Photogrammetric Map Checking

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Checking of photogrammetric mapping by field methods can be costly and time consuming. Unless such checking is thorough there is no assurance that portions not actually covered by field checks will comply with specifications. Recognizing these disadvantages, the California Division of Highways has developed a system of photogrammetric analysis preliminary to field checking.

Photogrammetric analysis consists of reviewing the compilation data in the form of map manuscripts, contact prints with control information identified thereon, diapositives, and field survey notes, as submitted by the mapping contractor. The results of the analysis are used as a basis for recommending field checks.

This paper discusses the development of the checking system, and its performance in routine practice. Photogrammetric analysis is an integral part of over-all checking procedures, and the results of numerous field checks are included. Also included is a discussion of the direct and indirect benefits toward improvement of mapping specifications.

● TOPOGRAPHIC MAPS make it possible for the highway engineer to study, analyze, plan, and design without extensive trips to the field. Viewed in this way, we recognize that the map brings the field into the office, thereby providing the engineer with a basis for increasing his productivity. This presumes that the map is reliable and that the engineer-user has confidence in it.

Many highway engineers have had difficulty accepting topographic maps as being sufficiently accurate for their needs. This has been especially true with their slow acceptance of topographic maps made by photogrammetric methods. In many instances the lack of confidence in the photogrammetric map originated with misunderstanding about how it was made. On the other hand, critical analysis was needed to establish accuracy standards sufficient for the requirements for highway planning and design.

The California Division of Highways has been using photogrammetric mapping for highway design since 1950. From the very start, photogrammetric products were obtained from private sources by competitive bidding procedures. With the advent of the Federal Highway Act of 1956, increased demand for planning and design data required extensive photogrammetric output by private firms. During the past four years about 1,850 mi of design-type mapping have been accomplished, with 578 mi obtained in the peak fiscal year of 1956-57. The current demand is for approximately 300 mi per year.

The subject of this paper should be placed in proper perspective by reviewing the procedure by which this organization obtains its mapping. It is the opinion of the author that the Division of Highway's system of checking photogrammetric maps is especially applicable when contracting for a large volume of work.

The procedure for obtaining photogrammetric mapping by the Division of Highways is composed of several well-defined steps:

1. Prequalification of bidders. All prospective bidders must be experienced in performing similar work, list clients for whom past work was satisfactorily completed, and submit complete information concerning technical organization, equipment and plant facilities, and financial resources. They must also have a registered civil engineer or licensed land surveyor in their employ who is responsible for all technical performance under the terms of the contract.

2. General specifications. The over-all policies, both legal and technical, under which the Division of Highways operates, are incorporated in a set of specifications entitled, "Photogrammetry, General Specifications." These specifications serve as a basic guide to contract performance, and are effectively up-dated by the special provisions for particular contracts.

3. The mapping project. An area where up-to-date map data is needed is reviewed for the type of map required and the extent of desired coverage. In addition the proposed project is analyzed for methods and procedures aimed at producing the map data within specified accuracy tolerances.

4. Special provisions. The special provisions modify and amplify the general specifications. Included as part of these provisions are plan sheets showing location of project, mapping limits, ground cover conditions, existing horizontal and vertical control, and specified flight lines. The results of all the planning are incorporated in the text and on the plan sheets.

5. Bidding and award. A bid list is drawn up, composed of those qualified bidders who have demonstrated that they can handle the type of job in question, especially considering capacity of the firm in relation to the size of the job. Sealed proposals are received, and award is ordinarily made on the basis of the lowest bid.

6. Production. Upon award of the contract all production as specified in the special provisions is the direct responsibility of the contractor. Any variations from the special provisions are mutually agreed on by the contractor and the State and covered by contract change order.

7. Checking. The checking of all materials and data required under the contract commences on delivery or shortly thereafter. Checking is the main subject of this paper, and will therefore be discussed in greater detail.

