing Right-of-Way plans, location maps, US Geological Survey (USGS) Quad Maps, etc., must be obtained prior to start of work to help formulate a basis upon which Project Control and highway alignments can be produced and documented.

b. Projects will be established using the most current Horizontal and Vertical datums and be represented by the most current version of the Pennsylvania State Plane Coordinate System, unless otherwise stated from the DCS.

Chapters 3 and 4 explain the fundamentals of datums and coordinate systems. Regardless of the coordinate system, all Project Control established is to follow the accuracy guidelines established in Chapter 4.0.

B. Methods of Obtaining Preliminary Survey Data

a. Conventional Surveys

This classification of field survey is the classic method crews utilize to obtain preliminary survey data. Because these surveys were traditionally performed without modern day equipment such as total station instruments, data collectors, and GNSS equipment, the approach for a classic survey is grounded in a time when most tasks were labor intensive and sometimes redundant. Using this approach, the foundational element for all preliminary data collected such as topography, cross-sections, and profiles are baselines established in the field.

Parts of a Conventional Preliminary Survey:

- Establish and Stake-Out Baselines: The basis for establishing baselines and stationing should be noted in the field notes (Existing Plan, Straight Line Diagram (SLD), Arbitrary, Etc.) and the geometry/curve data noted in the field book.
- Establish Vertical Control: Benchmarks should be set at adequate intervals throughout the project area and elevations established by differential leveling.
- Measurement of Topography: Traditionally, the typical method of collecting topography was performed by measuring to topographic features at right angles and distances from stationing along baselines. Depending upon equipment, topography can also be measured by angles and distances from traverse points and baseline stations established on the site. Field notes consist of a sketch of the baseline(s) with stations and offsets noted to topographic features as well as detailed sketches with adequate dimensions to enable drafters to plot the data. If traverse points were established on a project, a sketch of the locations and coordinates shall also be shown.
- Measurement of Profiles: Profiles are vertical differences at intervals along a defined alignment. The alignment can be an existing feature such as a pipe or driveway located during the topographic survey, as well as a proposed alignment staked in the field. Benchmarks will be pre-established in the standard manner to the nearest 0.01 feet and tie-ins made to those benchmarks during the process of running profiles. Profile readings for existing pavement elevations will be recorded to the nearest 0.01 feet for all centerline points at stations and intermediate breaks. Readings on grade stakes set along or offset from an alignment will be taken and recorded to the nearest 0.01 feet. Elevations will be taken of flow lines of pipes and small culverts and profiles of the ground or stream at the inlet and outlet of the pipe or culvert extended for a distance of at least 50 feet beyond each end. Profiles will be taken at low points or at other advisable locations in like manner if no culvert exists at present. Profiles will be plotted to facilitate the establishment and correct location of drainage structures and ditches. At intersecting roadways and drives, profile elevations will be taken for such distances as may be affected by construction.
- Measurement of Cross-Sections:_ A cross-section is a vertical section of the surface of the ground taken perpendicular to the centerline or established baseline over the area where cross-sections will be measured. In addition, readings are taken at locations where there is a change in the terrain. Cross-sections are gathered at specific intervals as designated by the Preliminary Survey request with the maximum interval of 50 feet and at the requested offset distances perpendicular to the centerline of the project. Additional cross-sections will be taken, and construction grades will be established in areas where heavy grading is deemed advisable to reduce steep grades or to secure the necessary width in heavy cuts. Cross-section data will extend beyond the proposed right-of-way line with the goal being the cross-

section taken out a far enough distance on the existing ground beyond the template grade for that station. To begin cross-sectioning, differential levels are run from the nearest benchmark to the part of the line to be cross-sectioned.

Elevations should be checked with all available benchmarks and should close within 0.05 feet. Rod readings will be taken at all breaks. Existing pavement elevations are recorded to the nearest 0.01 feet and natural ground elevations are recorded to the nearest 0.05 feet. Distances to culvert end walls, pavement edges, and ground shots should be carefully measured and recorded to the nearest 0.05 feet. Those points must be on a line perpendicular to the centerline or baseline unless otherwise noted. Particular care must be taken to keep the shots at right angles when cross-sections extend out beyond 50 feet.

Cross-sections are recorded in notes opposite the station number in fractional form with the rod reading as the denominator and distance from centerline or baseline as the numerator. Care must be taken to record readings correctly as to left or right of the centerline.

Note that although conventional survey methods are rarely used to perform a complete preliminary survey, knowing the methods and procedures for obtaining data are important. Certain situations encountered in the field may require a conventional approach to capture the data needed. Having an understanding of conventional procedures is also important when examining older plans and field notes.

b. 3-Dimensional Surveys

This classification of field survey is the current method used to collect preliminary survey data. In addition to using electronic total station instruments, GNSS equipment is also frequently utilized to collect data by means of RTK and RTN methods. 3 Dimensional surveys allow for collecting topographic data 3-dimensionally, meaning collected topography points have an elevation and code associated with them, allowing recorded topography to also serve as a triangulated network with elevations between points able to be interpolated by CADD programs.

In addition to topographic features, terrain data should be collected to produce an accurate network. Data such as tops and bottoms of slopes as well as random points should be collected. Adequate control points with accurate coordinates and elevations should be pre-established in the survey area to collect the data from various locations. Check shots should be taken to the backsight for each set-up to ensure the correct set-up information is entered in the data collector.

A 3-Dimensional Survey is comprised of several components. These components are:

- Control points are established with horizontal coordinates on the project area at safe and convenient locations to capture the data required for the survey.
- Differential leveling is performed to establish elevations on the control points along with benchmarks being established on the project site.
- Data are collected and recorded electronically in a data collector or similar device and are imported into a CADD program, which will automatically plot topography based on codes and linework commands. Special notes such as utility pole numbers, pipe sizes, building types, etc., are either recorded in the field book or attached to points as an attribute that can be annotated on the drawing.
- Terrain surfaces are generated based upon data collected and analyzed for accuracy and proper coverage of the site.

- Baselines are established geometrically in CADD, as needed, to identify recovered Right of Way baselines from plans, as well as for identifying areas needing baseline control such as a stream or creek. Deed plots can also be performed as needed and analyzed compared to recovered monumentation.

10.2 TYPES OF PRELIMINARY SURVEYS

A. Flat Chain Surveys

This classification of field surveys consists of establishing existing roadway stations. Since there is no control, there is no requirement for referencing. Resurfacing, maintenance, and minor improvement projects use this type of survey. Plans developed from such surveys are straight strip without changes in horizontal. All distances measured by this method should be to the nearest 1 foot. Topography taken as part of this survey uses the plus and offset method based upon the centerline of an existing roadway as the frame of reference. This type of survey is employed to produce/re-produce RMS data.

B. Two-Dimensional Surveys (X, Y)

This classification of field surveys consists of establishing horizontal control with referenced monumentation. Projects using this type of survey do not require changes in the vertical component (profile or cross-sectional), therefore vertical control is not established. An existing roadway serves as the frame of reference for applying typical sections. Projects where the application of a typical section (resurfacing, reconstruction without widening, etc.) does not require volumetric computations (cut and fill) or slope staking, use this classification of survey. A boundary or Right-of-Way survey where the survey is only considering horizontal location, would also fall under this classification.

C. Three-Dimensional Surveys

This classification of field survey consists of establishing both horizontal and vertical control and is considered the standard type of survey for engineering design. From this type of survey, new alignments and re-alignments can be designed, as well as calculating areas and volumes. The deliverable from this type of surface would include CADD files with highly accurate topography, terrain surfaces, and geometric data.

D. Bridge/Hydrologic/Wetland Location Surveys

Bridge surveys are performed to obtain accurate data required for designing new structures or rehabilitating existing structures. The following special items should be investigated as part of a bridge preliminary survey:

- Name of stream or branch, intersecting roadway or railroad
- Direction of flow, number of lanes or tracks
- Number and length of spans
- Clear width between roadway curbs and wheel guards
- Clear width between parapets, girders, trusses, and handrails
- Width of sidewalks
- Type and general condition of superstructure
- General condition of abutments, piers, wings, etc.
- Minimum vertical clearance and location of the minimum clearance
- BMS Identification of Structure (County-SR-Seg-Offset)
- Survey the location of any wetland boundaries that may be marked out

i. Procedure (Conventional Method) - The roadway centerline will be established 1000 feet to either side of the crossing. At the crossing, a control point will be established on the roadway centerline from which a stream reference baseline will be developed. The plus (+) at the point of intersection between the roadway centerline and the stream reference baseline, as well as the angle between the roadway centerline and the stream reference baseline, will be recorded. The stream reference baseline will be extended for a minimum of 500 feet in both the upstream and the downstream directions. The stream reference baseline will be located parallel to the stream to ensure that all cross-sections will be taken perpendicular to the stream. From the stream reference baseline, offsets to the stream edges will be taken at 50 feet intervals or less and recorded. The result of these notes will give an accurate plot of the stream for at least 500 feet on each side of the roadway centerline.

ii. Procedure (3-Dimensional Method) - The limits of survey and data obtained for this procedure are the same as the conventional method noted above, with the difference being the channel/roadway/structure data are recorded by modern survey methods to produce topography and terrain models of the project area. Structure details and unusual circumstances or conditions are detailed using sketches and/or photographs as well as point annotation. Communication with other units involved with the project such as Utilities or Environmental is also important as the survey should also locate wetland and utility mark-outs.

Note that every bridge, culvert, and drainage survey is unique, and requirements of the preliminary survey will depend on the intended design. The Survey Unit should work closely with the bridge designer to ensure all needed data is captured during the survey. Whether the survey is performed conventionally or by modern 3-dimensional methods, the following may or may not need to be considered:

- A minimum of one benchmark will be established on each side of an approved structure site. The location for each benchmark will be easily accessible for both preliminary surveys and final surveys. In addition, benchmarks will be used to obtain all cross-section information for the structure and/or roadway.
- Topography will be recorded, in detail, within the site so that all existing conditions that may affect structure layout or design are noted.
- Data will be obtained so that the adequacy (or inadequacy) of an existing structure to support highway traffic, volumes, loads, or flood discharge can be determined. A waterway opening may be sufficient and the alignment for highway traffic satisfactory, but the roadway width may be too narrow. Consider that certain types of bridges can be widened economically, and decks replaced on existing substructures. Meetings with structural designers and the District Chief of Surveys (DCS) should be conducted prior to the start of work to fully establish the level of effort required to produce the information needed to complete the bridge design. Measurements beyond standard topography, cross-sections, or bridge sketches may be needed for detailing superstructures and substructures; determining plumb, batter, or squareness; or unusual circumstances for unique structures.
- Where a new structure over a stream is required data should be collected in and around the waterway so that a proper waterway opening can be designed.
- For waterway design, the stream bed slope and the water surface slope should be obtained for a minimum distance of 500 feet on each side of the bridge. If there is a dam or other similar structure within 1000 feet, its height, type, and any other physical details must be recorded. Maximum flood elevations and dates of occurrence will also be recorded. Flood information for the two highest known flood incidences will be recorded for all bridge spans 100 feet or greater. The angle between the stream and the highway centerline will also be recorded.

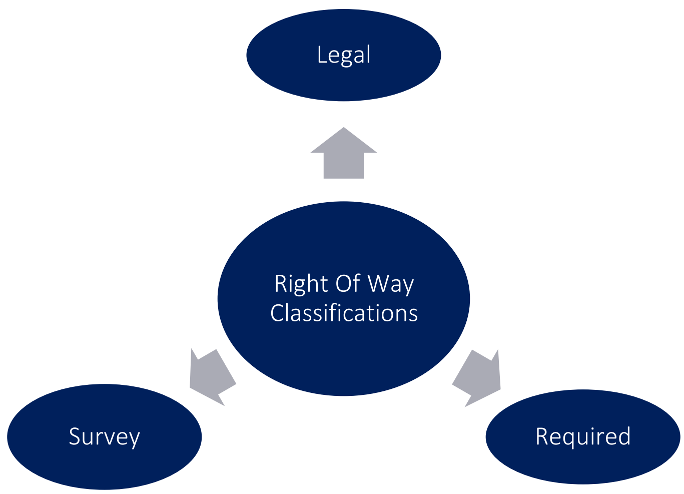
- Data for potential channel relocation will be obtained so that the proposed channel section efficiency can be computed. In addition, all data pertaining to a retaining wall or to a fill located within the lines of the existing 100-year floodplain will be obtained. This information can then be used to determine the impact of these obstructions on the floodplain. Cross-sections will be recorded for the full width of the existing channel, including overflow channel, and at least up to the 100-year floodplain elevation.

CHAPTER 11 – ROUTE LOCATION AND RIGHT-OF-WAY

11.0 DEFINITIONS

Right-of-Way Alignment Classifications:

- Survey – the inclusion of survey data when describing alignment implies the alignment was established or staked in the field.
- Legal – The record alignment or right-of-way established by recorded plan, deed, road docket, or field survey.
- Required – The proposed alignment or right-of-way take established by proposed plan.



Construction Alignment Classifications:

- Survey R/W and Construction – The Right-of-Way alignment coincides with the Construction alignment.
- Construction – Typically used when the Right-of-Way alignment does not coincide with the Right-of-Way alignment position and/or stationing.

Alignment Descriptors:

- Centerline – Alignment that most nearly follows the center of the traveled portion of the roadway.
- Baseline - Alignment used to perform work and/or used to describe legal and/or required right-of-way, and normally is not in the center of the traveled portion of the roadway.

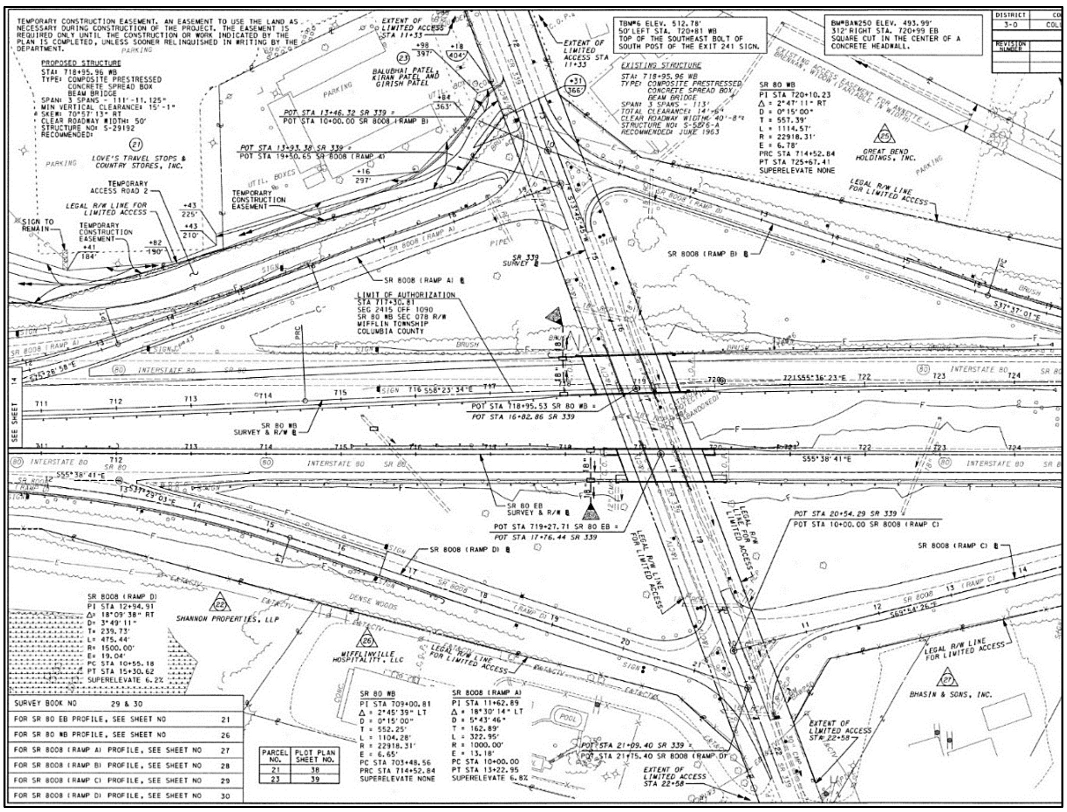
Examples of Alignment Classifications with Descriptors:

- **Survey Centerline** - Same as Legal Right-of-Way Centerline and is the best fit alignment to existing Right-of-Way plans as field surveyed.
- **Survey Baseline** - A working baseline that is used in the field and may or may not coincide with Legal Right-of-Way Centerline.
- **Right-of-Way Centerline** - On Right-of-Way plans, this is a centerline from which Required right-of-way was derived. On construction plans, this is a new legal Right-of-Way centerline.

- **Right-of-Way Baseline** - On Right-of-Way plans, this is a baseline that Required right-of-way is taken from. On a Construction plan, this is a new Legal Right-of-Way baseline.
- **Construction Centerline** - This is a centerline from which a project is built and may not coincide with a survey centerline. Usually these are on Two Lane Two Directional Roadways and/or Four Lane Divided Roadways with median.
- **Construction Baselines** - This is a baseline from which a project or parts of a project are built and may not coincide with survey centerlines/baselines. Usually these are on Four Lane Divided Highways with a large Median or gore areas and access ramps.

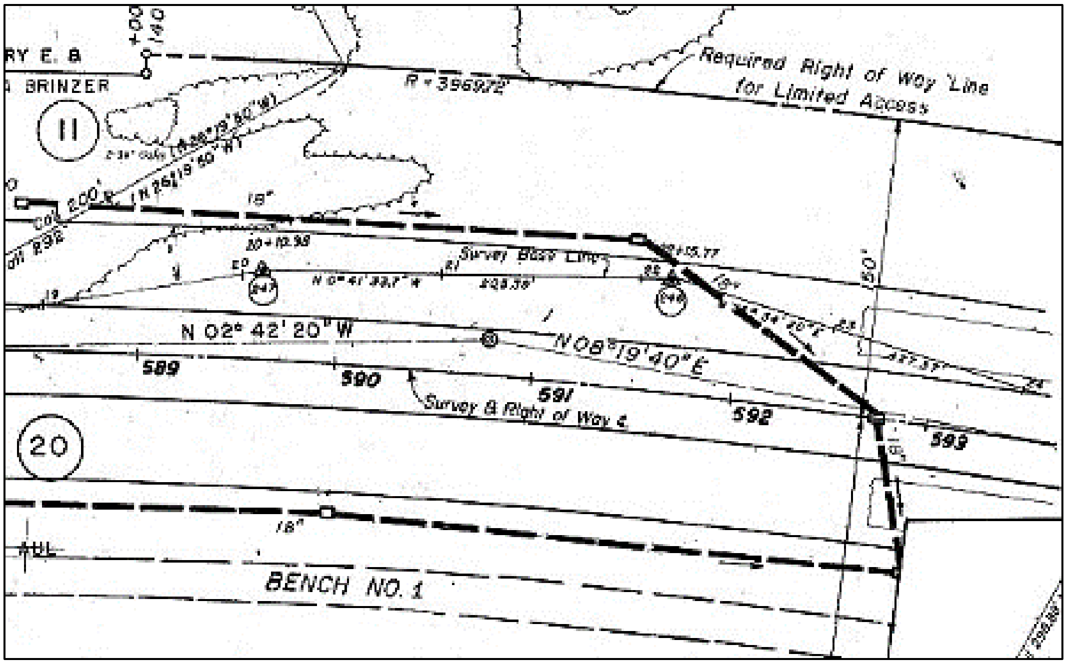
Note: When multiple alignments are used on the same plan, the reference alignment for all legal and required break points will be clearly indicated. A geometry sketch will be provided to show the correlation between the different alignment geometries.

Centerline and Baseline Examples



Right-of-Way Plan – 4 Lane Divided and Ramps

Figure 11.0.1



Combination Right-of-Way and Construction Plan with Multiple Baselines
Figure 11.0.2

11.1 COMPUTATIONS

Before field data may be used, it must be analyzed and adjusted to meet specific application needs. Some of the basic concepts that should be considered when performing data reduction are discussed in this section.

11.1.0 SURVEY COMPUTATIONS

Significant Figures. The number of significant figures recorded for a specific measurement is an indication of the accuracy attained. The number of significant figures for a measured quantity is defined as the number of sure or certain digits, plus one estimated digit. Computations involving the addition and subtraction of field measures result in an answer that does not contain significant digits farther to the right than occurs in the least precise number. The rule for multiplication and division is that the product or quotient will not contain more significant digits than are contained in the measurement with the fewest significant digits used in the calculation.

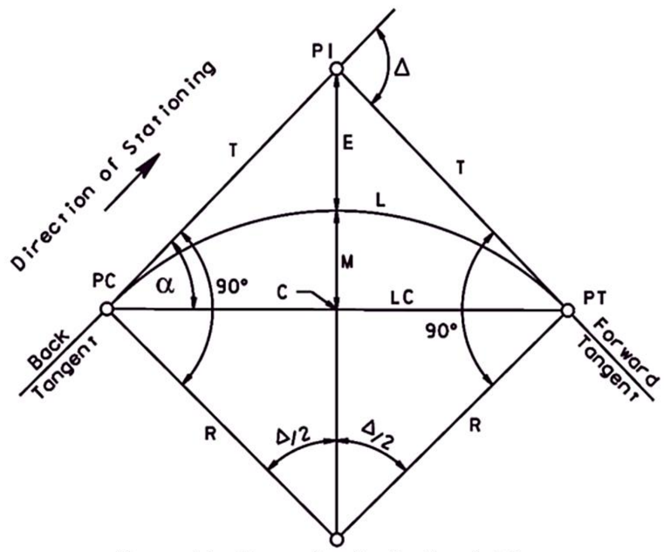
Rounding. Computations involving field measurements are also influenced by rounding off number methodologies. When a figure is to be rounded to fewer digits than the total number available, the procedure is as follows:

- When the first digit discarded is less than 5, the last digit retained should not be changed.
- When the first digit discarded is greater than 5, or if it is a 5 followed by at least one digit other than 0, the last digit retained should be increased by one unit.
- When the first digit discarded is equal to 5, followed by only zeros, the last digit retained should be rounded upward if it is an odd number, but no adjustment made if it is an even number.

Stationing. Designate stations at 100-foot intervals. Station example: 32+80.84.

11.1.1 CURVE CALCULATIONS

Simple Curves. For new survey baselines, all curves will be expressed by arc definition. Stationing along the arc length of a simple curve will be used for all computations. All curve data will be based upon the radius in feet (R) or degree of curve (D). The radius will be expressed in multiples of 10 feet increments for use with curve data calculations or degree of curve expressed in multiples of 30 minutes. All simple curve data computations will be based upon the information presented in Figure 11.1.1.



Geometric Elements of a Horizontal Curve

$$T = R \times Tan\left(\frac{\Delta}{2}\right)$$

$$LC = 2 \times R \times Sin\left(\frac{\Delta}{2}\right)$$

$$E = T \times Tan\left(\frac{\Delta}{4}\right) = R \times Sec\left(\frac{\Delta}{4}\right) - R$$

$$M = E \times Cos\left(\frac{\Delta}{2}\right) = R \times \left[1 - Cos\left(\frac{\Delta}{2}\right)\right]$$

$$L = \frac{\pi \times R \times \Delta}{180}$$

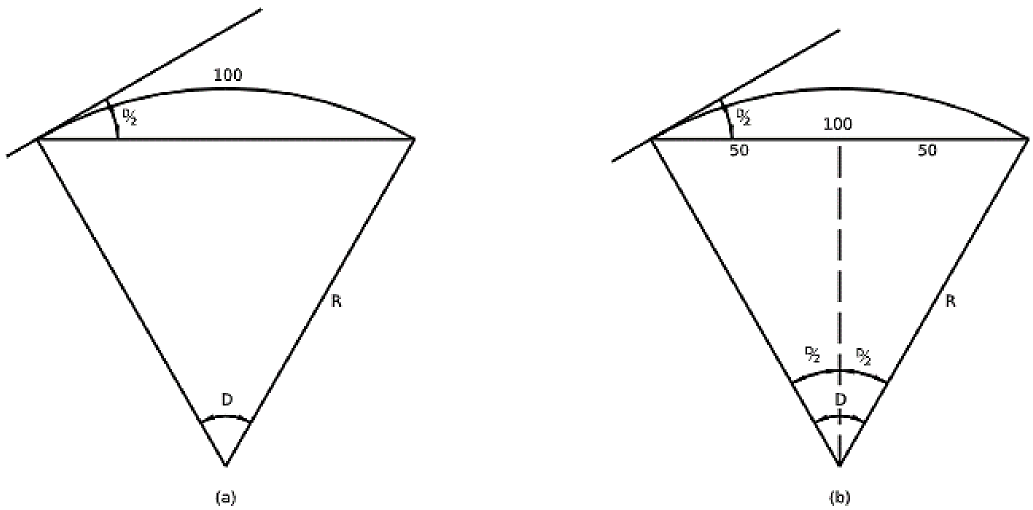
$$D = \frac{5729.578}{R}$$

$$\alpha = \frac{\Delta}{2}$$

PI = Point of Intersection
PC = Point of Curvature
PT = Point of Tangency
Δ = Deflection Angle between Tangents
T = Tangent Distance
E = External Distance
R = Radius
M = Middle Ordinate
LC = Long Chord (Distance between PC and PT)
C = Midpoint of Long Chord
L = Length of Curve
π = pi
D = Degree of Curvature
For determining PC and PT stations
PC STA = PI STA − T
PT STA = PC STA + L

Curve Formulas and Definitions
Figure 11.1.1

Arc vs. Chord Definition. The key parameters used to develop as-built curve data will include R, or D. The relationship between these two parameters is different depending upon the method used to establish the curve data (i.e., chord-definition or arc-definition). D is defined as either in Figure 11.1.2(a) the central angle which subtends a 100 feet arc or in Figure 11.1.2(b) the central angle which subtends a 100 feet chord. Chord definition curves will only be used in recreating historic plan data when called out in the original plan to establish centerline and right-of-way. The majority of historic plans will already be using arc definition curves for establishing centerline and right-of-way. All proposed or created alignments from field survey will utilize arc definition curves.

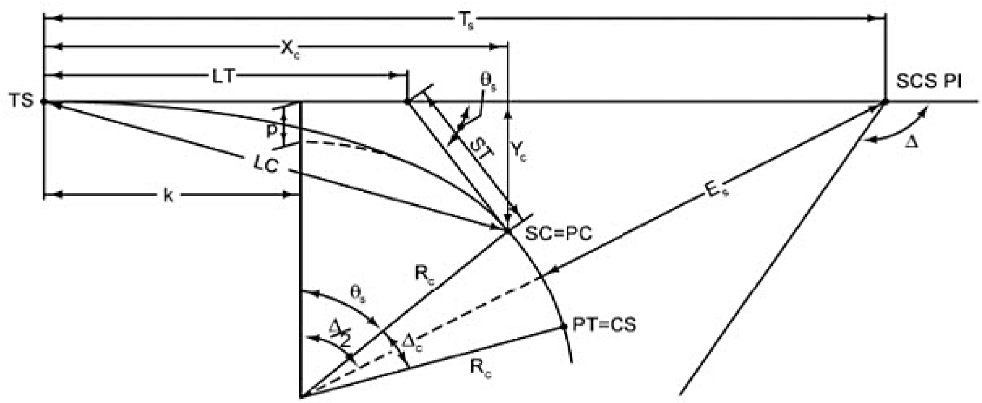


(a) Arc definition R=5729.578/D

(b) Chord definition R=50/SIN(D/2)
where R = radius (in feet)
D = degree of curve (in degrees)

Arc Definition versus Chord Definition
Figure 11.1.2

Transition (Spiral) Curves. Stationing along the arc of spiral curves will be used for all computations. The circular curve data will be based upon the radius in feet. For new survey baselines, the radius should be expressed in multiples of 10 feet increments for use with spiral curve data calculations. All spiral curve data computations will adhere to Figure 11.1.3.



Spiralled Curve Terminology

R_c = Radius of Circular Curve

D_c = Degree of Curvature

T_s = Tangent Distance

△ = Delta – Deflection Angle

E_s = External Distance

LC = Long Chord

LT = Long Tangent

Ls = Length of Spiral

L = Length of Adjoining Circular Curve

θ_s = Central angle of spiral arc Ls

△ = Total central angle of the circular curve

$\triangle_c$ = Central angle of circular curve

ST = Short Tangent

Xc = Tangent Distance to SC

Yc = Tangent Offset to SC

k = Abscissa distance, TS to shifted PC

p = Offset from initial tangent to shifted PC

Transition (Spiral) Curve Formulas and Definitions

Figure 11.1.3

11.2 PLAN MONUMENTATION AND REFERENCING REQUIREMENTS

The District Chief of Surveys (DCS) will be responsible for ensuring that the proper method and procedure are used prior to signing and sealing the right of way plan.

Acceptable monumentation types and procedures for right-of-way plans must include one or more methods below. The DCS will be responsible for ensuring that the proper method and procedure are used prior to signing and sealing the right-of-way plan. Permanent ground monuments and references must be set in the field, or existing control monuments located and shown on all plans. Simple coordinate listings of centerline control, right-of-way breaks, or control traverse will not be accepted in lieu of ground control. When multiple referencing methods are chosen, centerline referencing, monumented right-of-way, traverse control, and existing monumented features must complement each other, and not result in redundant excessive reference stations.

The final right-of-way plans must have sufficient permanent ground monuments set and/or referenced to be able to recreate the entire Survey and R/W baseline in the field. In selecting permanent objects and/or setting reinforcement bars for referencing, care must be exercised to ensure that a centerline point can be reestablished by direct or offset occupation of not less than two (2) reference points, each having backsights and foresights of sufficient length and angular separation to accurately determine the location of the centerline point. Alternate referencing may only be used at the discretion of the DCS.

A. Centerline Monumentation and Referencing:

This method is ideal for long corridor and highway projects. Centerline control points will be accurately and permanently referenced using the method described below. The references will be constructed with 24-inch NO 5-rebar, or a solid stable feature to guarantee future recovery of the centerline before and after construction is completed. All rebar set should be marked with a cap made of plastic or other suitable material, identifying the monument purpose and entity that set the marker.

Centerline Reference monumentation procedure is as follows:

- For curves 1,000 feet or longer, both the PC and PT will be permanently referenced.
- On tangent sections, POTs will be permanently referenced at intervals not to exceed 1,500 feet on most roadways and not more than 5,000 feet on highways having long sight distances.
- At least one permanently referenced POT must be visible from each permanently referenced PC or PT. These pairs of adjacent permanently referenced points will enable the centerline to be reestablished.
- Permanent witness marks will not be placed at references set for recovering centerline control points.
- Centerline Reference control is permitted to be set out to the required right-of-way.
- Both right angle and angle distance methods are acceptable.

