Photogrammetry Guide

Photogrammetry Section, Design Division

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Overview

Photogrammetry mapping projects use targeted, surveyed control points, combined with aerial photography or digital imagery, to produce graphical 2D and 3D maps along with digital ortho-rectified imagery. It is TxDOT policy that a Texas Registered Professional Land Surveyor (RPLS) be directly responsible for the setting and surveying of the ground control targets and an American Society of Photogrammetry and Remote Sensing (ASPRS) Certified Photogrammetrist be directly responsible for aerial mapping.

The following sections address Control Targets, Field Surveys, Aerial Photography, Mapping, Field Checks, Reports and Photogrammetry Deliverables.

Control Targets

I. Target Design

In the past it was necessary for control targets to be large enough to be visible on hard-copy contact prints. Digital or "soft-copy" photogrammetry has made contact prints no longer necessary. There- fore, large targets are no longer necessary for most TxDOT projects. Likewise, "box" targets, used to indicate the beginning and ending of a flight strip, are also no longer necessary.

Figure 1 shows the typical target size currently used for a TxDOT project with a film scale of 1"=250' (1:3000) or with a digital Ground Sample Distance (GSD) of 5 centimeters. Target size may vary with different film scales or digital image pixel sizes.

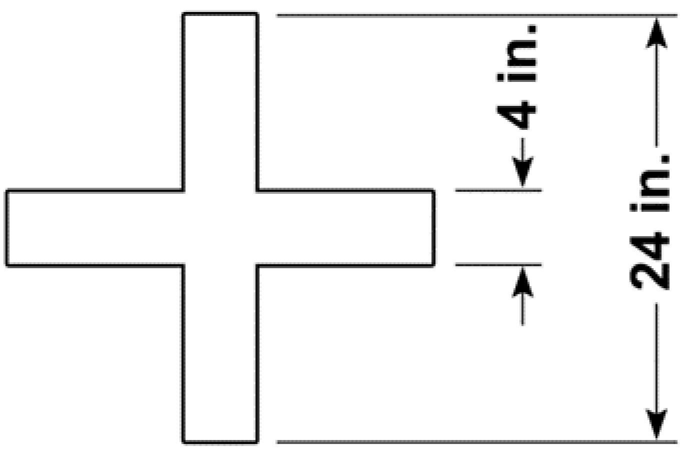

Figure 1. Typical target dimensions.

Good contrast between the target and the background surface is important. Therefore, a white target should be used on a dark background. A black target should be used on a light background. Figures 2 and 3 show the use of background surface and contrasting targets. It is the responsibility of the surveyor to make certain that the target has good contrast with the background surface.

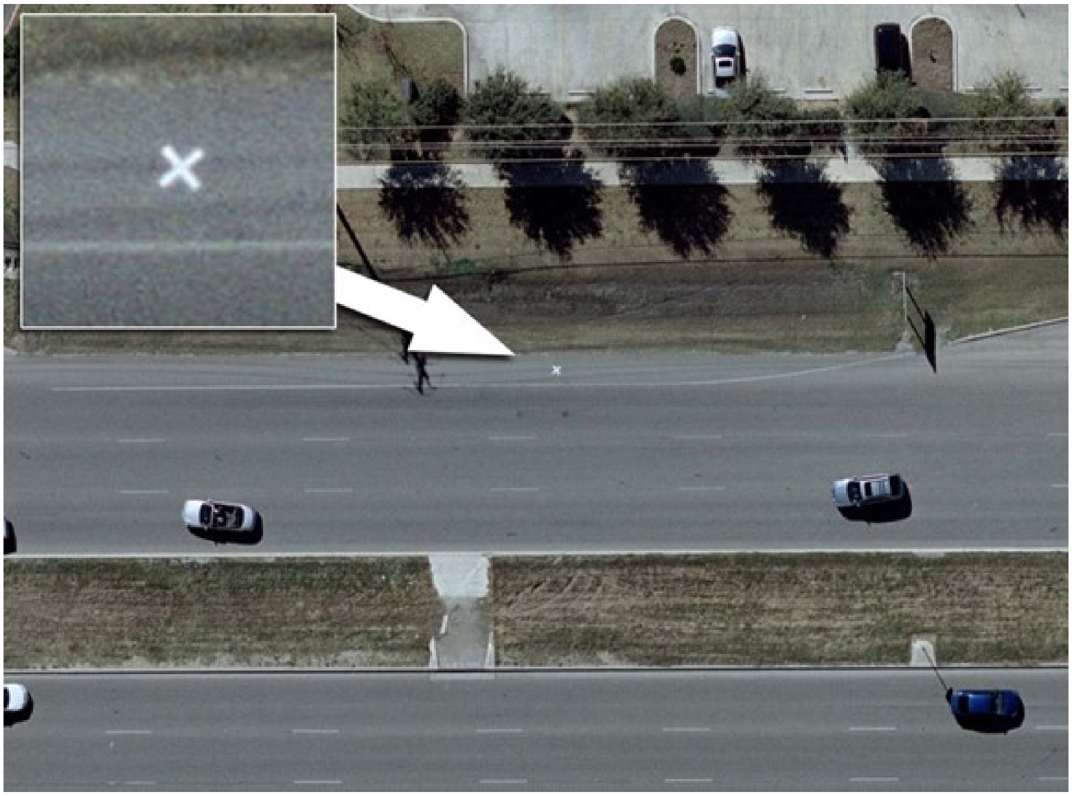

Figure 2. White target on dark background surface.

