User's Guide to Photogrammetric Products and Services

State of California • Department of Transportation
Engineering Service Center • Office of Engineering Technology
Geometronics Branch • Photogrammetry Section

User's Guide to Photogrammetric Products and Services

May 1996

Design, Layout and Digital File Preparation by the:

Office of Program/Project Management and Support
Management Services and Technical Development Branch
Technical Publications Unit

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User's Guide to Photogrammetric Products and Services

Purpose

This User's Guide will provide an easy-to-understand compilation of the processes, characteristics, and time requirements for photogrammetric products and services for Project Engineers and other Caltrans users.

Process Overview

Caltrans Photogrammetry, including the Engineering Service Center (ESC), Photogrammetry Section and District Photogrammetry personnel, provides a wide range of photogrammetric services to units within Caltrans. The primary focus of Caltrans Photogrammetry is to provide engineers with mapping services for project development, but many other (internal and external) organizations take advantage of the reproduction products and services using Caltrans' extensive film library.

Key Photogrammetric Units

- **District Surveys**
- **District Photogrammetry Coordinator**
- **ESC Photogrammetry Section**
- **Private Photogrammetry Contractors**

Basic Responsibilities

- **District Surveys**
  Performs field control surveys
  Performs field terrain line interpolation surveys
- **District Photogrammetry Coordinator**
  Provides liaison with engineers
  Performs photogrammetric project planning (with ESC assistance)
  Orders and checks photography
  Assists ESC in map checking (CADD, visual)
  Performs map digitizing checking (CADD, visual)
  Assists ESC in contract administration

- **ESC Photogrammetry Section**

  Provides photogrammetry expertise/assistance and Project Management

  Executes/administers all photogrammetry contracts (with District assistance)

  Densifies control through aerotriangulation

  Performs map checking for accuracy (visual checking at District request)

  Performs all photogrammetric DTM data capture

  Performs all photogrammetric cross-sectioning

  Compiles in-house mapping (about 15%, generally reserved for complex, difficult-to-contract projects)

  Performs CADD digitizing (limited)

  Performs CADD DTM preparation (limited)

- **Private Photogrammetry Contractors**

  Perform all aerial photography

  Perform most laboratory/reproduction work (with HQ Reprographics)

  Perform about 85% of map compilation

  Perform CADD digitizing and data conversions

The District Photogrammetry Coordinator

The key person in obtaining all types of photogrammetric products and services is the District Photogrammetry Coordinator. Coordinators have the expertise and available information to assist users in correctly ordering photogrammetric products. The Photogrammetry Coordinator is the first person to contact for advice on how to acquire photogrammetric products.

Contract Information

Types of Photogrammetry Contracts

- **Aerial Photography**

  Precision (for use with photogrammetric plotters)

  North

  South

  District-1 Area

  District-11 Area

  General

  North

  South

  Highway Inventory

  North

  South

- **Reproduction**

  General

  Rush

- **Vendor-Owned Aerial Photography**

  South (San Diego Area)

- **Blanket, 3-D, Digital Map Compilation**
- **Blanket Map Digitizing**
- **Blanket Map Metric and Datum Conversions**
- **Blanket Map 2-D to 3-D Conversions**

Contract Restrictions and Constraints

All State contracts are controlled by various restrictions and constraints imposed by legislation. These rules are complex and are intended to make the State contracting process as fair as possible to all qualified contractors. The rules include advantageous provisions for minority-owned, women-owned, disabled veteran-owned businesses and also small businesses. The procedures differ for State and Federal funding sources. The contract preparation, award, and approval processes are complicated and time consuming because of these rules.

APPROXIMATE TIME REQUIRED..... (Contract processing and approval) 55 working days

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Use of Consultant Services for Mapping (Contracting Out)

When consultants are used to perform work that requires mapping as part of the larger overall effort, it can be advantageous to include the mapping within the consultant contract to avoid coordination and scheduling issues. If mapping is included in consultant contracts, the contract should include the photogrammetry specifications included in the "A&E Consultant Services Manual", in Appendix 3.4.4a-2.1, pages 1 through 10. Upon request, the ESC Photogrammetry Section will provide the required information for editing the aerial photography, plus furnishing the symbol sheet and CADD information. The Section can also provide the necessary aerotriangulation review and map checking. Efforts that are limited to mapping (i.e., no other work) generally should be accomplished through the Caltrans photogrammetric mapping process and the contracts established for this process.

When consultants are providing mapping, make sure they have access to all the information necessary to meet Caltrans standards. Failure to make the consultants aware of the standards will result in increased project costs and delays.

Project Management

Project Management was initiated in ESC Photogrammetry in 1991 using Primavera software to improve scheduling and delivery time for photogrammetric products (see **Time Requirements, Project Management Guidelines**, page 36). Beginning in 1993, the project management procedures were revised to improve photogrammetry scheduling and product delivery. Since the photogrammetry process is a joint District-ESC Photogrammetry operation, a cooperative effort is necessary to make Project Management an effective system for photogrammetry.

TIP

Use Project Management to your advantage. Reports are available from Photogrammetry to track your project to ensure it is on schedule. Working Project Management "backwards", you can determine the latest dates which various phases in the mapping process have to be completed to meet your PS&E date.

Aerial Photography

Caltrans aerial photography is obtained under several contracts covering the state (see **Types of Photogrammetry Contracts**, page 4), plus vendor-owned aerial photography (library photography taken by various aerial photography firms for clients other than Caltrans, or for speculation). Caltrans aerial photography is divided into two major categories, *precision* and *general*. Precision photography, 152 mm focal length, (230 mm × 230 mm format) is used for mapping and other applications requiring measurements on photogrammetric plotters. General aerial photography is used for highway inventory and other non-metric uses where precise measurements are not required. Precision photography can also be used for general purposes (enlargements, etc.). Black and white, color, and black and white and color infrared film may be specified. Focal lengths of 152 mm, 210 mm, and 305 mm, all 230 mm × 230 mm format, are available. Additionally, 610 mm focal length, 230 mm × 460 mm format cameras are available. Photography may be flown at altitudes ranging from 1,000 to 20,000 feet*. Photo scales from approximately 1:600 to 1:36 000 are available. Enlargements of new and existing photography up to 10 times and larger, in some cases, are available. Enlargements (or reductions) can be printed on several types of material depending on the proposed use of the photography. See your District Photogrammetry Coordinator for the selection of materials, their uses, and cost. Aerial photography is one of the least expensive components in the photogrammetric mapping process and can be obtained in a short time.