Reference Circle (Right-angle Method)

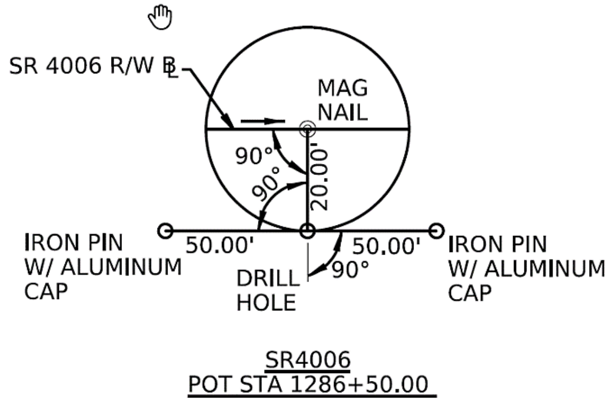
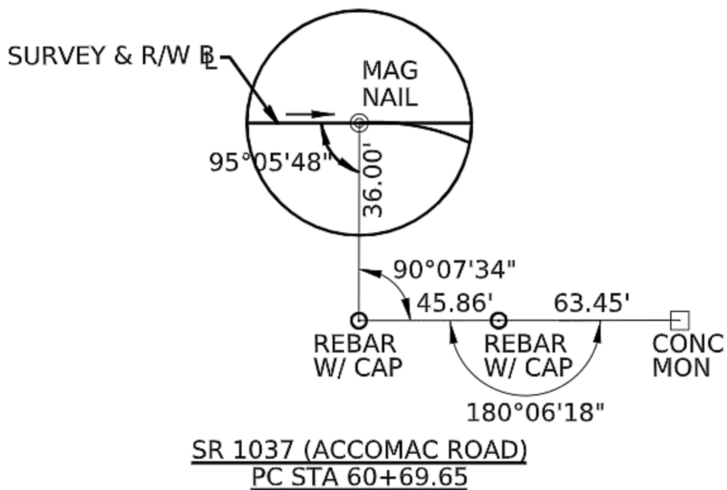


Figure 11.2.1



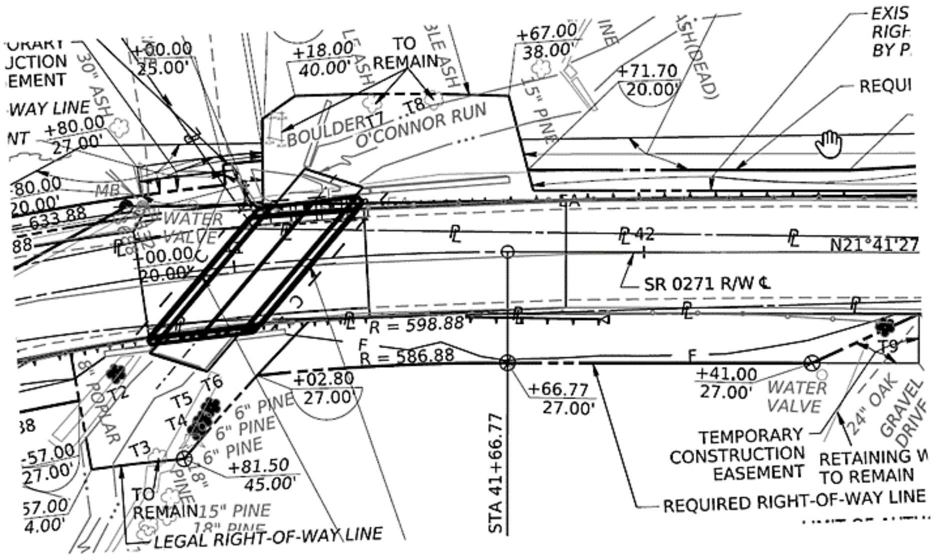
Reference Circle (Angle-distance Method)
Figure 11.2.2

B. Right-of-Way monumentation procedure is as follows:

This method is ideal for projects with extensive required right-of-way takes. Right-of-Way monuments will be constructed with either 24-inch NO 5-rebar with a plastic cap or other cap suitable for center punching, or a solid stable feature to guarantee future recovery of the legal right-of-way.

- After required right-of-way acquisition and prior to construction, designated break points and/or other points on the right-of-way line will be permanently monumented.

- Designation of points to be monumented will provide for a direct line of sight to another monumented right-of-way point on either side of the highway, or to a monument referencing the centerline.
- Permanent witness markers will not be placed at permanently monumented right-of-way monuments.



Right-of-Way Monumentation
Figure 11.2.3

C. Traverse monumentation procedure is as follows:

This method is ideal for projects with limited right-of-way widths or small required right-of-way strip takes. The project survey control will be used to reference the Survey and R/W baseline to the set field control.

- Traverse Stations will be marked with a permanent stable marker and reviewed and approved with the DCS.
- All Traverse Stations will be referenced using the swing-tie and/or station and offset method.
- A complete Traverse geometry sketch will be shown on the plan.
- All Traverse Stations will either be shown on the plan with a station and offset call out to the Survey and R/W baseline or be displayed in the reference circles.
- Traverse Stations coordinate listings will be placed on the summary of project coordinates page to include Point Name, Northing, Easting, Description, and Bearing and Distance between stations.

SUMMARY OF TRAVERSE CONTROL POINT COORDINATES					
POINT NAME	COORDINATES*		DESCRIPTION	BEARING	DISTANCE
	NORTH	EAST			
11	276838.9494	2366305.5253	MAGN	N07°30'00"W	1291.34'
12	278119.2706	2366136.9664	H&T	N36°46'01"W	497.90'
13	278518.1380	2365838.9775	MAGN	N18°12'50"W	362.02'
14	278862.0127	2365725.8492	MAGN	N03°23'17"W	375.37'
15	279236.7608	2365703.6827	MAGN	N16°28'04"E	259.95'
16	279486.0606	2365777.3841	MAGN	N07°19'18"E	358.44'
17	279841.5961	2365823.0761	MAGN	N18°04'20"E	855.45'
18	280654.8791	2366088.4717	MAGN	N02°51'23"W	723.84'
19	281377.8358	2366052.4129	MAGN	N02°05'54"E	416.79'
20	281794.3584	2366067.6769	MAGN	N02°28'25"W	347.73'
21	282141.7745	2366052.6691	MAGN	N12°51'54"W	342.87'
22	282476.0397	2365976.3259	MAGN	N34°06'13"W	477.34'
23	282871.2791	2365708.6855	MAGN	N31°21'33"W	566.55'
24	283355.0566	2365413.8466	MAGN	N34°11'39"W	378.50'
25	283668.0000	2365201.0000	MAGN	N06°41'24"W	506.45'
26	284171.0000	2365142.0000	MAGN		

NOTE: FOUR (4) PLACE COORDINATES ARE USED FOR COMPUTATION PURPOSES ONLY AND DO NOT IMPLY A PRECISION BEYOND TWO (2) PLACES.

*COORDINATES ESTABLISHED FROM FIELD SURVEY

Traverse Station Coordinate Listing

Table 11.2.4

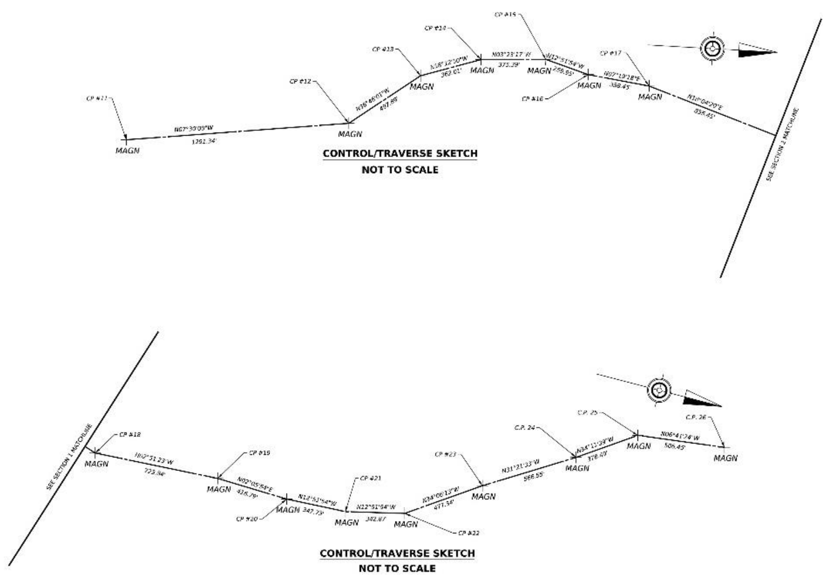
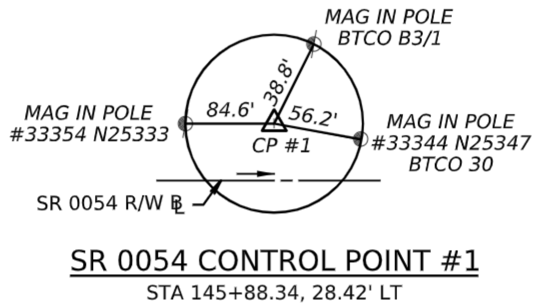


Figure 11.2.5

Traverse Geometry Sketch



Reference Circle (Swing-tie Method)
Figure 11.2.6

D. Existing Project Control Monumentation procedure is as follows:

This method is ideal for projects where there is sufficient existing control on the project site to recover the legal right-of-way. This method can easily be combined with the three methods above to add important recovered existing monuments to the plan.

- The monuments that may be used as plan monumentation include recovered existing survey monuments, existing right-of-way monuments, existing PennDOT or NGS control stations, etc.
- An existing monument's coordinate listing will be placed on the summary of project coordinates page to include Route, Station Offset, Northing and Easting, and Description.

- Existing monuments will be noted on the plan sheet with the monument type and Station Offset call out to the Survey and R/W baseline.
- Existing Monumentation near property lines is not to be construed as or labeled Property Monuments.

SUMMARY OF EXISTING CONTROL STATIONS

BASED ON PA STATE PLANE COORDINATE SYSTEM (SOUTH ZONE)

POINT	COORDINATES*	
	NORTH	EAST
11	276838.9494	2366305.5253
12	278119.2706	2366136.9664

NOTE: FOUR (4) PLACE COORDINATES ARE USED FOR COMPUTATION PURPOSES ONLY AND DO NOT IMPLY A PRECISION BEYOND TWO (2) PLACES.

Summary of Existing Control Stations

Figure 11.2.7

E. Benchmarks:

Field established benchmarks are the basis of the vertical control survey for the project. All project benchmarks must be noted on the plan sheets as shown in Figure 11.2.8.

- Existing benchmarks will be shown on the plan sheet with Benchmark name, Elevation, Description, Location, Station and Offset from Survey and R/W baseline.
- Existing benchmarks will be plotted in the plan and be clearly indicated with benchmark name.

BM A, ELEV. 1923.00
SQUARE CUT ON CONCRETE CURB
ALONG SR 2007 AT
STA 36+92, 17.3' LT. OF ℄

Benchmark Call-out

Figure 11.2.8

11.3 GENERAL NOTES FOR RIGHT-OF-WAY AND CONSTRUCTION PLANS

> For all PennDOT Right of Way and Construction plans, care is to be taken to properly record the horizontal and vertical datums upon which the survey and design are based within the General Notes on the plan.

For all PennDOT Right-of-Way and Construction plans, care is to be taken to properly record the horizontal and vertical datums upon which the survey and design are based within the General Notes on the plan. The General Notes will also include the survey methods used to obtain this information. For horizontal datum information, General Notes will state the Pennsylvania Coordinate System, Zone, Datum, and Epoch used in the survey, and the method used to determine that information. Acceptable methods for establishing horizontal control include GNSS Static, GNSS RTK or RTN, OPUS or OPUS Projects, and Traverse from known monuments.

For vertical datum information, the General Notes will indicate the Datum and GEOID Model used in the survey and the method used to determine that information. Acceptable methods for establishing vertical control include Differential Leveling from a known monument, GNSS Static, GNSS RTK or RTN, OPUS or OPUS Projects, and Traverse (trig-leveling) from known monuments.

<u>Examples of notations for Horizontal datums used and survey methods are as follows:</u>

The Horizontal Control is based on the Pennsylvania Coordinate System, North Zone (3701). North American Datum NAD83 (2011) EPOCH 2010.00. Determined by Traverse from existing PennDOT control stations G107 and G108.

The Horizontal Control is based on the Pennsylvania Coordinate System, South Zone (3702). North American Datum NAD83 (2011) EPOCH 2010.00 Determined by GNSS RTN (KeyNetGPS) on Project Control Stations.

The Horizontal Control is based on the Pennsylvania Coordinate System, South Zone (3702). North American Datum NAD83 (2011) Determined by OPUS on Project Control Station X16-001.

<u>Examples of notations for Vertical datums used and survey methods are as follows:</u>

The Vertical Control is based on the North American Vertical Datum NAVD88 Determined by Differential Leveling from existing PennDOT control station K017.

The Vertical Control is based on the North American Vertical Datum NAD88 Determined by GNSS RTN (PennDOT CORS Network) on Project Control Station S22-002.

The Vertical Control is based on the North American Vertical Datum NAD88 Determined by OPUS Projects on Project Control Stations BM 3 and BM 7.

11.4 PROCEDURES FOR REESTABLISHMENT OF RIGHT-OF-WAY CENTERLINE

When establishing a right-of-way centerline or baseline, all sources of legal right-of-way must be researched. These sources of right-of-way legal documentation include prior Right-of-Way Plans and/or Condemnation of Right-of-Way Plan sets, subdivision plans as recorded at the appropriate County Recorder of Deeds Office(s), recorded deeds, road dockets, and in some instances use of the appropriate rules governing establishment of right-of-way based on statute rules.

When Right-of-Way or Condemnation Plan sets exist, the reference monumentation shown on the plan will hold precedent to tie down the centerline/baseline geometry for determining legal right-of-way widths. In the event the prior monumentation is lost, disturbed, or otherwise deemed inaccurate, the existing geometry of the roadway must be held and recreated using a best fit analysis from the field survey.

If there are no prior Right-of-Way or Condemnation Plan sets of record, then the geometry of the right-of-way centerline/baseline shall be determined from the establishment of the roadway centerline using a best fit analysis from the field survey, existing recorded documentation from the County Recorder of Deeds Office, and applying appropriate widths as determined from the statutes.

CHAPTER 12 – VOLUMETRIC SURVEYS

12.0 VOLUMETRIC SURVEYS

Volumetric surveys are used to determine the amount of material in a stockpile or on a project site.

Volumetric surveys are used to determine the amount of material in a stockpile or on a project site. Borrow pits are an example of a volumetric survey and could be used to determine the available material on site. Another common example is determining the amount of material removed from slope engineering projects. This chapter outlines acceptable methods and requirements for volumetric surveys.

UAS Data Collection of a milling pile in District 1-0

Figure 12.0.1

12.1 METHODS

1. Cross-sections
2. Three-dimensional Survey
3. UAS/Photogrammetry
4. Lidar
5. Alternative methods approved by the Department

Requirements. All distances will be read and recorded to within 0.05 feet. Reference points for control baselines will be recorded to within 0.01 feet. Bench levels will be run over the offset stakes to the nearest 0.05 feet and elevations checked against benchmarks throughout the project.

Procedures. No area will be surveyed until the site and material has been approved by either the District Construction Engineer or the Assistant District Construction engineer. The approximate amount of borrow or fill needed will be determined prior to staking to determine the approximate limits of the site. The site must be cleared, grubbed, and stripped of all sod and other unsuitable materials before cross-sections are taken. The area needs to be free of all equipment and other obstructions. The area is surveyed for a preliminary survey and then for a final survey. The difference in the two surveys is calculated and the volume is determined. The same control must be used for both surveys. Before the final survey can begin, the bottom of the area will be leveled off and the sides smoothed up and left in a presentable condition. The inspector-in-charge is responsible for confining work on the site to the area cleared and surveyed. If the limits of the area need to be extended, then the survey will be extended before additional work is undertaken.

12.1.1 CROSS-SECTIONS

When staking a site, a baseline will be established well outside site limits. Baselines will be straight and without any angles or turns. End stakes of baselines will be referenced, and a sketch made in a project field book showing the staking diagram. The survey party chief will exercise good judgment in staking baselines to show the true contour of the surface of the site to be measured.

At least two benchmarks will be established near the site on the same datum governing the project.

Final cross-sections will be taken after all planned work is completed. All irregularities in the contour of the site will be recorded. Final cross-sections will be run for the entire distance between the stakes on each baseline and will be checked for elevation and distance. Final cross-sections will always be taken at each limit of the work or changed area, even if a preliminary cross-section was not taken at that location. Care will be exercised in taking final cross-sections to show any waste material that may be rolled up by a shovel at the edges of the site. All material (excepting sod and other objectionable materials removed prior to the original cross-sectioning of the site) excavated from within the confines of the site and wasted as unsuitable material will be measured as a solid if the site of the waste disposal is not covered by preliminary cross-sections.

For more information on preliminary surveys, see Chapter 10.

12.1.2 THREE-DIMENSIONAL SURVEY

The topography method can be performed with a conventional total station or GNSS instruments.

Control should be placed outside of survey limits in a safe place for use when conducting a final survey. Points will be located with Northing, Easting, and Elevations with the help of a data collector. Files will need to be downloaded with the assistance of software to create a surface.

A final survey should be conducted with the same control and method.

Final volumes will be determined by comparing preliminary surfaces with final surfaces.

For more information on preliminary surveys, see Chapter 10.

12.1.3 UAS/PHOTOGRAMMETRY METHOD

> In some cases, traditional photogrammetry from manned aircraft may be appropriate….

The UAS method requires that pilots follow the requirements presented in Chapter 8.5.

Ground control should be established outside of the survey area using aerial targets. These should be used for both the preliminary and final surveys.

This method works best when the area is smooth and clear of obstructions. Weather may present challenges, as well.

All imagery recorded by UAS platforms shall be downloaded and processed in photogrammetric software capable of creating a 3D mesh of existing and final surfaces.

Final volumes will be determined by comparing the preliminary surface and the final surface.

In some cases, traditional photogrammetry from manned aircraft may be appropriate, especially on larger sites, difficult to access areas, or where vegetation prohibits the use of UAS. For more information, see Chapters 8 and 9.

For more information on UAS surveys, see Chapter 8.5.

12.1.4 LIDAR METHOD

> The lidar method is typically performed by a static scanner.

The lidar method is typically performed by a static scanner.

Main control should be established outside the survey area for use when recording data for both preliminary and final surveys.

The 3D point cloud data shall be downloaded and processed in software capable of creating 3D mesh surfaces.

Final volumes are determined by comparing preliminary and final surfaces.

Airborne or UAS based lidar may also be considered for use on certain projects. For more information on lidar, see Chapter 8.

12.1.5 ALTERNATIVE METHODS

As technology advances, alternative methods for volumetric surveys may be acceptable but must be approved by the District Chief of Surveys (DCS).

12.2 DELIVERABLES

Deliverables required include survey books and all files as outlined below:

Survey book

- Sketch of site layout
- Description of site location
- Control information and layout
- Any field notes

Survey files

- All files that were created
- Preliminary surface
- Final surface

Report

Final volume reports include:

- Date
- Crew names
- Site map/directions to site
- Address (if known)
- Control datums (both horizontal and vertical)
- Total volume
  - Cubic Yards
  - Cubic Feet

CHAPTER 13 – CONSTRUCTION SURVEYS

13.0 CONSTRUCTION SURVEYS

> Construction surveys are performed by reestablishing centerlines and providing contractors with stakes from which locations and elevations of new or modified highways and/or structures can be determined.

Construction surveys are performed by reestablishing centerlines and providing contractors with stakes from which locations and elevations of new or modified highways and/or structures can be determined.

There are six types of construction surveys that the Department utilizes.

- Type A
- Type B
- Type B Modified
- Type C
- Type D
- Type D Modified

Specific descriptions of each type can be found in PennDOT Publication 408, Specifications, Section 686. Please make sure you are using the contracted version of Publication 408 because it does receive updates regularly.

13.1 AUTOMATED MACHINE GUIDANCE (AMG)

When contractors elect to utilize AMG for construction, the DCS will be supplied with their Survey Control Report as laid out in Publication 408, Section 686. Form S-686-AMG-1 (see Appendix C.13.1.1), will be completed, signed, and sealed by the Professional Land Surveyor, registered in Pennsylvania, which is responsible for the work. Control tolerances and site calibration requirements can be found in Chapter 7. Quality control testing must be performed by contractors and reported on Form S-686-AMG-2 (see Appendix C.13.1.2), upon completion of the work.

13.2 CONSTRUCTION STAKE-OUT SKETCH FEATURES AND GUIDELINES

> Vertical and horizontal datums should be noted on sketches along with epochs, and method used to obtain them.

A stake-out sketch shall be shown, preferably on the first or second sheet of the structure drawings. There should be ample open space outside of the sketch to allow wing and barrier line extensions for stake point recordings. Sketches need not be to scale. Frequently, exaggerations of curvature, angle, etc., are necessary to show the information clearly.

Sketches shall be as simple as possible, but as complete as possible so that structures will be constructed according to the plans.

All necessary tie-in dimensions between highway alignment, working points, lines of structure, and other control points shall be shown in feet, to two decimal places.

Sketches shall show baselines along with shapes of the exterior faces of substructure components (abutments and wingwalls). All corners shall be referenced by showing work points and distances to baselines. Wingwall angles to the front face of abutments shall also be referenced. Work point coordinates may be shown on the plan.

For intermediate piers, the skew angles between centerlines of the piers and the baseline are required. Locations of pier centerline intersections with a baseline shall be tied to other parts of a substructure by baseline dimensions. Distances from a baseline to the centerline of roadway along the centerlines of piers shall be indicated. Stations of intersection points at a baseline shall also be shown. Distances between the outside faces of each barrier shall be shown.

For multi-level structures, each level shall be sketched separately, but referenced to a common baseline.

A stake-out shall be referenced to one straight baseline, except in cases of dual structures, where two straight baselines, properly referenced to each other, can be used. A baseline will be the centerline of the highway (if tangent), or the long chord connecting the points where the centerline of the highway intersects the face of the abutments on a curved highway, or the tangent line at the point of intersection of highways or the highway and a stream or river. Generally, dimensioning along a long chord is preferred on sketches for viaducts with a long series of spans. In special situations, some other baseline can be used if particularly convenient.

Vertical and horizontal datums should be noted on sketches along with epochs, and method used to obtain them.

Stake-outs for box culverts shall include inside faces of walls, ends of the culvert, and front faces of wingwalls. Reinforced concrete arch culverts and metal culverts shall be treated similarly.

13.3 BRIDGE STAKE-OUT PROCEDURES

After work has started, the position cannot be adjusted without considerable cost and lost time. The centerline of the bridge will be monumented by driving hubs (outside of the construction area) at each side of the structure.

Following are procedures that may alleviate discrepancies or inconsistencies when staking-out a structure.

Establishing the centerline and stationing of a structure will be checked by the DCS or the survey party chief in sufficient detail to verify its location.

After work has started, a structure's position cannot be adjusted without considerable cost and lost time. The centerline of a bridge will be monumented by driving hubs (outside of the construction area) at each side of the structure.

When possible, a backsight will be set online so that, in case line of sight over a structure is blocked by forms, the centerline can always be determined. These centerline hubs will always be tacked and referenced to objects that will not be disturbed during construction.

Faces of abutments, centerlines of piers, outside lines of parapets, and other needed working lines will be referenced by at least two stakes on each side of a bridge. Face lines of wings will be run and referenced by at least two stakes. All stakes will be protected by contractors in an approved manner. The lines of the tops of abutments will be staked when faces of abutments are battered. Locations of all stakes will be shown on a sketch provided either in the notes or on a form furnished by the District.

The District Bridge Engineer will furnish Inspectors-in-Charge (IIC) with all elevations and measurements necessary for construction of the structure.

The structure stake-out sketch and reference stake locations shall be recorded in a Department D-428 survey field book.

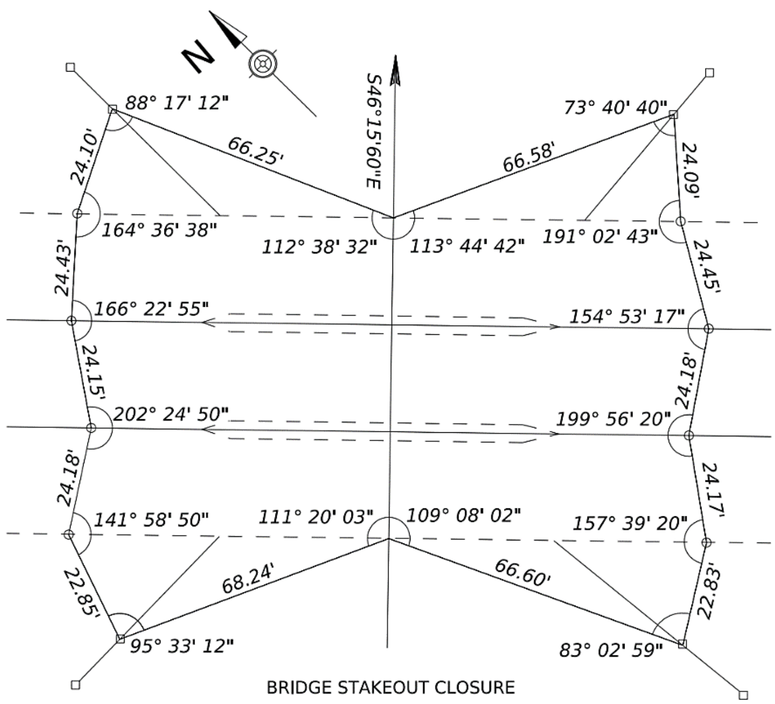
Original stake-out field notes shall be recorded in survey field books. When other copies are required, this information shall be taken from the original survey field books.

A complete centerline tie shall be made at the ends of a structure to ensure proper location.

No changes will be made in the preliminary survey field books. However, any errors or discrepancies found in the preliminary survey notes, or on the drawings, will be noted in the preliminary and construction field books. When there has been an office change made on the drawings, the new line will be established in the field and, if necessary, new cross-sections will be taken. These changes will be incorporated in both the preliminary and construction survey field books.

An error of closure on the stake-out shall be recorded in the survey field book. This error of closure shall reflect a comparison between measured and computed angles and distances of a traverse around the near line of the offset stakes of all working lines. An acceptable error of closure shall meet the minimum of 1:10,000 or a positional accuracy of 0.05-feet plus 20 ppm for each offset point.

- Run a closed traverse around the near line of offset stakes of all working lines. On projects where various phase stake-out is required, run the intermediate traverse as the stake-out progresses.
- Upon completion of an acceptable closure of the perimeter traverse of 1:10,000 or better, compute the individual closures between each pier and abutment lines. These computations may be made in the field by the party chief or in the office by a member of the District Bridge Unit.
- Record this sketch and closure in a survey field book to be made readily available for inspection. See Figure 13.3.1.



Bridge Stake-out Closure
Figure 13.3.1

13.4 GENERAL CONSTRUCTION STAKE-OUT SPECIFICATIONS

The field books of the preliminary survey, drawings, and Special Provisions of the contract will be thoroughly reviewed by the survey party before beginning.

All distances will be read and recorded to within 0.03 feet, except for the reference distances to the limit of project points.

- Reference points will be recorded to within 0.01 feet.
- Bench level elevations will be established on the offset stakes to the nearest 0.01 feet and the elevations checked against the benchmarks throughout the project.

The field books of the preliminary survey, drawings, and Special Provisions of the contract will be thoroughly reviewed by the survey party before beginning. The survey party will then locate original points of tangency and curvature on the ground from original notes. If any office changes appear on the drawings, they will be run in, and the points of curvature and tangency staked and referenced to at least three permanent objects outside the construction area. The notes will indicate all relocation areas and their relation to the original centerline.

When alignment changes have been made, the centerline equation will be compared with that shown on the drawings. Either new cross-sections must be taken off the new alignment or the offset distance must be measured between the original centerline and the new alignment at the preliminary cross-section locations.

All reference points that have been, or will be, either disturbed or destroyed by the construction will be placed outside the construction area and will be accurately described and noted in the field book. The construction centerline will be established over the entire project, if possible, before any work is done. This will enable the survey party chief and the inspector-in-charge to choose any point on the centerline at any location and view the project as a whole before any work starts.

When a construction survey cannot be completed before a contractor starts operations, the inspector-in-charge will secure the plan of operation, including where the contractor will commence operations. A survey party chief's work will be arranged to supply contractors with sufficient stakes and information to ensure that the work will not be delayed.

Bench levels will be performed, and benchmarks checked for location and elevation.

- Any benchmarks that have been destroyed or damaged, or that will be disturbed by new construction, will be reestablished, or replaced in locations where they will not be disturbed.
- It will be a contractor's responsibility to record all information on reestablished benchmarks in the notes and to mark the set of plans used by the survey corps.
- Both an inspector-in-charge and the DCS will be informed of benchmark changes by contractors.

Stakes set for slopes, limits of grading, etc., will be based on the offsets and elevations shown on the cross-sections. These construction stake locations are to be set at 50 feet intervals and at all control points (PCs, PTs, POCs, and POTs).

For rough grade, construction stakes will be referenced with three hubs and guards. Construction stakes will be established by driving a hub flush with the ground and by providing a guard stake behind it. A hub protruding out of the ground is easily destroyed and subject to frost heave. The guard stakes will identify stations and offsets of the construction stakes from the centerline. The hub will have a transit tack placed in the top to denote the exact location of offset and elevation. For fine grade, construction stakes will be referenced with a 12 inch spike driven flush with the ground.

Construction stakes will be placed beyond the limits of construction and inside the right-of-way. It is advisable to place construction stakes on a parallel line on tangents, and possibly on curves, if terrain and topographic features will not cause a costly delay in time.

Stakes will be placed at 25 feet intervals or less on sharp horizontal curve locations (less than 300 feet radius). On grades of more than four percent, an offset stake will be set on each side of each designated grade point. Slope stakes will be placed when the top of cut slopes, or the toe of embankments are more than 5 feet vertically above or below the finished grade line. The rounding of slopes in cut sections will be disregarded in the placing of slope stakes, and stakes will be placed at the intersection of the normal theoretical slope line with the present ground line. Limit of slope stakes will be placed for the rounding of slopes.

Stakes used on a construction survey will be placed well beyond the limits of construction, so the stakes can be referred to during construction and can be available for the final survey.

Bench level elevations will be established over these offset stakes to the nearest 0.01 feet and the elevations checked against the benchmarks throughout the project. All information will be recorded on a grade sheet such as form D-413. A copy of Form D-413 as found in Appendix C.13.4.1. At a minimum, grade sheets will carry the proper identification as found at the top of Form D-413 and all the entries found on D-413. The date prepared and the number of the field book from which the stake elevations and distances are copied will be included on completed grade sheets. The survey party chief will compute and check the stake elevations in the field and will forward the field book to the District immediately. The District will generally prepare the grade sheets. If a construction survey has been delayed and the contractor is working, it may be necessary for the survey party chief to prepare grade sheets in the field so as not to delay the contractor's operations. In such cases, the survey party chief will prepare 3 copies of the grade sheets and have them checked by the inspector-in-charge. One copy will be given to the contractor, one copy to the inspector-in-charge, and one copy to the District. The District will also receive the field book. The DCS will prepare grade sheets in the regular manner and forward sufficient prints to the field with a letter advising the inspector-in-charge that the grade sheets prepared in the field were found correct. Any discrepancies found by the DCS will be noted and corrected immediately in the field.

When stakes are replaced in the field, the DCS will have new grade sheets prepared for the affected section and will forward all prints to the field. Any revisions to grade sheets will be noted as ‘superseded’ and dated accordingly. The inspector-in-charge will cross out, or void the data superseded on all copies of the original grade sheets.