Figure 3. Black target on light background surface.

II. Target Location and Placement

The location of control targets is dependent on project conditions including:

- The ability to safely place and maintain the target
- The size and shape of the project area
- The accuracy required for the project
- Project terrain
- Accessibility to place the target

TxDOT has developed basic standard configurations to be used as a guideline.

There are two classifications of control network designs: conventional control networks, and control networks supplemented with airborne GPS (ABGPS) data. ABGPS supplemented control networks are preferred because the technique greatly reduces the number of targets required. The use of ABGPS to supplement ground control can improve field crew safety by reducing or eliminating the need to work near busy roadways. However, some projects may require a conventional target layout to serve a dual purpose. For example, targets may be used as aerial control and as control for construction staking. Guidelines for both type of network (conventional and ABGPS supplemented) are provided in the following paragraphs. Note that the layouts provided must have all three coordinates; a northing, an easting, and an elevation determined by the Surveyor.

III. Conventional Layout

Figure 4 shows the legacy conventional control layout used by TxDOT. The layout was developed to combine the needs of aerial mapping with the needs of construction staking. This design was once used frequently but is now considered obsolete.

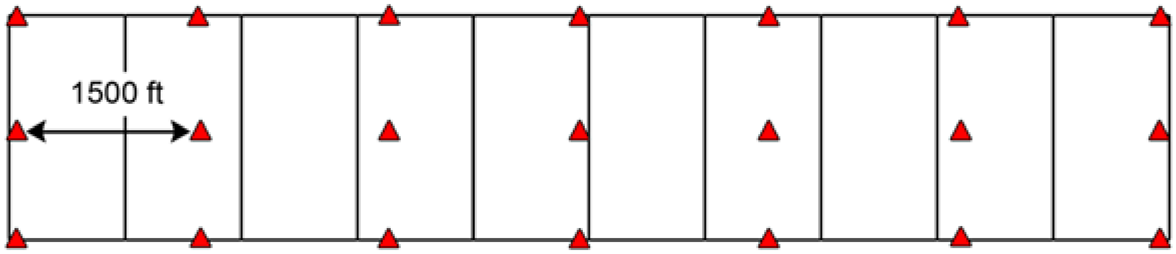

Figure 4. Legacy conventional control target layout.

On occasion, there may still be a need to combine control for construction with control for aerial mapping using a 1500 foot spacing of centerline targets. In those situations, a single wing target alternating between the left and right side of the centerline is sufficient. The use of alternating wings reduces the overall number of targets required. An illustration of the alternating wing control layout is shown in Figure 5.

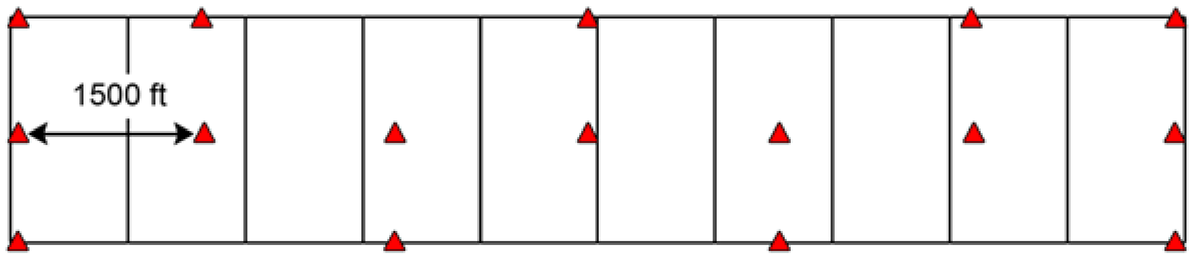

Figure 5. Conventional control layout with alternating wing targets.

When aerial mapping control is not being dual purposed, the centerline targets are not necessary– the project can be entirely controlled with wing targets. The spacing between wing targets can be increased to two base distances regardless of the photo scale (film imagery), or pixel size (digital imagery). Figure 6 shows the basic conventional control target layout for a TxDOT aerial map- ping project when the control is only being used for aerial mapping and ABGPS is not being used. The maximum distance of the target perpendicular to the flight line is the edge of the neat model. In the case of 1"=250' photo scale using film, this perpendicular distance is about 850 feet.

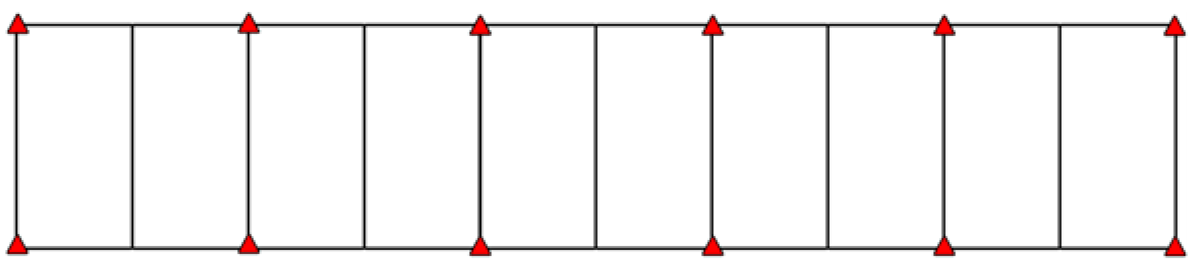

Figure 6. Basic conventional control target layout.