APPROXIMATE COST ..... $200 (1 km of 1:3000, 230 mm × 230 mm)

APPROXIMATE TIME REQUIRED..... 10 working days (weather dependent)

TIP

Aerial photography is a bargain. Have your project flown early to record the "before" conditions. You will find a variety of uses for this photography. It's cheap "insurance".

* Flight altitudes are expressed in feet, internationally.

Figure 1. 1:3000 Aerial Photograph (Reduced to 85%)

California Index of Aerial Photography

ESC Photogrammetry has a large library of film dating back to the 1950's (and older), which was photographed for Caltrans and other cooperating agencies. This photography is indexed annually on District maps and is available for your District from the Photogrammetry Coordinator. A statewide index is available in the ESC Photogrammetry Section. Prints and enlargements can be made from this photography through Photogrammetry reproduction contracts. Vendor-owned photography and photography from other sources are also available.

Highway Inventory Photography

Highway Inventory Photography is 1:2400, 230 mm × 460 mm format, non-stereo, non-metric, aerial photography of the State Highway System. The entire 26 000 km system is photographed every five years. Approximately one-fifth of the highway system is photographed each year with emphasis on newly completed projects. Special flights of 230 mm × 460 mm format photography may be requested at anytime. This photography is for pictorial coverage only, maps cannot be compiled using this photography. Highway Inventory Photography is widely used for a variety of tasks including traffic and accident studies, highway improvement planning, public meeting displays, survey and mapping control planning, and mapping ground cover information. This photography can be enlarged up to 10 times with usable photographic resolution.

APPROXIMATE COST ..... $125-$500 (5 km of 1:2400, 230 mm × 460 mm)

APPROXIMATE TIME REQUIRED..... 10-20 days (weather dependent)

TIP

The Cal-Index and the Inventory photography contain a wealth of information of conditions as existing at the time of photography. This information is available for your use to help plan and design your project. You can use existing photography or have your project "custom flown" to meet your special requirements.

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Figure 2. 1:2400 Highway Inventory Aerial Photograph (Reduced to 85%)

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Photography for Planning Purposes (Overflights)

Small scale photography, 1:9600 and smaller, is useful to aid survey parties in planning and locating photo control premark positions. This is especially true in areas where the existing maps are out-of-date or in rural and mountainous areas where it is difficult to locate specific positions on USGS quad maps. Aerial photography is relatively inexpensive compared to the time surveyors may spend to locate points on inadequate maps.

APPROXIMATE COST ..... $220-$300 (5 km of 1:12 000, 230 mm × 230 mm)

APPROXIMATE TIME REQUIRED..... 10 days (weather dependent)

TIP

This is a big time saver for photo control surveyors on projects where it's tough to locate your ground position. No more guessing where to place your premarks. Get it flown early.

Color and Infrared Photography

Practically all the photography used for Caltrans mapping is black and white. Black and white photography is better than color and color infrared (IR) for metric (mapping) photogrammetry. Color photography is superior for photo interpretation in some applications, e.g., environmental purposes, accident investigation, public displays, and geological purposes. Infrared photography, both color and black and white, is best suited for land use studies and locating water features or diseased vegetation. All of these types of photography are available under existing contracts, if needed.

APPROXIMATE COST ..... $200 (1 km of 1:3000, 230 mm × 230 mm)

APPROXIMATE TIME REQUIRED..... 10 working days (weather dependent)

TIP

Geologists and environmentalists like color and color IR, but it's also excellent for public displays and information. If you need it, order it.

Figure 3. 1:12 000 Aerial Photograph (Reduced to 85%)

Special Aerial Photography (Accident Studies, Flood and Earthquake Damage)

Special photography is available if there is a natural or man-made disaster. For example, one day after the 1989 Lomo Prieta earthquake, the U.S. Air Force photographed the entire area affected by the earthquake. A panoramic camera mounted in a U-2 aircraft flying at an altitude of 65,000 feet was used for the photography. If there is a necessity for special aerial photography in a situation like this, your District Photogrammetry Coordinator can assist you.

TIP

The ESC Photogrammetry Section tries to get aerial photography immediately after significant disasters, but you may have ideas for photography we haven't considered. Talk to your Photogrammetry Coordinator.

Mosaics

Mosaics are made from multiple individual aerial photographs that are fitted together systematically to give the appearance of one photograph. Mosaics are useful where it is required to have photographic detail available over a large area. A skilled mosaic maker can cut and match the photographs in such a manner that the joins are difficult to detect by the untrained eye. However, it is virtually impossible to assemble a mosaic where all the joined images match perfectly due to a variety of geometric and photographic conditions that cannot be controlled.

APPROXIMATE COST	$800 - $2200, 455 mm × 760 mm area, 230 mm × 230 mm, 1:24 000 photos, 2× enlargement, 910 mm × 1520 mm, 1:12 000 cronapaque final, includes aerial photography
APPROXIMATE TIME REQUIRED.....	20 working days (weather dependent)

TIP

Mosaics aren't perfect, but they are great for showing you and the public the "big picture" of your plans.

Aerotriangulation

Aerotriangulation is the process of expanding a skeletal network of project field control to provide the dense control network required to reference each individual photogrammetric stereo model to the project datum. Diapositives (positive prints on film or glass plates) are pugged (small holes drilled into the photographic emulsion) to provide a visually identifiable point that can be measured in the stereo model. Each premark and pug point is precisely measured using the stereoplotter coordinate system. The measured points are transformed to a coordinate system based on the camera fiducial (index) points with the center of the photograph as the XY coordinate origin. The point positions are also corrected for lens and film distortion, earth curvature, and atmospheric refraction.

Initial approximations of the XY ground coordinates and the flying heights of the first and last photo in each flight line are provided as input into the aerotriangulation program. The program uses these values to calculate the XYZ coordinates and the direction of flight for each photo in the flight line. The rotations about the X and Y axes are assumed to be zero. Then, based on the fact that the center of the lens, a photo point, and a corresponding ground point lie on a straight line and using the measured pugs and premarks, the photos are moved and rotated in space until all the lines are straight. This, of course, is all done by computer using an iterative process until preset accuracy requirements are achieved. The results of these calculations are the space coordinates and the rotations about XYZ axes of all the photos and the XYZ ground coordinates of all premarks and pug points. These values provide the information necessary to control the individual models and compile the maps, measure photogrammetric data such as digital terrain model points, and read cross-sections.