Accurate cross-sections will be recorded within the area of proposed improvements before a contractor starts grading operations. If cross-sections taken during a preliminary survey still show true conditions, then they may be used without further work. However, if there has been any change in the contour of the ground surface, or if original cross-sections were taken during the winter months and there is a general change due to frost or ice action, or if decisions to change lines have been made, then construction cross-sections will be taken before the contractor starts operations. A design may necessitate new or additional cross-sections. Care will be exercised when recording profiles and cross-sections where side roads and approaches are to be constructed. Additional cross-sections will be taken to include areas where structures, special ditches, or channel changes are made. Prints of construction cross-sections will be forwarded to the field as soon as possible.

Special structures will be staked well ahead of actual grading operations. This practice enables contractors to perform such work as building culverts, drains, sewers, and like structures as early as possible in order to obtain adequate settlement of the backfill. However, the survey corps will set stakes for large culverts, box culverts, channel changes, and all bridges.

When producing a spiral curve stake-out, it is advisable that the survey party chief refer to the tables and computations as given in either, "Transition Curves for Highways," by Joseph Barnett or in, "Route Location and Design," by Thomas F. Hickerson, published by the United States Printing Office and McGraw-Hill Book Company, respectively. However, if a spiral is designed in the office and placed on a plan as a construction centerline, it is easier to compute the offsets from the simple curve than establish the spiral on its own centerline. This is applicable to a simple curve with spirals at each end. First, establish the simple curve centerline followed by the TS, SC, CS, and ST.

NGS and PennDOT benchmarks are established as a permanent record and extreme care will be exercised to preserve their value. If possible, they will not be disturbed until permission has been obtained. However, if NGS or PennDOT benchmarks are disturbed, the contractor and/or the inspector-in-charge will immediately notify the DCS. Should the DCS decide that a NGS or PennDOT benchmark must be relocated, the DCS will make necessary arrangements to have the mark reset as per Publication 408, Section 686. Surveys to relocate these marks will be performed using methods and procedures as required to retain the accuracy of the original mark. Please refer to Chapter 5 to find out more about benchmark placement.

The centerlines of bridges will be staked. Stationing will be carried from locations established accurately at 50 feet on either side of the bridge. Structures will be located as shown on the drawings and by using bridge stake-out sheets furnished by the District.

Work points will be located and referenced with sufficient ties established to the centerline. Figure 13.3.1 shows the suggested method for staking a bridge layout from structure drawings. It should be noted that the dimensions of a bridge layout are shown to two (2) decimal places of a foot. The original bridge layout from the structure drawings will provide hundredths of a foot dimensions for all measurements.

CHAPTER 14 – FINAL 'AS-BUILT' SURVEYS

14.0 FINAL 'AS-BUILT' SURVEYS

Final 'As-Built' surveys are used to determine payable quantities and items associated with construction projects, such as excavation, paving, and other miscellaneous items.

Final "As-Built" surveys are used to determine payable quantities and items associated with construction projects, such as excavation, paving, and other miscellaneous items. As-Builts are also used to graphically show roadways in relation to their centerlines and elevations shown on the drawings. Conventional survey procedures or three-dimensional total station survey procedures, as discussed in Chapter 10, will be used to perform these final surveys.

REQUIREMENTS

All distances will be read and recorded to within 0.05 feet, except for the reference distances to the limit of project points. Reference points will be recorded to within 0.01 feet.

PROCEDURES

All information (i.e., stations and intermediate pluses shown in the preliminary notes) from the preliminary survey will be accurately reproduced to establish the final survey line. If (due to the development for office relocation or other reason) a construction survey has been made and new cross-sections taken, then it will be necessary to reproduce the construction line in its entirety. Field books of the preliminary survey and the construction survey, together with the drawings, will be examined to determine the alignment used in construction. Vertical and horizontal datums should be noted in all field books along with the corrections.

Locations of all stations and intermediate pluses on the preliminary survey or on the construction centerline will be accurately marked on the pavement with paint. The paint mark will be an encircled dot so the cross-section party will have no difficulty locating these points. They also serve as a checking system during the plotting of final survey notes. Key horizontal control points (PCs, PTs, POCs, and POTs) will be marked with a painted 'X' surrounded by a circle and the station plus. Any PIs located on the pavement will also be located in the same manner. If preliminary control references have been destroyed during construction, then new references must be established and recorded.

Horizontal survey centerline chaining is used to relocate preliminary or construction stationing. Final cross-sections are taken at the exact location of preliminary or construction cross-sections to secure accurate earthwork quantities.

14.1 VOLUMETRIC SURVEYS

PROCEDURES

Final cross-sections will be taken at all stations and pluses and at the same angles to the centerline as the original cross-sections from the preliminary or construction survey. This will provide for the coordination of sections and the development of accurate earthwork quantities. Additional final sections will be taken at the beginning and end of all cuts and fills. The District office will interpolate the preliminary sections at these stations. Final cross-sections will be extended on each side of the centerline. The last two readings for each cross-section on each side will be original ground elevations and will be marked as 'OG.' Other critical elevation readings include the bottom of fill 'BF,' the top of cut 'TC,' and the edge of pavement 'EP.'

Ground elevations, as noted on preliminary or construction surveys, will be checked against elevations obtained on final surveys. All discrepancies in elevations will be noted and explained. If a section falls at an inlet or outlet of a pipe, that section will be taken as if there were no break in the slope line, thus assuring accurate earthwork quantities in each direction.

Cross-sections on channel changes are usually taken shortly after completion. However, additional material may have been washed in, thereby necessitating additional cleaning. New cross-sections showing the material washed in, and final cross-sections after its removal, will then be taken for the accurate determination of quantities. When not shown on the drawings, a channel layout sketch will be prepared showing the location of the established traverse line with respect to the roadway. This sketch will be sufficiently accurate and complete such that, when plotted, the channel and roadway cross-sections can be tied in to eliminate overlapping of sections.

Final cross-sections of borrow pits will be taken as outlined in Chapter 12.

No cross-section elevations will be required in grading sections where no 'Borrow' has been used, and in fill areas completed that are beyond the theoretical cross-section limits. In waste areas, in which measurements of embankments would not be involved in the determination of the pay quantity for excavation, cross-section elevations of the fill areas will not be required beyond the outer edges of the shoulders provided the fill slopes have been constructed properly to at least the slope as planned. The outer limits of these final cross-sections will be marked "SLW" (Shoulder Limit in Waste Areas), and embankment quantities will not need to be computed.

The benchmarks established as indicated on the construction drawings will be checked and their elevations will be recorded. Department standard benchmarks placed during construction on bridges and other permanent structures will be described in detail to be easily located in the future. Benchmark elevations will be measured and recorded to the nearest 0.01 feet. They will be identified in the notes as new benchmarks established during construction. Any old benchmarks damaged or destroyed will also be indicated in the notes. Final drawings will void such damaged or destroyed benchmarks and will show the data for the new benchmarks established during the construction. See Publication 408, Section 686, for additional instructions on PD Disks destroyed during construction.

Measurements for the determination of final pay quantities will have been taken by the inspectors during construction or by the survey party at the time of the final survey. Usually, the inspector-in-charge for a project has recorded measurements for all items in the contract except roadway excavation, borrow, large amounts of waste material (that need cross-sectioning), parallel ditches within the cross-section area, bridge cross-sections, and approaches for which preliminary or construction cross-sections were taken.

The survey party chief will determine the work necessary to complete final estimates and drawings in advance.

The survey party chief will determine the work necessary to complete final estimates and drawings in advance.

Final cross-sections, profiles, and measurements will be taken on all side approaches to a highway where grading has been performed (unless the quantity of cut and fill are slight and previously measured and computed by the inspectors). Layout sketches and measurements are necessary to enable the District office to accurately determine the amount of cut or fill.

14.2 STRUCTURAL AND SURFACE SURVEYS

Cross drains, inlets and manholes will be measured and recorded, and reported along with all subsequent measurements. The station plus for inlets, outlets, centerline crossings, the types and sizes of pipes, and the types of end_walls will be recorded. Elevations of inlets top of grate, manholes, and the flow lines at inlet and outlet ends will also be recorded. The inverts and slope calculations of all pipes will also be provided in the report.

All other structures such as sanitary manholes, gas valves, water valves, etc., will be measured and recorded along with rim elevations and references to centerline stations and offsets.

Surface measurements will be used in linear measurements of pavement and a recheck will be made to verify the results. The quantities of the distinct types of pavement surfaces will also be computed. Widening on curves will be measured on 10 feet chords and aprons. Clear and accurate sketches will be shown for all additional paving beyond the normal width of the standard section and for the transition from one width to another.

Curbing, guiderail, underdrain, and related items will be measured (in accordance with the Specifications) and located by station pluses after a pavement segment has been surface chained. The identification (type, size, etc.) of contract items will be recorded.

Subsurface drain outlet end_walls, standard pipe culvert end_walls, inlets, and similar physical items, will be located by station pluses when surface chaining.

Place special emphasis on securing accurate quantities for all material wasted throughout the project (particularly at channels and ditches). The amount of waste material, when not obtainable by cross-sections, will be measured by average dimensions and recorded with a sketch in the field book showing its location with relation to the highway.

Survey party chiefs will confer with inspectors-in-charge to determine if all final computations and sketches relating to bridges, culverts, and channel changes, have been prepared. Survey party chiefs will obtain any additional information when making final surveys.

CHAPTER 15 – MONITORING SURVEYS

15.0 MONITORING SURVEYS

Monitoring surveys are performed on physical structures, roadways, and natural areas to identify and record movement over time. Field surveys are performed and compared to as-built data for change detection. After monitoring baseline survey is established, a monitoring schedule is determined, and all subsequent surveys are then compared to the baseline survey. Monitoring surveys can be performed on slopes, sink holes, roadway surfaces, bridges, walls, etc.

15.1 MECHANICALLY STABILIZED EARTH WALL (MSE) WALL MONITORING

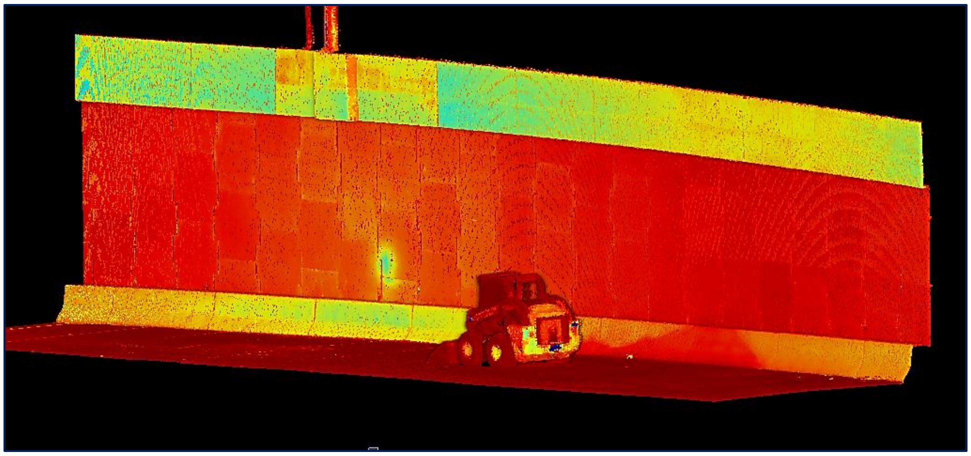
A. MSE Wall Definition

An MSE wall can be defined as any retaining wall that uses interlocking shaped panels (precast facing elements), which are tethered and anchored into compressed backfill (see PennDOT Publication 238, Section 2.15.1.1).

MSE Wall Example (MSE 36-0030-0261-1167)
Figure 15.1.1

B. Inspection Guidelines and Frequencies

i. A three-dimensional survey meeting the criteria below must be completed for MSE walls with a length in excess of 100 feet, and an exposed height of at least 20 feet at any point along its length.



Same MSE wall as in Figure 15.1.1. This image shows lidar scan intensity values.
Figure 15.1.2

ii. See PennDOT Publication 238, Section 2.15, Retaining Walls for detailed information on types of inspections, inspection frequencies, and typical cycles. Engineering District Offices, in coordination with the Bridge Office (BMS2), will be responsible for requesting three-dimensional surveys through either the District Chief of Surveys or the Photogrammetry and Surveys Section for all initial MSE wall inventories and in-depth inspections.

Permanent monumentation will be established outside of areas potentially affected by future wall movement.

C. Control Requirements

If permanent monumentation is required, follow the guidelines in Chapter 4.1. All permanent monuments will be referenced and recorded on Form D-428. Permanent monumentation will be established outside of areas potentially affected by future wall movement.

D. Three-dimensional Survey Requirements

All field surveys will be performed with lidar technology. A minimum of one (1) three-dimensional coordinate shall be furnished every 0.25-feet horizontally and 0.25-feet vertically along the entire length of the wall. The horizontal and vertical relative point accuracy will be 0.01-feet. Lidar scan files will be referenced together for analysis to ensure coverage across the entire MSE wall. The final lidar scan file will be georeferenced to the permanent control monumentation on site, if applicable.

E. Lidar Scan Analysis

Initial inventory scan data will be analyzed for general plumbness, tile consistency, and any abnormalities in the scan (further listed in PennDOT Publication 238, Section 2.15.4). This scan will be archived for future analysis and comparison scans. In-depth or other special inspection scan data will be analyzed as in the initial inventory. Data will then be compared to that of initial inventory scans and any other archived scan data. Such analyses will be performed to detect movement of at least 0.02 feet of any panel along MSE walls.

F. **Reporting**

The following reports are to be provided for each wall or grouped walls (MSE walls in proximity to one another):

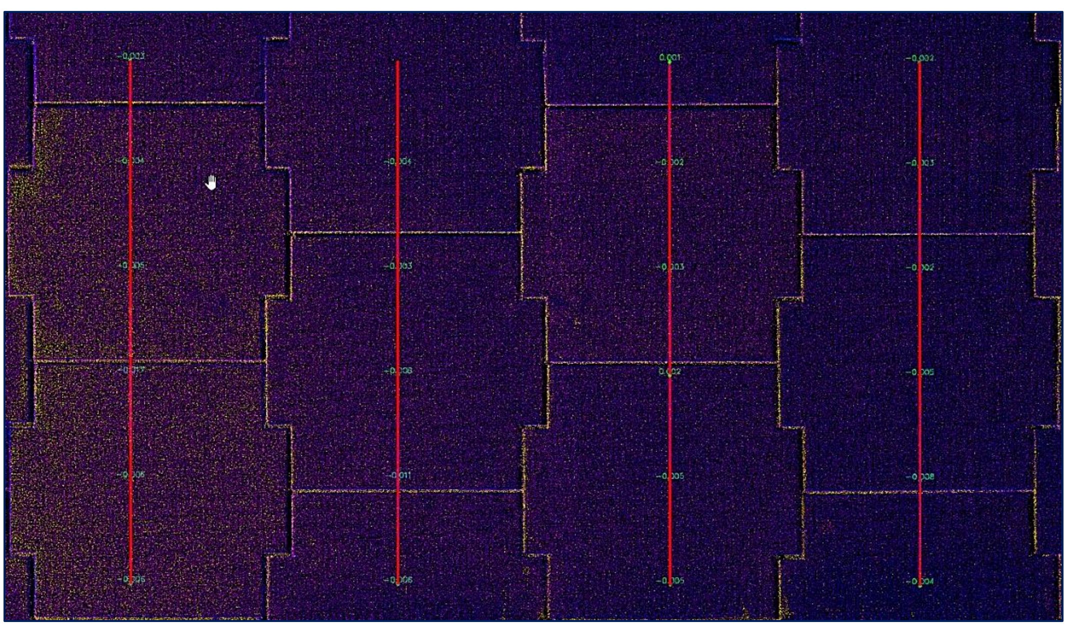
i. Scan Report – Survey narrative and control, and georeferenced registration reports showing cloud to cloud error and an image to verify cloud alignment, if applicable. The report must also show the grid to ground scale factor that must be applied to the final deliverables.

ii. MSE Wall Analysis Reports – These will have a consistent format and structure:

   a. Dates – list all dates for field activities (recon, survey 1, survey 2 scan 1, scan 2, etc.)
   b. Project Location – image and description of where the wall is located
   c. Site Conditions – initial site and MSE wall conditions, as observed
   d. Weather – a brief narrative of actual conditions at time of scanning
   e. Approach – a summary of how the project was scanned and the equipment/software used
   f. Evaluation – a detailed explanation of how the data was processed leading to given results
   g. Results – quantifiable information provided in spreadsheets, charts, maps, or otherwise, explaining the data collected (baseline offsets, panel deviations, point analysis and hotspot analysis to highlight problematic areas)
   h. Recommendations – based upon the results, what are the recommended next steps? (Change in scan frequency, maintenance, other collection methods, etc.)
   i. Summary – overview of all reported topics

Example of scan data analytics depicting MSE wall movement

Figure 15.1.3



G. Deliverables

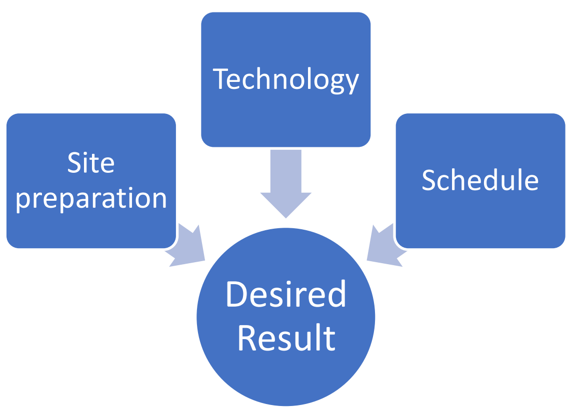
All delivered items are to be neatly organized, consistently named, and compressed where possible.

Upon project completion, the following items will be delivered together through digital delivery, removable media, or other method approved by the Department. All delivered items are to be neatly organized, consistently named, and compressed where possible.

i. Scan Report
ii. Field data – all *unedited* scan files, and survey files
iii. CADD data - Surface files, cross-sections, profiles, spreadsheets
iv. Media - Maps (displaying project location and any other details), images, annotated screenshots, shop drawings, etc.
v. Correspondence
vi. Documents – including any planning, or other relevant project information

15.2 OTHER STRUCTURAL AND SLOPE MONITORING

When it is determined that a project is to undergo monitoring or analysis, the correct planning must be performed before a survey is requested. The DCS or PSS will be contacted to help the requestee determine the correct course of action in site preparation, technology utilized, and schedule of observation(s), etc., to acquire the desired results for analysis.



Monitoring Project Development Chart
Figure 15.1.4

APPENDIX A – GLOSSARY OF TERMS

Accuracy - is the degree of closeness, or conformity, of measurements to their true value.

Analytical Aerial Triangulation (AAT) – Traditionally defined as a method used to densify ground control throughout a photogrammetric dataset, AAT can now also refer to processes used to create DSMs from UAS or terrestrial photography.

Arc-Definition - is the relationship between the radius, R, and the degree of curve, D, for a circular curve. The degree of curve, D is defined as the central angle which subtends a 100 ft arc. R = 5,729.58/D.

Assumed Plane Coordinates - is a coordinate system based on either a rectangular surface or a flat surface. Assumed plane coordinates are represented by an arbitrary grid system.

Bifurcated - is a descriptive term used with highways for divided baselines.

Breaklines – Lines in a DTM that force an edge in triangulation. Soft breaklines such as road edges create triangle edges along the road edge. Hard breaklines define a change in the surface such as a cliff, ridge, or a stream bottom.

Cartesian - is a plane coordinate system forming a grid. The system defines an 'X' axis (also represents easting values) and a 'Y' axis (also represents northing values) to establish the grid.

Chord-Definition - is the relationship between the radius, R, and the degree of curve, D, for a circular curve. The degree of curve, D is defined as the central angle which subtends a 100 ft chord. R=50/sin(D/2).

Class - is a division or grouping within a specific order.

Combined Scale Factor - Product of the Elevation Factor and the Scale Factor.

Compass Rule - is an adjustment procedure performed for the balancing of a control traverse. The compass rule applies corrections to latitudes and departures in proportion to the distances of each course. It should be noted that the compass rule assumes that all angles and distances have been measured with equal precision.

Continually Operating Reference Station (CORS) - CORS facilities collect and record, in a continuous automated manner, the GPS data at a known location that are required for relative positioning.

Datum – an abstract coordinate system with a reference surface (such as sea level) that serves to provide known locations to begin surveys and create maps.

Digital Elevation Model (DEM) – an electronic file containing x, y, and z coordinate points that define the bare earth surface. These files can be used in modeling software to generate contours. DEMs do not contain breaklines or planimetric features.

Digital Surface Model (DSM) – Sometimes referred to as reality models and similar to a DEM, this term is generally used to describe automatically generated surface models from UAS photography or lidar data. DSMs usually have photo-realistic colorization. A DSM is not bare earth because it includes natural and built features.

Digital Terrain Model (DTM) – an electronic file containing breaklines and points consisting of x, y, and z coordinates. DTM's are more reliable than digital elevation models (DEM)because they include breaklines. DTMs may contain other intelligently collected data such as planimetry, but the surface triangulation ignores these features and is bare earth.

District Chief of Survey (DCS) - Manager of the entire survey unit for each District.

Double-Centering - is a method of aligning the vertical cross hair of a conventional transit.

Eastings - are the "X" values of coordinates represented on a plane coordinate system.

Elevation Factor - converts distances between the geodetic distances on the ellipsoid surface and the horizontal ground distances. This factor is computed from the z-elevation of the point.

Error - Absolute – The error in positions of data points compared to their true position on a datum. An example would be the coordinates of a single object in a geospatial product compared to its true position on earth.

Error – Relative – The error in measurements from point to point within a dataset. An example would be the width of a roadway (road edge to road edge) measured from a geospatial dataset as compared to its real-world width.

Existing Conditions Survey – A topographic survey by conventional or remote sensing technologies recording the existing conditions of a site prior to any project work. It includes planimetric features and a DTM.

Existing Ground Confidence Level – Refers to reporting methodologies for an existing conditions survey. It includes a map test with reported root-mean-square error and descriptions of the various technologies and methods used to collect the model.

Federal Geodetic Control Subcommittee (FGCS) - responsible for the coordination, management, development, and dissemination of geodetic control data through multiple federal and non-federal agencies.

Geodetic - is a coordinate system established by the shape of the earth, or a large part of its surface.

Geoid – a mathematical representation of the earth's surface that is updated and revised every few years by the National Geodetic Survey (NGS).

Geospatial – A generic term to describe any dataset that includes location information.

Global Navigation Satellite System (GNSS) - system of multiple satellite constellations (GPS, GLONASS, Galileo, Beidou, QZSS, etc.) that provides positioning, navigation, and timing services on a global scale.

Global Positioning System (GPS) – is the United States three-dimensional, satellite surveying system based on observations of radio signals of the NAVSTAR Global Positioning System. These observations are reduced to establish their equivalent Cartesian coordinates (X, Y, Z). These coordinates can then be converted to geodetic coordinates (latitude, longitude, and height above-reference ellipsoid).

Ground Sample Distance (GSD) – An acronym for Ground Sampling Distance. Can be the size of a pixel on a photograph or the spacing of lidar points on the ground.

“Hard” Conversion – is a procedure to develop a new rounded, rationalized metric number computed from a US conventional measurement.

Inertial Measurement Unit (IMU) – An electronic device that measures the movement, acceleration, and orientation of the device to which it is attached. It is critical for most mobile or airborne remote sensing technologies.

International Foot – established in 1957 it is defined as 1 foot = 0.3048 meters exactly.

Least Squares Method - is an adjustment technique performed for the balancing of survey data. Least square adjustments are often performed for bench level circuits and control traverses.

Lidar – An acronym for light detection and ranging. It is a remote sensing technology using the reflection of active lasers. The result is a cloud of three-dimensional points. Lidar can be collected from static positions, aerial vehicles, or any number of terrestrial vehicles.

Metadata - A set of data that describes and gives information about another dataset. Here, it usually includes info such as date of survey, weather conditions, personnel, etc.

Monumentation - is the act of referencing specific control points throughout a survey project.

North American Datum of 1927 (NAD 27) - is the second horizontal geodetic datum (first – North American Datum) of continental extent in North America. It was originally established by the US Coast and Geodetic Survey (USC&GS).

North American Datum of 1983 (NAD 83) - is the third horizontal geodetic datum of continental extent in North America. It was established by the National Geodetic Survey (NGS) of the United States, the Geodetic Survey of Canada (GSC), and the Danish Geodetic Institute (responsible for surveying in Greenland).

North American Vertical Datum of 1988 (NAVD 88) – is the third vertical reference system of continental extent in North America, established by NGS, and used to establish vertical control in Pennsylvania after January 1, 1996.

National Spatial Reference System (NSRS) - is a compilation of all current control points and their respective coordinates established by the National Geodetic Survey (NGS).

National Geodetic Survey (NGS) - is the governing organization within the continental United States mainly responsible for establishing control points and reference systems.

National Geodetic Vertical Datum of 1929 (NGVD 29) - is the second vertical reference system (first – LMSL - Local Mean Sea Level) of continental extent in North America. It was originally established by the US Coast and Geodetic Survey (USC&GS) and used to establish vertical control in Pennsylvania prior to January 1, 1996.

Northings - are the "Y" values of coordinates represented on a plane coordinate system.

Online Positioning User Service (OPUS) - provided for free by NGS to compute NSRS coordinates.

Online Positioning User Service – Database (OPUS-DB) – provided for free by NGS to compute NSRS coordinates and publish the results for future surveyors to use with a minimum submission of 2 hours of GNSS data.

Online Positioning User Service – Projects (OPUS-Projects) – provided for free by NGS to compute NSRS coordinates, with the use of numerous and various types of GNSS data and publish the results for future surveyors to use.

Online Positioning User Service – Rapid Static (OPUS-RS) – provided for free by NGS to compute NSRS coordinates, with a minimum submission of 15 minutes of GNSS data.

Order - is a division or grouping of specific accuracy requirements.

Orthophotography – Photography, usually aerial photography, which is photogrammetrically and geometrically corrected so that it has a uniform scale throughout, and each pixel is placed on its correct relative or geographic location.

Parallax Errors - are apparent focusing flaws as a result of a maladjusted instrument.

Planimetry – Survey measurements made on a plane. Typically used here to describe physical objects such as road edges, buildings, utilities, etc. collected on a map. When combined with a DTM, it becomes a model.

Precision - is the degree of consistency among a group of measurements.

Remote Sensing - Gathering and processing information about an object without direct physical contact. Generally used here to describe lidar or photogrammetry but can include radar, sonar, infrared or other technologies.

Root-mean-square error (RMSE) - It is a measure of error distribution in a dataset. It indicates that about 67% of data points in a set should have errors less than the RMSE value. No error in the dataset should be more than three times the RMSE.

Real Time Kinematic (RTK) - is a real time positioning technique which based on the differential of GNSS signals received by two or more receivers at different locations with one being temporarily fixed.

Real Time Network (RTN) - is a real time positioning technique which based on the differential of GNSS signals received by two or more receivers at different locations with one being permanently fixed and integrated into a network.

Rounding - is a methodology to discard non-significant digits.

Scale Factor – is a measure of distortion that accounts for the difference between a distance on a curved surface (Earth), and that same distance when projected onto a mapping plane or grid at a given point on a projected map.

Sexagesimal System - is a system established by the number 60. All angular measurements in surveying are based on the sexagesimal system.

Significant Figures - is the number of sure or certain digits, plus one estimated digit.

"Soft" Conversion - is an exact re-stating of a US conventional measurement in its equivalent metric term.

State Plane Coordinate System of 1927 (SPCS 27) - is the original plane coordinate mapping system established for the United States by the US Coast and Geodetic Survey (USC&GS) and used in Pennsylvania prior to January 1, 1996. It incorporates both the North American Datum of 1927 (NAD 27) information and the National Geodetic Vertical Datum of 1929 (NGVD 29) information.

State Plane Coordinate System of 1983 (SPCS 83) - is the plane coordinate mapping system adopted in Pennsylvania after January 1, 1996. It incorporates both the North American Datum of 1983 (NAD 83) information and the North American Vertical Datum of 1988 (NAVD 88) information.

State Plane Coordinate System (SPCS) - is a coordinate system developed for each particular state. Within each SPCS, a central meridian, an origin, and a rectangular coordinate grid has been developed by the National Geodetic Survey (NGS).

Stationing - is a standard system of marks established at set (measured) distances along a line.

Swing Tie - is a method of referencing control and alignment points to fixed topography. A minimum of three (3) fixed topographic features are established radial to the point being referenced.

Thalweg – is the deepest part in a stream or valley cross-section.

Two Peg Test - is a common procedure used to adjust the horizontal cross hair of a leveling instrument.

Truncate - is a methodology to discard non-significant digits.

Unmanned Aerial System (UAS) – Commonly referred to as drones. Usually, ‘system’ refers to a manufacturer integrated camera/video sensor.

Unmanned Aerial Vehicle (UAV) – Commonly referred to as drones. Usually, ‘vehicle’ refers to a drone which has the capability of being outfitted with consumer selected payloads which may include lidar sensors.

US Coast and Geodetic Survey (USC&GS) - is the governing organization that proceeded NGS that is responsible for determining the geodetic positions (latitudes and longitudes) and elevations of monumented points throughout the United States.

US Geological Survey (USGS) - is the governing organization within the United States responsible for preparing maps of the entire country.

US Survey Foot - is the conversion factor (1200 m / 3937 ft) applied to a US conventional measurement in terms of feet to obtain the metric equivalent in terms of meter. One (1) US survey foot equals 1200/3937 meters.

Virtual Reference Station (VRS) – is a Trimble Real Time Network that is a real time positioning technique which based on the differential of GNSS signals received by two or more receivers at different locations with one being permanently fixed and integrated into a network.

APPENDIX B – SAMPLE D-428 (FIELD BOOK) ENTRIES

1. D-428 INDEX PAGE INFORMATION

D-428 (5-18)

IF FOUND PLEASE RETURN TO
PENNSYLVANIA DEPARTMENT OF TRANSPORTATION

District Executive: John Doe
Address: 55 Keystone Industrial Park
Dunmore PA 18512
Start Date: 6/23/18 End Date: 9/2/18
SR: 006 Section No: 001
Municipality: Tunkhannock County: Wyoming
District/Consultant: District 4 Survey Crew

Crew	Title
Bill Barton	Survey Supervisor
John Long	Survey Tech
Jim Saw	Survey Tech

Survey Type: Preliminary, Construction, Final, Bridge, R/W,
Other:

Contents	Page
Narrative	1
Traverse Notes	2-5
Traverse Sketch	6
Leveling Notes	7-13
References	14-20
Topo Data	20-40
R.O.W. Stakeout	41-48

Pennsylvania Coordinate System
Zone: North Zone 3701
Combined Factor: 0.999923361
Horizontal Datum: NAD 83(2011)
Established by: GNSS - RTN - VRS
Vertical Datum: NAVD 88 (GEIOD 18)
Established by: Differential Leveling - NGS Mon W57(LY1708)
Right of Way Source: Plan (4-0 Wyoming Tunkhannock 006 001
Existing Plan No.: 6001
Road Docket No.: N/A
Misc. Project Notes: Preliminary was completed for a bridge replacement.

