Chapter 6
Survey Procedures

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6.1 Notekeeping

6.1.1 General

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

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

1. Field notes perpetuate a survey even when stakes have rotted and monuments are obliterated. Good field notes make it possible to re-establish lost monuments or other measured data. Conversely, incomplete, illegible or incorrect field notes cause the time and money invested in the survey to have been wasted.

2. Field notes of boundary or right-of-way surveys, together with diaries and survey crew reports, are important documentation in court cases arising between the Department and landowners or contractors.

3. Field notes are the means of communication between field and office personnel. The office personnel should be able to understand and process the data without needing additional explanations.

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

6.1.2 Types of Notes

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

1. **Sketch and/or Description Notes** - The main purpose of sketch notes is to clarify information shown in other types of notes, as described below in #3 and #4, and to prevent misinterpretation thereof. Sketches increase the efficiency with which notes are taken and subsequently interpreted in the office. Description notes are a written narration of the survey procedure and of the measurement to clarify information shown in other types of notes, as described below in #3 and #4. Whenever the field crew observes a noteworthy circumstance, it should also be recorded in writing.

2. **Tabular Notes** - Tabular notes are records of measurements referenced to survey stations or topographic features. Tabular notes may or may not require the use of a sketch, but one should make an effort to include one. The advantage of this type of note taking is that it does not depend on electronic devices. That is also the main disadvantage in that the transportability of data is limited.

3. **Modular Notes** (Preprinted Forms) - Modular notes are those in which original raw values are entered on special forms. The forms are generally designed as a "trade off" between ease in recording notes in the field and computer input needs. In some cases, computer operators are trained to input into the computer directly from the modular form. In other cases, the field information is transferred manually to special forms.

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

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

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

A system of codes needs to be developed that will identify topographic and terrain features, such as a road, stream, tree, power pole, etc. Codes are also needed for computer drafting instructions, such as the start of a linear feature and the placement of topographic feature. Note sheets with point number, feature code, specific description and an occasional sketch, for unusually hard to define situations, could save a return trip to the field.

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

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

The advantages of electronic notes are:

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

The disadvantages of electronic notes are:

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

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

6.1.3 Arrangement of Notes

6.1.3.1 Title Page

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

6.1.3.2 Header Information

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

6.1.3.3 Record Information

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

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

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

6.1.3.4 Observations and Measurements

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

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

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

Some guidelines to follow when recording measurements are:

1. Always record the full raw value as called out by the instrument operator. Do not set the instrument to compute reduced measurements. Do not record only the sums or the differences or the mean of a series of raw values. Also, do not record only "corrected" sums, differences or means.

2. Record significant figures only and clearly indicate the decimal portion of a measured value.

3. Do not erase any observation. If a blunder is made in recording a "call out", or if an observation is rejected, draw a slash through the entry without destroying the legibility of the erroneous entry. Erasures diminish, and often destroy, the credibility of field notes.

4. Do not discard a page with erroneous records. To void a page, draw a diagonal across the page and write the word “VOID” in large letters.

5. Write clear and legible notes. A professional looking set of notes is likely to be of professional quality.

6.1.3.5 Descriptions

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

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

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

6.1.3.6 Suggestions for Recording Notes

- Make notes dark enough to be reproducible.
- Use standard abbreviations and symbols.
- Be consistent in style and lettering. Write tabulated figures inside and off column rulings. Align decimal points and digits vertically.
- Do not crowd information to a point where numbers or letters are hard to distinguish or some information is covered. Do not try to economize on paper. Do not write in margins of notes.
- Use drafting aids to produce neat drawing.
- Draw sketches to approximate scale. Exaggerate details on a separate diagram if clarity is thereby improved.
- Orient sketches and entries according to standard mapping procedure.
- Draw framework of sketch before measurements begin.

