CHAPTER 25

GPS Survey Control Network

NOTE: This chapter is currently being re-written and its content will be included in Chapter 106 in the future.

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CHAPTER 25

GPS SURVEY CONTROL NETWORK

25-1.0 GENERAL

The primary purpose for employing the global positioning system (GPS) is to establish more-accurate survey control in road design by improving angular control on a long, narrow traverse. Employing GPS technology saves time during the survey because the conventional traverse and the level circuits need to be run in only one direction.

The traditional use of the United States Coast and Geodetic Survey (USC&GS) for horizontal control results in a repeatability error that is outside an acceptable tolerance. A GPS control survey can minimize such error because it will facilitate a reference to state-plane coordinates (SPC) which will allow future control to be re-established within a tolerance of only about 0.1 ft. Establishing control by referencing SPC will become increasingly important once the Federal Base Network/Cooperative Base Network (FBN/CBN), formerly known as the High Accuracy Reference Network (HARN), has been completed and adjusted. If a section corner or centerline-control monument is based on adjusted FBN/CBN SPC, it can be readily and accurately re-established by use of a local monument that is also based on FBN/CBN SPC.

This Chapter provides guidelines and procedures for employing GPS technology and establishing a GPS survey-control network.

25-2.0 GUIDELINES AND PROCEDURES

25-2.01 Horizontal Control

Where practical, an INDOT project survey should be based on North American Horizontal Datum 1983 (NAD 83) with adjusted FBN/CBN SPC. The SPC should only be used for reference purposes or to re-establish control. The topography data should not be collected under SPC.

The SPC should be transformed to a local coordinate system upon completing the control network. Such a capability is available in most GPS software packages. To achieve optimal results, create a local Transverse Mercator projection for a north-south strip and a local Lambert Conformal Conic projection for an east-west strip, or an Oblique Mercator projection for an angled strip. Establish the local coordinate system on a value that is not an SPC (e.g., 10 000, 10 000). For a distance within the conventional measurement range (e.g., < 5500 ft), the difference between local grid and actual ground measurements should be negligible, thus minimizing the need for SPC grid-to-ground conversions.

Both the FBN/CBN SPC network coordinates based on NAD 83 horizontal datum, and the local grid coordinates, should be submitted for each centerline control point or section corner. The SPC data should not be used for general topography. Until the adjusted FBN/CBN coordinates are published, constrain the final GPS adjustments to only one NAD 83 horizontal control.

25-2.02 Vertical Control

The Department prefers that the North American Vertical Datum 1988 (NAVD 88) be used for the vertical control of a project that is based on National Geodetic Survey (NGS) benchmarks. Many of the existing GPS software packages require that NAVD 88 datum be used for elevation calculations. The National Geodetic Survey includes all of the previous records of the USC&GS database which should not be confused with the U.S. Geological Survey (USGS). The accuracy of other datum (e.g., USGS, INDOT) is not as dependable because some of the recorded benchmarks were based on estimates or trigonometric observations.

All NGS data for the State is available on computer CD. Copies may be purchased from the National Geodetic Survey. Optionally, the NGS data may be obtained through the internet under Products and Services at http://www.ngs.noaa.gov. The data may be extracted by a PID, a station name, or an area that is defined by latitude and longitude.

To maintain vertical control, at least three reliable benchmarks should be established. These benchmarks should be spaced evenly within the network. Only one benchmark should be fixed at a time, as the orthometric height is constrained during final GPS adjustment. Compare the difference between the calculated and the published elevations before constraining to other orthometric benchmark elevations.

25-2.03 Research

A source for obtaining horizontal and vertical controls is the NGS geodetic control diagrams. These diagrams illustrate the position of each horizontal monument, including the lines of observation, and the level circuit between each vertical benchmark. Unfortunately, geodetic control diagrams are no longer published by NGS, and their availability is limited. Computer mapping software is available that will process NGS control data and produce graphical displays.

The standard USGS quadrangle maps should identify a majority of the horizontal and vertical controls that may be required for a project.

During the research effort, the name of a particular monument should be identified so that its location description and its published data may be obtained. The monument's latitude and longitude should be recorded for use in plotting GPS obstructions during schedule planning. Only one NGS horizontal control is required to tie a project to the SPC system. However, one large geometrically-solid triangle may be necessary if the control's location is far from the project (e.g., up to a 12-mi radius for static observations).

