An Introduction to Survey Methods and Techniques

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J. Paul Guyer, P.E., R.A., Fellow ASCE, Fellow AEI

CED CANADA
engineering.ca
CPD FOR THE PROFESSIONAL

Continuing Education and Development, Inc.

P: (877) 322-5800
info@cedengineering.ca

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CONTENTS

1. OLDER TOPOGRAPHIC SURVEYING METHODS. This section provides an overview of the past and present instruments and methods used to perform topographic surveys of sites, facilities, or infrastructure. Prior to the advent of total stations, GPS, LIDAR, and data collector systems, transit and plane table topographic surveying methods and instruments were once standard. They are rarely used today, other than perhaps for small surveys when a total station or RTK system is not available. However, the basic field considerations regarding detail and accuracy have not changed, and field observing methods with total stations or RTK are not significantly different from the older survey techniques briefly described in the following sections.

1.1 TRANSIT-TAPE (CHAIN). Transit tape topographic surveys can be used to locate points from which a map may be drawn. The method generally requires that all observed data be recorded in a field book and the map plotted in the office. Angles from a known station are measured from another known station or azimuth mark to the point to be located and the distance taped (or chained) from the instrument to the point. Transit-tape surveys typically set a baseline along which cross-section hubs were occupied and topographic features were shot in on each cross-section. The elevation of an offset point on a section is determined by vertical angle observations from the transit. The slope or horizontal distance to the offset point is obtained by chaining. The accuracy may be slightly better than the plane table-alidade method or very high (0.1 ft or less), depending upon the equipment combinations used. Transits are still used by some surveying and engineering firms, although on a declining basis if electronic total station equipment is available. Transit-tape surveys can be used for small jobs, such as staking out recreational fields, simple residential lot (mortgage) surveys, and aligning and setting grade for small construction projects. Assuming the project is small and an experienced operator is available, this type of survey method can be effective if no alternative positioning method is available. Detailed procedures for performing and recording transit tape topographic surveys can be found in most of the survey texts.

1.2 CHAINING. 100, 200, 300, or 500-foot steel tapes are used for manual distance measurement methods. Woven, cloth, and other types of tapes may also be used for lower accuracy measurements. Maintaining any level of accuracy (e.g., better than 1: 5,000) with a steel tape is a difficult process, and requires two experienced persons. Mistakes/blunders are common. Tapes must be accurately aligned over the points (using plumb bobs), held at a constant, measured tension, and held horizontally (using hand levels). Subsequent corrections for tape sag/tension, temperature, and slope may be necessary if a higher accuracy is required. Taping methods, errors, and corrections are not covered in this discussion but may be found in any of the basic surveying texts.

1.3 TRANSIT-STADIA. Transit-stadia topographic surveys are performed similarly to transit-tape surveys described above. The only difference is that distances to offset topographic points are measured by stadia "tacheometry" means-- i.e., using the distance proportionate ratio of the horizontal cross hairs in the transit telescope. The multiple horizontal crosshairs in the transit scope can be used to determine distance when observations are made on a level rod at the remote point. This distance measurement technique has been used for decades, and is also the basis of plane table survey distance measurement. The three horizontal crosshairs in the transit are spaced such that the upper and lower crosshair will read 1.0 ft on a rod 100 ft distant from the transit--a "stadia constant" ratio of 100:1. (Not all instruments have an even 100:1 stadia constant). The accuracy of a stadia-derived distance is not good—probably about 1:500 at best. Thus, a 500 ft shot could have an error of ± 1 ft. Additional errors (and corrections) result from inclined stadia measurements, i.e., when the shot is not horizontal. Reduction of the stadia intercept values to a nominal slope distance, then reduction to horizontal, requires significant computation or use of tables. Transit-stadia was often used like a modern day total station in that topo detail could be densified (typically using radial survey methods) from a single instrument setup. All observed data was recorded in a field book, and occasionally optionally plotted in the field. Transit-stadia techniques are likewise rarely performed today if a total station is available. Details on stadia measurement methods are found in any surveying textbook.

1.4 TRANSIT/THEODOLITE-EDM. Electronic Distance Measurement (EDM) instruments were first developed in the 1950s, primarily for geodetic operations. In the 1970s, more compact EDM units were mounted atop or alongside transits and theodolites--thus replacing manual chaining or optical stadia distance measurement. Observed data were still recorded in field books for later office hand plotting. These crude transit-EDM combinations were the early forerunner of the modern total stations. During this time, methods were developed for automated drafting of observed features--after individual angles and distances and features were encoded on punch cards and input to a computer/plotter system.

Figure 2-5

Plane (no pun intended) table and alidade--Wild T-2 theodolite at right

(USC&GS, ca 1960s)

1.5 PLANE TABLE SURVEYING. The plane table and alidade were once the most common tools used to produce detailed site plan maps in the field. The Egyptians are said to have been the first to use a plane table to make large-scale accurate survey maps to represent natural features and man-made structures. Plane table mapping is rarely done today--plane table surveying has, for most purposes, been replaced by aerial photogrammetry and total stations, but the final map is still similar. Plane table surveys were performed well into the 1980s, and perhaps into the 1990s. A plane table survey system is described as follows: A blank map upon which control points and grid ticks have been plotted is mounted on the plane table. The table is mounted on a low tripod with a specially made head--see Figure 2-5 above. The head swivels so that it can be leveled, locked in the level position, and then be rotated so that the base map can be oriented. The base map is a scaled plot of the ground control stations. Thus, with the table set up over one of the stations, it can be rotated so that the plotted stations lie in their true orientation relative to the points on the ground. Spot elevations and located features are located with an alidade, an instrument that uses optical stadia to determine distance (similar to the transit stadia). The error of a map produced with a plane table and alidade varies across the map as the error in stadia measurements varies with distance. Horizontal errors may range from 0.2 ft at 300 feet, to 10 ft or more at 1,000 feet. Since the elevation of the point is determined from the stadia measurement, relative errors in the vertical result. The plane table survey resulted in a “field-finished” map product, with all quality control and quality assurance performed in the field by the party chief/surveyor. The site plan map delivered from the plane table was immediately suitable for overlaying design detail. Modern day electronic survey and CADD systems are still attempting to attain the same level of “field-finish” capability that the plane table once produced.