Most TxDOT aerial mapping projects are in a strip configuration, with strips of photography aligned along roadways. However, depending on the project, a block configuration may provide a more efficient means to collect aerial photography and to produce aerial mapping. The conventional control layout for a block configuration generally follows along the same lines as the conventional strip configurations. Figure 7 shows the typical conventional control layout for a block of aerial photography.

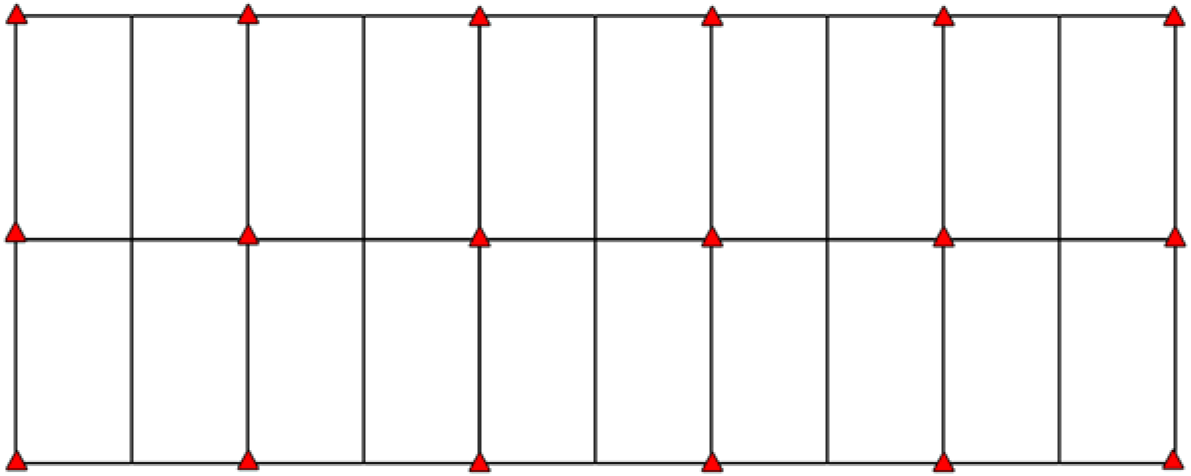

Figure 7. Conventionally controlled block layout.

IV. Airborne GPS Supplemented Layout

The basic strip configuration for control targets supplemented with ABGPS data is shown in Figure 8. The maximum spacing between pairs of control targets is 6 model bases regardless of the photo scale (film) or pixel size (digital).

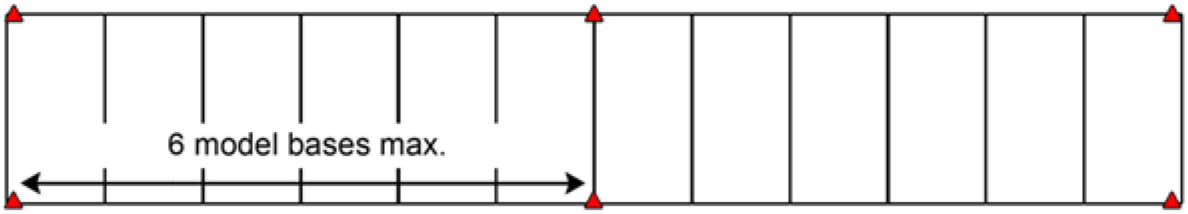

Figure 8. ABGPS supplemented ground target layout.

From Figure 8, it should be obvious that supplementing ground targets with airborne GPS significantly reduces the number of targets required. However, because there are fewer targets, the exact position of each target becomes more critical to ensure that project requirements are met.

One of the many advantages of using airborne GPS is that it can significantly reduce the number of targets that fall on private property. This is desirable because gaining right-of-entry (ROE) to pri- vate property can require considerable time and effort and can significantly increase costs for TxDOT.

When designing a control network it is often the case that a decision has to be made: set one target on private property or set two targets on public land or roadways on either side of the private prop- erty. Setting two targets increases the overall number of targets placed in the field and it shortens the distance between pairs of control points. However, in almost every case it is preferable to set the two targets on the public land to avoid the need to enter private property.

Similarly, at the beginning and ending of a photo strip, private property can often be avoided by slightly extending flight lines past the mapping area to include nearby public land or roadways. If there is any question as to using more targets to avoid private property versus obtaining ROE, the TxDOT District Survey Coordinator should be consulted. In any event, the maximum spacing of 6 model bases between pairs of control targets cannot be exceeded.

Figure 9 shows a block configuration using ground control targets supplemented with airborne GPS.

The critical elements of this configuration are:

- the perimeter of the block has a control target at a maximum spacing of 6 model bases,
- a check point is required in the interior of the block a maximum of 8 model bases with a check point between each adjacent strip, and
- the end of each strip is controlled by a pair of control points.