APPROXIMATE COST ..... $930 (1 km of 1:3000, 230 mm × 230 mm)

APPROXIMATE TIME REQUIRED ..... 10 working days

TIP

Aerotriangulation is primarily used for photo control densification, but can be used for determining accurate coordinates of any premarked point. The Photogrammetry Section is currently working on improving photogrammetric pavement elevation accuracy. Accuracy is enhanced by automatically painting small premarks on the pavement at approximately 15 m intervals. If we are successful, this will reduce the time surveyors will have to be on the roadway, thus making their jobs safer. Automatic painting of regular premarks is also available.

Mapping

Topographic mapping from aerial photography is the most requested photogrammetric product (except photographic reproductions). The most common mapping scales are 1:500 and 1:200 with 0.5 m and 0.25 m contour intervals, respectively. The same photography can be used to produce direct digital mapping, digital terrain models, terrain line interpolation, and photogrammetric cross-sections. The maps and other products are made using computer-driven (analytical) plotters. The photography to produce the above products is flown between 1,000 and 2,400 feet above the ground for 1:500 mapping and 1,000 to 1,500 feet above the ground for 1:200 mapping.

The nominal *planning* mapping width for a single flight line, with a 152 mm focal length camera, is the same as the flying height above the ground or between 305 m (1,000 feet) and 730 m (2,400 feet) for the above examples. The planning mapping widths allow for a lateral flying tolerance of 13 mm at photo scale on either side of the flight line. After the photography is taken, generally, it can be used to map within 25 mm of the edge of the photographs (the central 180 mm). This provides mapping widths of 355 m and 850 m, respectively, for flying altitudes of 1,000 and 2,400 feet.

Approximately 85 percent of Caltrans map compilation is done under contract by California photogrammetric mapping firms. The Photogrammetry Section currently has a number of contractors available under direct digital map compilation contracts. The mapping contracts are awarded to a number of contractors on an annual basis. The lowest bidder of the contractors is assigned all the mapping they can compile within the required time limits. If the lowest bidder cannot meet the delivery schedule, the compilation is offered to the next lowest bidder until one of the contractors can meet the delivery schedule. Regular and rush orders are available at 1.5 and 0.9 days per model, respectively (a model is 275 m along the line of flight using photography flown at 1,500 feet above the ground). Rush orders are extra cost. The work is paid for on a per square meter of mapping (at map scale) basis. The more lines drawn by the contractor per square meter, the higher the payment. Currently, all of Caltrans contract mapping is compiled using direct digital map compilation contracts.

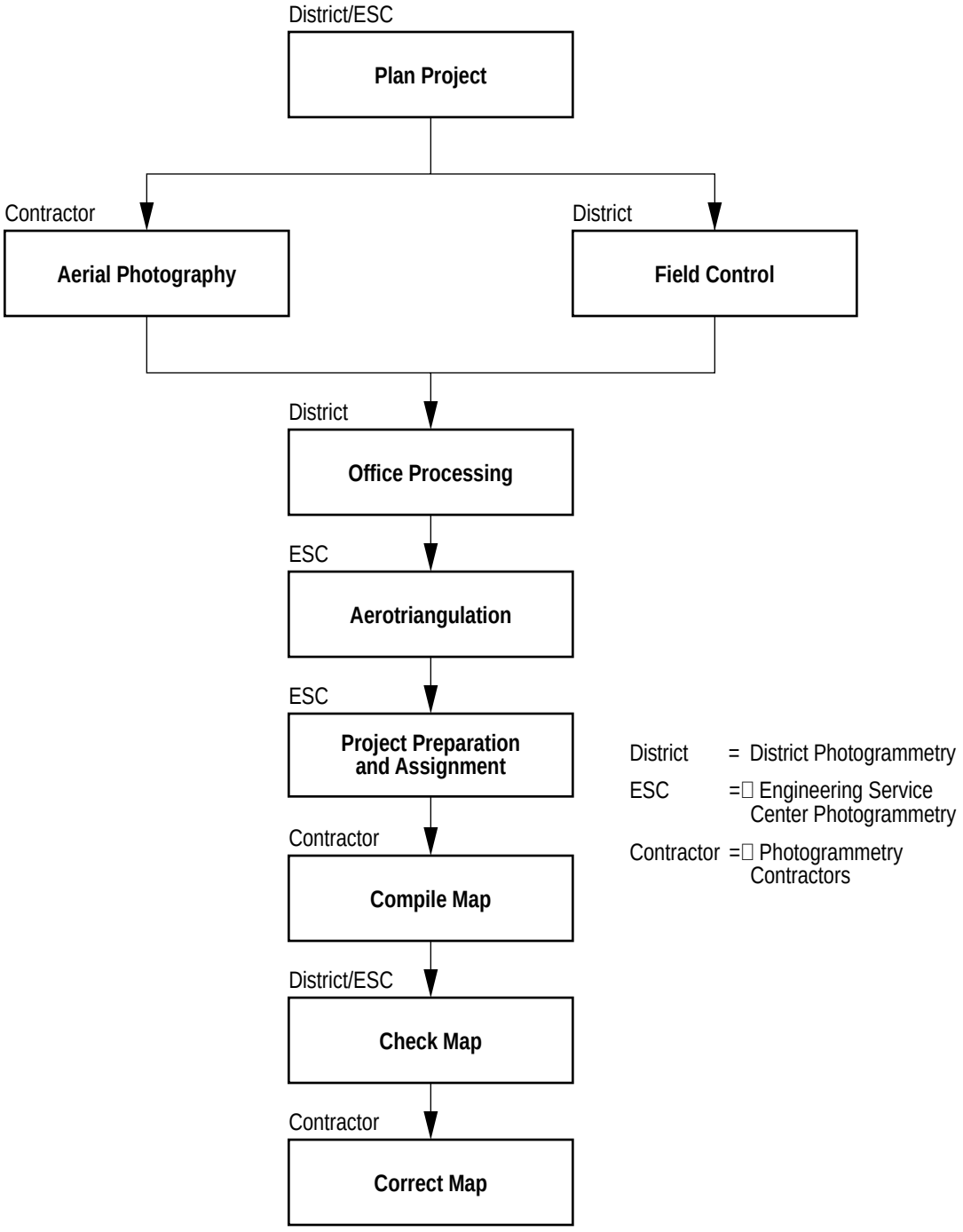

Figure 4. Photogrammetric Mapping Process

Digital Mapping Products

3-D Direct Digital Mapping

Direct digital maps are compiled in 3-D directly from the aerial photography into a CADD file. This method is currently used by both ESC Photogrammetry and mapping contractors to produce maps. Traditionally, maps were compiled on a manuscript, then inked or scribed in final form, and then digitized. This process requires "drawing" the maps three times with the consequent possibility of errors. Using direct digital mapping, the map is compiled directly into the CADD file by the photogrammetric plotter operator, edited on a workstation, and plotted as a final product. This method eliminates the drafting and digitizing steps and reduces the possibility of error. The deliverables are mylar final plots and the CADD file on tape. The 3-D features include contours, spot elevations, roadway delineation, waterways, retaining walls, and terrain break lines. These features are used as input to the CAiCE digital terrain modeling system that will produce cross-sections on any alignment or contour maps at any interval (see **CAiCE**, page 26).

