# Chapter 6
# Ground Control Requirements for Photogrammetric Mapping

## 6-1. General

This chapter covers ground control requirements for photogrammetric mapping projects. Control surveys associated with photogrammetric mapping projects shall be in compliance with the July 1, 1998, "Public Review Draft FGDC Geospatial Positioning Accuracy Standards, Part 4: Standards for Architecture, Engineering, Construction (A/E/C) and Facility Management." The fundamental requirements for control network configuration, point location, and image characteristics are discussed in this text. However, the overview presented is not intended to be used for field survey design or survey procedural instruction. The USACE specification writer or photogrammetric engineer should refer to appropriate survey standards and specifications for guidance in designing the project control surveys. Current standards should be employed. Outdated unrevised standards can provide outdated technology and procedure guidance and cost the Government unnecessary time and money. Listed below are some of the current (at the time of the publication of this Engineer Manual) publications that may be used.

July 1, 1998, Public Review Draft, "FGDC, Geospatial Positioning Accuracy Standard, Part 4"

EM 1110-1-1002, "Survey Markers and Monumentation"

EM 1110-1-1003, "Navstar Global Positioning System Surveying"

## 6-2. Coordinate Reference Systems

The coordinate reference system is the backbone of a mapping project. It provides the framework to tie together all field survey and map data. The coordinate reference system must be specified for the final map product. Typically, the State Plane Coordinate zone or the Universal Transverse Mercator (UTM) zone in which the project is located is used to define a mapping coordinate system. The North American Datum of 1983 (NAD 83 HPGN) and the North American Vertical Datum of 1988 are the most current horizontal and vertical datums as of this publication. NAD83 and NAVD88 should be used for most USACE projects within the continental United States unless unique circumstances make the use of these datums unreasonable. NAD27 and National Geodetic Vertical Datum of 1929 (NGVD29) are horizontal and vertical datums that have been used for USACE projects for many years. USACE Commands may choose to continue the use of these datums for specific projects. The photogrammetric engineer must be familiar with the reference datum, the coordinate system definition, and the methods required to transform all data into the final map coordinate system. Reference datums and coordinate systems used shall be clearly identified as part of the ground control META data and in specifications for surveying contractors performing photogrammetric ground control data collection. Chapter 3 reviews the definitions of the datums and coordinate systems typically encountered in mapping. Several sources in Appendix A provide detailed information on datums, coordinate systems, and map projections.

## 6-3. Ground Control Requirements for Photogrammetric Mapping

Field surveying for photogrammetric control is generally a two-step process. The first step consists of establishing a network of *basic control* in the project area. This basic control consists of horizontal control monuments and benchmarks of vertical control that will serve as a reference framework for subsequent surveys. The second step involves establishing *photo control* by means of surveys originating from the basic control network. Photo control points are the actual points appearing in the photos (photo identifiable points or panel points) that are used to control photogrammetric operations. The accuracy of basic control surveys is generally of higher order than subsequent photo control surveys. According to FGDC Standards, Part 4 (FGDC 1998), control surveys accuracies may be specified in either positional tolerance accuracy or relative closure ratio accuracy. Control survey accuracies are usually measured in relative closure ratios rather than positional tolerance. The horizontal and vertical control survey types recommended in Table 2-1 coupled with the FGDC Horizontal and Vertical Accuracy Standards stated in Tables 5-1 and 5-2 shall be used to establish survey control accuracies for USACE photogrammetric mapping projects. It is imperative that a geodesist with photogrammetric control experience in the geographic area of the project be an integral part of the ground control planning team. The geodesist should specifically be considered in the final placement of not only basic control but also photo control to ensure required accuracies are met and time and costs are kept to a minimum. GPS technology is now an integral part of almost any field survey project to include photogrammetric control surveys. Increased satellite availability, improved receiver processing and software along with more accurate geoid models have enhanced the reliability and accuracy of GPS measurements. GPS is one of several tools that may be used in establishing photogrammetric ground control. GPS technology does have limitations that must be understood and dealt with when planning and executing a ground control project. Proper employment of GPS in obtaining photogrammetric survey control can contribute to decrease cost and time in the field. Further information regarding GPS technology, theory, and planning can be obtained from several sources to include EM 1110-1-1003, “Navstar Global Positioning System Surveying.”

*a. Basic control.* A basic control survey provides a fundamental framework of control for all project-related surveys, such as property surveys, photo control surveys, location and design surveys, and construction layout. The accuracy, location, and density of the basic control must be designed to satisfy all the project tasks that will be referenced to the control. The National Geodetic Referenced System (NGRS) has been established and is maintained by the Federal Government through the National Geodetic Survey (NGS). The NGRS consists of more than 270,000 horizontal control monuments and more than 600,000 benchmarks throughout the United States. The NGS continues to establish, upgrade, maintain, and disseminate geodetic control information. Relative accuracies within the current NGRS vary. GPS technology appears to provide reference points with more consistent and more accurate locations than those established by more conventional methods. The NGS along with many states have created High Precision Geodetic Networks, (HPGNs). The HPGNs-fit GPS derived reference point locations to less accurate state networks. Established HGPNs should be considered in the planning and establishment of control when possible for USACE photogrammetric projects. Procedures for GPS ground control establishment should follow guidance provided in EM 1110-1-1003, “NAVSTAR Global Positioning System Surveying.”