8. Acceptance. For practical purposes the acceptance of a map merely means that the contract is completed and the contractor is authorized to receive final payment for his efforts under the terms of the contract. It sometimes happens that acceptance is complicated by circumstances that had developed during production phases. It is especially important that a thorough review be made at this time to ascertain the reasons for the difficulties, whether they were extenuating and beyond the control of either the State or the contractor, or whether the difficulties could have been prevented by either party. In other words, this is the last opportunity to review and analyze for the purpose of improving future contract procedures and specifications.

These eight steps comprise a complete system for obtaining photogrammetric mapping, and negligence in the performance of any one of them may contribute to an unsatisfactory product.

The Division of Highways has developed a system of map checking that is particularly satisfactory as a part of the over-all method of map procurement. This system is divided into two steps: (a) photogrammetric review or analysis, and (b) field checks dependent largely on the results of photogrammetric analysis.

A corollary to the map checking program is the influence it has had on the acceptability of the maps by the engineer-user. The application of this program has prevented poor jobs from reaching their destinations, so to speak, and over a period of time confidence in the photogrammetric methods has been attained.

SPECIFICATIONS AND PROCEDURES

Accuracy specifications for large-scale mapping are an outgrowth of National Map Accuracy Standards. The so-called Standards are not entirely satisfactory, but they do serve as a foundation for incorporating the requirements for highway design maps. Investigations have demonstrated that mapping specifications, wherein earthwork quantities are to be considered, must recognize the fundamental importance of statistical accuracy (1, 2, 3).

Current California accuracy specifications (4) for a typical project with mapping at 1 in. = 50 ft with 2-ft contours and/or spot elevations can be summarized as follows:

In areas not obscured by brush or field crops:

1. 90 percent of the contours shall be within 1.0 ft.
2. 90 percent of the spot elevations shall be within 0.5 ft.
3. The arithmetic mean shall not exceed:
   ± 0.40 ft for 20 points tested,
   ± 0.30 ft for 40 points tested,
   ± 0.20 ft for 60 or more points tested.

These limiting tolerances for the arithmetic mean are based on a standard deviation of 0.6 ft and 99 percent probability. Exact values computed on this statistical basis have been rounded out to the next higher 0.1 ft. In establishing such tolerances two factors should be recognized:

1. The desirability of testing small segments of the mapping to minimize varying systematic errors. This is necessary if anticipated balances of earthwork quantities between individual cuts and fills are to be maintained.
2. The effects of irregular ground surface and even minor amounts of ground cover on photogrammetric readings at the map scales now being used.

About 98 percent of California contracts are with firms that use the Kelsh-type plotter as the basic photogrammetric instrument. Methods and procedures, as required in the special provisions of the contract, are directed toward this type of instrumentation together with the associated phases of photography and supplemental control.

Before 1956, a minimum of detailed specifications was included in the special provisions of each contract. With the start of photogrammetric analysis, it was immediately apparent that greater emphasis had to be given to the principles of photogrammetric engineering if satisfactory mapping was to be obtained. The current detailed specifications provide a fairly complete outline of procedures that the mapping contractor must observe, and constitute a sound (though conservative, in some respects) approach to the making of large-scale maps by photogrammetry. Although certain items are considered standard, each project is individually planned before the writing of the specifications.

The major technical considerations follow in logical order:

Aerial Photography

The proper planning of aerial photography centers around the photogrammetric instrument to be used. Hence, for the Kelsh-type plotter careful flight planning is essential because of projection limitations. Special attention is given to the range of relief to be accommodated on any one flight line in relation to mapping width. Reasonable tolerances in flight altitude and position are allowed in planning so that complete stereo-coverage within the limitations of the projection equipment is assured. Adequate aerial photography is absolutely necessary, for this is the initial phase upon which all subsequent phases depend.

Aerial photography must be taken with precision cameras that have satisfactory calibration certificates. Usually 6-in. focal length cameras are required, although on occasion 8¼-in. focal lengths have been permitted and even encouraged in areas of moderately heavy vegetative growth.