APPROXIMATE COST	Direct Digital Mapping, $50-$100 per hectare, 1:500 mapping
APPROXIMATE COST	Direct Digital Mapping, $250-$500 per hectare, 1:200 mapping
APPROXIMATE TIME REQUIRED*	Direct Digital Mapping, 1 to 7 months, depends on project size and priority

TIP

Some users don't need 3-D maps and don't want to work with them. These 3-D maps can be easily converted to 2-D. See your CADD Coordinator. Save the 3-D file in case you need it later. The conversion from 2-D to 3-D is much more difficult.

*Note: Time required for mapping, digital terrain models, and terrain line interpolation begins when photo control and related materials are submitted to ESC Photogrammetry. The longer mapping times are for 30 model increments (8.2 km at 1:500 mapping). See your Photogrammetry Coordinator or District Surveys Engineer for photo control surveying scheduling and time requirements. (See **Time Requirements (Working Days)**, page 36 and **Photogrammetric Project Tasks**, page 38).

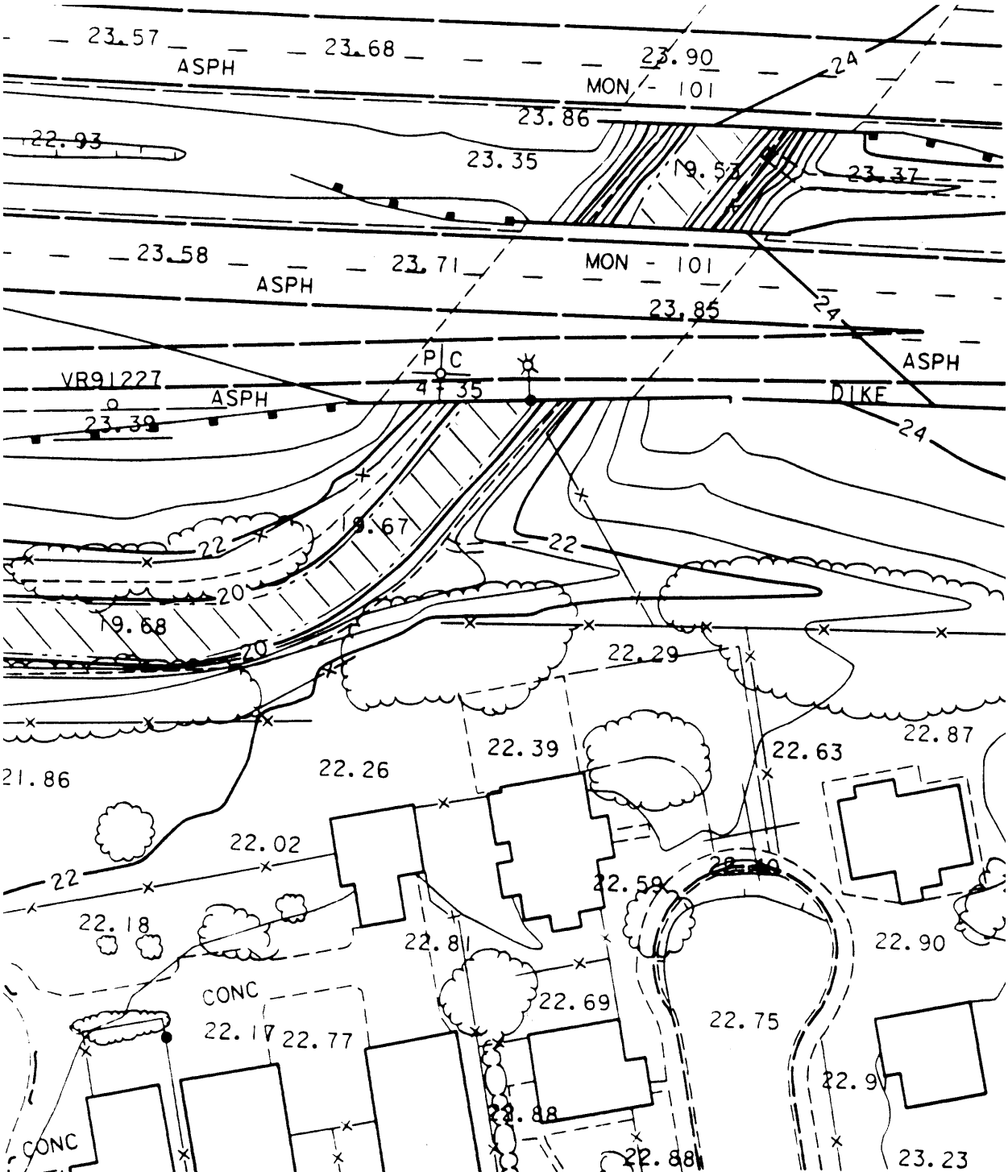

Figure 5. 1:500 Mapping (Sample, Reduced to 80%)

Expedite Mapping

Mapping and the creation of other photogrammetry products are complex processes consisting of many individual steps to the completion of the finished product. This is normally a somewhat lengthy process that must be initiated as early as possible. Because it is not always possible to request mapping early, there are provisions to reduce the time required to produce mapping products for small projects (2 km or less). Larger projects may also be expedited, but other projects in your district may have to be reprioritized (delayed) to accommodate a rush project. The capacity to map expedited projects comes at the expense of projects that are well-planned, thus the number of these projects should be minimized. Expedited projects must be jointly approved by the District Surveys Engineer and the Chief of ESC Photogrammetry. See your Photogrammetry Coordinator if you require an expedited mapping project.

Preliminary maps (unchecked) are available for use much sooner than the final corrected maps. Normally, most of the errors in preliminary maps are in the symbology and not in the accuracy of the maps. (See* Typical Time Requirements for Mapping, Subtotal Preliminary Maps (Unchecked), Working Days, *page 37.)