(1) Horizontal basic control points should be angle points in traverses or vertices of network triangles. Vertical basic control points should be turning points in level routes. Vertical control obtained by GPS should be checked by conventional level loops for selected points to check accuracy of the geoid model in the project area. Conventional survey side shots or open traverses should not be used to locate basic control. Second or Third-Order plane surveys will generally be of sufficient accuracy to establish basic control for most, if not all, USACE photogrammetric mapping projects. See also the guidance in Table 2-1.

(2) In planning the basic control survey, maximum advantage should be taken of existing, or project, control established in the area by the USACE Command. Basic control may also be established with HPGN, NGRS, or USGS reference points. In many locations, local control points exist such as those established for State agency and urban area networks. Care should be exercised before using any control points to verify that they are adequately interconnected or are adequately connected to the national network (i.e., NGRS).

*b. Photo control.* Photo control points are photo identifiable or panel points that can be measured on the photograph and stereomodel. Photo control points are connected to the basic control framework by short spur traverses, intersections, and short level loops. Lengthy side shots and open traverses should be avoided.

Photo control surveys are local surveys of limited extent. Photo control points are surveyed to the accuracy required to control the photogrammetric solution. The accuracy requirement for photo control points should generally be Third Order and, in some instances, Second Order as established in Table 2-1.

(1) Characteristics. Photo control points should be designed by considering the following characteristics: location of the control point on the photograph; positive identification of the image point; and measurement characteristics of the image point. GPS derived photo control points require special consideration. The locations of GPS points must be in a location that will allow for the required GPS horizon parameters to be met.

(a) Location. Of the characteristics listed in (1) above, location is always the overriding factor. Photo control points must be in the proper geometric location to accurately reference the photogrammetric solution to the ground coordinate system. Horizontal photo control points should define a long line across the photographic coverage. The horizontal control accurately fixes the scale and azimuth of the solution. Vertical photo control should define a geometrically strong horizontal triangle spanning the photographic coverage. The vertical control accurately fixes the elevation datum of the solution. The location should be established in accordance with current photogrammetric practice considering the project area and the map accuracy requirements.

(b) Identification. The identification of the photo control points on the aerial photographs is critical. Extreme care should be exercised to make this identification accurate. The surveyor should examine the photo control point in the field using a small pocket stereoscope with the aerial photographs. Once a photo control point is identified, its position on the photograph should be pricked using a sharp needle. A brief description and sketch of each point should be made on the reverse side of the photograph. Each photo control point should be given a unique name or number.

(c) Measurement. Subject to the constraints imposed by location considerations, photo control points should be designed to provide accurate pointing characteristics during photogrammetric measurements. Furthermore, control points should not be located at the edge of the image format, since image resolution and distortion are both degraded at the edge of the format. Photo control points falling in the outside 10 to 15 percent of the image format should be rejected.

(2) Horizontal photo control. Images for horizontal control have slightly different requirements from images for vertical control. Because their horizontal positions on the photographs must be precisely measured, images of horizontal control points must be very sharp and well-defined horizontally. Care should be exercised to ensure that control points do not fall in shadowed areas.

(3) Vertical photo control. Images for vertical control need not be so sharp and well-defined horizontally. Points selected should, however, be well-defined vertically. Since measurements are typically made stereoscopically, good vertical control points should have characteristics that make it easy for the operator to accurately put the floating mark at the correct elevation. Vertical control points are best located in small, flat, or slightly crowned areas with some natural features nearby that assist with stereoscopic depth perception.

(4) When GPS methods are employed, photo control images should be discrete, since these procedures create a precise spatial coordinate (X,Y,Z).

*c. Control point distribution.* If photo control is being established for the purpose of orienting stereomodels in a mapping instrument for planimetric and / or topographic map compilation, the control point distribution depends upon the mapping procedures that are employed to adjust the imagery to the earth. The exact location of specific control is site dependent. The survey crew should be provided with current photography of the project area to assist in establishing the location of control points. Additional information regarding ground control point distribution can be found in Chapters 7 and 8. Figure 6-1 is a typical ground