Figure 2-6

Leica TCR 705 Reflectorless Total Station

2. TOTAL STATIONS. Total stations were first developed in the 1980s by Hewlett-Packard (Brinker and Minnick 1995). These instruments sensed horizontal and vertical angles electronically instead of optically, and combined them with an EDM slope distance to output the X-Y-Z coordinates of a point relative to the instrument's X-Y-Z coordinates. Electronic theodolites operate in a manner similar to optical instruments. Angle readings can be to 1" with precision to 0.5". Digital readouts eliminate the uncertainty associated with reading and interpolating scale and micrometer data. The electronic angle-measurement system eliminates the horizontal- and vertical-angle errors that normally occur in conventional theodolites. Measurements are based on reading an integrated signal over the surface of the electronic device that produces a mean angular value and eliminates the inaccuracies from eccentricity and circle graduation. These instruments also are equipped with a dual-axis compensator, which automatically corrects both horizontal and vertical angles for any deviation in the plumb line. An EDM device is added to the theodolite and allows for the simultaneous measurements of the angle and the distance. With the addition of a data collector, the total station interfaces directly with onboard microprocessors, external PCs, and software. The ability to perform all measurements and to record the data with a single device has revolutionized surveying. Total stations perform the following basic functions:

Types of measurements:

- Slope distance
- Horizontal angle
- Vertical angle

Operator input to total station data collector:

- Text (date, job number, crew, etc.)
- Atmospheric corrections (PPM)
- Geodetic/grid definitions
- HI & HR
- Descriptor/attribute of setup point, backsight point, sideshot point, stakeout point, etc.

In general, there are three types of total station operating modes:

- Reflector--total station requires a solid reflector or retroreflector signal return from the remote point to resolve digital angles and distances. Prisms are attached to a pole positioned over a feature. Requires two-man field crew--operator and rodman.
- Reflectorless--the total station will resolve (and coordinate) signal returns off natural features. Distances may be far more limited than those obtained from reflectors ... typically less than 1,000 ft. Allows for more economical one-man field crew operation.
- Robotic--total station self-tracks single operator/rodman at remote shot or stakeout points. One-man crew operation, with operator normally based at remote rod point.

Figure 2-7

RTK base station and radio link transmitter--and rover with backpack

3. REAL TIME KINEMATIC (RTK) GPS. RTK survey methods have become widely used for accurate engineering and construction surveys, including topographic site plan mapping, construction stake out, construction equipment location, and hydrographic surveying. RTK survey systems operate in a similar fashion as the robotic total station, with one major exception being that a visual line of sight between the reference point and remote data collection point is not required. Both RTK and total stations use similar data collection routines and methods, and can perform identical COGO stake out functions. Kinematic surveying is a GPS carrier phase surveying technique that allows the user to rapidly and accurately measure baselines while moving from one point to the next, stopping only briefly at the unknown points, or in dynamic motion such as a survey boat or aircraft. A reference receiver is set up at a known station and a remote, or rover, receiver traverses between the unknown points to be positioned. The data is collected and processed (either in real-time or post-time) to obtain accurate positions to the centimeter level. Real-time kinematic solutions of X-Y-Z locations using the carrier (not code) phase are referred to as "real-time kinematic" (RTK) surveys. However, included in this definition are "post-processed real-time kinematic" (PPRTK) techniques where the kinematic solution is not actually performed in "real-time." RTK (or PPRTK) survey techniques require some form of initialization to resolve the carrier phase ambiguities. This is done in real-time using "On-the-Fly" (OTF) processing techniques. Periodic loss of satellite lock can be tolerated and no static initialization is required to regain the integers. This differs from other GPS techniques that require static initialization while the user is stationary. A communication link between the reference and rover receivers is required to maintain a real-time solution.

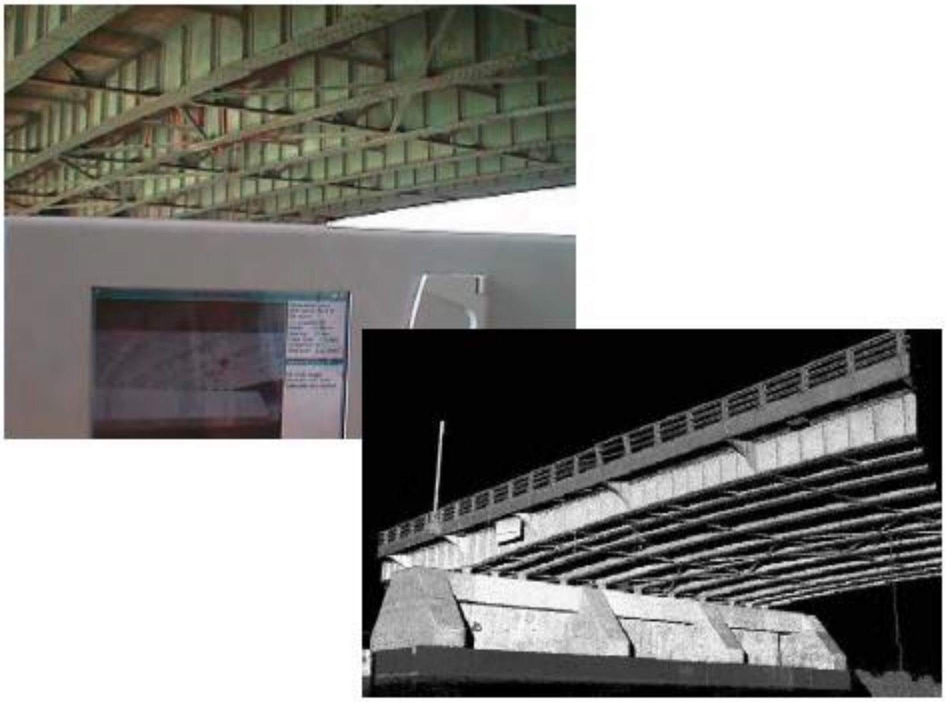


Figure 2-8

Optech LIDAR scanner and resultant image of underside of Bridge

4. TERRESTRIAL LIDAR (LASER) SCANNING. Laser scanning instruments have been developed that will provide topographic detail of structures and facilities at an extremely high density, as shown in Figure 2-8 above. These tripod-mounted instruments operate similarly to a reflectorless total station. However, they are capable of scanning the entire field of view with centimeter-level pixel density in some cases. A full 3D model of a project site or facility results from the scan. This model must be edited and feature attributes added.