6.2 Preliminary Surveys

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

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

6.2.1 Research

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

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

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

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

6.2.2 Reconnaissance and Gathering Data

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

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

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

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

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

6.2.3 Horizontal Control

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

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

6.2.3.1 Base Control

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

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

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

6.2.3.2 Supplemental Control

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

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

6.2.4 Vertical Control

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

6.2.4.1 Base Control

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

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

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

6.2.4.2 Supplemental Control

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

6.2.5 Alignment

6.2.5.1 Computing Existing Alignment

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

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

6.2.5.2 Establish Centerline

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

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

6.2.5.3 Profiles

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

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

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

6.2.5.4 Cross Sections

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

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

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

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

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

6.2.6 Topographic Data

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

1. FENCES

Include the fence type and location of existing gates.

2. UTILITIES

A. Gas and Petroleum Pipelines

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

B. Water and Sewer Lines

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

C. Power Lines

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

D. Telephone Lines

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

3. BUILDINGS

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

4. DRAINAGE COURSES

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

5. DRAINAGE STRUCTURES

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

6. RAILROADS

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

6.2.7 Right-of-Way

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

6.3 Construction Surveys

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

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

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

6.3.1 Horizontal Control

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

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

6.3.1.1 Traverse Style Base Control

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

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

2. Monuments can be used for both horizontal and vertical control, which makes use of total station capabilities.

3. Monuments can be set at optimum spacing for the staking accuracies required and the type of equipment being used.

4. The same monument would be used for setting all phases of the construction, including restoration of stakes obliterated during construction.

5. Distance, direction and elevation calculations can be made from any control point to any desired construction stake. This calculation can be done in the office, before leaving for the field, or by calculating inverses in the field with hand-held calculators.

6.3.1.2 Supplemental Control Monuments

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

1. Set monuments by closed traverse between the highest order base control economically available. Never use previously set, unchecked points to set other control or construction stakes.

2. Set points where they can be used for setting all phases of construction staking.

3. Set points where they are accessible by vehicle, if possible. A vehicle can often be used to protect the instrument person from wind, and hand carrying equipment to inaccessible points is time consuming.

4. Generally, try to pick point locations where the instrument is above all stages of the work. This is particularly advantageous for structures.

5. Flag and protect points so they are easy to find and will not be disturbed by equipment.

6. Generally, space control points on both sides of the road to assure that any required staking point will be within approximately 200 meters (650 feet) from a control point.

Staking from Supplemental Control

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

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

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

6.3.1.3 Secondary Control

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

6.3.1.4 Centerline Control

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

Some advantages of the centerline method are:

1. Straightforward and easily understood.

2. Familiar to construction personnel.

3. Provides actual on-the-ground checks of the centerline. Also provides easy on-the-ground checks for critical clearance points.

4. Requires less computations.

Some disadvantages of the centerline method are:

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

2. Intermediate steps of establishing each centerline station point must be set and occupied to set each construction control stake.

3. Adapts poorly to steep terrain and often requires more brush cutting.

4. The Survey is never "closed", unless the ends of the project are tied to base control stations. Positional accuracy is difficult to determine.

6.3.1.5 Alignment Control

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

6.3.1.6 Reference Points

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

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

6.3.1.7 Control Stakeout Methods

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

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

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

1. Any section of the project can be set at any time.

2. Once methods are developed, it is generally faster and can be done with as few as two people. Three crew members are generally the most efficient, as rod people can move ahead while the new angle is being turned and the other rod person is painting or completing installation of the set station mark.

3. Generally provides the best setup and sighting conditions.

4. Points can be accurately re-established to their original position at any stage of the construction.

5. Coordinate calculations for curves can be pre-figured in the office and tabulated for simple reference in the field.

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

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

- The three dimensional coordinates of all the points to be staked out are stored in the roving receiver.
- A base station is set up on a known point.

- The rover and the base station receivers are initialized to establish a relative position between them.
- The rover and the base receivers communicate measurements via a radio (usually FM) frequency.
- Since the coordinates of the rover are measured and updated continuously, it is relatively easy to compute the direction and distance to the construction stake to be staked out. This information is then displayed and made available to the surveyor.

The main advantages of the real time GPS method are:

1. One base receiver can serve many rovers simultaneously. This makes this method very efficient.
2. Less control is needed for the project because line-of-sight does not have to be maintained. The only limitation is the range of the radio communication between the rover and the base.