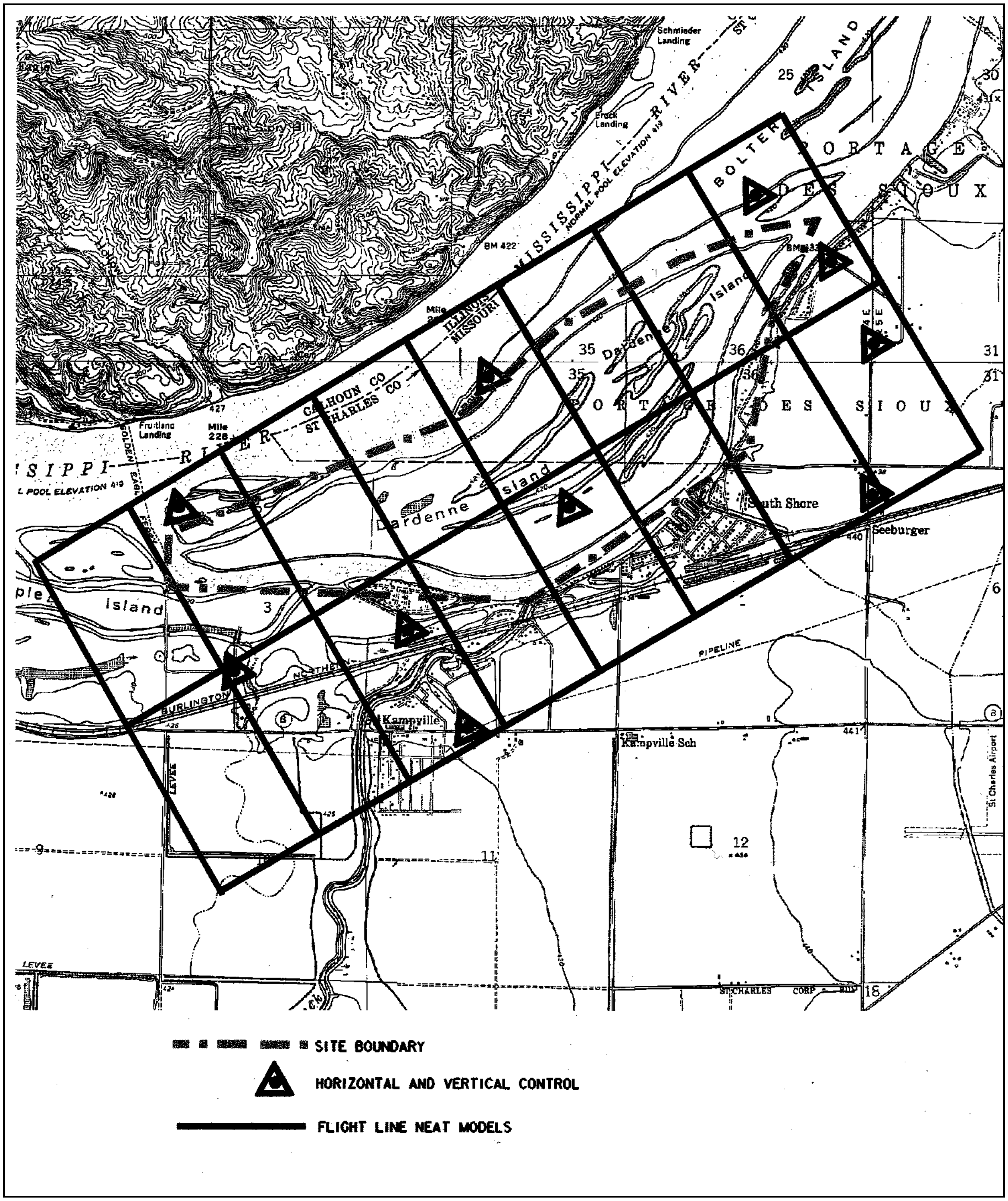



**Figure 6-1. Typical ground control plan**

control plan for aerotriangulation, showing the approximate neat models for each photograph required to cover the project boundary and the approximate locations of ground control.

(1) The absolute geometric minimum amount of photo control needed in each stereomodel is four points. In small projects requiring just a few models this control can be established on the ground by conventional field surveys. Figure 6-2 is a diagram of the ground control point distribution, assuming all of the survey points were to be located by ground survey methods.