5. TOPOGRAPHIC DATA COLLECTION PROCEDURES. Uniform operating procedures are needed to avoid confusion when collecting topographic survey data, especially for detailed utility surveys. The use of proper field procedures is essential to prevent confusion in generating the final site plan map. Collection of survey points in a meaningful pattern aids in identifying map features. The following guidelines are applicable to all types of topographic survey methods, including total stations and RTK systems.

5.1 ESTABLISH PRIMARY HORIZONTAL and vertical control for radial survey. This includes bringing control into the site and establishing setup points for the radial survey. Primary control is usually brought into the site from established NSRS monuments/benchmarks using static or kinematic GPS survey methods and/or differential leveling. Supplemental traverses between radial setup points can be conducted with a total station as the radial survey is being performed. A RTK system may require only one setup base; however, supplemental checkpoints may be required for site calibration. Elevations are established for the radial traverse points and/or RTK calibration points using conventional leveling techniques. Total station trigonometric elevations or RTK elevations may be used if vertical accuracy is not critical--i.e., ± 0.1 ft.

5.2 PERFORM RADIAL SURVEYS to obtain information for mapping. Set the total station or RTK base over control points established as described above. Measure and record the distance from the control point up to the electronic center of the instrument (HI), as well as the height of the prism or RTK antenna on the prism pole (HR). To prevent significant errors in the elevations, the surveyor must report and record any change in the height of the prism pole. For accuracy, use a suitable prism and target that matches optical and electrical offsets of the total station. Use of fixed-height (e.g., 2-meter) prism poles is recommended for total station or RTK observations, where practical.

5.3 COLLECT TOPOGRAPHIC FEATURE data in a specific sequence. Collect planimetric features (roads, buildings, etc.) first. Enter ground elevation data points needed to fully define the topography. Observe and define break lines. Use the break lines in the process of interpolating the contours to establish regions for each interpolation set. Contour interpolation will not cross break lines. Assume that features such as road edges or streams are break lines. They do not need to be redefined. Enter any additional definition of ridges, vertical, fault lines, and other features.

5.4 DRAW A SKETCH OF PLANIMETRIC FEATURES. A field book sketch or video of planimetric features is an essential ingredient to proper deciphering of field data. The sketch may also be made on a pen tablet PC. The sketch does not need to be drawn to scale and may be crude, but must be complete. Numbers listed on the sketch show point locations. The sketch helps the CADD operator who has probably never been to the jobsite confirm that the feature codes are correct by checking the sketch.

5.5 OBTAIN POINTS IN SEQUENCE. The translation of field data to a CADD program will connect points that have codes associated with linear features (such as the edge of road) if the points are obtained in sequence. For example, the surveyor should define an edge of a road by giving shots at intervals on one setup. Another point code, such as natural ground, will break the sequence and will stop formation of a line on the subsequent CADD file. The surveyor should then obtain the opposite road edge. Data collector software with "field-finish" capabilities will facilitate coding of continuous features.

5.6 USE PROPER COLLECTION TECHNIQUES. Using proper techniques to collect planimetric features can give automatic definition of many of these features in the CADD design file. This basic picture helps in operation orientation and results in easier completion of the features on the map. Improper techniques can create problems for office personnel during analysis of the collected data. The function performed by the surveyor in determining which points to obtain and the order in which they are gathered is crucial. This task is often done by the party chief. Cross training in office procedures gives field personnel a better understanding of proper field techniques.

5.6.1 MOST CREWS WILL MAKE and record 250 to over 1,000 measurements per day, depending on the shot point detail required. This includes any notes that must be put into the system to define what was measured. A learning curve is involved in the establishment of productivity standards. A crew usually has to complete five to six mapping projects to become confident enough with their equipment and the feature coding system to start reaching system potential.

5.6.2 A ONE OR TWO-PERSON survey crew is most efficient when the spacing of the measurements is less than 50 feet. When working within this distance, the average rod person can acquire the next target during the time it takes the instrument operator to complete the measurement and input the codes to the data collector. The instrument operator usually spends about 20 seconds sighting a target and recording a measurement and another 5-10 seconds coding the measurement. The same time sequences are applicable for a one-man topographic survey using a robotic total station or RTK.

5.6.3 WHEN THE GENERAL SPACING of the measurements exceeds 50 feet, having a second rod person may increase productivity. A second rod person allows the crew to have a target available for measurement when the instrument operator is ready to start another measurement coding sequence. Once the measurement is completed, the rod person can move to the next shot, and the instrument operator can code the measurement while the rod people are moving. If the distance of that move is 50 feet or greater, the instrument will be idle if you have only one rod person.

5.6.4 COMMUNICATION BETWEEN ROD person and instrument person is commonly done via radio or cell phone. The rodmen can work independently in taking ground shots or single features; or they can work together by leapfrogging along planimetric or topographic feature lines. When more than one rod person is used, crew members should switch jobs throughout the day. This helps to eliminate fatigue in the person operating the instrument.

6. AUTOMATED FIELD DATA COLLECTION. Since the 1990s, survey data collection has progressed from hand recording to field-finish data processing. Prior to the implementation of data collectors, control survey data and topographic feature data were recorded in a standard field book for subsequent office adjustment, processing, and plotting. Modern data collectors can perform all these functions in the field. This includes least squares adjustments of control networks, full feature attributing, symbology assignment to features, and on-screen drafting/plotting capabilities. Data collectors either are built into a total station or are separate instruments. A separate (independent) data collector is advantageous in that it can be used for a variety of survey instruments--e.g., total station, digital level, GPS receiver. Field data collector files are downloaded to an office PC platform where the field data can be edited and modified so it can be directly input into a CADD or GIS software package for subsequent design and analysis uses. Many upgraded CADD/GIS software packages can directly download field data from the collector without going through interim software (e.g., CVTPC). Subsequent chapters in this discussion provide additional information on data collectors and the transition of field collected data to office processing systems.

6.1 FIELD SURVEY BOOKS. Even with fully automated data collection, field survey books are not obsolete. They must be used as a legal record of the survey, even though most of the observational data is referenced in a data file. Field books are used to certify work performed on a project (personnel, date, time, etc.). They are also necessary to record detailed sketches of facilities, utilities, or other features that cannot be easily developed (or sketched) in a data collector. When legal boundary surveys are performed that involve ties to corners, it is recommended that supplemental observations and notes be maintained in the field book, even though a data collector is used to record the observations.

