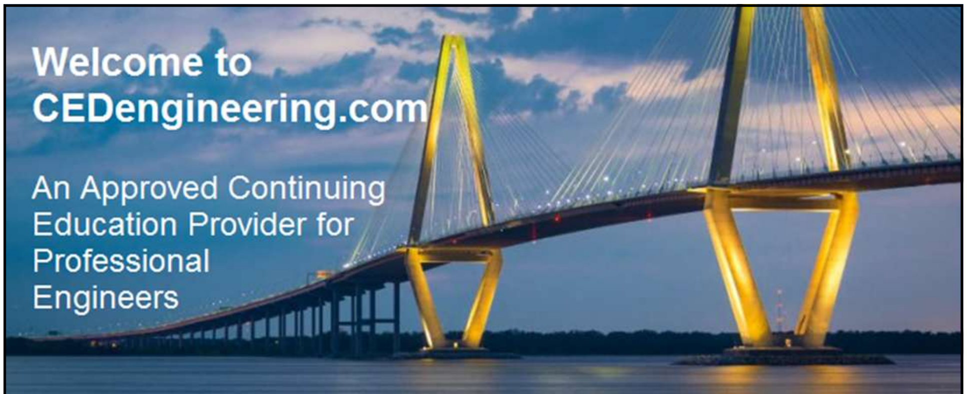

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CONTROL AND TOPOGRAPHIC SURVEYING

Course No: L03-306 - Course Credit: 3 PDH

Prepared by:

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Hosted by:

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LEARNING OBJECTIVES

1. To understand vertical reference systems, including NGVD 29, NAVD 88, and other vertical datums, and their role in defining elevation in surveying projects.
2. To explain orthometric elevations, WGS 84 ellipsoidal heights, and their relationship through geoid models and geoid undulations.
3. To explore methods for determining and transforming elevations, including GPS-based techniques, vertical datum transformations, and transition strategies between datums.
4. To examine the planning and execution of control and topographic surveys, including project requirements, data sources, and survey design considerations.
5. To analyze methods for establishing and extending survey control using NSRS, local networks, CORS, and OPUS.
6. To understand the role of field data collectors and coordinate geometry (COGO) functions in recording, processing, and computing survey data in the field.

GEODETIC REFERENCE DATUMS AND LOCAL COORDINATE SYSTEMS

SECTION III. Vertical Reference Systems

- A vertical datum is the surface to which elevations or depths are referred to or referenced.
- There are many vertical datums used within CONUS.
- The surveyor should be aware of the vertical control datum being used and its practicability to meet project requirements. .

National Geodetic Vertical Datum of 1929 (NGVD 29)

- NGVD 29 was established by the United States Coast and Geodetic Survey (USC&GS) 1929 General Adjustment by constraining the combined US and Canadian First Order leveling nets to conform to Mean Sea Level (MSL).
- It was determined at 26 long-term tidal gage stations that were spaced along the east and west coast of North American and along the Gulf of Mexico, with 21 stations in the US and 5 stations in Canada.
- NGVD 29 was originally named the Mean Sea Level Datum of 1929.
- It was known at the time that the MSL determinations at the tide gages would not define a single equipotential surface because of the variation of ocean currents, prevailing winds, barometric pressures, and other physical causes.

- The name of the datum was changed from the Mean Sea Level Datum to the NGVD 29 in 1973 to eliminate the reference to sea level in the title.
- This was a change in name only; the definition of the datum established in 1929 was not changed.
- Since NGVD 29 was established, it has become obvious that the geoid based upon local mean tidal observations would change with each measurement cycle.
- Estimating the geoid based upon the constantly changing tides does not provide a stable estimate of the shape of the geoid.

North American Vertical Datum of 1988 (NAVD 88)

- The NAVD 88 datum is the product of a vertical adjustment of leveled height difference measurements made across North America.
- This reference system supersedes the NGVD 29 vertical reference framework.
- NAVD 88 was constrained by holding fixed the orthometric height of a single primary tidal benchmark at Father's Point / Rimouski, Quebec, Canada and performing a minimally constrained general adjustment of US-Canadian-Mexican leveling observations.
- Most Third Order benchmarks, including those of other Federal, state and local government agencies, were not included in the NAVD 88 adjustment.
- The vertical reference surface is therefore defined by the surface on which the gravity values are equal to the control point value.

- NAVD 88 elevations are published orthometric heights that represent the geometric distance from the geoid to the terrain measured along the plumb line.
- Orthometric height corrections were used to enforce consistency between geopotential based vertical coordinates and measured leveled differences.
- NAVD 88 is the most compatible vertical reference frame available to relate GPS ellipsoidal heights to orthometric heights.
- Note also that NGVD 29 is no longer supported by NGS; thus, USACE commands should be transitioning all older project vertical control to NAVD 88.
- The differences in orthometric elevations between the superseded NGVD 29 and NAVD 88 references are significant--upwards of 1.5 meters in places, as depicted in the figure on the following slide.
- Therefore, it is important that these two reference systems not be confused.
- Given the local variations, there is no direct transformation between the two systems, and a site calibration/transformation must be performed as explained in subsequent sections.

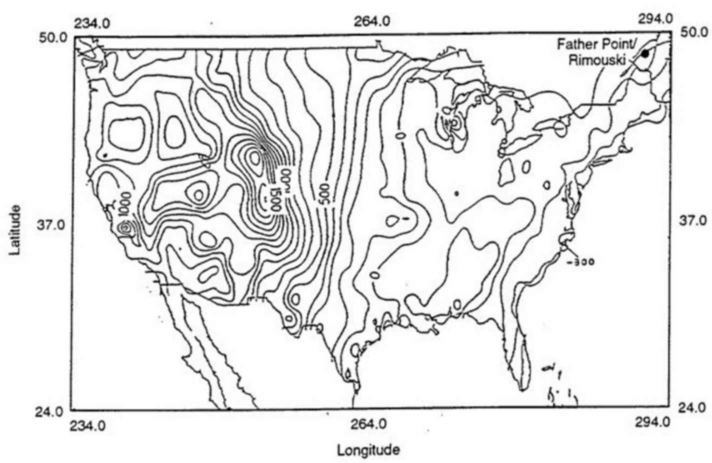

Figure 1: NGVD 29-NAVD 88 elevation differences in mm.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

- The Federal Geodetic Control Subcommittee (FGCS) of the Federal Geographic Data Committee (FGDC) has affirmed that NAVD 88 shall be the official vertical reference datum for the US.
- The FGDC has prescribed that all surveying and mapping activities performed or financed by the Federal Government make every effort to begin an orderly transition to NAVD 88, where practicable and feasible.

Other Vertical Reference Datums and Planes

- a. Mean Sea Level datums.
    - Some vertical datums are referenced to mean seal level.
    - Such datums typically are maintained locally or within a specific project area.
    - The theoretical basis for these datums is local mean sea level.
    - Local MSL is a vertical datum based on observations from one or more tidal gaging stations.
    - NGVD 29 was based upon the assumption that local MSL at 21 tidal stations in the US and 5 tidal stations in Canada averaged 0.0 ft on NGVD 29.
    - The value of MSL as measured over the Metonic cycle of 19 years shows that this assumption is not valid and that MSL varies from station to station.

- b. Great Lake datums.
  - Depths in the Great Lakes and connecting channels are referenced to the International Great Lakes Datum (IGLD) of 1985.
  - IGLD 85 represents a low water datum from which navigation is maintained.
  - A separate datum is established for each of the Great Lakes.
  - The datum must be adjusted for slope in the connecting channels between the Great Lakes.
  - These datums undergo periodic adjustment.
  - For example, the IGLD 55 was adjusted in 1985 to produce IGLD 85.
  - IGLD 85 has been directly referenced to NAVD 88 and originates at the same point as NAVD 88.

- c. Other vertical datums.
  - Other areas may maintain and employ specialized vertical datums.
  - For instance, vertical datums maintained in Alaska, Puerto Rico, Hawaii, the Virgin Islands, Guam, and other islands and project areas.
  - Specifications and other information for these particular vertical datums can be obtained from the particular District responsible for survey related activities in these areas, or the National Ocean Service (NOS).

- d. Tidal areas.
  - Tidal datums usually are defined by the range and phase of the tide and usually are referenced to a mean lower low water elevation, or MLLW.
  - In offshore coastal areas, CONUS navigation projects are generally referenced to a MLLW datum established by NOS or the Corps from long-term gage observations.
  - This MLLW reference plane is not a flat surface but slopes as a function of the tidal range in the area.
  - Tidal range can increase or decrease near coastal entrances; thus the MLLW must be accurately modeled throughout the navigation project.
  - The required grade at all points on the navigation project is dependent on tidal modeling--requiring determination of the elevation of the MLLW datum plane from a series of gage observations at each point.

- e. Inland river areas.
  - River datums are usually referenced to a low water reference plane (LWRP), such as the LWRP 1974 reference used in the unregulated portion of the Mississippi River.
  - Like tidal MLLW, the low water river datum must be determined from gage/staff observations at sufficient points along the river to adequately define the surface.
  - The spacing of these observations must be sufficient to allow linear interpolation between staff gage points.
  - For a river like the Mississippi that drops 0.5 ft/mile, gages or benchmarks may be required at least every quarter- to half-mile in order to reference hydrographic surveys.

- f. Controlled river pools.
    - Between river control structures, low water pools are used to reference maintained navigation depths.
    - Since these pools themselves may exhibit some slope, sufficient gages/benchmarks within the pools should be established to account for any minor slope.
- g. Reservoir pools.
    - Depths in controlled reservoirs are usually referenced to a national vertical datum (e.g., NGVD 29 or NAVD 88).

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Orthometric Elevations

- Orthometric elevations are those corresponding to the earth's irregular geoidal surface, as illustrated in the figure below.

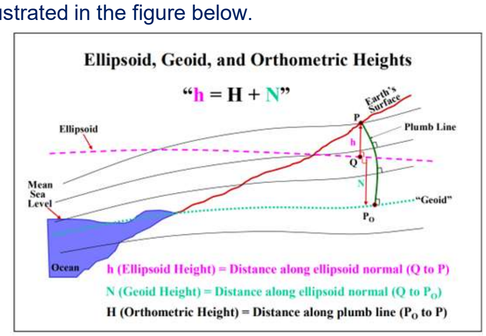

Figure 2: Ellipsoid, geoid, and orthometric surface definitions and relationships (NGS).

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

- Measured differences in elevation from spirit leveling are generally relative to the local geoidal surface--a spirit level bubble (or pendulum) positions the instrument normal to the direction of gravity, and thus parallel with the local slope of the geoid, which approximates mean sea level near coastal points.
- The orthometric height of a point is the distance from the geoid (or a related reference surface) to the point on the earth's surface, measured along the line perpendicular to every equipotential surface in between.
- A series of equipotential surfaces can be used to represent the gravity field.
- One of these surfaces, the geoid, is specified as the reference system from which orthometric heights are measured.
- The geoid itself is defined as an equipotential surface.
- Natural variations in gravity induce a smooth, continuous, curvature to the plumb line, and therefore physical equipotential surfaces which are normal to gravity do not remain geometrically parallel over a given vertical distance (the plumb line is not quite parallel to the ellipsoidal normal).

- Elevation differences between two points are orthometric differences, a distinction particularly important in river/channel hydraulics.
- Orthometric heights for the continental United States (CONUS) are generally referenced to the NGVD 29 or the updated NAVD 88.
- The NGVD 29 reference datum more closely approximates mean sea level--the NAVD 88 does not.
- Tidal reference datums (e.g., MLLW) vary geographically over short distances and must be accurately related to NAVD 88 and/or NGVD 29 orthometric heights.
- GPS derived ellipsoidal heights shown in Figure 2 must be converted to local orthometric elevations in order to have useful engineering and construction value.
- This transformation is usually done by a form of "site calibration" using known orthometric elevations of fixed benchmarks and/or geoid undulation models for the project area.
- These transforms are further explained below.

WGS 84 Ellipsoidal Heights

- GPS-determined heights (or height differences) are referenced to an idealized mathematical ellipsoid which differs significantly from the geoid; thus, GPS heights are not the same as the orthometric heights needed for standard USACE projects (local engineering, construction, and hydraulic measurement functions).
- Accordingly, any WGS 84 referenced ellipsoidal height obtained using GPS must be transformed or calibrated to the local orthometric vertical datum.
- This requires adjusting and interpolating GPS-derived heights relative to fixed orthometric elevations.

- Over short distances--less than 1 km--elevation differences determined by GPS can usually be assumed to be orthometric differences.
- These elevation differences would then be of sufficient accuracy for topographic site plan mapping, such as those acquired using RTK total station methods.
- However, at greater distances, a site calibration with surrounding benchmarks must be performed in order to adjust RTK ellipsoidal heights down to the local vertical datum.
- For some surveys (e.g., offshore navigation), a predicted geoid model may be used if no other vertical control is available to calibrate the model.

Orthometric Height and WGS 84 Ellipsoidal Elevation Relationship

- Geoidal heights represent the geoid-ellipsoid separation distance and are obtained by taking the difference between ellipsoidal and orthometric height values.
- Knowledge of the geoid height enables the evaluation of vertical positions in either the geodetic (ellipsoid based) or the orthometric height system.
- The relationship between a WGS 84 ellipsoidal height and an orthometric height relative to the geoid can be obtained from the following equation, and depicted graphically in Figure 2.

$$h = H + N$$

- where
  - o h = ellipsoidal height (WGS 84)
  - o H = elevation (orthometric--normal to geoid)
  - o N = geoidal undulation above or below the WGS 84 ellipsoid
- and by convention the geoid undulation "N" being a positive height above the ellipsoid.

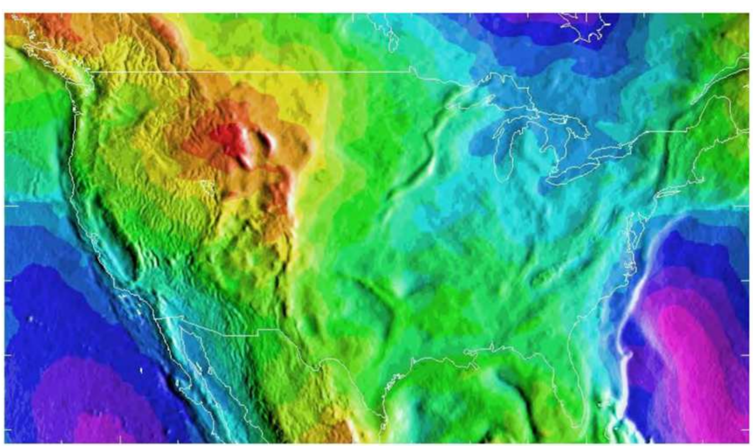

Figure 3: Geoid undulation model of North America--depicts geoid undulation N relative to the WGS 84 ellipsoid.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

Geoid Undulations and Geoid Models

- Due to significant variations in the geoid, sometimes even over small distances, elevation differences obtained by GPS cannot be directly equated to orthometric (or spirit level) differences.
- This geoid variation is depicted as a surface model in Figure 3.
- Geoid modeling techniques are used to obtain the parameter "N" in the above equation from which ellipsoidal heights can be converted to orthometric elevations.
- These geoid models (e.g., Geoid 90, Geoid 93, Geoid 96, Geoid 99, Geoid 03, etc.) are approximations based on observations by the NGS.
- Each successive geoid model is more accurate.
- In time, these models may improve to centimeter-level accuracy.
- On some small project areas where the geoid stays relatively constant, elevation differences obtained by GPS can be directly used without geoid correction.
- Geoid models are not compatible with the superseded NGVD 29.

- a. Geoid height values at stations where either only " h "or " H " is known can be obtained from geoid models which are mathematical surfaces representing the shape of the earth's gravity field.
  - The geoid model is constructed from a truncated functional series approximation using a spherical harmonics expansion and an extensive set of globally available gravity data.
  - The model is determined from the unique coefficients of the finite series representing the geoid surface.
  - Its accuracy depends on the coverage and accuracy of the gravity measurements used as boundary conditions.
  - Former geoid models produced for general use limit absolute accuracies for geoid heights to no less than 1 meter.
  - More recent geoid models have shown a significant increase in absolute accuracy for geoid heights to a few centimeters.

- b. In practice the shape of the geoid surface is estimated globally as a function of horizontal coordinates referenced to a common geocentric position.
    - Specific geoid height values are extracted from the model surface at the node points of a regular grid (e.g., a 2-minute x 2-minute grid spacing).
    - Biquadratic interpolation procedures can be used within a grid cell boundary to approximate the geoid height at a given geodetic latitude and longitude.
    - For example, the NGS GEOID 96 model for the United States indicates geoid heights (N) range from a low of (-) 51.6 meters in the Atlantic to a high of -7.2 meters in the Rocky Mountains.

- c. GPS surveys can be designed to provide elevations of points on any local vertical datum.
    - This requires connecting to a sufficient number of existing orthometric benchmarks from which the elevations of unknown points can be "best-fit" or "site calibrated" by some adjustment method--usually a least squares minimization.
    - This is essentially an interpolation process and assumes linearity in the geoid slope between two established benchmarks.
    - If the geoid variation is not linear--as is typically the case--then the adjusted (interpolated) elevation of an intermediate point will be in error.
    - Depending on the station spacing, location, local geoid undulations, and numerous other factors, the resultant interpolated/adjusted elevation accuracy is usually not suitable for accurate (i.e., ± 0.01 ft) construction surveying purposes; however, GPS-derived elevations may be adequate for small-scale topographic mapping control and hydrographic surveying applications where ± 0.1 ft accuracy is sufficient.

Using GPS to Densify Orthometric Elevations

- DGPS observation sessions produce 3-D geodetic coordinate differences that establish the baseline between two given stations.
- The expected accuracy of ellipsoidal height difference measurements is based on several factors, such as GPS receiver manufacture type, observation session duration, and the measured baseline distance, but it does not depend greatly on prior knowledge of the absolute vertical position of either occupied station.
- Dual frequency, carrier phase measurement based GPS surveys are usually able to produce 3-D relative positioning accuracies under 30 mm at the 95% confidence level over baseline distances less than 20 km, depending on the type of GPS surveying method used.
- This situation exists mainly because GPS range biases are physically well correlated over relatively short distances and tend to cancel out as a result of forming double differences for carrier phase data processing.

- In contrast, GPS absolute code positioning accuracy will contain the full effects of any GPS range measurement errors.
- Geoidal height differences describe the change in vertical position of the geoid with respect to the ellipsoid between two stations.
- These relative geoidal heights can be more accurate than the modeled absolute separation values within extended areas because the relative geoidal height accuracy is based on the continuous surface characteristics of the geoid model, where only small deviations between closely spaced points would be expected.
- The regional trend or slope of the geoid at a given point will not be highly sensitive to local gravity anomalies especially in non-mountainous areas.

- Differential GPS can accurately measure ellipsoidal height differences from GPS satellites.
- GPS surveys output vertical positions in geodetic coordinates defined with respect to the WGS 84 reference ellipsoid.
- The ellipsoidal height value at a given point is based on the distance measured along the normal vector from the surface of the reference ellipsoid to the unknown point.
- The practical accuracy of WGS 84 as a vertical reference frame for collecting elevation data depends on the actual ellipsoidal height values assigned to benchmarks or other physically defined control points.

Vertical Datum Transformations

- There are several reasons for USACE commands to convert authorized and future projects to NAVD 88.
  - Differential leveling surveys will close better.
  - NAVD 88 height values are available in convenient form from the NGS database.
  - Federal surveying and mapping agencies will stop publishing on NGVD 29.
  - NAVD 88 is recommended by ACSM and FGCS.
  - Surveys performed for the Federal government require use of NAVD 88.
  - NAVD 88 provides a reference to estimate GPS derived orthometric heights.
- The last bullet above is a primary reason for transforming project control to NAVD 88.
- The conversion process entails one of two levels of effort.
  - (1) Conversion of all elevations to NAVD 88 by readjustment or releveling.
  - (2) Adding a datum note based on an approximate conversion (VERTCON).

- a. VERTCON.
  - VERTCON is a software program developed by NGS that converts elevation data from NGVD 29 to NAVD 88.
  - Although the VERTCON software has been fully incorporated into the software application package CORPSCON, it will be referred to below as a separate program.
  - VERTCON uses benchmark heights to model the shift between NGVD 29 and NAVD 88 that is applicable to a given area.
  - In general, it is only sufficiently accurate to meet small-scale mapping requirements.
  - VERTCON should not be used for converting benchmark elevations used for site plan design or construction applications.
  - Users input the latitude and longitude for a point and the vertical datum shift between NGVD 29 and NAVD 88 is reported.
  - The root-mean-square (RMS) error of NGVD 29 to NAVD 88 conversion, when compared to the stations used to create the conversion model, is ±1 cm; with an estimated maximum error of ± 2.5 cm.
  - Depending on network design and terrain relief, larger differences (e.g., 5 to 50 cm) may occur the further a benchmark is located from the control points used to establish the model coefficients.
  - For this reason, VERTCON should only be used for approximate conversions where these potential errors are not critical.

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- b. Datum note.
  - henever maps, site drawings, or spatial elevation data are provided to nonUSACE users, they should contain a datum note that provides, at minimum, the following information:
    - *The elevations shown are referenced to the *[NGVD 29] [NAVD 88] and are in *[feet] [meters]. Differences between NGVD 29 and NAVD 88 at the center of the project sheet/data set are shown on the diagram below. Datum conversion was performed using the *[program VERTCON] [direct leveling connections with published NGS benchmarks] [other]. Metric conversions are based on *[US Survey Foot = 1200/3937 meters] [International Survey Foot = 0.3048 meters].*

Vertical Transition Plan from NGVD 29 to NAVD 88

- a. General.
  - A change in the vertical datum on a project will affect USACE engineering, construction, planning, and surveying activities.
  - The cost of conversion could be substantial at the onset.
  - There is a potential for errors in conversions inadvertently occurring.
  - The effects of the vertical datum change can be minimized if the change is gradually applied over time; being applied to future projects and efforts, rather than concentrated on changing already published products.
  - In order to insure an orderly and timely transition to NAVD 88 is achieved for the appropriate products, the following general guidelines should be followed.

- b. Conversion criteria.
  - Maps, engineering site drawings, documents, and associated spatial data products containing elevation data may require conversion to NAVD 88.
  - Specific requirements for conversion will, in large part, be based on local usage--e.g., that of the local sponsor, installation, etc.
  - Where applicable and appropriate, this conversion should be recommended to local interests.

- c. Newly authorized construction projects.
    - Generally, initial surveys of newly authorized projects should be referenced to NAVD 88.
    - In addition to design/construction, this would include wide-area master plan mapping work.
    - The project control should be referenced to NAVD 88 using conventional or GPS surveying techniques.
    - All planning and design activities should be based upon NAVD 88.
    - All maps and site drawings shall contain datum notes.
    - If the sponsor/installation requires the use of NGVD 29 or some other local vertical reference datum for continuity, the relationship between NGVD 29 and NAVD 88 shall be clearly noted on all maps, engineering site drawings, documents, and associated products.

- d. Active projects.
    - On active projects where maps, site drawings, or elevation data are provided to non-USACE users, the conversion to NAVD 88 should be performed.
    - This conversion to NAVD 88 may be performed the next time the project is surveyed or when the maps/site drawings are updated for other reasons.
    - Civil works projects may be converted to NAVD 88 during the next maintenance or repair cycle in the same manner as for newly initiated civil works projects.
    - However, if resources are not available for this level of effort, redraw the maps or drawings and add the necessary datum note.
    - Plans should be made for the full conversion during a later maintenance or repair cycle when resources can be made available.
    - Military installations should remain on NGVD 29 or the local vertical datum until a thoroughly coordinated effort can be arranged with the MACOM and installation.
    - An entire installation's control network should be transformed simultaneously to avoid different datums on the same installation.
    - MACOMs should be encouraged to convert to NAVD 88.
    - However, the respective MACOMs are responsible for this decision.

- e. Inactive projects.
  - For inactive projects or active projects where maps, site drawings, or elevation data are not normally provided to non-USACE users, conversion to NAVD 88 is optional.
- f. Work for others.
  - Projects for other agencies will remain on NGVD 29 or the current local vertical datum until a thoroughly coordinated effort can be arranged with the sponsoring agency.
  - Other agencies should be encouraged to convert their projects to NAVD 88, although the decision to convert rests with the sponsoring agency.
  - However, surveys, maps, and drawings should have the datum note described below added before distribution to non-USACE users.
  - If sponsoring agencies do not indicate a preference for new projects, NAVD 88 should be used.

- g. Miscellaneous projects.
  - Other projects referenced to strictly local datum, such as, beach nourishment, submerged offshore disposal areas, historical preservation projects, etc., need not necessarily be converted to NAVD 88.
  - However, it is recommended that surveys, maps and drawings have a clear datum reference note added before distribution to non-USACE users.

- h. Real Estate.
  - Surveys, maps, and plats prepared in support of civil works and military real estate activities should conform as much as possible to state requirements.
  - Many states are expected to adopt NAVD 88 (by statute) as an official vertical reference datum.
  - This likewise will entail a transition to NAVD 88 in those states.
  - State and local authorities should therefore be contacted to ascertain their current policies.
  - Note that several states have adopted the International Foot for their standard conversion from meters to feet.
  - In order to avoid dual elevations on USACE survey control points that have multiple uses, it is recommended that published elevations be based on the US Survey Foot.
  - In states where the International Foot is the only accepted standard for boundary and property surveys, conversion of these elevations to NAVD 88 should be based on the International Foot while the control remains based on the US Survey Foot.

Vertical Control in Areas Subjected to Subsidence or Sea Level Rise

- Published elevations relative to the vertical datums in high subsidence areas must be used with caution.
- This is due to the uneven temporal and spatial movement of the land.
- Thus, any geodetic or terrestrial-based elevation is not constant and must be periodically observed and adjusted for local subsidence.
- Likewise, hydraulic or sea level based reference datums are subject to variations due to subsidence and sea level rise at each gage site.
- Sea level datums also have time varying astronomical components making their reference definition more complex than terrestrial based datums.
- Hydraulic low water reference datums used to define navigation and flood protection elevations on the Mississippi River may also be subject to subsidence and other long-term variations, and thus these datums are spatially and temporally variable.