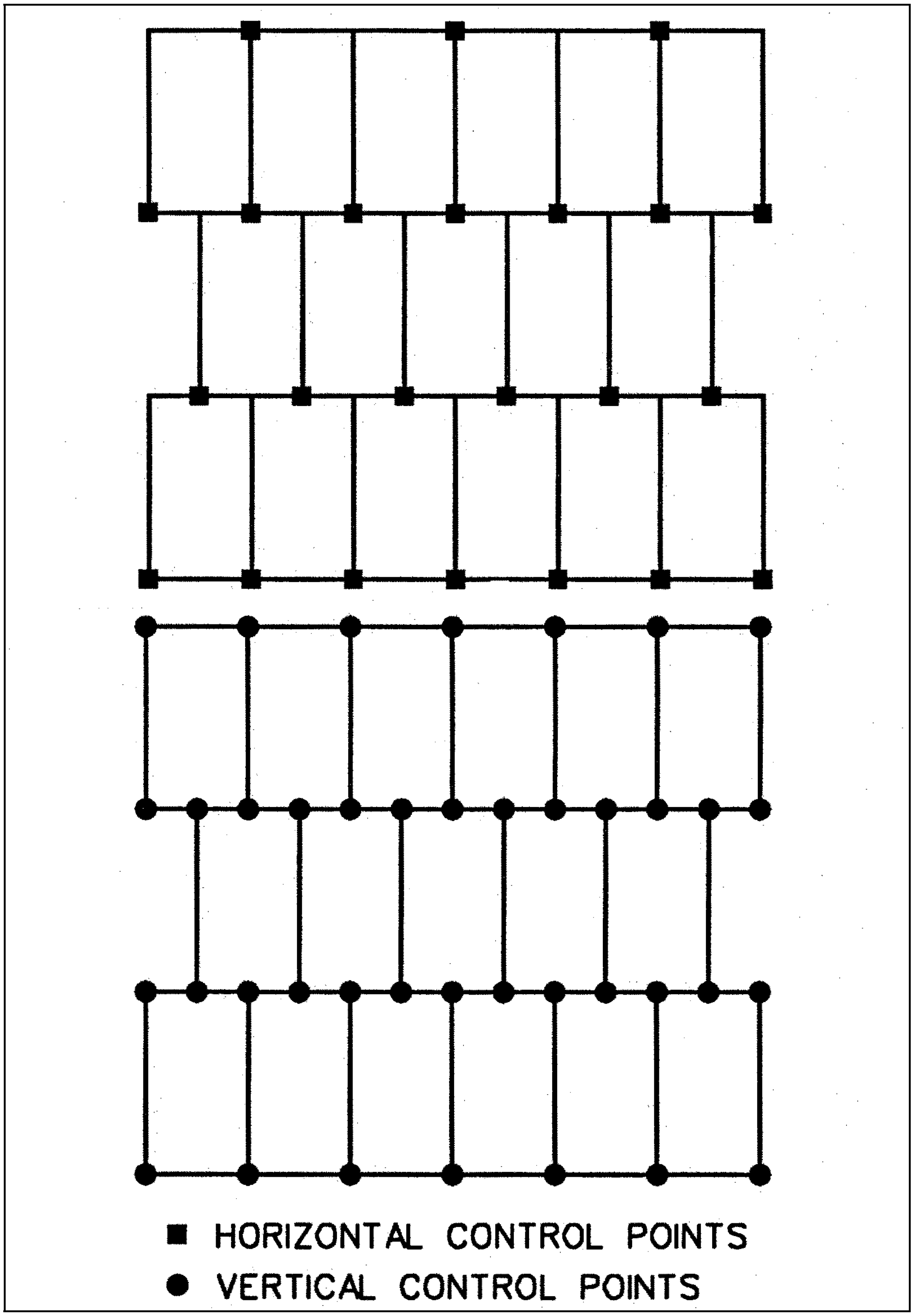



**Figure 6-2. Conventional photo control point configuration**

(2) On most projects requiring more than a few stereomodels, a skeletal pattern of strategic field control points is established. A network of six or more supplemental photo control points per photograph are generated by aerotriangulation (airtrig, AT) procedures. In this process (discussed in Chapter 8), the amount of ground control required can be significantly reduced. Generally, aerotriangulation procedures make it is necessary to provide field control points only in every third model in a flight strip. Some project sites may allow for even fewer (dependent on the map scale, final products and specific site). Figure 6-3 is a diagram of the ground control point distribution if aerotriangulation procedures supplement ground survey control.