6.2 FIELD COORDINATE GEOMETRY (COGO) COMPUTATIONS. Most data collectors now have a full field capability to perform any surveying computation required. Some of the main field computational capabilities that are found on state-of-the-art data collectors include:

- Coordinate computations from radial direction-distance observations
- Multiple angle/direction adjustments
- Offset object correction (horizontal or vertical)
- EDM meteorological, slope, and sea level reductions
- Horizontal grid and datum transformations
- Vertical datum transformations
- GPS baseline reductions (static, kinematic)
- Traverse adjustments (various methods)
- Inverse and forward position computations
- Resections (2, 3 or more point adjustments)
- Level net adjustments (trig or differential)
- RTK site calibration adjustments (regression fits)
- Construction stake out (slope, horizontal & vertical curves, transition/spiral curves, etc.)

6.3 FEATURE CODING AND ATTRIBUTING. Data collectors are designed to encode observed topographic features with a systematic identification. Similar features will have the same descriptor code--e.g., "BS" for "backsight" and "EP" for "edge of pavement." Features that are recorded in the data collector can have additional attributes added. Attributes might include details about the feature being located (e.g., the number of lamps and height of a light pole).

6.4 FIELD GRAPHIC AND SYMBOLOGY DISPLAYS. Many field data collectors have symbology libraries which can be assigned to standard features, e.g., manholes, culverts, curb lines, etc. Plotted display of collected points with symbology can be viewed on the data collector display screen, or transferred to a portable laptop screen that has a larger viewing area. This allows for a visual view in the field of observed data in order to check for errors and omissions before departing the job site. This capability is, in effect, a modern day form of a plane table.

6.5 DATA TRANSFER. Digital survey data collected in the field is transferred from the data collector to a laptop or desktop PC for final processing and plotting in CADD (e.g., MicroStation, AutoCAD). Both original and processed data observations are transferred. Original (raw) data includes the unreduced slope distances, HIs, HRs, backsight and foresight directions, etc. Field processed data includes items such as reduced horizontal distances, adjusted coordinates, features, attributes, symbology, etc. Many field-finish software packages can generate level/layer assignments that will be compatible with CADD packages.

7. METHODS OF DELINEATING AND DENSIFYING TOPOGRAPHIC FEATURES.

A variety of methods can be used to tie in planimetric features or measure ground elevations. Some type of systematic process is used to ensure full coverage of a job site--e.g., running cross-sections from a centerline baseline or a grid pattern. Feature accuracy will also vary: an invert elevation will be shot to 0.01 ft whereas ground shots on irregular terrain are recorded to the nearest 0.1 ft; the horizontal location of a building corner or road centerline will be to the nearest 0.01 ft but a tree can be positioned to the nearest foot.

7.1 CROSS-SECTION SURVEY METHODS. Most site plan topographic surveys are performed relative to project baselines. This is often called the "right-angle offset technique". A baseline is established along a planned or existing project axis (e.g., road centerline) using standard traverse control survey methods, as shown in Figure 2-9. Intermediate points are set and marked at regular intervals along the baseline (at 50-ft or 100-ft stations with intermediate stations added at critical points). The intermediate points are marked with 2x2 inch wooden hubs, PK nails, or temporary pins with flagging. Station hubs are occupied with a transit or total station and cross-sections are taken normal to the baseline alignment. Points along the cross-section offsets are shot for feature and/or elevation. Offset alignment is done either visually, with a right-angle glass, or transit, depending on the accuracy required. Distances along offsets are measured by chaining, stadia, or EDM (i.e., total station). Detailed notes and sketches of ground shots and planimetric features are recorded in a standard field book, electronic data collector, or both. Notekeeping formats will vary with the type of project and data being collected. General industry standard notekeeping formats should be used. Examples of selected topographic baseline notes are shown in Figures 2-10 and 2-11.