- Subsidence is the lowering or sinking of Earth's surface, often quantified relative to non-sinking portions of the Earth's crust.
- It is especially pronounced in portions of California, Texas, and Louisiana.
- In Southern Louisiana, subsidence is occurring at a rate of up to 0.1 foot every three years in some areas.
- There are many potential factors that contribute to subsidence, such as the geologic composition of the area and withdrawal of ground water and oil.
- The rate of subsidence is not always constant and can vary from epoch to epoch (survey to survey) due to many factors, such as compaction, removal of subsurface fluids, and geologic events.
- Therefore, one cannot predict future subsidence with any degree of accuracy.

- The table below illustrates the large variability in subsidence rates of change occurring over a relatively small region in Louisiana.
- These rates were determined from periodic First-Order, Class II leveling surveys by NOAA.

Table 1
Apparent Benchmark Movement Rates

Benchmark Designation	Rates of Movement in Millimeters per year
A 148 (AU0429)	-11.01
PIKE RESET (BH1164)	-6.99
231 LAGS (BH1073)	-16.08
A 92 (BH1136)	-7.39

Table 1: Apparent Benchmark Movement Rates.
(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

- Subsidence can be measured and/or periodically monitored using either conventional leveling procedures or GPS techniques contained in NOAA 1997 (Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm)).
- Determining subsidence rates requires long-term observations and considerable analysis.
- As an example, Figure 4 on the following slide contains a map showing the estimated amount of subsidence along the route between New Orleans and Venice, LA.
- The leveling for this line was performed by NOAA in 1984 and adjusted to the NGVD 29 datum at that time.
- In 1991, NGS adjusted the entire CONUS to the NGVD 29 datum in preparation for the NAVD 88 adjustment.

- In Southern Louisiana, an extensive "GPS Derived Height" network was completed establishing new heights (elevations) for 85 benchmarks in Southern Louisiana.
- This adjustment, known as NAVD 88 (2004.65), held control outside of the subsidence area to establish new NAVD88 adjusted heights for the 85 benchmarks.
- Because the 1991 NAVD 88 adjustment held control outside of the area, as did the NAVD 88 (2004.65) adjustment, the change in the heights reflects the apparent movement of the marks between the observation periods.
- In order to determine the amount of subsidence from the time the original leveling was done, it is necessary to determine the amount of movement between the original adjustment and the 1991 national readjustment of the NGVD 29 and then the amount of movement between the original NAVD 88 adjustment and the NAVD 88 (2004.65) adjustment.

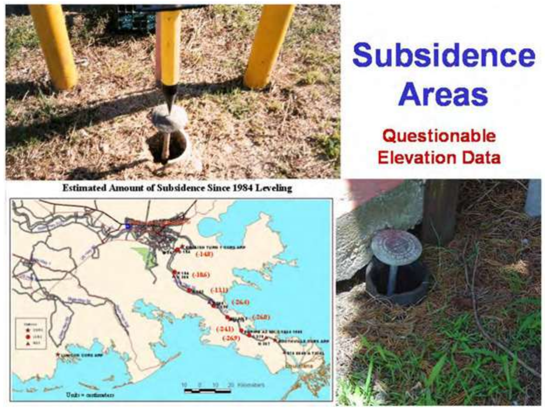


Figure 4: Estimated subsidence (in centimeters) in the New Orleans to Venice region. Photos depict relative ground subsidence of benchmarks attached to deep driven rods.

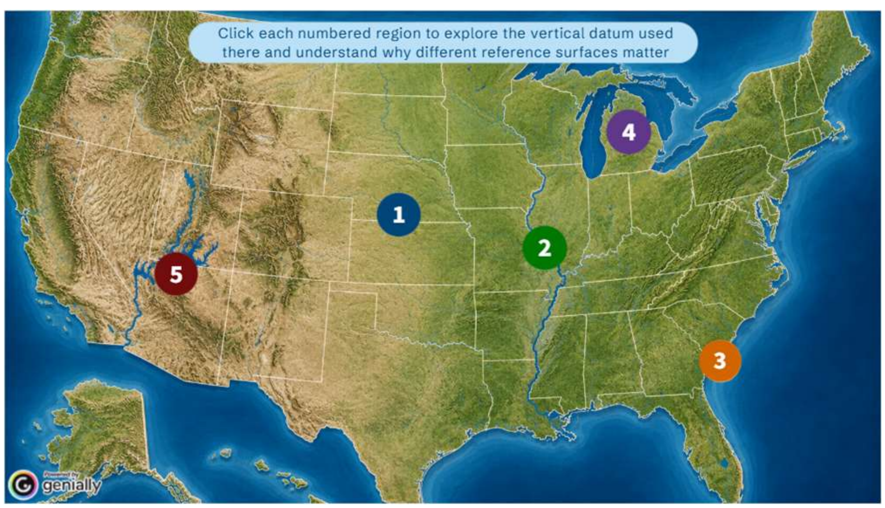
(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

- Monitoring subsidence or sea level changes on flood control, hurricane protection, or coastal (tidal) navigation projects requires continuous leveling or GPS surveys between water level recording gages and fixed benchmarks.
- Vertical datums (NAVD 88 and tidal lower low water datums) must be periodically updated to reflect changes due to subsidence or sea level rise.

Mandatory Standards

- Spatial data collected for projects shall be referenced to the updated NAD 83 and NAVD 88 reference datums established by the National Oceanic and Atmospheric Administration (NOAA).
- Navigation projects referenced to tidal datums shall be updated to the latest tidal epoch (currently 1983-2001) in accordance with the statutory requirements in Section 224 of the Water Resources Development Act of 1992.
- Flood control or hurricane protection structure elevations shall be referred to the hydrodynamic surface model datum used in the design analysis.

Check the next slide to explore an interactive GIF about Vertical Datums Across America



PLANNING AND CONDUCTING CONTROL AND TOPOGRAPHIC SURVEYS

Purpose

- This chapter provides general guidance on planning control and topographic surveys.
- Requirements and methods for extending nationwide control networks into a facility project site are described. Sources of geodetic control data are described.
- Guidance is also provided on selecting map scales, feature location tolerances, and contour intervals for typical engineering and construction projects.
- Actual procedural examples of projects performed by various Districts are found in the appendices to this manual.

Project Requirements from Using Agency

- Topographic survey requests originate from the using agency.
- The requestor might be an internal District office division, an outside Army installation, or another Federal or State agency.
- Often these requests are general in nature, and often accompanied with a request for a cost estimate to perform the survey.

- In many cases, the survey details, site conditions, scope, and accuracy requirements are not specified; or, more often than not, the actual work required far exceeds the given budgeted amount.
- Often, in such cases, the surveyor must meet with the requesting District element or outside agency and modify the accuracy and scope in order to stay within budget.
- Such budgetary driven compromises do not always result in an optimum survey in the user's estimation; however, the burden is often placed on the surveyor to design a survey accuracy and density that will best satisfy the design/construction requirements that the requesting entity desires.

- It is rare that the requesting user ever obtains the detail required for the project.
- Likewise, it is equally rare that the surveyor is able to perform the quality of survey he feels is necessary to adequately define the project conditions.
- In many cases, an advance site visit may be needed in order to assess the actual conditions and provide a reliable budget estimate (time and cost) to the requesting agency.

Figure 5: An advance site visit would be essential in planning for conditions such as this (Portland District).
(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

- a. Sample topographic survey request.
  - The following excerpt is taken from a site plan mapping Scope of Work in Pittsburgh District, for a survey of a tract of land adjacent to Hannibal Lock and Dam on the Ohio River.
  - The purpose of the survey was to develop site plans for construction of new facilities on a parcel adjacent to the Hannibal Lock.
  - The originating agency's request may not have been as detailed as this version sent to an AE contractor--it may have only requested a topographic site plan survey without any detailed map scale, accuracy, or utility requirements.

- *General Surveying and Mapping Requirements.*
  - *(1) General site plan feature and topographic detail mapping compiled at a target scale of 1"= 50 ft, 1 ft contour interval for that area annotated on furnished exhibit.*
    - *Collect all existing pertinent features, drainage characteristics, drainage structures, channels, inlets and outlets, etc.*
    - *Collect all surface utility data and conduct a thorough search for evidence of subsurface utilities.*
    - *An underground gas line runs through a portion of the site. Gas line markers are visible.*

- *(2) Set control monumentation as required to adequately control construction layout.*
  - *Monumentation shall be set in an area outside the construction limits so as not to be disturbed during construction phases.*
  - *Existing control monumentation within the vicinity may be used in lieu of setting new monumentation.*
  - *All control monumentation, set or found, shall be adequately described and referenced in a standard fieldbook.*

- *(3) Based on information established by record and by field survey, establish and delineate on the ground, with capped re-bars and witness posts, that portion of the Ohio DOT right-of-way bounding Tract 113; commencing at the edge of the right bank of the Ohio River, thence continuing along Tract 113 and Ohio Route 7.*
  - *This is a critical element that will need to be properly delineated on the ground and properly annotated on the map to ensure the site is contained within COE property.*
  - *At a minimum, this portion of the field work shall be performed under the on-site direction of a Professional Land Surveyor duly registered in the State of Ohio.*

- The above scope effectively describes the requirements of the survey.
- It does not specify all survey details that could be listed.
- For instance, it does not state what topographic elevation density is required on ground shot points.
- These types of details are usually left to the field surveyor to develop--presuming he knows the purpose of the site plan mapping project and is familiar with subsequent design and construction requirements.
- It is therefore critical that the field survey crew be made knowledgeable of the ultimate purpose of a project so that they can locate critical features which may impact on future construction.

- b. Checklist format.
  - An alternate method of describing the survey requirements is a checklist form.
  - The following checklist in Figure 6 on the following slide is used by FEMA and notes critical requirements that a user/requestor must specify.

PLANNING AND CONDUCTING CONTROL AND TOPOGRAPHIC SURVEYS (CONT'D)
Control and Topographic Surveying – Part 3
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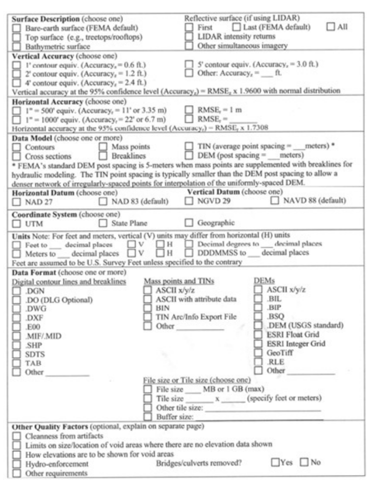

Surface Description (choose one)
- ☐ Bare-earth surface (FEMA default)
- ☐ Top surface (e.g., treetops/rooftops)
- ☐ Bathymetric surface

Reflective surface (if using LIDAR)
- ☐ First ☐ Last (FEMA default) ☐ All
- ☐ LIDAR intensity returns
- ☐ Other simultaneous imagery

Vertical Accuracy (choose one)
- ☐ 1' contour equiv. ($Accuracy_z$ = 0.6 ft.)
- ☐ 2' contour equiv. ($Accuracy_z$ = 1.2 ft.)
- ☐ 4' contour equiv. ($Accuracy_z$ = 2.4 ft.)
- ☐ 5' contour equiv. ($Accuracy_z$ = 3.0 ft.)
- ☐ Other: $Accuracy_z$ = ___ ft.

Vertical accuracy at the 95% confidence level ($Accuracy_z$) = $RMSE_z$ x 1.9600 with normal distribution

Horizontal Accuracy (choose one)
- ☐ 1" = 500' equiv. ($Accuracy_r$ = 11' or 3.35 m)
- ☐ 1" = 1000' equiv. ($Accuracy_r$ = 22' or 6.7 m)
- ☐ $RMSE_r$ = 1 m
- ☐ $RMSE_r$ = _______

Horizontal accuracy at the 95% confidence level ($Accuracy_r$) = $RMSE_r$ x 1.7308

Data Model (choose one or more)
- ☐ Contours ☐ Mass points ☐ TIN (average point spacing = ___meters) *
- ☐ Cross sections ☐ Breaklines ☐ DEM (post spacing = ___meters)

* FEMA's standard DEM post spacing is 5-meters when mass points are supplemented with breaklines for hydraulic modeling. The TIN point spacing is typically smaller than the DEM post spacing to allow a denser network of irregularly-spaced points for interpolation of the uniformly-spaced DEM.

Horizontal Datum (choose one)
- ☐ NAD 27 ☐ NAD 83 (default)

Vertical Datum (choose one)
- ☐ NGVD 29 ☐ NAVD 88 (default)

Coordinate System (choose one)
- ☐ UTM ☐ State Plane ☐ Geographic

Units Note: For feet and meters, vertical (V) units may differ from horizontal (H) units
- ☐ Feet to ___ decimal places ☐ V ☐ H
- ☐ Meters to ___ decimal places ☐ V ☐ H
- ☐ Decimal degrees to ___ decimal places
- ☐ DDDMMSS to ___ decimal places

Feet are assumed to be U.S. Survey Feet unless specified to the contrary

Data Format (choose one or more)

Digital contour lines and breaklines
- ☐ .DGN
- ☐ .DO (DLG Optional)
- ☐ .DWG
- ☐ .DXF
- ☐ .E00
- ☐ .MIF/.MID
- ☐ .SHP
- ☐ SDTS
- ☐ TAB
- ☐ Other ________

Mass points and TINs
- ☐ ASCII x/y/z
- ☐ ASCII with attribute data
- ☐ BIN
- ☐ TIN Arc/Info Export File
- ☐ Other ________

DEMs
- ☐ ASCII x/y/z
- ☐ .BIL
- ☐ .BIP
- ☐ .BSQ
- ☐ .DEM (USGS standard)
- ☐ ESRI Float Grid
- ☐ ESRI Integer Grid
- ☐ GeoTiff
- ☐ .RLE
- ☐ Other ________

File size or Tile size (choose one)
- ☐ File size ____ MB or 1 GB (max)
- ☐ Tile size ______ x ______ (specify feet or meters)
- ☐ Other tile size: ____________
- ☐ Buffer size: ____________

Other Quality Factors (optional, explain on separate page)
- ☐ Cleanness from artifacts
- ☐ Limits on size/location of void areas where there are no elevation data shown
- ☐ How elevations are to be shown for void areas
- ☐ Hydro-enforcement   Bridges/culverts removed? ☐Yes ☐ No
- ☐ Other requirements

Figure 6: Digital Topographic Data Requirements Checklist (FEMA).
(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

Topographic Survey Planning Checklist

- Upon receipt of a user's request for a topographic survey, as part of the planning process it is best to logically resolve many of the variables associated with a proposed site.
- The following planning checklist may be used as a general outline for that process.
- This checklist may also be useful in reviewing a topographic survey request with the end user.
- The remainder of the sections in this chapter will address some of these items.
- This checklist is taken from the Corps PROSPECT Survey III course.

- PROJECT PLANNING OBJECTIVE
  - Identify considerations for planning and producing a survey.
  - Identify issues to be addressed when requesting or discussing proposed work.
- END-USE OF MAP OR DATA
  - How will the data or map be used?
  - Site planning
  - Construction plans and specs
  - Management
  - GIS
  - Will you count each tree, species, size?
  - Plot boundary
  - Compute areas

- PROJECT PLANNING
  - Thoroughly read request from user. (Request may be different than verbal agreement)
  - What is the purpose of the survey?
  - What did the site look like a year ago? What will it look like in one year?
- SITE CONSIDERATIONS
  - Has the requestor walked the site recently?
  - (Not a drive-by performed 2 years ago.) Have you personally walked the site this season?
  - Safety hazards to consider:
  - Steep slopes
  - Busy roads
  - Flagger, road signs
  - High speed railroad
  - switching railroad
  - Berries
  - Poison oak, poison ivy, nettles
  - Tide
  - Weather patterns
  - Local mentality

- DELIVERABLE FORMAT
  - Assume CADD environment
  - Does file or map have to match existing data?
  - What software will be used to view data?
  - Engineering software for manipulation.
  - Will a variety of output files be required?
- COORDINATE SYSTEM
  - Horizontal
  - State plane
  - State plane on what zone
  - True state plane, or at ground surface
  - Local
  - Military coordinate system
  - Recommend something that can be recovered. Perpetual coordinate system usually better.

- STATIONING
  - Stationing is a disjointed coordinate system where one axis is the STATION and the other is OFFSET, and the STATION axis rotates at every PI.
  - Distances are usually ground distances.
  - (State plane coordinates might have to be adjusted.)
  - Great for linear surveys such as roads, railroads and levees.
- VERTICAL COORDINATE SYSTEM
  - NAVD 88 (specify adjustment date)
  - MSL or NGVD 29 or NGVD 29 (XX)
  - 1912 Adjustment
  - MLLW
  - City or Local
  - Base
  - Recommend a perpetual vertical system and conversion to datum used.

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- UNITS OF MEASURE
  - Foot
  - U.S. Survey Foot
  - International Survey Foot
  - Meter
  - River mile, nautical mile
  - Ground distances
  - Grid distances
- FILE TYPE
  - .DGN
  - .DWG
  - .SHP
  - ASCII
  - .DXF
  - .COT
  - .TIF
  - .WTIF

- FILE SIZE
  - Some files are just too large for PC.
  - Match into existing or planning new software or computer.
  - Does file size equate to sheet size?
  - Are sheets necessary?
- EXISTING CONTROL
  - Decide what BM to hold ... 2 or more.
  - Decide what horizontal to hold.
  - Have these monuments been re-set?
  - Always check between 2 or more existing monuments.
  - Update reference ties.
  - Protect during construction or relocate.

- CONTROL MONUMENTS
  - Set or reference permanent control
  - The Same Control should be used for:
  - Project boundary recovered or set
  - Map for design
  - Plans and specs
  - Construction
  - As-Builts
  - Operation of facility as necessary
  - Project boundary should be recovered or re-set.
  - Construction as per EM 1110-1-1002
  - Digging permit?
  - Rebar below frost line
  - Stamped or capped
  - Reference ties
  - Reference closest boundary
  - Drive-to/To-reach
  - Set in protected place and set witness post

- CONTROL SURVEY
  - Different procedure than mapping
  - Whatever it takes to meet (EM 1110-1-1004, Chapter 3).
  - Typically 2 sets of angles and differential levels
  - Qualify monument coordinates with a level of accuracy.
  - Archive
- CONTROL DIAGRAM
  - Original Monuments
  - (Origination of horizontal and vertical)
  - Monuments set (type and designation)
  - Grid coordinates
  - Coordinate System
  - Ground Distance/Grid Distance/Combination Factor and Grid Factor, etc.
  - Reference ties

- CONTROL DIAGRAM
  - Build control diagram for:
    - Mapping
    - Design
    - Construction plans and specs
    - Archive

- DELIVERABLES
  - X-section plots
  - Topographic map
  - Digital Terrain Model
  - Ink on mylar
  - Paper check plots
  - Color
  - Black/White
  - Digital files only
  - Digital file specifications/format
  - Levels
  - Font size
  - Line weights

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  - Global origin
  - Sheet size
  - Title block format
  - Seed files in relevant coord. Sys/units
  - Boundary plat
  - File with the county
  - Metadata
  - Field-book
  - Computation files
  - Daily reports
  - Project Surveyor's Report (pertinent data, relevant comments by locals)
  - County reports
  - Digital media type (CD, DVD, tape)

- OTHER CONSIDERATIONS
  - Manhole (MH) work
  - Size, type of each pipe flowing into MH
  - Direction of flow
  - Invert and rim elevation of MH
  - Confined space precautions
  - Only survey what you can see.
  - If locates, then call out as such.
  - Bridge detail
  - Standard bridge sketch
  - Structural detail
  - Cross-section upstream and downstream
  - Profile across bridge deck + 300 ft
  - Low steel elevation
  - Orientation to flow
  - Drill holes

- Locate before drilling. (Stake for digging permit.)
- Survey after drilling. (Provide coordinate and elevation on perpetual coordinate system.)
- Piezometers
- Where do you want the elevation?
- Are they locked? Have they been located or read recently?
- Photographs of site
- Keep a logical record.
- Helpful for office when mapping.
- Show nearest utility hook-ups.
- Water
- Fire Hydrants
- Power
- Sanitary, storm etc.
- Keys
- Do we need any keys for access?
- Right of entry
- Knock on the door first
- Tree/brush clearing permits
- ROE in hand

- SECURITY
  - Notify installation/project office in advance (need POC)
  - Name, purpose, duration
  - Restricted area
  - Security escort required? Security briefing
  - E-mail
  - Clothing requirement, safety clothing
  - Radio contact, pager

- SPECIAL CONDITIONS
  - Survey or map during:
    - Low pool
    - Maximum pool
    - Winter
    - After or before Leaf Drop
    - Conform to base or project operations.
    - Base operations
    - Flight schedule
    - Operation schedule (spillway at dam)
    - Low tide, high tide
    - Not during:
      - Duck hunting season, deer hunting season
      - Calving or nesting season
      - Fish migration

- SCHEDULE
  - Is this time critical?
  - Could we save money by waiting?
  - Produce field-work now, and office later.
  - Will work be contracted?
  - How long to advertise, select, negotiate?
  - Fiscal year (dated money)
- OPTIONS TO COMPLETE WORK
  - In-House
  - IDC
  - Credit card
  - Neighboring districts
  - Other engineering contracts in the district
  - Other agencies

- FUNDING
  - Seed money to provide intelligent estimate
  - Is proposed work probable?
  - What kind of estimate is required?
  - Format of estimate
  - Cover your estimate
  - Clearly state all assumptions
  - Provide proposed Schedule of Obligation and Expenditure, if contracted.
- PROJECT PLANNING, OFFICE
  - Research
  - Control
  - In-house
  - State
  - County
  - Municipality or Military Installation
  - Land corners
  - Previous work in area

- SAFETY ISSUES
  - Weather
  - Gunnery
  - Operations
  - Tides
  - Bugs
  - Mud, Sand
  - UNEXO
  - HTRW Site Safety Plan

- EQUIPMENT
  - Radios
  - Batteries
  - Cables
  - Chargers
  - Place to charge
  - Water jug
  - First Aid/CPR
  - Metal detector
  - Chain saw
  - Drill
  - Waders or hip boots
  - Work vest
  - Long rod

- Steel tape
- Pocket tape
- Total station
- Reflectorless
- Robotic
- Data collection
- Need to download daily.
- Computer with software and place
- Level
- Prism pole
- Triple prism
- Lead line
- GPS
- Is site GPS friendly?

- VEHICLES
  - 4 x 4
  - ATV & trailer
  - Boat
  - Skiff
  - Work boat
  - Fisherman's tube
  - Parking at project or secured at hotel
- MATERIALS
  - Hubs/Stakes
  - Lath
  - Flagging
  - Paint
  - Nails
  - Monuments
  - Rebar

Rights-of-Entry

- When entering property to conduct a survey, rights of the property owner will be respected.
- The following paragraphs outline some minimum guidelines that should be followed.
- a. Permission.
  - Whenever necessary, permission to enter a military installation and other private property may be acquired by the District prior to entering such property.
  - While on the military installation, members of the survey crew will adhere to all of the stipulations (e.g., rules, regulations, directives, verbal guidance, etc.) set forth by the Installation Commander or his designated representative.
  - The same basic guidelines are applicable when the right to enter private property is given.

- b. Protection of property.
  - Government and private property shall be protected at all times.
  - Every effort should be made not to damage or cut trees, shrubs, plants, etc. on the property.
  - If line cutting or other modifications must be done, the Installation Commander, or in the case of private property, the private property owner, is the only person who can grant permission to do so.
  - It shall be standard practice that property entered shall be returned to its condition prior to entry once the survey is completed.
  - Gates and other structures should be left in the position in which they were found prior to entry.
  - If a gate is closed, do not leave it open for any long period of time.
  - Return all borrowed property (e.g., keys, maps, etc.) as instructed by the property owner or designated representative.

- c. Monuments.
  - Survey points should be placed in such a way as to not obstruct the operations of an installation or the property owners, or be offensive to their view.
  - Monuments set as a result of the survey should be set below ground level to prevent damage by or to any equipment or vehicles; especially grass cutting tractors.
  - Extra care must be taken when setting a survey point at or near airports.
  - Any temporary marks set on military installations or private property will be removed as soon as possible after the survey work is completed, or at the request of the Installation Commander, property owner, and/or designated representative.
  - Permission should be obtained before painting permanent aerial mapping targets on paved surfaces.

Sources of Existing Geospatial/Survey Data

- When a request for a survey of a given project site is received, the first effort should be to research the files to ascertain if a survey of the same site has already been performed.
- Policies and procedures for performing searches of geospatial clearinghouse databases are prescribed in EM 1110-1-2909 (Geospatial Data and Systems).
- However, given the highly detailed scale of topographic surveys, and the need for current conditions, it is highly improbable that an archived survey of sufficient detail can be found at these geospatial data shopping sites.

- Regardless, NSRS control will still be needed to reference the topographic mapping.
- A variety of databases can be accessed to obtain horizontal and vertical control from various local, state, and federal agencies.
- One or more of the following sources of existing geospatial data may need to be researched before performing a topographic survey.
- These files may be located in the District Office, the installation or base, county clerk's office, or a local public works/utility company.

- Installation As-built drawing files.
  - The requesting installation may have detailed hard copy or digital files of topographic surveys, utility drawings, or real estate tract maps.
- District Office files.
  - Archived drawing files for the project site.
- Aerial photo archives.
- Utility drawings.
  - Electric, sanitary, storm, cable, telephone, fiber optic, etc.
- Recorded plats and related real property surveys.
  - Consult local county courthouse, District Real Estate Division files, local surveyor's archival files, etc.
- USGS topographic quadrangle maps.
  - USGS quadrangle maps may be used for general location references.
  - General small-scale orthophoto imagery can be downloaded from a number of web sites, if this imagery is needed for a background to design plans drawings and specifications.

- NGS control.
  - Published National Geodetic Survey control can be downloaded at www.ngs.noaa.gov.
  - This site allows simple search options for all NSRS control points in the region of the project.
- State, county, city, and regional agency control.
  - Some states and regional/local agencies maintain web sites for searching control in their areas.
- District control.
  - Corps control on a project or Army installation may be available in archived files.