Until very recently experience with cronar-base aerial film has been lacking. However, from our limited experience to date we are encouraged by the prospects this modern film promises to offer. Some of the mystifying vagaries in relative orientation have disappeared, and model definition seems to be improved. Consideration is being given to the mandatory use of the film on future projects.

Diapositives are required to be made on glass that at least 0.130-in. thick, and with the emulsion surface down. The metrical data pertaining to diapositives has been reported previously (5).

Supplemental Control

The basic concept of supplemental photo-control for large scale, small contour interval mapping is that each neat model area must be fully controlled and that its absolute orientation should not depend on the orientation of adjoining models. In other words, the bridging of control is not permitted.

The arrangement and placement of wing points for vertical control in model corners is the responsibility of the contractor. However, in order to convey the single-model concept, wording similar to the following is included in the special provisions: "Establish and use for supplemental vertical control points, placed advantageously near the four corners of each model used in compilation within a radius of 5 in. from the center of the two photographs forming the neat model. No point should be located more than 3.5 in. from the X-axis of either photograph. The four points should be located to form a rectangular pattern for the corner control of any neat model."

In addition to the four-corner vertical control points, a fifth vertical control point is required near the center of the neat model. This specification is frequently modified if a specified or existing horizontal control line runs along the middle of the mapping strip and ground elevations are available at the monuments.

The pre-marking of all or a portion of the vertical control before photography is sometimes specified, especially in flat terrain devoid of definitely photo-identifiable features. This is applicable to farm lands, deserts, and grassy terrain. The common practice is to locate pre-marks on the ground along the margins of the mapping strip at uniform intervals of 200 to 300 ft. Elevations need be established on only those points that fall near model corners, but may be established on all the points if the contractor so elects.

In line with the single-model concept, at least two well-spaced horizontal control points should be located in each model. For many years, three horizontal points have been required, the extra point serving as a check.

Primary horizontal control is usually done by State forces, with monuments set at intervals of 1,000 to 2,000 ft through the center of the mapping strip. The current trend is to require supplemental horizontal control to be traversed between the primary monuments. In order to take advantage of the necessary taping, the supplemental points are located at tape-lengths of 200 to 300 ft.

Pre-marking of horizontal control has become standard practice. Further, with elevations established on the pre-marks, vertical control throughout the center of the mapping strip is readily available. This procedure is fairly routine and especially adaptable to flat terrain conditions.

Compilation

Before the availability of mylar polyester films, considerable difficulty was encountered with manuscript materials. The mylar films, of which several commercial varieties are obtainable, have virtually eliminated "paper stretch" as a source of error in photogrammetric compilation. The use of this type of material is a specification requirement.

The results of prior planning and production (photography and control) directly affect compilation. If the planning has been satisfactory, and production of photography and control progress accordingly, compilation difficulties are greatly minimized. The most important remaining source of error is the amount of vegetative growth existing at the time of photography. In areas of heavy cover, specifications provide for relaxed accuracy tolerances, as previously noted, and must be indicated by dashing the contours. Field completion surveys are necessary under very heavy growth conditions.

Spot elevations are required to supplement contours in locations where interpolation of elevations would be troublesome. Typical features are tops, saddles, depressions, benches, and places where the ground is so flat that contour spacing exceeds 2 in. at map scale.

Ordinarily all planimetric detail visible in the model must be shown. There are certain exceptions, such as very small buildings. However, important planimetric features not visible in the models are sometimes required, indicating the necessity of field completion surveys.

Delivery Schedules

Delivery schedules specify that all materials pertinent to compilation be included in required shipments of completed maps. From the date the compilation materials are received, the State has 90 days in which to complete the checking of the maps.

The foregoing outline of specifications may be modified according to individual job requirements, but in the main constitute the essential considerations for the making of large-scale photogrammetric maps to the specified accuracy tolerances. In addition, careful planning of the basic production operations affords a better understanding of the map checking problem.