The GPS network should incorporate as many existing monuments as practical. Existing centerline control and section-corner monuments should be researched and located during the survey. Road plans and field books may be obtained from the Planning Division's Research and Documents Library Team. Information pertaining to section corners may be obtained from the county surveyor's office. Other useful information may be acquired by researching deeds for surrounding property or by interviewing local surveyors. Property owners must be given advanced notice (i.e., Notice of Survey) before a survey party can access monuments or section corners on private property. Chapter 22 provides additional information regarding preliminary research and survey notice.

25-2.04 Reconnaissance

Preliminary research will identify most of the control points within the survey limits, with a general description of the monument. However, a field reconnaissance should be employed to physically locate the monument and to find or set additional project controls. Such an operation may require that the centerline location be calculated from existing points so that additional centerline control can be staked out to know where to look for a known monument.

If a monument is a potential candidate for inclusion in the GPS network, satellite vehicle (SV) obstructions (e.g., trees, buildings, power lines) should be plotted, as illustrated in Figure 25-2A, GPS Station SV Obstruction Chart, and logged in the computer. A schedule of observation times can then be computed. Reference drawings should be made on the back of the obstruction chart. See Figure 25-2B, Reference Drawing. These drawings should be made for each GPS monument that is either found or set.

Because there may be an unforeseen delay in returning to the project site, each monument should be marked and referenced. Each section corner, either found or apparent, must be referenced and recorded. Figure 26-1C illustrates the Department's format for a section-corner reference card.

Once the FBN/CBN system is completed, adjusted, published, and used in the network, the SPC should be placed on all reference drawings.

25-2.05 Network Design

As practical, at least one NGS horizontal control monument and three NGS vertical control monuments should be incorporated in the control network. Additional random monuments may need to be set to create a geometrically strong network.

Two pairs of intervisible points, one pair located at each end of the project, are required so that beginning and ending bearings may be used to close the conventional traverse angles. For a project longer than 3 mi, an additional pair, located near the center of the project, should be considered so that two shorter traverses can be constructed. This should minimize errors that are associated with closing a long traverse.

The control networks should be collected using either static or fast static observations. Either kinematic or real-time kinematic (i.e., RTK) observations may be used for other singular control points. Where a random point must be set for the purpose of general control or strength-of-figure, do not set the monument near the centerline or a property line as the random point can then be mistaken for such monumentation. All control points should be kept within the project right-of-way or on public property. The spacing of the final centerline control monuments and the benchmarks should not exceed 1000 ft.

25-2.06 Scheduling

Prior to developing a schedule, determine the date upon which the field observations will be conducted. If GPS observations have not been conducted recently, a new ephemeris should be collected because satellite orbits are altered frequently. An old ephemeris is not reliable. After plotting the obstructions and computing the observation times for all points in the GPS control network, a schedule should be made to accommodate those points having limited visibility. To avoid rescheduling, the ephemeris should be less than one week old. A new ephemeris should be collected the day before conducting the scheduled observations, and the schedules should be checked for alterations.

The best geometric control network is one that is composed of triangles similar to a steel bridge structure. A single observation session produces a number of measured baselines that is equal to the number of receivers used minus one. Therefore, the optimal number of receivers to use in network design is four. However, with more forethought and difficulty, the task may be conducted with two or three receivers.

The first observation setup should be on the fixed horizontal control point. If four receivers are being used, three receivers should be set up in a triangular configuration that will measure the three desired baselines. The fourth receiver (i.e., the dummy) should be set at a point on the next desired triangle. For each subsequent observation session, the farthest receiver is moved to the next point in the network. During each session, it is ideal to obtain a measured baseline for each leg of the triangle. This will produce redundancy for more-accurate least-squares-adjustment results.

For fast static observations that are collecting L1 and L2 frequencies with P-code, the required time for a 15-s epoch is as follows:

1. 20 min or longer for four an observable satellite vehicle;
2. 15 to 20 min for five satellite vehicles; and
3. 8 to 10 min for six or more satellite vehicles.

A schedule may incorporate 15-min observation periods with an average of 25-min relocation times similar to the example provided in Figure 25-2C, Fast Kinematic GPS Observation Sheet. Each session's receiver must collect data simultaneously from the same satellites during the same minimum time period. Radio communication between each receiver's operator is desired so that, if a problem occurs, an allowance can be made to immediately avoid an erroneous observation session.