- The FGDC National Geospatial Data Clearinghouse is a potential source for imagery data within or surrounding a project site.
- The Geospatial Data Clearinghouse is a collection of over 250 spatial data servers that have digital geographic data primarily for use in Geographic Information Systems (GIS), image processing systems, and other modeling software.
- Generally, at this time the data is of small-scale resolution, which means there are few uses for large-scale topographic mapping.
- These data collections can be searched through a single interface based on their descriptions, or "metadata."

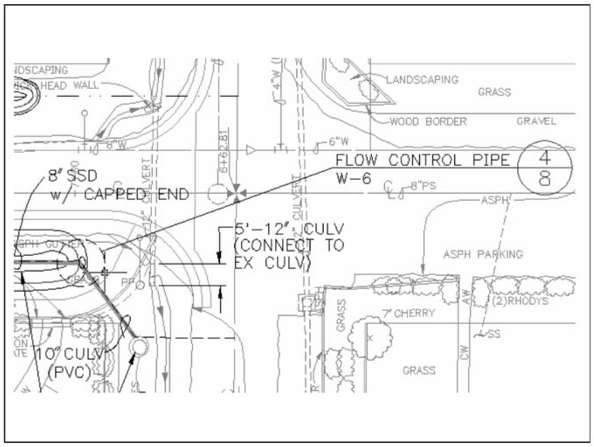

Figure 7: Portion of a typical as-built utility map depicting proposed modifications.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

Project Control for Topographic Detail Surveys

- Topographic surveys of facilities, utilities, or terrain must be controlled to some reference framework, both in horizontal and vertical.
- This reference framework should consist of two or more permanently monumented control points and/or benchmarks located in the vicinity of the project.
- These project control points can then be used to perform supplemental topographic surveys of the project.
- This concept is illustrated in Figure 8 on the next slide.

- In the figure here, the points on the ends of the baseline would be tied in by differential levels to two or more or the local benchmarks shown.

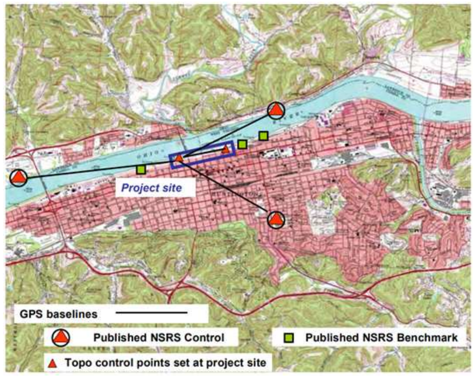

Figure 8: Project control: NSRS and local control.
(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

- In this example of a survey site located along the Ohio River, NSRS control is brought in from three existing points using static GPS observations.
- A single point on the western end of the survey site is positioned.
- A baseline in the project area is established from the westernmost point using GPS.
- From these two intervisible points, subsequent topographic detail is surveyed using either a total station or RTK methods.

- LIDAR scans of the bridge across the Ohio River could be made relative to points set from the westernmost new point.
- In CONUS, connections are usually made to the NSRS.
- In OCONUS locales, connections to local reference frameworks can be made.
- Simple references to the satellite-based WGS-84 framework system may be also used, using a UTM grid for local reference.
- Vertical control is usually established relative to the nearest existing benchmarks.

- a. Project control relative accuracy.
    - In general, horizontal and vertical accuracy of the control points used to control topographic surveys need only be to Third-Order, relative to themselves.
    - In practice, if these control points in and around the project site have been interconnected by total station traverse, differential leveling, or static/kinematic DGPS techniques, their relative accuracy will be far greater--upwards of 1:50,000 to 1:100,000 type closures are expected.
    - Positional accuracies within a project site should be around the ± 0.2 ft level in X-Y, and better than ± 0.1 ft in the vertical.

- b. Project control absolute accuracy.
    - The absolute accuracy of project control is that defined relative to some local, statewide, or nation-wide reference framework.
    - These frameworks might be the NSRS that is maintained be the National Geodetic Survey or an installation geodetic network that was in turn connected to the NSRS.
    - Maintaining a good relative accuracy with an adjoining installation project control network is far more important than accurate connections to distant NSRS networks.
    - Likewise, connections to adjoining property boundary monuments are significantly more critical than connections to distant NSRS networks.

- c. Boundary control.
    - Topographic surveys involving real property boundaries must always be connected to established property corners, section corners, or adjoining right-of-way boundaries.
    - Locations of structures, buildings, roads, utilities, etc. must be shown relative to the property boundaries.
    - Likewise, stakeout of planned construction must be performed relative to these boundaries--and surveyed relative to applicable property corner pins.
    - NSRS framework coordinates may be placed on property corner marks; however, subsequent stakeout work should never be performed relative to distant NSRS control--in other words, one should always occupy and/or connect to the nearest adjoining property boundary corners.

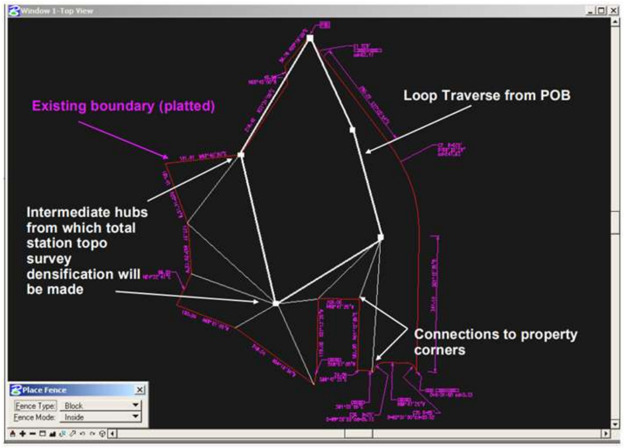

Figure 9: Setting additional topographic survey control points relative to platted property corners.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

- d. Local project control.
  - On some occasions, there is no existing horizontal or vertical control within the immediate vicinity of a project.
  - Two options are available:
    - Perform detailed surveys relative to an arbitrary coordinate system established for the project-- e.g., set two permanent reference points, assume arbitrary coordinates of 5,000-10,000-100 (X-Y-Z) for one of the marks.
    - Perform traverse, leveling, and/or GPS control surveys to bring in NSRS referenced control to the project site.
  - The first option listed above used to be more common; however, with the ease of extending control with GPS (either autonomous or differential), it is now fairly simple to establish some form of NSRS control on a project; or, at minimum, reference to the WGS 84 ellipsoid.

Establishing NSRS Control at a Project Site

- A variety of factors must be considered in deciding whether and how to connect project sites to an external spatial coordinate network.
- These include:
  - Cost:
    - Bringing distant horizontal and vertical control to a project site can be costly, and may exceed the cost of performing the detailed topographic survey itself.
  - Policy.
    - Command, Agency, District, or Installation policy may mandate that all site plan work shall be referenced to the NSRS.
    - If this is the case, then it is up to the surveyor to perform this connection in the most cost-effective manner as possible.

  - Accuracy (horizontal and vertical).
    - The horizontal and vertical accuracy of topographic features relative to the NSRS must be rigorously and sensibly defined.
    - Most project sites have no real requirement for rigorous connections to a NSRS.
    - For example, the horizontal location of a Reserve Center motor pool building need not have precise geographic coordinates relative to the NSRS.
    - However, the location of a lock guidewall must be accurately located relative to the NSRS since this feature will be depicted on independent navigation charts.
    - Likewise, the first floor elevation of the motor pool building relative to NGVD 29 is of little significance if the Reserve Center is located well outside any flood plain.
    - For example, absolute NSRS positional accuracies of the motor pool building would be adequate at the ± 10 ft level in X-Y, and ± 3 ft in the vertical, whereas its local topographic survey accuracy relative to an adjoining property line would be around the ± 0.1 ft level in X-Y, and a floor elevation better than ± 0.02 ft relative to local utility connections.

- Distance from NSRS network.
  - The distance useable published horizontal control points or vertical benchmarks are from the project site will have an impact on cost.
  - In particular, if a distant benchmark requires a lengthy level line to bring in accurate vertical control, costs can rapidly escalate.
  - More options are available for bringing in horizontal control to a project site, such as GPS static options using CORS networks.
- Depending on many of the factors listed above (and many others), the method and accuracy of bringing in project control can be designed.
- The following paragraphs describe some of the common techniques that can be employed in establishing horizontal and vertical control relative to a NSRS network.

Project Control Densification Methods

- a. Horizontal control.
  - Horizontal control is most effectively connected to the NSRS published network into a project site by one of the following methods:
    - Traverse surveys
    - Static GPS surveys
    - Kinematic GPS surveys
  - Traverse surveys with a total station are practical if the existing control is fairly close to the project site, i.e., within a few turning point setups.
  - General procedures for performing conventional traverse surveys are covered in Chapter 3.
  - If traverse surveys would take more than a few hours, then a static GPS observation may prove more practical.
  - At least two external NSRS network points should be occupied.
  - Alternatively, a static GPS survey could be conducted at a point set on the project site using the NGS CORS network to adjust the point.
  - Since most topographic site plan mapping surveys require only Third-Order accuracy relative to the NSRS, short-term (1 or 2 hour) GPS observations are normally the most cost-effective methods for extending control to a project site.

- b. Vertical control.
  - If vertical control is required to a higher accuracy than can be achieved using GPS survey techniques, then conventional leveling methods must be used.
  - Depending on the distance of the level run, Third-Order methods are usually sufficient.
  - Either single-wire or digital leveling may be used.
  - See EM 1110-1-1009 (Structural Deformation Surveying) if more accurate leveling methods are required--e.g., precise leveling with two-sided invar rods.
  - Total station trigonometric leveling may be performed over short distances.

Check the next slide to explore an interactive GIF about The Survey Planning Dashboard

Extending Control from a Local Project or Installation Network (Patrick AFB)

- Most topographic surveys are performed on existing installation or civil works project sites where NSRS or boundary control is readily available.
- Depending on the distance of this control from the survey site, either total station traverse or static GPS surveys are used to establish local control.
- Vertical control will typically be brought in by running Third Order levels from two existing benchmarks.
- If boundary surveys are required, then all property corners should be recovered and tied in as part of the survey.

- The figure below (from a Trimble Geomatics Office screen capture) illustrates a constrained adjustment network for a Louisville District in-house control survey at an Army Reserve Center at Patrick AFB, Florida.

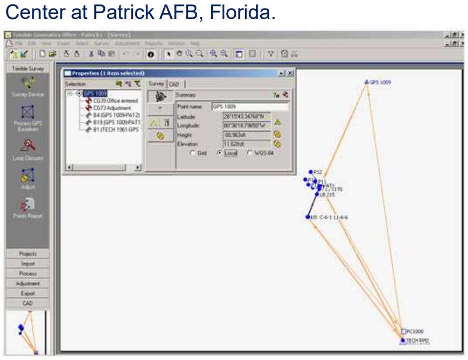

Figure 10: Horizontal and vertical control extended to project site from external NSRS points.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

- GPS control is established from one-hour static and 5 to 15 min fast-static observations at three fixed NSRS control points--TECH 1961 (N-E-h) from the south, GPS 1009 (N-E) from the north, and BM PC1000 (e) from the south; where "N-E" are fixed horizontal coordinates, "h" is a fixed ellipsoidal height, and "e" is a fixed orthometric elevation.
- Station PAT1 at the Patrick AFB site is thereby controlled.
- From PAT1, 10 additional control points within the site are radiated from short-term (less than 5 min) kinematic GPS observations.
- These points are used as subsequent total station occupations.

- The figure below shows various control and topographic observations that were performed on the Patrick AFB survey.

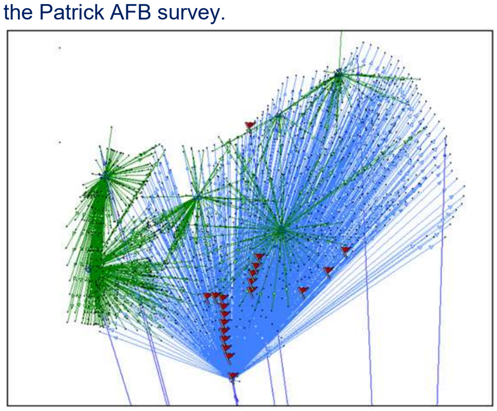

Figure 11: Total Station and RTK surveys at Patrick AFB.
(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

- On this project, both total station and RTK topographic surveys were performed.
- The occupied radial points were positioned by fast static GPS observations from the primary installation/NSRS control point some 2,500 ft south of the site.
- The blue lines represent GPS baselines (Fast Static or RTK) and the green lines are terrestrial (total station) observations.
- All the observations were imported into TGO for a constrained adjustment (only redundant control points receive any adjustment--the radial RTK or total station observations are not adjusted).

Extending Control from a Distant Network Using Continuously Operating Reference Stations (CORS)

- The National Geodetic Survey coordinates the maintenance of a permanent network of continuously operating GPS receivers that can be used to establish NSRS control at virtually any place in CONUS.
- The use of CORS stations eliminates the need to occupy full baselines, as in the previous example.
- A single GPS receiver is set up at a primary control point in the project site, and 1 to 2 hour static GPS observations are recorded.
- These observations become the end of any number of selected baselines using stations in the CORS network.
- Static GPS observations made at a project site can be adjusted to any number of nearby CORS stations, using the NGS User Friendly CORS Web site.

- a. The following example illustrates extending NSRS control to a project site using the CORS data network maintained by the NGS.
  - The figure below depicts an extension of NSRS control to a remote site where a detailed topographic survey is required.

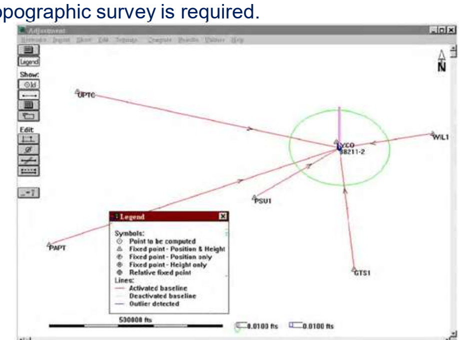

Figure 12: Connections to multiple CORS stations to adjust coordinates of a remote point.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

- The point of this example is to illustrate a practical, rapid (one hour observing time), and cost-effective method of extending NSRS horizontal and vertical control into a project site.
- In this example (a structure survey on a remote mountain in Pennsylvania), a one-hour static GPS observation was made at a monument set near the facility to be surveyed.
- The specified NSRS absolute accuracy required was only ± 10 feet horizontal and ± 3 feet vertical.
- The one-hour static observation was connected to six CORS stations as shown below.
- The six baselines were reduced and an adjusted position for the topographic reference point was computed using least squares software.

- b. Figure 12 above shows the unknown control point "88211-2" being connected to six CORS stations at various locations in Pennsylvania--PAPT, PSU1, GTS1, UPTC, WIL1, and LYCO.
  - RINEX data recorded for each of these CORS stations was downloaded from the Internet and each of the six baselines was reduced using standard baseline reduction software.
  - A standard constrained adjustment using the weighted baseline reduction data is then performed to arrive at the adjusted position of the point "88211-2."
  - The output of this adjustment is shown below with notes shown in blue italics:

```
Adjustment type         :  Constrained
Number of observations  :  18              [6 baselines -- X, Y, and Z]
Number of unknowns      :  3
Degrees of freedom      :  15
Number of groups        :  1
88211-2         Lat:  41 11 30.397202 N ±   0.00960 [m]  ± 0.03 ft
                Lon:  76 58 35.163335 W ±   0.01280 [m]  ± 0.04 ft
                Hgt:         517.6770 m ±   0.01286 [m]  ± 0.04 ft
```


- The above result indicates that the resultant CORS-adjusted position has a high relative accuracy estimate--at the ± 0.1 ft level.
- This accuracy is more than adequate to reference the horizontal location of subsequent total station observations made from "88211-2."
- The height shown (517.677 m) may have adjusted to the ± 0.1 ft level, but this elevation is based on the WGS 84 ellipsoid height reduced to NAVD 88 using the published geoid model (GEOID 03) at this location--a predicted correction.
- Thus, while this CORS-adjusted elevation is well within the ± 3 ft accuracy specification, use of the predicted geoid model may degrade the absolute accuracy to no better than ± 0.5 ft.
- If the project required a better vertical accuracy relative to adjacent utility systems, then conventional differential level lines should be run rather than use GPS-derived vertical elevations.

- c. The following output from this CORS connection scheme shows a Leica SKI "Mean Position" option based on the six baselines (the mean position is not the same as the least squares position).

```
Mean coordinates and differences:
---------------------------------

Point id: 88211-2

WGS84 Coordinates:
[WGS 83Lat-Long/NAVD 88 Hgt       Geocentric coordinates]
Lat:      41 11 30.39723 N    X:     1083261.795 m
Lon:      76 58 35.16313 W    Y:    -4683333.242 m
Hgt:             517.695 m    Z:     4178814.491 m

Reference  Date(YY/MM/DD)       dLat         dLon         dHgt
--------------------------------------------------------------------------
LYCO      04/05/28 12:58:25   -0.002 m      0.000 m     -0.005 m  fixed
WIL1      04/05/28 13:04:35   -0.003 m      0.090 m      0.078 m
GTS1      04/05/28 12:58:25    0.002 m      0.106 m      0.095 m
PAPT      04/05/28 12:58:25   -0.014 m     -0.077 m      0.175 m  > 150 miles
UPTC      04/05/28 13:05:10   -0.022 m      0.123 m      0.060 m
PSU1      04/05/28 12:58:25   -0.022 m     -0.025 m      0.077 m
```


- Also shown are the differences in Lat-Long-Hgt for each baseline relative to the mean position.
- These differences clearly indicate that the more distant baselines (PAPT, GTS1, and UPTC) are of lesser quality; however, they would provide results well within the desired tolerances if used separately.
- In practice, not all six of these CORS observations would have been used on this project--they are used in this example for illustrative purposes to show that even CORS points 100 to 200 miles distant can provide fairly reliable results.
- Since CORS point LYCO was less than 10 miles away from the project site, and has a fixed baseline solution (all the others were "float" solutions), this CORS point and a second check point (e.g., PSU1) would have been adequate in practice.
- It is always advisable to include a third CORS site for a blunder check.
- CORS-derived positions can be computed the same day as the observations are made.

- d. In obtaining CORS data sheets from the NGS, care must be taken to use the correct published coordinates shown on the sheet and input those values in the GPS adjustment program.
  - The typical datasheet that is downloaded with a CORS dataset is shown below for a point in Ohio near Gallipolis Lock and Dam on the Ohio River--Figure 13 on the next slide.
  - On this example, the coordinates for antenna phase center (ARP) are used (note options regarding use of L1 and L2 phase centers).
  - Ignore all "ITRF" positions--use only published NAD 83 positions.
  - The ellipsoid height on this CORS sheet (169.501 m) is based on GPS observations at this point and is referenced to NAD 83.
  - The NGS Data Sheet for this point (PID = DF4048) shows its GEOID 03 height.
  - No NAVD 88 elevation is indicated since this CORS ARP point has not been connected to the vertical network.
  - These CORS position and ellipsoid heights can be changed and may not be the same as the downloaded RINEX position and ellipsoid heights.
  - Thus, care must be taken when using CORS stations to ensure that coordinates used in the adjustment are those published.
  - In rare cases, errors in published CORS ellipsoid heights have been encountered; thus, redundant CORS points are advised.

PLANNING AND CONDUCTING CONTROL AND TOPOGRAPHIC SURVEYS (CONT'D)

Control and Topographic Surveying – Part 3
L03-306
3 PDH

```
        Antenna Reference Point(ARP): GALLIPOLIS CORS ARP
        -------------------------------------------------
                           PID = DF4048

ITRF00 POSITION (EPOCH 1997.0)
Computed in Feb., 2003 using 24 days of data.
    X =    668399.969 m     latitude    =  38 50 39.17620 N
    Y =  -4929212.710 m     longitude   = 082 16 40.10632 W
    Z =   3978967.616 m     ellipsoid height =  168.250   m

ITRF00 VELOCITY
Predicted with HTDP_2.7 February 2003.
    VX =  -0.0164 m/yr      northward =   0.0012 m/yr
    VY =  -0.0017 m/yr      eastward  =  -0.0165 m/yr
    VZ =   0.0011 m/yr      upward    =   0.0003 m/yr

NAD_83 POSITION (EPOCH 2002.0)
Transformed from ITRF00 (epoch 1997.0) position in Feb., 2003.
    X =    668400.506 m     latitude    =  38 50 39.14896 N
    Y =  -4929214.152 m     longitude   = 082 16 40.09229 W
    Z =   3978967.747 m     ellipsoid height =  169.501   m

NAD_83 VELOCITY
Transformed from ITRF00 velocity in Feb., 2003.
    VX =   0.0000 m/yr      northward =   0.0000 m/yr
    VY =  -0.0001 m/yr      eastward  =   0.0000 m/yr
    VZ =   0.0000 m/yr      upward    =   0.0000 m/yr

L1 Phase Center of the current GPS antenna: GALLIPOLIS CORS L1 PC C
--------------------------------------------------------------------
The D/M element, chokerings, radome antenna
(Antenna Code = TRM29659.00     UNAV) was installed on 11/14/02.
      The L2 phase center is 0.020 m above the L1 phase center.
                           PID = DF9327
ITRF00 POSITION (EPOCH 1997.0)
Computed in Feb., 2003 using 24 days of data.
    X =    668399.982 m     latitude    =  38 50 39.17622 N
    Y =  -4929212.792 m     longitude   = 082 16 40.10624 W
    Z =   3978967.684 m     ellipsoid height =  168.358   m

The ITRF00 VELOCITY of the L1 PC is the same as that for the ARP.

NAD_83 POSITION (EPOCH 2002.0)
Transformed from ITRF00 (epoch 1997.0) position in Feb., 2003.
    X =    668400.519 m     latitude    =  38 50 39.14899 N
    Y =  -4929214.235 m     longitude   = 082 16 40.09221 W
    Z =   3978967.815 m     ellipsoid height =  169.609   m

The NAD_83 VELOCITY of the L1 PC is the same as that for the ARP.

 * Latitude, longitude, and ellipsoid height are computed from their corresponding
Cartesian coordinates using dimensions for the GRS 80 ellipsoid:
semi-major axis = 6,378,137.0 meters  flattening  =1/298.257222101
 * WARNING: Mixing of antenna types can lead to errors of up to 10 cm. in height
unless antenna-phase-center variation is properly modeled.
```

Use NAD 83 POSITION of ARP in Adjustment

Figure 13: CORS antenna reference data.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

The NGS Data Sheet

See file dsdata.txt for more information about the datasheet.

```
DATABASE = Sybase ,PROGRAM = datasheet, VERSION = 7.09
1        National Geodetic Survey,   Retrieval Date = NOVEMBER 16, 2004
DF4048 ***********************************************************************
DF4048  CORS         -  This is a GPS Continuously Operating Reference Station.
DF4048  DESIGNATION -  GALLIPOLIS CORS ARP
DF4048  CORS_ID      -  GALP
DF4048  PID          -  DF4048
DF4048  STATE/COUNTY-  OH/GALLIA
DF4048  USGS QUAD    -  RODNEY (1983)
DF4048                          *CURRENT SURVEY CONTROL
DF4048 ___________________________________________________________________
DF4048* NAD 83(CORS)-  38 50 39.14896(N)    082 16 40.09229(W)     ADJUSTED
DF4048* NAVD 88      -
DF4048 ___________________________________________________________________
DF4048  EPOCH DATE   -        2002.00
DF4048  X            -     668,400.506 (meters)                     COMP
DF4048  Y            -  -4,929,214.151 (meters)                     COMP
DF4048  Z            -   3,978,967.746 (meters)                     COMP
DF4048  ELLIP HEIGHT-          169.50  (meters)         (02/??/03) GPS OBS
DF4048  GEOID HEIGHT-          -33.71  (meters)                     GEOID03
DF4048  HORZ ORDER   -  SPECIAL (CORS)
DF4048  ELLP ORDER   -  SPECIAL (CORS)
DF4048
DF4048.ITRF positions are available for this station.
DF4048.The coordinates were established by GPS observations
DF4048.and adjusted by the National Geodetic Survey in February 2003.
DF4048.The coordinates are valid at the epoch date displayed above.
DF4048.The epoch date for horizontal control is a decimal equivalence
DF4048.of Year/Month/Day.
DF4048.The PID for the CORS L1 Phase Center is DF9327.
DF4048
DF4048.The XYZ, and position/ellipsoidal ht. are equivalent.
DF4048
DF4048.The ellipsoidal height was determined by GPS observations
DF4048.and is referenced to NAD 83.
DF4048.The geoid height was determined by GEOID03.
DF4048
DF4048;                  North          East     Units Scale Factor Converg.
DF4048;SPC OH S     -    93,742.541   619,289.825   MT  0.99998005   +0 08 27.6
DF4048
DF4048!             -  Elev Factor  x  Scale Factor =   Combined Factor
DF4048!SPC OH S     -   0.99997341  x   0.99998005  =   0.99995346
DF4048
DF4048                         SUPERSEDED SURVEY CONTROL
DF4048.No superseded survey control is available for this station.
DF4048
DF4048_U.S. NATIONAL GRID SPATIAL ADDRESS: 17SLD8910900264(NAD 83)
DF4048_MARKER: STATION IS THE ANTENNA REFERENCE POINT OF THE GPS ANTENNA
DF4048
DF4048                          STATION DESCRIPTION
DF4048'DESCRIBED BY NATIONAL GEODETIC SURVEY 2003
DF4048'STATION IS A GPS CORS.  LATEST INFORMATION INCLUDING POSITIONS AND
DF4048'VELOCITIES ARE AVAILABLE IN THE COORDINATE AND LOG FILES ACCESSIBLE
DF4048'BY ANONYMOUS FTP OR THE WORLDWIDE WEB.
DF4048'   FTP CORS.NGS.NOAA.GOV: CORS/COORD  AND  CORS/STATION_LOG
DF4048'   HTTP://WWW.NGS.NOAA.GOV  UNDER PRODUCTS AND SERVICES.
```

Figure 14: NGS Data Sheet.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

- e. Azimuth orientation at the topographic project site is easily performed as part of the process of bringing in CORS control.
  - A second GPS receiver is set up at a marked point 500 to 1,000 ft distant from the first GPS point.
  - GPS observations over the short baseline are made concurrently with the CORS baseline connections.
  - The fixed solution over this short baseline will provide adequate azimuth orientation for subsequent topographic work at the project site.
  - (Note that a solid fixed solution is required over this baseline).
  - Either end of the baseline can be used to fix the CORS-derived X-Y-Z position.
  - The absolute accuracy over a 1,000 ft baseline will be between 10 and 30 seconds, depending on the quality of the short baseline solution.
  - This azimuth is adequate assuming the survey site is small and no real property connections are required.
  - If the site has deeded boundary alignments (e.g., bearings shown along a road or boundary), then these deeded bearings should be used for azimuth reference if this alignment is the established reference.
  - GPS derived azimuths would have to be corrected to fit the local orientation.