Structures (Bridge) Site Maps

Structure site maps are compiled at a scale of 1:200 with 0.25 m contour intervals. The structure site maps are separate map sheets from the 1:500 design maps, but are usually compiled from the same photography. The structure sites are compiled simultaneously and the extra contours and spot elevations are eliminated in the copied, 1:500, map files. In order to have the structure sites exactly match the 1:500 mapping, both scales must be compiled in combination. If the structure sites are done separately, after the 1:500 mapping, they will not match exactly. Whenever structure sites are needed, it is recommended that they be ordered with the 1:500 mapping even if the exact locations are not known.

APPROXIMATE COST	Direct Digital Mapping, $250-$500 per hectare, 1:200 mapping
APPROXIMATE TIME REQUIRED	Direct Digital Mapping, 1 to 7 months

Use "planimetry only" maps where contours are not needed. Map delivery is faster because of the reduced time required for the field control and the simpler mapping.

Digital Map Types

The Caltrans Photogrammetry Section has been producing digital maps since 1983. The maps available for project development may be the early 2-D digital maps or the latest 3-D metric maps with break lines. The maps available depend on the date of compilation and the modifications made on the maps since initial compilation. Some of the digital maps available are:

- **2-D hand digitized (flat digital maps)**
- **2-D direct digital (flat digital maps)**
- **3-D direct digital (contours and spot elevations only)**
- **3-D direct digital (contours, spot elevations, roadway, water, retaining walls, and other features)**
- **3-D direct digital (contours, spot elevations, roadway, water, retaining walls, breaklines, and other features)**

The maps may be on the North American Datum (NAD) of 1927 or 1983 with or without epoch dates, and the National Geodetic Vertical Datum of 1929 or the North American Vertical Datum of 1988. The maps may have a global origin to place the mapping in the center of the design plane or a global origin based on a Caltrans Design Plane in either NAD27 or NAD83 and metric or U.S. units. The user should contact the District Photogrammetry Coordinator as early as possible for information on the maps they are using. If necessary, data conversions are available to convert from 2-D to 3-D, NAD27 to NAD83, and from U.S. units to metric units. Again, see your District Photogrammetry Coordinator.

2-D versus 3-D CADD Mapping

Since Caltrans began using CADD in 1983, there has been some confusion about what can be done with a CADD topographic map. To date, most of the CADD maps produced by the Photogrammetry Section in-house and through contracts are 2-D maps. These maps are simply "flat" hardcopy maps that are digitized into the CADD system. The 2-D maps can also be produced by direct compilation into the CADD system from the aerial photography (see **Digital Map Types**, page 23). All of these maps have only two dimensions. Cross-sections, digital terrain models, or terrain line interpolation are not available from 2-D maps, other than the same traditional, manual methods that are used on the hardcopies.

2-D maps can easily be converted to 3-D maps in the Intergraph CADD system, but are still "flat" until the contours and spot elevations are individually, physically moved (in the CADD file) to the correct elevations. Even then, valid cross-sections are not available because the contours do not include the "critical" or "break" lines. For example, cross-sections crossing ridge lines will be flat as they intersect the two highest, but equal elevation contours. The actual ridge will not show on the cross-section because there is no elevation available for it on the contour map. The same condition is true for all "break lines". Any method that uses hand-input of the elevation values is prone to errors that are difficult to locate and correct. The Photogrammetry Section and several Caltrans digitizing contractors have "semiautomatic" methods for conversion of contours from "flat" to the correct elevations that are more reliable than manual conversion. However, the best methods for gathering data for DTM or TLI input are those that record the data automatically, such as, encoded photogrammetric plotters or the total station survey systems.

Don't design with old "flat" maps. Get them converted to 3-D, and use the modern techniques. It is more difficult at first, but later you will wonder how you did it the old way.

CADD Digitizing

CADD digitizing is the process used to convert existing hardcopy maps into digital CADD maps. Nearly all digitizing is done by blanket contractors. Most of the digitizing work is currently 3-D; however, 2-D may be requested (see **2-D versus 3-D CADD Mapping**, page 23). Digitizing is also available on a "rush" or regular delivery basis. The deliverables from the contractor are computer tapes of the digital maps and hard copies for checking purposes. The checking is done by overlaying the original map on the digitized map and verifying that the map was correctly digitized and by checking the CADD file for proper levels, colors, and elevations, etc. The digitizing checking is a District responsibility. Digitizing is being used less frequently.

APPROXIMATE COST ..... (Digitizing) $35-$85 per hectare

APPROXIMATE TIME REQUIRED..... (Digitizing, no mapping) 1 to 3 months

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CADD Map Conversions

The Caltrans Photogrammetry Section has contracts available to convert existing CADD maps from one datum to another, for example, NAD 1927 to NAD 1983, 2-D to 3-D, or U.S. units to metric. See your Photogrammetry Coordinator, if you need files converted.

Approximate Cost	(Datum Conversion)	$ 6-$10 per hectare, 1:500
	(2-D to 3-D)	$10-$15 per hectare, 1:500
	(U.S. to Metric)	$10-$15 per hectare, 1:500
Approximate Time	(Datum Conversion)	2 km, 10-15 days
	(2-D to 3-D)	2 km, 16-20 days
	(U.S. to Metric)	2 km, 10-15 days

CADD Scanning

Scanning service of maps is available. Hardcopy maps may be submitted to Office Engineers to be scanned into digital maps. The scanned maps are scaled in the X and Y directions and moved and rotated to the correct position in the design plane. Scanned maps are not as planimetrically accurate as regular CADD maps. Additionally, scanned maps are on one level and in one color; however, they are a fast method to get existing mapping in the CADD system for preliminary work. The scanned maps should be replaced with regular CADD maps when they are available.

APPROXIMATE COST	(Map Scanning)	$20-$35 per hectare
APPROXIMATE TIME REQUIRED.....	(Map Scanning)	5 to 10 days

Scanning existing hardcopies is a "quick and dirty" way to get your mapping into CADD. It is well worth consideration to get a head start on your project design.

Digital Terrain Products

Digital Terrain Models

Digital terrain models (DTMs) are mathematical representations of the ground. The data is gathered photogrammetrically by collecting the ground break data on regular interval "scan lines", similar to field cross-sections, plus collecting the "break or critical line" data (drains, ridges, retaining walls, etc.). Digitized contours can also be used for DTM input but must include break lines for a more accurate representation of the ground. Small DTMs can be created in the field using the Total Station Survey System. The surface representing the ground is created by triangles formed from the DTM points that have X, Y, and Z coordinates. These files are called triangulated irregular network (TIN) files. Contours or cross sections are then formed by linear interpolation of the lines connecting the apexes of the triangles. Once the DTM is created, accurate contours can be plotted for any area. In addition, cross-sections can be computed for any alignment within the DTM limits.