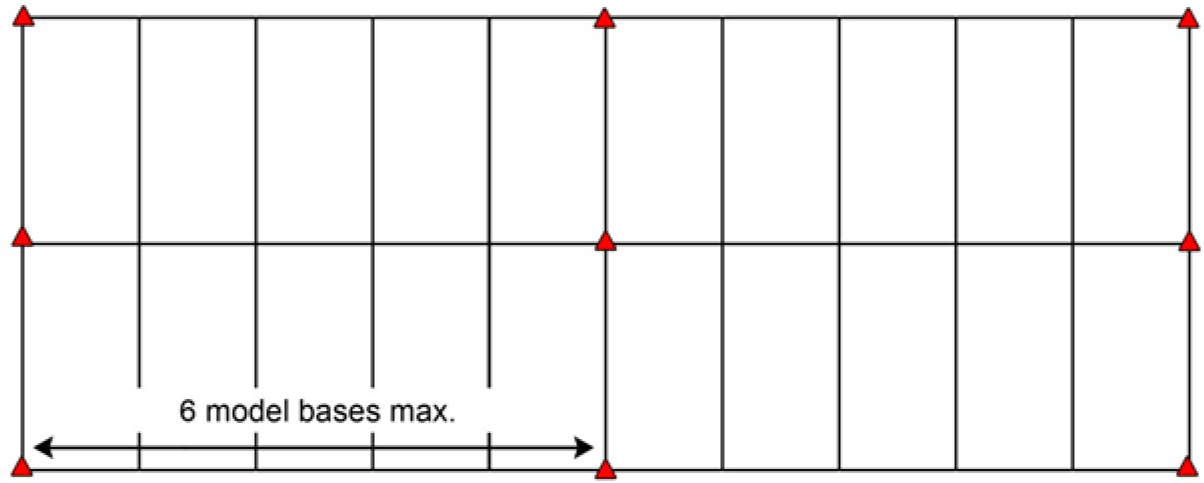

Figure 9. Block configuration using ground control targets supplemented with airborne GPS.

In Figure 9, notice that the targets located between the strips are shared. If, for some reason, the targets cannot be shared, each strip is required to have two targets at the strip ends.

As mentioned, check points are required in the interior of the block at a maximum spacing of 8 model bases. When the initial analytical solution is performed, the internal points are held out as a check points. The residual values of the check points are evaluated to detect blunders in the solution. The residual values of the check points are recorded and reported in the project Analytical Triangulation Report. For the final analytical solution, the internal points are used as additional control points.

An asymmetrical block is shown in Figure 10. Asymmetrical blocks have the same requirements as symmetrical blocks, which includes a pair of control targets at the end of each strip and an internal check point(s) as shown.

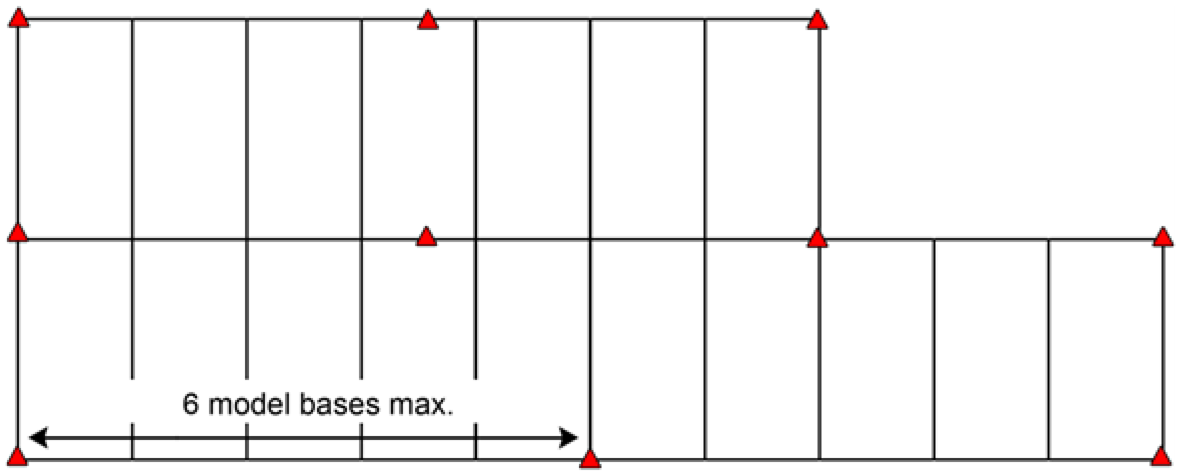

Figure 10. Asymmetrical block with airborne GPS supplemented ground control targets.

Note in Figure 10, the upper flight strip consists of seven models. This exceeds the 6 model maximum between targets along the perimeter of the block. Therefore, a target has been inserted resulting in a base distance of approximately 3.5 models between targets on the perimeter of the upper strip. Also, note the requirement for a check target interior to the block. A check point is required despite the block having fewer than 8 bases. A least one internal check point is required for every block regardless of the block size.

As an option to placing a pair of control points at the beginning and ending of each strip, it is acceptable to use crossing strips. Crossing strips are commonly used to reduce the overall number of control targets required (particularly in large blocks), or to help avoid areas in which placing a target would be difficult or hazardous. A typical block configuration with crossing strips is shown in Figure 11. The requirement for the crossing strip is a pair of control targets at the beginning and ending of the crossing strip and a spacing of no more than 6 base distances between pairs of control points along the crossing strip.