On-Line Positioning User Service (OPUS)

- OPUS is a free on-line baseline reduction and position adjustment service provided by the National Geodetic Survey.
- OPUS provides an X-Y-Z baseline reduction and position adjustment relative to three nearby national CORS reference stations.
- It performs the solution similarly to the manual adjustment illustrated above and can be used for establishing accurate horizontal control relative to the NSRS.
- It is simpler to operate in that only the user's observed data needs to be uploaded as opposed to downloading three or more CORS RINEX files.
- It can also be used as a quality control check on previously established control points. OPUS input is performed "on-line" by entering a required minimum period static, dual-frequency GPS RINEX, or other acceptable native format data.
- The resultant adjustment is returned in minutes via e-mail.
- Either the ultra-rapid or the precise ephemeris is used for the solution.

- The various data on the web page screen are entered, e.g., e-mail address, RINEX file path, antenna height, and local SPCS code.
- The antenna height in meters is the vertical (not slope) distance measured between the monument/benchmark and the antenna reference point (ARP).
- The ARP is almost always the center of the bottom-most, permanently attached, surface of the antenna.
- If 0.0000 meters is entered for the height, OPUS will return the position of the ARP.

- The type of antenna is selected from the drop down menu.
- OPUS computes an average solution from the three baselines.
- NGS baseline reduction software is used for the solutions.
- Output positions are provided in both ITRF and NAD 83.
- An overall RMS (95%) confidence for the solution is provided, along with maximum coordinate spreads between the three CORS stations for both the ITRF and NAD 83 positions.
- An orthometric elevation on NAVD 88 is provided using the current geoid model.
- The orthometric accuracy shown is a function of the spread between the three redundant baseline solutions.
- OPUS is also recommended as a check on existing USACE control.

Establishing Approximate Control for an Isolated or OCONUS Construction Project

- When confronted to perform a topographic survey for design or construction at a remote (OCONUS) project site, the following options are available:
  - Establish a local (arbitrary) coordinate system--e., g., set and mark a primary point with X-Y-Z coordinates 10,000-10,000-100 (meters or feet).
    - (It is recommended that the arbitrary X-Y coordinates be sufficiently different (e.g., 5,000-10,000) to avoid potential confusion between coordinates.
    - Also ensure that negative coordinates will not occur over the project site).
  - Set and mark a secondary point 500 to 1,000 ft distant for azimuth orientation.

- Establish the azimuth orientation between the two points (i.e. a baseline) using either:
  - Arbitrary azimuth of 000 deg.
  - Estimated azimuth (scaled from map or photo)
  - Magnetic azimuth (from transit or hand held compass)
  - Perform astronomic observation (Solar or Polaris)
  - Perform 8 to 15 minute GPS baseline observation, holding autonomous position at the primary end of the baseline
  - Gyroscope
- Perform topographic surveys relative to these two points.
  - No grid or sea level corrections are applied to observed distances--a tangent plane grid is assumed.

- a. No georeferenced control.
  - Georeferenced control is rarely required for construction--an arbitrary system described above is totally adequate for all design, stakeout, and construction.
  - In addition, an arbitrary grid system can be established in minutes--the baseline is quickly marked with stakes, hubs, rebar, or PK nails at each end.
  - Topographic surveys using a total station or RTK can then be immediately conducted, starting at one end of the arbitrary baseline.
  - If needed, supplemental control traverses can be run to set additional marked control points around the project site.
  - Optionally, RTK radial control points can also be set relative to the baseline.

- b. Georeferencing using autonomous GPS.
  - If georeferenced control is required on this isolated project, then autonomous GPS positioning could be used to put approximate georeferencing on the primary control point.
  - Georeferencing can be performed at any time.
  - All data that was observed on the arbitrary grid system can later be translated (and rotated) to a planer georeferenced coordinate system.
  - If only approximate georeferenced control is needed (± 20 ft), then an autonomous position from a handheld GPS receiver is adequate (e.g., Garmin, PLGR), and noting on all survey records that any resultant coordinates are approximate.
  - A few minute visual recording of the position is sufficient.
  - Likewise, a quick autonomous GPS position on the other end of the baseline will establish a rough geodetic azimuth for the baseline--accurate to only ± 1 deg at best.
  - If the receiver will convert Lat/Long to the local UTM zone, then the UTM coordinate system may be used to reference the project.
  - A Lat/Long coordinate for the primary point on the baseline should not be shown to an accuracy greater than the nearest 0.1 second.
  - A UTM coordinate should not be shown to better than the nearest meter.

- c. Long-term static GPS observations.
  - If a more precise georeferencing is required, then longer term static GPS observations must be made at the primary point on the baseline.
  - Most GPS receivers can average long-term autonomous GPS positions--over say 24 hours.
  - This will derive a WGS 84 3D position accurate to approximately ± 2 meters.
  - A higher accuracy (better than ± 1 meter) will be attained if geodetic quality GPS receivers are available.
  - If two geodetic receivers are available, then a fixed solution can be achieved over the short baseline with only a few minutes of static observations.

- d. Transformations.
  - All databases and drawings must clearly note the approximate georeferencing of the project, the method by which it was performed, and the estimated accuracy of the primary reference point.
  - Also clearly indicate that the project is referenced to WGS 84.
  - The vertical datum is referenced either to the WGS 84 ellipsoid or to the approximate local geoid if a worldwide geoid model is available.
  - Clearly note on drawings which vertical datum was held.
  - If required, the project may also be referenced to a local OCONUS horizontal datum if the transformation parameters are known or are imbedded in the GPS receiver.
  - Previous topographic observations on an arbitrary coordinate system may be transformed to the WGS 84/UTM grid using standard transformation routines found in most COGO software packages.
  - These routines will also automatically apply grid and sea level corrections during the transformation--assuming these are significant.

Determining Required Map Scale and Contour Interval

- General guidance for determining project-specific mapping requirements is contained in Table 2 at the end of this section and in Table 3 in the next section.
- Table 2 may be used to develop specifications for map scales, feature location tolerances, and contour intervals for typical engineering and construction projects.
- Functional activities are divided into military construction, civil works, real estate, hazardous waste, and emergency management.
- It is absolutely essential that surveying and mapping specifications originate from the functional requirements of the project, and that these requirements be realistic and economical.
- Specifying topographic map scales or accuracies in excess of those required for project planning, design, or construction results in increased costs to USACE, local sponsors, or installations, and may delay project completion.
- However, the recommended standards and accuracy tolerances shown in Table 2 should be considered as general guidance for typical projects--variance from these norms is expected.

- a. Mapping scope/limits.
  - Mapping limits should be delineated so only areas critical to the project are covered by detailed ground topographic surveys.
  - The areal extent of detailed, large-scale, site plan surveys should be kept to a minimum and confined to the actual building, utility corridor, or structure area.
  - Outside critical construction perimeters, more economical smaller scale plans should be used, along with more relaxed feature location accuracies, larger contour intervals, etc.

- b. Target scale and contour interval specifications.
  - Map scale is the ratio of the distance measurement between two identifiable points on a map to the same physical points existing at ground scale.
  - The errors in map plotting and scaling should exceed errors in measurements on the ground by a ratio of about 3 to 1.
  - Stated in a different manner, a ratio can be established as a function of the plotter error divided by the allowable scale error.
  - For example, if a digital plotter has an accuracy of 0.0008 ft (0.25 mm) and scaled map distances must be accurate to 0.5 ft, then 0.0008/0.5 ≈ 1/600; or the ratio becomes 1:600 or 1 inch = 50 feet.
  - Table 2 provides recommended map scales and contour intervals for a variety of engineering applications.
  - The selected target scale for a map or construction plan should be based on the detail necessary to portray the project site.
  - Surveying and mapping costs will normally increase exponentially with larger mapping scales; therefore, specifying too large a site plan scale or too small a contour interval than needed to adequately depict the site can significantly increase project costs.
  - Topographic elevation density or related contour intervals must be specified consistent with existing site gradients and the accuracy needed to define site layout, drainage, grading, etc., or perform quantity take offs.
  - Photogrammetric mapping flight altitudes or ground topographic survey accuracy and density requirements are determined from the design map target scale and contour interval provided in the contract specifications.

- c. Feature location tolerances.
    - This requirement establishes the primary surveying effort necessary to delineate physical features on the ground.
    - In most instances, a construction feature may need to be located to an accuracy well in excess of its plotted/scaled accuracy on a construction site plan; therefore, feature location tolerances should not be used to determine the required scale of a drawing or determine photogrammetric mapping requirements.
    - In such instances, surveyed coordinates, internal CADD grid coordinates, or rigid relative dimensions are used.
    - Table 2 indicates recommended positional tolerances (or precisions) of planimetric features.
    - These feature tolerances are defined relative to adjacent points within the confines of a specific area, map sheet, or structure--not to the overall project or installation boundaries.
    - Relative accuracies are determined between two points that must functionally maintain a given accuracy tolerance between themselves, such as adjacent property corners; adjacent utility lines; adjoining buildings, bridge piers, approaches, or abutments; overall building or structure site construction limits; runway ends; catch basins; levee baseline sections; etc.
    - Feature tolerances should be determined from the functional requirements of the project/structure (e.g., field construction/fabrication, field stakeout or layout, alignment, locationing, etc.).
    - Few engineering, construction, or real estate projects require that relative accuracies be rigidly maintained beyond a 5,000-ft range, and usually only within the range of the detailed design drawing for a project/structure (or its equivalent CADD design file limit).
    - For example, two catch basins 200 ft apart might need to be located to 0.1 ft relative to each other, but need only be known to ±100 ft relative to another catch basin 6 miles away.
    - Likewise, relative accuracy tolerances are far less critical for small-scale GIS data elements.
    - Actual construction alignment and grade stakeout will generally be performed to the 0.1 ft or 0.01 ft levels, depending on the type of construction.

- d. Maintaining relative precision on a topographic survey.
    - Ideally, all features located throughout a site area will have the same relative precision.
    - In practice, the relative precision of the points located furthest from the project control points will tend to have more error than points located directly from control monuments.
    - In order to maintain the required accuracy for a project, a primary project control net or loop is established to cover the entire project.
    - Secondary project control loops or nets are constructed from the primary project network.
    - This helps to ensure that the intended precision will not drop below the tolerance of the survey.
    - In lieu of increasing control requirements, the target map scale may be reduced in outlying areas.
    - This trade-off between survey control and scale either increases project costs or the scale is reduced below usable limits in some cases.

- e. Optimum target scale.
  - The requesting agency (or surveyor) should always use the smallest scale which will provide the necessary detail for a given project.
  - This will provide economy and meet the project requirements.
  - Once the smallest practical scale has been selected given the recommended options from Table 2, determine if any other future map uses are possible for this project which might need a larger scale.
  - If no other uses are of practical value, then the optimum map scale has been determined.

- f. Determining optimum contour interval.
  - The contour interval is the constant elevation difference between two adjacent contour lines.
  - The contour interval is chosen based on the map purpose, required vertical accuracy (if any was specified), the relief of the area of concern, and somewhat from the map target scale.
  - Steep slopes (large relief) will cause the surveyor to increase the contour interval in order to make the map more legible.
  - Flat areas will tend to decrease the interval to a limit which does not interfere with planimetric details located on the topographic map.

- (1) As a general rule, the lower limit for the contour interval is 25 lines per inch for even the smallest map scales.
  - The checklist to find the proper contour interval is:
    - Intended purpose of the map.
    - The desired accuracy of the depicted vertical information.
    - Area relief (mountainous, hilly, rolling, flat, etc.).
    - Cost of extra field work and possibility of plotting problems for selecting a smaller contour interval.
    - Other practical uses for the intended map.

- (2) Following the above checklist, contour interval ranges are recommended in Table 2 for the types of projects typically encountered in USACE.
  - If a specific vertical tolerance has been specified as the purpose for the mapping project, then the contour interval may be determined as a direct proportion from Table 2 for the type of project site.
  - Otherwise, the stated map accuracy of the vertical information will be in terms of the selected contour interval within the limits provided by Table 2.
- (3) Any contour drawn on the map will be correct to a stated fraction of the selected contour interval.
  - Because interpolation is used between spot elevations, the spot elevations themselves are required to be twice as precise as the contours generated by the spot elevations.

- g. CADD level/layer descriptors.
  - The use of CADD or GIS equipment allows planimetric features and topographic elevations to be readily separated onto various levels or layers and depicted at any scale.
  - Problems may arise when scales are increased beyond their originally specified values, or when so-called "rubber sheeting" or "warping" is performed.
  - It is therefore critical that these geospatial data layers, and related metadata files, contain descriptor information identifying the original source target scale and designed accuracy.

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PLANNING AND CONDUCTING CONTROL AND TOPOGRAPHIC SURVEYS (CONT'D)

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Project or Activity	Target Map Scale SI/IP	Feature Position Tolerance Horizontal SI/IP	Vertical SI/IP	Contour Interval SI/IP	Survey Accuracy Hor/Vert
DESIGN, CONSTRUCTION, OPERATION & MAINTENANCE OF MILITARY FACILITIES					
Maintenance and Repair (M&R)/Renovation of Existing Installation Structures, Roadways, Utilities, Etc					
General Construction Site Plans & Specs:	1:500	100 mm	50 mm	250 mm	3rd-I
Feature & Topographic Detail Plans	40 ft/in	0.1-0.5 ft	0.1-0.3 ft	1 ft	3rd
Surface/subsurface Utility Detail Design Plans	1:500	100 mm	50 mm	N/A	3rd-I
Elec, Mech, Sewer, Storm, etc	40 ft/in	0.2-0.5 ft	0.1-0.2 ft		3rd
Field construction layout		0.1 ft	0.01-0.1 ft		
Building or Structure Design Drawings	1:500	25 mm	50 mm	250 mm	3rd-I
40 ft/in	0.05-0.2 ft	0.1-0.3 ft	1 ft	3rd	
Field construction layout		0.01 ft	0.01 ft		
Airfield Pavement Design Detail Drawings	1:500	25 mm	25 mm	250 mm	3rd-I
40 ft/in	0.05-0.1 ft	0.05-0.1 ft	0.5-1 ft	2nd	
Field construction layout		0.01 ft	0.01 ft		
Grading and Excavation Plans	1:500	250 mm	100 mm	500 mm	3rd-II
Roads, Drainage, Curb, Gutter etc.	30-100 ft/in	0.5-2 ft	0.2-1 ft	1-2 ft	3rd
Field construction layout		1 ft	0.1 ft		
Recreational Site Plans	1:1000	500 mm	100 mm	500 mm	3rd-II
Golf courses, athletic fields, etc.	100 ft/in	1-2 ft	0.2-2 ft	2-5 ft	3rd
Training Sites, Ranges, and Cantonment Area Plans	1:2500	500 mm	1000 mm	500 mm	3rd-II
	100-200 ft/in	1-5 ft	1-5 ft	2 ft	3rd
General Location Maps for Master Planning	1:5000	1000 mm	1000 mm	1000 mm	3rd-II
AM/FM and GIS Features	100-400 ft/in	2-10 ft	1-10 ft	2-10 ft	3rd
Installation boundaries, roads, buildings	100 ft/in				
Installation regional location	2,000 ft/in				
Installation vicinity map	1,000 ft/in				
Space Management Plans	1:250	50 mm	N/A	N/A	N/A
Interior Design/Layout	10-50 ft/in	0.05-1 ft			
As-Built Maps: Military Installation Surface/Subsurface Utilities (Fuel, Gas,	30 to 100 ft/in	100 mm	100 mm	250 mm	3rd-I
Electricity, Communications, Cable,		0.2-1 ft	0.2 ft	1 ft	3rd
Storm Water, Sanitary, Water Supply,	1:1000 or 50-100 ft/in (Army)				
Treatment Facilities, Meters, etc.)	1:500 or 50 ft/in (USAF)				

Table 2: Recommended Accuracies And Tolerances: Engineering, Construction, And Facility Management Projects.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

Project or Activity	Target Map Scale SI/IP	Feature Position Tolerance Horizontal SI/IP	Vertical SI/IP	Contour Interval SI/IP	Survey Accuracy Hor/Vert
Housing Management GIS (Family Housing, Schools, Boundaries, and Other Installation Community Services)	1:5000 100-400 ft/in	10000 mm 10-15 ft	N/A	N/A	4th 4th
Environmental Mapping and Assessment Drawings/Plans/GIS	1:5000 400 ft/in	10000 mm 10-50 ft	N/A	N/A	4th 4th
Emergency Services Maps/GIS Military Police, Crime/Accident Locations, Post Security Zoning, etc.	1:10000 400-2000 ft/in	25000 mm 50-100 ft	N/A	N/A	4th 4th
Cultural, Social, Historical Plans/GIS Archeological sites, habitat, endangered species, wildlife, wetlands	1:5000 400 ft/in	10000 mm 20-100 ft	N/A	N/A	4th 4th
Runway Approach and Transition Zones: General Plans/Section	1:2500 100-200 ft/in	2500 mm 5-10 ft	2500 mm 2-5 ft	1000 mm 5 ft	3rd-II 3rd
Approach maps	1:5000 (H)	1:1000 (V)			
Approach detail	1:5000 (H)	1:250 (V)			
Runway end location	N/A	1 ft	0.2 ft	N/A	3rd
Airport Obstruction & NAVAID Surveys					
Airport Obstructions	N/A	20 ft	3 ft	N/A	3rd-II
NAVAID-visual	N/A	20 ft	N/A	N/A	3rd-II
NAVAID-electronic--radar	N/A	20 ft	100 ft	N/A	3rd-II
NAVAID-WAAS (absolute)	N/A	5 cm	10 cm	N/A	3rd
NAVAID-WAAS (relative)	N/A	1 cm	0.2 cm	N/A	2nd
Primary & Secondary Control Points	N/A	3 cm	4 cm	N/A	2nd
DESIGN, CONSTRUCTION, OPERATIONS AND MAINTENANCE OF CIVIL TRANSPORTATION & WATER RESOURCE PROJECTS Site Plans, Maps & Drawings for Design Studies, Reports, Memoranda, and Contract Plans and Specifications, Construction plans & payment					
General Planning and Feasibility Studies, Reconnaissance Reports	1:2500 100-400 ft/in	1000 mm 2-10 ft	500 mm 0.5-2 ft	1000 mm 2-10 ft	3rd-II 3rd
Flood Control and Multipurpose Project Planning, Floodplain Mapping, Water Quality Analysis, and Flood Control Studies	1:5000 400-1000 ft/in	10000 mm 20-100 ft	100 mm 0.2-2 ft	1000 mm 2-5 ft	3rd-II 3rd
Soil and Geological Classification Maps 400 ft/in	1:5000 20-100 ft	10000 mm	N/A	N/A 4th	4th
Land Cover Classification Maps 400-1000 ft/in	1:5000 50-200 ft	10000 mm	N/A	N/A 4th	4th

Table 2: Recommended Accuracies And Tolerances: Engineering, Construction, And Facility Management Projects.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

PLANNING AND CONDUCTING CONTROL AND TOPOGRAPHIC SURVEYS (CONT'D)

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Project or Activity	Target Map Scale SI/IP	Feature Position Tolerance Horizontal SI/IP	Vertical SI/IP	Contour Interval SI/IP	Survey Accuracy Hor/Vert
Archeological or Structure Site Plans & Details (Including Non-topographic, Close Range, Photogrammetric Mapping)	1:10 0.5-10 ft/in	5 mm 0.01-0.5 ft	5 mm 0.01-0.5 ft	100 mm 0.1-1 ft	2nd-I/II 2nd
Cultural and Economic Resource Mapping Historic Preservation Projects	1:10000 1000 ft/in	10000 50-100 ft	N/A	N/A	4th 4th
Land Utilization GIS Classifications Regulatory Permit Locations	1:5000 400-1000 ft/in	10000 mm 50-100 ft	N/A	N/A	4th 4th
Socio-Economic GIS Classifications	1:10000 1000 ft/in	20000 mm 100 ft	N/A	N/A	4th 4th
Grading & Excavation Plans	1:1000 100 ft/in	1000 mm 0.5-2 ft	100 mm 0.2-1 ft	1000 mm 1-5 ft	3rd-I 3rd
Flood Control Structure Clearing & Grading Plans (e.g., revetments)	1:5000 100-400 ft/in	2500 mm 2-10 ft	250 mm 0.5 ft	500 mm 1-2 ft	3rd-II 3rd
Federal Emergency Management Agency Flood Insurance Studies	1:5000 400 ft/in	1000 mm 20 ft	250 mm 0.5 ft	1000 mm 4 ft	3rd-I 3rd
Locks, Dams, & Control Structures Detail Design Drawings	1:500 20-50 ft/in	25 mm 0.05-1 ft	10 mm 0.01-0.5 ft	250 mm 0.5-1 ft	2nd-II 2nd/3rd
Spillways & Concrete Channels Design Plans	1:1000 50-100 ft/in	100 mm 0.1-2 ft	100 mm 0.2-2 ft	1000 mm 1-5 ft	2nd-II 3rd
Levees and Groins: New Construction or Maintenance Design Drawings	1:1000 100 ft/in	500 mm 1-2 ft	250 mm 0.5-1 ft	500 mm 1-2 ft	3rd-II 3rd
Construction In-Place Volume Measurement Granular cut/fill, dredging, etc.	1:1000 40-100 ft/in	500 mm 0.5-2 ft	250 mm 0.5-1 ft	N/A	3rd-II 3rd
Beach Renourishment/Hurricane Protection Project Plans	1:1000 100-200 ft/in	1000 mm 2 ft	250 mm 0.5 ft	250 mm 1 ft	3rd-II 3rd

Table 2: Recommended Accuracies And Tolerances: Engineering, Construction, And Facility Management Projects.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

Project or Activity	Target Map Scale SI/IP	Feature Position Tolerance Horizontal SI/IP	Vertical SI/IP	Contour Interval SI/IP	Survey Accuracy Hor/Vert
Project Condition Survey Reports					
Base Mapping for Plotting Hydrographic Surveys: line maps or aerial plans	1:2500 200-1000 ft/in	10000 mm 5-50 ft	250 mm 0.5-1 ft	500 mm 1-2 ft	N/A N/A
Dredging & Marine Construction Surveys	1:1000	2000 mm	250 mm	250 mm	N/A
New Construction Plans--Rock	100 ft/in	6 ft	1 ft	1 ft	N/A
New Construction Plans--Soft material	100 ft/in	6 ft	2 ft	1 ft	N/A
Maintenance Dredging Drawings	1:2500 200 ft/in	2000 mm 6 ft	500 mm 1 or 2 ft	500 mm 1 ft	N/A N/A
Offshore Geotechnical Investigations Core Borings /Probings/etc.	-	5000 mm 5-15 ft	50 mm 0.1-0.5 ft	N/A	N/A 4th
Structural Deformation Monitoring Studies/Surveys					
Reinforced Concrete Structures: Locks, Dams, Gates, Intake Structures, Tunnels, Penstocks, Spillways, Bridges	Large-scale vector movement diagrams or tabulations	10 mm 0.03 ft (long-term)	2 mm 0.01 ft	N/A	N/A N/A
Earth/Rock Fill Structures:Dams,Floodwalls, Levees, etc--slope/crest stability & alignment	(same as above)	30 mm 0.1 ft (long term)	15 mm 0.05 ft	N/A	N/A N/A
Crack/Joint & Deflection Measurements: piers/monoliths--precision micrometer	tabulations	0.2 mm 0.01 inch	N/A	N/A	N/A N/A

Table 2: Recommended Accuracies And Tolerances: Engineering, Construction, And Facility Management Projects.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

Project or Activity	Target Map Scale SI/IP	Feature Position Tolerance Horizontal SI/IP	Vertical SI/IP	Contour Interval SI/IP	Survey Accuracy Hor/Vert
REAL ESTATE ACTIVITIES: ACQUISITION, DISPOSAL, MANAGEMENT, AUDIT Maps, Plans, & Drawings Associated with Military and Civil Projects					
Tract Maps, Individual, Detailing Installation or Reservation Boundaries, Lots, Parcels, Adjoining Parcels, and Record Plats, Utilities, etc.	1:1000 1:1200 (Army) 50-400 ft/in	10 mm 0.05-2 ft	100 mm 0.1-2 ft	1000 mm 1-5 ft	3rd-I/II 3rd
Condemnation Exhibit Maps	1:1000 50-400 ft/in	10 mm 0.05-2 ft	100 mm 0.1-2 ft	1000 mm 1-5 ft	3rd-I/II 3rd
Guide Taking Lines/Boundary Encroachment Maps: Fee and Easement Acquisition	1:500 20-100 ft/in	50 mm 0.1-1 ft	50 mm 0.1-1 ft	250 mm 1 ft	3rd-I/II 3rd
General Location or Planning Maps	1:24000 2000 ft/in	10000 mm 50-100 ft	5000 mm 5-10 ft	2000 mm 5-10 ft	N/A 4th
GIS or Land Information System (LIS) Mapping, General					
Land Utilization and Management, Forestry Management, Mineral Acquisition	1:5000 200-1000 ft/in	10000 mm 50-100 ft	N/A	N/A	3rd 3rd
Easement Areas and Easement Delineation Lines	1:1000 100 ft/in	50 mm 0.1-0.5 ft	50 mm 0.1-0.5 ft	N/A	3rd 3rd
HAZARDOUS, TOXIC, RADIOACTIVE WASTE (HTRW) SITE INVESTIGATION, MODELING, AND CLEANUP					
General Detailed Site Plans HTRW Sites, Asbestos, etc.	1:500 5-50 ft/in	100 mm 0.2-1 ft	50 mm 0.1-0.5 ft	100 mm 0.5-1 ft	2nd-I/II 2nd/3rd
Subsurface Geotoxic Data Mapping and Modeling	1:500 20-100 ft/in	100 mm 1-5 ft	500 mm 1-2 ft	500 mm 1-2 ft	3-II 3rd
Contaminated Ground Water Plume Mapping/Modeling	1:500 20-100 ft/in	1000 mm 2-10 ft	500 mm 1-5 ft	500 mm 1-2 ft	3rd-II 3rd
General HTRW Site Plans & Reconnaissance Mapping	1:2500 50-400 ft/in	5000 mm 2-20 ft	1000 mm 2-20 ft	1000 mm 2-5 ft	3rd-II 3rd

Table 2: Recommended Accuracies And Tolerances: Engineering, Construction, And Facility Management Projects.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

1. Target map scale is that contained in CADD, GIS, and/or AM/FM layer, and/or to which ground topo or aerial photography accuracy specifications are developed. This scale may not always be compatible with the feature location/elevation tolerances required. In many instances, design or real property features are located to a far greater relative accuracy than that which can be scaled at the target (plot) scale, such as property corners, utility alignments, first floor or invert elevations, etc. Coordinates/elevations for such items are usually directly input into a CADD or AM/FM database.