Figure Appendix B.1

2. D-428 TRAVERSE SKETCH AND COORDINATE TABULATION

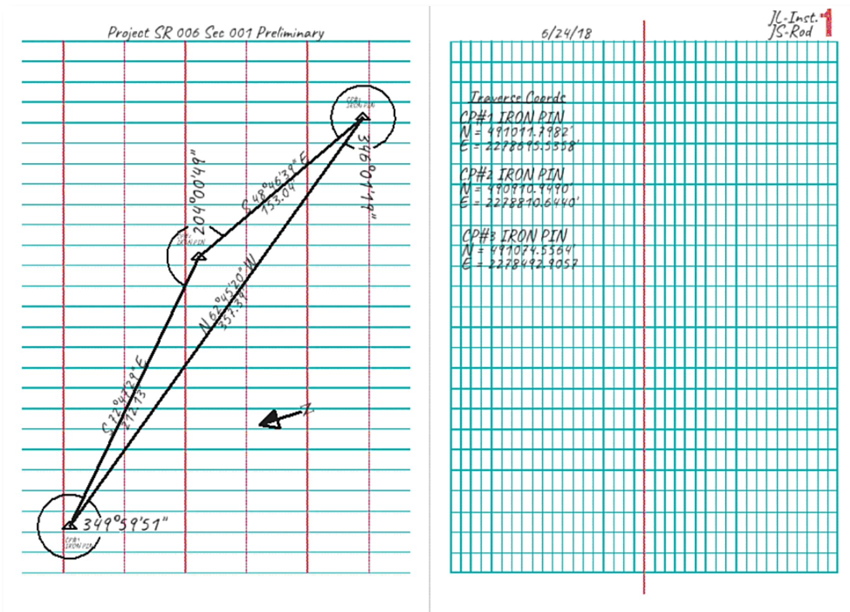


Figure Appendix B.2

3. D-428 DIFFERENTIAL LEVEL NOTE OBSERVATIONS

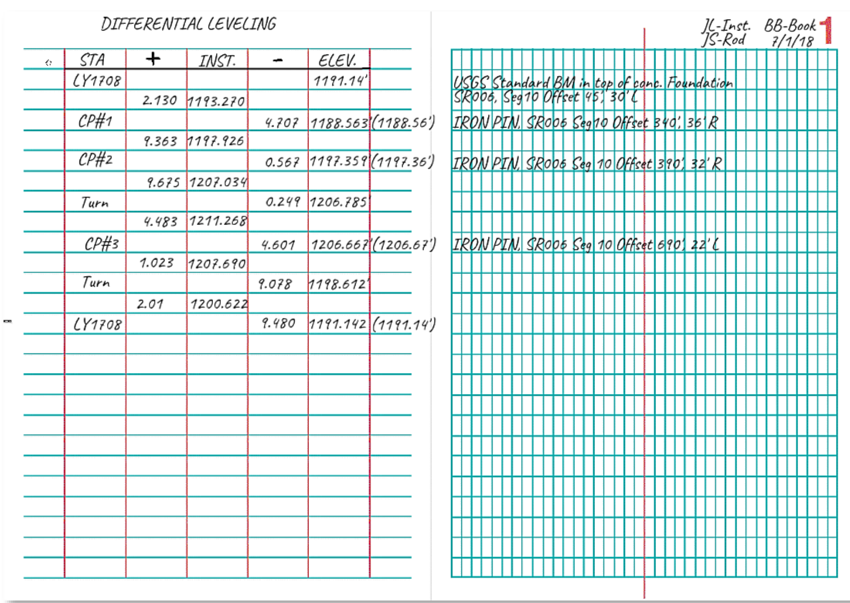


Figure Appendix B.3

4. D-428 SKETCH OF REFERENCE SET AT 90° FROM BASELINE/CENTERLINE

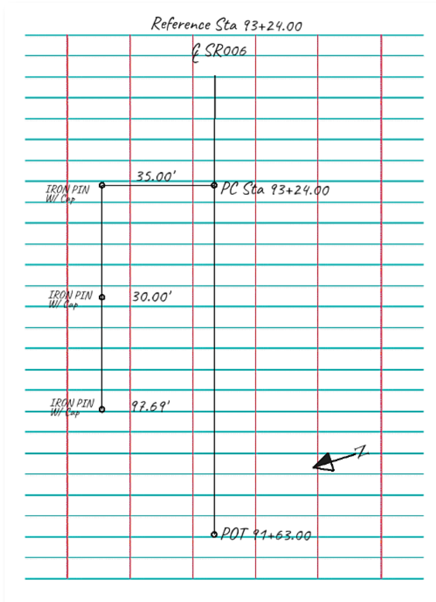


Figure Appendix B.4

5. D-428 CONTROL SWING TIE SKETCH

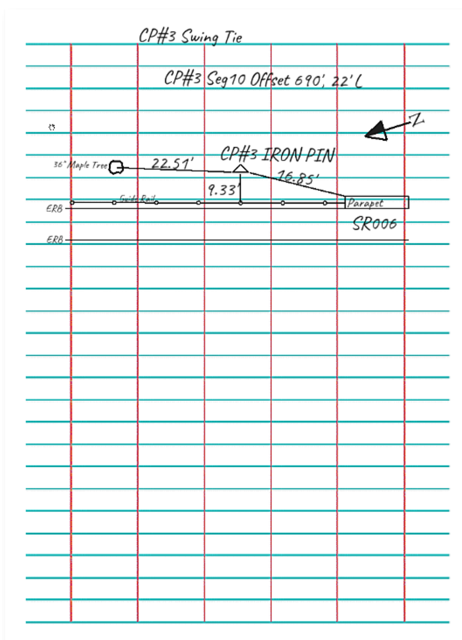
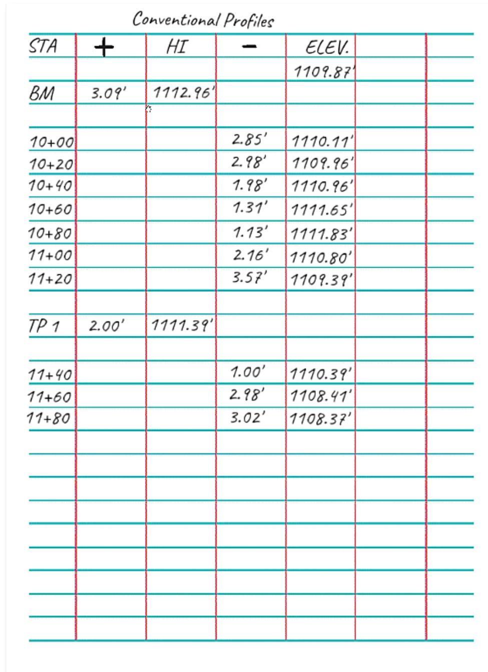


Figure Appendix B.5

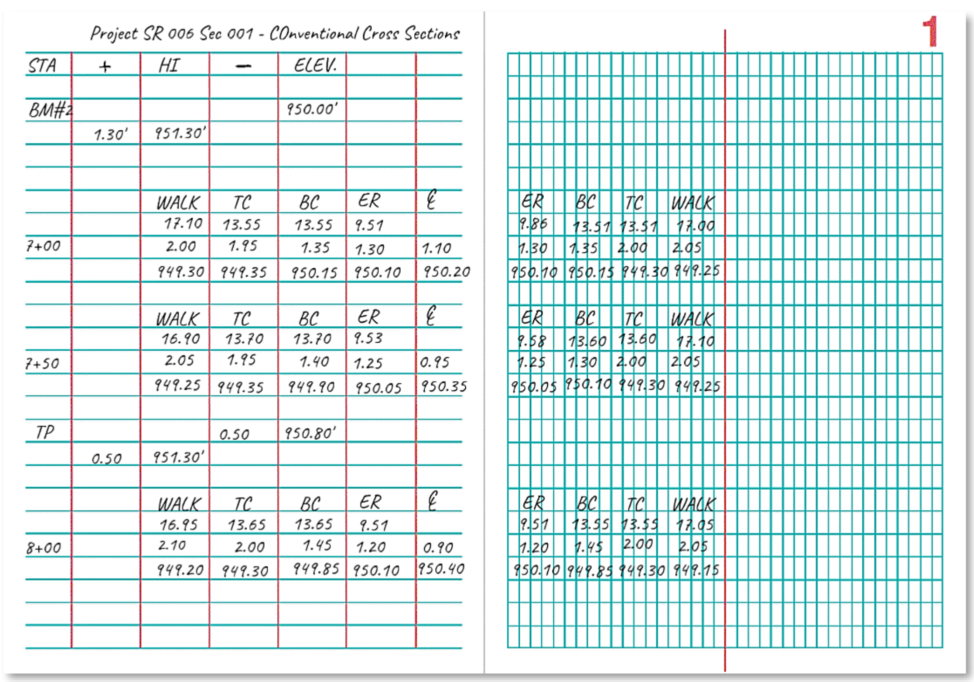
6. D-428 CONVENTIONAL PROFILE NOTES AND CONVENTIONAL CROSS-SECTIONS



Conventional Profiles

STA	+	HI	−	ELEV.
				1109.87'
BM	3.09'	1112.96'		
10+00			2.85'	1110.11'
10+20			2.98'	1109.96'
10+40			1.98'	1110.96'
10+60			1.31'	1111.65'
10+80			1.13'	1111.83'
11+00			2.16'	1110.80'
11+20			3.57'	1109.39'
TP 1	2.00'	1111.39'		
11+40			1.00'	1110.39'
11+60			2.98'	1108.41'
11+80			3.02'	1108.37'

Figure Appendix B.6.1



Project SR 006 Sec 001 - COnventional Cross Sections

STA	+	HI	−	ELEV.		
BM#2				950.00'		
	1.30'	951.30'				
		WALK	TC	BC	ER	℄
		17.10	13.55	13.55	9.51	
7+00		2.00	1.95	1.35	1.30	1.10
		949.30	949.35	950.15	950.10	950.20
		WALK	TC	BC	ER	℄
		16.90	13.70	13.70	9.53	
7+50		2.05	1.95	1.40	1.25	0.95
		949.25	949.35	949.90	950.05	950.35
TP			0.50	950.80'		
	0.50	951.30'				
		WALK	TC	BC	ER	℄
		16.95	13.65	13.65	9.51	
8+00		2.10	2.00	1.45	1.20	0.90
		949.20	949.30	949.85	950.10	950.40

ER	BC	TC	WALK
9.86	13.51	13.51	17.00
1.30	1.35	2.00	2.05
950.10	950.15	949.30	949.25
ER	BC	TC	WALK
9.58	13.60	13.60	17.10
1.25	1.30	2.00	2.05
950.05	950.10	949.30	949.25
ER	BC	TC	WALK
9.51	13.55	13.55	17.05
1.20	1.45	2.00	2.05
950.10	949.85	949.30	949.15

1

Figure Appendix B.6.2

7. D-428 EXAMPLES OF STRUCTURE STAKE-OUT SKETCHES

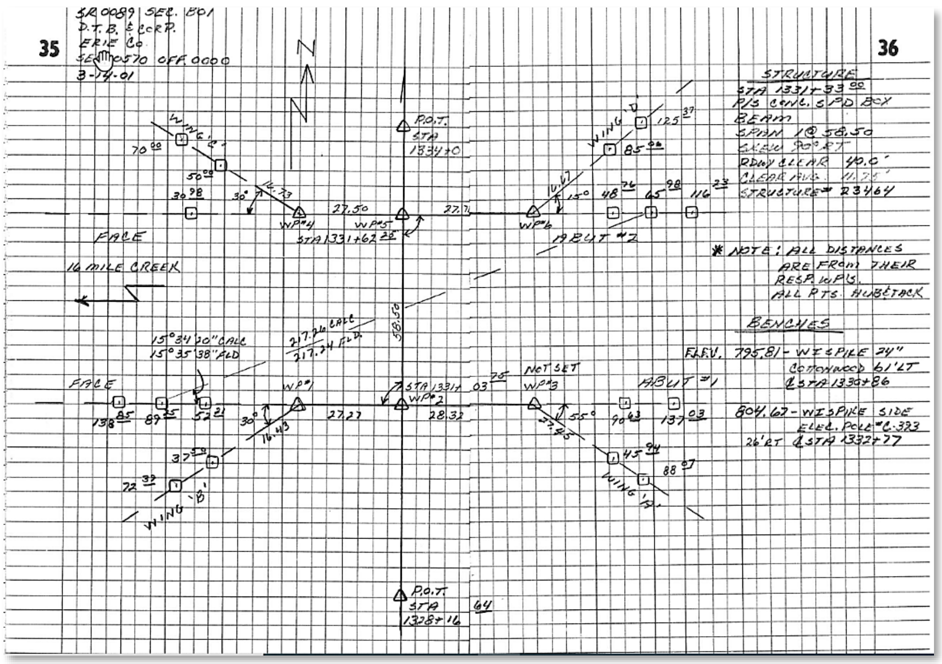


Figure Appendix B.7.1

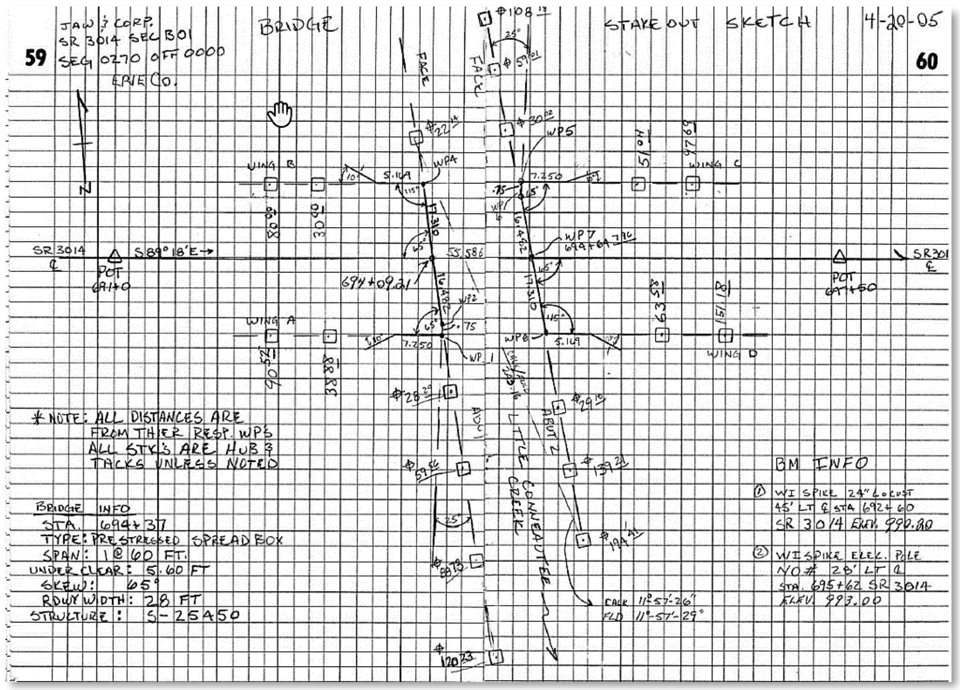


Figure Appendix B.7.2

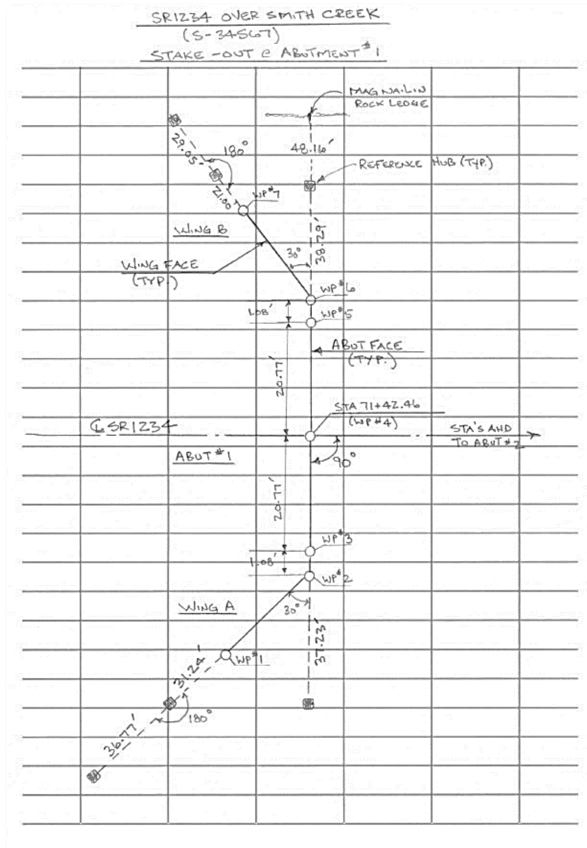


Figure Appendix B.7.3

APPENDIX C – FORMS AND GUIDES

Appendix C serves as a directory for the various forms and guides referenced throughout this publication. The list includes a thumbnail image and a link to the electronic document. References all start with C, referring to Appendix C, and then the following two numbers refer to the chapter and section that refers to the document. The last number is the document number.

DOCUMENT REFERENCE EXPLANATION

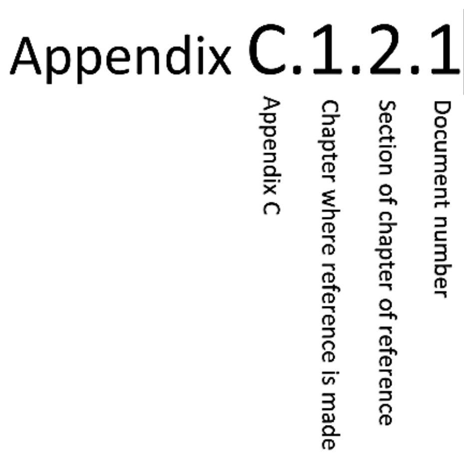


Figure Appendix C.1

DISTRICT SURVEY REQUEST

Survey Request Form

PA Department of Transportation Engineering District Enter your name here

To be completed by the Survey Unit:
Assigned Survey Corp.: Select a name here.
Start Date: Click here to enter a date.
Completion Date: Click here to enter a date.

Date: Click here to enter a date.

ECMS Number: Click here to enter job no.

Requested By: Enter your name here

Unit: Choose an item. **Type of Survey:** Choose an item.

County(ies): Choose an item., Choose an item.

Municipality(ies): Choose an item., Choose an item., Choose an item.

State Route: Enter S.R. here **Section Number:** Enter Section No. here

Beginning Segment: Enter Segment here **Beginning Offset:** Enter Offset here

Ending Segment: Enter Segment here **Ending Offset:** Enter Offset here

Description of Work Required: *(Please provide a detailed description of the survey required in the box below)*

Required File Type/Format: Enter type/format here

Intent to enter letters mailed? Choose an item. **Date:** Click here to enter a date.
Attachments;
☐ **Tax Maps** ☐ **Deeds** ☐ **FEMA Study Map** ☐ **SLD Printouts** ☐ **RMS Printouts**
☐ **NOITE Letters** ☐ **Other (Plans, Sketches, Survey Books):** Click here to enter text.

Funding Information/Payroll Charge Numbers:

Rec. Cost Ctr.:	Enter 10 digit Rec. Cost Ctr. No. here
WBS:	Enter 20 digit WBS No. here
Rec. Order:	Enter 5 digit Rec. Order No. here
Fund:	Enter 10 digit Fund Code here

Appendix C.1.2.1

Appendix C.1.2.1 is an example of a District Survey Request. Contact your District Chief of Surveys for a District specific request form or to obtain a digital copy of this form.

PHOTOGRAMMETRY (MOBILE LIDAR) REQUEST FORM

PHOTOGRAMMETRIC SERVICES REQUEST FORM

Send All Requests To:
Bureau of Construction and Materials
Photogrammetry & Surveys Section
Attn: Photogrammetry and Surveys
81 Lab Lane
Harrisburg, PA 17110
email: PSSrequest@pa.gov
Phone: 717.425.5944

Request Date:
Due Date:

Photogrammetry/Lidar Request Form

pennsylvania DEPARTMENT OF TRANSPORTATION

Please submit a separate form for each project location.
Include a KML or other digital map with the project area delineated.

PROJECT INFORMATION

County:		State Route:		Section:	
Project Name:					
Cost Center:		WBS:		Fund:	

CONTACT INFORMATION

Contact Person:		Title:		District:	
Email:		Phone:		Unit:	
Survey Chief:		Reviewed:		Date:	

AERIAL PHOTOGRAPHY REQUEST

VERTICAL
Scale:
☐ Color
☐ Color IR
OBLIQUE
☐ Color

PHOTO PRODUCTS
☐ 9"x9" Prints
☐ Enlargement
Size:
☐ Digital Files

SPECIAL REQUEST

OTHER COLLECTION METHODS
☐ Mobile Lidar Collection
☐ Aerial Lidar Collection
☐ UAS or Drone Aerial Capture *
☐ Aerial Imagery ☐ Aerial Lidar
* UAS Coordinator Approval Required

MAPPING & ORTHOPHOTOGRAPHY REQUEST

☐ Digital Mapping and/or ☐ Digital Orthophotography
MAPPING SCALE REQUIRED: ORTHO SCALE REQUIRED:

GEODETIC SURVEY REQUEST

☐ **Relative** *(meets map accuracy within the project, but may not tie accurately to adjoining / future projects)*
Examples: betterment and overlay projects
☐ **Absolute** *(meets map accuracy within the project and will tie accurately to adjoining / future projects)*
Examples: final design and corridor projects

Field Surveys to be performed by:
☐ District or ☐ Photogrammetry & Surveys Section

ADDITIONAL INFORMATION

Photogrammetry & Surveys Section Use Only:
PAMS Code: ______ **Completed on:** ______

Appendix C.1.2.2

Appendix C.1.2.2 is a Photogrammetry Request form. This form can be used in consultation with your survey chief to request photogrammetry, mobile or aerial lidar, ground penetrating radar, infrared photography, and other types of remote sensing. Please contact the Photogrammetry and Surveys Section for a digital copy of the latest request form.

STATIC LIDAR REQUEST FORM

PHOTOGRAMMETRIC SERVICES
REQUEST FORM

Send All Requests To:
Eng. Automation and Services Division
Photogrammetry & Surveys Section
Attn: Photogrammetry and Surveys
81 Lab Lane
Harrisburg, PA 17110
Email: PSSrequest@pa.gov
Phone: 717-425-5944

PHOTOGRAMMETRY & SURVEYS SECTION

Request Date:	
Due Date:	

pennsylvania
DEPARTMENT OF TRANSPORTATION

Please submit a separate form for each project and provide a location map.

County:		S.R.:		Section:	
Project Name:				Rec Order:	
Project Description:					
CCenter:		WBS:		Fund:	
District:				Contact Person:	
Phone:		Email:			
Additional Info./Special Requests					

Below This Line - Photogrammetry & Surveys Section Use Only:

STATIONS	CONTROL	RESOLUTION	OPTIONS
		☐ Low ☐ Medium ☐ High ☐ Highest Custom ☐	☐ Images ☐

Provide a sketch of the AOI:

Scan Metadata
- File name of raw data:
- Date of capture:
- Scanning system and serial #:
- Project Description:
- Weather conditions:
- Registration method:
- Registration accuracy:

PAMS Code: ____________

Spring 2016 Photogrammetric Request Form

Appendix C.1.2.3

Appendix C.1.2.3 is a Static or Terrestrial Lidar Request Form available from the Photogrammetry and Surveys Section (PSS). Your District Chief of Surveys may have a District specific form or may request scanning surveys from PSS.

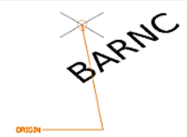
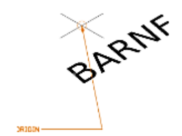
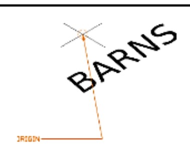
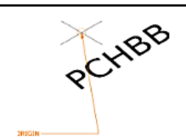
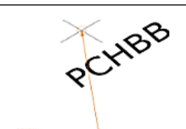
SURVEY CODES

Modeling Standards Manual
Draft Version 1.3 5/2023

6.0 Survey – Feature Codes

LEGEND

(A) ATTRIBUTE
(L) LINEAR FEATURE
(P) POINT FEATURE
(T) INCLUDED IN TERRAIN

Building Site (*V-BLDG*)			
Code/Feature Definition	**Description**	**Cell**	**Level**
BARNCB	*BARN CONCRETE BLOCK (L)(T)*		*POINT* *V-BLDG-PT* *LINEAR* *V-BLDG-BARN*
BARNF	*BARN FRAMED (L)(T)*		*POINT* *V-BLDG-PT* *LINEAR* *V-BLDG-BARN*
BARNSID	*BARN SIDING (L)(T)*		*POINT* *V-BLDG-PT* *LINEAR* *V-BLDG-BARN*
BARNBR	*BARN BRICK (L)(T)*		POINT *V-BLDG-PT* LINEAR V-BLDG-BARN
BPORBR	*BOTTOM PORCHBRICK (L)*		*POINT* *V-BLDG-PT* *LINEAR* *V-BLDG-PRCH-BOTM*
BPORBRE	*BOTTOM PORCHBRICK (L)(T)*		*POINT* *V-BLDG-PT* *LINEAR* *V-BLDG-PRCH-BOTM*

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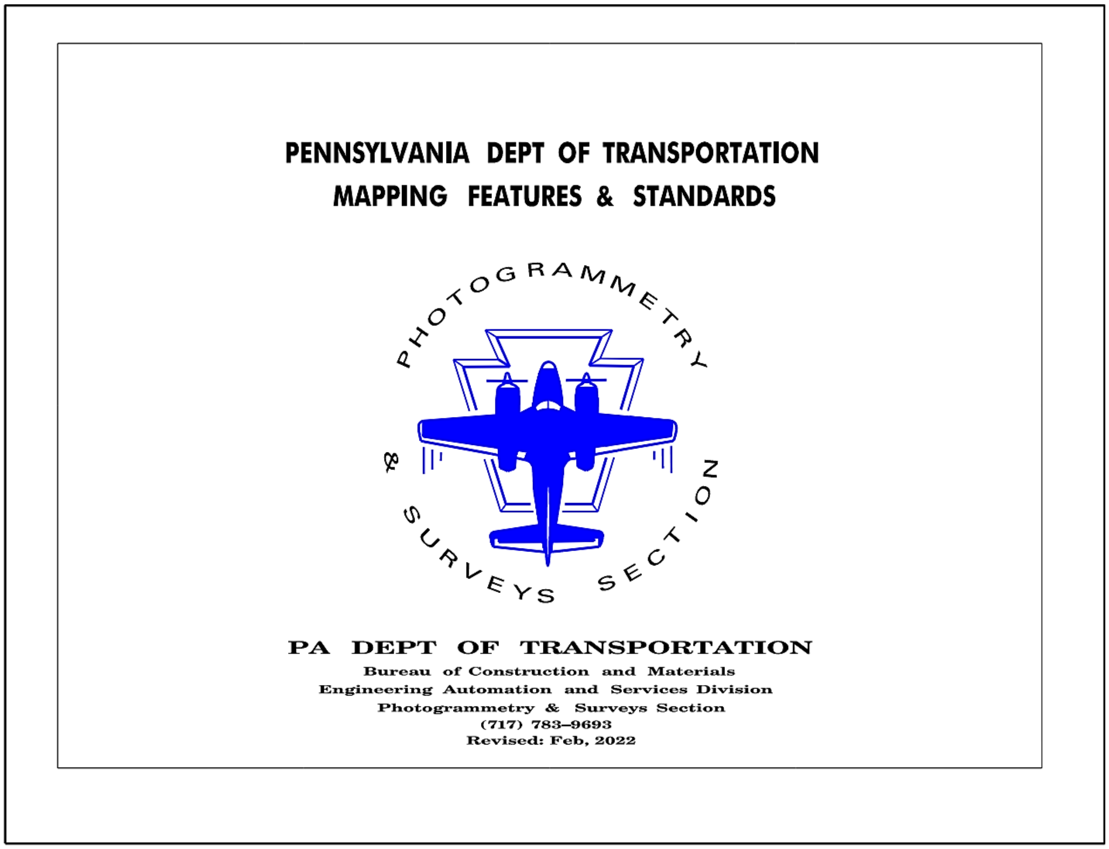
Appendix C.1.5.1

Appendix C.1.5.1 is a screen shot from the CADD Survey Codes list. Please see the Modeling Standards Manual or contact CADD services to get the full list.

PHOTOGRAMMETRY FEATURES AND STANDARDS



PENNSYLVANIA DEPT OF TRANSPORTATION
MAPPING FEATURES & STANDARDS

PHOTOGRAMMETRY & SURVEYS SECTION

PA DEPT OF TRANSPORTATION
Bureau of Construction and Materials
Engineering Automation and Services Division
Photogrammetry & Surveys Section
(717) 783-9693
Revised: Feb, 2022

Appendix C.1.6.1

Appendix C.1.6.1 is a screenshot of the cover of the Photogrammetry and Surveys Mapping Features and Standards guide. Please contact the Photogrammetry and Surveys Section to obtain a copy of this guide.

EXISTING GROUND CONFIDENCE LEVEL (ECGL) VERIFICATION AND FORM

Existing Ground Confidence Level Verification and Form

S.R. **0006-001**
County: **Bradford**
Location: SR 0660 Intersection

RMSE Elev. Type	
Base Map (FT)	0.2051
Hard Surfaces (FT)	0.0473
Other (see narrative)	

Base Map: The base mapping is conventional ground survey.

Hard Surfaces: Terrestrial (static) lidar was collected to increase density of data on the corridors of SR 0006 and 0660 (Charlston Rd).

Other: Terrestrial lidar was used to create the surface shoulder to shoulder for SR 0006 and 0660 (Charlston Rd.). It was used to supplement off corridor where possible.

Ground Survey: The survey was based on the National Spatial Reference System (NSRS). The vertical is based on the North American Vertical Datum 1988 (NAVD 88) and the horizontal based on the North American Datum - 1983 (NAD 83)(2011), Pennsylvania North Zone.

Elevation Established by: Benchmark elevations are based on NAVD88 as published by the National Geodetic Survey (NGS) and PennDOT. All project elevation were established by GPS observations and adjusted holding the elevation of NGS benchmark "B254" - PID: KY0290 fixed in the final network adjustment.

Appendix C.2.2.1

Appendix C.2.2.1 is a screenshot of the front cover of the ECGL Verification and Form. Contact the Photogrammetry and Surveys Section for a copy of the form or for help in completing it.