25-2.07 Equipment Preparation

Charge all batteries before conducting the field observations. Check and adjust tribrachs for both level and optical plummet. Tighten the tripods to eliminate wobble. If a prism pole is used in a kinematic observation, adjust the spirit bubble so that an accurate location can be obtained. Set the correct parameters for the type of observations being made on all receivers (e.g., type of observation, type of antenna, type of antenna height measurement, the epoch time length, the local time zone). The file name is the concatenation of a unique four-character name of the observed monument, the Julian date, and the session number (e.g., BASE1941). Ensure that a sufficient number of observation forms have been prepared for all of the planned sessions.

25-2.08 Field Observations

A failure to adhere to the planned observation schedule will produce an erroneous session. If radio contact cannot be maintained between receiver operators, adhering to the planned schedule becomes important. If a receiver battery needs to be changed, it should be changed during a scheduled move because the data-collection period must be both synchronized and continuous. Some receivers have the capability of maintaining power during a battery change. Points that do not have to be a part of the control network may be collected by employing GPS kinematic observations. The observation forms provided in Figure 25-2D, GPS Field-Data Sheet, and Figure 25-2E, Special Situation and Station Description Sheet, should incorporate the following information.

1. project name;
2. project location;
3. USGS quadrangle-map identification;
4. observation date;
5. type of receiver and antenna including serial numbers;
6. observer's name;
7. station name and identification;
8. each session's start and stop observation times;
9. antenna heights and how they were measured (e.g., true vertical, slope to ground plane); and
10. conflicting occurrences including the time span (e.g., a battery change, a large truck that stopped and obscured the target for more than 1 min).

Review the observation forms for potential problems that can be corrected during a subsequent session in the field.

25-2.09 Downloading Receivers

Review the data-collection observation forms for changes that may be required in the file information. Download the data from each receiver and check file names, point names, antenna heights, and fixed-control information.

25-2.10 Data Processing

One control point should be fixed both horizontally and vertically (i.e., ellipsoidal height) for baseline processing. To process baseline data, specify the generation of all baselines and select the set of independently-measured baselines. Review the ratios, reference values, and solution types of the detailed summary to determine measurement quality. The results should then be saved. Visually check the network map for gross errors. Determine the closure on both the network perimeter and additional circuits and check the vertical benchmarks. Save and print the results. Baseline closures should be more accurate than 1 in 100 000. If an observation session is erroneous, then recompute the observation times under a different time frame and repeat the observation session. Once quality data has been collected for each baseline, begin the least square's adjustment and constrain to only one fixed horizontal control monument. The results should be compared with other known quantities so that particularly erroneous points can be isolated. Upon completing the fully-constrained adjustment and the time frame, repeat the observation session. Quality data should be changed to State Plane Coordinates (i.e., either east or west). Save and print the results for reference purposes. A local plane coordinate system then should be created. This can be either a Transverse Mercator projection for a north-south route, a Lambert Conformal Conic projection for an east-west route, or an Oblique Mercator projection for an angled route. The planes will be so close to the ground that the resulting difference between grid and ground distances will be negligible. The result should then be saved and printed as it will become the control for all ground work. Verify the results during the bench-level circuits and the conventional traverse which will need to be run in order to set the centerline control and the fly stations for topography.

25-2.11 Conventional Traverse

After the network is finalized, the conventional traverse for local control and centerline stakeout can begin at the two intervisible GPS control points, then continued to the next two intervisible GPS control points. Centerline control points should not be spaced at more than 1000 ft. Run a bench-level circuit between either benchmarks or GPS control points. Temporary benchmarks should be set, where practical, within the right of way and should not be more than 1000 ft apart.

25-2.12 Submittals

So that other projects with common control monumentation may benefit from previously collected data, the information to be submitted is as follows:

1. raw .data files that have been downloaded from receivers;
2. copies of the GPS station satellite vehicle obstruction charts;
3. GPS field-data sheets;
4. a network diagram illustrating the measured baselines; and
5. adjusted SPC and Local Projection coordinates with projection definition.