2. The feature position or elevation tolerance of a planimetric feature is defined at the 95% confidence level. The positional accuracy is relative to two adjacent points within the confines of a structure or map sheet, not to the overall project or installation boundaries. Relative accuracies are determined between two points that must functionally maintain a given accuracy tolerance between themselves, such as adjacent property corners; adjacent utility lines; adjoining buildings, bridge piers, approaches, or abutments; overall building or structure site construction limits; runway ends; catch basins; levee baseline sections; etc. The tolerances between the two points are determined from the end functional requirements of the project/structure (e.g., field construction/fabrication, field stakeout or layout, alignment, locationing, etc.).

3. Horizontal and vertical control survey accuracy refers to the procedural and closure specifications needed to obtain/maintain the relative accuracy tolerances needed between two functionally adjacent points on the map or structure, for design, stakeout, or construction. Usually 1:10,000 Third-Order (I) control procedures (horizontal and vertical) will provide sufficient accuracy for most engineering work, and in many instances of small-scale mapping or GIS rasters, Third-Order, Class II methods and Fourth-Order topo/construction control methods may be used. Base- or area-wide mapping control procedures shall be specified to meet functional accuracy tolerances within the limits of the structure, building, or utility distance involved for design or construction surveys. Higher order control surveys shall not be specified for area-wide mapping or GIS definition unless a definitive functional requirement exists (e.g., military operational targeting or some low gradient, flood control projects).

Table 2: Recommended Accuracies And Tolerances: Engineering, Construction, And Facility Management Projects.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

Recommended Guidelines for Army Installation Maps and Drawings

- Table 3 below is extracted from the "CADD/GIS Technology Center Guidelines for Installation Mapping and Geospatial Data".
- It contains guidance on recommended scales for various types of military installation maps.
- The map class refers to the ASPRS standards.

NOTE: UNLESS OTHERWISE SPECIFIED THE INSTALLATION LAYOUT MAP WILL BE USED AS A BASE FOR THE PREPARATION OF OTHER SPECIFIED MAPS.

MAP AND GRAPHIC LAYERS *M=mandatory* *O=optional* *TBD=to be determined*		MAP SCALE 1"=xxxxft	MAP CLASS-ACCURACY	CONTOUR INTERVAL (feet)	DESCRIPTION AND FEATURES SHOWN
A- NATURAL AND CULTURAL RESOURCES A-1 AREAS OF CRITICAL CONCERN	M	1"=400ft 1:4,800	Class 1	5	Shows historic and archeological sites, areas of threatened and endangered species, primary habitat areas, flood plains, wetlands, coastal zones, lakes, rivers, water bodies, soils and soil boring locations, and similar information.
A- NATURAL AND CULTURAL RESOURCES A-2 MANAGEMENT AREAS	O	1"=400ft 1:4,800	Class 1	5	Shows surface/subsurface geology, paleontology, topography, hydrology and surface drainage, vegetation areas, forests, commercial timber areas, agricultural outleasing areas, fish and wildlife areas, prime soils, grounds maintenance areas, outdoor recreation areas, pest management areas, and similar information.

Table 3: Recommended Installation Mapping Guidelines.
(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

NOTE: UNLESS OTHERWISE SPECIFIED THE INSTALLATION LAYOUT MAP WILL BE USED AS A BASE FOR THE PREPARATION OF OTHER SPECIFIED MAPS.

B- ENVIRONMENTAL QUALITY B-1 ENVIRONMENTAL REGULATORY AREAS	M	1"=400ft 1:4,800	Class 1	5	Shows hazardous waste generation points, hazardous waste storage facilities, solid waste disposal and recycling points, fuel tanks, Resource Conservation and Recovery Act sites, installation restoration program sites/areas, and similar information.
B- ENVIRONMENTAL QUALITY B-2 ENVIRONMENTAL EMISSIONS AREAS	O	1"=400ft 1:4,800	Class 1	5	Shows sources of air emissions, wastewater Non-point Pollution Discharge Elimination System (NPDES) point source discharges, storm water non-point discharges, drinking water supply, electromagnetic radiation sources, sources of radon emissions and similar information.
C-INSTALLATION LAYOUT AND VICINITY C-1 INSTALLATION LAYOUT	M	1"=100ft 1:1,200	Class 1	2	Shows the installation boundary; buildings (facility identification numbers and type: permanent, semi-permanent, temporary); structures; roads and parking areas; walkways and trails; railroads; fences; recreation areas; cemeteries; training ranges; contours; water areas; coordinate grid; embankments; below/above ground tanks; embankments; spot elevations and survey control; neighboring land use (outside installation boundary); historic buildings and places, archeological sites and similar information.
C-INSTALLATION LAYOUT AND VICINITY C-2 OFF-INSTALLATION SITES	M	1"=400ft 1:4,800	Class 1	5	Shows the same information as the installation layout map, but this map is prepared for those facilities that are outside the installation's primary boundary.
C-INSTALLATION LAYOUT AND VICINITY C-3 INSTALLATION REGIONAL LOCATION	O	1"=2,000ft 1:24,000	NA	20	Shows information of interest to regional planning and major transportation systems, cities, towns, political jurisdictions, DoD installation boundaries, aeronautical data, woodlands, recreation areas, towers, significant physical characteristics of the region and other similar information.
C-INSTALLATION LAYOUT AND VICINITY C-4 INSTALLATION VICINITY	O	1"=1000ft 1:12,000	Class 1	10	Shows the installation boundary, airfield and operations areas, major roads, proposed roads and highways, railroads, bombing and test ranges, vertical obstructions, topography, recreation areas, waterways and bodies, towers and similar information.

Table 3: Recommended Installation Mapping Guidelines.
(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

NOTE: UNLESS OTHERWISE SPECIFIED THE INSTALLATION LAYOUT MAP WILL BE USED AS A BASE FOR THE PREPARATION OF OTHER SPECIFIED MAPS.

C-INSTALLATION LAYOUT AND VICINITY C-5 AERIAL PHOTOGRAPHIC COVERAGE AND CONTROL STATIONS	O		NA	NA	Prepared as an index of the aerial photographic coverage for the installation, shows the center point of individual photographs as well as the location of survey control stations and control points used for the aerial photography.
C-INSTALLATION LAYOUT AND VICINITY C-6 INSTALLATION BOUNDARY	M	Legal Records	Class 1	1	Shows the land area comprising the installation boundary including survey monuments.
D- LAND USE D-1 INSTALLATION LAND USE D-1.1 FUTURE LAND USE	M	1"=400ft 1:4,800	Class 1	5	Shows installation land use including airfields; maintenance and repair areas; manufacturing industrial areas; supply/ storage areas; administration areas; training and ranges areas; troop and family housing; community facilities (commercial and service); medical facilities; outdoor recreation; open spaces; and similar information
D- LAND USE D-2 OFF SITE LAND USE D-2.1 FUTURE OFF SITE LAND USE	O	1"=400ft 1:4,800	Class 1	5	Shows off-site land use including airfields; maintenance and repair areas; manufacturing industrial areas; supply/ storage areas; administration areas; training and ranges areas; troop and family housing; community facilities (commercial and service); medical facilities; outdoor recreation; open spaces; and similar information
D- LAND USE D-3 REAL ESTATE	O	1"=400ft 1:4,800	Class 1	2	Shows the land area comprising the installation including parcel information on fee title, lease, license, permit and easement areas inclusive of tract, acreage, data of acquisition, lease period and similar information.
D- LAND USE D-4 EXPLOSIVE SAFETY QUANTITY-DISTANCE CLEARANCE ZONES (QD-ARCS)	M	1"=400ft 1:4,800	Class 1	5	Same as installation layout map, but includes the distance clearance zones for explosives.
D- LAND USE D-5 HAZARD ANALYSIS CONSTRAINTS	M	1"=400ft 1:4,800	Class 1	5	Same as installation layout map, but includes areas of catastrophic potential to include flooding, subsidence, avalanche, erosion, earthquake, tsunami, snowfall, windstorm, volcanic ash and similar information.
D- LAND USE D-6 COMPOSITE CONSTRAINTS	M	1"=400ft 1:4,800	Class 1	5	Same as installation layout map, but emphasizes areas of catastrophic potential from natural occurrences e.g., flooding, subsidence, avalanche, earthquake, tsunami and technological occurrences, accident potential zones, hazardous noise areas, noise contours, environmental

Table 3: Recommended Installation Mapping Guidelines.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

NOTE: UNLESS OTHERWISE SPECIFIED THE INSTALLATION LAYOUT MAP WILL BE USED AS A BASE FOR THE PREPARATION OF OTHER SPECIFIED MAPS.

					management areas and other similar information.
D- LAND USE D-7 AREA DEVELOPMENT	O	1"=100ft 1:1,200	Class 1	2	Same as installation layout map, but includes information on the planned development of areas within the installation.
E-AIRFIELD OPERATIONS E-1 ON-BASE OBSTRUCTIONS TO AIRFIELD CRITERIA	M	1"=1,000ft 1:12,000	Class 1	5	Same as airport pavement map and includes information on any obstructions to navigation and ground movement of aircraft within the installation boundary.
E-AIRFIELD OPERATIONS E-2 APPROACH/DEPARTURE ZONE OBSTRUCTIONS (to 10,000 feet)	M	1"=800ft	Class 1	5	Shows obstructions within the glide angle approach zone and other similar information within the distance specified.
E-AIRFIELD OPERATIONS E-3 APPROACH/DEPARTURE ZONE OBSTRUCTIONS (from 10,000 feet to 10 miles)	M	1"=2,000ft 1:24,000	Class 1	10	Shows obstructions within the glide angle approach zone and other similar information within the distance specified.
E-AIRFIELD OPERATIONS E-4 AIRSPACE OBSTRUCTION-VICINITY	M	1"=1,000ft 1:12,000	Class 1	10	Shows obstructions within the vicinity of the airfield, but not those already shown on approach/departure zone maps, topography, cities, towns, other obstructions, water courses and water bodies and similar information.
E-AIRFIELD OPERATIONS E-5 TERMINAL ENROUTE PROCEDURES (TERPS) AUTOMATION	M	TBD	TBD	TBD	Shows all NAVAIDS with latitude and longitude.
E-AIRFIELD OPERATIONS E-6 AIRFIELD/AIRSPACE CLEARANCES	O	1"=100ft 1:1,200	Class 1	2	Shows airfield waivers, clear zones, primary surface, transitional surface (7:1), approach and departure surface (50:1) approach and taxiway clearances, wing tip clearances, turning radii, and other similar information necessary for aircraft movement on the ground.
E-AIRFIELD OPERATIONS E-7 AIRFIELD PAVEMENT	O	1"=400ft 1:4,800	Class 1	5	Shows runways, taxiways, aprons, warm-up pads, hardstands, helipads, stabilized shoulders, overruns and similar information.
E-AIRFIELD OPERATIONS E-8 AIRFIELD PAVEMENT DETAILS	O	1"=100ft 1:1,200	Class 1	2	Shows runways, taxiways, aprons, warm-up pads, hardstands, helipads, stabilized shoulders, overruns and similar information, but includes cross sections and elevation profiles.
E-AIRFIELD OPERATIONS E-9 AIRCRAFT PARKING E-9.1 PROPOSED AIRCRAFT PARKING	O	1"=100ft 1:1,200	Class 1	2	Shows the parking plan for aircraft including alert hangars, refueling outlets, blast fences, aircraft orientation, control tower, fire station, cargo holding pads, maintenance

Table 3: Recommended Installation Mapping Guidelines.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

NOTE: UNLESS OTHERWISE SPECIFIED THE INSTALLATION LAYOUT MAP WILL BE USED AS A BASE FOR THE PREPARATION OF OTHER SPECIFIED MAPS.

					docks, maintenance lights, aircraft revetments and similar information.
E-AIRFIELD OPERATIONS E-10 AIRFIELD LIGHTING SYSTEMS	O	1"=100ft 1:1,200	Class 1	2	Shows the major components of airfield lighting system including runway, taxiway, end reference lights, location size and type of underground ducts, obstruction lights, stand-by generator equipment and similar information.
F- Reserved					
G-UTILITY SYSTEMS G-1 WATER SUPPLY SYSTEM	M	1"=50ft 1:600	Class 1	1	Shows all significant components of the water supply system.
G-UTILITY SYSTEMS G-2 SANITARY SEWERAGE SYSTEM	M	1"=50ft 1:600	Class 1	1	Shows all significant components of the sanitary sewerage system.
G-UTILITY SYSTEMS G-3 STORM DRAINAGE SYSTEM	M	1"=50ft 1:600	Class 1	1	Shows all significant components of the storm drainage system.
G-UTILITY SYSTEMS G-4 ELECTRICAL DISTRIBUTION SYSTEM (STREET AND AIRFIELD)	M	1"=50ft 1:600	Class 1	2	Shows all significant components of the electrical distribution and exterior lighting systems.
G-UTILITY SYSTEMS G-5 CENTRAL HEATING/COOLING SYSTEMS	M	1"=50ft 1:600	Class 1	1	Shows all significant components of the central heating/cooling systems.
G-UTILITY SYSTEMS G-6 NATURAL GAS DISTRIBUTION SYSTEM	M	1"=50ft 1:600	Class 1	2	Shows all significant components of the natural gas distribution system.
G-UTILITY SYSTEMS G-7 LIQUID FUEL SYSTEM	M	1"=50ft 1:600	Class 1	1	Shows all significant components of the liquid fuel system.
G-UTILITY SYSTEMS G-8 CATHODIC PROTECTION SYSTEM	O	1"=100ft 1:1,200	Class 1	2	Shows all significant components of the cathodic protection system for all underground utility systems and structures subject to electrochemical corrosion.
G-UTILITY SYSTEMS G-9 CATHODIC PROTECTION SYSTEM DETAILS	O	1"=50ft 1:600	Class 1	2	Shows all significant components of the cathodic protection system including details of other utilities in proximity to ground beds for all underground utility systems.
G-UTILITY SYSTEMS G-10 INDUSTRIAL WASTE AND DRAIN SYSTEM	O	1"=50ft 1:600	Class 1	2	Prepared when these systems are of such a complexity or nature it requires the production of a separate map to portray their characteristics.
G-UTILITY SYSTEMS G-11 COMPOSITE UTILITY SYSTEM	M	1"=100ft 1:1,200	Class 1	2	Shows the water, sanitary sewer, storm drainage, electrical, central heating/cooling, gas compressed air, industrial waste and other utility systems combined on a single map.

Table 3: Recommended Installation Mapping Guidelines.

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G-UTILITY SYSTEMS G-11.1 CENTRAL AIRCRAFT SUPPORT SYSTEMS	O	1"=50ft 1:600	Class 1	2	Shows all the utilities systems that serve the airfield apron and related servicing of aircraft.
G-UTILITY SYSTEMS G-12 FIRE PROTECTION SYSTEMS AND UTILITIES	M	1"=400ft 1:4,800	Class 1	5	Shows fire hydrants, water deluge systems, safety buffer distances, vehicle maneuverability areas, and similar information related to fire protection or safety.
G-UTILITY SYSTEMS G-13 OTHER UTILITY SYSTEMS	O	1"=100ft 1:1,200	Class 1	2	Show utilities not displayed on other maps.
H-COMMUNICATION AND NAVAID SYSTEMS H-1 INSTALLATION-WIDE COMMUNICATIONS AND COMPUTER SYSTEMS	M	1"=400ft 1:4,800	Class 1	5	Uses the installation layout map as a base to show installation-wide communications systems.
H-COMMUNICATION AND NAVAID SYSTEMS H-2 NAVAID SYSTEMS	M	1"=400ft 1:4,800	Class 1	5	Shows NAVAID components such as radio transmitters, radio relay facilities, high and ultra high frequency direction finders, radio beacon shelters, GCA units, RAPCON units, PAR structures, TACAN buildings and facilities and similar information.
I-TRANSPORTATION SYSTEM I-1 COMMUNITY NETWORK - ACCESS TO BASE	M	1"=400ft 1:4,800	Class 1	10	Shows all major arterial, collector streets that have direct relationship to the installation and local streets providing access to the installation.
I-TRANSPORTATION SYSTEM I-2 ON-BASE NETWORK	M	1"=400ft 1:4,800	Class 1	2	Shows the transportation network including parking areas, sidewalks, bike/hike/jogging trails on the installation.
I-TRANSPORTATION SYSTEM I-2.1 FUTURE ON-BASE NETWORK	O	1"=400ft 1:4,800	Class 1	2	Shows the planned transportation network including parking areas, sidewalks, bike/hike/jogging trails on the installation.
J-ENERGY SYSTEMS	O	1"=100ft 1:1,200	Class 1	2	Shows data related to the installation's energy planning systems.
K-ARCHITECTURAL COMPATIBILITY	O	1"=400ft 1:4,800	Class 1	2	Shows the installation's architectural compatibility zones and architectural districts.
L-INSTALLATION LANDSCAPE DEVELOPMENT AREA	O	1"=400ft 1:4,800	Class 1	2	Shows the installation's landscape areas and planned flora.
M-FUTURE DEVELOPMENT M-1 CURRENT	M	1"=400ft 1:4,800	Class 1	5	Shows the current installation layout; e.g. streets, parking lots, buildings, utilities etc; to include those facilities presently under development.
M-FUTURE DEVELOPMENT M-2 FUTURE DEVELOPMENT SHORT-TERM (1-5 YEARS)	M	1"=400ft 1:4,800	Class 1	5	Shows planned development on the installation including streets and parking lots, buildings, utilities and

Table 3: Recommended Installation Mapping Guidelines.

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					similar information.
M-FUTURE DEVELOPMENT M-2 FUTURE DEVELOPMENT SHORT-TERM (> 5 YEARS)	M	1"=400ft 1:4,800	Class 1	5	Shows the facilities that will be developed beyond a five-year time frame on the installation including streets and parking lots, buildings, utilities and similar information.
O-FORCE PROTECTION 0-1 SURGE CAPABILITY (BEDDOWN AND SUPPORT)	O	1"=400ft 1:4,800	Class 1	5	Show areas that can be suited for temporary billeting of troops in the case of surge requirements.
O-FORCE PROTECTION 0-2 PHYSICAL SECURITY	M	1"=400ft 1:4,800	Class 1	5	Shows security fences, proposed and existing access points, sensor devices, location of security police units, fire stations and other similar information.
O-FORCE PROTECTION 0-3 DISASTER PREPAREDNESS CRASH GRID	M	1"=400ft 1:4,800	Class 1	5	Shows all buildings and building numbers with hospitals and fallout shelters, protection factors and similar information.
O-FORCE PROTECTION 0-4 INSTALLATION SURVIVABILITY	O	1"=400ft 1:4,800	Class 1	5	Prepared for installations to show operational contingencies.
P-PORTS AND HARBORS	O	1"=100ft 1:1,200	Class 1	2	Shows berths, breakwater, channel, cable and pipeline areas, hazard areas, dry dock, navigation aides, jetties, wrecks, bouys, piers, quays, reefs, safety fairway, wharf, and other similar information.
R- TRAINING COMPLEX R-1 RANGE AREA	0	1"=400ft 1:4,800	Class 1	5	Shows surface danger zones, target areas, impact areas, dudded areas, bomb circles, firing points, firing fans and lanes, range control points, and other similar information.
R- TRAINING COMPLEX R-2 TRAINING AREA	0	1"=400ft 1:4,800	Class 1	5	Shows landing zones, drop zones, bivouac areas, training sites, foot traffic areas, perimeter defense, obstacle course areas, drill fields, marching areas and other similar information.

Table 3: Recommended Installation Mapping Guidelines.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

Topographic Survey Equipment Selection and Planning Guidance

- This section discusses the selection of topographic survey instruments and methods for a given project.
- There is no set formula for deciding on a particular instrument (transit-tape, transit-stadia, plane table, total station, RTK, Laser) or survey densification technique (cross-sections, grid matrix, random).
- This is because of the large number of variables involved that will impact the use of one instrument or method versus another.
- These variables also have a major impact on productivity and cost.
- Some of these variables are discussed in the following paragraphs.

- Size of project.
  - A simple stakeout of a baseball field can be accomplished easily with a transit and 100/300 ft steel tape--a total station or RTK would be overkill for such a project.
  - On the other hand, a detailed site plan survey of a multi-acre planned commissary site would require a more productive instrument, such as a total station or RTK.
- Complexity of project.
  - If only ground elevation shots are required at a site, survey data hand recorded in a field book would suffice.
  - A project with many different feature levels, and with attribute options for each feature, would be more effectively surveyed using an electronic data collector--with a "field-finish" option if available.

- Project location.
  - A remote or hazardous site location may dictate the type of equipment used.
  - Lengthy mob/demob travel times will significantly increase costs, as will sites that can only be reached on foot.
- Project time constraints.
  - A quick delivery suspense date may require use of electronic "field-finish" survey techniques; perhaps even laser techniques if a complex structure is involved.
  - Specified overtime may increase costs.
- Project cost constraints.
  - Always a driving factor--may preclude use of terrestrial laser technique.
  - Or the cost may dictate a one-man crew with a robotic total station.

- User/requestor preferences.
  - The originating office may have a preference for a particular survey method, including detailed data acquisition specifications.
  - This user preference may or may not be the most economical method.
- Project accuracy specifications.
  - The requested accuracy requirements from the using office may be unrealistically tight, and may preclude using a particular method even though it might have sufficed for the work.
  - For example, if 0.2 ft horizontal accuracy is specified for all feature locations, a transit-tape or transit-stadia survey method is ruled out.
  - Over specifying accuracy is probably the biggest cost driver on a project.
- Tree coverage.
  - Dense canopy cover will eliminate use of RTK methods.
  - If canopy is low (less than 20 to 25 ft) an expandable prism pole may be used to reach over the canopy.

- Ground vegetation.
  - Heavy ground vegetation typically precludes use of laser/LIDAR survey methods.
  - If vegetation is thick, line clearing may be needed to obtain direct total station shots.
  - RTK may be more productive in such areas.
- Above ground and underground utility detail required.
  - If complex utility infrastructure needs to be mapped, a total station may be the most practical method.
  - If detailed attribute sketches are required, a pen tablet type notebook may be preferable to a field book.
  - Utility work can represent 50% or more of the survey cost.

- Site elevation relief.
  - A site with high relief will make obtaining ground shots difficult, particularly if climbing or rappelling is required to access shot points.
  - This might occur on highly complex mechanical facilities where it is difficult to occupy overhead HVAC lines with a reflector or GPS antenna.
  - Site relief will also be a major factor in productivity estimates, particularly if dense vegetation is also involved.
  - A reflectorless total station may be the best solution in these areas.

- Ground topographic shot density requirements.
  - Usually the terrain gradient dictates the shot density required to model the ground.
  - In some cases, the requesting agency may dictate a certain "post spacing," which may or may not make any sense given the ground relief.
  - Determining the optimum shot spacing density has traditionally been left to the experienced field surveyor.
  - This was the case when a plane table was the method of choice for developing site plans for design.
  - The field Party Chief based the amount of ground relief detail he collected on the project design requirement, and verified coverage before leaving the field.
  - This is still true of electronic data collectors--the Party Chief must confirm that the shot density is sufficient to generate a DTM that is adequate for the project purpose.
  - The critical component is the project purpose--dense topographic data is not needed on a site where little, if any, excavation will be performed.
  - Thus, it is critical that the Party Chief have knowledge of the planned/proposed design and construction effort, and base the collection density on that criteria.

- Instrument availability.
  - Not all survey organizations have a full complement of instrumentation technologies available.
  - A smaller firm may have only an electronic total station but has not invested in an expensive RTK system.

- Instrument data collection productivity.
  - Data collection productivity is highly dependent on the type of feature data being collected and the instrument used to collect the data.
  - Collection rates can be as long as a few minutes per feature in the case of a transit or plane table where slope distances must be hand reduced and recorded or plotted.
  - Transit and plane table surveys typically collected between 100 and 200 points in a day.
  - The other extreme is a terrestrial laser that can collect thousands of points/sec (without any attribution).
  - Data collection rates for a total station or RTK system are roughly the same--both use a similar data collection system with nearly identical COGO options.
  - Continuous ground shot points can be collected every few seconds--as long as it takes the rod/prism-person to move between points.
  - (Some systems have a "continuous" tracking mode which will update the points every second or so).
  - When different features are shot, the descriptor codes (and perhaps attributes) must be entered into the data collector.
  - If a two-digit descriptor code is used, shots can be completed in a few seconds.
  - Additional time will be required depending on the amount of attribution.
  - A feature requiring a detailed field sketch may require a few minutes to complete.
  - Thus, depending on the nature of the project and features, a total station or RTK system can collect anywhere from 300 to 2,000 points in a day.

- Data collector requirements.
  - The requesting agency may dictate a particular data collector format be used, in addition to mandating use of a data collector itself (no field book option).
- Final product deliverable format.
  - The requesting agency usually mandates a specific CADD or GIS deliverable format.
  - This may impact the field data collection method.
- Crew or instrument operator experience.
  - Plane table surveys are probably not a survey option any more given few experienced plane table operators are still employed.
  - Most engineers and surveyors can operate a transit or level, read stadia, or use a steel tape.
  - Thus, these methods would be effective for a small topographic survey or stake out if a total station crew is unavailable.
  - ("Small" means less than one day).