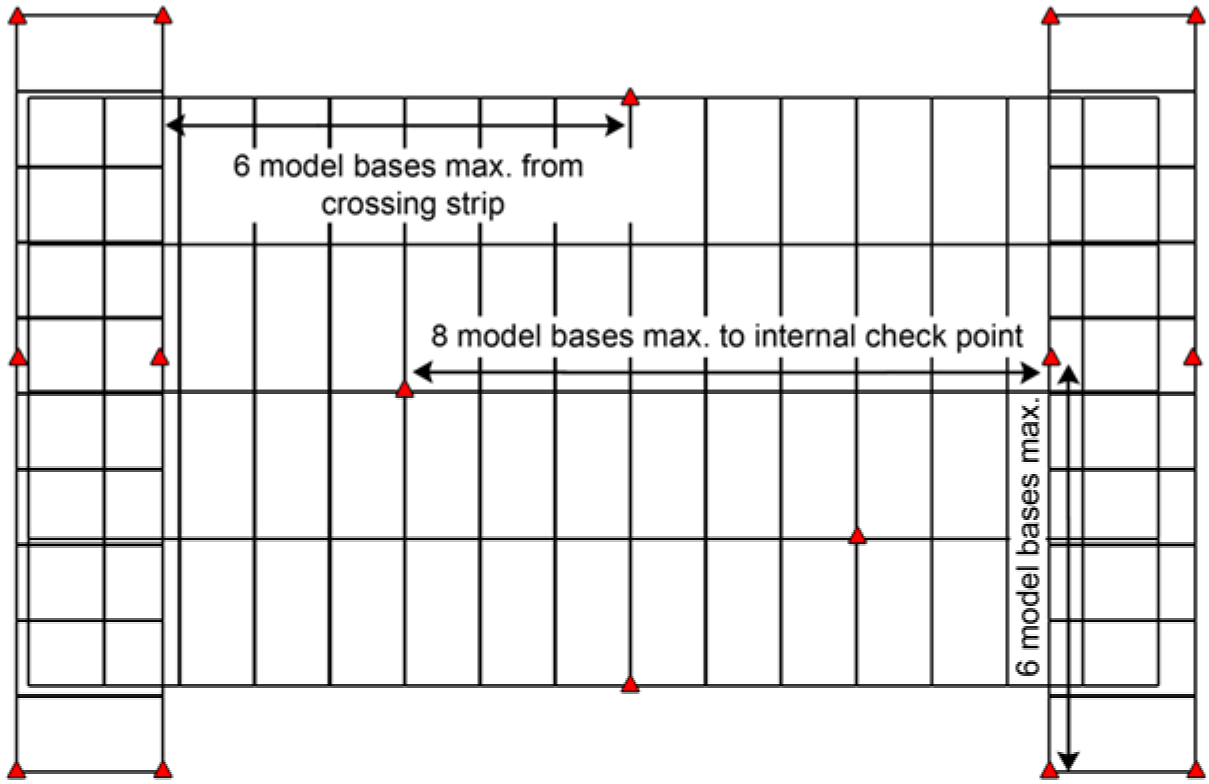

Figure 11. Block with crossing strips.

The same 6 model base limitation extends to the exterior strips of the main block from the edge of the crossing strip as shown. Again, internal check points are required at a maximum spacing of 8 model bases within the block between adjacent strips.

V. Strip ties

All photo strips require two control targets at the strip ends. In a block layout, targets can be shared between adjacent strips. For corridor-type projects, a minimum of one control target is required to fall within the overlap area between two overlapping strips to tie the strips together, provided that enough image tie points are passed between the overlapping strips to form a strong tie.

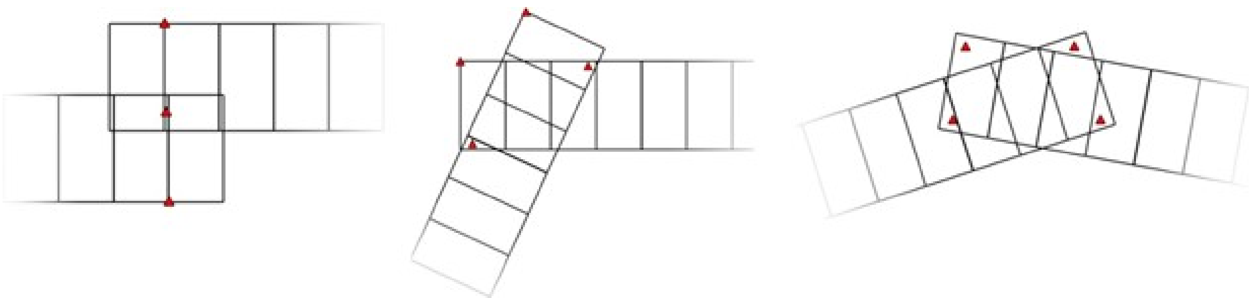

Figure 12. Typical strip ties for airborne GPS supplemented ground control.

The target layout diagrams in Figures 4 to 12 are provided as a general guideline to follow when developing control for TxDOT aerial mapping projects. However, in all circumstances it is the responsibility of the contracted consultant to ensure that the ground control layout is sufficient to meet the accuracy requirements of the project.

VI. Accuracy Requirements

All targets shall have both horizontal and vertical coordinates determined by land surveying. The accuracy requirement for aerial control points is provided in the TxDOT Survey Manual.