CAiCE

Caltrans uses the CAiCE (pronounced, casey) digital terrain model software package for the Hewlett-Packard engineering workstations. CAiCE interfaces to IGRDS and Advocate to produce cross-sections and profiles from an IGRDS alignment. CAiCE will accept DTM point terrain files, including "break" or "critical" lines, for the production of cross-sections and contours. Additionally, CAiCE will accept Intergraph, 3-D, contour map design files as input for the production of a DTM. Critical lines may be added to these files for additional accuracy. This data can subsequently be used to create cross-sections or recreate contour maps at any contour interval.

APPROXIMATE COST ..... (CAiCE) $10-$15 per hectare, 1:500 mapping

APPROXIMATE TIME REQUIRED ..... (CAiCE, from existing 3-D digital mapping) 1 to 3 months

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TIP

CAiCE is a true DTM as opposed to TLI, which we call a "poor man's DTM". TLI is an excellent system and has served its purpose well, but now we are advancing to a more universal and user friendly system, CAiCE.

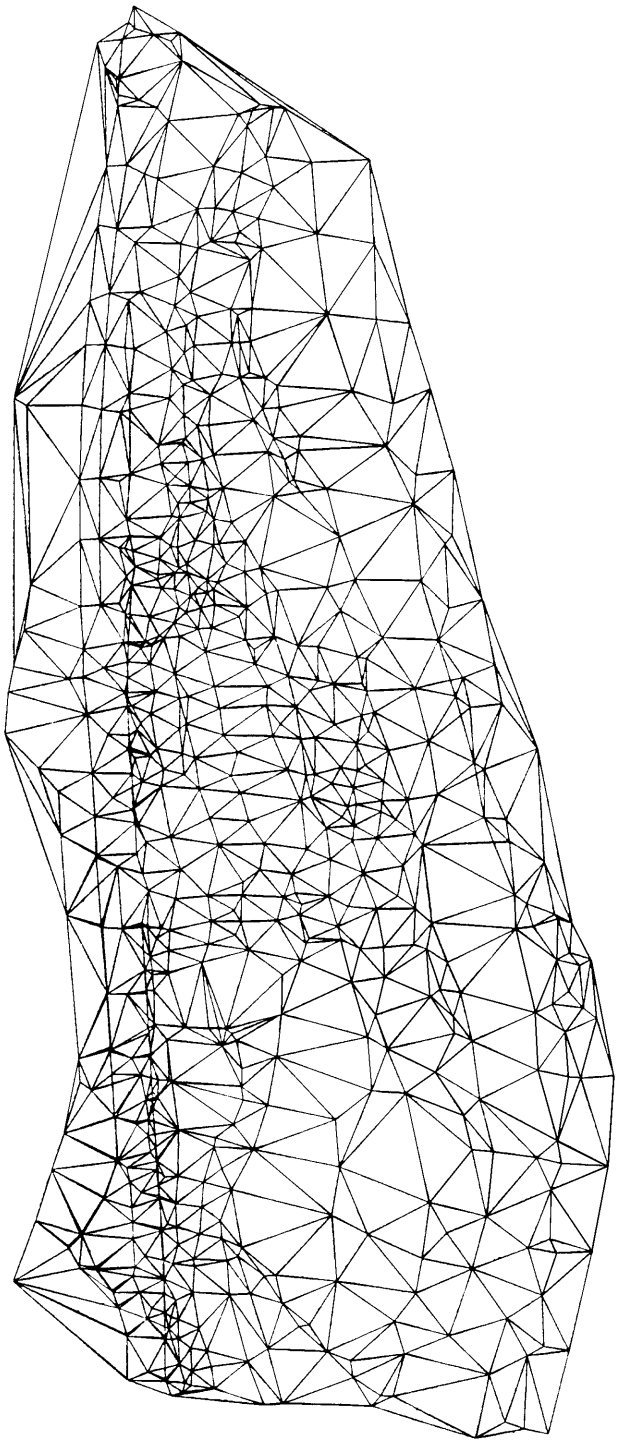

Figure 6. DTM Triangle (TIN) File (Sample)

Photogrammetric Terrain Line Interpolation

Terrain line interpolation (TLI) is a Caltrans-developed method of gathering terrain data for cross-sections that allows for the generation of new, normal cross-sections for any alignment change. "Critical lines", i.e., break lines are measured photogrammetrically throughout the mapping limits. A centerline and cross-section lines are mathematically superimposed over the break lines. Cross-section "shots" are computed by linear interpolation along the break lines at the points where they intersect cross-section lines. Cross-section shots are recorded *only* where the cross-sections intersect the break lines. Where the break lines are perpendicular to the centerline, it is possible for the cross-section normal to miss the break lines and no cross-section shots will be available. In these areas, special lines are created approximately parallel to the centerline by interpolation between the break lines. Thus, shots will occur when the cross-sections intersect the interpolated lines. The TLI method will create valid cross-sections for any alignment within the mapping limits. This method is a simplified digital terrain model. The same procedure is used in the field to get pavement break lines using a total station. These lines can be combined with the photogrammetric lines to create cross-sections with field-surveyed pavement accuracy. The TLI files that are created photogrammetrically are normally prepared by ESC Photogrammetry and delivered to the Districts for cross-section processing.

APPROXIMATE COST ..... (TLI) $50-$200 per hectare

APPROXIMATE TIME REQUIRED..... (TLI, no mapping) 2 to 6 months

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TIP

TLI will be replaced by CAiCE. However, the methods of gathering data for TLI, using both field and photogrammetric methods, will continue.