MAP CHECKING PROGRAM

The fundamental rule serving to govern map checking procedures is that the method used to check the map should be capable of a higher order of accuracy than the method used to make the map. An academic interpretation of this rule often leads to confusion and may not produce the desired results. With the variations in survey procedures now available, any number of acceptable alternatives are at the disposal of the engineer, depending upon scale and contour interval of the map, accuracy specifications, ground cover conditions, and nature of the terrain.

As an example, the use of stadia may or may not be applicable for the checking of photogrammetric maps. Stadia is considered suitable for checking small-scale, large contour interval mapping, such as 1 in. = 200 ft with 10-ft contours. Errors inherent in the method are not critical at that scale and contour interval. However, the application of stadia to the checking of the usual design scale map at 1 in. = 50 ft with 2-ft contours is more restricted, and must be used with considerable judgment. On the other hand, the use of transit traverse for checking of large-scale maps of rugged, timbered terrain may not be justified, especially considering reduced accuracy tolerances in such situations.

For large-scale mapping, field checks require relatively high survey technique in order to discriminate photogrammetric errors. As reported in the article, "Terrain Data for Earthwork Quantities" (2), the taking of cross-section data by routine field procedure proved to be less accurate than by photogrammetric procedure. In this test a precise field survey was made for the purpose of comparison, permitting the segregation of errors in both the routine field survey and the various photogrammetric surveys. It is interesting to note, however, that had the precise survey not been made, the differences between the photogrammetric survey and the routine field survey would have been undoubtedly attributed to errors in the photogrammetric work. The common assumption that field survey is naturally superior to photogrammetric survey is not necessarily valid and frequently leads to erroneous conclusions.

The cost of field survey can be prohibitive, especially if a thorough check of the mapping is desired. The practice of running one field profile on each map sheet without regard to the number of stereomodels comprising the sheet is hardly a thorough check. If the stereomodel is to be considered an independent compilation unit, theoretically it should be checked accordingly. A map sheet may comprise one model or several models. It is not suggested, however, that such field checking is warranted, unless detailed method and accuracy specifications are unknown.

The Division of Highways recognized the map checking problem associated with the volume of mapping required for the planning and design studies. In 1956, a Kelsh plotter was purchased for the sole purpose of checking contract work. It became necessary, therefore, to require the mapping contractors to deliver their compilation materials, consisting essentially of manuscripts, control-photographs showing identifications and values, and diapositives, along with completed map sheets. These materials are necessary for the resetting of stereomodels in order to investigate the probable areas of weakness. Accordingly, field survey parties are advised to check these areas for compliance with accuracy specifications.

Although confidence was expressed in this initial endeavor, the procedure was in reality on trial. For one thing, one hesitates to call it "checking" because the findings had to be substantiated by field survey. Also, frequently there was doubt because the data furnished by various contractors was sometimes so indefinite that findings were unavoidably inconclusive. It was apparent that method specifications had to be improved in order to assure reasonably that accuracy tolerances could be attained. Consequently, the over-all approach has developed more logically as a photogrammetric analysis because the entire photogrammetric procedure for large-scale mapping is investigated. Two positive outcomes are now recognized:

1. The improvement of specifications to assure with greater certainty the possibility of meeting required accuracy tolerances for design-type maps.
2. The reduction of checking costs by isolating the probable weak areas of the mapping, which permits the more expensive field checking to be concentrated in the recommended areas.

During the 23½-month period from January 1959 through the middle of December 1960, 2,349 models were investigated, using 3 Kelsh-type plotters. This is equivalent to about 400 mi of design mapping, or approximately 2/3 of the total mileage acquired during this period, involving 20 contractors and 69 contracts. Approximately 26 percent, or 600 models, were recommended for further field checking. This amounts to a reduction of 74 percent in field checking on the basis of checks in every model. It is emphasized at this point that many models recommended for field checking were of borderline accuracy and very few were actually rejected. Detailed records were kept on the results of 62 of the 69 contracts. A more detailed breakdown of results follows, showing a distribution according to findings on the 62 contracts.