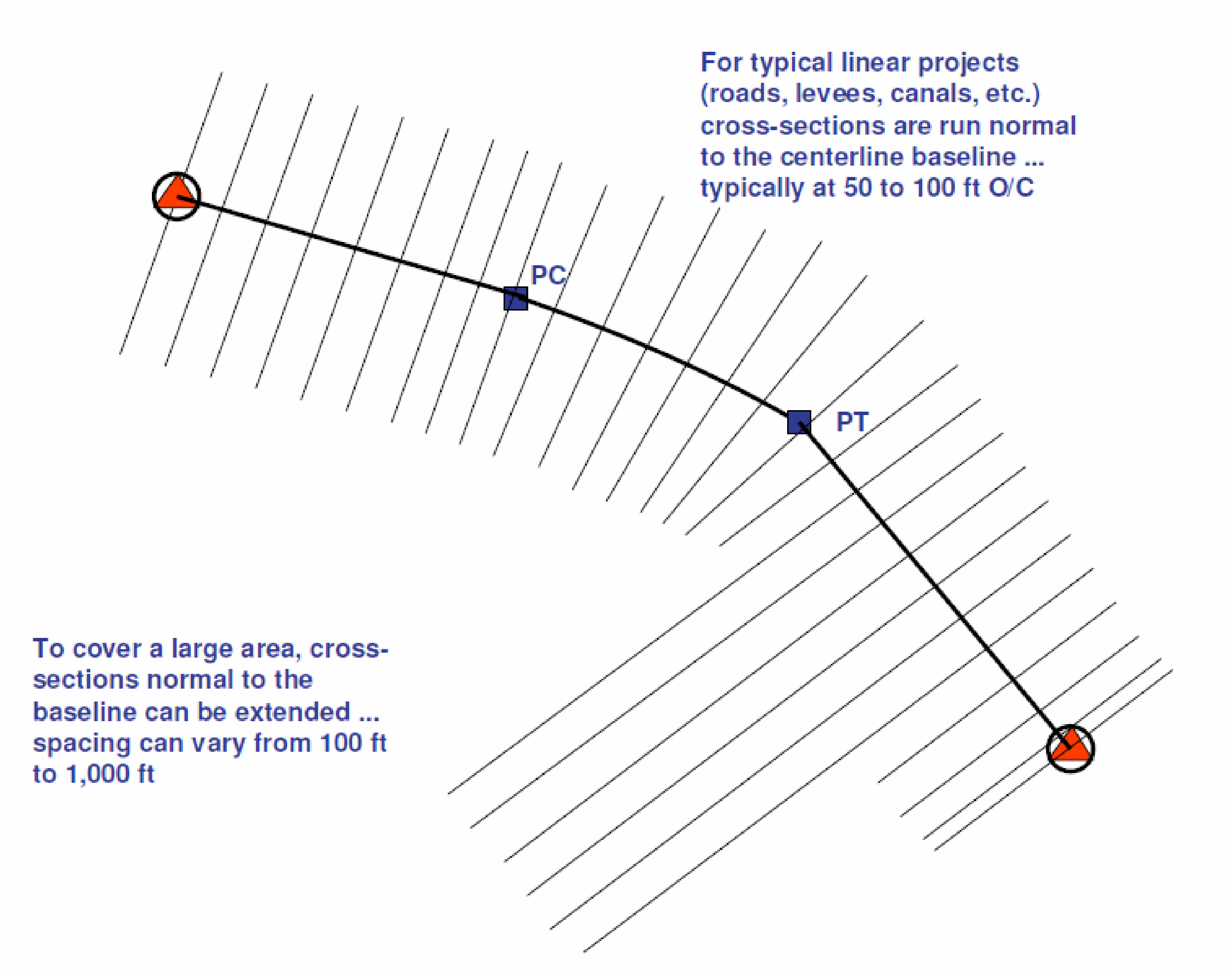


Figure 2-9

Illustration of cross-sections alignments run normal to established baselines

A grid pattern of cross-sections is also used for topographic survey of large areas, such as wetlands, orchards, swamps, etc. This is also illustrated in Figure 2-9 above where the cross-sections southeast of the PT extend a considerable distance from the baseline. In general, the maximum distance to extend the baseline is a function of the feature accuracy requirements and the precision of the survey instrument. For total stations, ground shots on a prism rod out to 1,000 ft and greater are usually acceptable. Transit stadia distances should not extend out beyond 500 ft. If coverage beyond 1,000 ft is needed, then additional baselines need to be run through the area and intermediate cross-sections should be connected between these baselines. (In current practice, this is rarely performed anymore--radial methods with a total station or RTK system are far more productive).

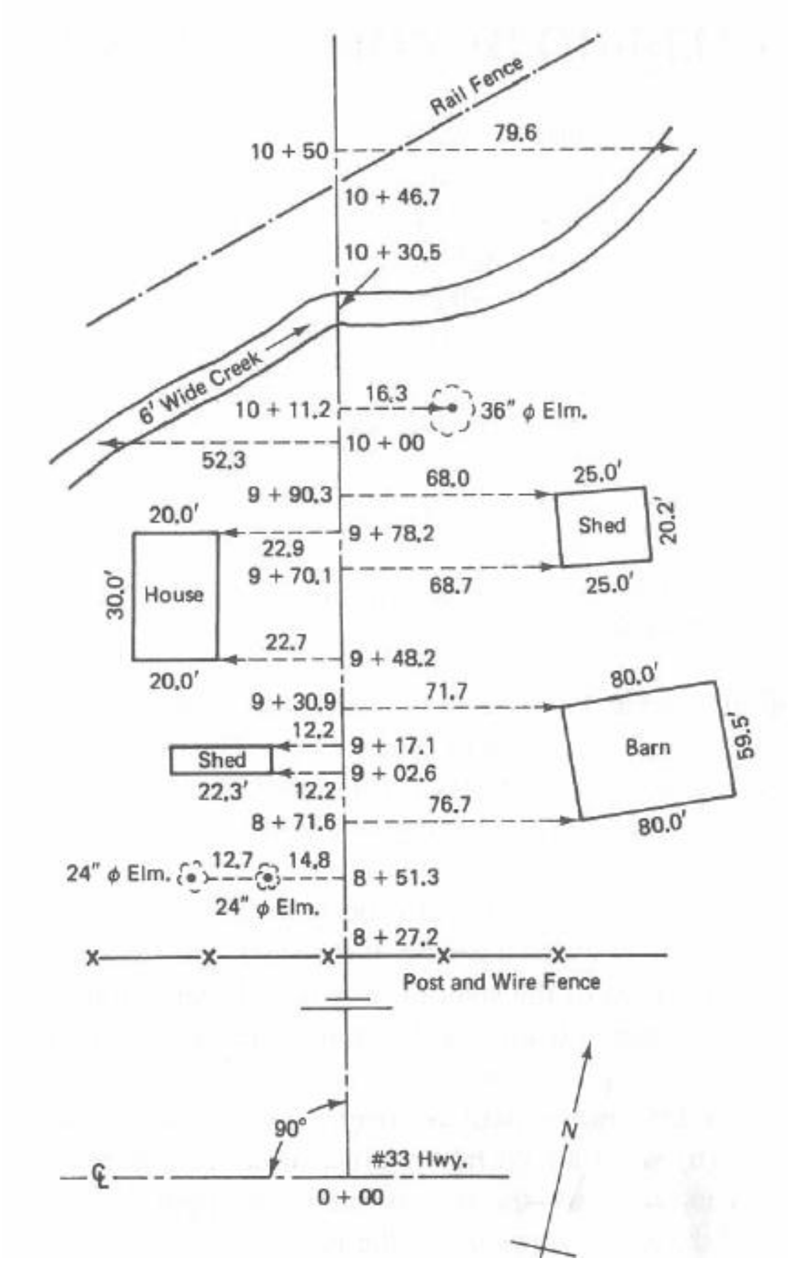
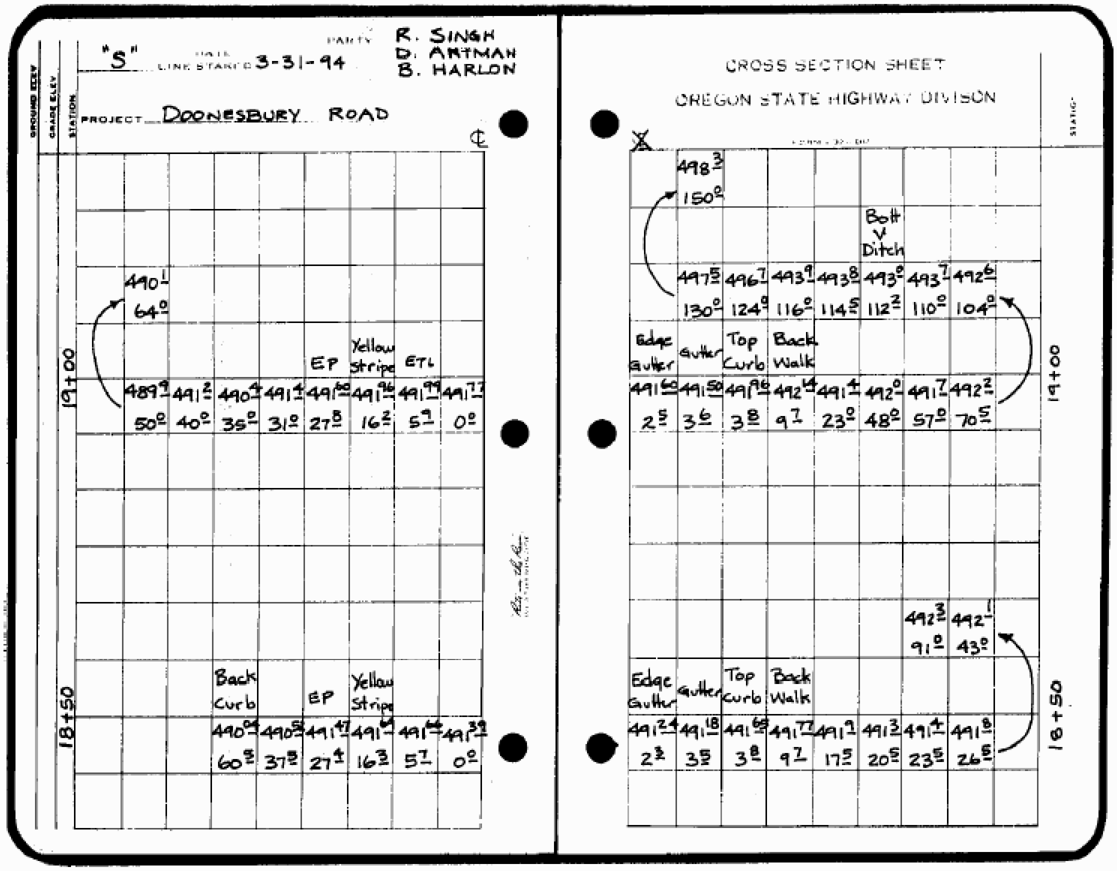