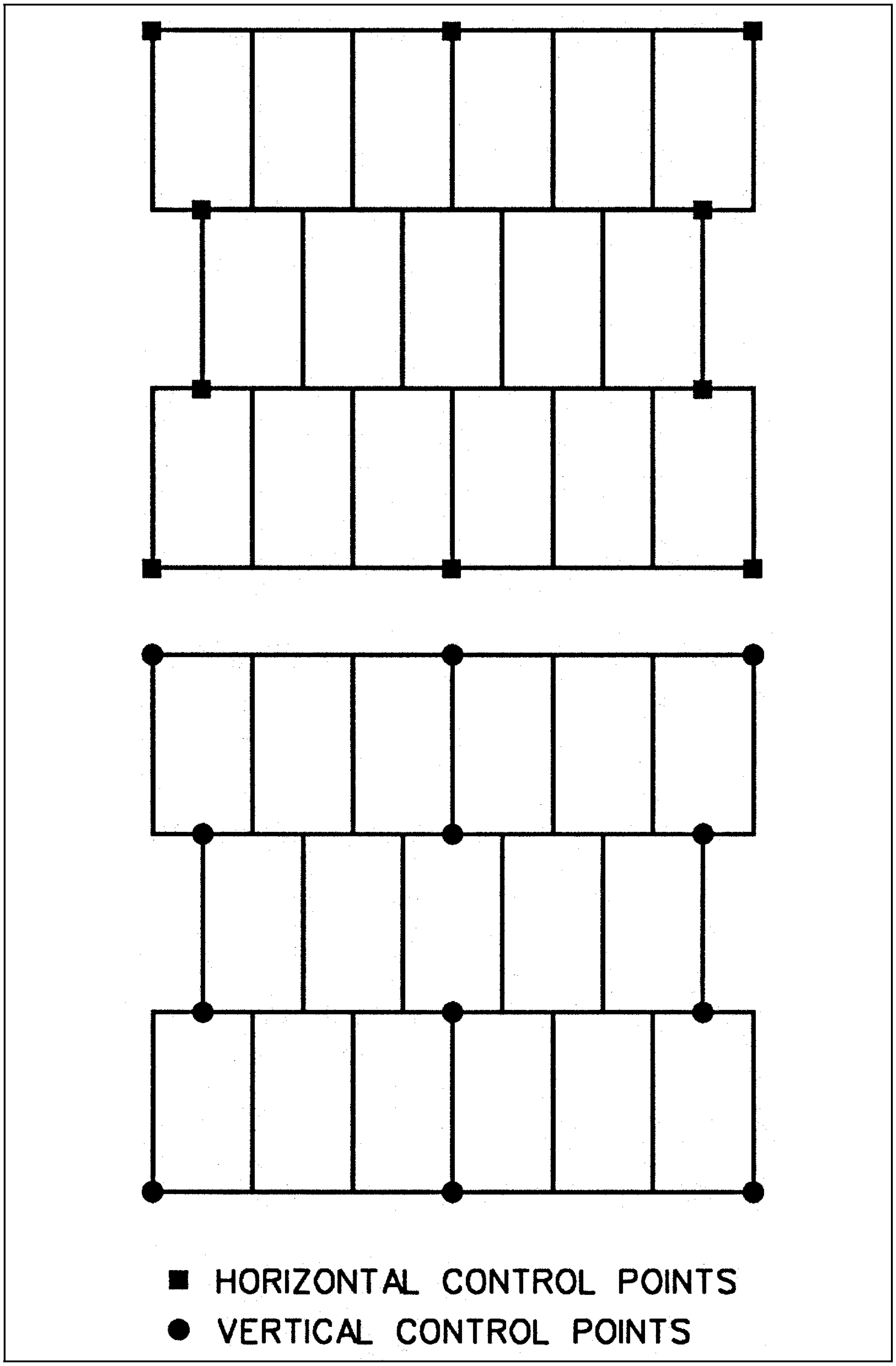



**Figure 6-3. Photo control point configuration for aerotriangulation**

(3) If airborne GPS procedures are integrated into the photographic flight the amount of primary ground control points required may be further reduced. Airborne GPS projects generally require a block of imagery that includes the mapping area. Photo control point configuration for an airborne GPS project should include horizontal and vertical points at defining corners of the block plus selected skeletal horizontal/vertical points selection throughout the block. The amount of additional skeletal primary ground control is based on

considerations such as map accuracy, terrain, geoid model in the project area, equipment, and available network control. A Contractor with proven experience should be used for airborne GPS projects. The amount and location of ground control necessary is site and equipment dependent. The primary ground control points and airborne GPS points (at photo centers) can be used in the aerotringulation solution.

(4) The information that is gathered at field control stations may be derived in either of two ways:

(a) Conventional field survey procedures utilizing traversing for horizontal coordinated and spirit leveling for vertical elevations. This is common practice for small projects numbering a few stereomodels.

(b) GPS procedures may also be employed for establishing ground control. GPS may be used in conjunction with conventional leveling and in some instances may be the sole tool used. In many projects GPS may be used for both horizontal and vertical control. The decision to use GPS for either horizontal or vertical control shall be based on accuracies required for the mapping project and the accuracies attainable from the GPS procedures employed by the survey crew. GPS technology involves the ranging signal data captured from navigational satellites by ground receivers. The time and location data captured is processed into spatial (X,Y,Z) coordinates at ground location to be established. Several accepted GPS procedures are available to include static and kinematic methods. The methods to be employed depend upon equipment available, site conditions and accuracies required. For more information regarding GPS and GPS procedures refer to EM 1110-1-1003, "Navstar Global Positioning System Surveying." At this time it is common practice to consider utilizing GPS technology for establishing ground control for map scales of 1 in. = 50 ft or smaller, as well as contour intervals of 2 ft or greater.

## 6-4. Marking Photo Control

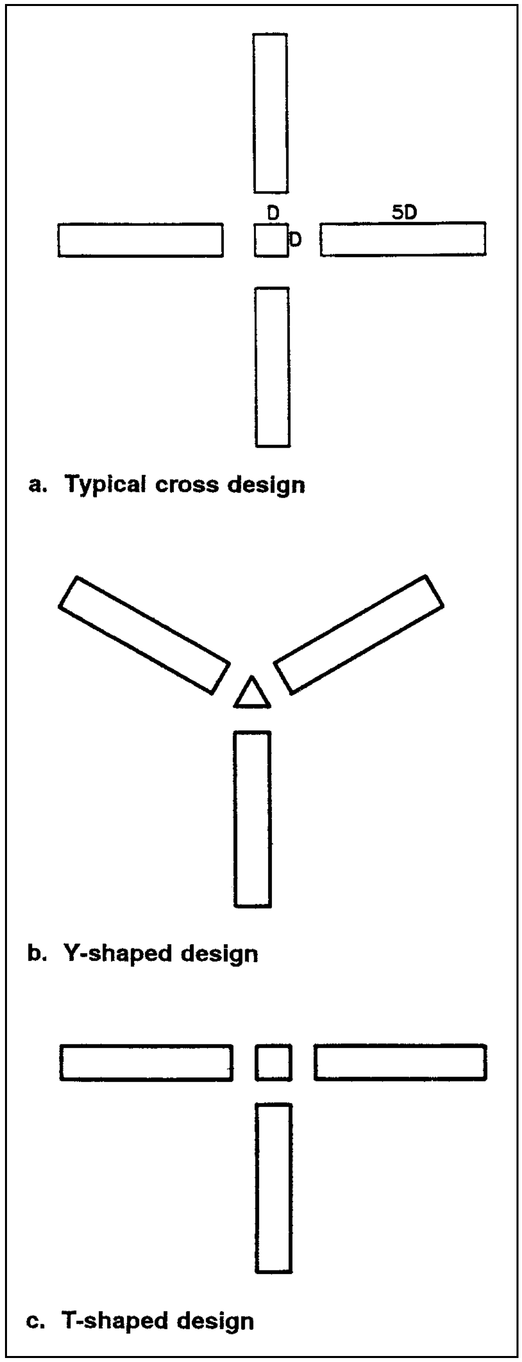
Photo identifiable control points can be established by marking points with targets before the flight or by selecting identifiable image points after the flight.