Table 1 shows the record for individual contracts by stereomodels. In this type of work it is generally impossible to differentiate precisely between the models that are substandard and those that are borderline. Thus, those recommended for field checks are subdivided according to the extent of check the photogrammetrist believes necessary.

An explanation of row headings will demonstrate the significance of the recommendations for field checks. Between those models determined satisfactory (or "OK") and those requiring field checking, lies an indefinite zone that comprises models that are "probably OK." Within this latter category further subdivision is made to separate control from compilation problems. Control problems are of two types, vertical and horizontal, but occasionally both types occur. Compilation problems, on the other hand, may stem from several different sources:

1. Omissions, either planimetric or topographic (such as buildings or poles), or top contours, depression contours, significant spot elevations, and other map-worthy features required in the specifications.
2. Generalized topography, especially in rugged terrain, resulting from hasty compilation.
3. Systematic differences in elevation between the contract map and the reset model, indicating the possibility of systematic errors.
4. Ground cover, especially those small areas not so indicated on the contract map, that probably do not conform to standard accuracy requirements.
5. Weak areas, usually isolated and small, wherein vertical disagreements between the contract map and the reset model are apparent.
6. Minor differences between the contract map and the reset model comprising several of the previously mentioned sources.
7. Erratic compilation wherein nothing too definite can be isolated and the causes are unknown, other than simply careless workmanship.

Miscellaneous comments are usually confined to those models that are poorly illuminated, and therefore difficult to read, and to models that indicate vague photographic problems suggested by residual parallax.

Models classified in this indefinite zone of "probably OK" are noteworthy to the extent that the problems associated with them are not considered significant enough to cause rejection if subjected to field checking. In other words, they undoubtedly conform to the 90 percent concept expressed in the accuracy requirements. If, in the judgment of the photogrammetrist, any or a combination of the various classifications are significant to warrant field investigation of particular models, then the type of field check is suggested that should reveal whether the model meets specifications.

A spot check, meaning a scattering of field elevations in the model area to determine the trend of errors, is suggested when vertical control problems or general brush conditions are serious enough to make standard accuracy problematical. This is a sort of borderline condition, difficult to pinpoint definitely.

A limited field check is usually confined to specific areas that are either large enough to cause the model to fail to meet the 90 percent concept or significant enough regardless of size to give rise to problems in the design phase. An an illustration, errors in particular vertical control points may not have been resolved during compilation to the satisfaction of the State's photogrammetrist, perhaps making a definite portion of the model suspect for vertical accuracy. However, if the errors had been resolved to his satisfaction, the model would have been classified as probably OK, noting the difficulties with vertical control.

Should brush-covered draws or other drainage features indicate serious vertical errors, a limited field check of the specific area would be suggested. Such areas are typical of the problems that later arise during design and cause doubt as to the reliability of the entire mapping. Because of this, it is fairly common practice to require before compilation field profiles of particular drainage features to control the plotting of contours on the manuscript.

A complete model check is recommended for those models that are so erratic that compliance with accuracy standards is extremely doubtful. It sometimes happens in these situations that the contractor had at the time of compilation information that enabled him to meet specifications, whereas without this information the State's photogrammetrist was obliged to recommend complete field checking.

Table 2 is a summary of the photogrammetric analysis record of individual contracts listed in Table 1. In this form, it is a record of individual contractors.