- The following tables provide rough guidance for determining the density of shots needed to delineate planimetric features and terrain topography.

Planimetric Feature	Recommended Spacing of Shots along Feature Target Scale 1" = 30 ft	1" = 50 ft	1" = 100 ft
Linear features (curbs, roads, buildings, utilities)	30 ft	50 ft	100 ft
Irregular features (breaklines, contours, shoreline, walkways, etc.)	10 ft	15 ft	30 ft
Rectangular or circular utility features (junction boxes, manholes, catch basins, etc.) detail corners or perimeter limits if objects maximum dimension is larger than	5 ft	10 ft	20 ft
Circular curves (roads, curbs, etc.) Delineate curve with	3 points	3 points	3 points

Table 4: Nominal Data Density Shot Intervals for Various Planimetric Features.
(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

	Recommended Post Spacing (Density) of Shots on Ground Contour Interval		
Terrain Gradient (% slope)	1 ft	2 ft	5 ft
< 1 %	50 ft (25 pts/acre)	100 ft (10 pts/acre)	250 ft (4 pts/acre)
< 5 %	10 ft (440 pts/acre)	20 ft (120 pts/acre)	50 ft (25 pts/acre)
<10 %	5 ft (1,600 pts/acre)	10 ft (440 pts/acre)	25 ft (80 pts/acre)
> 10 %	[as required to delineate feature]		

Table 5: Nominal Post Spacing Intervals and Density (Shots per Acre) for Topographic Ground Detail.
(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

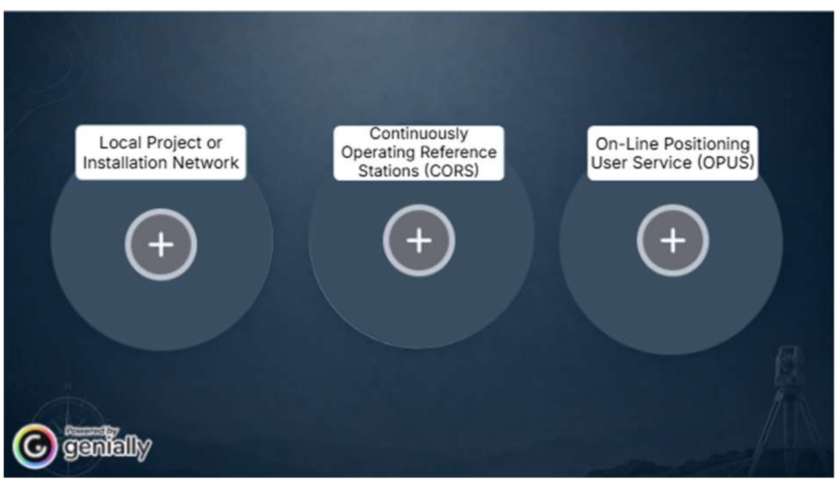
- Given the large number of variables listed above, estimating topographic survey productivity is difficult-- especially if underground utility location is required.
- Past experience on similar sites is probably the most reliable estimate.
- Use of estimating ratios, such as "acres/day" and "$/acre" may be of some value; however, these ratios are only representative to a particular site.
- For example, the 30-acre site (Topographic Survey of Hannibal Lock & Dam, Proposed Nationwide DGPS Antenna Site (Pittsburgh District)) was surveyed at a cost of $425/acre at a productivity rate of 5 acres/day.
- This is a relatively flat, clear site (mowed grass with isolated trees), with few utilities.
- If this site had been heavily vegetated and treed, requiring extensive line clearing, the cost/acre could easily have doubled or tripled.

Nominal Site Condition	Estimated rate (acres/day)
<u>Topography</u>	
Flat, clear ground (no vegetation)	5 to 10 acres/day
Flat, isolated trees	4 to 8 acres/day
Flat, heavily treed (traverse reqd)	3 to 6 acres/day
Flat, heavily treed & vegetated (traverse & line cutting)	1 to 2 acres/day
Rolling terrain, clear ground (no vegetation)	3 to 5 acres/day
Rolling terrain, isolated trees	1 to 2 acres/day
Rolling terrain, heavily treed	0.5 to 1 acres/day
Rolling terrain, heavily treed & vegetated	0.2 to 0.5 acres/day
<u>Planimetry</u>	
Rural, isolated buildings & roads	10 acres/day
Urban, subdivision	1 acre/day
Installation, military	2 acres/day
Lock and Dam area	2 acres/day

Table 6: Matrix of Estimated Productivity Rates (Acres/Day) for Various Site Conditions.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

Check the next slide to explore an interactive GIF about Three Ways to Tie Into the Grid



FIELD DATA COLLECTORS AND COORDINATE GEOMETRY FUNCTIONS

Purpose

- This chapter provides guidance on data collectors that are used to record topographic field data observed with total stations and RTK systems.
- Data collector features are described along with standard coordinate geometry (COGO) options.
- Some traditional route surveying parameters are also outlined at the end of the chapter.

Field Survey Notes--Manual and Electronic

- Field survey notes can be collected either manually or electronically.
- Manual methods include field books or plane table sheets.
- Electronic methods include both internal and external data collectors interfaced with various survey instruments (total station, GPS receiver, or LIDAR).
- Electronic data collectors record, store, and transfer field data without the need to key in individual measurements, providing significant time savings in gathering and processing field data and eliminating reading and recording errors.

- However, not all supplemental feature data or detail sketches are easily encoded in a data collector.
- It is often better to draw detailed sketches of critical features in a traditional field survey book; or optionally on a digital notebook tablet.
- Sketches of features can also be supplemented with digital photos--video and digital cameras can be used to supplement the field sketch and provide a very good record of the site conditions for the CADD operator, design engineer, and user of the topographic map.
- Each District will have their own policy regarding how field notes are to be kept--manually and/or electronically.

- An important distinction is made when written field notes are not required, and the data collector is used exclusively as an "electronic field book."
- These electronic files are usually sufficient for submittal without identical hand entries from a field book.
- However, some Districts may require that a duplicate written field book be kept for electronically recorded data--for data safeguarding and legal issues.
- When duplicate field books are kept of electronically recorded data, the entries are compared to the files generated by the data collection processing.
- All field book data are written in the format set by each District.
- There is no Corps standard for field book data formats.

- a. Four types of manual field book notes are kept in practice:
  - sketches,
  - tabulations,
  - descriptions, and
  - combinations of these.
  - The most common type is a combination form, but an experienced recorder selects the version best fitted to the job at hand.
  - The location of a reference point may be difficult to identify without a sketch, but often a few lines of description are enough.
  - Benchmarks are also described. In note keeping this axiom is always pertinent: when in doubt about the need for any information, include it and make a sketch.
  - It is better to have too much data than not enough.

- b. Topographic locations are numbered according to data record numbers (or feature codes), be they manually or electronically recorded.
  - These feature codes depict what type of location and where locations were measured.
  - This helps office personnel import digital field drawings into final design drawings.
  - More important, blunders and mislabeled feature codes may be caught before costly design errors are made.
  - The finished map and the sketch should be similar.
  - Sketches are not required to be at any scale.
  - The suggestions listed below will help eliminate some common mistakes in manually recording field notes in a survey book (or optionally on an equivalent digital tablet device):
    - Letter the notebook owner's name and address on the cover and first inside page.
    - Title, index, and cross-reference each new job or continuation of a previous one.
    - Sign surname and initials in the lower right-hand corner of the right page on all original notes.
    - Use a hard pencil or pen, legible and dark enough to copy.
    - Begin a new day's work on a new page.
    - Immediately after a measurement, always record it directly in the field book rather than on a sheet of scrap paper for copying it.
    - Do not erase recorded data.
    - Use sketches instead of tabulations when in doubt.
    - Avoid crowding.

FIELD DATA COLLECTORS AND COORDINATE GEOMETRY FUNCTIONS (CONT'D)

- c. Some features are often too complex to be fully detailed in a data collector; thus, a field book sketch is required.
  - The figure on the following slide is such an example of a sketch that depicts details for a steam utility system that would be impractical to input in a digital data collector.
  - The general orientation of the object would be captured in the data collector, and the points referenced on the sketch.
  - A note should be entered into the data collector referencing additional attribute data is provided in the field book (including page number).

FIELD DATA COLLECTORS AND COORDINATE GEOMETRY FUNCTIONS (CONT'D)

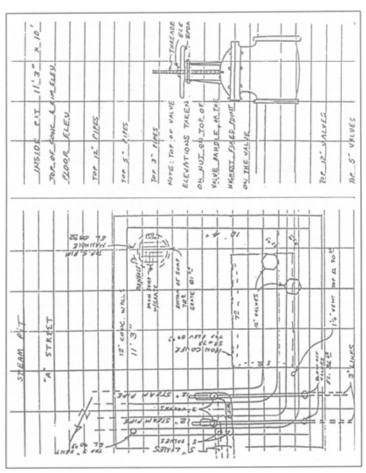


Figure 15: Sample from field book depicting utility details.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

Functional Requirements of a Generic Data Collector

- A well-functioning and efficient data collector is vital to performing detail surveys using a total station or RTK system.
- Assumptions or oversights made at the time of equipment purchase can force a survey operation into equipment problems on the job for the economic life of the equipment.
- Listed below are some options to consider when purchasing a field data collector:
  - Weatherproof, designed for rugged/durable field use.
  - Nonvolatile memory ensures data safety.
  - Allow the storage of at least 5,000 or more points, including full descriptor and attribute information.
  - Full search and edit routines immediately on the spot.
  - Optional screen view of mapped data points.
  - Compatibility with a variety of electronic total stations, digital levels, and/or GPS systems.
  - Formatting must be very flexible for manual entry, even for various CADD leveling tasks.
  - Capability to use two files in the collector: one file for collection, the other file for processed data for stakeout tasks.
  - Data collector must communicate with and remotely operate the total station.
  - All the features of the total station should be usable with the data collector purchased.
  - The data collector must be compatible with the software.
  - The data collector must be compatible with the data dictionary.

- In evaluating a data collector system for purchase, the following questions should be asked:
  - Can I view and store coordinates in the electronic data collector in the field?
  - Is the data collector environmentally rugged? What are the environmental limitations of the hardware?
  - Can I upgrade the data collector to the latest software version easily and inexpensively?
  - Can I create control jobs that can be accessed from any routine in the data collector?
  - What data in the data collector will I be able to edit in the field and how will that affect my raw data?
  - Will the data collector be compatible with all of the total stations I own?
  - Do I have a choice of output formats in the data collector?
  - What level of training and support is offered at the time of purchase, and what level can I expect after I have had the data collector long enough to know what questions to ask?
  - What type of feature coding and attribute capability does the data collector have?
  - Can I set up the parameters and configurations in the data collector to the way I like to survey?
  - What numbers of electronic devices, total stations, etc., are supported in the basic configuration?
  - What types of data are supported? (raw data, coordinate data point list, roadway alignment, archive data files, and descriptions)

- Can I perform separate tasks for collection of traverse points vs. topographic features or side shots?
- Supports State Plane Coordinate input?
- Memory capacity?
- Is the collection of raw data the same as indicated on the survey instrument? (PPM & Prism Constant)
- Is the unit capable of utilizing data from two different coordinate files at the same time?
- Supports auto mapping?
- Supports North and South Azimuth References?
- Supports user definable parameters? (Angle/distance tolerances, observation sequence for direct and reverse observations)
- Capable of producing stakeout reports, cut/fill, relative to design elevation?
- Generate location of next stakeout point from rodman's positions?
- Supports stakeout of a line?
- Downloading/uploading capability? Can it be done remotely via modem?
- Data collection software or data collector itself should output the following:
    - Point number
    - Coordinates
    - Elevations
    - Feature code

General Software Features on a Data Collector

- Field data collectors are either self-contained within a total station or external units attached by cable or wireless (Bluetooth) connection to the survey instrument.
- Some of the more salient software features found on a data collector are outlined below, as taken from POB 2004b.
- Not all data collectors must contain all these software features to be acceptable--many of these features may not be required for standard Corps work.
- In addition, the more features that are included, the higher the cost of the data collector.

- a. Cost.
  - The average data collector software package will cost some $1,500 to $2,000; however software packages are available as low as $150 and over $3,000 at the high end.
  - (These costs do not include the actual microprocessor hardware).
- b. Computer.
  - Some software packages will operate on a variety of operating systems while others are specific to a single system.
  - The most common systems include CE.Net, CE, Microsoft, HP-48, and iPAQ.
  - The newest systems have color display screens and will provide field-finish views of collected data.
  - Screen displays should ideally include viewing of points, features, and associated attribute data entered during the survey.

- c. Supported instruments.
  - Data collector software may support only a specific brand of total station or can support (and connect with) a variety of electronic survey instruments, such as digital levels, static GPS, kinematic GPS, laser rangefinders, robotic total stations, etc.
  - Obviously, software that encompasses all this versatility will cost more.
  - The advantage of having a data collector that can perform many functions is obvious: the same instrument can be used with either a total station or GPS/RTK system.
- d. Storage capacity.
  - Most software can store almost an unlimited number of jobs and points, restricted only by the storage available in the data collector device.

- e. Calculations.
  - The software should be able to calculate coordinates from raw data observations, perform inverse computations, calculate intersections, perform traverse computations and adjustments, perform 2-point and 3-point resections (total stations), perform site calibrations (RTK), and perform area computations.
  - Other desirable features would include a variety of stakeout options--to lines, curves, and slopes (including navigation to points), least-squares adjustments or regressions, volume and cut/fill computations, etc. Some of these COGO functions will be described later in this chapter.
- f. Background images.
  - The software should be able to import, orient, and display background images from a variety of file formats, such as MicroStation, AutoCAD, and ESRI, and display generic *.JPG, *.TIF, etc. type images.

Feature or Descriptor Codes for Topographic Field Data

- Field codes or data collection codes are a means by which the surveyor controls the map compilation process.
- Feature codes for each shot are placed on the data collector.
- The code designations and sequencing will vary depending on the data collector and processing software.
- Typically, features are described in the data collector by means of some numeric or alphanumeric description.
- Strings of like features (e.g., curb lines, edges of roads, buildings) or polylines are identified by additional coding.

- Feature coding is an integral part of the field data acquisition phase.
- It defines characteristics of an object(s) and how they are represented on the final map--as points, lines, or areas.
- In addition, they can define the type of annotation, line weight, layer, or cell symbol to be placed on the map.
- Whether data are recorded by hand or electronically, one of the most critical survey operations is the recording of a code or description to properly identify the point during processing.
- For example, in a topographic or planimetric survey, identification of points which locate the position of curbs, gutters, centerlines, manholes, and other similar features are essential for their correct plotting and contour interpolation.
- Since the field crew can virtually produce the map from the field data, this eliminates the need for many field book sketches.

- a. Feature code library.
  - The coding scheme is designed so the computer can interpret the recorded data without ambiguity to create a virtually finished product.
  - Normally a feature or descriptor code “library” is established for a given project.
  - This library consists of the common object features that will be shot.
  - During the survey, these feature/descriptor codes can be called up in the data collector after each shot, as a quality control check.
  - If additional attribute information is needed on a point, this can be typed into the controller.
  - These feature/descriptor codes associated with each topographic point shot are later downloaded to a CADD and/or GIS system.
  - If additional attribute detail is provided, this information will stay with that point in the CADD/GIS system.

- b. Typical descriptors used in a library.
  - Currently, there is no established descriptor code standard for topographic features.
  - Either numerical point codes or alphanumeric point feature codes can be entered into the data collector.
  - Each District either has their own feature library standard, or accepts data in whatever format a contractor submits it in.
  - Some projects are unique, and new descriptor codes are developed for that work.
  - This variability may entail additional effort during subsequent inputs of datasets into CADD packages.
  - The following is a partial list of alphabetic descriptor names for common features.
  - These same features will have various descriptors in different Districts, as will be illustrated in subsequent lists.
  - Whenever districts require specialized point codes, then the attribute file may be edited to include these changes.

- 1X2 STAKE
- 2X2 HUB/TACK
- A/G FUEL TANK
- A/G STEAM LINE
- A/G WATER VALVE
- AC@PCC JOINT
- AIR RELIEF VALVE
- AIRCRAFT TIE-DOWN
- ALUM MON
- ARCH CREST
- ARCH END
- ARCH START
- ARCH TOE
- ASPHALT
- ASPHALT PATCH
- B/L
- BARBED WIRE
- BENCHMARK
- BLDG CORNER
- BOLT
- BRASS CAP
- BREAKER BOX
- BREAKLINE
- BREAKLINES
- BRIDGES
- BUILDING LINE
- BUOY
- C/L
- C/L ROAD
- C/L ROAD
- C/L RR TRACK
- CABLE TV
- CATCH BASIN
- CDHD
- CDHU
- CHAIN LINK
- CHISELED X
- CLOSING CORNER
- COE MON
- COMMUNICATION
- CONC MON
- CONC. PATCH
- CONIFEROUS
- CONTROL
- CROWN
- CULVERT
- CURB
- CURTAIN DRAIN
- CUT-OFF FENCE POST
- DECIDUOUS

- DOLPHIN
- DOWN GUY
- DRAIN
- DRAIN PIT
- DRIVEWAY
- EDGE ROAD
- EDGE ROAD
- ELECTRICAL
- ELECTRICAL MH
- ELECTRICAL OUTLET
- ELECTRICAL SPLICE
- ELECTRICAL VAULT
- END OF BRIDGE
- EXPANSION JOINT
- EXPOSED SEWER
- PIPE
- FILED X
- FILLER PIPE U/G TANK
- FIRE ALARM
- FIRE HYDRANT
- FLOODWALL
- FLOW DITCH
- FUEL
- FUEL PIT
- FUEL TANK VENT
- PIPE
- GAS
- GAS LINE
- GAS METER
- GAS PAINT MARK
- GAS VALVE
- GEOTECH
- GPS MON
- GRATED STORM MH
- GROUND SHOT
- GROUNDING ROD
- GUY POLE
- HAND DRILL HOLE
- HAZARDOUS WASTE VAULT
- HEADWALL
- HEATING
- HOMESTEAD CORNER
- HYDRO
- LIGHT POLE
- MEANDER CORNER
- MON

- MONITORING DEVICE
- NAIL
- NGS MON
- O/H COMM
- O/H PIPE
- O/H POWER LINE
- ORNAMENTAL
- PAD
- PAINT STRIPE
- PBM
- PHONE BOOTH
- PICTURE POINT
- PIER TOE
- PIER TOP
- PILING
- PIPE
- PK NAIL
- PORCH
- POWER @ BLDG
- POWER POLE
- POWER
- POLE/TRANS
- PVC PIEZOMETER
- PVC SLOPE INDICATOR
- QUARTER CORNER
- RAMP
- REBAR
- REBAR/CAP
- REFERENCE POINT
- RETAINING WALL
- RISER
- ROAD WORK
- ROCK
- RR SPIKE
- RWY LIGHT
- SANITARY
- SANITARY CLEANOUT
- SANITARY LINE
- SANITARY MH
- SECTION CORNER
- SHOULDER ROAD
- SIDEWALK
- SIGN
- SIXTEENTH CORNER
- SLOPE
- SLOPE BREAK
- SOUNDING

- SPRINKLER CONTROL VALVE
- STEAM MH
- STEAM PIT
- STEEL GUARD POST
- STEPS
- STORM
- STORM MH
- SWITCH BOX
- TBM
- TELE @ BLDG
- TELE SPLICE BOX
- TELEPHONE MH
- TELEPHONE POLE
- TEST WELL
- TOE
- TOE CONC DRAIN
- TROUGH
- TOE/RIPRAP
- TOP
- TOP CONC DRAIN
- TROUGH
- TOP OF RAIL
- TOP STRUCTURE
- TOP/RIPRAP
- TOPOGRAPHIC
- TOWER LEG
- TRAFFIC SIG CONTROL BOX
- TRANSFORMER
- TREE LINE
- U/G CABLE MARKER
- U/G COMM
- U/G COMM BOX
- U/G CONDUIT
- U/G STREET LIGHTING BOX
- USGS MON
- WATER
- WATER LINE
- WATER METER
- WATER MH
- WATER STANDPIPE
- WATER VALVE
- WE/WS
- WELL HEAD
- WITNESS CORNER
- WOOD FENCE
- WOOD GUARD POST

Table 7: Typical Descriptors used in a Feature Library.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

- c. Project specific descriptors.
  - Individual projects will often have unique repeating features, necessitating additional feature codes.
  - An example of a field feature coding scheme for a specific hydraulic design project in Tulsa District is shown below:

B = BEGIN
E = END
BK = BREAK
RIP = RR = RIP RAP
ISL = ISLAND
BEED = CHANNEL BED
CHBS = CHECK BACKSIGHT
CON = CONCRETE
CP = CONTROL POINT

TB = TOP BANK
FL = FLOW LINE
H WALL = HEAD WALL
FEN = FENCE
RP = REFERENCE POINT
G PT = GUARD RAIL POST
SC A = SCOUR AREA
BNK = BANK

- d. Creating unique descriptor codes.
  - This is done in the software provided with or accompanying the data collector.
  - Alphanumeric codes may also be used for a specific feature.
  - The following process is excerpted from TDS 1999 and is typical of basic feature coding options that are used in most data collectors today.

TDS-HP48GX DESCRIPTOR CODE TABLES

- *One of the best ways of improving the productivity of data collecting is to speed up the process of keying in point descriptors.*
- *The Descriptor Code Table is provided for this purpose.*
- *Basically, the Descriptor Code Table is a text file in the TDS-48GX that contains a list of commonly-used point descriptors.*
- *The descriptor table is a list of codes or abbreviations that are associated with a descriptor.*
- *These codes may be keyed into the descriptor field in place of the full descriptor.*
- *When one of these codes is found in a descriptor field, the TDS-48GX will replace the code with its associated descriptor.*

- *Once the TDS-48GX user has established a Code Table of commonly used descriptors, whenever the descriptor prompt appears in the TDS-48 program, a code may be keyed in.*
- *The TDS-48 will insert the complete descriptor from the code table in the place of the code in the Coordinate and Raw Data files.*
- *The Code Table is actually a special text file in the TDS-48. It requires the unique name "DESCRIPT.TXT."*
- *The Code Table itself is composed of a series of lines of text.*
- *Each line of text consists of the code followed by a single space and the full descriptor.*

- *An example of a Code Table would appear as:*

1	*POB*
02	*HUB*
CB	*CURB*
T4	*OAK TREE*
POB	*PT. OF BEGINNING*
F	*FENCE*
f	*FENCE*

- *Codes may be up to seven characters in length and may consist of any alphanumeric characters.*
- *Examples of these are: 02, CB, and T4.*
- *The code is case sensitive, which means that the "F" and "f" codes are not the same and could have different descriptors.*
- *If you want an upper or lower case "F" to be interpreted as FENCE you need to enter it twice (as above).*
- *The code and the descriptor are separated by one space, and the remainder of the line is the descriptor that is linked to this code.*
- *The descriptor may contain alphanumeric characters, spaces, punctuation or symbols; basically anything that can be typed into a descriptor from the keyboard.*

- *During a survey, when the TDS-48 requests a descriptor (usually after the total station has taken a shot), you may key in the full descriptor such as CURB; or you may key in the corresponding code, such as CB, as a "shorthand" notation to indicate the CURB.*
- *In either case, the full descriptor CURB will be stored in the job file.*
- *If the data is being collected manually, the code may be keyed into the descriptor line of the Traverse/Sideshot Screen before the [TRAV] or [SIDES] softkeys are pressed.*
- *As stated above, the TDS-48 will store the full descriptor from the table into the job file, not the code.*

Using Codes With Keyed In Descriptors And Combining Codes

- *Often you want to use a descriptor from the Code Table, but you would like to add additional characters to the descriptor from the keyboard.*
- *As an example, suppose you wanted to use the descriptors "NE 1/4 CORNER" and "SE 1/4 CORNER."*
- *Assume that the descriptor "1/4 CORNER" has been keyed into a Code Table under the code "15."*
- *To combine text and codes from the Code Table, use the "+" key in the following way:*
- *When the descriptor prompt appears in the display and you want the descriptor to read "NE 1/4 CORNER," key in "NE+15."*
- *The TDS-48 will combine the keyed-in descriptor "NE" with the descriptor associated with code 15 to create the complete descriptor "NE 1/4 CORNER."*

- *Codes may also be concatenated with keyed in descriptors.*
- *For example, if you wanted a series of points with descriptors TOP OF CURB A1, TOP OF CURB A2, TOP OF CURB A3, etc., you would setup TOP OF CURB in a Descriptor Code Table with code 23, for example.*
- *Then in response to the descriptor prompt, key in 23+A1, 23+A2, 23+A3, etc.*
- *Codes may also be concatenated with other codes.*
- *Assume you have code descriptor pairs for: T TREE, T1 PINE, T2 OAK and T3 MAPLE.*
- *The result of the following entries: T1+T; T2+T; T3+T; would be: PINE TREE; OAK TREE and MAPLE TREE.*
- *This technique may be used to concatenate up to three descriptor codes or text segments.*

Descriptor Codes and Level Assignments for Various Topographic Features

- The following listing contains an example of standardized coding for various features encountered on USACE civil and military projects.
- Both an alpha and numeric code are given.
- The four-digit "#Code" corresponds to the level number assignment, the first two digits representing the level (or first digit when only 3 digits are shown).