The network diagram should be provided on a copy of the USGS quadrangle map. By maintaining a database of raw project data, multiple networks may be tied and processed together.

A standard program function for transferring data is to make a backup copy of all project files. For Trimble receiver software, this function is located under the menu selection; GPSurvey, Desktop, Project, Backup. If the GPS data has been collected using another brand of receiver software, the data transfer may require the use of the RINEX file format. The Department requires that all data be backed up in both formats (i.e., standard and RINEX) before it is deleted.

A hardcopy of the results should also be submitted. This should include the following.

1. <u>Processed Baseline Summary</u>. A detailed summary of the processed baseline that provides the ratios, reference values, solution types, and the quality of the measurements shall be included.

2. <u>Closure Log</u>. Include a closure log that provides the combinations of network loops and the validity checks of the measurements. This should include the outer perimeter and the inner loops and benchmark loops. All combinations of loops should be investigated to locate the weakest link in the network. The precision and the delta misclosures for the Northing, Easting, and the elevation should be identified for each loop.

3. <u>Summary of Covariances</u>. Include a summary of covariances that provides the precision on each baseline resulting from the redundancy of measurements.

4. <u>Map-Projection Transformation Sheet, SPC</u>. A map-projection transformation sheet that illustrates the transformation parameters from the geodetic coordinates (i.e., latitude, longitude) to map coordinates (i.e., State Plane Coordinates east or west) for each point

should be included. This should include the coordinates, the scale, and the convergence angle.

5. Map-Projection Transformation Sheet, Local Coordinates. Include a map-projection transformation sheet that provides the transformation parameters from the geodetic coordinates to map coordinates for each point in the local coordinate grid. This should include the type of projection in addition to the coordinates, the scale, and the convergence angle.

6. Final Coordinate Adjustment Summary. The final coordinate adjustment summary for each point should also be included. This should indicate the points that are fixed horizontally or vertically. The summary also should indicate whether the elliptical or the orthometric height was held fixed. The orthometric height is preferably held fixed.

7. Long Inverse Printout. Include printouts of long inverses (i.e., full-information inverses) between control points and indicate the inverse information for the local grid and the geodetic ground distances. This should be conducted for a short, a long, and an average distance. In comparing this information, the locally-defined grid distance should be within 0.03 ft of the ground distance.

This information should be compiled and printed from the software through a standard report selection. If the software does not have this capability, contact the Production Management Division's Surveys Team for alternatives.

STATION NAME: *K 71 RESET 1956* PID: *KA0837* QUAD MAP NAME: *MANSFIELD*

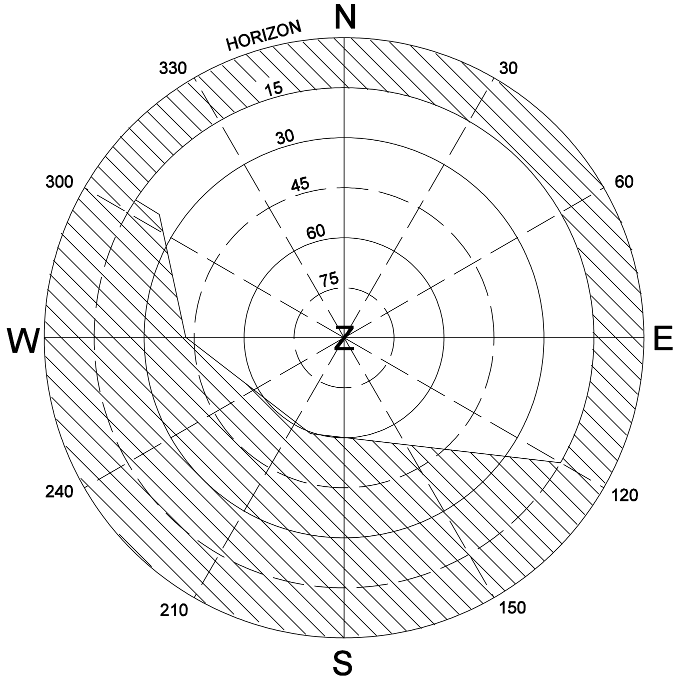
DATE: *7-2-96* LATTITUDE: *87°06′ 19″ W*