TABLE 1

PHOTOGRAMMETRIC ANALYSIS RECORD STEREOMODELS, INDIVIDUAL CONTRACT

CONTRACTOR	A		B								C			D	E	F
CONTRACT NUMBER	1	2	1	2	3	4	5	6	7	8	1	2	3	1	1	1
OK - (No Comments)	16	13	30	36	13	9	16	7	6	15	7	11	9	3	8	5
PROBABLY OK																
Control																
vertical		2	1	3	1	8	3								1	4
horizontal						2										
both																
Compilation																
omissions	3		1			2			1	1	2					
generalized																
systematic	3		1	2			1			2		1			1	
ground cover	1								1				1		1	
weak areas	8	1	3	1				2				2			2	2
minor diff	1	4		2			1		1							
erratic			1	2		3			1	1	2		1			
Miscellaneous	2	2	1													
FOR FIELD CHECKING																
spot check					2	6				1					3	
limited check	3		4	4	5	2	2			1			1	1	3	
complete check	2		5	6	3									1	1	1
TOTAL STEREOMODELS	39	22	47	56	24	32	23	9	10	21	11	14	12	5	20	12

CONTRACTOR	G					H						
CONTRACT NUMBER	1	2	3	4	5	2	3	4	5	6	7	8
OK - (No Comments)	20	22	25	10	12	4	14	8	4	9	12	7
PROBABLY OK												
Control												
vertical		1				1	1	2		3	2	
horizontal												
both												
Compilation												
omissions			4					3		7		
generalized			13			1					1	
systematic							1	1	1			
ground cover	1							5		1		
weak areas			1		1	2	2		1	2		
minor diff					2							
erratic	2							5	1	7	2	
Miscellaneous			2	1			1	6		1		
FOR FIELD CHECKING												
spot check				3					4	4		3
limited check	1	4		3	3	2	1	1	3		3	3
complete check	5				1	1	1	12	6	4	1	
TOTAL STEREOMODELS	29	27	45	17	19	11	21	43	20	38	21	13

CONTRACTOR	I		J		K			L					
CONTRACT NUMBER	1	2	1	2	1	2	3	1	2	3	4	5	6
OK - (No Comments)	27	6	14	39	14	41	6	25	26	12	2	20	8
PROBABLY OK													
Control													
vertical	1		1		1	2		1	1				
horizontal													3
both													
Compilation													
omissions	1					1			1				1
generalized			1				1			1			
systematic	1	1	2	1		1			2	15		1	
ground cover								1		1		1	
weak areas	1	1		1	2	8	2	4	3	1		1	3
minor diff			1			1		1	2				
erratic										4		1	3
Miscellaneous	1		2		1				1			3	
FOR FIELD CHECKING													
spot check	2		1					1	2	1		3	1
limited check	1	18		6		2	1	3	5	7		5	6
complete check		2	2			4	1			13		1	2
TOTAL STEREOMODELS	35	28	24	47	18	60	11	36	43	55	2	36	27

CONTRACTOR	M		N										
CONTRACT NUMBER	1	2	1	2	3	4	5	6	7	8	9	10	11
OK - (No Comments)	5	25	28	24	10	12	27	10	29	6	18	20	4
PROBABLY OK													
Control													
vertical		1	2	9		8			1	2			
horizontal					1		2						
both										1			
Compilation													
omissions		3		1		1							
generalized			1			1		1		1		2	
systematic		1	1	3			1		5			1	1
ground cover	3	2	9	9		3			1				
weak areas		1	4	6		4	4	1	2	1		1	1
minor diff		2		3		2	3	1	4			1	
erratic				1	2	2	1	1	1				
Miscellaneous									6				
FOR FIELD CHECKING													
spot check			1	3	1	1	2	2	8	2			1
limited check		2	6	7	2	7	2	2	19	1		6	1
complete check			6	3	2	1	8	2	7	1		4	1
TOTAL STEREOMODELS	8	37	58	69	18	42	50	20	83	15	18	35	9

CONTRACTOR	O	P	Q			R	S
CONTRACT NUMBER	1	1	1	2	3	1	1
OK - (No Comments)		10	3	17	8	49	4
PROBABLY OK							
Control							
vertical		1		2	1	2	
horizontal				5		1	2
both				4			
Compilation							
omissions				1	1		
generalized			1			2	
systematic						1	
ground cover			2	2	1	1	3
weak areas		2		1		2	1
minor diff				1			
erratic							2
Miscellaneous				1		2	
FOR FIELD CHECKING							
spot check					1	1	3
limited check			2	1	2	7	
complete check	4		1	1	1	4	5
TOTAL STEREOMODELS	4	13	9	36	15	72	20