FIELD DATA COLLECTORS AND COORDINATE GEOMETRY FUNCTIONS (CONT'D)

	Description	Alpha Code	# Code	Elevation	Main Feature/Level Designation
1	BUILDING	BLDG	401	Random	Buildings
2		BUILDING			
3	HOUSE	HOUSE	402	DNC	Buildings
4	TRAILER	TRAILER	403	DNC	Buildings
5	GARAGE	GARAGE	404	DNC	Buildings
6	SHED	SHED	405	Breakline	Buildings
7	CABIN	CABIN	411	DNC	Buildings
8	PORCH	PORCH	412	Exterior	Buildings
9	STEPS	STEPS	413	Breakline	Buildings
10	OVERHANG	OVERHANG	414	DNC	Buildings
11	CL ROAD	CLRD	601	Breakline	Centerline
12		ROADCL			
13		CLROAD			
14	CL BRIDGE	CLBDG	602	Breakline	Centerline
15		BRIDGECL			
16		CLBRIDGE			
17	CL RAILROAD	CLRR	603	Random	Centerline
18		CLRAILROAD			
19		RAILROADCL			
20	CL ABANDONED RAILROAD	CLARR	604	Breakline	Centerline
21	CL DITCH	DITCHCL	605	Breakline	Centerline
22		CLDITCH			
23	CL CREEK	CLCRK	606	Breakline	Centerline
24		CLD			
25		CREEKCL			
26		CLCREEK			
27	CENTERLINE	CENTLINE	607	Breakline	Centerline
28		CLINE			
29	CL SWALE	CLSWALE	608	Breakline	Centerline
30		CLSWL			
31	CL BERM	CLBERM	609	Breakline	Centerline
32	CL WALL	CLWALL	610	DNC	Centerline
33	CL STONE WALL	CLSTWALL	611	DNC	Centerline
34		STWALLCL			
35	CL DIKE	CLDIKE	612	Breakline	Centerline
36		DIKECL			
37	EDGE DRIVEWAY	DRIVEWAY	801	Breakline	Roads, Parking Lots, Walks, Railroads, and Trails
38		EDGEDRIVEWAY			
39	EDGE PAVEMENT	PVMTEDGE	802	Breakline	Roads, Parking Lots, Walks, Railroads, and Trails
40	EDGE ROAD	EDGEROAD	803	Breakline	Roads, Parking Lots, Walks, Railroads, and Trails
41		ROADEDGE			
42	EDGE SHOULDER	EDGESHOULDE R	804	Breakline	Roads, Parking Lots, Walks, Railroads, and Trails
43		SHOULDEREDG E			

FIELD DATA COLLECTORS AND COORDINATE GEOMETRY FUNCTIONS (CONT'D)

44	EDGE SIDEWALK	ESW	805	Breakline	Roads, Parking Lots, Walks, Railroads, and Trails
45		ESWALK			
46		EWALK			
47		SW			
48	EDGE TRAIL	EDGETRAIL	806	Breakline	Roads, Parking Lots, Walks, Railroads, and Trails
49		TRAILEDGE			
50	BRIDGE CORNER	BRIDGECOR	807	Breakline	Roads, Parking Lots, Walks, Railroads, and Trails
51		CORBRIDGE			
52	PIER TOP	PIERTOP	808	DNC	Roads, Parking Lots, Walks, Railroads, and Trails
53		TOPPIER			
54	PIER TOE	PIERTOE	809	DNC	Roads, Parking Lots, Walks, Railroads, and Trails
55		TOEPIER			
56	RAILROAD SWITCH	RRSW	851	DNC	Roads, Parking Lots, Walks, Railroads, and Trails
57	CONCRETE EDGE	CONCEDGE	901	Breakline	Concrete Joint Layout
58		EDGECONC			
59	EXPANSION JOINT	CONCJOINT	902	Breakline	Concrete Joint Layout
60		EXPANJOINT			
61	CURB TOP BACK	BC	903	Breakline	Concrete Joint Layout
62		LBC			
63		CURBTB			
64		TBCURB			
65	CURB FRONT EDGE	CURBFE	904	Breakline	Concrete Joint Layout
66	CURB FLOW LINE	CURBFL	905	Breakline	Concrete Joint Layout
67	CURB/PAVEMENT	CURBPVMT	906	Breakline	Concrete Joint Layout
68	CURB-CUT	CURBCUT	907	Random	Concrete Joint Layout
69	CONCRETE	CONCRETE	1001	Random	Concrete Joint Elevations
70	HIGHWAY SIGN	HIGHWAYSIGN	1301	Random	Pavement Markings and Signs
71	SPEED SIGN	SPEEDSIGN	1302	Random	Pavement Markings and Signs
72	STOP SIGN	STOPSIGN	1303	Random	Pavement Markings and Signs
73	YIELD SIGN	YIELDSIGN	1304	Random	Pavement Markings and Signs
74	TURN SIGN	TURNSIGN	1305	Random	Pavement Markings and Signs
75	STOP AHEAD SIGN	STOPAHEADSIG N	1306	Random	Pavement Markings and Signs
76	STREET SIGN	STREETSIGN	1307	Random	Pavement Markings and Signs
77	CURVE SIGN	CURVESIGN	1308	Random	Pavement Markings and Signs
78	BRIDGE SIGN	BRIDGESIGN	1309	Random	Pavement Markings and Signs
79	MILE MARKER	MILEMARKER	1310	Random	Pavement Markings and Signs
80	REFLECTOR	REFLECTOR	1311	Random	Pavement Markings and Signs
81	SIGN	SIGN	1312	DNC	Pavement Markings and Signs
82	WEIGHT LIMIT SIGN	WEIGHTLIMITSIG N	1313	Random	Pavement Markings and Signs
83	RR X-ING SIGN	RRXINGSIGN	1317	Random	Pavement Markings and Signs
84	RR SIGN	RRSIGN	1318	Random	Pavement Markings and Signs
85	BILLBOARD	BBOARD	1319	DNC	Pavement Markings and Signs
86		BILLBRD			
87	DIST-TO-GO	DISTTOGO	1321	Random	Pavement Markings and Signs
88	PAINT STRIPE	PAINTSTRIPE	1322	Random	Pavement Markings and Signs
89	PARKING METER	PARK	1323	DNC	Pavement Markings and Signs
90	MAIL BOX U.S.	USMAILBOX	1394	DNC	Pavement Markings and Signs
91		MAILBOXUS			
92	RESIDENT SIGN	RESIDENTSIGN	1395	Random	Pavement Markings and Signs
93	MAIL BOX RESIDENTIAL	RESMAILBOX	1398	Random	Pavement Markings and Signs

FIELD DATA COLLECTORS AND COORDINATE GEOMETRY FUNCTIONS (CONT'D)

94		MAILBOXRES			
95	FLAG POLE	FPOLE	1399	Random	Pavement Markings and Signs
96		FLAGPOLE			
97	WALL TOP EDGE	WALLTOPEDGE	1401	Breakline	Structures and Headwalls
98	WALL BOTTOM	BOTWALL	1402	Breakline	Structures and Headwalls
99		WALLBOT			
100	PUMP	PUMP	1403	Breakline	Structures and Headwalls
101	FLOODGATE	FLOODGATE	1404	Breakline	Structures and Headwalls
102	STEEL GUARD POST	STEELPOST	1470	Breakline	Structures and Headwalls
103	WOOD GUARD POST	WOODPOST	1471	Breakline	Structures and Headwalls
104	POST	POST	1472	Random	Structures and Headwalls
105	CORRUGATED STEEL-FLOW LINE	CMP	1601	DNC	Culverts
106	REINFORCED CONCRETE-FLOW LINE	RCP	1602	DNC	Culverts
107	PVC-FLOW LINE	PVCFL	1603	DNC	Culverts
108	TOP CULVERT-BASE FILL	TOPCULBASFIL	1604	DNC	Culverts
109	BOX-FLOW LINE	BOXFL	1605	DNC	Culverts
110	TOP OF PIPE CULVERT	TOPCULVERT	1606	Breakline	Culverts
111	RIPRAP	RIPRAP	1801	Random	Riprap
112	RIPRAP TOP	RRAPTOP	1802	Breakline	Riprap
113		TOPRRAP			
114	RIPRAP TOE	RRAPTOE	1803	Breakline	Riprap
115		TOERRAP			
116	WATER EDGE	WE	1901	Breakline	Water Features
117	THALWEG	THALWEG	1902	Breakline	Water Features
118	BED	BED	1903	Random	Water Features
119	TREE-DEC	CYPRESS TREE	2101	DNC	Vegetation
120		DOGWOOD			
121		DTREE			
122		MAPLE			
123		OAK			
124	TREE-CON	CTREE	2102	DNC	Vegetation
125		FERN			
126		PINE			
127		SPRUCE			
128	TREE	TREE	2103	DNC	Vegetation
129	TREE LINE	TL	2104	DNC	Vegetation
130	STUMP	STUMP	2105	DNC	Vegetation
131	GROUND IN TIMBER	INTREES	2106	Random	Vegetation
132	SHRUB	SHRUB	2107	Random	Vegetation
133	SHRUB LINE	SHRUBLINE	2108	Random	Vegetation
134	BRUSH	BRUSH	2109	Random	Vegetation
135	BRUSH LINE	BRUSHLINE	2110	Random	Vegetation
136	CULTIVATION	CULT	2111	Random	Vegetation
137	LAWN EDGE	LAWNEDGE	2112	Breakline	Vegetation
138		EDGELAWN			
139	BARBED WIRE FENCE	BWFENCE	2301	Random	Fences, Guard Rails
140		FENCEBW			
141	CHAIN LINK FENCE	CLFENCE	2302	Random	Fences, Guard Rails
142		FENCECL			
143	WOOD FENCE	WFC	2303	Random	Fences, Guard Rails
144	STOCK FENCE	STOCKFEN	2304	Random	Fences, Guard Rails
145		FENCESTK			
146	GATE EDGE	GATE	2305	Random	Fences, Guard Rails
147		GATEEDGE			

FIELD DATA COLLECTORS AND COORDINATE GEOMETRY FUNCTIONS (CONT'D)

148		EDGEGATE			
149	FENCE CORNER	CORFENCE	2306	Random	Fences, Guard Rails
150		FENCECOR			
151	GUARDRAIL	GRAIL	2308	Random	Fences, Guard Rails
152	CATTLE GUARD	CATGUARD	2309	Random	Fences, Guard Rails
153	PROPERTY PIN	PPIN	2501	DNC	Boundary Lines / Cadastral-R/W
154		PROPPIN			
155	BLOCK CORNER	BLOCKCOR	2502	DNC	Boundary Lines / Cadastral-R/W
156	PLSS CORNER	SECCOR	2503	DNC	Boundary Lines / Cadastral-R/W
157	R/W-CAP	RWCAP	2509	DNC	Boundary Lines / Cadastral-R/W
158	R/W-MON	RWMON	2510	DNC	Boundary Lines / Cadastral-R/W
159	R/W-PIN	RWPIN	2511	DNC	Boundary Lines / Cadastral-R/W
160	R/W-REBAR	RWREBAR	2512	DNC	Boundary Lines / Cadastral-R/W
161	STATION MARKER	STAMARKER	2513	DNC	Boundary Lines / Cadastral-R/W
162	CONTROL HORIZ	HCON	2701	Breakline	Survey Control Points, Baselines
163	CONTROL VERT	BM	2702	DNC	Survey Control Points, Baselines
164		VCON			
165	CONTROL H/V	HVCON	2703	DNC	Survey Control Points, Baselines
166	GAUGE	GAUGE	2704	DNC	Survey Control Points, Baselines
167	CONTROL SECONDARY	SECCON	2705	DNC	Survey Control Points, Baselines
168		CONSEC			
169	BASELINE	BASELINE	2706	DNC	Survey Control Points, Baselines
170	PHOTO HORIZ	PHOTOH	2707	DNC	Survey Control Points, Baselines
171		HPHOTO			
172	PHOTO VERT	PHOTOV	2708	DNC	Survey Control Points, Baselines
173		VPHOTO			
174	PHOTO H/V	PHOTOHV	2709	DNC	Survey Control Points, Baselines
175		HVPHOTO			
176	BS STATION	BSSTATION	2710	DNC	Survey Control Points, Baselines
177	INST STATION	INSTSTATION	2711	DNC	Survey Control Points, Baselines
178	FS STATION	FSSTATION	2712	DNC	Survey Control Points, Baselines
179	CONTROL CHECK	CONCHECK	2713	DNC	Survey Control Points, Baselines
180	ELEVATION CHECK	ELEVCHECK	2714	DNC	Survey Control Points, Baselines
181	DUNE TOP	TOPDUNE	2903	Breakline	Breaklines
182		DUNETOP			
183	DUNE TOE	BOTDUNE	2904	Breakline	Breaklines
184		TOEDUNE			
185		DUNETOE			
186	BANK TOP	TB	2905	Breakline	Breaklines
187		BANKTOP			
188		TOPBANK			
189	BANK TOE	BB	2906	Breakline	Breaklines
190		BOTBANK			
191		TOEBANK			
192		BANKTOE			
193	CUT TOP	CUTTOP	2907	Breakline	Breaklines
194		TOPCUT			
195	CUT TOE	CUTTOE	2908	Breakline	Breaklines
196		TOECUT			
197		BOTCUT			
198	FILL TOP	TOPFILL	2909	Breakline	Breaklines
199		FILLTOP			
200	FILL TOE	BOTFILL	2910	Breakline	Breaklines
201		TOEFILL			
202		FILLTOE			
203	BREAK TOP	BREAKTOP	2911	Breakline	Breaklines
204		TOPBREAK			

FIELD DATA COLLECTORS AND COORDINATE GEOMETRY FUNCTIONS (CONT'D)

205	BREAK TOE	BREAKTOE	2912	Breakline	Breaklines
206		TOEBREAK			
207	SWALE TOP	SWALETOP	2913	Breakline	Breaklines
208		TOPSWALE			
209	SWALE TOE	SWALETOE	2914	Breakline	Breaklines
210		TOESWALE			
211	RAILROAD BALLAST TOP	TRRBAL	2915	Breakline	Breaklines
212	RAILROAD BALLAST TOE	BRRB	2916	Breakline	Breaklines
213	BREAK LINE	BRK	2999	Breakline	Breaklines
214		BRKLINE			
215	GROUND	GND	3001	Random	Spot Elevation
216		NG			
217		SPOT			
218		SUR			
219		GROUND			
220	SLOPE	SLOPE	3002	Random	Spot Elevation
221		SLP			
222	GRAVEL	GRAVEL	3003	Random	Spot Elevation
223	SAND	SAND	3004	Random	Spot Elevation
224	LAWN	LAWN	3005	Random	Spot Elevation
225		GRASS			
226	PAVEMENT	PVMT	3006	Random	Spot Elevation
227		PAVEMENT			
228	ROCK	ROCK	3007	Random	Spot Elevation
229	SHOULDER	SHOULDER	3009	Random	Spot Elevation
230	BORE HOLE	BORE	3401	DNC	Bores, Holes, and Text
231		BOREHOLE			
232	TEST PIT	TPIT	3402	DNC	Bores, Holes, and Text
233		TESTPIT			
234	PERC TEST	PERCTEST	3403	DNC	Bores, Holes, and Text
235	STAND PIPE	STANDPIPE	3404	DNC	Bores, Holes, and Text
236	CDHD	CDHD	3405	DNC	Bores, Holes, and Text
237	CDHU	CDHU	3406	DNC	Bores, Holes, and Text
238	MONITORING DEVICE	MONDEVICE	3407	DNC	Bores, Holes, and Text
239	PVC PIEZOMETER	PVCPIEZ	3408	DNC	Bores, Holes, and Text
240	PVC SLOPE INDICATOR	PVCSLPIN	3409	DNC	Bores, Holes, and Text
241	TEST WELL	TESTWELL	3410	DNC	Bores, Holes, and Text
242	WELL HEAD	WELLHEAD	3411	DNC	Bores, Holes, and Text
243	CONC DRAIN TROUGH TOP	CONCDTTOP	3501	Breakline	Storm Sewerlines and Manholes
244		TOPCONCDT			
245	CONC DRAIN TROUGH TOE	CONCDTTOE	3502	Breakline	Storm Sewerlines and Manholes
246		TOECONCDT			
247	GRATED STORM MH	GRSTMH	3503	DNC	Storm Sewerlines and Manholes
248	STORM MH	SDRMH	3504	DNC	Storm Sewerlines and Manholes
249		STORMMH			
250		MHSTORM			
251	CATCH BASIN	CB	3505	Random	Storm Sewerlines and Manholes
252		EDGECB			
253	DRAIN PIT	DRAINPIT	3506	DNC	Storm Sewerlines and Manholes
254	CURTAIN DRAIN	CURTAINDRN	3509	DNC	Storm Sewerlines and Manholes
255	FLOW LINE IN STORM	FLISTORM	3510	DNC	Storm Sewerlines and Manholes
256	FLOW LINE OUT STORM	FLOSTORM	3511	DNC	Storm Sewerlines and Manholes
257	TOP OF PIPE STORM	TOPSTORM	3512	DNC	Storm Sewerlines and Manholes

FIELD DATA COLLECTORS AND COORDINATE GEOMETRY FUNCTIONS (CONT'D)

258	SANITARY MH	SSMH	3701	DNC	Sanitary Sewerlines, and Manholes
259		SANMH			
260		MHSAN			
261	FLOW LINE IN SEWER	FLISEWER	3702	DNC	Sanitary Sewerlines, and Manholes
262	FLOW LINE OUT SEWER	FLOSEWER	3703	DNC	Sanitary Sewerlines, and Manholes
263	TOP OF PIPE SEWER	TOPSEWER	3704	DNC	Sanitary Sewerlines, and Manholes
264	SANITARY LINE	SSLINE	3706	DNC	Sanitary Sewerlines, and Manholes
265	CLEAN OUT	CLEANOUT	3707	DNC	Sanitary Sewerlines, and Manholes
266	LIFT STATION	LIFTSTA	3708	DNC	Sanitary Sewerlines, and Manholes
267	LEACH LINE	LEACHLINE	3709	DNC	Sanitary Sewerlines, and Manholes
268	SEPTIC TANK	SEPTICTANK	3710	DNC	Sanitary Sewerlines, and Manholes
269	DRYWELL	DRYWELL	3711	DNC	Sanitary Sewerlines, and Manholes
270	DRAIN FIELD	DRAINFIELD	3712	DNC	Sanitary Sewerlines, and Manholes
271	SANITARY SEWER FORCE MAIN	SSMAIN	3713	DNC	Sanitary Sewerlines, and Manholes
272	WATER VALVE	WATERVALVE	3901	DNC	Water Lines, Fire Hydrants, and Water Tanks
273	AIR RELIEF VALVE	AIRVALVE	3902	DNC	Water Lines, Fire Hydrants, and Water Tanks
274	RISER	RISER	3903	DNC	Water Lines, Fire Hydrants, and Water Tanks
275	WATER MH	WATERMH	3904	Random	Water Lines, Fire Hydrants, and Water Tanks
276		MHWATER			
277	WELL	WELL	3905	Random	Water Lines, Fire Hydrants, and Water Tanks
278	WATER LINE	WATERLINE	3906	Random	Water Lines, Fire Hydrants, and Water Tanks
279	WELL HOUSE	WELLHOUSE	3907	Random	Water Lines, Fire Hydrants, and Water Tanks
280	FIRE HYDRANT	FH	3908	Random	Water Lines, Fire Hydrants, and Water Tanks
281		HYD			
282	WATER METER	WATERMETER	3909	DNC	Water Lines, Fire Hydrants, and Water Tanks
283	END ABUTMENT	ENDABUT	3910	DNC	Water Lines, Fire Hydrants, and Water Tanks
284	WATER SERVICE	WATERSER	3911	DNC	Water Lines, Fire Hydrants, and Water Tanks
285	CURB STOP	CURBSTOP	3912	DNC	Water Lines, Fire Hydrants, and Water Tanks
286	SPRINKLER HEAD	SPKLR	3913	Random	Water Lines, Fire Hydrants, and Water Tanks
287	PUMP	WATERPUMP	3915	Random	Water Lines, Fire Hydrants, and Water Tanks
288	GAS VALVE	GASV	4102	DNC	Gaslines, Features, and Valves
289		GVALVE			
290		GASVALVE			
291	GAS TANK	GASTANK	4103	DNC	Gaslines, Features, and Valves
292	GAS METER	GASM	4104	DNC	Gaslines, Features, and Valves
293	GAS LINE	GASL	4105	DNC	Gaslines, Features, and Valves
294		GASLINE			
295	GAS MH	GASMH	4106	Breakline	Gaslines, Features, and Valves
296		MHGAS			
297	GAS WITNESS POST	GASWITPOST	4107	Random	Gaslines, Features, and Valves
298	FUEL PUMP	FUELPUMP	4109	DNC	Gaslines, Features, and Valves
299	FILLER PIPE U/G TANK	FILLPIPEUGTAN K	4110	Random	Gaslines, Features, and Valves
300	A/G FUEL TANK	AGFUELTANK	4111	Random	Gaslines, Features, and Valves

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FIELD DATA COLLECTORS AND COORDINATE GEOMETRY FUNCTIONS (CONT'D)

301	FUEL TANK PIPE VENT	FUELTANKPIPEVENT	4112	Random	Gaslines, Features, and Valves
302	FUEL PIT	FUELPIT	4113	DNC	Gaslines, Features, and Valves
303	POWER POLE	PPOLE	4301	DNC	Powerlines, Lights, and Telephone Poles
304	POWER DROP	PDROP	4302	DNC	Powerlines, Lights, and Telephone Poles
305	U/G POWER LINE	UGPOWER	4303	Random	Powerlines, Lights, and Telephone Poles
306		UNELEC			
307	O/H POWER LINE	OHE	4304	DNC	Powerlines, Lights, and Telephone Poles
308		OVEL			
309	LOW WIRE POWER	LOWWIREP	4305	Random	Powerlines, Lights, and Telephone Poles
310	LIGHT POLE	LP	4306	DNC	Powerlines, Lights, and Telephone Poles
311		LPOLE			
312	GUY POLE POWER	GUYPOLEELEC	4307	Random	Powerlines, Lights, and Telephone Poles
313	GUY ANCHOR POWER	GUYPOWER	4308	Random	Powerlines, Lights, and Telephone Poles
314	TRANSFORMER	TRANSFOR	4309	DNC	Powerlines, Lights, and Telephone Poles
315	ELECTRIC MH	ELECMH	4310	Random	Powerlines, Lights, and Telephone Poles
316		EMH			
317		MHELEC			
318	SERVICE POLE	SERVPOLE	4311	Random	Powerlines, Lights, and Telephone Poles
319	ELECTRIC METER	ELECMETER	4312	DNC	Powerlines, Lights, and Telephone Poles
320	POWER PED	POWERPED	4313	Random	Powerlines, Lights, and Telephone Poles
321	ELECTRIC DUCT	ELECDUCT	4314	DNC	Powerlines, Lights, and Telephone Poles
322	YARD LIGHT	YARDLIGHT	4315	DNC	Powerlines, Lights, and Telephone Poles
323	ELECTRIC JUNCTION BOX	EBOX	4316	DNC	Powerlines, Lights, and Telephone Poles
324		ELECBOX			
325	TOWER LEG	TOWERLEG	4317	Random	Powerlines, Lights, and Telephone Poles
326	TRAFFIC LIGHT POLE	TLP	4318	DNC	Powerlines, Lights, and Telephone Poles
327	TRAFFIC LIGHT SIGNAL BOX	TLSB	4319	DNC	Powerlines, Lights, and Telephone Poles
328	FIRE ALARM	FIREALARM	4320	DNC	Powerlines, Lights, and Telephone Poles
329	RAILROAD SIGNAL POST	RRSIGPOST	4321	Random	Powerlines, Lights, and Telephone Poles
330	RAILROAD SIGNAL BOX	RRSIGBOX	4322	Random	Powerlines, Lights, and Telephone Poles
331	RUNWAY LIGHT	RUNWAYLIGHT	4323	Random	Powerlines, Lights, and Telephone Poles
332	THRESHOLD LIGHT	THRESHLIGHT	4324	Random	Powerlines, Lights, and Telephone Poles
333	TELEPHONE POLE	TELEPOLE	4340	Random	Powerlines, Lights, and Telephone Poles
334	PHONE DROP	PHONEDROP	4341	Random	Powerlines, Lights, and Telephone Poles
335	U/G PHONE LINE	UGPHONE	4342	Random	Powerlines, Lights, and Telephone Poles
336		UNTEL			
337	O/H PHONE LINE	OVTEL	4343	DNC	Powerlines, Lights, and Telephone Poles
338		OHPHONE			
339	GUY POLE PHONE	GUYPOLEPHONE	4344	Random	Powerlines, Lights, and Telephone Poles
340	GUY ANCHOR PHONE	GUYPHONE	4345	Random	Powerlines, Lights, and Telephone Poles
341	TELEPHONE MH	TELMH	4346	DNC	Powerlines, Lights, and Telephone Poles
342	PHONE PED	PHONEPED	4347	DNC	Powerlines, Lights, and Telephone Poles
343	PHONE BOX	PHONEBOX	4348	DNC	Powerlines, Lights, and Telephone Poles
344	PHONE SUBSTATION	PHONESUB	4349	DNC	Powerlines, Lights, and Telephone Poles
345	PHONE BOOTH	TBOOTH	4350	DNC	Powerlines, Lights, and Telephone Poles
346	LOW WIRE PHONE	LWPHONE	4351	DNC	Powerlines, Lights, and Telephone Poles
347	REPEATER	REPEATER	4352	DNC	Powerlines, Lights, and Telephone Poles
348	U/G FIBER OPTIC	FIBERUG	4361	Random	Powerlines, Lights, and Telephone Poles
349		UGFIBER			
350	FIBER POST	FIBPOST	4362	Random	Powerlines, Lights, and Telephone Poles
351	U/G CABLE/FIBER MARKER	UGCAFBMKR	4363	Random	Powerlines, Lights, and Telephone Poles
352	U/G CABLE TV	TVUG	4371	Random	Powerlines, Lights, and Telephone Poles

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FIELD DATA COLLECTORS AND COORDINATE GEOMETRY FUNCTIONS (CONT'D)

