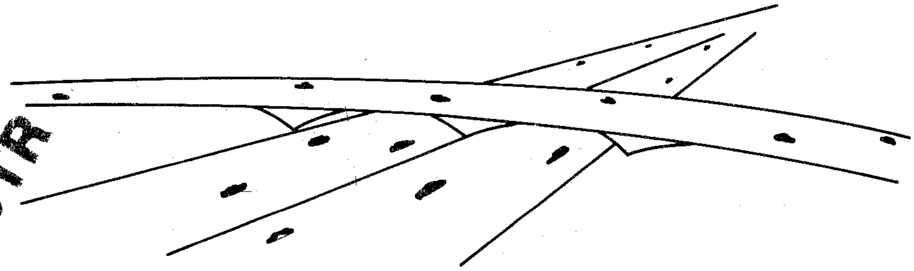

DEPARTMENTAL RESEARCH

Report Number : 38-1F

DETERMINATION OF ACCURACIES IN EARTHWORK QUANTITIES FROM PHOTOGRAMMETRICALLY MADE SURVEYS

TEXAS HIGHWAY DEPARTMENT

DETERMINATION OF ACCURACIES IN EARTHWORK QUANTITIES FROM PHOTOGRAMMETRICALLY MADE SURVEYS

By

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Research Report Number 38-1F

Determination of Accuracies in Earthwork Quantities
From Photogrammetrically Made Surveys
1-8-63-38

Conducted by

Division of Automation
The Texas Highway Department
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ABSTRACT

Cross-sections from four construction projects with varying types of terrain were taken both by field methods and photogrammetric methods. Selected profile elevation differences between the two types of data yielded normal percentage distribution curves and an average difference of .03 ft between their standard deviations. The volumetric difference between the two types of cross-sections was expressed in terms of an average depth spread over the entire plane area involved. This difference was .03 yd for photogrammetric data. A probable maximum volumetric error on a proposed project can be estimated by multiplying .03 yd by the number of square yards of area to be disturbed. Volume error expressed as a percentage of total volume will be greater for projects with light grading. The horizontal difference in placement of cross-section points affected the volume more than differences in elevation. Photogrammetric data is sufficiently accurate for design and pay quantities.

DETERMINATION OF ACCURACIES IN

EARTHWORK QUANTITIES FROM PHOTOGRAMMETRICALLY MADE SURVEYS

I. INTRODUCTION

Background

Changes in existing highway design procedures should not be made without evaluating the economic and physical effects of such changes. To some degree a new procedure must be evaluated in terms of an old procedure. Most highway design and construction practices are changed by a process of evolution. Old concepts are exposed to new procedures which in turn lead to new concepts.

The introduction of photogrammetry into the operating design procedures of the Texas Highway Department was not made without testing, evaluation, and study. The advantages of aerial photography for route location studies and the production of planimetric maps were soon apparent to the average Resident Engineer. The availability of contours obtained by photogrammetric methods allowed the Resident Engineer to study the terrain, to determine the approximate right-of-way requirements, and in some areas to use the contours as a basis for earthwork computations. Because of the size and varied terrain in the State of Texas, the Resident Engineers throughout the State developed earthwork procedures unique to their area of the State.

The Districts in which the terrain was mountainous or rugged did not have any great difficulties in determining earthwork quantities and drainage paths from contour maps, but problems were encountered where terrain was flat or gently rolling. In flat areas the volumes of excavation for a five mile project ranged from 10,000 cubic yards to several hundred thousand cubic yards, while the Districts in the mountainous areas moved millions of cubic yards on a five mile project. The accuracy of the cross-sections determined by contour interpolation in relatively flat areas was questionable and the one-half contour interval was insufficient for drainage problems where special ditch grades of near 1% were common. Because of this, the contour interpolated cross-sections appeared limited to the mountainous and rolling terrain sections of the State.