OBSERVER: *JOHN SMITH* LONGITUDE: *39° 43′ 21″ N*

NAVD 88 ORTHOMETRIC HEIGHT: *737.66 ft 3rd ORDER*

HORIZ. AZ. GEOID HEIGHT: *-108.83 ft*

VERT. ∠ ELLIPSOIDAL HEIGHT: *628.83 ft*



OBST#	DESCRIPTION	FROM AZ.	FROM ELEV.	TO AZ.	TO ELEV.
1	TREES	120°	15°	135°	45°
	"	135°	45°	200°	60°
	"	200°	60°	270°	40°
	"	270°	40°	305°	20°
	"	305°	20°	305°	15°
2	STANDARD 15° MASK	305°	15°	120°	15°

GPS STATION SV'S OBSTRUCTION CHART
Figure 25-2A

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MONUMENT TYPE: *STANDARD BENCH MARK DISK IN CONCRETE MONUMENT*

STAMPING ON DISK: *USC&GS BENCH MARK "K 71 RESET" 1956*

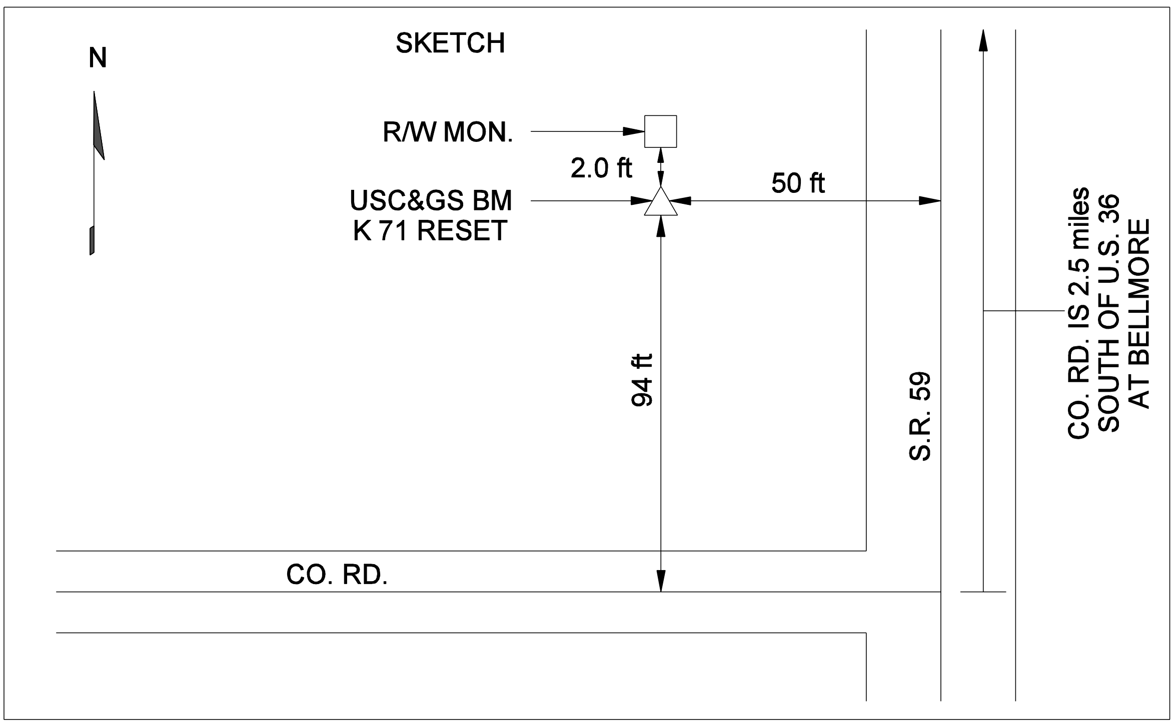
PHYSICAL CONDITION: *EXCELLENT CONDITION - PROTRUDING 0.5 ft*

COMMENTS ON SUITABILITY FOR GPS OBSERVATIONS: *SOME EXTENSIVE OBSTRUCTIONS BUT HAS POTENTIAL*

"GPS PLAN" CALCULATED OBSERVATIONS TIMES FOR: 7-12-96 15" EPOCHS WITH 5 SV's MIN.

7:54 TO 8:52 A.M. IND. TIME
9:12 TO 9:30 A.M.