RECORD OF SURVEY CONTROL

APPENDIX C-3

pennsylvania
DEPARTMENT OF TRANSPORTATION

RECORD OF SURVEY CONTROL

STATION NAME:	V23-001	PROJECT SR:	0158-L10	COUNTY:	LAWRENCE

GENERAL INFORMATION

Monument Type:	IRON PIN W/ CAP	*Control Type:*	Horiz-Vert	*PAMS:*	12501
Stamping:	Penndot D-11	*Established by:*	PennDOT	*NGS PID:*	N/A
Horizontal Datum:	NAD83(2011)	*Vertical Datum:*	NAVD88	*GEOID:*	GEOID18

CONTROL TIES

Horizontal Coordinates were determined by:	GPS-Post Processing
Elevation was determined by:	GPS-Post Processing

GEODETIC COORDINATES

Latitude:	N 41°05' 15.44639"	*Meridian Convergence:*	-1°41' 30"
Longitude:	W 80°21' 26.76842"	*Projection Scale Factor:*	1.00002125
Ellipsoid Height (US FT):	1096.88	*Combined Scale Factor:*	0.99996881

PENNSYLVANIA COORDINATE SYSTEM

Northing (US survey foot):	649702.316	*Pennsylvania Coordinate Zone:*	South 3702
Easting (US survey foot):	1249803.53	*Horizontal Order Accuracy:*	1 cm
Elevation (US survey foot):	1208.433	*Vertical Order Accuracy:*	1 cm

TO REACH CONTROL POINT

From I-376 (Exit 9-Mitchell Road): Travel east on mitchell road 0.3 mi. to Glen Road; Travel northeast on Glen Road 1.1 mi. to S.R. 18; Travel north on S.R. 18 0.8 mi. to mark on right in grass island at intersection of S.R. 18 & S.R. 158.

LOCATION MAP

CLOSE-UP VIEW

HORIZON VIEW

MARK RECOVERY

Reported on:	2023-MAY-19	*Agency:*	District 11-0	*Suitable for GPS?*	Yes-High
Reported by:	JGB	*Condition:*	Good	*Recovery Notes:*	

Appendix C.4.4.1

Appendix C.4.4.1 is a screenshot of the resulting Record of Survey Control datasheet output from the PennDOT Photogrammetry Asset Management System. Contact the Photogrammetry and Surveys Section for access.

FORM S-686-AMG-1

LAND SURVEYOR'S STAMP(STAMP AFTER RECEIVING PENNDOT APPROVAL OF CONTRACT CONTROL PLAN)

PROJECT NAME:	
ECMS#	DATE:
CONTRACTOR:	
LAND SURVEYOR:	
Phone #:	

Attach the Contract Plans and Survey Control Drawings to this form

PENNDOT CONTRACT CONTROL PLAN Form S-686AMG-1

Oct-14

Complete and submit via e-mail to the Inspector in Charge for forwarding to the District Chief of Survey
Approval of this Contract Control Plan by PENNDOT does not relieve contractor of any obligations included in any other specification of this contract
All establishment or re-establishment of contract primary or secondary control shall be done in accordance with the Department's "Surveying and Mapping Manual"- Pub. 122M

1) **The contractor's surveyor shall review the Survey Control Drawings (attached), and identify all horizontal and vertical control that were <u>unrecovered</u> in the field**

- IF ALL HORIZONTAL AND VERTICAL POINTS WERE RECOVERED INTACT, CHECK HERE ◯

OR

- IF ANY POINTS WERE UNRECOVERED COMPLETE TABLE BELOW

UNRECOVERED POINTS	
HORIZONTAL	VERTICAL

The following survey control network diagrams (choosen by contractor) will illustrate the control that the contractor will use on this project

- IF PENNDOT CONTRACT PLANS DIAGRAM(S) ARE TO BE USED, CHECK HERE ◯ AND NOTE SHEET # OF ATTACHED CONTRACT PLAN DRAWINGS. OTHERWISE, ATTACH OTHER DIAGRAM(S).

PER CONTRACT PLANS		AS SHOWN ON SHEET
GPS Primary Control Diagram used	◯	Sheet:
Survey Baseline Control Diagram used:	◯	Sheet:
Survey Benchmanrk Control Used:	◯	Sheet:

2) **Existing Control**

- CONTRACTOR SHALL DETERMINE IF ANY EXISTING CONTROL IS DISTURBED OR OUT OF TOLERANCE FROM ITS ORIGINAL POSITIONING

HORIZONTAL		VERTICAL	
Points disturbed:	Points out of tolerance:	Points disturbed:	Points out of tolerance:
.	.	.	
.	.	.	

3) If all adjusted coordinates and elevations agree (within tolerence) with the Contract Plans, check here ◯

OR

- List the final adjusted coordinates and/or elevations of any control points that differ from the contract plans

- Attach the Control Survey Report documentating the contractor's survey used to check the existing control

Survey Method used to check the existing control points (check all that apply)
◯Automatic level, ◯Total station,◯GPS, ◯Tape

HORIZONTAL			VERTICAL	
Point	Northing	Easting	BM#	Elevation

4) **Is additional control to be set by the contractor for stakeout?**
◯No ◯Yes List Additional Control:____

How will additional control be established?

Survey Method (check all that apply)
◯Automatic level, ◯Total station,◯GPS, ◯Tape

5) **How will the additional control be used?**

Survey Method (check all that apply)
◯Automatic level, ◯Total station,◯GPS, ◯Tape
Note: survey stakes may be required regardless of the survey method, as ordered by Inspector in Charge

6) **Datum(s)**

Vertical Datum:___________ Horizontal Datum:__________ Combined factor:___________________

7) **CORS Network**

- Will the contractor be utilizing the NGS CORS Network? ◯Yes ◯No
- If Yes, choose GPS RTK setting below (choose one)
- Will a "site calibration" be used to "localize" the CORS to the existing control points? ◯Yes ◯No
- If Yes, attach the computations showing the hortizontal and/or vertical transformation parameters

◯Nearest (single baseline RTK)	OR	◯Network RTK (NRTK)

8) **Will the contractor utilize Automated Machine Guidance (AMG)?**
◯No ◯Yes Base Station Details:____

Approved PENNDOT: ____ Date:____________________

I, ______________________________ Inspector in Charge, have reviewed this plan and accept it.
Date:____________________

PLEASE SUBMIT WITH LAND SURVEYOR'S STAMP & SIGNATURE AFTER RECEIVING APPROVAL FROM PENNDOT

Appendix C.13.1.1

Appendix C.13.1.1 is screenshot of standard PennDOT form S-686-AMG-1 available from your District Chief of Surveys or the Photogrammetry and Surveys Section.

FORM S-686-AMG-2

Grade Verification Report (S-686-AMG-2)				
ECMS #				
State Route No.				
Section				
Equipment Used				
Date	**Station**	**Offset**	**Plan Grade Elevation**	**Field Verified Elevation**
Department Representative:		**Contractor Representative:**		
Name				

Appendix C.13.1.2

Appendix C.13.1.2 is screenshot of standard PennDOT form S-686-AMG-2 available from your District Survey Chief or the Photogrammetry and Surveys Section.

FORM D-413 GRADING SHEET

GRADE SHEET

PENNDOT

STATE PROJECT						
SYS	SR	SUB PROJECT	PHA	SECTION	DIST	CO

Page ______ Of ______
County ___________________________
Route, Sec________________________
Seg, Off__________________________
Twp, Boro, City____________________

Station	Elevation of Top of Stake	Elevation of Finished Grade at Center Line	Top of Stake to Finished Grade		Distance from Stake to Center Line of Proposed Roadway	
			Cut	Fill	Left Stake	Right Stake

Prepared By ___________________________

Checked By __________________________

FORM D-413 REV 12-01

Appendix C.13.4.1

Appendix C.13.4.1 is screenshot of standard PennDOT form D-413 Grading Sheet available from your District Survey Chief.

APPENDIX D – QUALITY ASSURANCE/QUALITY CONTROL PLAN FOR DEVELOPMENT OF RIGHT-OF-WAY AND CONSTRUCTION PLANS

PROCEDURES AND GUIDELINES

PRE-SURVEY ACTIVITIES

— Review project scope of work.

— Obtain tax map details from County Tax Office.

— Research all deeds of properties that adjoin proposed survey area and obtain all called for recorded retracement or subdivision plats.

— Research all turnbacks, abandonments, local roads, railroads, and Highway Occupancy Permits.

— If necessary, contact licensed Pennsylvania Professional Land Surveyor who conducted adjoining property surveys and acquire plats or plans of survey.

— Obtain all previous right-of-way records and/or plans such as right-of-way, as-built, and road dockets, etc.

— Obtain any previous PennDOT or PDH survey books.

— Obtain existing horizontal and vertical control data within project area.

FIELD SURVEY ACTIVITIES

— Field view project site.

— Establish horizontal and vertical control on the project site in accordance with PennDOT Publication 122, Surveying and Mapping Manual.

— In the field, establish legal right-of-way baseline/centerline using reference ties and old geometry from right-of-way plans and/or survey books. Use valid recorded alignment stationing for longitudinal stationing. Use RMS Segment and Offset if as-built plans do not exist.

— Correct legal right-of-way baseline/centerline must be established if alignment of record exists. Re-established alignment must conform to reference ties. There is an obligation to use old, existing, preliminary reference ties in absence of <u>superior</u> evidence.

— If as-built alignment were monumented, the monuments could define alignment in a location other than centerline of pavement. Consideration must be given to the typical sections on as-built plans that may show the relationship of baselines to what was built or widened on only one side of the roadway.

— If as-built alignment was not monumented but contains preliminary or swing ties, alignment must be established that will conform to all existing evidence (e.g., topographical, extrinsic evidence, property pins, if confirmed).

— If, and only when no other evidence exists (such as recorded instruments or field evidence), then centerline of existing roadway (beaten path) may be used, even when creating first time geometry.

— Established legal right-of-way baseline and/or centerline shall be tied geometrically (by field angles and distances) to survey baselines and traverses.

- Any alignment produced must be developed to conform to the correct legal right-of-way alignment, if extended to major control points beyond the limits of authorization. Any alignment, either inside or outside areas of authorization, must be developed to conform to legal right-of-way both longitudinal and transversely.
- Permanent alignment references shall conform to PennDOT Publication 122, Surveying and Mapping Manual.
- By state law, when using the Pennsylvania State Plane Coordinate System, the North American Datum of 1983 (NAD 83) will be used. It is strongly recommended to note the Combined Factor used when using State Plane Coordinates.
- By Department policy, the vertical datum to be used for benchmark elevations will be the North American Vertical Datum of 1988 (NAVD 88). It is strongly recommended that all benchmark elevations be established by differential leveling, with such notes entered in Form D-428 (survey field book) along with detailed to-find descriptions, such as ties to segment and offsets. Other methods to establish benchmark elevations and any decision to use the superseded National Geodetic Vertical Datum of 1929 (NGVD 29) will only be done with the concurrence of the District Chief of Surveys.
- Assumed or arbitrary horizontal and vertical datum shall not be used without prior approval of the District Chief of Surveys. All assumed coordinate and vertical data shall be on the same base datum (e.g., bridge and roadway).
- Topography - detailed description to include utility names and pole ID numbers, signs (type and description), guide rail (types and end treatment), drainage (size and types), existing property corners and physical lines of property possession, permanent buildings (including type of structure), all permanent improvements constructed by the occupier of the property.
- Field verification of vertical accuracy shall be accomplished by obtaining ’check’ observations of previously established benchmarks and/or traverse or mapping control points at each instrument set-up during topographic data collection. To uncover blunders, conventional cross-sections or check profiles may be run if any errors are found in the DTM produced.
- NGS (previously USC & GS), USGS, PennDOT/PDH monuments - locate/describe existing monuments. If monument(s) will be affected, contact appropriate NGS/USGS and/or District Chief of Surveys and reference in accordance with appropriate agency policies.
- Request for Survey Data, see Appendix C.1.2.1
- All field notes shall be recorded legibly in Form D-428.

FINAL DESIGN ACTIVITIES

- Right-of-Way breaks on property lines should be avoided. If required to be on property lines, the property line or lines must be confirmed by field survey.
- Referencing required right-of-way lines to spiraled roadway alignments shall be avoided. Right-of-Way lines shall not be developed that are concentric and parallel to spiral geometry. Survey and right-of-way alignments with simple curves and tangents shall be used.
- GNSS requirements should be confirmed by reviewing with District Chief of Surveys. GNSS activity shall comply with this manual.
- Plan references and ties must exist to permit the re-establishment of the legal right-of-way alignment.
- A licensed Pennsylvania Professional Land Surveyor shall direct the deed plotting and compilation process. Existing property lines and corners located by the field survey shall be given careful consideration during this process.

- All found property line monumentation is recommended to be tied to the right-of-way baseline/centerline alignment by station and offset.
- Review right-of-way lines with the Pennsylvania Professional Land Surveyor in charge of the project.
- Review control references and right-of-way line break point monumentation with District Chief of Surveys.
- Check validity and accuracy of coordinate tables for roadway controls and bridge stake out work points.
- When Pennsylvania State Plane Coordinates are used, the combined factor shall be noted in the general notes and in the project coordinate tabulations. If a combined factor was not used, explicitly note that information.
- All alignments shall be established at 50 feet intervals or at major control points, referenced with permanent monuments and recorded in Form D-428 as per Chapter 13.3 in this manual.
- All intersecting alignments shall be geometrically tied to mainline; station and skew angle shall be noted, "On curves, skew angle shall be tangent to curve."
- Reference vertical control with permanent benchmarks outside areas of construction by differential leveling. Minimum spacing for project benchmarks will not exceed 1,000 feet. There must be a minimum of two benchmarks per project. Enter with detailed descriptions tied to segment and offset in Form D-428 (field book). See Chapter 5.4 of this manual for specifics.
- Review status of any existing affected associated right-of-way plans (e.g., dedications, donations, viewers' plans, vacations, abandonments, navigable streams, etc.).

FIELD SURVEY INFORMATION REQUIRED FOR STRUCTURES

- Collect enough topographic data to create a DTM in the area affected by the structure (the structure may be raised, and approaches may be adjusted). Pay particular attention to modeling the stream bed capturing the thalweg, all significant changes in slope, scour holes, gravel bars and debris piles. Under certain circumstances a conventional stream baseline, stream cross-sections, and stream profile may be utilized in lieu of a DTM. Consult the District Chief of Surveys for concurrence.
- Data for areas outside of the DTM where hydraulic cross-sections are needed can be collected by total station or by GNSS RTK observations. The observed points must be established such that they can be used to construct a cross-section that is perpendicular to stream flow and the direction of flow in the floodplain (perpendicular to contour lines). Where the channel meanders through a floodplain, broken or dog-leg sections may be necessary. All subsections of a cross-section so created should be straight lines. Cross-sections should not overlap. More points should be surveyed in the channel than in the floodplain. The points surveyed comprising a cross-section should be so noted in the survey field book (D-428).
- If using conventional procedures, orient baselines along a stream with stations increasing downstream and making Station 10+00 approximately the center of the bridge. Locate the channel from the baseline so that the alignment of the stream is obtained.
- Obtain pier dimensions and shape so that the amount of obstruction within the stream can be determined.
- Obtain elevations of the bottom of beams at each contact with substructure members (needed for both fascia beams). More points may be needed if irregular, (e.g., Arch).
- Obtain sufficient elevations along the profile of the channel (elevation spacing to be no more than 50 feet apart) so that an average slope may be determined.

- Full cross-sections shall be obtained for hydraulic sections and will be located perpendicular to stream flow. If a baseline is utilized for data capture, the baseline angle shall be shown. See Figure Appendix D.1.1.
  - Minimum 500 feet upstream and 500 feet downstream
  - At each face of structure an elevation of the bottom of beam will be obtained, a top of roadway for each point along the ground will also be obtained corresponding to the bottom beam locations.
- Locate the toe of a wingwall or any break point near the structure that shows a change from the mainstream section to the face of structure section.
- Locate and record any site where another stream joins the mainstream channel (one immediately downstream; one immediately upstream from the tributary intersection). Refer to Survey Request for specifics of how much of the joining stream must be located.
- Locate any change in typical section such as a narrowing of channel, change of slope, etc.
- When possible, extend DTM or cross-sections to elevations approximately 10 feet above the deck.
- Stream cross-sections shall be at 90° to stream flow except for sections at a face of structure. Sections at a face of structure and at ends of wingwalls must be parallel to the centerline of road.
- Note elevations of located physical features such as edge of road, edge of stream, wingwalls, woods, etc.
- Note type of ground cover and changes in ground cover on hydraulic cross-sections such as dense brush, woods, lawn, goldenrod, and weed field, etc.
- At bends in a stream outside of DTM, take one cross-section just above bend and one just below bend.
- Always take one hydraulic cross-section located one span length upstream from upstream bridge opening. This cross-section is required to perform scour estimates for a proposed structure.
- If a multi-span bridge, the upstream cross-section should be located upstream the total of span lengths. For example: two spans @ 60 feet each, locate upstream cross-sections 120 feet above bridge site.

PURPOSE OF HYDRAULIC SURVEY

The quantity of water that will flow through a channel area is calculated based upon the historical volume (in inches) of rain falling in a specified time period and the frequency (in years) of occurrences. The rate combined with the total drainage area allows the amount of water that will flow through the channel and under/over the bridge to be calculated.

The slope of the channel is critical since this will help determine the velocity of the flow of water. The steeper the slope, the faster the water flows, allowing more water to flow through a channel section. This illustrates why we need the various sections. We do not want to raise water elevations when comparing existing and proposed bridges. The four cross-sections at the bridge, the profile of the road, and pier shapes and sizes are needed to determine the effects a bridge has on the stream flow and water elevations.

This information is entered into a computer model so that water surface elevations for different storm frequencies can be computed. Bridges are typically designed for a 50-year storm, a storm that occurs once every 50 years. The Department's goal is to provide a new structure with a low chord elevation two feet higher than the design storm elevation, or one foot higher than the 100-year risk assessment storm, whenever possible.

The information needed for the stream survey is just like that required for a road survey. Any change in alignment, size, shape, slope, or any obstruction that will impede the flow of water or that may change the water course or elevation must be recorded.

SURVEY BOOK AND FIELD NOTE FORMAT (FORM D-428)

- All field survey books should use a format and index consistent with Form D-428.
- Index should include all separate activities performed (e.g., alignment, control points, traverse and closure, benchmark level runs, segment/offset reference to project station, basis of bearing, and reference or ties to re-establish line).
- Contents should include sketches for all alignments, sketches for preliminary ties, coordinates for control points and sketches of control traverses/baselines and/or GNSS networks.
- Recorded documentation should include sufficient data to establish all project horizontal and vertical control easily and accurately.
- Establish control points in the field, occupy, record angles, and determine equalities where necessary, including references. 'Paper Points' are not acceptable.
- Page one should contain the surveyor's report, list major items encountered during the survey (e.g., plans used, horizontal and vertical datums, combined factor, existing controls held to produce alignments/traverses, property corners or monuments used, bearing datum, State Plane or arbitrary coordinates, RMS stations and conversion to segment and offsets, and other pertinent information). This information may be of assistance to designers or surveyors during project site visits.
- All D-428 information will conform to the guidelines set forth in this manual.
- Survey data obtained from an electronic data collector's file(s) shall be referenced in the survey field books and the electronic data file(s) will be considered a part of the survey field book and will be delivered with the survey field book.

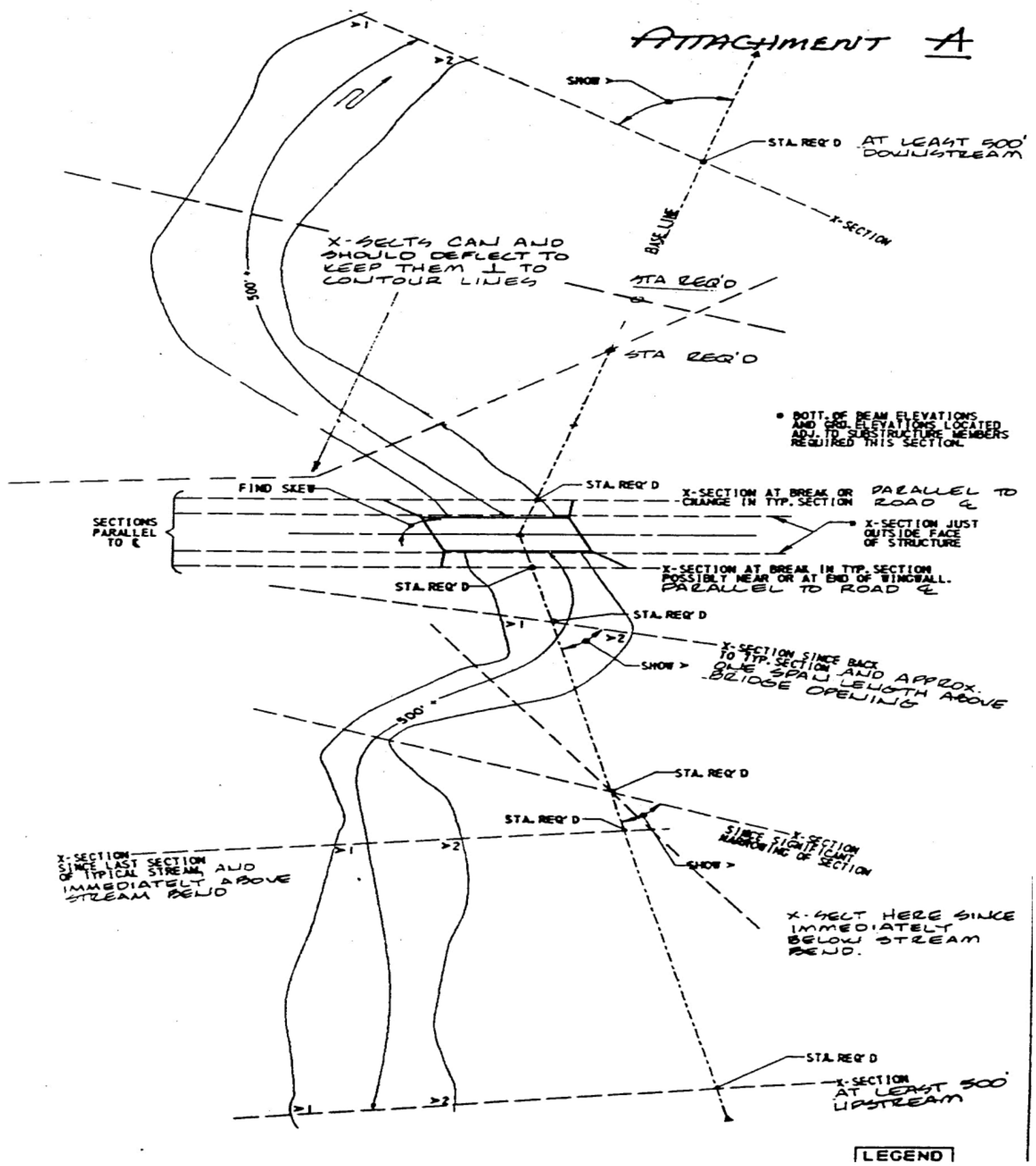


Figure Appendix D.1.1

APPENDIX E – SAMPLE MAPPING CONTROL SURVEY REPORT AND EXISTING GROUND MODEL REPORT

The following is a sample survey report for Department projects. This report contains data from different projects and is not intended to be read as a whole. It is intended to serve as an outline for content. Sections may be included or removed as each project warrants.

The first 7 sections focus on a mapping control project for photogrammetry. This would be typical of a control report for any type of map or model. It is critical to report on all activities related to the ground control survey so that as issues arise throughout the project, the report can be used to reconstruct the original control survey. All supplemental surveys such as right-of-way or utility surveys should be based on this original control and a thorough report will save effort in those phases. Future projects may tie into or overlap past projects and again a thorough report will save effort.

It is usually necessary to share this mapping control report as an interim report as it will be useful as the mapping project progresses. Any map test data will be withheld in this preliminary report so that it is not shared with individuals involved in the development of the existing ground model.

Finally, existing ground (EG) models intended for design projects shall have a section in the final report. Regardless of the technology employed, at a minimum, the report should include…

1. What technologies were used to build the EG.
    a. A narrative and possibly maps indicating what technologies were used and where within the model they were used.
2. How the various DTMs were combined to create the complex terrain
    a. A narrative describing how the various models from different sources were combined into a single existing ground model along with any special challenges.
3. An Existing Ground Confidence Level Assessment
    a. See Chapter 2.2 for more information. This is either map testing results or a statement saying the model was produced to meet a particular map accuracy (more mature processes with well-established expectations).
4. The location of and names of the actual models to be used.

Each project will of course vary. However, the following report contains data that should be found in a Map Control Report and an Existing Ground Terrain Model Report

PennDOT Photogrammetry & Surveys Section

PRIMARY & MAPPING CONTROL SURVEY REPORT

Contents

Sample Survey Report

INTRODUCTION

The Pennsylvania Department of Transportation (PennDOT) performed a mapping control survey in Delaware County along State Route 0476 for Aerial mapping. The project is for pavement preservation and shoulder widening. All field work was done by PennDOT District 6-0 survey field crews with assistance from the survey technicians in the Photogrammetry and Surveys Section. Data reduction, processing, adjustments, and office computations were done by P&S Survey Technicians and Geodetic Surveys Manager. The mapping control was intended to support consultant aerial photographic acquisition and in-house extraction, compilation, and mapping along the state route. The map below shows the location of the project.

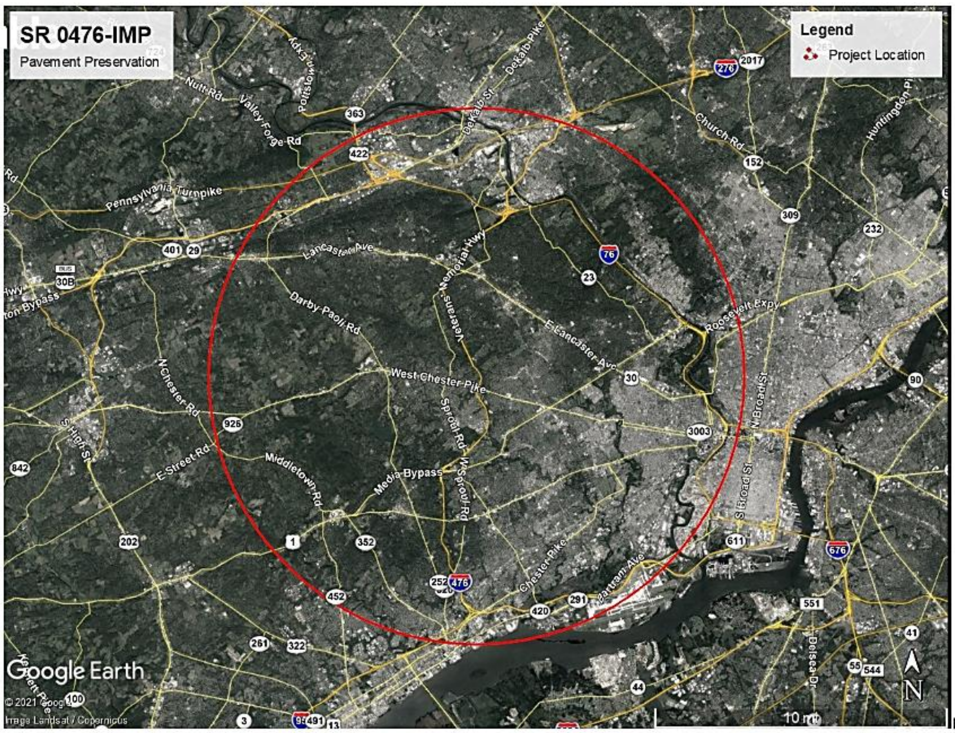


Figure 1 - Project Location

Project Survey Control is referenced to the National Spatial Reference System (NSRS):

Horizontal datum for this project is North American Datum of 1983 [NAD83 (2011)]
Pennsylvania Coordinate System South Zone (3702)
Vertical datum is North American Vertical Datum of 1988 [NAVD88]
Geoid model [GEOID18] was used for the determination of Orthometric Heights

Sample Survey Report

RECONNAISANCE

Existing Survey Control Stations					
Description (TBC Prefix)	**Points**	**Designation**			
KeyNet VRS Base Stations (CK)	3	FTML			
		HKG2			
		VU01			
NGS Control Stations (CN)	5	G 270			
		J 270			
		K 1			
		P 270			
		WESTGATE			
NGS Control Stations (CN) **NOT USED IN SURVEY**	10	227.15 LM TWP			
		E 270			
		F 270			
		L 270			
		PDH			
		Q 270			
		S 270			
		U 270			
		X 369			
		Y 270			
PennDOT Control Stations (CP)	31	BAW 101	BM CIH 1	F105	R21-010
		BAW 109	BM CIH 2	F106	
		BAW 111	F19-002	F107	
		BAW 112	F19-003	F108	
		BAW 113	F098	F109	
		BAW 114	F100	F110	
		BAW 115	F101	F112	
		BAW 118	F102	F113	
		BAW 119	F103	F114	
		BAW 121	F104	F115	
PennDOT Control Stations (CP) **NOT USED IN SURVEY**	4	BAW 105			
		BAW 107			
		BAW 108			
		NUBO-3			

Table 1 – Existing Survey Control Stations

Sample Survey Report

Point Identification				Datum / Accuracy			
				Horizontal		Vertical	
Station Designation	PAMS Code	NGS PID	Comments	Datum	Orde r	Datu m	Order, Class
CK_FTML	9393	N/A	KeyNetGPS VRS Base Station	NAD83 (2011)	CORS	NAVD8 8	Ellip Only
CK_HKG2	9320	N/A	KeyNetGPS VRS Base Station	NAD83 (2011)	CORS	NAVD8 8	Ellip Only
CK_VU01	9321	N/A	KeyNetGPS VRS Base Station	NAD83 (2011)	CORS	NAVD8 8	Ellip Only
G 270	1105	JU085 1	NGS IDB Benchmark	NAD83 (2011)	50cm	NAVD8 8	Second, 0
J 270	1106	JU084 6	NGS IDB Benchmark	NAD83 (2011)	Scale d	NAVD8 8	Second, 1
K 1	1198	KV184 0	NGS IDB Benchmark	NAD83 (2011)	2cm	NAVD8 8	First, 1
P 270	1107	KV190 7	NGS IDB Benchmark	NAD83 (1986)	Scale d	NAVD8 8	Second, 1
WESTGATE	N/A	JU084 3	NGS IDB Benchmark	NAD83 (2011)	1m	NAVD8 8	Second, 0
227.15 LM TWP	977	KV190 1	NGS IDB Benchmark	NAD83 (1986)	Scale d	NAVD8 8	Second, 0
E 270	1104	JU081 4	NGS IDB Benchmark	NAD83 (1986)	Scale d	NAVD8 8	Posted BM Ht
F 270	1114	JU085 3	NGS IDB Benchmark	NAD83 (1986)	Scale d	NAVD8 8	Second, 1
L 270	N/A	JU084 0	NGS IDB Benchmark	NAD83 (1986)	Scale d	NAVD8 8	Second, 0
PDH	7122	KV190 5	NGS IDB Benchmark	NAD83 (1986)	Scale d	NAVD8 8	Second, 0
Q 270	N/A	JU084 5	NGS IDB Benchmark	NAD83 (1986)	Scale d	NAVD8 8	Second, 0
S 270	1108	KV190 6	NGS IDB Benchmark	NAD83 (2011)	Scale d	NAVD8 8	Second, 1
U 270	7652	KV190 3	NGS IDB Benchmark	NAD83 (1986)	Scale d	NAVD8 8	Second, 1
X 369	5583	JU221 6	NGS IDB Benchmark	NAD83 (2011)	Scale d	NAVD8 8	First, 1
Y 270	8472	KV183 9	NGS IDB Benchmark	NAD83 (2011)	10cm	NAVD8 8	First, 1
BAW 101	8475	N/A	PennDOT Benchmark	NAD83 (2011)	5ft	NAVD8 8	Third
BAW 109	7732	N/A	PennDOT Benchmark	NAD83 (2011)	1m	NAVD8 8	Third