VII. Additional Requirements

In addition to the requirements provided in the previous paragraphs, the following requirements apply to placement of targets in the field:

- A signed right-of-entry letter with landowners must be obtained prior to entering private property.
- The target shall be clear of any obstruction that may obscure the target on the aerial imagery. When standing on the target there should be a clear view of the sky from 45° above the horizon to zenith.
- The target should be placed flush to the ground. Any vegetation that may grow beneath the tar- get should be removed prior to placing the target.
- Survey measurements are to be made at the center point of the target with the elevation measured on the surface of the target at the center point.
- Targets should not be placed in a shady or shadowed area. It is advisable to inspect potential target locations for shadows that may obscure the target.
- Placing a target beneath overhead wires should be avoided if at all possible. Overhead wires can make three dimensional photogrammetric measurements difficult.
- Targets should be placed on as level an area as possible, and
- Targets placed on private property will be picked up promptly once the aerial flight mission has been approved unless other arrangements have been made with the landowner.

Other considerations affecting the selection of target location and include:

- Selecting a safe work zone, preferably away from vehicular traffic,
- A hard surface on which a target can be painted. A painted target is generally more durable than a cloth target or a target made with other materials, and
- Other project specific situations such as placing a target on a public street to avoid a right-of- entry for private land.

VIII. Documentation and Deliverables

Documentation and deliverables for control targets consists of both textual and graphical information. Textual information shall be submitted using the Ground Control Submission Form. TxDOT contractors should request this form from the TxDOT District Survey Coordinator.

Graphical information shall include a map showing the location of the control targets as placed on the ground. The map shall include a north arrow and scale bar. Each control target shall be labeled with the target number.

Field Surveys

All field surveying activities shall be conducted in accordance with current TxDOT safety requirements relating to land surveying. All targets shall be in place prior to acquisition of aerial photography and shall be checked and maintained until the aerial photography mission is completed.

In general, the RPLS can move a target from the indicated position on the layout map. The distance the target can move depends on the layout (conventional or ABGPS supplemented), and the scale of the photography. For a typical 1:3000 photo scale (film) or 5 cm (digital) ABGPS supplemented project, the target can move from the planned position up to 450 feet parallel to the flight direction. The RPLS should avoid moving the target either further away or closer to the flight line because doing so can result in the target being outside of the photo coverage or can reduce the target's effectiveness.

Aerial Photography

I. General

Metric aerial cameras are required for engineering design level aerial photography. For project photography acquired using a film based aerial camera, a current USGS camera calibration is required. At such time that the USGS approves and accepts in situ calibration, TxDOT will issue guidance on in situ calibration procedures and requirements for reporting in situ calibration results for film based aerial cameras.

For project photography acquired using a digital aerial camera, the camera manufacturer's calibration report or a Statement of Compliance with the manufacturer's calibration and maintenance recommendations is acceptable. At such time that the USGS approves and accepts in situ calibration, TxDOT will issue guidance on in situ calibration procedures and requirements for reporting in situ calibration results for digital aerial cameras.

II. Flight requirements

The aircraft(s) used for aerial photography shall be maintained and operated in accordance with all regulations required by the U.S. Department of Transportation, Federal Aviation Administration (FAA).

The design of the aircraft shall be such that when the camera is mounted with all of its parts within the outer structure of the aircraft, an unobstructed field of view is obtained. The field of view shall be shielded from exhaust gases, oil, effluence, and air turbulence. If a glass port is interposed between the camera lens and the terrain to be photographed, the port shall be of optical quality, free from scratches and blemishes, and shall not degrade the resolution or accuracy of the camera.

Project flights may enter or be within areas of controlled or restricted airspace. All approvals necessary to assure that required clearances are achieved must be obtained prior to the flight mission.

When the flight plan and location of any project fall within positive-control airspace, the aircraft must contain the appropriate equipment to operate in such positive-control areas with the purview of the Federal Aviation Regulations. All Military Operation Areas (MOA) shall be identified in advance of the flight and all flight approvals and security clearances obtained from the U.S. Department of Defense.

Aerial photography shall not be taken unless visibility is greater than 10 miles and sustained winds at the surface are less than 20 mph. Wind gusts at the surface shall not exceed 30 mph. Photography will not be acquired when the ground is obscured by snow, haze, smoke, dust, clouds, or cloud shadows.

Flight height shall not be in excess of five (5) percent above or below the required height above mean terrain to achieve the specified film negative scale or digital image ground pixel size.

Exposure overlap along the line of flight shall average sixty (60) percent plus or minus two (2) percent. Side lap between parallel flight strips shall be average thirty (30) percent plus or minus five (5) percent unless otherwise specified.

Crab, as measured from the line of flight and as indicated by the principal points of consecutive photographs, shall not change by more than five (5) degrees between any two consecutive photo frames, and shall not average more than five (5) degrees on any one flight line, nor more than two (2) degrees for the entire project.

Tilt, defined as the departure of the optical axis of the camera from a plumb line, shall not exceed five (5) degrees on any single photograph nor more than one (1) degree for a single flight line. Relative tilt between consecutive photo frames shall not exceed six (6) percent.

III. Film Titling and Digital Image Naming

For projects using aerial film, each photo frame shall be titled. Titling shall be on the left side of the image frame, regardless of the flight direction. The title will include the aerial photo date, the project Service Request Number (SRN), or Project ID as directed by the TxDOT District Survey Coordinator, the highway or project name, the photo strip and photo frame number. An example of film titling is shown in Figure 13.