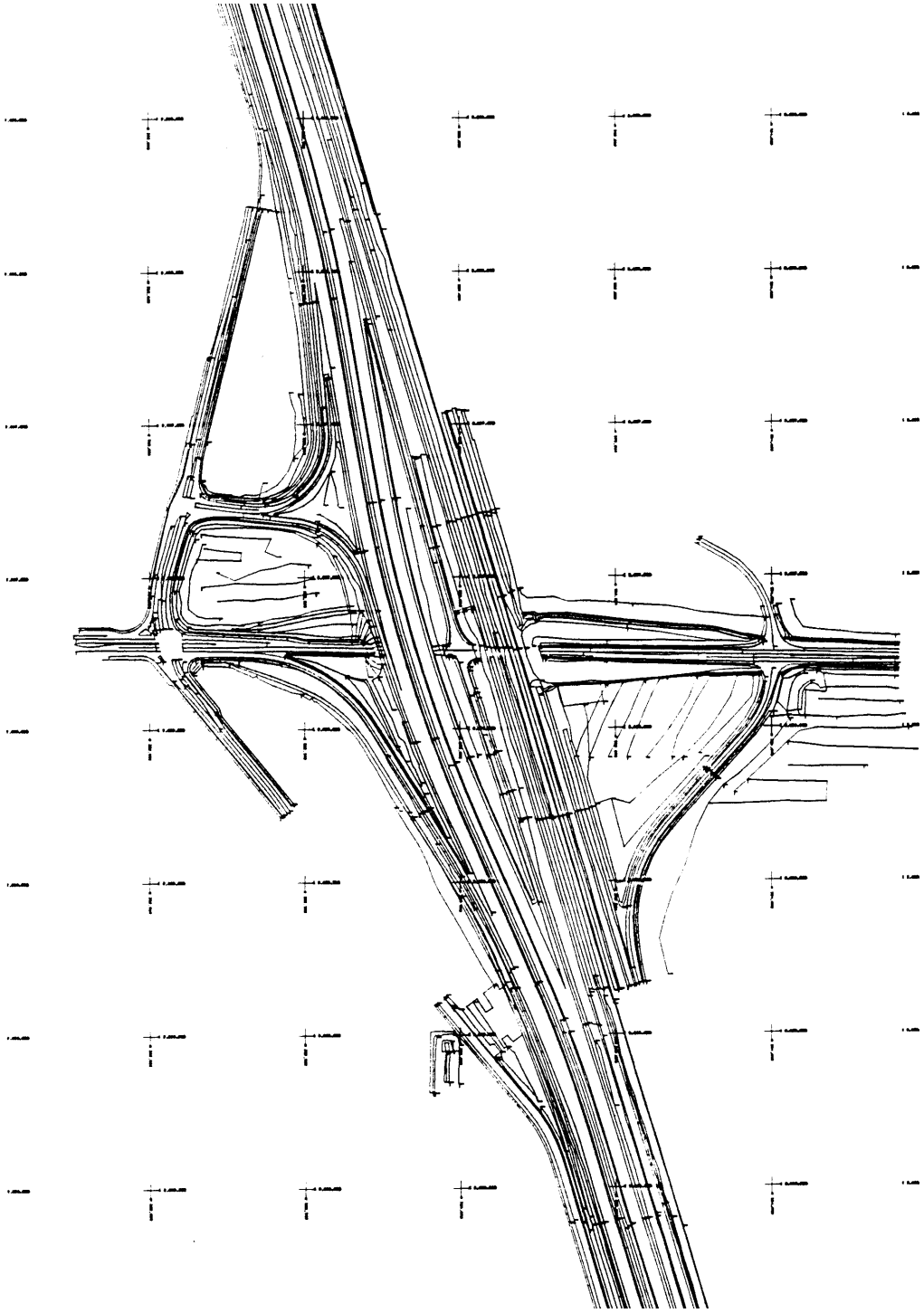

Figure 7. TLI File (Sample)

Terrain Line Interpolation from 3-D Digital Maps

3-D CADD contour maps can be used as input to TLI. The addition of critical lines, to create a more accurate TLI file, and TLI processing are currently done by ESC Photogrammetry.

APPROXIMATE COST ..... (Contour Map TLI) $50 -$125 per hectare

APPROXIMATE TIME REQUIRED..... (TLI, no mapping) 2 to 6 months

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Terrain Line Interpolation from 2-D CADD Maps

2-D CADD maps can be converted to 3-D terrain line interpolation input files that are then used to produce cross-sections (see **Photogrammetric Terrain Line Interpolation**, page 28). The conversion from 2-D to 3-D may be done by either ESC Photogrammetry or digitizing contractors. In addition to converting contours and spot elevations to 3-D, break lines are also digitized to improve the accuracy of the cross-sections. The resultant cross-sections are similar to cross-sections "hand picked" from a contour map.

Digital Map Checking

Checking of digital maps has been in the past, and is currently, a district responsibility. In a digital environment, the quality of the initial product has an impact on the delivery time and cost of subsequent products such as digital terrain models and terrain line interpolation. Some of the older digital maps were not checked and may have erroneous data. If the digital map data is not valid, extra time must be used to correct the deficiencies before the DTM or TLI can be completed. Thus, the delivery of the DTM or TLI is delayed and Caltrans is paying for corrections that should have been made at the mapping or digitizing contractor's expense. Recent digital map specifications require more breakline data and, therefore, require less time to process than older maps. With all digital mapping, quality control of the initial digital data is essential to the efficient delivery of succeeding products.

Photogrammetric Cross-Sections

Photogrammetric cross-sections are measured from the aerial photography in the same manner that cross-sections are taken in the field, using stationing, offset distance left and right, and the elevation. The cross-sections are transmitted to the requestor in the RDS format. The requestor must provide the alignments for the main and ramp centerlines and the cross-section limits. This method of gathering cross-sections is only valid for the original alignment. Any alignment changes will cause the cross-sections to be either off even stations, not perpendicular to the new centerline, or both. Recently, TLI procedures have essentially replaced traditional photogrammetric cross-sections. It is also possible to convert traditional cross-sections to TLI format.

APPROXIMATE COST ..... (X-Sections) $1000-$1600 per km

APPROXIMATE TIME REQUIRED..... (X-Sections, no mapping) 2 to 4 months

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TLI has essentially replaced photogrammetric cross-sections and now CAiCE is in the process of replacing TLI. In the future, cross-sections and average-end area calculations will be replaced by DTMs and surface comparisons for quantity calculations.

Mapping Quality Control

Map Checking

All photogrammetric maps are checked by both the ESC Photogrammetry Section and the District Photogrammetry Staff. ESC Photogrammetry checks representative samples of each map for accuracy and completeness by using photogrammetric plotters. The District checks visually for missing contours, wrong symbology, incorrect fonts and font sizes, and other cartographic errors. District personnel also check visually to ensure that all planimetric features have been compiled on the maps by using a stereoscope and the aerial photographs. ESC Photogrammetry may check the maps visually at the District's request. The district is also responsible for checking the digital map files to verify that the contractor's work meets specifications. Map checking is a critical task to ensure accuracy in the production of photogrammetric mapping.

APPROXIMATE COST ..... (Map Checking, Districts and ESC) $30-$40 per hectare

APPROXIMATE TIME REQUIRED..... (Map Checking, Districts and ESC) 1 to 3 months

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Map Accuracy

Caltrans photogrammetric map accuracy standards are as follows:

The position of all coordinate grid ticks and all monuments shall not vary more than 0.3 mm from their coordinated position.