Table 2 – PAMS codes in RED to be updated on PennDOT PAMS website. Stations in GREEN are recon only stations not used in survey

Sample Survey Report

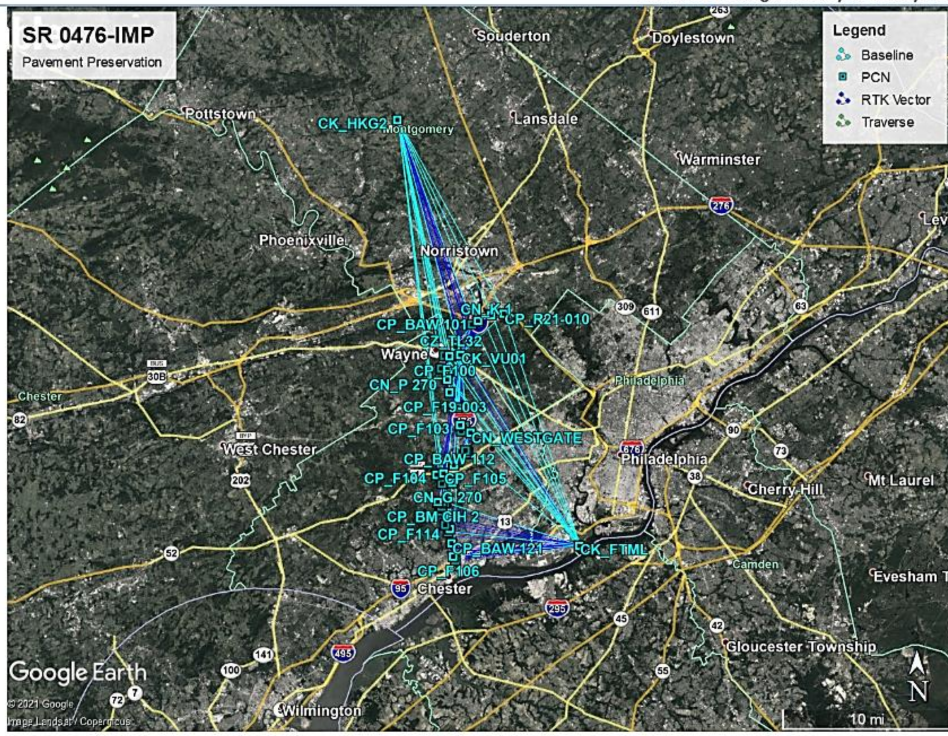


Figure 2 – Existing Control Location [Horizontal- Yellow squares, Vertical- Blue with white diamonds]

New Survey Control Stations		
Description (TBC Prefix)	**Points**	**Designation**
Traverse Points (CZ)	16	GPS-X
Mapping Control Stations (H)	61	H21-04-XXX
Map Test Points (MT)	10	MT21-04-XX

Table 3 – New Survey Control Stations

Sample Survey Report

PennDOT Photogrammetry & Surveys Section

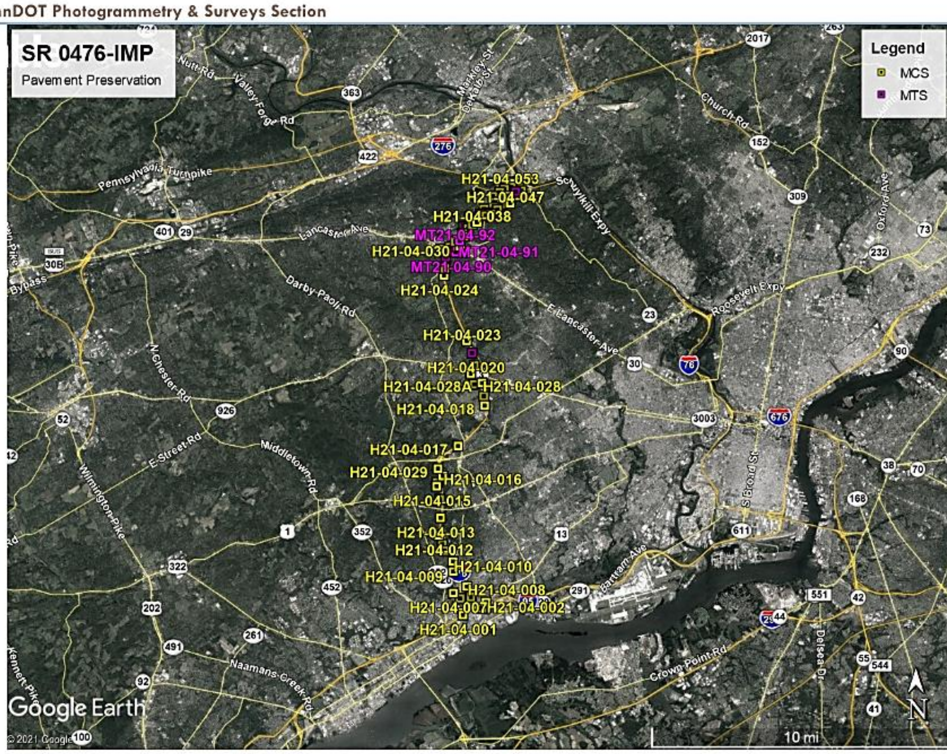


Figure 3 – New Control Location [LiDAR- Red (N/A), Map Test- Purple, Traverse Points- Green, Mapping Control- Yellow]

Page 6

Sample Survey Report

FIELD METHODOLOGIES

District 6-0 Survey Crews performed a Primary Control Network (PCN), Mapping Control Survey (MCS) and Map Test Survey (MTS) by observing aerial mapping control targets and photo identifiable (ID) features with GPS/ VRS and storing vectors and utilizing total station to make conventional observations. All available static, VRS, and terrestrial observations were processed individually then loaded into one large TBC file for adjustment.

Static GPS Survey

GPS static data was downloaded from KeyNet and brought TBC to adjust all static observations with vectors from the PennDOT CORS network. The coordinates from the adjusted static observations were added to TBC and set as control.

RTK/ VRS Survey

Trimble R8s antennas were used while logged into the KeyNet VRS survey network and Topcon Hiper V antennas were also used in a base/rover method. Each station was occupied a minimum of 2 times. Each occupation was observed for a minimum of 300 epochs (approximately 5 minutes). This information was downloaded into Trimble Business Center (TBC) 5.60for processing. All vectors were computed from the KeyNet VRS Base Stations **FTML, HKG2 and VU01**.

Terrestrial Observations

A Trimble V Series total station was used with Trimble TSC3 Survey Controller for terrestrial observations to establish coordinates from eccentric points where actual station locations could not be initialized using VRS. The following points were gathered using this method xxxx – xxxx.

Leveling

Leveling was performed to carry an elevation from NGS benchmark Y 270 however the benchmark was ultimately disabled and not used in the project because there were errors in the supplemental total station observations which created numerous errors in TBC when attempting to compute network adjustments.

Sample Survey Report

LEAST SQUARES ADJUSTMENTS

Final Horizontal & Vertical Adjustment

Adjustment was then performed with the KeyNetGPS VRS Base Station, **VU01,** held fixed 2D and held **F19-002** fixed in the Elevation Component. This adjustment passed the chi square test with a reference network factor of 1.02 and 1160 degrees of freedom. This Final adjustment fixes one KeyNet VRS Base Station in the Horizontal component and a PennDOT benchmark with 3cm accuracy in the Vertical Order in the Elevation component. The Horizontal control checks within an average of +/- 0.076' with one standard deviation of 0.036'. The Vertical control checks within an absolute average of +/- 0.051' with one standard deviation of 0.036'.

NETWORK ADJUSTMENT STATISTICS

Number of Iterations for Successful Adjustment:	3
Network Reference Factor:	1.02
Chi Square Test (95%):	Passed
Precision Confidence Level:	95%
Degrees of Freedom:	1160

Post Processed Vector Statistics

Reference Factor:	1.07
Redundancy Number:	161.17
A Priori Scalar:	1.23

RTK Vector Statistics

Reference Factor:	1.01
Redundancy Number:	998.06
A Priori Scalar:	1.66

Total Station Observation Statistics

Horizontal Circle Reading:	**Reference Factor:**	1.00	**Redundancy Number:**	0.00	**A Priori Scalar:**	1.00
Vertical Angle:	**Reference Factor:**	0.17	**Redundancy Number:**	0.20	**A Priori Scalar:**	1.00
Slope Distance:	**Reference Factor:**	2.20	**Redundancy Number:**	0.57	**A Priori Scalar:**	1.00

Set-Up Errors

GNSS

Error in Height of Antenna:	0.005 sft
Centering Error:	0.005 sft

Table 4 – TBC Ver. 5.60 Network Adjustment Statistics

Sample Survey Report

SUMMARY

Primary Control and Mapping Control Networks were established using GPS/ VRS and Terrestrial Observations in support of mapping of a section of SR0476. The estimated accuracy of the new stations with respect to the NAD83 (2011) datum is ±0.05 ft. and NAVD88 datum is ±0.10 ft. The network was constrained to one KeyNet VRS Base Stations horizontally and a PennDOT benchmark with 3cm accuracy vertically.

One level loop was performed for the project, but due to associated errors, the data was not used.

PROJECT GRID COORDINATES AND ELEVATIONS

Primary Control Network Results

H21-04_D6-0476-IMP		Primary Control Network (PCN)	
Project file data		**Coordinate System**	
Project Name:	Pavement Preservation	**Name:**	United States/State Plane 1983
County:	Delaware	**Datum:**	NAD83 (2011)
Modified:	6/7/2021 1:08:21 PM (UTC:-4)	**Zone:**	Pennsylvania South 3702
Control Type:	Primary Control Network (PCN)	**Geoid:**	GEOID18 (Conus)
Reference number:	PAMS Code 4807A	**Vertical datum:**	NAVD88
Surveyed by:	District 6 Survey Crew & PSS	**Prepared by:**	Robert Bradbury, PLS & Phillip Hendrickson, Photo Tech II
Comment 1:	KeyNetGPS survey of Primary, Mapping, and Map Test Controls		
Comment 2:	TBC Final Adjustment fixed KeyNET CORS V0U1 in Horizontal and F19-002 in Vertical		
Comment 3:	Leveling performed on published controls to establish vertical coordinates for eccentric points		

Point List

ID	Northing (US survey foot)	Easting (US survey foot)	Elevation (US survey foot)	Feature Code	Projection Scale Factor	Combined Scale Factor	Meridian convergence angle
CK_FTML	207942.8894	2681169.1924	44.5080	PCN	1.0000094560	1.0000124934	1°38'51"
CK_HKG2	337983.5566	2621072.7849	296.9520	PCN	0.9999663921	0.9999575669	1°31'00"
CK_VU01	265862.9663	2642646.0224	507.5010	PCN	0.9999852931	0.9999662508	1°33'44"
CN_G 270	226384.4378	2641203.2856	298.4410	PCN	1.0000005708	0.9999914795	1°33'23"
CN_J 270	235542.7689	2645651.5625	160.8590	PCN	0.9999967584	0.9999942514	1°34'02"
CN_K 1	278452.4036	2651868.9235	57.2350	PCN	0.9999812394	0.9999837456	1°35'04"
CN_P 270	258181.0533	2638780.3773	273.8640	PCN	0.9999879542	0.9999800721	1°33'10"
CN_WESTGATE	241987.8914	2646456.8446	305.8770	PCN	0.9999941614	0.9999847253	1°34'10"
CP_BAW 101	276528.1770	2647836.3112	124.3410	PCN	0.9999818135	0.9999811100	1°34'30"
CP_BAW 109	243823.4411	2644592.4719	196.9230	PCN	0.9999934163	0.9999891922	1°33'55"

Sample Survey Report

CP_BAW 111	232941.1823	2642757.1890	314.2800	PCN	0.9999978039	0.9999879591	1°33'38"
CP_BAW 112	231889.2077	2641580.0942	329.8100	PCN	0.9999982308	0.9999876427	1°33'28"
CP_BAW 113	225984.1050	2638048.9923	211.0910	PCN	1.0000007069	0.9999957927	1°32'57"
CP_BAW 114	218924.4174	2638154.7709	195.9010	PCN	1.0000038203	0.9999996295	1°32'56"
CP_BAW 115	217403.1571	2637657.9075	191.0030	PCN	1.0000044997	1.0000005427	1°32'52"
CP_BAW 118	213282.5024	2639358.0470	58.8330	PCN	1.0000064038	1.0000087660	1°33'05"
CP_BAW 119	220129.4095	2639009.4592	112.6940	PCN	1.0000032915	1.0000030797	1°33'03"
CP_BAW 121	207674.6673	2641482.4316	82.1370	PCN	1.0000090559	1.0000103033	1°33'21"
CP_BM CIH 1	220222.7193	2639073.1996	106.6780	PCN	1.0000032506	1.0000033265	1°33'04"
CP_BM CIH 2	220272.7669	2636869.9626	217.5810	PCN	1.0000032017	0.9999979747	1°32'46"
CP_F19-002	261498.6935	2636801.7712	321.6860	PCN	0.9999867540	0.9999765921	1°32'54"
CP_F19-003	254229.2018	2639615.8835	226.4880	PCN	0.9999894022	0.9999837792	1°33'16"
CP_F098	275391.9272	2645934.6278	193.5270	PCN	0.9999821603	0.9999781474	1°34'14"
CP_F100	265381.1260	2639284.4811	371.7990	PCN	0.9999854270	0.9999728743	1°33'16"
CP_F101	265520.2289	2637674.0854	343.7340	PCN	0.9999853642	0.9999741548	1°33'03"
CP_F102	242396.9177	2643571.9862	229.8950	PCN	0.9999939679	0.9999881660	1°33'46"
CP_F103	244195.5223	2643181.7999	265.5540	PCN	0.9999932553	0.9999857501	1°33'44"
CP_F104	228690.6396	2636297.0847	142.4290	PCN	0.9999995236	0.9999978943	1°32'43"
CP_F105	229167.6814	2638411.3832	214.4590	PCN	0.9999993447	0.9999942711	1°33'01"
CP_F106	203587.6399	2642079.8042	33.5040	PCN	1.0000110221	1.0000145951	1°33'25"
CP_F107	202371.6848	2642833.4300	13.5200	PCN	1.0000116221	1.0000161506	1°33'31"
CP_F108	235849.5386	2645734.1646	154.1060	PCN	0.9999966331	0.9999944492	1°34'03"
CP_F109	236419.4830	2645046.7522	238.4440	PCN	0.9999963916	0.9999901755	1°33'57"
CP_F110	249580.2195	2642145.9575	225.3140	PCN	0.9999911676	0.9999855933	1°33'36"
CP_F112	220312.3898	2638112.7778	178.5440	PCN	1.0000031990	0.9999998386	1°32'56"
CP_F113	220163.5059	2639381.6040	112.0900	PCN	1.0000032807	1.0000030979	1°33'07"
CP_F114	212088.7069	2640871.7831	133.1740	PCN	1.0000069756	1.0000057829	1°33'17"
CP_F115	211069.4159	2640355.1132	107.2940	PCN	1.0000074437	1.0000074884	1°33'13"
CP_R21-010	278977.6922	2655746.9166	53.0570	PCN	0.9999811082	0.9999838123	1°35'36"
CZ_TL32	268308.2631	2641076.9298	444.9010	PCN	0.9999844477	0.9999684041	1°33'32"
CZ_TL32A	268460.0382	2641287.4977	441.5000	PCN	0.9999843985	0.9999685177	1°33'33"

Table 6 – Primary Control Network adjustments processed in TBC ver. 5.60.

Mapping Control Station Results

H21-04_D6-0476-IMP		Mapping Control Stations (MCS)	
Project file data		**Coordinate System**	
Project Name:	Pavement Preservation	**Name:**	United States/State Plane 1983
County:	Delaware	**Datum:**	NAD83 (2011)
Modified:	6/7/2021 1:08:21 PM (UTC:-4)	**Zone:**	Pennsylvania South 3702

Sample Survey Report

PennDOT Photogrammetry & Surveys Section

Control Type:	Mapping Control Stations	**Geoid:**	GEOID18 (Conus)
Reference number:	PAMS Code 4807A	**Vertical datum:**	NAVD88
Surveyed by:	District 6 Survey Crew & PSS	**Prepared by:**	Robert Bradbury, PLS & Phillip Hendrickson, Photo Tech II
Comment 1:	KeyNetGPS survey of Primary, Mapping, and Map Test Controls		
Comment 2:	TBC Final Adjustment fixed KeyNET CORS V0U1 in Horizontal and F19-002 in Vertical		
Comment 3:	Leveling performed on published controls to establish vertical coordinates for eccentric points		

Point List

ID	Northing (US survey foot)	Easting (US survey foot)	Elevation (US survey foot)	Feature Code	Projection Scale Factor	Combined Scale Factor	Meridian convergence angle
H18-22-022	203270.7377	2645685.9959	20.1140	MCS_Aerial	1.0000112232	1.0000154362	1°33'55"
H18-22-037	214288.0211	2638464.6117	128.6900	MCS_Aerial	1.0000059295	1.0000049515	1°32'58"
H18-22-052	225070.3918	2637238.4699	106.7860	MCS_Aerial	1.0000010938	1.0000011668	1°32'50"
H21-04-001	202011.2155	2642423.6563	18.9560	MCS_Aerial	1.0000117922	1.0000160608	1°33'28"
H21-04-002	204380.5096	2646412.9804	42.0900	MCS_Aerial	1.0000106962	1.0000138582	1°34'01"
H21-04-003	203509.5705	2646431.2323	30.3410	MCS_Aerial	1.0000111173	1.0000148413	1°34'01"
H21-04-004	203670.8450	2643377.4667	22.0950	MCS_Aerial	1.0000109989	1.0000151174	1°33'36"
H21-04-005	205200.9228	2643737.4325	67.2950	MCS_Aerial	1.0000102661	1.0000122232	1°33'39"
H21-04-005A	205203.1170	2643735.5128	67.3090	MCS_Aerial	1.0000102651	1.0000122214	1°33'39"
H21-04-006	204901.2802	2641853.9726	57.7760	MCS_Aerial	1.0000103855	1.0000127978	1°33'24"
H21-04-006A	204850.8950	2641866.2793	58.6390	MCS_Aerial	1.0000104099	1.0000127809	1°33'24"
H21-04-007	205823.9820	2640641.4864	80.7620	MCS_Aerial	1.0000099270	1.0000112402	1°33'14"
H21-04-008	207021.4779	2642976.1215	73.8790	MCS_Aerial	1.0000093856	1.0000110279	1°33'33"
H21-04-009	209599.9117	2640527.4742	45.5670	MCS_Aerial	1.0000081343	1.0000111305	1°33'14"
H21-04-010	211347.5965	2640431.4997	112.2270	MCS_Aerial	1.0000073149	1.0000071237	1°33'13"
H21-04-011	213181.9933	2638860.3393	124.7250	MCS_Aerial	1.0000064439	1.0000056553	1°33'01"
H21-04-012	215833.3333	2637796.9637	123.9060	MCS_Aerial	1.0000052142	1.0000044652	1°32'52"
H21-04-013	218906.8909	2638014.3550	193.4630	MCS_Aerial	1.0000038265	0.9999997523	1°32'55"
H21-04-014	222143.7405	2637810.3419	188.7700	MCS_Aerial	1.0000023830	0.9999985343	1°32'54"
H21-04-015	224395.5841	2637188.7853	115.2600	MCS_Aerial	1.0000013872	1.0000010545	1°32'49"
H21-04-016	226235.6240	2638219.5480	233.0370	MCS_Aerial	1.0000006001	0.9999946367	1°32'58"
H21-04-017	231549.9980	2640768.8804	288.8540	MCS_Aerial	0.9999983640	0.9999897342	1°33'21"
H21-04-018	238719.0607	2645257.3099	224.2180	MCS_Aerial	0.9999954581	0.9999899240	1°34'00"
H21-04-019	240351.4457	2645039.6308	239.2030	MCS_Aerial	0.9999947986	0.9999885494	1°33'58"
H21-04-020	244278.2207	2642635.2661	293.4920	MCS_Aerial	0.9999932170	0.9999843762	1°33'39"
H21-04-021	242382.3357	2643303.7921	248.3260	MCS_Aerial	0.9999939708	0.9999872875	1°33'44"
H21-04-022	245714.9699	2643225.7573	223.5840	MCS_Aerial	0.9999926630	0.9999871663	1°33'44"
H21-04-023	249960.9174	2641761.9797	224.9790	MCS_Aerial	0.9999910193	0.9999854616	1°33'33"
H21-04-024	261271.8367	2637483.6875	320.4190	MCS_Aerial	0.9999868405	0.9999767384	1°33'00"
H21-04-025	265905.2389	2636753.6483	343.7170	MCS_Aerial	0.9999852238	0.9999740165	1°32'55"

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H21-04-026	266266.7066	2638382.8009	340.3010	MCS_Aerial	0.9999851153	0.9999740709	1°33'09"
H21-04-027	262511.0155	2637603.5028	335.1360	MCS_Aerial	0.9999864063	0.9999756026	1°33'01"
H21-04-028	242654.5982	2644663.5574	173.3510	MCS_Aerial	0.9999938777	0.9999907795	1°33'56"
H21-04-028A	242640.4990	2644666.5137	173.7860	MCS_Aerial	0.9999938833	0.9999907643	1°33'56"
H21-04-029	227481.3748	2637344.9952	221.9260	MCS_Aerial	1.0000000532	0.9999946219	1°32'51"
H21-04-030	266500.3760	2640181.9271	434.1180	MCS_Aerial	0.9999850523	0.9999695214	1°33'24"
H21-04-031	267247.4400	2639319.1871	392.3710	MCS_Aerial	0.9999847902	0.9999712574	1°33'17"
H21-04-032	268195.5906	2640843.2983	443.6920	MCS_Aerial	0.9999844835	0.9999684977	1°33'30"
H21-04-033	268669.1204	2640544.1005	402.9710	MCS_Aerial	0.9999843213	0.9999702837	1°33'27"
H21-04-034	269609.1260	2641508.2672	427.7630	MCS_Aerial	0.9999840152	0.9999687933	1°33'35"
H21-04-035	269895.9312	2640749.7612	339.8770	MCS_Aerial	0.9999839126	0.9999728939	1°33'29"
H21-04-036	270336.8987	2642214.6400	372.2820	MCS_Aerial	0.9999837791	0.9999712109	1°33'42"
H21-04-037	271429.1663	2641685.3933	291.9590	MCS_Aerial	0.9999834126	0.9999746875	1°33'37"
H21-04-038	270727.6088	2643002.8802	441.9390	MCS_Aerial	0.9999836565	0.9999677580	1°33'48"
H21-04-039	272211.0975	2643602.8778	292.5530	MCS_Aerial	0.9999831724	0.9999744193	1°33'54"
H21-04-040A	271925.4789	2644515.1608	376.9450	MCS_Aerial	0.9999832745	0.9999704850	1°34'01"
H21-04-041	273123.4987	2644167.5706	278.8010	MCS_Aerial	0.9999828789	0.9999747849	1°33'58"
H21-04-042	272281.8745	2645349.7024	404.5850	MCS_Aerial	0.9999831649	0.9999690540	1°34'08"
H21-04-043	273050.9908	2646547.7987	363.4290	MCS_Aerial	0.9999829239	0.9999707817	1°34'18"
H21-04-044	273375.8761	2645839.1467	282.1810	MCS_Aerial	0.9999828116	0.9999745553	1°34'12"
H21-04-045	274020.8241	2647205.8589	243.7490	MCS_Aerial	0.9999826141	0.9999761963	1°34'24"
H21-04-046	274332.2309	2645886.4634	177.6140	MCS_Aerial	0.9999825015	0.9999792473	1°34'13"
H21-04-046A	274335.6359	2645907.1971	178.0640	MCS_Aerial	0.9999825006	0.9999792249	1°34'13"
H21-04-047	274236.9609	2648741.1519	409.6670	MCS_Aerial	0.9999825577	0.9999682062	1°34'37"
H21-04-048	275540.1849	2648464.3418	183.9480	MCS_Aerial	0.9999821350	0.9999785790	1°34'35"
H21-04-049	275380.6521	2645657.6341	196.6010	MCS_Aerial	0.9999821615	0.9999780018	1°34'11"
H21-04-050	276153.2879	2646869.6131	148.4670	MCS_Aerial	0.9999819246	0.9999800673	1°34'22"
H21-04-051	276470.8073	2650692.0393	168.7970	MCS_Aerial	0.9999818569	0.9999790257	1°34'54"
H21-04-052	277142.2661	2648897.0910	145.3940	MCS_Aerial	0.9999816275	0.9999799179	1°34'39"
H21-04-052A	277116.9100	2648889.9367	145.4330	MCS_Aerial	0.9999816354	0.9999799240	1°34'39"
H21-04-053	277495.6750	2647729.3869	245.7380	MCS_Aerial	0.9999815053	0.9999749993	1°34'29"
H21-04-054	276919.9549	2650172.7092	89.3940	MCS_Aerial	0.9999817093	0.9999826760	1°34'49"
H21-04-055	277921.4674	2648628.3894	189.6340	MCS_Aerial	0.9999813785	0.9999775554	1°34'37"
H21-04-056	276689.7912	2647692.6633	180.9090	MCS_Aerial	0.9999817608	0.9999783529	1°34'29"

Table 7 – Mapping Control Station adjustments processed in TBC ver. 5.60.

Sample Survey Report

Map Testing Survey Results

Table 8 – Excluded in report for consultant delivery

BENCHMARK NOTE	PUBLISHED
BENCHMARK ELEVATIONS ARE BASED ON NAVD88 AS PUBLISHED BY THE NATIONAL GEODETIC SURVEY (NGS) AND PENNDOT. ALL PROJECT ELEVATIONS WERE ESTABLISHED BY GPS OBSERVATION AND NETWORK ADJUSTMENT, LEVELING WAS NOT USED FOR THE SURVEY ADJUSTMENTS.	

Sample Survey Report

PennDOT Photogrammetry & Surveys Section

ALIGNMENTS AND RIGHT OF WAYS

Existing Alignments

The existing alignment was created using the following.

SUMMARY OF PROJECT COORDINATES
BASED ON THE PA STATE PLANE COORDINATE SYSTEM NORTH ZONE
NAD 88 (2011) (OPUS)
AVERAGE COMBINED FACTOR = 0.999939615

ROUTE	STATION	POINT	COORDINATES ** NORTH	COORDINATES ** EAST	BEARING
SR 6 R/W ℄	1394+04.18	POB	583536.0261	2119785.3209	N 62°07′57" E
	1442+54.34	POE	585803.1368	2124073.0047	
SR 4002 R/W ℄	309+09.58	POB	584743.4758	2120208.0369	S 87°07′53" E
	312+69.22	PC	584725.4777	2120567.2278	
	314+68.65	PI	584715.4974	2120766.4067	S 75°23′34" E
	316+66.68	PT	584665.2035	2120959.3895	
	319+66.36	PC	584589.6295	2121249.3746	
	320+90.33	PI	584558.3636	2121369.3451	N 86°59′20" E
	322+12.35	PT	584564.8764	2121493.1517	
	324+77.00	POE	584578.7786	2121757.4316	
SR 660 R/W ℄	547+29.00	POB	584578.7786	2121757.4316	N 86°59′20" E
	562+55.82	POE	584658.9848	2123282.1386	
SR 4002 SPUR R/W ℄	800+00.00	PC	584556.0177	2121431.1930	S 88°35′11" E
	800+31.22	PI	584555.2476	2121462.3993	
	800+62.40	PT	584556.8874	2121493.5720	N 86°59′20" E
	800+63.03	PC	584556.9204	2121494.1985	
	801+14.13	PI	584559.6051	2121545.2346	
	801+53.99	PT	584514.4253	2121569.1234	S 27°52′03" E
	801+85.12	POE	584486.9048	2121583.6748	
RELOCATED SR 660 R/W ℄	1547+29.00	POT	584877.5504	2122322.4871	S 27°52′03" E
	1548+33.46	PC	584785.2083	2122371.3130	
	1550+25.11	PI	584615.7839	2122460.8960	N 86°59′20" E
	1551+74.55	PT	584625.8516	2122652.2814	
	1555+00.00	POE	584642.9482	2122977.2850	

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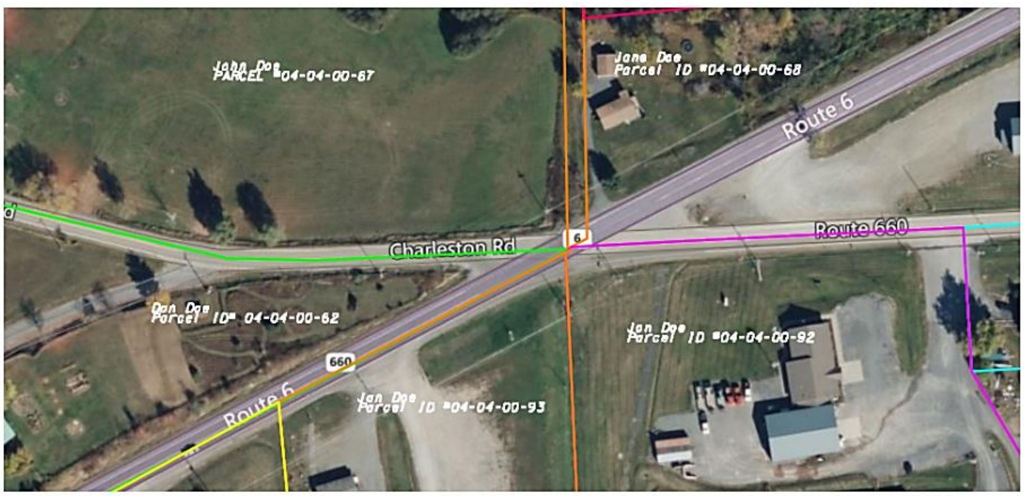
Sample Survey Report

PROPERTY INFORMATION

Deed Mosaic

The deed mosaic below was created using the best information at the time. Proper steps will need to be taken to make sure all information shown is still up to date and accurate.

Points located and used to build deed mosaic



Sample Survey Report

EXISTING GROUND TERRAIN REPORT

Collection Methods, Accuracies, and Density

Collection Methods

Conventional Topographic Survey

District 3 Survey crews completed a full convention topographic survey for an intersection redesign. Topographic data was collected at a general cross-section interval of 25 feet (average point density less than 25'). Every data point is highly intelligent as a technician placed the rod location on each observation. The resulting survey has a vertical point accuracy range of +/- 0.03' hard surface and +/- 0.07' vegetated areas. The terrain surface from the conventional topographic survey is the sole data source for all areas outside of the paved shoulders and is integrated with the lidar scan data for the areas within the paved surfaces. All data from this survey was processed and verified using Bentley Open Roads Designer (ORD) Release 1 2021.