3. It is very easy to reset any destroyed point.

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

6.3.2 Vertical Control

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

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

1. **Check monuments** - If there has been a long delay between the time the base vertical survey was conducted and the completion of the design plans, the condition of the base monuments should be field checked. Each monument should be checked for possible disturbance or settlement, and whether it is in satisfactory condition. Benchmarks that are to be used in the project should also be reflagged for easy location.

2. **Plan benchmark locations** - Design plans should be thoroughly reviewed and a set of plans marked up with the approximate location of existing benchmarks and locations where construction control benchmarks will be required. Such planning can save considerable field time and assure that required benchmarks will be established at their optimum location on a timely basis.

3. **Plan BM establishment** - The planning process should determine which bench-lines should be established for the initial grade staking (normally earthwork on mainlines and service roads), final grade staking, structure staking and vertical control monumentation. Each benchline should be planned to reduce the difficulty and length of level runs required to establish the subsequent benchmarks.

6.3.2.1 Bench Mark Spacing

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

1. A secondary line of semi-permanent benchmarks along one right-of-way line spaced at 300 meters (or approximately 1,000 feet) or less horizontal distance, the primary line being the permanent base control monuments. In heavy construction or rough terrain, a benchline may be required on both right-of-way lines.

2. Successive benchmarks should not be separated (vertically) by more than two "turns" or 7 meters (or approximately 24 feet) in elevation. Relative elevation and ease of access to bench marks is more important than the horizontal distance between them.

3. Bridge sites and major drainage sites should have at least two benchmarks placed outside the area to be disturbed.

4. At interchanges, at least one benchmark should be established for each quadrant in addition to those required for the structure(s).

6.3.2.2 Bench Mark Location

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

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

1. Place in stable, undisturbed original ground.

2. Establish on abutments or wing walls of older existing structures that have become stabilized.

3. Locate near "join" lines of cross streets, intersection of sidewalks and existing facilities outside of the construction area.

4. Select locations with locally level terrain. A benchmark on top of a high slope is not as desirable as one lower on the slope, provided all other criteria can be met. Quite often, the positions of horizontal (traverse) points are not compatible with project use of benchmarks, but are compatible with other considerations. In such instances, benchmarks in more usable locations should be established from the traverse control.

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

6.3.2.3 Marking Bench Marks

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

6.3.2.4 Leveling Accuracies

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

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

6.3.3 Earthwork Staking

6.3.3.1 Cross Sections and Slope Staking (Grading)

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

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

Marking Slope Stakes

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

Slope Staking with a Total Station

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

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

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

Determination of the ground elevation of the staking point.

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

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

DE = the vertical component of the slope distance

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

DE = the vertical component of the slope distance + HR - HI.

6.3.3.2 Borrow Areas

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

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

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

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

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

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

Salient points and ground slope break line data may be recorded in total station data collectors, downloaded into computers and processed into digital terrain models from which cross sections may be interpolated and plotted. Very accurate volumes may be calculated by comparing grid files of the original ground with that of the excavation or fill.

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

6.3.3.3 Structure Staking

Major Structure Staking

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

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

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

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

Reference Markers - All reference markers should be iron pins or tacked hubs set to line and grade as accurately as practicable. Although certain tolerances do exist between the various components of a structure, those tolerances should be preserved, as much as practicable, for subsequent measurements.

In general, all major working lines for abutments, footings, columns and centerline should be referenced with two intersecting lines of stakes. At least the two stakes nearest the component should be on line with, and at a set distance from, the component. Outer stakes may be set for line only. All reference markers should be double guarded and lathed on line where required for "eyeball" sight in. Each guard stake should be marked to identify the station and/or offset from the component. If the stake controls elevation, the cut, fill or flow line information should be included.

Where many stakes or much information is required, a stake numbering system can be used and each marker identified on the guard stake by number only. A listing of each marker would then be furnished to the contractor.

Special Items - Separate pages in the structure field notes should be maintained for such pay items as excavation, back fill material, rip rap, wire mesh, etc., in order to compute and document quantities.

Minor Structure Staking

Minor structures consist of reinforced concrete boxes, reinforced concrete pipe and corrugated metal or plastic pipe installations. The same general procedures for staking and documentation of the various pay items apply as described previously for major structures.