TABLE 2

PHOTOGRAMMETRIC ANALYSIS RECORD: SUMMARY OF STEREOMODELS, INDIVIDUAL CONTRACTORS

CONTRACTOR	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
OK - (No comments)	29	132	27	3	8	5	89	73	33	53	61	93	30	188		10	28	49	4
PROBABLY OK																			
Control																			
vertical	2	16			1	4	1	10	1	1	3	2	1	22		1	3	2	
horizontal		2										3		3			5	1	2
both														1			4		
Compilation																			
omissions	3	5	2				4	10	1		1	2	3	2			2		
generalized							13	2		1	1	1		6			1	2	
systematic	3	6	1		1			3	2	3	1	18	1	12				1	
ground cover	1	1	1		1		1	6				3	5	22			5	1	3
weak areas	9	6	2		2	2	2	10	2	1	12	12	1	24		2	1	2	1
minor diff.	5	4					2			1	1	3	2	14			1		
erratic		8	3				2	15				8		8					2
Miscellaneous	4	1					3	8	1	2	1	4		6			1	2	
FOR FIELD CHECKING																			
spot check		9			3		3	12	2	1		8		21			1	1	3
limited check	3	18	1	1	3		11	16	19	6	3	26	2	53			5	7	
complete check	2	14		1	1	1	6	27	2	2	5	16		35	4		3	4	5
TOTAL STEREOMODELS	61	222	37	5	20	12	137	192	63	71	89	199	45	417	4	13	60	72	20
Number of Jobs	2	8	3	1	1	1	5	8	2	2	3	6	2	11	1	1	3	1	1

Table 3 is derived from Table 2, the values being expressed in percent. Thus, as a record summarizing the performance of individual contractors, Table 3 provides a quick reference. However, the tabulated data should not be interpreted too rigorously in all cases.

For instance, the record for contractor D is not realistic because only five models were reset on the one project investigated. In this particular case, the photogrammetric work was compiled with a universal instrument. The five models were reset in a similar instrument belonging to another agency. Time did not permit a more thorough analysis, therefore the record is not indicative of the contractor's potential performance.

For contractor I, Table 3 shows 36 percent of the models recommended for further field checking. This was caused largely by the fact that contract I-2, Table 1, shows 20 models out of 28 suggested for further field checking. This contract required standard accuracy mapping throughout, specifying field completion surveys in the areas of heavy ground cover. During photogrammetric analysis it was not certain how much field completion was actually accomplished, and the recommendation for field checks merely indicated that the areas in question could not have been compiled photogrammetrically to the required accuracy. The field completion surveys had been made as required and no models were rejected as a result.

Of the 62 mapping contracts investigated, 2 (O-1 and S-1) were found to be very poor because of failure to follow specifications. Both of these contracts were willingly corrected by the respective contractors.

TABLE 3

PHOTOGRAMMETRIC ANALYSIS RECORD:
PERCENT OF STEREOMODELS, INDIVIDUAL CONTRACTORS

CONTRACTOR	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
OK - (No comments)	48	59	73	60	40	42	65	38	52	75	69	47	67	45		77	47	68	20
PROBABLY OK																			
Control	3	8			5	33	1	5	2	1	3	2	2	6		8	20	4	10
Compilation	34	14	24		20	17	17	24	8	8	18	24	27	21		15	17	8	30
Miscellaneous	7	1					2	4	2	3	1	2		2			1	3	
FOR FIELD CHECKING	8	18	3	40	35	8	15	29	36	13	9	25	4	26	100		15	17	40
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Number of Jobs	2	8	3	1	1	1	5	8	2	2	3	6	2	11	1	1	3	1	1

Table 4 summarizes the photogrammetric analysis record for the 62 projects. It is noted here that only 128 models, or 7.4 percent, of the 1,739 that had been reset were recommended for complete field checking, compared with 174, or 10.0 percent, for limited field checking. Without the advance information furnished by photogrammetric analysis, extensive and unproductive field effort would be unavoidably expended.