*a. Premarking.* Premarking photo control points is recommended. Marking control points with targets before the flight is the most reliable and accurate way to establish photo control points. Survey points in the basic control network can also be targeted to make them photo identifiable. When the terrain is relatively featureless, targeting will always produce a well-defined image in the proper location. However, premarking is also a significant expense in the project because target materials must be purchased, and targets must be placed in the field and maintained until flying is completed. The target itself should be designed to produce the best possible photo control image point. The main elements in target design are good color contrast, a symmetrical target that can be centered over the control point, and a target size that yields a satisfactory image on the resulting photographs.

(1) Location. Target location should be designed according to the characteristics for photo control points discussed in paragraph 6-3b. The optimum location for photo control points is in the triple overlap area; however, when control is premarked, it is difficult to ensure that the target will fall in the center of the triple overlap area when the photography is flown. Care should be taken that targets are not located too near the edge of the strip coverage so that the target does not fall outside of the neat model.

(2) Material. Targets may be made of cloth or plastic or may be painted on plywood, fiberboard, or similar sheet material or on pavement or flat rock outcrops. Flexible targets may be made by assembling pieces of the material to form the pattern or by printing the pattern on sheet material. Cloth, paint, and other material used for targets should have a nonglossy matte surface. Targets should be held in place by spikes, stakes, small sandbags, chicken wire, or any other means necessary to keep them in position and maintain flatness.

(3) Shape. Targets should be symmetrical in design to aid the operator in pointing on the control point. A typical cross design suggested by Wolf (1983) is illustrated in Figure 6-4. Similar leg and center panel designs can be developed in Y, T, and V shapes if field conditions require alternate shapes as illustrated in Figure 6-5. The center panel should be centered over the control point, since this is the image point at which measurements will be taken. The legs help in identifying the targets on the photos and also in determining the exact center of the target should the image of the center panel be unclear.