Digitizing photogrammetric cross-section data directly from a stereo image offered speed and accuracy over the contour interpolated method which had been used. Most project photography in Texas was at a scale of 1"=200', from which 1"=40' maps were compiled. Topography was generally contoured at a one-foot interval, with an accuracy of one-half a contour interval. Taking cross-section data directly from a stereo image allowed the specification for elevation accuracy to be lowered to approximately $\pm$ 0.25 ft, or one-fourth the contour interval.

Research Project HPR 1-8-62-28 (Determination of Capabilities of Electronic Equipment for Use in Photogrammetry[1]) evaluated the equipment and procedures involved in digitizing the cross-section data directly from a stereo image. This procedure offered reduced project cost since it eliminated expensive contouring on many projects. It also offered, it was thought, more accurate data for earthwork computations.

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[1] Mangum, S. E., Jr., Determination of Capabilities of Electronic Equipment for Use in Photogrammetry. Division of Automation, Texas Highway Department, 1966.

How accurate was this data compared to field methods? Did accuracy change with varying types of terrain? How were the earthwork quantities affected?

There have been studies on obtaining cross-section data by photogrammetric methods but so far the information available concentrated on either the theoretical analysis of photogrammetry or the comparisons of earthwork by using the contour interpolation process and normal field methods. One study covering the latter method appeared in the Highway Research Record.[2]

What was needed for proper evaluation of the accuracy of earthwork derived from data obtained by digitizing directly from a stereo image was a practical approach in obtaining comparative data under semi-controlled conditions on actual construction projects. The selected projects were to reflect the varied terrain found in the State and to be within economical and practical limits.

The specific objectives of this study were as follows:

1. Determine the accuracy relationship between photogrammetric cross-section data and field cross-section data.
2. Determine these accuracies for various types of terrain.
3. Apply the knowledge gained from 1 and 2 in determining resulting earthwork differentials on highway construction projects.
4. Prepare and publish a report on the findings of this study.

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[2]Dickenson, L. A., and P. E. Warneck, "Comparative Accuracies of Field and Photogrammetric Surveys." Highway Research Record, Number 109, 1966, 49-58.

Purpose

The purpose of this report is to describe the procedures and equipment used to collect the necessary data, to explain the methods used in analyzing the data, and to compare the accuracy of earthwork derived from photogrammetrically extracted data with that of normal field methods.

Scope

The methods and procedures used to arrive at the conclusions and recommendations in this report are based on those in current practice within the Texas Highway Department. The findings are derived in part from and affected by the equipment used by the Department in their normal operations. No attempt has been made to extrapolate or compare results with other photogrammetric equipment or other field practices.

Organization

This report is divided into five parts: the first part describes the four highway construction projects used as test sections for this study; the second part outlines the methods and equipment used to obtain the comparative data; the third part presents the data and the procedures used for evaluation; the fourth part gives a mathematical analysis of the data and describes the results of using this data in the computation of earthwork quantities. The fifth part states the conclusions reached in the study.

II. DESCRIPTION OF TEST SECTIONS

The data for this study was selected from sections of proposed or current construction projects. Two prime considerations governed the selection, construction schedule and type of terrain. The construction schedule had to be such that field cross-section data could be obtained before any clearing or earthwork was done by the contractor. The proposed schedule also had to coincide with the time period allotted to this study. The Resident Engineer was required to have the necessary personnel to place the vertical control panels and obtain their elevations.

The requirement of terrain type was not imposed until all other requirements were met. A summary of the test sections selected follows.

I.H. 10, Kendall County

Figure 1, Page 7, is an oblique photograph of a section of Interstate Highway 10 in Kendall County. Cross-sections on this 2-mile test segment reflect typical interstate conditions. The terrain is hilly and rocky with a maximum elevation differential along a cross-section of approximately 40 feet.

Two sets of photogrammetric cross-sections were taken on this project, one before clearing operations began and the other after the contractor had cleared the right-of-way of vegetation.

U.S. 82, Crosby County

The Crosby County section is in the western part of the State and cuts across the White River bed. The test area is in three sections, the total length of which is 1.3 miles. The area includes two sections of flat terrain with rugged terrain in the middle. Figure 2, Page 7, shows a typical escarpment.