TO REACH: 2.5 mi SOUTH FROM BELLMORE ALONG SR 59 FROM THE JUNCTION OF US 36, IN THE NORTHWEST QUATER OF THE JUNCTION WITH A BLACKTOP ROAD LEADING WEST, 50 ft WEST OF THE CENTERLINE OF THE HIGHWAY, 92 ft NORTH OF THE CENTERLINE OF THE ROAD LEADING WEST, 2 ft SOUTH OF A CONCRETE INDIANA R/W MARKER, AND ABOUT 5 ft HIGHER THAN THE HIGHWAY.



REFERENCE DRAWING

Figure 25-2B

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FAST KINEMATIC GPS OBSERVATION
TIMES FOR DES #8574910 RACCOON LAKE
July 11, 1996

RECEIVER LOCATION	BEGIN TIME	QUIT TIME		MOVE TIME
	SESSION 1			
BASE @ BM J-71	8:35	8:50		
ROVER 1 @ BM L-71				
ROVER 2 @ 0550	9:00	9:15	ALTERNATIVE	
ROVER 3 @ 0551				
ROVER 2 MOVES TO 0550 & ROVER 3 MOVES TO 0551				25'
	SESSION 2			
BASE @ BM J-71	9:15	9:30		
ROVER 1 @ BM L-71				
ROVER 2 @ 0551	9:40	9:55	ALTERNATIVE	
ROVER 3 @ 0550				
ROVER 3 MOVES TO BM K-71				25'
	SESSION 3			
BASE @ BM J-71	9:55	10:10		
ROVER 1 @ BM L-71				
ROVER 2 @ 0551	10:20	10:35	ALTERNATIVE	
ROVER 3 @ BM K-71				
ROVER 1 MOVES TO 0618				25'
	SESSION 4			
BASE @ BM J-71	10:35	10:50		
ROVER 1 @ 0618				
ROVER 2 @ 0551	11:00	11:15	ALTERNATIVE	
ROVER 3 @ BM K-71				
ROVER 2 MOVES TO 0617				25'
	SESSION 5			
BASE @ BM J-71	11:15	11:30		
ROVER 1 @ 0618				
ROVER 2 @ 0617	11:40	11:55	ALTERNATIVE	
ROVER 3 @ BM K-71				

FAST KINEMATIC GPS OBSERVATION SHEET
Figure 25-2C

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PROJECT NAME: DESIGN # 8574910		LOCATION:	RACCOON LAKE
OBSERVER: JOHN SMITH		QUAD MAP(s):	MANSFIELD
RECEIVER TYPE: TRIMBLE 4000 SSI	(ROVER3)	SERIAL NUMBER:	11640
ANTENNA TYPE: TRIMBLE COMPACT L1/L2 W/GROUND PLANE		SERIAL NUMBER:	24895

****

SESSION FILE NUMBER:	16401931 SESSION 1	16401932 SESSION 2	16401933 SESSION 3	SESSION 4
STATION NAME:	0551	0550	BMK71	
TYPE OF MONUMENT	"+" ON HDWL	US CORP/ENG BM MM13	USCGS BM K 71	
JULIAN DAY:	193	193	193	
MM DD YY:	7-12-96	7-12-96	7-12-96	
GREENWICH TIME -	START: 13:48:15	START: 14:21:30	START: 15:12:15	START:
(TO BE COMPLETED AT LOG - IN)	STOP: 14:15:30	STOP: 14:55:45	STOP: 16:57:15	STOP:

****

ANTENNA HEIGHT MEASUREMENTS

TYPE OF MEAS.: UNCORRECTED TO EDGE OF GROUND PLANE

		Session 1	Session 2	Session 3	Session 4
BEGIN	1ST	5.41 ft	5.89 ft	4.85 ft	ft
	2ND	5.43 ft	5.89 ft	4.85 ft	ft
	3RD	5.42 ft	5.89 ft	4.86 ft	ft
	MEAN	5.42 ft	5.89 ft	4.85 ft	ft
END	1ST	5.41 ft	5.89 ft	4.85 ft	ft
	2ND	5.43 ft	5.89 ft	4.85 ft	ft
	3RD	5.42 ft	5.89 ft	4.86 ft	ft
	MEAN	5.42 ft	5.89 ft	4.85 ft	ft

****

INDIANA LOCAL TIME				
START:	8:48	9:21	10:12	
STOP:	9:15	9:55	11:57	

SYNC RATE: SET TO 15" EPOCHS MIN. SV's: 4 ELEV. MASK: 15 deg MAX. PDOP: 7

WEATHER: SUNNY, MILD, SLIGHT WIND

SPECIAL INSTRUCTIONS:

POINT # 0551 IS A CUT "+" ON TOP CENTER OF HEADWALL ON NORTH SIDE OF DAM ROAD AT OFFICE.