Field checking data based on the information provided by photogrammetric analysis show a definite correlation of results. Whenever enough field data are available, it is the practice of some District offices to make a statistical analysis as illustrated by Figure 1. The derivation of the cumulative frequency curve is explained in the article, "Photogrammetric Map Accuracy" (1).

TABLE 4

PHOTOGRAMMETRIC ANALYSIS RECORD: SUMMARY, 62 PROJECTS, 19 CONTRACTORS

	Summary by Category Models	(%)	Summary by Item Models	(%)
OK - (No comments)	915	52.6	915	52.6
Probably OK:				
Control:	91	5.2		
vertical			70	4.0
horizontal			16	.9
both			5	.3
Compilation:	334	19.2		
omissions			35	2.0
generalized			27	1.6
systematic			52	3.0
ground cover			50	2.9
weak areas			91	5.2
minor diff.			33	1.9
erratic			46	2.6
Miscellaneous	33	1.9	33	1.9
For field checking:	336	21.1		
spot check			64	3.7
limited check			174	10.0
complete check			128	7.4
Total	1,739	100.0	1,739	100.0

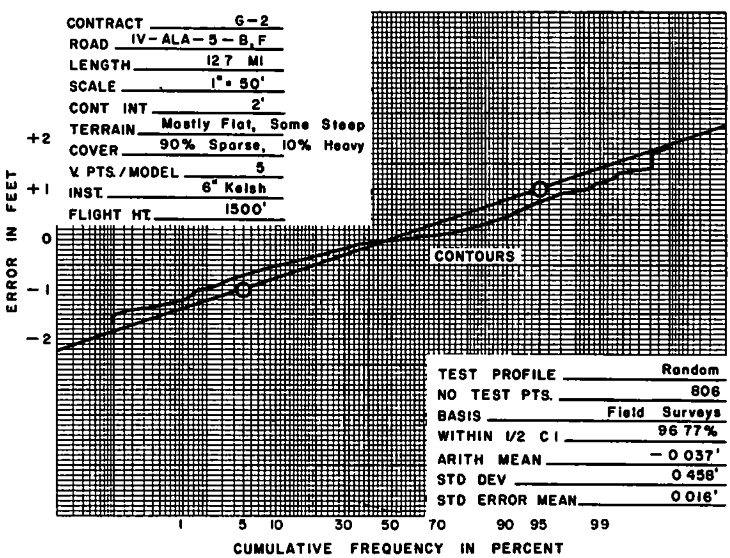

Figure 1.

For contract G-2, 27 models had been reset (Table 1), or about 36 percent of the total number of models covering the project. This was considered to be sufficient to anticipate a satisfactory job. Subsequent field checks based on random profiles demonstrated that excellent mapping was performed. Figure 1 very adequately summarizes the results. Because of heavy brush in certain draws, 4 models had been recommended for limited field checking.

CONCLUSIONS

The photogrammetric map checking system used by the California Division of Highways was developed to investigate the accuracy of large-scale design mapping obtained under contract. The volume demand for this type of mapping was caused by the accelerated highway program stimulated by the Federal Highway Act of 1956.

Two direct benefits of the program have been demonstrated:

1. Reduction in field checking time and effort.
2. Continuous analysis and consequent improvements of mapping specifications.

Adequate mapping specifications are absolutely necessary to guarantee satisfactory results. Of 62 contracts investigated, 2 were found to be substandard. In both cases, the contractors had failed to follow specifications.

The over-all records of the map checking program prove that whenever good specifications are diligently followed standard accuracy mapping will be assured.

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