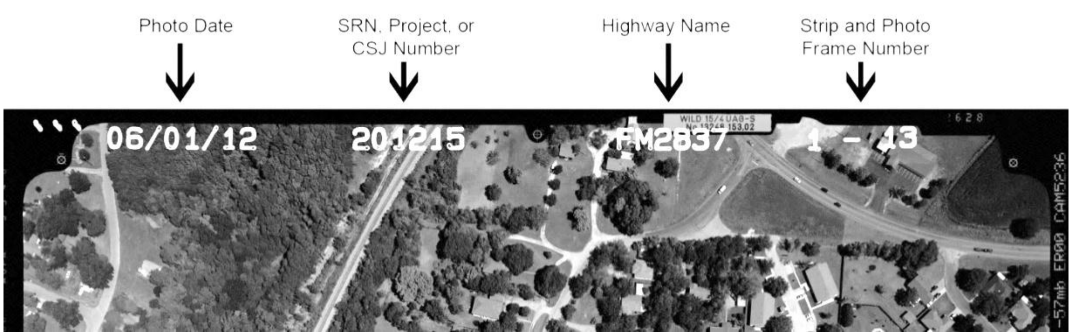

Figure 13. Example of film titling.

For imagery acquired using a digital camera, the same information as found in the film titling will be captured in the digital image file name and on the flight log that accompanies the imagery. The digital image file name will consist of the SRN, Project, or Project ID, followed by a dash character field separator, the strip number, followed by a dash character field separator, and the photo frame number. An example of a digital image file name is:

201219-2-005.tif

In this example, "201219" is the project SRN, "-" is the first field separator, "2" is the strip number, "-" is the second field separator, and "005" is the photo frame number. The photo frame number shall be padded with leading zeros to match the number of digits in the highest numbered photo frame. For example, if this project were to have a highest numbered photo frame with four digits, then the photo frame number in the example above would be "0005" to match the number of digits in the highest numbered frame.

Aerial photography metadata for both film and digital camera systems shall consist of the flight log filled out by the flight crew during the flight. At a minimal the flight log shall record the date of the aerial photography, the SRN, highway or project name, the aircraft and camera used, and the strip and photo frame numbers for each strip flown.

All imagery, whether film or digital, is the property of TxDOT. Original aerial film is a deliverable and will be archived in the TxDOT film vault located in Austin. Digital imagery is to be delivered to TxDOT on DVD or on a non-returnable solid-state hard-drive for archiving.

Mapping

I. Accuracy standard

The TxDOT map accuracy standards for maps created using aerial photography is the Class 1 of the American Society for Photogrammetry and Remote Sensing (ASPRS) Specifications and Standards Committee Standards for Large-Scale Maps (ASPRS 1990)

Map accuracy depends on all of the individual components that go into the mapping process: ground control accuracy, precision, and spatial geometry; aerial photo acquisition, quality, and processing; analytical triangulation equipment and procedures; and map compilation equipment, procedures, and accuracy. A mapping project can be designed to meet a particular accuracy specification. However, the actual accuracy of the resulting map can only be determined by an independent field check using equipment with a higher order of accuracy than those used to produce the map being checked.

The TxDOT map accuracy standard allows production of photogrammetrically derived maps to adhere to the Class 1 ASPRS standard without the necessity of a field check provided the proper equipment and procedures are used. However, periodically TxDOT may contract or perform field checks to ensure that the required accuracy has been met.

The TxDOT accuracy standard places limits on the root mean square error (RMSE) for individual position components: northing, easting, and elevation. The limiting horizontal RMSE for large scale (1:20,000 or larger) Class 1 maps is 0.01" at the specified map scale. Design level mapping has a limiting RMSE for the X and Y coordinates individually of 0.4 feet. The limiting vertical RMSE for large scale maps is 1/3 of the indicated contour interval for general elevation points and 1/6 of the indicated contour interval for spot elevations on well-defined features. A one foot contour interval is the typical for TxDOT design level mapping unless otherwise specified. A map compiled for a one foot contour interval has a limiting RMSE of 0.33 feet for general terrain and 0.17 feet for well-defined terrain features.

II. Analytical triangulation

A preliminary simultaneous bundle adjustment should be carried out using a minimal amount of control points along the block perimeter. All additional control points should be treated as check points. The results from this minimally controlled adjustment should meet the following criteria:

- The Standard Error of Unit Weight (σ_0) should be less than 1.0. This applies to the individual XYZ residual RSME values on a strip-by-strip and block-wise basis. The σ_0 value is calculated by dividing the RMSE value by the á priori standard deviation. A σ_0 > 1.0 may indicate an overly optimistic estimate of á priori standard deviations and potentially can hide problem points,
- The residual for any image coordinate should not exceed 15 micrometers,
- The RMS for ground control residuals should not exceed 1/15,000 of the flying height above the average terrain elevation for XY and 1/10,000 of the flying height above the average terrain elevation for Z,
- The maximum residual in any ground control coordinate should not exceed 2.5 times the RMS value for the ground control residuals stated above,
- The RMS of the discrepancy (the difference between the computed coordinate value and the surveyed coordinate value) in check point coordinates should not exceed 1/15,000 of the flying height above the average terrain elevation for XY and 1/10,000 of the flying height above the average terrain elevation for the Z, and
- The discrepancy of an individual check point coordinates should not exceed 2.5 times the RMS for the check point discrepancies stated above.

If the above criteria are met, the preliminary adjustment solution indicates that there are no blunders or gross errors in the photo measurements or ground control measurements. If the last item in the above criteria fails testing, the input data should be checked for blunders.