Figure 2-10

Sketch of profile line and cross-section



"S" DATE LINE STARTED 3-31-94

PARTY R. SINGH
D. ARTMAN
B. HARLON

PROJECT DOONESBURY ROAD

CROSS SECTION SHEET

OREGON STATE HIGHWAY DIVISON

19+00

490^{1} / 64^{0}

EP, Yellow Stripe, ETL

489^{9} 491^{2} 490^{4} 491^{4} 491^{60} 491^{96} 491^{99} 491^{77}

50^{0} 40^{0} 35^{0} 31^{0} 27^{8} 16^{2} 5^{9} 0^{0}

498^{3} / 150^{0}

Bott V Ditch

497^{5} 496^{7} 493^{9} 493^{8} 493^{0} 493^{7} 492^{6}

130^{0} 124^{9} 116^{0} 114^{5} 112^{2} 110^{0} 104^{0}

Edge Gutter, Gutter, Top Curb, Back Walk

491^{60} 491^{50} 491^{96} 492^{14} 491^{4} 492^{0} 491^{7} 492^{2}

2^{5} 3^{6} 3^{8} 9^{7} 23^{0} 48^{0} 57^{0} 70^{5}

18+50

Back Curb, EP, Yellow Stripe

490^{04} 490^{5} 491^{47} 491^{64} 491^{64} 491^{39}

60^{8} 37^{8} 27^{4} 16^{3} 5^{7} 0^{0}

492^{3} 492^{1} / 91^{0} 43^{0}

Edge Gutter, Gutter, Top Curb, Back Walk

491^{24} 491^{18} 491^{65} 491^{77} 491^{9} 491^{3} 491^{4} 491^{8}

2^{3} 3^{5} 3^{8} 9^{7} 17^{5} 20^{5} 23^{5} 26^{5}

Figure 2-11

Example of field book notes showing location relative to centerline and elevation data from two cross-sections spaced 50-ft C/C

7.2 RADIAL SURVEY METHODS. (Figure 2-12). Plane tables were especially suited to radial survey methods; thus, most surveys using total stations or RTK now utilize this technique. Radial observation are made with the instrument (total station or RTK base station) set up over a single point that has full project area visibility (or in the case of RTK, can encompass radio or cell phone ranges well beyond visible limitations with a total station). Thus, topographic features, baseline stakeout, and elevations be surveyed without having to occupy separate stations along a fixed baseline. COGO packages will automatically compute radial distances and azimuths to linear or curved baseline stations, and visually guide the stakeout process. RTK surveys methods are a unique form of radial survey methods—RTK controller COGO packages are used to reduce GPS observations and guide alignment. Planimetric and ground elevation coverage is performed in a systematic pattern to ensure that the project site is adequate covered. This was straightforward on a plane table--the drawing could be viewed for omissions. On electronic data collector devices, verifying coverage before breaking down the instruments is not as easy. Data collector display screens are typically small and not all field data may have been collected using "field-finish" string (polyline) type coding.