**a. Typical cross design**

**b. Y-shaped design**

**c. T-shaped design**

**Figure 6-4. Typical cross design for ground panel**

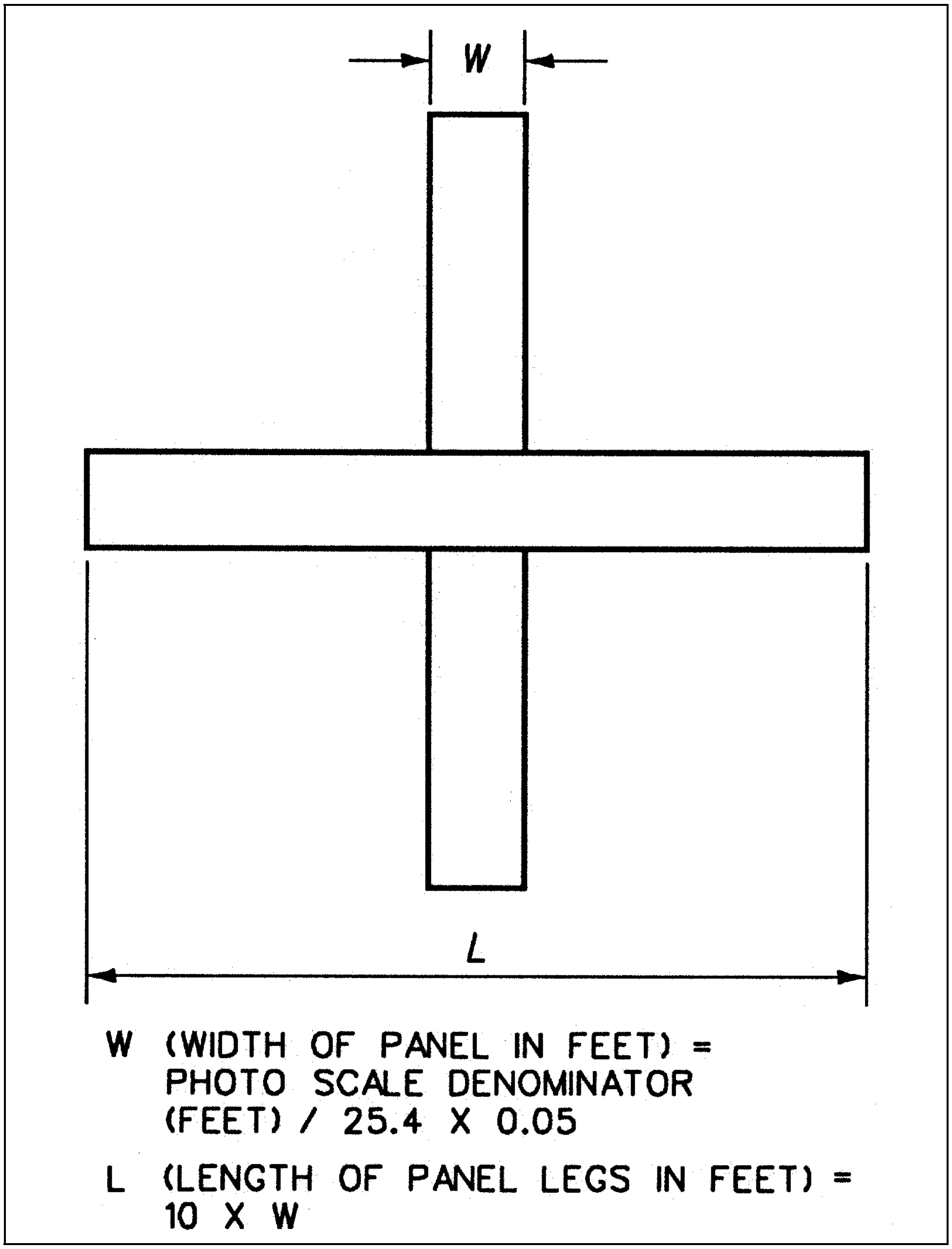



**Figure 6-5. Typical ground control panel designs**

(4) Size. Target sizes should be designed on the basis of intended photo scale so that the target images are the optimum size for pointing on the photos. Target size is related to the size of the measuring mark in the comparator and stereoplotter instruments used. An image size of about 0.050 mm square for the central panel is a typical design value. As shown in Figure 6-5, if the ground dimension of the central panel of the target is *D*, then the leg width should also be *D*, leg length should be 5*D*, and the open space between the central panel and the leg should be *D*. Target sizes are readily calculated once photo scale and optimum target image size are selected. If, for example, a central panel size of 0.050 mm is desired and photography at a scale of 1:12,000 is planned, then *D* should be 2.0 ft.

(5) Maintenance. All targets should be maintained in place and protected from or restored after damage by man, animals, or weather until photography has been taken. As soon as feasible after photography has

been taken, each target should be inspected. If the inspection reveals that the target has been moved from its proper position or otherwise disturbed in any way, this fact should be reported in the photo control survey report. Damaged or lost targets will require that the photography on which the targets should appear be replaced with a new flight if the lost targets will jeopardize meeting the accuracy requirement for the photogrammetric product. As an alternative to replacing or relocating lost targets and replacing the deficient photography, unless the photography will be used for Class 1 mapping aerotriangulation, it may be permissible to substitute natural images for the lost targets when acceptable natural images are present and suitably located to replace all lost targets.

*b. Postmarking photo identifiable control.* Postmarking photo control after the photography is flown is a method that may be used to save time during the aerial flight phase for selected projects and for Class 3 mapping. In some instances, this method can save time during the aerial flight phase of a project and reduce ground control costs by having a current image of the site from which the ground survey crew can plan the ground survey mission. The postmarking method consists of examining the photography after it is flown and choosing natural image features that most closely meet the characteristics for horizontal or vertical photo control points. The selected features are then located in the field and surveyed from the basic control monuments. One advantage of postmarking photo control points is that the control point can be chosen in the optimum location (the corners of neat models and in the triple overlap area). The principal disadvantage of postmarking is that the natural feature is not as well defined as a targeted survey monument either in the field or on the image.

*c. Airborne Global Positioning System (ABGPS) Control.* ABGPS technology may also be employed for photo control. This procedure involves establishing the horizontal and vertical location of the principal point of every photo at the instant of exposure. The principal point of each image must be transposed to its corresponding earth location. The location data are processed with a selected geoid model and ellipsoid to establish the principal point location on the earth. The data produced from the flight also include flight aberrations and positional parameters at each exposure. Ground control requirements, when utilizing ABGPS, can be significantly reduced. GPS theory indicates that, if all conditions are ideal (i.e., satellite configuration and signal, geoid model consistency), no additional ground control should be required. In practice, this is not an acceptable risk considering the cost of deploying equipment and personnel to revisit the project site if problems surface after the flight. Therefore, minimal ground control should be planned. The amount of ground control required depends upon such factors as:

(1) Size of project area.

(2) Regularity of project shape.

(3) Constancy of geoid model throughout the project area.

(4) Accuracy, integrity and location of the existing monument control used to verify the geoid model prior to the flight.

(5) Reliability of the aerotriangulation system (including hardware and software).

(6) ASPRS Map Class

(7) Photo Negative Scale

ABGPS flights are usually flown in blocks to obtain sufficient photo control for aerotriangulation procedures. In order to increase the amount of control available for aerotriangulation procedures and map accuracy some ABGPS projects may require increased forward, sidelap and/or cross flight strips at various locations.