At least 90 percent of all well-defined planimetric features shall be within 0.6 mm of true ground position, and all shall be within 1.3 mm of true ground position.

At least 90 percent of all contours shall be within one-half of the contour interval of true elevation, and all contours shall be within one contour interval of true elevation, except as follows –

In densely wooded areas where the ground is obscured by dense brush or tree cover, contours shall be plotted as accurately as possible while making maximum use of spot elevations obtained from the stereoscopic model in places where the ground is visible. In those areas where spot elevations can be obtained photogrammetrically, at least 90 percent of all contours shall be within one contour interval or one-half the average height of the ground cover, whichever is greater, of true elevation. Contours in such areas shall be shown with dashed lines.

Orchard, vineyards, and other areas devoted to crops will be considered as open areas and are therefore not subject to larger tolerances in vertical accuracy.

In areas not obscured by grass, weeds, or brush, at least 90 percent of all spot elevations shall be within 0.25 contour interval of true elevation, and all shall be within 0.50 contour interval of true elevation.

In addition to the accuracy specified above for contours and spot elevations, the following shall apply:

The arithmetic mean of contours and spot elevations in open areas shall not exceed plus or minus the following values for the points tested on each map sheet.

Number of Points Tested	Maximum Arithmetic Mean
20	+/–0.24 Contour Interval
40	+/–0.18 Contour Interval
60 or more	+/–0.12 Contour Interval

Any contour that can be brought within the specified vertical tolerance by shifting its position 0.6 mm shall be accepted as correctly compiled.

All Caltrans mapping, whether from the ESC Photogrammetry Section, blanket mapping contractors, or consultant mapping firms, must adhere to these accuracy standards.

TIP

Project Engineers must be aware of the significance of dashed contours on photogrammetric maps. When the ground is obscured by trees, shadows or buildings, the contours cannot be drawn as accurately as when the ground is visible. These contours are only required to be accurate to half the height of the ground cover. If these areas are critical to your design, request field data to replace the dashed contours. This is your responsibility. See your District Photogrammetry Coordinator or District Surveys Engineer.

Symbol Sheet

The "Drafting Standards and Symbols for Design Mapping by Photogrammetric Methods" (Symbol Sheet) is available from the ESC Photogrammetry Section. The Symbol Sheet is available to all users of Caltrans photogrammetric mapping to aid in the interpretation of the various lines and symbols used in photogrammetric mapping. *All Caltrans mapping, whether from the ESC Photogrammetry Section, blanket mapping contractors, or consultant mapping firms, must adhere to these standards*.

TIP

Get a Symbol Sheet and learn how to use it. They are available from ESC Photogrammetry.

How to Order Photogrammetric Products

The District Photogrammetry Coordinator is the key person in this process. Part of the Photogrammetry Coordinator's duties is to help you order the correct photogrammetric product for your specific application.

MORE TIPS

Some more tips to improve your mapping service:

- ***Designate good mapping limits***
- ***Request only what you need***
- ***Do not request contours, unless required***
- ***Prioritize areas for large projects***
- ***Coordinate mapping needs with District Surveys***
- ***Request "Expedite" only when necessary***
- ***Obtain mapping in "k" or zero (0) phase whenever possible***
- ***Know your Photogrammetry Coordinator well***

LAST TIP

We are proud of our District Photogrammetry Coordinators and personnel. Take advantage of their expertise and services. They can make your job easier.

Time Requirements (Working Days)

Project Management Guidelines (Contract Mapping)

Activity	Project Size	Lead Time	Time Requirements
Project Lead		3	0
Planning, ESC		0	3
Aerotriangulation, ESC	0 to 5 models	5	7
	6 to 20 models	5	10
	21 to 40 models	5	12
	41 to 80 models	5	15
	81 to 100 models	5	25
	100+ models	5	25 days/100 models
Contract Preparation, ESC		5 (*1 Rush*)	10 (*3 Rush*)
Compilation, Contractor*			
Regular			1.2 to 3 days/model plus 12 days shipping and mobilization
Rush			0.7 to 1.1 days/model plus 4 days shipping and mobilization
Check, District			1 sheet/day
Check, ESC		various	30 days total 1 sheet/day
Corrections, Contractor		6 (*3 Rush*)	10 (*5 Rush*)
Scanning, ESC			2.5 sheets/day
Digitize, Contractor			3 days/sheet
Digitizing Corrections, Contractor			
less than 10 sheets			5 days
10 or more sheets			10 days

*Large Project are generally split and assigned to several contractors; maximum per contractor about 20 models.

Typical Time Requirements for Mapping

Aerotriangulation to Preliminary/Final Maps (Working Days)

Project Size (1:500 Mapping)	6 Models, 1.6 km Rush	6 Models, 1.6 km Emergency	20 Models, 5.5 km Normal
Lead Time	1	0	3
Aerotriangulation	8	3	15
Contract Preparation	4	1	15
Compilation	9	9	36-72
Subtotal Preliminary Maps (Unchecked)	**22**	**13**	**69-105**
Checking	2	2	30
Corrections	8	5	16
Total	**32**	**20**	**115-151**

Project Management Guidelines (Internal Projects)

ESC Photogrammetry Activities Time Requirements

Normal Lead Time	30 days
Expedite Lead Time	3 days
X-Sectioning	3 models/day
Digitizing	5 days/sheet
Compilation	3 days/model
Compilation and DTM/TLI	3.5 days/model
DTM (CAiCE) Processing (minimal data errors)	3 models/day
TLI Map Edit	1 model/day
TLI	1 model/day
TLI Processing	5 days
X-Section Processing	7 days

Photogrammetric Project Tasks

Task	Responsibility
1. Mapping Limits	Project Engineer
2. Scale and Contour Interval	Project Engineer
3. Flight Plan	District and ESC
4. Control Plan	District and ESC
5. Place Premarks	District
6. Survey Premarks (Control Surveys)	District
7. Aerial Photography	Contractor
8. Survey Calculations	District
9. Check Aerial Photos	District and ESC
10. Aerotriangulation	ESC
11. Contract Preparation	ESC
12. Map Compilation	Contractor
13. Map Checking	District and ESC
14. Map Corrections	Contractor
15. Map Acceptance	District
16. Map Digitizing	Contractor
17. Map Digitizing Checking	District
18. Map Digitizing Corrections	Contractor
19. Map Digitizing Acceptance	District

The first 15 steps of photogrammetric mapping are normally used in a production environment.