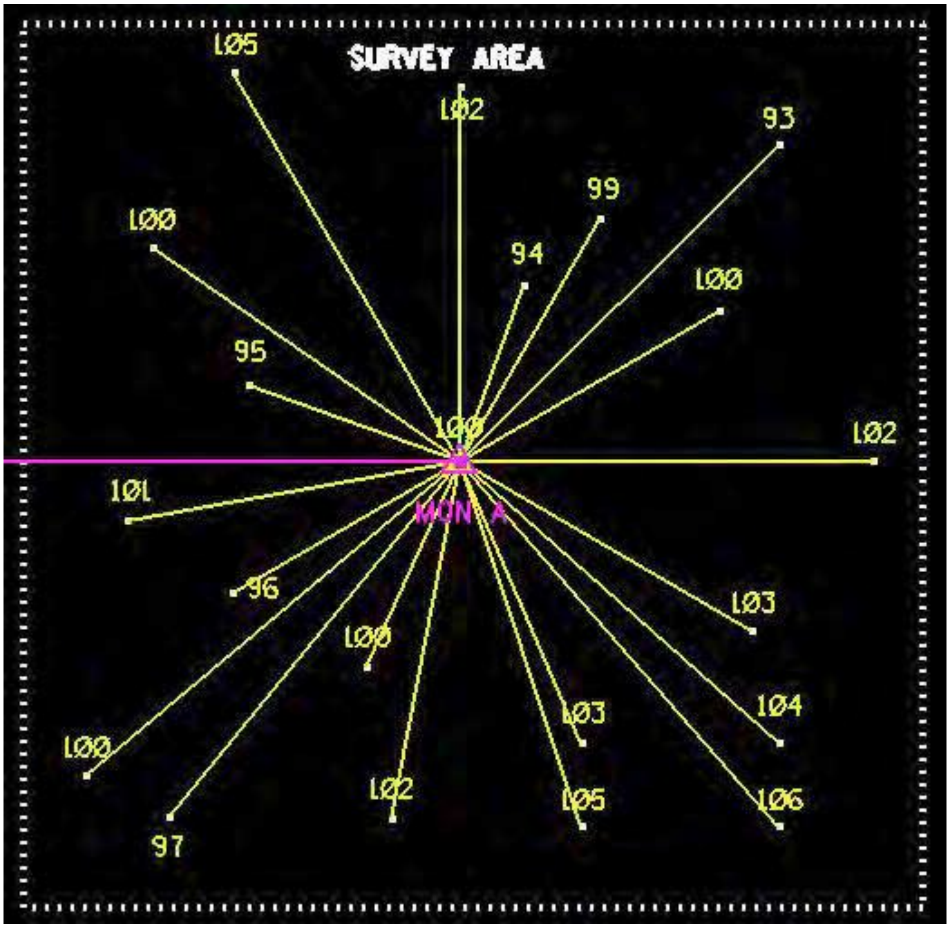


Figure 2-12

Topographic detail densification using radial survey methods--instrument set at point "MON A" and radial shot points (planimetric features or elevations) are observed

7.3 PLANIMETRIC FEATURES. Planimetric features are tied in using either cross-section or radial survey methods. The amount of detail required on a feature depends on the nature of the project and the size of the feature relative to the target scale. On small-scale topographic mapping projects, a generic symbol may be used to represent a feature; however, on a detailed drawing for this same project, the feature may be fully dimensioned. An example would be a 3 ft x 5 ft catch basin: on a 1inch = 400 ft scale map, this basin would be represented by a symbol at its center point but might be surveyed in detail (all four corner points located) on a 1inch = 30 ft site plan.

7.4 TOPOGRAPHIC ELEVATIONS AND CONTOURS. A variety of survey methods are used to develop the terrain model for a given project area. The technique employed is a function of the type of survey equipment, the detail required, and specified elevation accuracy. In addition, the technique may depend on whether traditional contours or a digital terrain model (DTM) is required.

7.5 CONTOURS FROM CROSS-SECTIONS. Contours can be directly surveyed on the ground or derived from a terrain model of spot elevations. When cross-section methods are employed, even contour intercepts along the offsets can be set in the field using a level rod. Alternatively, elevations can be taken at intervals along the cross-section where changes in grade or breaklines occur, and contour intercepts interpolated over the linear portions. If abrupt changes in grade (or breaks in grade) occur between crosssection stations, then supplemental cross-sections may be needed to better represent the terrain and provide more accurate cut/fill quantity takeoffs.

7.6 CONTOURS FROM RADIAL SURVEYS--SPOT ELEVATION MATRICES. It is often more efficient to generate contours from a DTM based on spot elevations taken over a project area. These surveys are normally done with a total station or RTK system; however, older transit-stadia or plane table methods will also provide the same result. The density of spot elevations is based on the desired contour interval and terrain gradient. In some instances, an evenly spaced grid of spot elevations may be specified (so-called "post" spacing). Flat areas require fewer spots to delineate the feature. Breaklines in the terrain are separately surveyed to ensure the final terrain model is correctly represented. Data points can be connected using triangular irregular network

(TIN) methods and contours generated directly from the TIN in various CADD packages (MicroStation InRoads, AutoCAD, etc.). The generated DTM or TIN also provides a capability to perform "surface-to-surface" volume computations.

7.7 DTM GENERATION FROM BREAKLINE SURVEY TECHNIQUE. The following guidance is excerpted from the California Department of Transportation (CALTRANS) Surveys Manual. It describes a technique used by CALTRANS to develop DTMs on total station topographic surveys. A DTM is a representation of the surface of the earth using a triangulated irregular network (TIN). The TIN models the surface with a series of triangular planes. Each of the vertices of an individual triangle is a coordinated (x,y,z) topographic data point. The triangles are formed from the data points by a computer program which creates a seamless, triangulated surface without gaps or overlaps between triangles. Triangles are created so that their sides do not cross breaklines. Triangles on either side of breaklines have common sides along the breakline. Breaklines define the points where slopes change in grade (the intersection of two planes). Examples of breaklines are the crown of pavement, edge of pavement, edge of shoulder, flow line, top of curb, back of sidewalk, toe of slope, top of cut, and top of bank. Breaklines within existing highway rights of way are clearly defined, while breaklines on natural ground are more difficult to determine. DTMs are created by locating topographic data points that define breaklines and random spot elevation points. The data points are collected at random intervals along longitudinal break lines with observations spaced sufficiently close together to accurately define the profile of the breakline. Like contours, break lines do not cross themselves or other break lines. Cross-sections can be generated from the finished DTM for any given alignments. Method: When creating field-generated DTMs, data points are gathered along DTM breaklines, and randomly at spot elevation points, using the total station radial survey method. This method is called a DTM breakline survey. Because the photogrammetric method in most cases is more cost effective, gathering data for DTMs using field methods should be limited to small areas or to provide supplemental information for photogrammetrically determined DTMs. The number of breaklines actually surveyed can be reduced for objects of a constant shape such as curbs. To do this, a standard cross section for such objects is sketched and made part of the field notes. Field-collected breaklines are identified by line numbers and type on the sketch along with distances and changes in elevation between the breaklines. With this information in the field notes, only selected breaklines need to be located in the field, while others are generated in the office based on the standard cross section. Advantages of DTM breakline surveys:

- Safety of field crews is increased because need to continually cross traffic is eliminated.
- Observations at specific intervals (stations) are not required.
- New sets of cross sections can be easily created for each alignment change.