Staking Notes - Staking notes are generally set up in the office from the plans as amended by the revised pipe list.

Excavation and Backfill - Most pipe or box installations require several types of excavation and backfill. During the staking processes, cross sections of sufficient width on either side of the installation should be taken to establish natural ground. The cross sections should be taken at sufficient distance beyond each end of the pipe to encompass the excavation anticipated.

Reference Markers - Reference markers may be either iron pins or tacked hubs. Except on approach pipe or other small installations, the ends of the installation should be referenced both on centerline and by fixture end offsets. The offset markers should be set 3 meters (5 to 10 feet) or more from centerline. Elevations should be taken on each marker and the offset distance, cut to flow line, type, size of pipe and designation of flared end, if applicable, are marked on the guard stakes.

A centerline marker should be set at 1 to 3 meters (3 to 10 feet) out from each pipe end with additional centerline markers set a sufficient measured distance to provide line of sight and distance reference in any area that will not be disturbed by construction. The terrain may dictate other reference marker layout. Information on the guard stake for the nearest to pipe reference marker should include station and offset distance on the backside and on the front side, size of pipe (if flared end is required), length of pipe, cut or fill to flow line, and grade per foot.

6.3.3.4 Centerline Monument Staking

Centerline monument assemblies and/or centerline reference monuments shall be set according to the construction plans and must be set under the direct supervision of a licensed professional surveyor. Following the completion of the centerline monuments, their locations should be checked. The monuments must check within a tolerance of the smaller of an error ratio of 1:10,000 for distance and alignment or a maximum positional error of 2 centimeters (0.06 feet). Failure to meet the tolerance will require the contractor to reset the monument assembly properly.

6.3.3.5 Right-of-Way Markers and Property Boundary Monuments

Right-of-way markers are monuments placed at points of curvature, points of tangency, points of compound curvatures along the necessary baselines. These are always mentioned in the right-of-way description. Right-of-way markers constitute the monumentation of the highway property. As such, they are used by others to make legal ties to the highway. If shown on the right-of-way plans, right-of-way monuments will be set prior to the start of construction activities under the direct supervision of a professional surveyor licensed in the State of New Jersey. The locations of these and other property boundary monuments of record shown on the construction plans, shall be referenced to the project control and checked prior to the start of clearing, excavation or grading activities. The contractor shall be responsible for replacing any right-of-way markers or property boundary monuments disturbed or destroyed during or by the construction activities. All markers or monuments replaced must be set under the direct supervision of a professional surveyor licensed in the State of New Jersey.

Private surveyors have the obligation to either accept the monumentation as a legal boundary or to reject it and re-establish the described boundary in accordance with their findings. Therefore, it is extremely important that right-of-way markers be staked to the closest tolerance practicable and that markers conform to the positions described by the highway description. If, for any reason, the disturbed or destroyed right-of-way markers or property boundary monuments cannot be reset in their original horizontal location, then the contractor's surveyor shall notify the Department's project supervisor. A witness monument or monuments may have to be set to replace the old one. The witness monument shall clearly show its relative position to the record marker or monument, and to the right-of-way or property boundary line it was identifying.

6.3.3.6 Right-of-Way Fence Staking

Right-of-way fence is normally constructed approximately 0.3 - 0.6 meters (1 to 2 feet) inside the established right-of-way. Normally, the centerline offsets, survey for right-of-way markers and other control surveys have basically established the fence line location. Some additional staking may be required, such as gate, end panel and brace panel locations.

Fence should be measured as construction progresses and gate, cattle guard, brace panel, and end panel installations documented in relation to the project stationing.

Construction area fencing should be staked prior to any construction activity in the area.

6.3.3.7 Curb and Gutter Staking

Tacked hubs should be set for radius points and as offsets from back of curb. The offset is normally 0.6 meters (2 feet) or a distance dictated by the contractor's operation. Offset stakes set outside the right-of-way must be approved in writing by the adjacent property owner. Guard stakes should show the station on the back side and offset distance and cut or fill to top of curb on the road side. Again, depending on the contractor's equipment and operation, the distance between offset stakes may vary from 5 to 30 meters (16 to 100 feet).