POINT #0550 IS A U.S. CORPS OF ENGINEERS BENCH MARK "MM 13" WITH A GIVEN ELEVATION OF 712.44 ft (217.152 m) (DATUM UNKNOWN).

POINT BMK71 IS USC&GS BENCH MARK "K 71 RESET 1956".

USE BACK OF SHEET TO DESCRIBE ANY ABNORMALITIES NOTED DURING THE SESSIONS

GPS FIELD DATA SHEET - STATIC OBSERVATION

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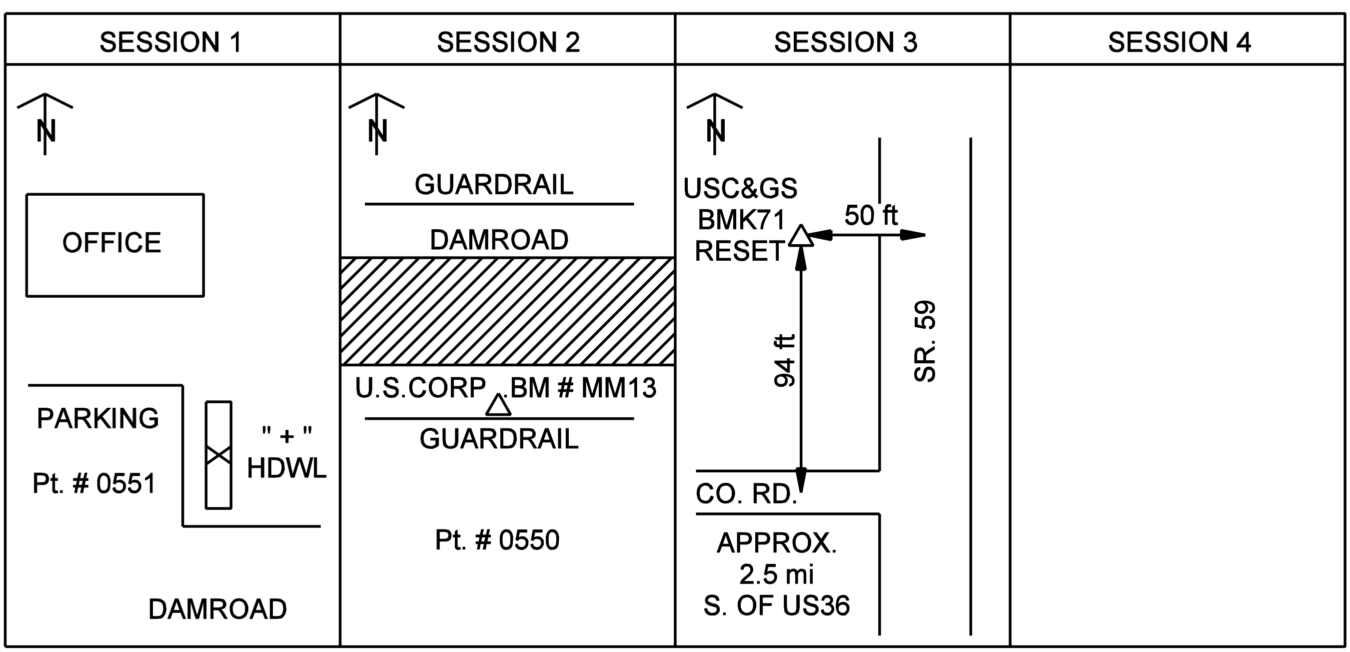
SPECIAL SITUATIONS (INCLUDE THE TIME OF THE OCCURRENCE)

CHANGED DEAD BATTERIES BETWEEN SESSIONS 3 & 4 AT 15:42 (10:42 LOCAL)

STATION DESCRIPTION



SPECIAL SITUATIONS AND STATION DESCRIPTION SHEET

Figure 25-2E

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