DTM survey guidelines:

- Remember to visualize the TIN that will be created to model the ground surface and how breaklines control placement of triangles.
- Use proper topo codes, point numbering, and line numbers.
- Use a special terrain code (e.g., 701) for critical points between breaklines, around drop
- Inlets and culverts, and on natural ground in relatively level areas.
- Make a sketch of the area to be surveyed identifying breaklines by number.
- Do not change breakline codes without creating a new line.
- Take shots on breaklines at approximately 20 m intervals and at changes in grade.
- Locate data points at high points and low points and on a grid of approximately 20 m centers when the terrain cannot be defined by breaklines.
- If ground around trees is uniform, tree locations may be used as DTM data points by using a terrain code of 701.
- Keep site distances to a length that will ensure that data point elevations meet desired
- Accuracies.
- Gather one extra line of terrain points 5 to 10 m outside the work limits.

Accuracy Standard: Data points located on paved surfaces or any engineering works should be located within ±10 mm horizontally and ± 7 mm vertically. Data points on original ground should be located within ± 30 mm horizontally and vertically.

Checking: Check data points by various means including reviewing the resultant DTM, reviewing breaklines in profile, and locating some data points from more than one setup.

Products: The surveys branch is responsible for developing and delivering final, checked engineering survey products, including DTMs, to the survey requestors. Products can be tailored to the needs of the requestor whenever feasible, but normally should be kept in digital form and include the following items:

- Converted and adjusted existing record alignments, as requested. (CAiCE project subdirectory)
- Surveyed digital alignments of existing roadways and similar facilities. (CAiCE project subdirectory)
- CAiCE DTM surface files. (CAiCE project subdirectory)
- 2-D CADD MicroStation design files, .dgn format.
- Hard copy topographic map with border, title block, labeled contours, and planimetry.
- File of all surveyed points with coordinates and descriptions. (CTMED, .rpt, format)

7.8 UTILITY SURVEY DETAIL METHODS. It is important to locate all significant utility facilities. Utilities are surveyed using either total station or RTK techniques. The CALTRANS Surveys Manual recommends that accuracy specifications for utilities that are data points located on paved surfaces or any engineering works should be located within ±10 mm horizontally and ±7 mm vertically. Data points on original ground should be located within ±30 mm horizontally and vertically. The following are lists of facilities and critical points to be located for various utilities--as recommended in the CALTRANS Surveys Manual.

Oil and Gas Pipelines

- Intersection point with centerlines and/or right of way lines
- For lines parallel to right of way – location ties necessary to show relationship to the right of way lines
- Vents
- Angle points
- Meter vaults, valve pits, etc.

Water and Sewer Lines

- Intersection point with centerlines and/or right of way lines
- For lines parallel to right of way – location ties necessary to show relationship to the right of way lines
- Manholes, valve boxes, meter pits, crosses, tees, bends, etc.
- Elevation on waterlines, sewer inverts, and manhole rings
- Fire hydrants
- Curb stops
- Overhead Lines
- Supporting structures on each side of roadway with elevation of neutral or lowest conductor at each centerline crossing point.
- On lines parallel to roadway, supporting structures that may require relocation, including overhead guys, stubs, and anchors

Underground Lines

- Cables/lines (denote direct burial or conduit, if known), etc.
- Manholes, pull boxes, and transformer pads
- Crossing at centerline or right of way lines
- For lines parallel to right of way – location ties as necessary to show relationship to the right of way lines
- Railroads
- Profile and location 60 m each side of the proposed roadway right of way lines

- Switch points, signal, railroad facilities, communication line locations, etc.

Checking: Utility data should be checked by the following means:

- Compare field collected data with existing utility maps
- Compare field collected data with the project topo map/DTM
- Review profiles of field collected data
- Include field collected data, which have elevations, in project DTM
- Locate some data points from more than one setup

7.9 ARCHAEOLOGICAL SITE/ENVIRONMENTALLY SENSITIVE AREA SURVEYS (CALTRANS). Archaeological and environmental site surveys are performed for planning and engineering studies. Surveys staff must work closely with the appropriate specialists and the survey requestor to correctly identify archeological and environmentally sensitive data points.

Method: Total station radial survey, GPS fast-static, kinematic, or RTK. Accuracy Standard: Data points located on paved surfaces or engineering works should be located within ±10 mm horizontally and ±7 mm vertically. Data points on original grounds should be located within ±30 mm horizontally and vertically. Review field survey package for possible higher required accuracy.

Checking: Check data points by various means including, reviewing the resultant DTM, reviewing breaklines in profile, and locating some data points from more the one setup.

Products:

- 3-D digital graphic file of mapped area
- Hard copy topographic map with border, title block, and planimetry (contours and elevations only if specifically requested)
- File of all surveyed points with coordinates and descriptions

7.10 SPOT LOCATION OR MONITORING SURVEYS (CALTRANS). Monitoring surveys are undertaken for monitoring wells, bore hole sites, and other needs.

Method: Total station radial survey, GPS fast static or kinematic

Accuracy Standard: Data points located on paved surfaces or any engineering works should be located within ±10 mm horizontally and ±7 mm vertically. Data points on original ground should be located within ±30 mm horizontally and vertically.

Checking: Observe data points with multiple ties.

Products:

- File of all surveyed points with coordinates and descriptions
- Sketch or map showing locations of data points

7.11 VERTICAL CLEARANCE SURVEYS (CALTRANS). Vertical clearance surveys are undertaken to measure vertical clearances for signs, overhead wires, and bridges.

Method: Total station radial method.

Accuracy Standard: Data points located on paved surfaces or any engineering works should be located within ±10 mm horizontally and ±7 mm vertically. Data points on original ground should be located within ±30 mm horizontally and vertically.

Checking: Observe data points with multiple ties.

Products:

- File of all surveyed points with coordinates and descriptions
- Sketch or map showing vertical clearances