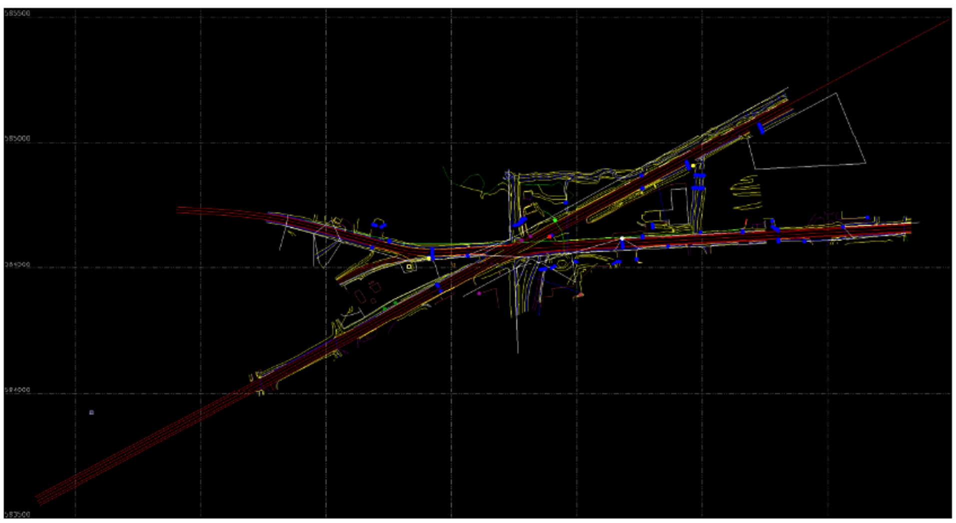
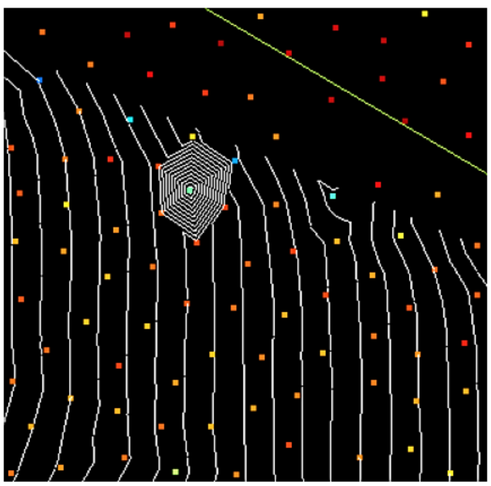


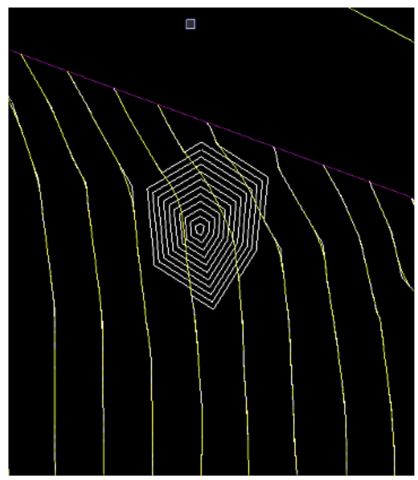
Image showing the Conventional Topo Linework

Sample Survey Report

Terrestrial Lidar Scanning

District 3 Survey crews completed terrestrial scanning of the entire project area. Scan stations were placed at approximately 250' to 300' interval on existing and set control stations utilizing a Trimble SX10 Total Station/ Scanner. The resulting scans were processed using Trimble Business Center (TBC) version 5.6. The scan stations were imported to TBC and used to produce classified point clouds and a terrain surface for the paved roadway. The resulting overall point cloud contained 300 million data points. Extract Point Cloud Regions tool was used to establish 5 classifications from the original Default Region. See Point Cloud section for more information of classifications. The Ground Region was then isolated and reduced to create a high-quality ground surface. Extracted Ground surface contained approximately 200 million data points after first extraction. Ground reduction began with a Spatial sampling of the Extracted Ground Region with a spacing of 1.50'. This resulted in 200,000 data points creating a roughly 1.50ft grid existing ground surface on the paved areas. The Shoulder lines from the conventional survey were then brought in to view the rough boundary of the required hard surface DTM. A selection of points outside of the boundary were eliminated from the Ground Reduction Point Cloud. A rough DTM was created to analyze any anomalies in the surface. Quick Contours at intervals of 1/10 of a foot were generated. Any resulting spikes in the DTM were then analyzed. If the spike was an anomaly on the surface, caused by poor ground extraction, that data point was eliminated, see images below to illustrate.


Example of point cloud data point anomaly.


Example of corrected contours in yellow.

Approximately 2 dozen data points were removed from the Point Cloud and a Final Surface was created. Quick contours were generated to ensure all anomalies were eliminated. This final DTM and 1-foot generated smoothed contours were analyzed in TBC. The Final Ground Reduction Surface was then exported as a LandXML file. The actual points were exported for Terrain construction in ORD. See image below of the 0.10' Contours overlaid on Google Earth. Resulting point density is 1.5 Foot interval of extracted data points. Low grade intelligence as the points are light returns from the scanner and every effort is made to eliminate out of tolerance data. Individual point accuracy is very high, 0.01' to 0.03', but every effort must be made to utilize good ground data.

Sample Survey Report

Image showing the Terrain extents of the Lidar Scans

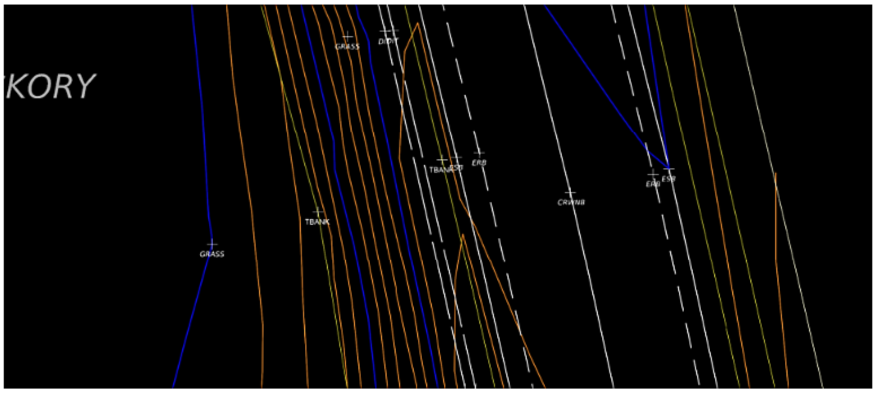
DEVELOPING A COMPLEX TERRAIN:

Combining DTM's

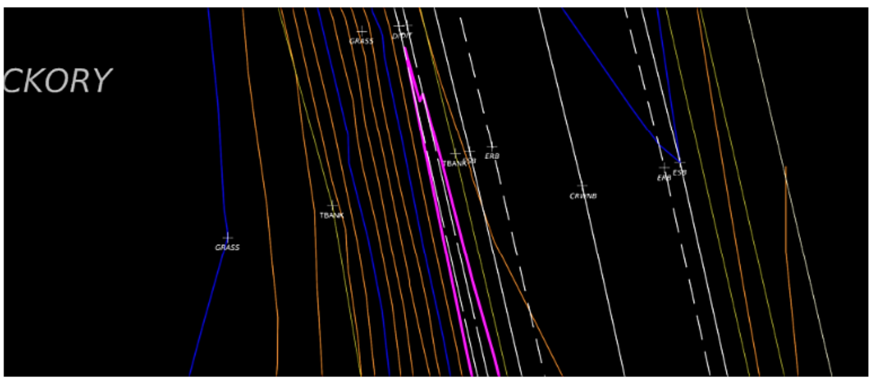
The DTM from the conventional data collected was then combined with the DTM that was created from the Lidar Data. The conventional data was used only on ground surfaces located off the roadway, or any other hard surface that data was not collected with lidar. The Lidar data was only used on hard surfaces or where accurate data could be obtained, i.e. bare ground.

The DTMs created from the ground survey and lidar data were combined using CADD tools. After review, issue around drainage areas were noted. During a second attempt to merge the two DTMs, special care was taken to ensure that ditch/drainage bottoms were included from the ground survey. Lidar data did not penetrate the vegetation in most ditches. The following screen shots illustrate the automatically merged complex terrain and the final complex terrain with lidar data manually removed around ditches and areas off the roadway.

Sample Survey Report



Original complex terrain (ground survey and static lidar) – Notice ditch at center



Complex terrain re-created, lidar data removed around the ditch – ditch contour highlighted

Final Model and Location

The final terrain intended to be used for design has been placed in ProjectWise at the following location…

pw:\\PDPRCADPWI02.penndot.lcl:Connect_Projects\Documents\OpenRoads_Projects\D03\08-Bradford\08000601-Surv.DGN

The file 08000601-Surv.dgn contains limited planimetric mapping in CADD and the final edit terrain as described above.

Sample Survey Report

POINT CLOUDS

Terrestrial lidar data collected for the project was used to create the CADD file and the terrain (DTM) contained in it. The lidar data is LAS and POD formats are included in the delivery for reference. However. great care should be taken in extracting any additional linework or measurements from these point clouds. Contact your District Chief of Surveys (DCS) or the Photogrammetry and Surveys Section (PSS) for help in extracting further measurements from the point clouds. Below is a list of the LAS files included in the delivery of the project.

08000601Ground.las

08000601Building.las

08000601Roadway.las

08000601OverheadWires.las

EXISTING GROUND CONFIDENCE LEVEL

The existing ground model was tested using 31 map test points on soft surfaces and 29 map tests on the corridors of SR 0006 and SR 0660. A separate Root-Mean Square Error (RMSE) was developed for the soft surfaces (base map) and the paved corridor (hard surfaces). All map test locations were withheld from the individuals responsible for collecting and processing the map data and final model. Where possible, topographic features such as drop inlets were used, however the map area did not contain enough features to do a robust horizontal test. Most test locations are random spot elevations used for a vertical test only.

Map test locations were randomly selected and distributed evenly throughout the model. These locations were communicated to survey crews on a digital map. Survey crews were able to adjust locations based on field conditions so long as the even distribution of points was not disturbed.

Map test points coordinates were derived from traverse operations. The estimated accuracy of the new stations with respect to the NAD83 (2011) datum is ±0.05 ft. and NAVD88 datum is ±0.05 ft. The network was constrained to the map control stations H21-05-004 and H21-05-015.

The results of the map testing indicate a vertical accuracy of 0.0473' RMSE on the paved roads and 0.2051' RMSE on all other surfaces within the model. See the attached Existing Ground Confidence Level Verification Form.

Sample Survey Report

Existing Ground Confidence Level Verification Form – Front Page

Existing Ground Confidence Level Verification and Form

			RMSE Elev.	Type
S.R.	**0006-001**			
County:	**Bradford**	**Base Map (FT)**	0.2051	
Location:	SR 0660 Intersection	**Hard Surfaces (FT)**	0.0473	
		Other (see narrative)		

Base Map:	The base mapping is conventional ground survey.
Hard Surfaces:	Terrestrial (static) lidar was collected to increase density of data on the corridors of SR 0006 and 0660 (Charlston Rd).
Other:	Terrestrial lidar was used to create the surface shoulder to shoulder for SR 0006 and 0660 (Charlston Rd.). It was used to supplement off corridor where possible.
Ground Survey:	The survey was based on the National Spatial Reference System (NSRS). The vertical is based on the North American Vertical Datum 1988 (NAVD 88) and the horizontal based on the North American Datum - 1983 (NAD 83)(2011), Pennsylvania North Zone.
Elevation Established by:	Benchmark elevations are based on NAVD88 as published by the National Geodetic Survey (NGS) and PennDOT. All project elevation were established by GPS observations and adjusted holding the elevation of NGS benchmark "B254" - PID: KY0290 fixed in the final network adjustment.

Sample Survey Report

PennDOT Photogrammetry & Surveys Section

Existing Ground Confidence Level Verification Form – Page 2

S.R. 0006-001
County: Bradford
Location: SR 0660 Intersection

Base Mapping Residuals

Check Point	GPS Eastings	GPS Northings	GPS Elevations	Map Eastings	Map Northings	Map Elevations	Difference in Eastings	Difference in Northings	Difference in Elevations	Squares of Eastings	Squares of Northings	Squares of Elevation
MT22-08-28	1,329,470.3125	435,024.9254	1,297.7100	1,329,470.3125	435,024.9254	1,297.7560	0.0000	0.0000	-0.0460	0.0000	0.0000	0.0021
MT22-08-29	1,329,460.2481	435,027.7738	1,298.0800	1,329,460.2481	435,027.7738	1,298.1110	0.0000	0.0000	-0.0310	0.0000	0.0000	0.0010
MT22-08-30	1,329,450.6086	435,028.5266	1,298.2700	1,329,450.6086	435,028.5266	1,298.3390	0.0000	0.0000	-0.0690	0.0000	0.0000	0.0048
MT22-08-31	1,329,440.8788	435,032.2225	1,298.9300	1,329,440.8788	435,032.2225	1,298.8170	0.0000	0.0000	0.1130	0.0000	0.0000	0.0128
MT22-08-32	1,329,431.4941	435,035.4001	1,299.0300	1,329,431.4941	435,035.4001	1,299.3550	0.0000	0.0000	-0.3250	0.0000	0.0000	0.1056
MT22-08-33	1,329,470.3116	435,024.9599	1,301.0200	1,329,470.3116	435,024.9599	1,301.0200	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
MT22-08-34	1,329,376.2465	435,162.0329	1,302.3200	1,329,376.2465	435,162.0329	1,302.8930	0.0000	0.0000	-0.5730	0.0000	0.0000	0.3283
MT22-08-35	1,329,370.4051	434,791.5789	1,312.9900	1,329,370.4051	434,791.5789	1,313.3330	0.0000	0.0000	-0.3430	0.0000	0.0000	0.1176
MT22-08-36	1,329,351.2455	434,785.9323	1,314.5100	1,329,351.2455	434,785.9323	1,314.7270	0.0000	0.0000	-0.2170	0.0000	0.0000	0.0471
MT22-08-37	1,329,331.9869	434,780.5814	1,316.3500	1,329,331.9869	434,780.5814	1,316.5260	0.0000	0.0000	-0.1760	0.0000	0.0000	0.0310
MT22-08-38	1,329,312.8597	434,774.9491	1,318.9700	1,329,312.8597	434,774.9491	1,319.1920	0.0000	0.0000	-0.2220	0.0000	0.0000	0.0493
MT22-08-39	1,329,293.8693	434,769.0277	1,320.3100	1,329,293.8693	434,769.0277	1,320.6310	0.0000	0.0000	-0.3210	0.0000	0.0000	0.1030
MT22-08-40	1,329,536.9983	434,476.8965	1,294.6400	1,329,537.7780	434,476.8550	1,294.7630	-0.7797	0.0415	-0.1230	0.6079	0.0017	0.0151
MT22-08-41	1,329,474.7157	434,631.7414	1,297.2200	1,329,474.7157	434,631.7414	1,297.3320	0.0000	0.0000	-0.1120	0.0000	0.0000	0.0125
MT22-08-42	1,329,429.8803	434,784.8928	1,307.6600	1,329,429.8803	434,784.8928	1,307.8120	0.0000	0.0000	-0.1520	0.0000	0.0000	0.0231
MT22-08-43	1,329,400.6261	434,905.3522	1,309.1700	1,329,400.6261	434,905.3522	1,309.1930	0.0000	0.0000	-0.0230	0.0000	0.0000	0.0005
MT22-08-44	1,329,475.3714	434,838.7427	1,299.3600	1,329,475.8900	434,839.1400	1,299.3530	-0.5186	-0.3973	0.0070	0.2689	0.1578	0.0000
MT22-08-71	1,329,360.1307	435108.2828	1,303.0400	1,329,360.1307	435108.2828	1,303.0400	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
MT22-08-46	1,329,525.7716	434,598.6636	1,295.6000	1,329,525.7716	434,598.6636	1,295.6560	0.0000	0.0000	-0.0560	0.0000	0.0000	0.0031
MT22-08-47	1,329,303.2010	435,070.3252	1,304.0600	1,329,303.2010	435,070.3252	1,304.2080	0.0000	0.0000	-0.1480	0.0000	0.0000	0.0219
MT22-08-48	1,329,312.8819	435,068.2567	1,303.5200	1,329,312.8819	435,068.2567	1,303.6340	0.0000	0.0000	-0.1140	0.0000	0.0000	0.0130
MT22-08-49	1,329,322.5953	435,065.8197	1,302.8600	1,329,322.5953	435,065.8197	1,302.9510	0.0000	0.0000	-0.0910	0.0000	0.0000	0.0083
MT22-08-50	1,329,332.2248	435,063.4152	1,302.2900	1,329,332.2248	435,063.4152	1,302.3730	0.0000	0.0000	-0.0830	0.0000	0.0000	0.0069
MT22-08-51	1,329,342.0464	435,060.9085	1,301.8000	1,329,342.0464	435,060.9085	1,301.8040	0.0000	0.0000	-0.0040	0.0000	0.0000	0.0000
MT22-08-52	1,329,222.4164	435,060.3288	1,311.4400	1,329,222.4164	435,060.3288	1,311.7060	0.0000	0.0000	-0.2660	0.0000	0.0000	0.0708
MT22-08-53	1,329,234.3822	435,044.3052	1,312.0400	1,329,234.3822	435,044.3052	1,312.2640	0.0000	0.0000	-0.2240	0.0000	0.0000	0.0502
MT22-08-54	1,329,246.4269	435,028.3124	1,313.1000	1,329,246.4269	435,028.3124	1,313.3670	0.0000	0.0000	-0.2670	0.0000	0.0000	0.0713
MT22-08-55	1,329,258.3766	435,012.4243	1,315.2300	1,329,258.3766	435,012.4243	1,315.4480	0.0000	0.0000	-0.2180	0.0000	0.0000	0.0475
MT22-08-56	1,329,270.1297	434,996.5239	1,317.9000	1,329,270.1297	434,996.5239	1,318.0710	0.0000	0.0000	-0.1710	0.0000	0.0000	0.0292
MT22-08-57	1,329,298.3993	435,135.6147	1,306.1230	1,329,298.3993	435,135.6147	1,306.1930	0.0000	0.0000	-0.0700	0.0000	0.0000	0.0049
MT22-08-58	1,329,309.9261	435,137.5147	1,305.9270	1,329,309.9261	435,137.5147	1,306.1230	0.0000	0.0000	-0.1960	0.0000	0.0000	0.0384
Notes:					Algebraic sum of Differences		-1.2983	-0.3558	-4.5210			
									Sum of Squares	0.8769	0.1596	1.2195
	Approved by:											
									Average Sum of Squares	0.4384	0.0798	0.0421
									Square Root of Average Sum of Squares	0.6621	0.2825	0.2051

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Sample Survey Report

Existing Ground Confidence Level Verification Form – Page 3

S.R. 0006-001
County: Bradford
Location: SR 0660 Intersection

Hard Surface Residuals

Check Point	GPS Eastings	GPS Northings	GPS Elevations		Map Eastings	Map Northings	Map Elevations	Difference in Eastings	Difference in Northing	Difference in Elevation	Squares of Eastings	Squares of Northing	Squares of Elevation
MT22-08-70	1,329,465.8718	434835.1719	1,300.3500		1,329,465.8718	434,835.1719	1,300.3410	0.0000	0.0000	0.0090	0.0000	0.0000	0.0001
MT22-08-71	1,329,360.1307	435108.2828	1,303.0400		1,329,360.1307	435,108.2828	1,303.0260	0.0000	0.0000	0.0140	0.0000	0.0000	0.0002
MT22-08-73	1,329,399.0692	434963.6967	1,301.0100		1,329,399.0692	434,963.6967	1,301.1740	0.0000	0.0000	-0.1640	0.0000	0.0000	0.0269
MT22-08-74	1,329,432.4669	434871.3867	1,299.9700		1,329,432.4669	434,871.3867	1,299.9790	0.0000	0.0000	-0.0090	0.0000	0.0000	0.0001
MT22-08-75	1,329,435.0984	434861.7276	1,299.8500		1,329,435.0984	434,861.7276	1,299.8730	0.0000	0.0000	-0.0230	0.0000	0.0000	0.0005
MT22-08-76	1,329,437.5561	434852.0322	1,299.7200		1,329,437.5561	434,852.0322	1,299.7420	0.0000	0.0000	-0.0220	0.0000	0.0000	0.0005
MT22-08-77	1,329,439.9403	434842.2789	1,299.5800		1,329,439.9403	434,842.2789	1,299.5820	0.0000	0.0000	-0.0020	0.0000	0.0000	0.0000
MT22-08-78	1,329,442.1721	434832.5624	1,299.4400		1,329,442.1721	434,832.5624	1,299.4400	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
MT22-08-79	1,329,310.9610	435097.017	1,304.8700		1,329,310.9610	435,097.0170	1,304.9620	0.0000	0.0000	-0.0920	0.0000	0.0000	0.0085
MT22-08-80	1,329,301.1938	435099.1104	1,305.3800		1,329,301.1938	435,099.1104	1,305.4740	0.0000	0.0000	-0.0940	0.0000	0.0000	0.0088
MT22-08-81	1,329,291.4504	435101.3041	1,305.9700		1,329,291.4504	435,101.3041	1,306.0080	0.0000	0.0000	-0.0380	0.0000	0.0000	0.0014
MT22-08-82	1,329,281.7885	435103.3552	1,306.5400		1,329,281.7885	435,103.3552	1,306.5530	0.0000	0.0000	-0.0130	0.0000	0.0000	0.0002
MT22-08-83	1,329,271.9843	435105.533	1,307.1200		1,329,271.9843	435,105.5330	1,307.0810	0.0000	0.0000	0.0390	0.0000	0.0000	0.0015
MT22-08-84	1,329,367.3501	435159.4672	1,304.0600		1,329,367.3501	435,159.4672	1,304.0580	0.0000	0.0000	0.0020	0.0000	0.0000	0.0000
MT22-08-85	1,329,310.4014	435300.7286	1,306.0600		1,329,310.4014	435,300.7286	1,306.0370	0.0000	0.0000	0.0230	0.0000	0.0000	0.0005
MT22-08-86	1,329,318.2472	435282.4938	1,305.8100		1,329,318.2472	435,282.4938	1,305.7520	0.0000	0.0000	0.0580	0.0000	0.0000	0.0034
MT22-08-87	1,329,326.1472	435264.1054	1,305.5500		1,329,326.1472	435,264.1054	1,305.5200	0.0000	0.0000	0.0300	0.0000	0.0000	0.0009
MT22-08-88	1,329,333.7590	435245.61	1,305.2600		1,329,333.7590	435,245.6100	1,305.2520	0.0000	0.0000	0.0080	0.0000	0.0000	0.0001
MT22-08-89	1,329,341.1031	435226.9433	1,304.9800		1,329,341.1031	435,226.9433	1,304.9540	0.0000	0.0000	0.0260	0.0000	0.0000	0.0007
MT22-08-90	1,329,399.2636	435075.0107	1,302.6500		1,329,399.0250	435,075.5700	1,302.6020	0.2386	-0.5593	0.0480	0.0569	0.3128	0.0023
MT22-08-91	1,329,513.7553	434587.8069	1,297.3700		1,329,513.7553	434,587.8069	1,297.3470	0.0000	0.0000	0.0230	0.0000	0.0000	0.0005
MT22-08-92	1,329,515.2339	434577.9664	1,297.2500		1,329,515.2339	434,577.9664	1,297.2430	0.0000	0.0000	0.0070	0.0000	0.0000	0.0000
MT22-08-93	1,329,516.6348	434567.9702	1,297.1200		1,329,516.6348	434,567.9702	1,297.1080	0.0000	0.0000	0.0120	0.0000	0.0000	0.0001
MT22-08-94	1,329,517.8578	434558.0314	1,296.9900		1,329,517.8578	434,558.0314	1,296.9740	0.0000	0.0000	0.0160	0.0000	0.0000	0.0003
MT22-08-95	1,329,519.1937	434548.1358	1,296.8600		1,329,519.1937	434,548.1358	1,296.8470	0.0000	0.0000	0.0130	0.0000	0.0000	0.0002
MT22-08-96	1,329,528.9649	434479.0318	1,295.8700		1,329,528.9649	434,479.0318	1,295.8280	0.0000	0.0000	0.0420	0.0000	0.0000	0.0018
MT22-08-97	1,329,533.4406	434432.2437	1,295.3400		1,329,533.4406	434,432.2437	1,295.3130	0.0000	0.0000	0.0270	0.0000	0.0000	0.0007
MT22-08-98	1,329,368.8603	435055.2352	1,301.7800		1,329,368.8155	435,055.0620	1,301.7900	0.0448	0.1732	-0.0100	0.0020	0.0300	0.0001
MT22-08-99	1,329,419.7210	435040.5875	1,298.4700		1,329,419.0200	435,041.1870	1,298.4700	0.7010	-0.5995	0.0000	0.4914	0.3594	0.0000
								0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
								0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Notes:							Algebraic sum of	0.9844	-0.9856	-0.0700			
									Sum of Squares	0.5503	0.7022	0.0603	
Approved by:									erage Sum of Squares	0.1376	0.1756	0.0022	
									Square Root of Average Sum of Squares	0.3709	0.4190	0.0473	

Sample Survey Report

APPENDIX F – PENNSYLVANIA STATE LAWS AND STANDARDS

F-1 PENNSYLVANIA COORDINATE SYSTEM LAW

The following is an excerpt of the Pennsylvania Coordinate System Law. To see the entire document, please visit…

https://www.legis.state.pa.us/WU01/LI/LI/US/PDF/1992/0/0161..PDF

PENNSYLVANIA COORDINATE SYSTEM LAW - OMNIBUS AMENDMENT

Act of Dec. 16, 1992, P.L. 1224,

No. 161 Cl. 76 Session of 1992 No. 1992-161

The Pennsylvania Coordinate System of 1983, North Zone, consists of a Lambert conformal projection of the North American datum of 1983, having a central meridian of 77 degrees 45 minutes west. The northern standard parallel is latitude 41 degrees 57 minutes and the southern standard parallel is latitude 40 degrees 53 minutes, along which parallels the scale shall be exact. The origin of coordinates is at the intersection of the meridian 77 degrees 45 minutes west longitude and the parallel 40 degrees 10 minutes north latitude. This origin is given the coordinates n==0 meters; e==600,000 meters.

The Pennsylvania Coordinate System of 1983, South Zone, consists of a Lambert conformal projection of the North American datum of 1983, having a central meridian of 77 degrees 45 minutes west. The northern standard parallel is latitude 40 degrees 58 minutes and the southern standard parallel is latitude 39 degrees 56 minutes, along which parallels the scale shall be exact. The origin of coordinates is at the intersection of the meridian 77 degrees 45 minutes west longitude and the parallel 39 degrees 20 minutes north latitude. The origin is given the coordinates n==0 meters; e== 600,000 meters.