The final adjustment should be a simultaneous bundle adjustment of the entire project data. All ground control points should be included in the adjustment with no points held out as check points. The final adjustment results should meet the following criteria:

- The Standard Error of Unit Weight (σ_0) should be less than 1.0. This applies to the individual XYZ residual RSME values on a strip-by-strip and block-wise basis. The σ_0 value is calculated by dividing the RMSE value by the á priori standard deviation. A σ_0 > 1.0 may indicate an overly optimistic estimate of á priori standard deviations and potentially can hide problem points,

- The residual for any image coordinate should not exceed 15 micrometers,
- The RMS for ground control residuals should not exceed 1/15,000 of the flying height above the average terrain elevation for XY and 1/10,000 of the flying height above the average terrain elevation for Z, and
- The maximum residual in any ground control coordinate should not exceed 2.5 times the RMS value for the ground control residuals stated above.

III. Map Compilation

The equipment used in the aerial mapping process is required to be capable of producing maps meeting the ASPRS Class 1 Accuracy Standard. See TxDOT Photogrammetry Feature Collection Standards.

Field Checks

Testing for map accuracy compliance may be performed for any map produced for TxDOT. TxDOT may contract testing to a vendor (typically independent from the aerial mapping vendor) or may conduct testing using state resources. For any testing effort, a written summary of the results of the testing is required.

The written summary will include the project SRN, highway, county, and the date(s) that the field check was performed. A brief summary of the field procedures and equipment used shall be included in the summary.

A table summarizing the results of the field check shall be provided to TxDOT and will include:

- The point number and a description of each check point.
- The XYZ coordinates for each point derived from the photogrammetric map data.
- The XYZ coordinates for each check point determined by field surveying.
- The difference between each of the coordinates and the RMSE value determined from the differences.

A minimum of 20 check points, evenly distributed throughout the project areas, are required for any field check task. This does not include any points withheld from the final quality statistics. For example, points withheld because of field blunders.

Points may be rejected from the statistical analysis resulting from the field check, but the reason for rejecting any check point must be documented. The fact that a point is a statistical outlier is not grounds to automatically reject any check point.

Reports

I. Analytical Triangulation Report

An analytical triangulation report is required for all aerial mapping projects performed for TxDOT. The report is intended to serve as a record of the project from the time of flight planning up until map compilation. At a minimum, the report should include a brief description of the project including the number of flight lines, the number of photo frames, date of analytical triangulation, and key statistics necessary to assess the accuracy and quality of the analytical triangulation processing and adjustment. Additional narrative that would be helpful to more fully explain how the project was processed or how the project progressed should be included in the report.

The analytical triangulation report should be brief and should require only one to two pages. Do not submit voluminous photo-by-photo statistics for the project. Photo-by-photo statistics should be either stored with the project or should be re-creatable if needed later, as would be the case if a problem with the data was to be found.

Key statistics to include in the analytical triangulation report are:

- The sigma value in microns for the block solution.
- The RMS value for the project control for the block solution as individual X, Y, and Z values.
- The maximum ground control residual for the block solution.
- If airborne GPS is being used, the RMS of the photo positions.

II. Airborne GPS Processing Report

The Airborne GPS Processing Report should be a brief summary of the processing of the ABGPS data. At a minimal, the report should identify if the solution is a single baseline solution, a network solution, or a Precise Point Positioning (PPP) solution.

If the solution is PPP, the specific technique used should be identified along with the latency of the precise ephemeris and clock data used.

If a base station(s) is/are used to post-process the GPS data collected by the aircraft, the report should include the distance of the base station(s) to the project site, the base station(s) data collection rate, the use (or non-use) of precise ephemeris and clock data, the processing datum, and geoid used to determine elevations.

The Airborne GPS Processing Report should include information necessary to evaluate the quality of the processing. Typically this will include graphs showing the number of satellites tracked, the PDOP, and, in the case of base station solutions, the forward and reverse processing separation.

If the post-processed data is submitted to TxDOT, it should be noted if the data has aircraft antenna eccentricities removed or a surface adjustment factor applied to the coordinate values. If the antenna eccentricities have not been removed from the data, an antenna eccentricity diagram should be included with the data. If a surface adjustment factor has been applied, the value of the surface factor applied should be noted.

Photogrammetry Deliverables

- If using a film-based aerial camera: film negatives delivered on the film roll. The film is to be delivered to the Design Division, Photogrammetry Section
- If using digital aerial camera: digital image frames delivered on DVD, on a non-returnable solid-state hard drive, or on a non-returnable solid-state flash drive. Delivery on DVD media is limited to projects with less than 40 GB of data. The storage media with images is to be delivered to the Design Division, Photogrammetry Section.
- Aerial flight data including a flight map showing the location of flight lines, exposure stations, and control target positions.
- An analytical triangulation report.
- An ABGPS processing report if ABGPS is used.
- Control point documentation (reference Control Targets, VIII. Documentation and Deliverables in this section).
- A MicroStation® two-dimensional (2D) design file containing planimetric features.
- A MicroStation® three-dimensional (3D) design file containing DTM data.
- A GEOPAK® TIN file created using the DTM data.
- Digital (Ortho-Rectified) Orthophotography.
- Any additional deliverable specified by the TxDOT District Survey Coordinator including, but not limited to, hard-copy aerial frame prints, control point diagrams, and field check documentation.