ABGPS flight planning should involve personnel with significant expertise in ABGPS aerotriangulation procedures and subsequent photo control requirements. A regular shaped ABGPS flight block of reasonable size should require the following minimum field control:

(a) A spatial (X,Y,Z) point in each of the four corners of the project. It would be even more judicious to place point pairs at these locations to provide redundancy.

(b) Six or more points (depending upon flight block size) scattered throughout the interior of the project. These points could be withheld from the aerotriangulation procedure so that their coordinates may be compared with the coordinates assigned by the aerotriangulation results.

(c) At least one static ground GPS receiver working in conjunction with the aircraft receiver. Two ground receivers are often employed. This arrangement allows the crew to compare results and check of the solutions and to highlight any malfunction of equipment.

Irregular shaped projects may require additional control and perhaps additional flight and ground data collection (i.e., cross flights). Large area projects may require additional receivers. Additional vertical control may be required along the boundaries of the mapping project to maintain level stereomodels on the exterior flight lines. However, if the project is planned with the first and last flight line photo centers outside the mapping boundary, this additional control may not be necessary. As ABGPS technology improves it is becoming the predominate tool used to establish photo control for large and small projects alike. Increased Contractors' experience coupled with reduction in the cost of equipment are driving the cost of this technology to be as competitive as conventional traverse and leveling procedures. However, experience of the Contractor is vital in realizing a successful ABGPS controlled project. Planning ABGPS projects that encompass large areas should include breaking the large areas into smaller segments. This will facilitate ground control logistics, and allow for additional checks of geoid undulations over the entire project. Ground control for ABGPS requires timing and logistical planning between the ground and aircraft crews. Breaking projects into reasonable data collection time frames will allow the field crew to review data sets in reasonable blocks and catch any blunders before they affect large portions of the total project.

## 6-5. Survey Accuracy Standards

Ground control should be established in accordance with the current FGDC Geospatial Positioning Accuracy Standards. Basic and photo control shall be to a level of accuracy commensurate with that specified for the final map product as established in Table 2-1). Careful planning and analysis of the basic control and photo control ground surveys should be agreed upon by the Government and the Contractor. The plan should ensure that sufficient accuracy will be obtained throughout the project area to meet aerotriangulation and map compilation criteria. FGDC relative accuracy standards for horizontal and vertical control are shown in Tables 6-1 and 6-2. All basic and photo control data will include FGDC compliant META data. The FGDC META data standards will be those in force at the time of issuance of the contract.

**Table 6-1**
**FGDC Horizontal Distance Accuracy Standards**

| Survey Classification | Minimum Distance Accuracy, Ratio |
|---|---|
| First Order | 1:100,000 |
| Second Order, Class I | 1:50,000 |
| Second Order, Class II | 1:20,000 |
| Third Order, Class I | 1,10,000 |
| Third Order, Class II | 1:5,000 |

Table 6-2
**FGDC Elevation Accuracy Standards**

| Survey Classification | Maximum Elevation Difference Accuracy, mm/km |
|---|---|
| First Order,Class I | 0.5 |
| First Order, Class II | 0.7 |
| Second Order, Class I | 1.0 |
| Second Order, Class II | 1.3 |
| Third Order | 2.0 |

The distance accuracy *1*:*a* is defined in Equation 6-1.

$$a = \frac{d}{s} \tag{6-1}$$

where

$a$ = distance accuracy denominator

$d$ = distance between survey points

$s$ = propagated standard deviation of distance between survey points obtained from a weighted and minimally constrained least squares adjustment

$$b = \frac{s}{\sqrt{d}} \tag{6-2}$$

The elevation difference accuracy $b$ is a ratio defined in Equation 6-2

where

$b$ = elevation difference accuracy ratio

$s$ = propagated standard deviation of elevation difference in millimeters between survey points obtained from a weighted and minimally constrained least squares adjustment

$d$ = distance between control points in kilometers measured along the level route

## 6-6. Deliverables

Unless otherwise modified by the contract specifications, the following materials will be delivered to the Government upon completion of the control surveys:

*a*. General report describing the project and survey procedures used including description of the project area, location, and existing control found; description of the basic and photo control survey network geometry; description of the survey instruments and field methods used; description of the survey adjustment method and results such as closures and precision of adjusted positions; justification for any survey points omitted from the final adjusted network and any problems incurred and how they were resolved.

*b*. Additional information required when GPS is a part of the project should include the following:

(1) Descriptions of all initial field control plan including all points to be occupied and referenced

(2) Geodetic Datum and Geoid Model used.

(3) Brand of receivers.

(4) Processing software.

(5) Raw data files in XXXXX format.

(6) Post processes data.

*c*. One set of paper prints showing all control points. The points should be symbolized and named on the image side, and the exact point location should be pinpricked through the print. ABGPS exposure control points are considered to be at the center of each exposure. The latitude, longitude, and ellipsoid elevation shall be in the border information for each exposure.

*d.* A list of the adjusted coordinates of all horizontal and vertical basic and photo control points.

*e*. Metadata fully compliant with the current FGDC Metadata Standards.