F-2 PENNSYLVANIA STATE PLANE COORDINATE SYSTEM – NAD83 – NORTH ZONE

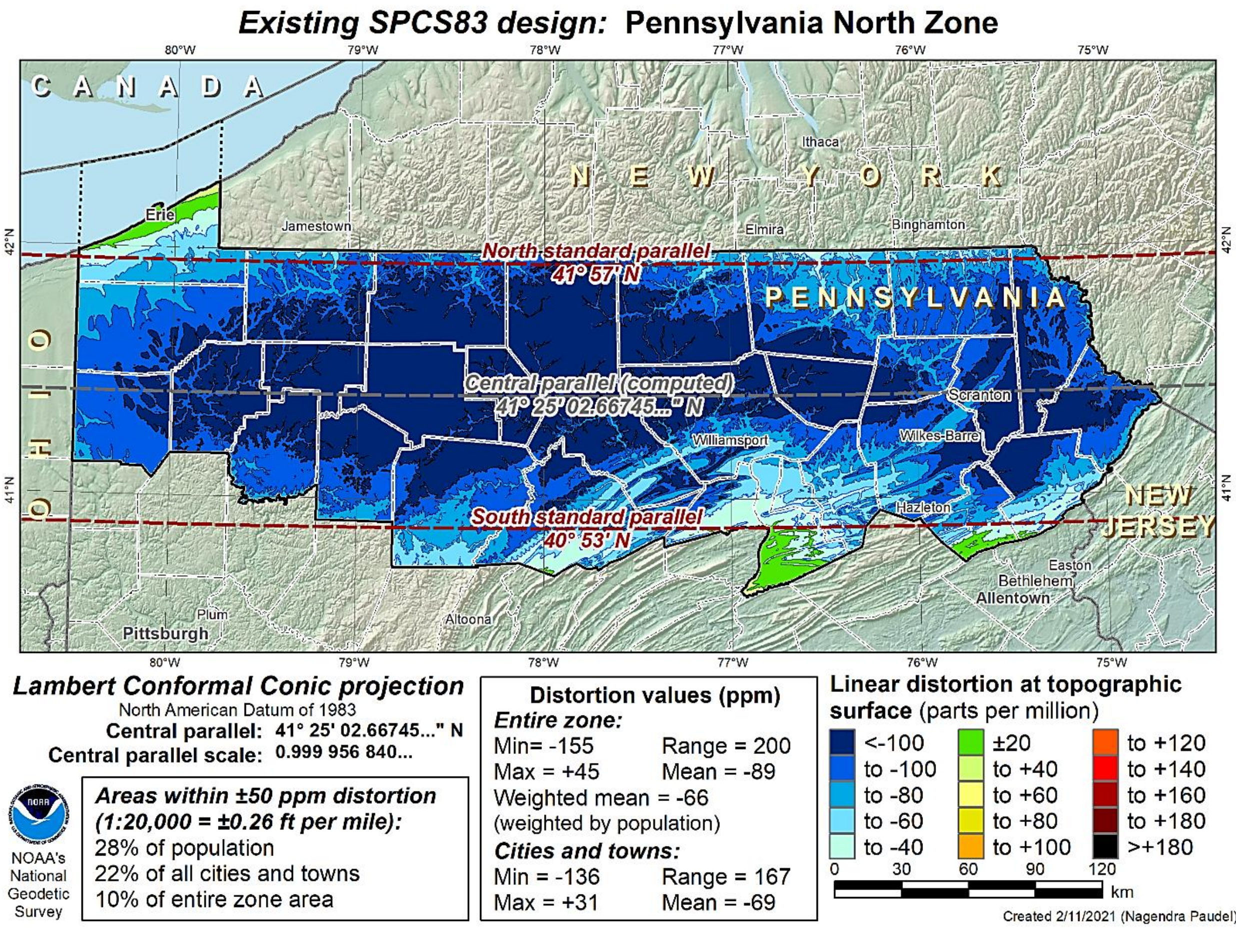

Figure Appendix F.2

For illustrative purposes only

F-3 PENNSYLVANIA STATE PLANE COORDINATE SYSTEM – NAD83 – SOUTH ZONE

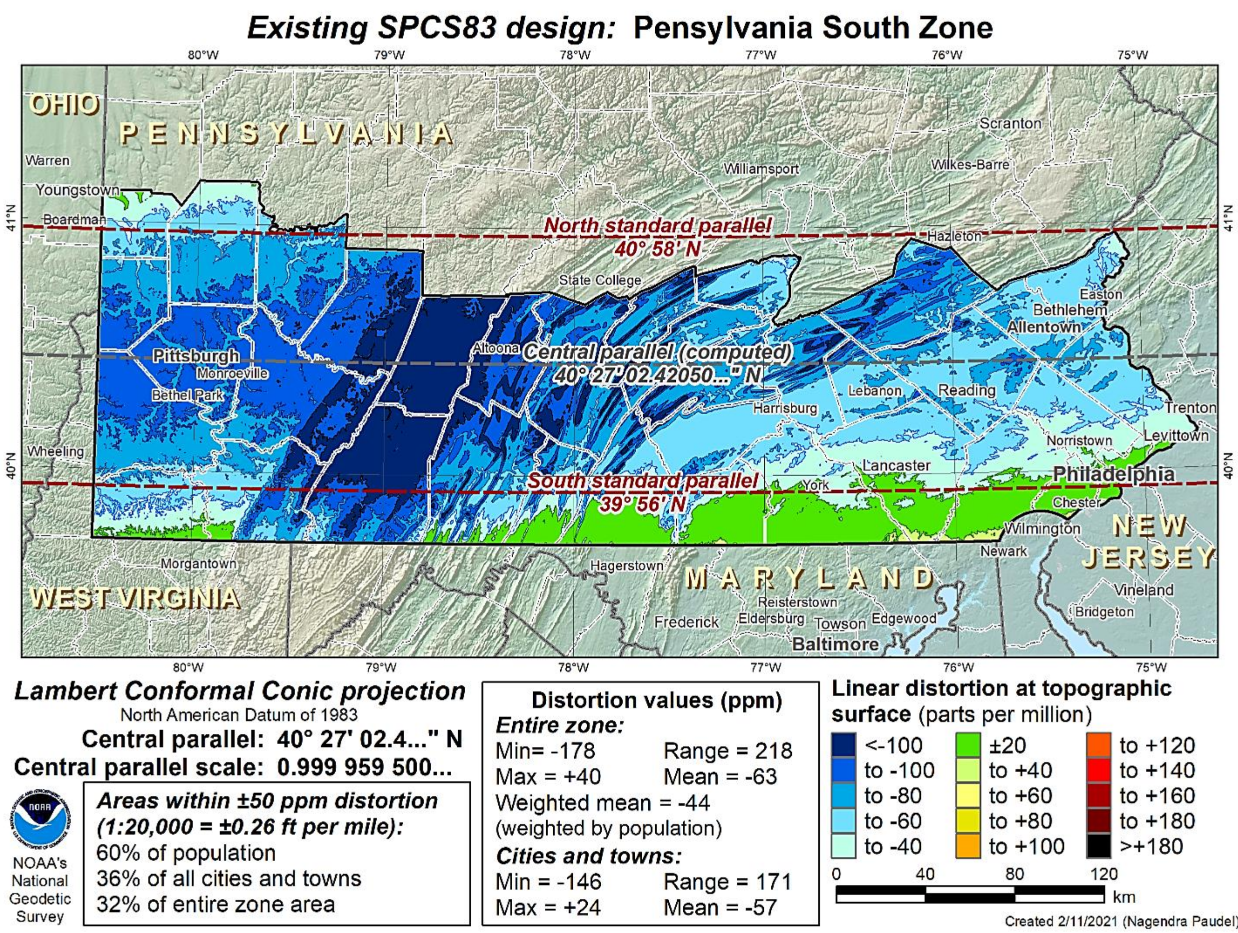

Figure Appendix F.3

For illustrative purposes only

F-4 PENNSYLVANIA STATE PLANE COORDINATE SYSTEM – NATRF2022 – ALL FOUR ZONES

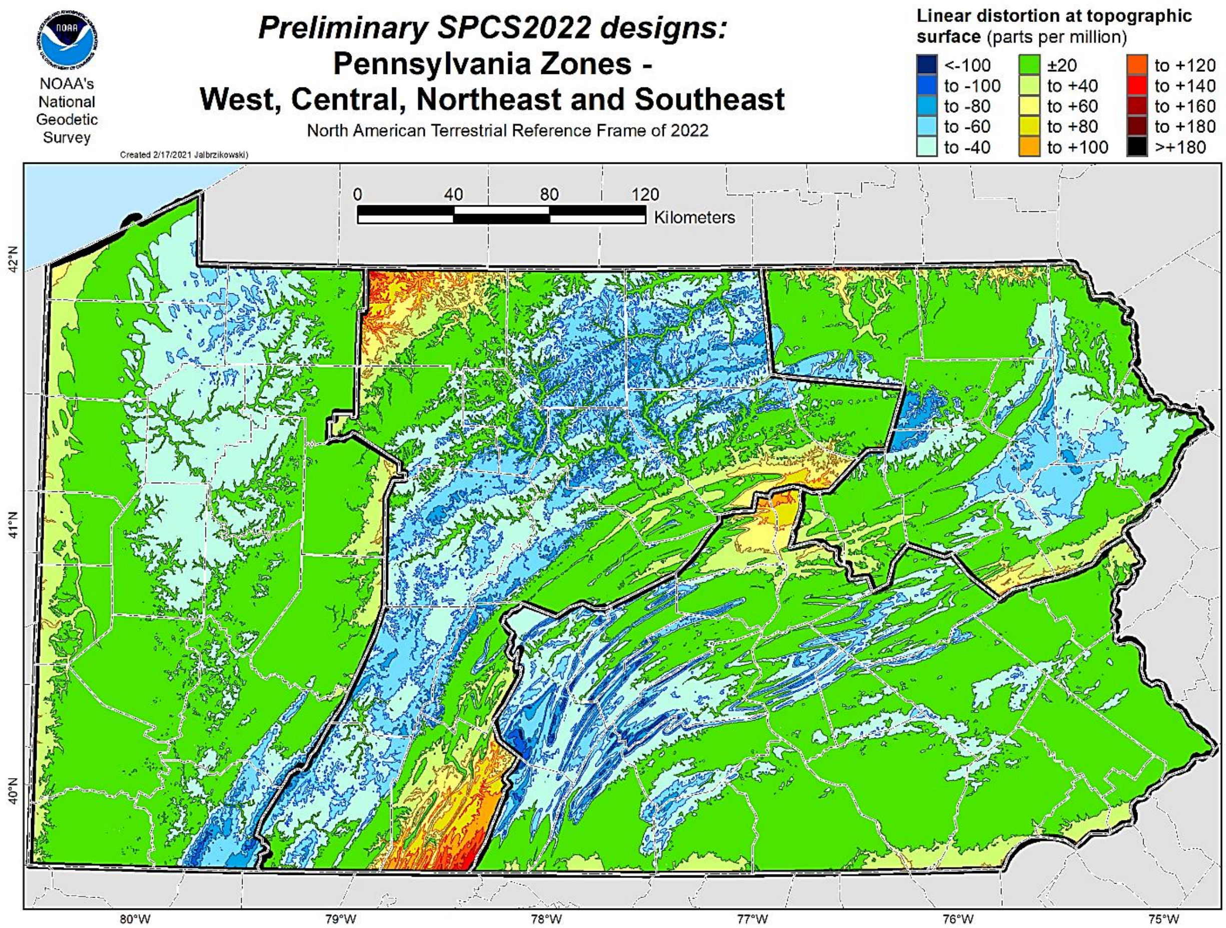

Figure Appendix F.4

Preliminary - for illustrative purposes only

F-5 PENNSYLVANIA STATE PLANE COORDINATE SYSTEM – NATRF2022 – ALL FOUR ZONES WITH PENNDOT DISTRICTS

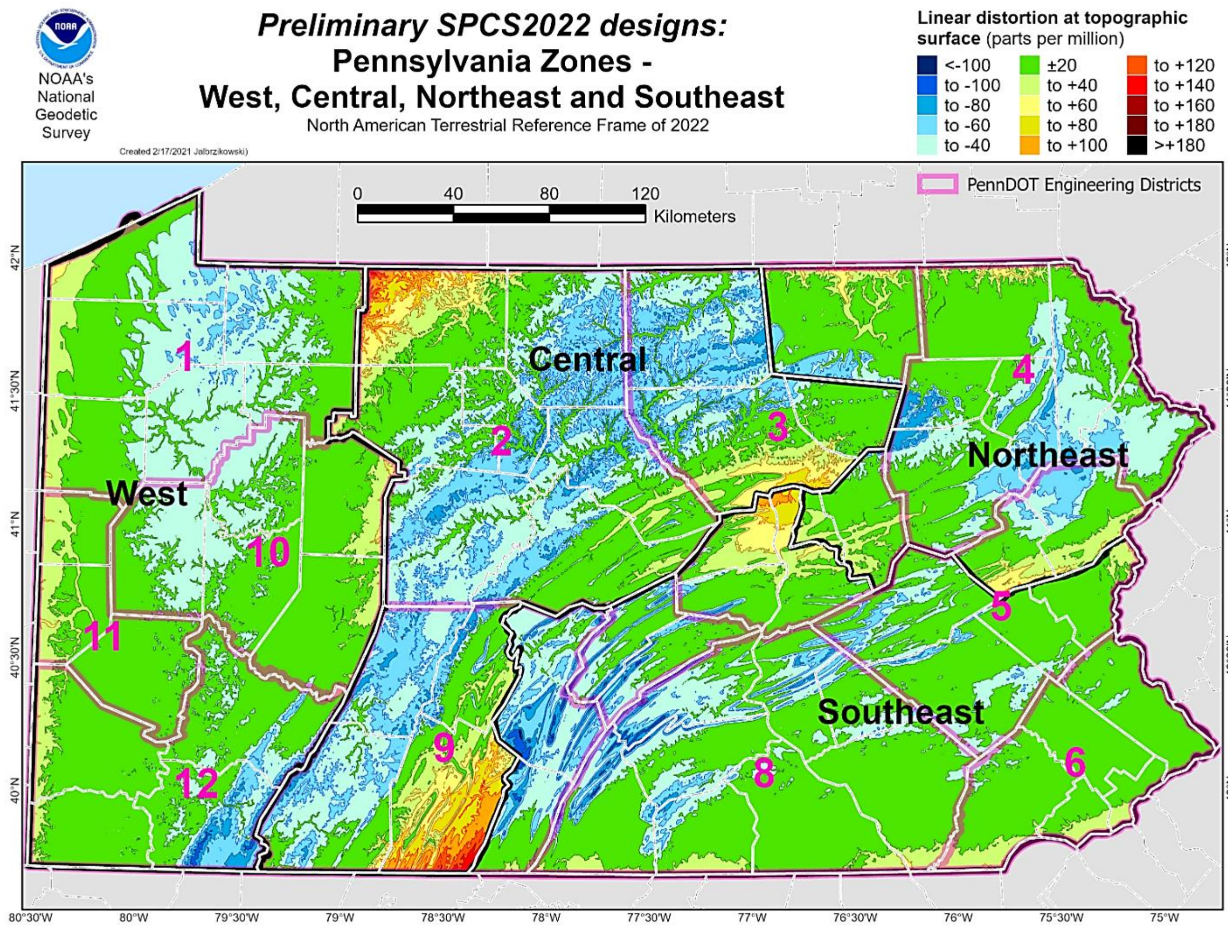

Figure Appendix F.5

Preliminary - for illustrative purposes only

F-6 PENNSYLVANIA STATE PLANE COORDINATE SYSTEM – NATRF2022 – WEST ZONE

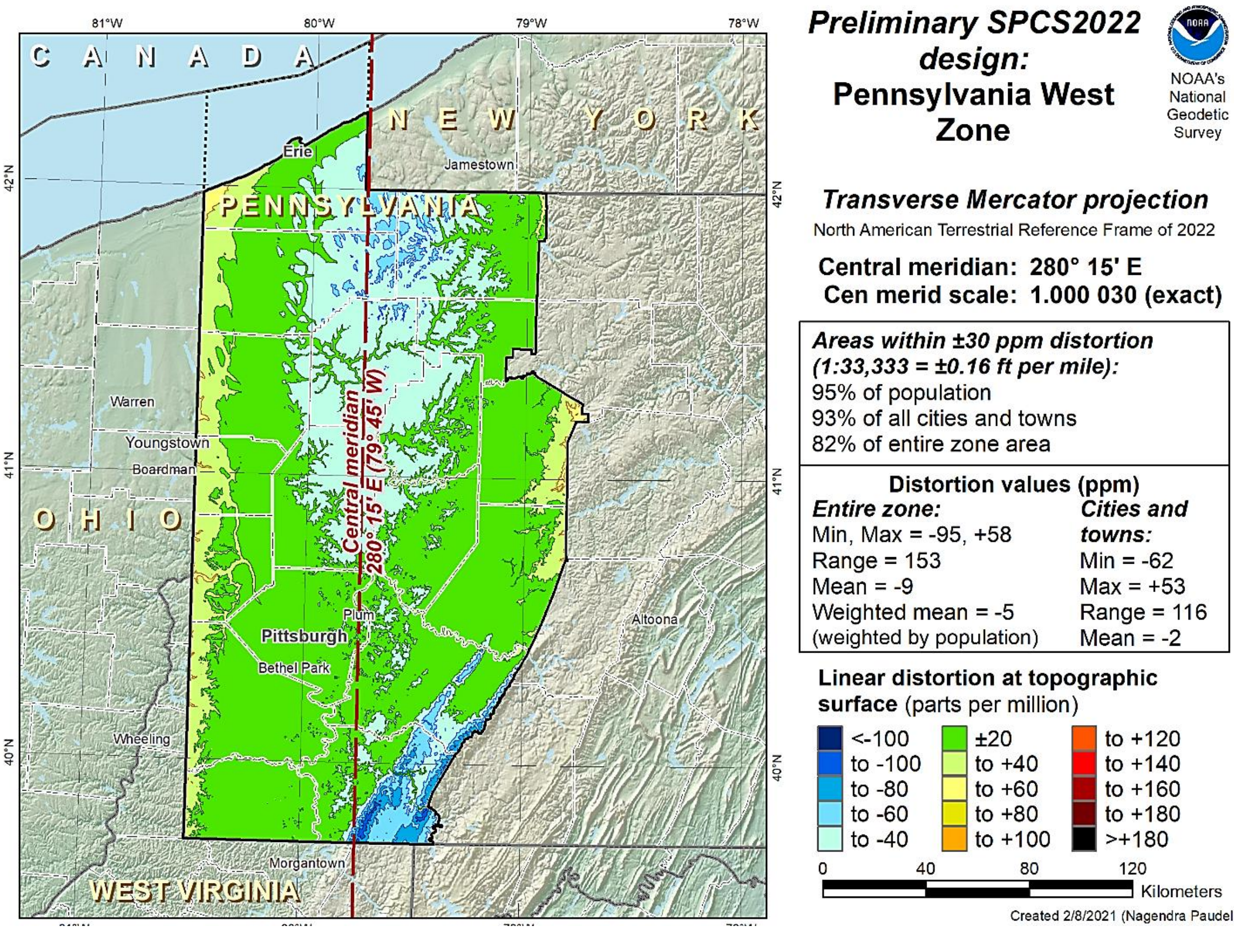

Figure Appendix F.6

Preliminary - for illustrative purposes only

F-7 PENNSYLVANIA STATE PLANE COORDINATE SYSTEM – NATRF2022 – CENTRAL ZONE

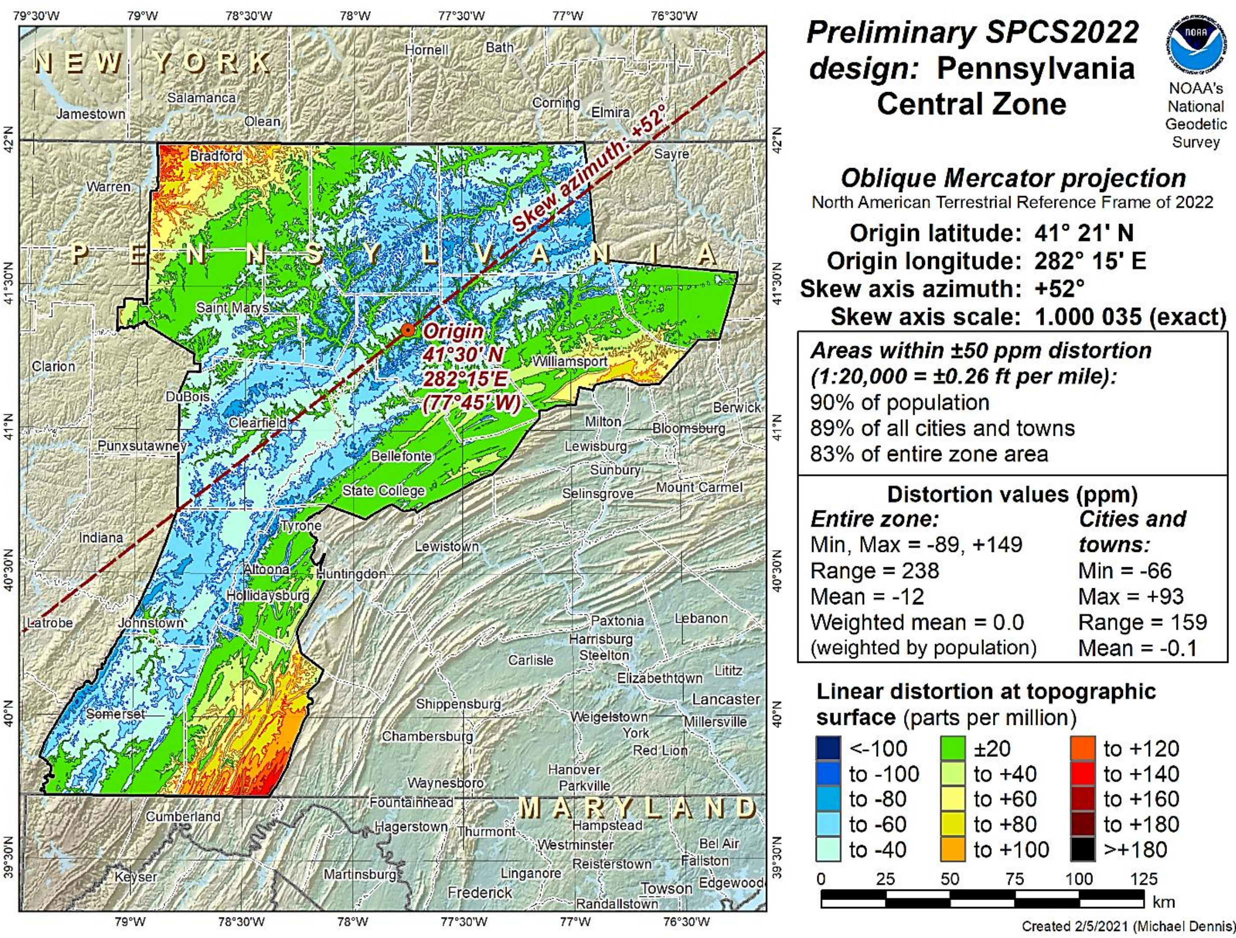

Figure Appendix F.7

Preliminary - for illustrative purposes only

F-8 PENNSYLVANIA STATE PLANE COORDINATE SYSTEM – NATRF2022 – NORTHEAST ZONE

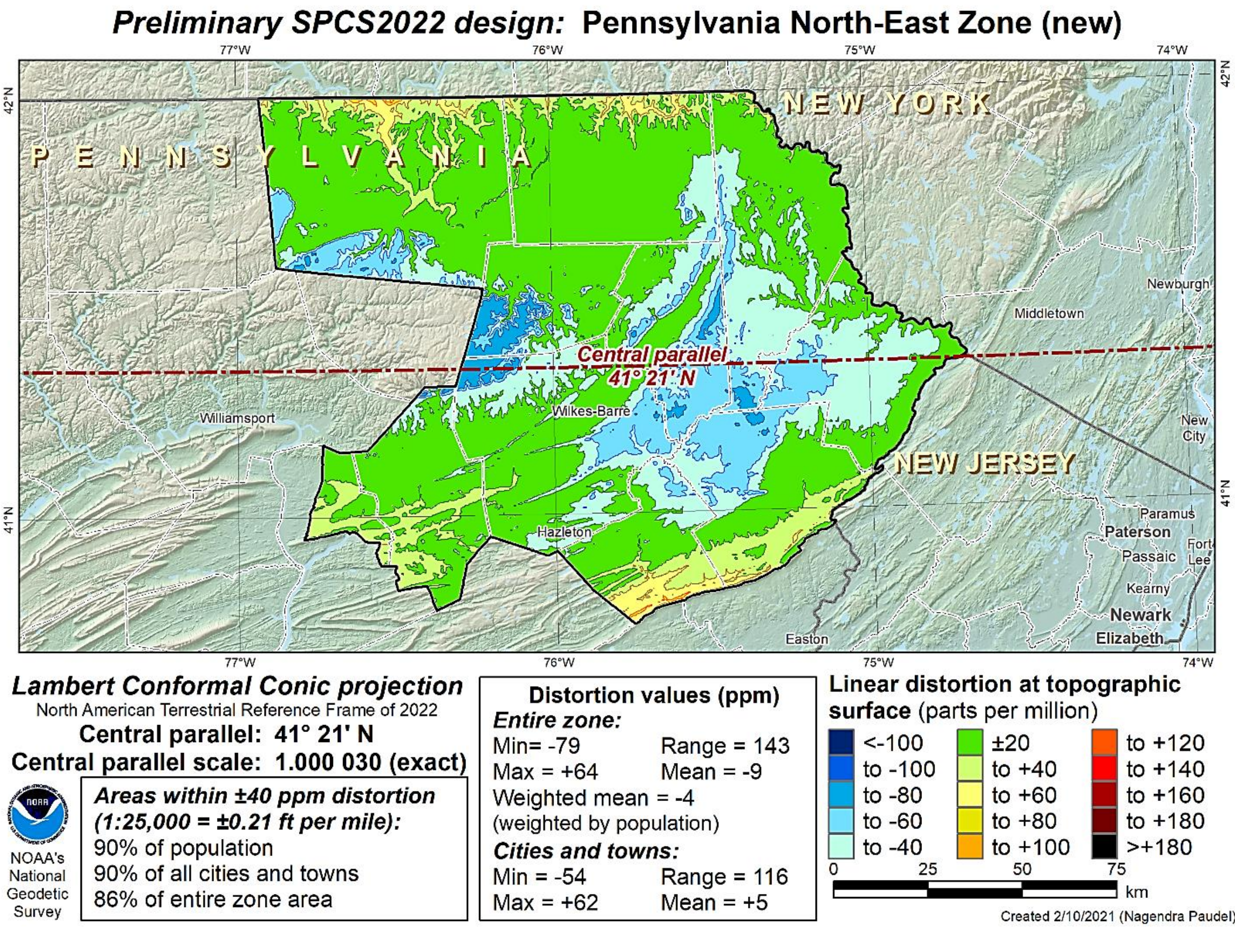

Figure Appendix F.8

Preliminary - for illustrative purposes only

F-9 PENNSYLVANIA STATE PLANE COORDINATE SYSTEM – NATRF2022 – SOUTHEAST ZONE

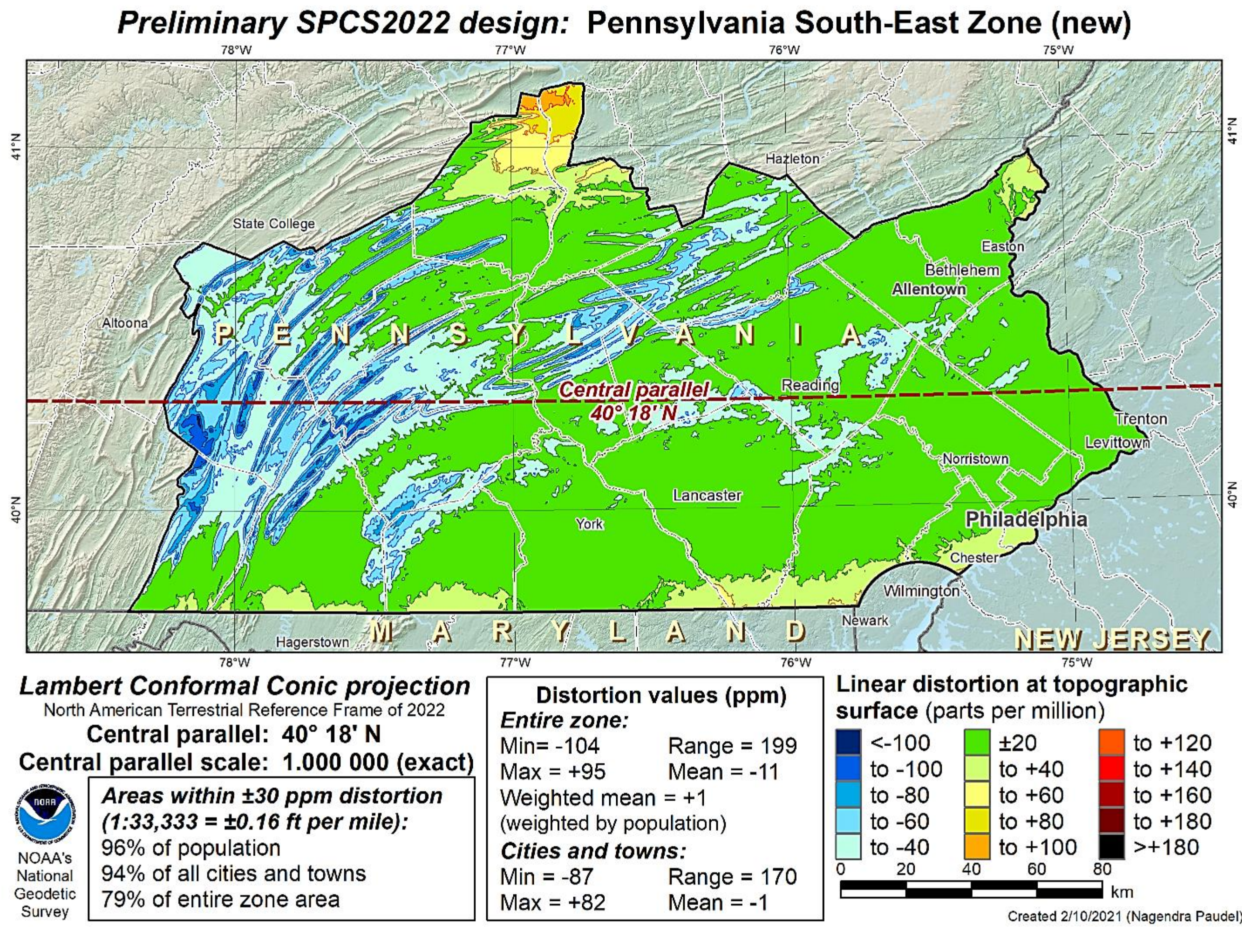

Figure Appendix F.9

Preliminary - for illustrative purposes only

F-10 PENNSYLVANIA STATE PLANE COORDINATE SYSTEM – NATRF2022 – SINGLE ZONE

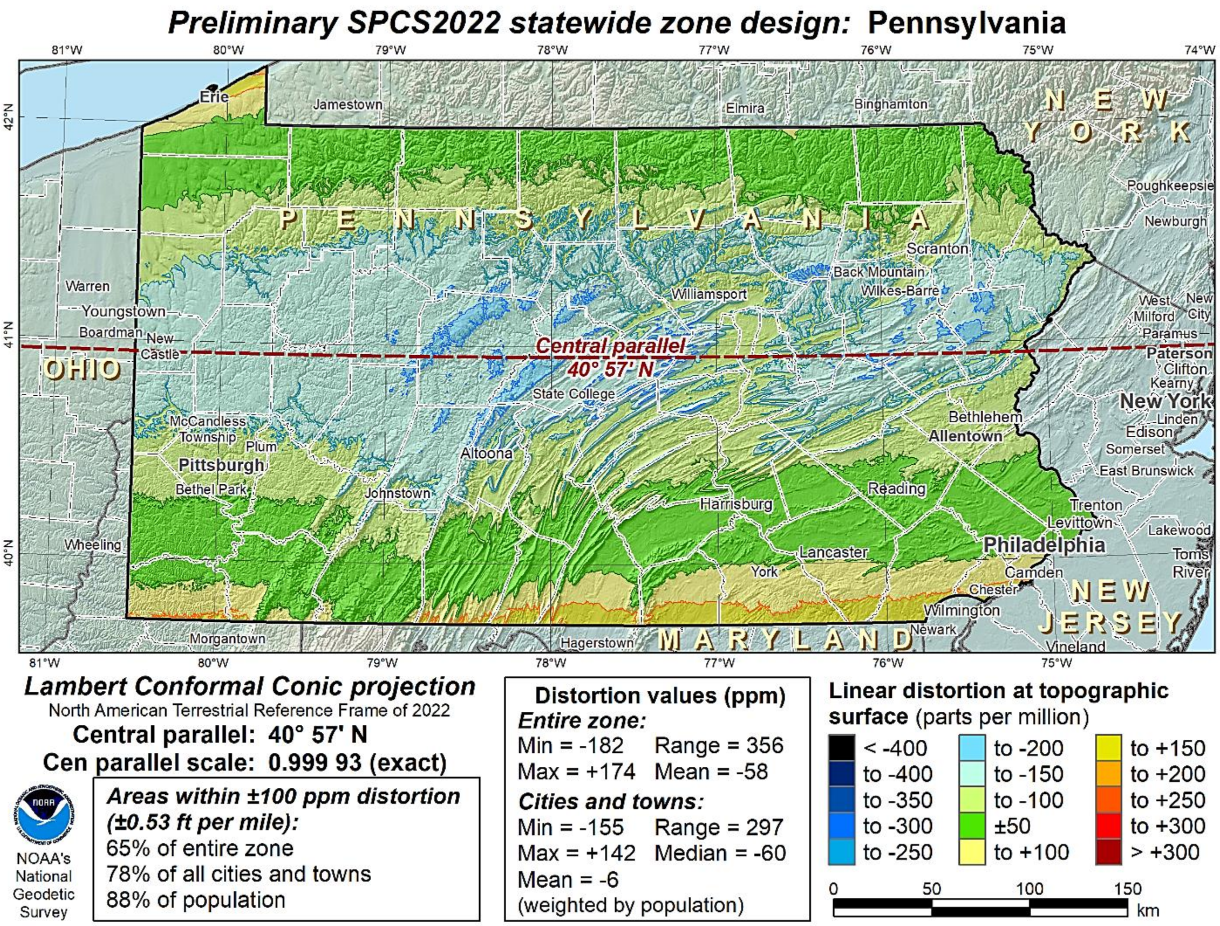

Figure Appendix F.10

Preliminary - for illustrative purposes only

F-11 FEDERAL AVIATION ADMINISTRATION (FAA) PART 107 RULES

The following are two hyperlinks to the Federal Aviation Administration (FAA) Part 107 Rules. To see the entirety of both documents, please visit…

https://www.faa.gov/uas/commercial_operators

https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-107

F-12 TITLE 18 OF THE PENNSYLVANIA CONSOLIDATED STATUTES 3505

The following is a hyperlink to Title 18 of the Pennsylvania Consolidated Statutes 3505. To see the entire document, please visit…

https://www.legis.state.pa.us/cfdocs/legis/LI/consCheck.cfm?txtType=HTM&ttl=18&div=0&chpt=35&sctn=5&subsctn=0