353		UGTV			
354	O/H CABLE TV	OHTV	4372	Random	Powerlines, Lights, and Telephone Poles
355	TV PED	TVPED	4373	Random	Powerlines, Lights, and Telephone Poles
356	SATELLITE DISH	SATDISH	4374	DNC	Powerlines, Lights, and Telephone Poles
357	SATELLITE BOX	SATBOX	4375	DNC	Powerlines, Lights, and Telephone Poles
358	STEAM LINE	STEAMLINE	4501	DNC	Steamlines, Features, and Valves
359	STEAM LINE VALVE	SLVALVE	4502	DNC	Steamlines, Features, and Valves
360	STEAM MH	STEAMMH	4503	DNC	Steamlines, Features, and Valves
361		MHSTEAM			
362	STEAM PIT	STEAMPIT	4504	DNC	Steamlines, Features, and Valves
363	SOUNDING	SNDG	4901	Random	Soundings
364		SOUNDING			
365	BORROW PIT TOP	BORPITTOP	5001	Breakline	Channel Lines, Disposal Areas
366		TOPBORPIT			
367	BORROW PIT TOE	BORPITTOE	5002	Breakline	Channel Lines, Disposal Areas
368		TOEBORPIT			
369	SPOIL TOP	SPOILTOP	5003	Breakline	Channel Lines, Disposal Areas
370		TOPSPOIL			
371	SPOIL TOE	SPOILTOE	5004	Breakline	Channel Lines, Disposal Areas
372		TOESPOIL			
373	RED BUOY	REDBUOY	5201	DNC	Navigation Aides and Annotation
374		BUOYRED			
375	GREEN BUOY	GRNBUOY	5202	DNC	Navigation Aides and Annotation
376		BOUYGRN			
377	NO WAKE BUOY	NOWAKE	5203	DNC	Navigation Aides and Annotation
378	SWIMMING BUOY	SWIMBUOY	5204	DNC	Navigation Aides and Annotation
379	STUDY GAUGE	STGAUGE	5205	DNC	Navigation Aides and Annotation
380	NAVIGATION LIGHT	NAVLIGHT	5206	DNC	Navigation Aides and Annotation
381	BUOY	BUOY	5207	DNC	Navigation Aides and Annotation
382	DOLPHIN	DOLPHIN	5208	DNC	Navigation Aides and Annotation
383	PILING	PILING	5209	DNC	Navigation Aides and Annotation
384	LEVEE CL	CLLEVEE	5301	Breakline	Levees, Dikes, and Annotation
385		LEVEECL			
386	LEVEE CROWN	LEVEECRN	5302	Breakline	Levees, Dikes, and Annotation
387		CRNLEVEE			
388	LEVEE TOP	LEVEETOP	5303	Breakline	Levees, Dikes, and Annotation
389		TOPLEVEE			
390	LEVEE SLOPE	LEVEESLP	5304	Random	Levees, Dikes, and Annotation
391		SLPLEVEE			
392	LEVEE TOE	TOELEVEE	5305	Breakline	Levees, Dikes, and Annotation
393		LEVEETOE			
394		BOTLEVEE			
395	BERM CROWN	BERMCRWN	5306	Breakline	Levees, Dikes, and Annotation
396		CRWNBERM			
397	BERM TOP	TBERM	5307	Breakline	Levees, Dikes, and Annotation
398		TOPBERM			
399		BERMTOP			
400	BERM SLOPE	BERMSLP	5308	Random	Levees, Dikes, and Annotation
401		SLPBERM			
402	BERM TOE	BBERM	5309	Breakline	Levees, Dikes, and Annotation
403		TOEBERM			
404		BERMTOE			
405	DIKE CROWN	DIKECRWN	5311	Breakline	Levees, Dikes, and Annotation
406	DIKE TOP	DIKETOP	5312	Breakline	Levees, Dikes, and Annotation
407		TOPDIKE			
408	DIKE SLOPE	SLPDIKE	5313	Breakline	Levees, Dikes, and Annotation
409		DIKESLP			
410	DIKE TOE	DIKETOE	5314	Breakline	Levees, Dikes, and Annotation

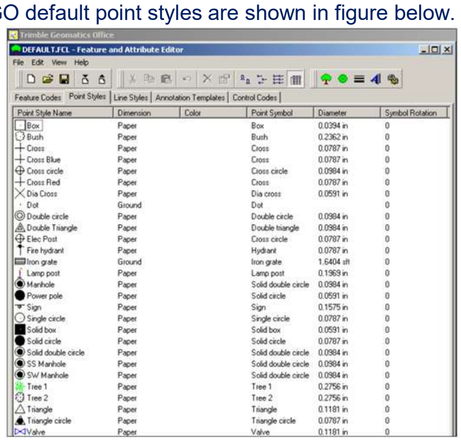
411		TOEDIKE			
412	PIPELINE	PIPELINE	5401	DNC	Pipe Lines, Structures, and Bridges
413	O/H PIPE	OHPIPE	5402	DNC	Pipe Lines, Structures, and Bridges
414	PIPELINE SUPPORT	PIPESUPP	5403	DNC	Pipe Lines, Structures, and Bridges
415	ASPHALT REVETMENT EDGE	ASPHREVEDGE	5701	Breakline	Revetments and Annotation
416	ASPHALT REVETMENT	ASPHREV	5702	Breakline	Revetments and Annotation
417	CONCRETE REVETMENT EDGE	CONCREVEDGE	5703	Breakline	Revetments and Annotation
418	CONCRETE REVETMENT	CONCREV	5704	Breakline	Revetments and Annotation
419	CONCRETE MAT REVETMENT EDGE	CONCREVMATE DGE	5705	Breakline	Revetments and Annotation
420	CONCRETE MAT REVETMENT	CONCREVMAT	5706	Breakline	Revetments and Annotation
421	SEE FIELD BOOK NOTE	NOTE	6301	DNC	Unassigned

Feature and Attribute Libraries for Topographic Field Data

- Most data collectors are now designed to hold detailed feature and attribute libraries.
- Attributes are subsets of a feature, describing standard detail about a common feature.
- For example, a CONCRETE_PIPE (Feature) may have selectable diameter attributes (24 IN, 36 IN, 48 IN, etc.).
- An unlimited number of attributes can be set up for a given common feature.
- The data collector software can be set up to prompt for selected attributes when a given feature (code) is shot. Unprompted attributes can optionally be assessed.
- Or, uncatalogued attributes can be added for a point.

- Feature libraries may be created on the data collector or on other PC software and uploaded to the data collector for use during survey operations.
- The following representative examples are taken from the Trimble Geomatics Office (TGO) Version 1.60, "Feature and Attribute Editor" default library--reference also Trimble Survey Controller Reference Manual.
- The feature and attribute library is created and edited in the TGO software and uploaded to the controller.
- Feature codes, point styles, line styles, etc. can be saved directly to a Trimble Survey Controller type data collector or to a generic ASCII file that could be uploaded to another data collector (e.g., a TDS-HP48GX).

- Some of the TGO default point styles are shown in figure below.



Point Style Name	Dimension	Color	Point Symbol	Diameter	Symbol Rotation
Box	Paper		Box	0.0394 in	0
Bush	Paper		Bush	0.2362 in	0
Cross	Paper		Cross	0.0787 in	0
Cross Blue	Paper		Cross	0.0787 in	0
Cross circle	Paper		Cross circle	0.0984 in	0
Cross Red	Paper		Cross	0.0787 in	0
Dia Cross	Paper		Dia cross	0.0591 in	0
Dot	Ground		Dot		0
Double circle	Paper		Double circle	0.0984 in	0
Double Triangle	Paper		Double triangle	0.0984 in	0
Elec Post	Paper		Cross circle	0.0787 in	0
Fire hydrant	Paper		Hydrant	0.0787 in	0
Iron grate	Ground		Iron grate	1.6404 sft	0
Lamp post	Paper		Lamp post	0.1969 in	0
Manhole	Paper		Solid double circle	0.0984 in	0
Power pole	Paper		Solid circle	0.0591 in	0
Sign	Paper		Sign	0.1575 in	0
Single circle	Paper		Single circle	0.0787 in	0
Solid box	Paper		Solid box	0.0591 in	0
Solid circle	Paper		Solid circle	0.0787 in	0
Solid double circle	Paper		Solid double circle	0.0984 in	0
SS Manhole	Paper		Solid double circle	0.0984 in	0
SW Manhole	Paper		Solid double circle	0.0984 in	0
Tree 1	Paper		Tree 1	0.2756 in	0
Tree 2	Paper		Tree 2	0.2756 in	0
Triangle	Paper		Triangle	0.1181 in	0
Triangle circle	Paper		Triangle circle	0.0787 in	0
Valve	Paper		Valve	0.1181 in	0

Figure 16: Example of Trimble Default Point Styles.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

- Additional features are easily added to the library using a feature/attribute editor, such as that shown in the figure below.
- Attributes can be added to existing or new features using software compatible with the data collector software.
- For example, the feature TREE in the TGO default library can be modified using the TGO software, and the modifications exported to the data collector, as shown below.

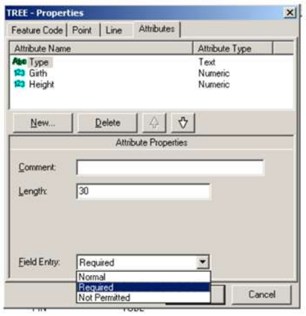


Figure 17: Example of Attribute Editor Options (Trimble).
(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

- The attributes for the feature TREE can be prompted for field entry, as shown in the pull down window.
- Numeric entries for GIRTH and HEIGHT can have default entries, minimum and maximum range, and decimal resolution.
- Any number of additional attributes can be added to this feature using this editor.
- When attributes are created, they should ideally conform to current USACE directed CADD/GIS standards.

Control Commands for Connecting Feature Line Strings

- Topographic features that have the same feature code may be connected by a line string if that is the nature of the physical object.
- Examples of connected line strings would be shots taken along a CENTERLINE, BREAKLINE, CURB, EDGE OF SIDEWALK, BUILDING, etc.
- The individual feature codes input for these continuous objects do not represent the fact that they may be connected by a line string.
- A "Control Command" in the data collector before and after a string of individual point codes is used to indicate that a series of shots are connected.
- For example, a command code "CL" may be used to signify a series of shots along a CENTERLINE, with codes such as "CL START "and "CL END" on each end of the string.

- a. Adding Control Commands to point codes provides many advantages over single point codes.
  - Real-time field graphical depiction of features, utilities, and facilities is viewable on the controller screen, as opposed to a display of unconnected points.
  - When the control-coded data is exported to a CADD or GIS platform, a significant amount of the mapping editing effort can be eliminated.
  - In effect, adding Control Codes approaches a "field-finish" topographic mapping product, not unlike the "field-finish" drawing that resulted from a plane table survey years ago.
  - Adding detailed Command Codes takes more care and time in the field; however, the advantages of cleaner editing will usually outweigh the lost time involved in the field.

- b. Each data collector software vendor has unique Command Code formats.
  - Users should ensure compatibility between the data collector software output and the CADD package that the final drawings will be developed on.
  - Some formats are compatible with only a specific mapping processor.
  - The feature codes tell how to group the points; the command codes tell how to connect the points.
  - For example, TDS ForeSight software has a code table that tells whether linework is required for a group of points and how it is to be plotted: e.g., symbol type, color, size, etc.
  - In the code table you assign each feature code or group of points a specific symbol, a line type, and several other parameters.
  - The code table is a function of the ForeSight program and is discussed in detail in its manual.

Field Coordinate Geometry Options

- Coordinate Geometry (COGO) functions are software routines that perform standard field (and office) survey computations.
- These COGO routines range from simple ones like inverse computations, to more complex computations such as circular and spiral curve stakeouts or least squares adjustments.
- Each data collector software package will contain a varying number of these COGO routines.
- Depending on the type of work an agency performs, only a small number of these COGO features will actually be used in practice.

- a. General.
  - COGO (from COordinate GeOmetry) was initially developed by Charles L. Miller of M.I.T. in 1959.
  - Since then, many improvements have been made, but the basic concept and vocabulary have remained the same.
  - COGO is a problem oriented system that enables the user with limited computer experience to solve common surveying problems.
  - The language is based on familiar surveying terminology, such as, Azimuth, Inverse, Bearing, etc.
  - This terminology is used to define the problem and generate a solution. COGO may be used to solve problems such as curve alignments, point offsets, distance, and direction between two points, intersections, etc.
    - (1) The basis of the system is a series of commands used to manipulate or compute points defined by a point number, x-coordinate, and y-coordinate on a plane surface.
      - These points are stored in what is referred to as the "coordinate table" and may be recalled by their point number in future computations.
    - (2) The mathematics used for the COGO computations are beyond the scope of this manual.
      - There are many textbooks published that describe the mathematical procedures in detail.
      - The Oregon DOT Basic Surveying--Theory and Practice manual (Oregon DOT 2000) is available on the Internet and describes many basic survey computations.
    - (3) There are many COGO packages on the market today.
      - Several are available for an office PC environment on the Internet free of charge.
      - However, COGO software compatible with a particular total station and data collector should be purchased as a package.

- b. Requirements.
  - A few general requirements for a COGO software package are as follows:
    - The ability to utilize a combined scale factor in its computations.
      - This will allow the user to calculate the ground distances when staking out a job, or reduce the measured distances to the reference vertical datum, and correct for the scale factor when the survey is to be tied to the SPCS.
    - The ability to rotate and scale (transform) the survey points to fit existing control.
      - When the surveyor uses field coordinates to perform the survey job, the survey can be transformed onto the SPCS by defining two points with their SPCS coordinates.
    - Compass traverse adjustment is sufficient for the majority of traverses established by the USACE. The ability to perform a least squares adjustment may be advantageous.
    - Must have the ability to work in bearings, north azimuth, or south azimuth.
    - Allow the export of the coordinate table to an ASCII file.
    - Allow the import of points from an ASCII, *.SHP, *.DGN, *.DFX, etc. file.

General COGO Computation Routines

- Each COGO software package on the market has a variety of computational routines.
- The figure here illustrates a screen display from a TDS COGO software package used on field data collectors.
- Most software packages have fairly common COGO functions that are grouped into the categories listed below.

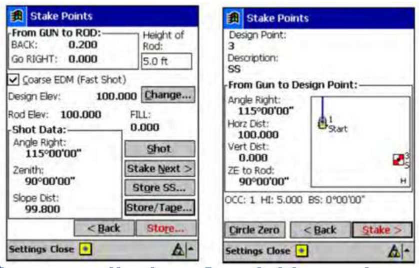


Figure 18: COGO screen displays for staking out a remote point (TDS COGO for Pocket PC).

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

- Forward Computation Commands used to calculate the coordinates for a point, given the coordinates of a known point and the distance and direction to the unknown point.
  - (1) LOCATE/AZIMUTH: Computes a point given an azimuth and distance from a known point.
  - (2) LOCATE/BEARING: Computes a point given a bearing and distance from a known point.
  - (3) LOCATE/ANGLE: Computes a point given a backsight point, angle, and distance.
  - (4) LOCATE/LINE: Computes a POT (point on tangent) given tangent end points and a distance.
  - (5) LOCATE/DEFLECTION: Computes a point given a backsight, deflection angle, and a distance.

- Inverse Computation Commands used to compute the distance and direction between two known points.
- Both the ground and grid distances should be given as output.
  - (1) INVERSE/AZIMUTH: Computes the distance and azimuth between two known points.
  - (2) INVERSE/BEARING: Computes the distance and bearing between two known points.
  - (3) TANGENT/OFFSET: Computes the distance offline and the distance down line given a known point and the ends of a known tangent.

- Intersection Commands used to calculate the coordinates of an unoccupied point as the intersection of two vectors of defined direction and/or distance from two known points.
- Included would also be the various stakeout options--to given templates, slopes, offset alignments, etc.
  - (1) LINE/LINE INT: Computes the coordinates of the point of intersection of two lines whose end points are known.
  - (2) RANGE/RANGE INT: Computes the coordinates of the intersection of two arcs with known radii and centers.
    - Two answers are possible, so the user must define the desired intersection.
  - (3) RANGE/AZIMUTH INT: Computes the coordinates of the intersection of a defined vector and an arc.
    - Two answers are possible, so the user must define the desired intersection.
  - (4) AZIMUTH/AZIMUTH INT: Computes the coordinates of the intersection of vectors with known direction.
  - (5) FORESECTION: This is an Azimuth/Azimuth intersection, measured by turning angles from two known points.

- Curve Commands allow the user to define curve parameters to use defined alignment in computations.
- Usually circular, transition, and vertical curves are included.
  - (1) ALIGNMENT: Given measured curve parameters, computes components of a curve such as:
    - Arc length
    - Long chord
    - Radius
    - Degree of curve
    - Tangent length
    - Center point coordinates
    - External distance
    - Mid ordinate
    - Central angle
    - Vertical curves
  - (2) STATION/OFFSET: Computes the coordinates of an unknown point, given a station and offset along the curve.
    - The reverse function is also available to compute the station and offset of a known point relative to the curve alignment.

- Traverse Adjustments. Traditional adjustments of traverses using either Compass Rule or Least Squares methods.
- Leveling Routines. Input and adjust single-wire, three-wire, digital, or precise leveling.
- Resection Computations. Two and Three-Point resection computations used for locating a total station relative to fixed points on a project.
- Astronomic Computations. Sun shots or Polaris azimuth observation reductions.
- Area Computation Commands which calculate the area of polygons and curve segments.
- The COGO package should calculate the area based on ground distances, not the reduced distances.
- Volume Computations used for cut/fill or measurement and payment. Most COGO software uses Average End Area volume formulas. More sophisticated software will be able to perform surface-to-surface volume computations based on a generated DTM or TIN from observed topographic shots.

- Coordinate Transformation Commands used to rotate, translate, scale, and best fit (warp) between coordinate systems, using either 3- or 7-point transformation routines.
- Graphical Display of COGO Functions. Provide a graphical screen display of COGO calculations, such as stakeout, curves, etc.
- The following paragraphs contain representative examples of some of the more commonly used COGO routines used in the field.
- These examples are taken from TDS HP-48GX software or the Trimble TSC software--COGO routines are all basically the same, regardless of the software vendor (e.g., 3-point resection algorithms are identical in output).

Total Station Resection Computations

- Generally, total stations are set up over known control points and oriented in azimuth to another fixed point.
- Often the total station must be set up at a remote point in order to observe areas not visible from the established control points.
- This typically occurs on property surveys where multiple corners have been recovered but cannot be physically occupied with the instrument.
- In such a case, the instrument is set up at an unmarked point that can see two or more of the property corners plus affords good visibility to the survey area.

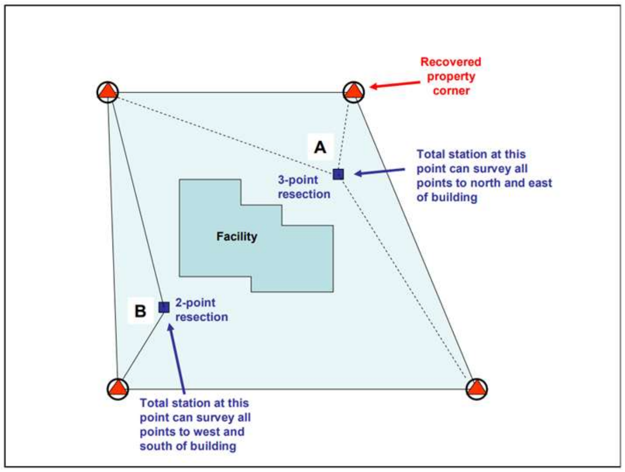
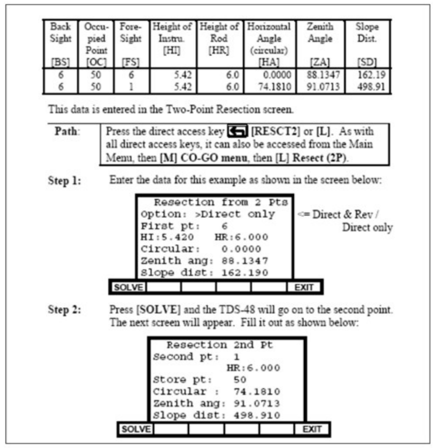


Figure 19: Two- and Three-point total station resections.
(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

- As illustrated in the previous figure, the total station is set at points A and B in order to delineate facilities, utilities, and topography on this site.
- From these two points, the entire project site (including the building exterior walls) can be viewed.
- To position the instrument relative to the recovered property corners, either two- or three-point resections can be performed, as shown at points B and A respectively.
- The rodman places the prism pole at each corner and shots are taken and saved in the data collector.

- In practice, only a two-point resection would be performed at both points A and B since the total station can measure distances to both points and the angle between them; providing a redundant solution of the instrument's position.
- (Three-point resections require only observing of the two angles--three directions--between the three points for a solution--a practice once performed with traditional transits or theodolites).
- Some COGO software will perform a least-squares adjustment of the resected position when redundant observations are obtained--i.e., both directions and distances on a two-point resection or three directions plus one or more distances on a three-point resection.
- Likewise, an adjustment would be performed if four or more points were used in a resection.
- Options for 2D and 3D resection adjustments are available on commercial COGO packages.

- The figure on the following slide is taken from Tripod Data System fieldwork software (TDS 1999).
- It illustrates a two-point resection on a HP 48 type data collector, which is similar to more current CE-based data collectors.
- In this example, the total station is set at point "50," and is backsighted on point "6" (assumed azimuth of 000 deg).
- A two-point resection is made between point "6" and point "1," as shown in the first table.
- The two field steps are shown on the following HP 48 menu screen displays. After the direction and distance to the second point is observed, pressing "SOLVE" on the HP 48 will initiate the resection computation.
- The solved X-Y-Z coordinates of the unknown point "50" will be displayed along with a comparison of the precision of the observation based on the redundancy in the solution.



Back Sight [BS]	Occu-pied Point [OC]	Fore-Sight [FS]	Height of Instru. [HI]	Height of Rod [HR]	Horizontal Angle (circular) [HA]	Zenith Angle [ZA]	Slope Dist. [SD]
6	50	6	5.42	6.0	0.0000	88.1347	162.19
6	50	1	5.42	6.0	74.1810	91.0713	498.91

This data is entered in the Two-Point Resection screen.

Path: Press the direct access key [RESCT2] or [L]. As with all direct access keys, it can also be accessed from the Main Menu, then **[M] CO-GO menu**, then [L] **Resect (2P)**.

Step 1: Enter the data for this example as shown in the screen below:

```
 Resection from 2 Pts
Option: >Direct only
First pt:    6
HI:5.420   HR:6.000
Circular:    0.0000
Zenith ang: 88.1347
Slope dist: 162.190
SOLVE                EXIT
```

<= Direct & Rev / Direct only

Step 2: Press [SOLVE] and the TDS-48 will go on to the second point. The next screen will appear. Fill it out as shown below:

```
 Resection 2nd Pt
Second pt:  1
           HR:6.000
Store pt:   50
Circular :  74.1810
Zenith ang: 91.0713
Slope dist: 498.910
SOLVE                EXIT
```

Figure 20: Screen displays from a HP 48 Two-Point Resection (Tripod Data Systems).

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

Line-Line Intersection Computations

- Often the center of a rectangular object cannot be sighted but the corners can be cut in from one of more set ups.
- An example might be a steel tower structure where all four legs can be sighted from a single total station setup point.
- The legs are shot with a prism at the base or at a constant elevation using a reflectorless total station.
- Given the coordinates of the four corners, the center of the object can be calculated.
- Most COGO routines can do this automatically and store the final coordinates of the object's center.

Figure 21: Steel tower structures requiring line-line intersections to compute center coordinates based on coordinates observed on each tower leg.

(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)

- Following is an excerpt from a TDS *.rw5 file showing multiple observations to four points. Initially the ground elevation of the approximate center of the tower is shot "FP3"--yielding a relative elevation of 101.18 ft as solved in the *.txt file from the data collector.
- Next, the four legs of a tower ("TL") are shot at a constant point about 60 ft above the ground--points FP5 thru FP8.
- The position of the center (Point 9 --"CTR TWR GROUND") is computed from the inversed intersection between the pairs of legs (shown as points 5 through 8 in the solved *.txt coordinate file).
- The ground elevation (101.18 ft) is manually input into the data collector to override the computed elevation at the elevated point on the tower that was actually shot.

```
SS,OP1,FP3,AR149.19000,ZE90.09150,SD86.790,--GROUND

SS,OP1,FP6,AR157.26250,ZE55.57200,SD97.338,--TL
SS,OP1,FP5,AR148.12250,ZE61.10000,SD113.340,--TL
SS,OP1,FP7,AR167.37450,ZE60.52150,SD112.328,--TL
SS,OP1,FP8,AR158.09550,ZE64.15150,SD126.306,--TL

SP,PN9,N 4909.8793,E 5036.6561,EL100.1800,--CTR TWR GROUND
```

- TDS solved *.txt file output:

```
3, 4925.3608054400,  5044.2881496600,  100.1864730500,   GROUND

5, 4915.6088197900,  5052.3105890000,  160.0797345600,   TL
6, 4925.5170666700,  5030.9428381600,  159.9132991600,   TL
7, 4904.1569677500,  5021.0213152200,  160.0990367500,   TL
8, 4894.3940359500,  5042.3136274700,  160.2847694200,   TL

9, 4909.8792864900,  5036.6560961400,  100.1800000000,   CTR TWR GROUND
```

Check the next slide to explore an interactive GIF about the COGO Function.

Which COGO Function Do You Need?

COGO software groups its functions into standard categories. For each field problem below, choose the correct COGO function category. You have 3 trials.

Start Challenge

Powered by genially

THANK YOU FOR LISTENING!

This concludes our presentation, and we hope that you enjoyed it.

For instructions on how to receive PDH credits, please continue till the end of the presentation.

REFERENCES

This interactive presentation was adapted from Section III of Chapter 5, and Chapters 6 and 7 of the document by the US Army Corps of Engineers, Control and Topographic Surveying, January 2007, EM 1110-1-1005.

COURSE PROVIDER BIOGRAPHY

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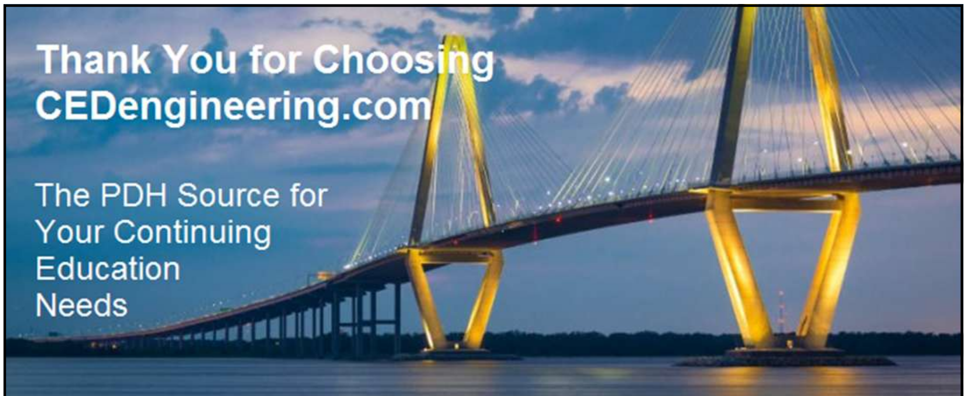
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