S.H. 360, Tarrant County

Figure 3, Page 8, is an oblique photograph of this entire test section. The section is approximately 1/2 mile long and traverses gently rolling terrain. This short project was chosen to reflect light volumetric earthwork quantities.

Loop 360, Travis County

This 3-1/2 mile section in Travis County, which is shown in Figure 4, Page 8, is part of a loop around the City of Austin and traverses rough terrain in the central Texas geological uplift area.

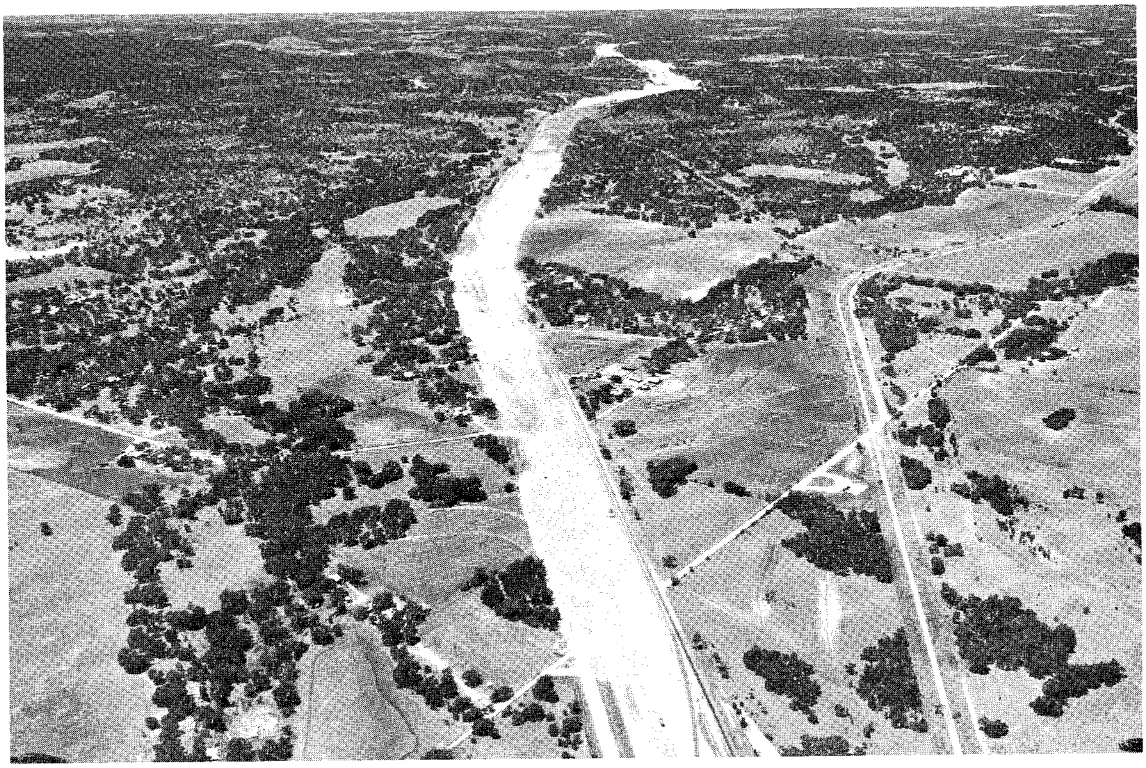

FIGURE 1. I.H.10, KENDALL COUNTY

FIGURE 2. U.S.82, CROSBY COUNTY

FIGURE 3. S.H. 360, TARRANT COUNTY

FIGURE 4. LOOP 360, TRAVIS COUNTY

III. METHODS AND EQUIPMENT

The determination of accuracies of earthwork quantities from aerial stereo photography depends not only on the equipment and operating procedures involved in photogrammetry, but also on the field methods to which it is compared. Therefore, it is necessary to determine the relative accuracy of cross-section data obtained by normal field methods before any meaningful comparison can be made.

In theory, a highway cross-section is a profile of the original ground taken perpendicular to a horizontal reference line. The cross-section consists of vertical and horizontal coordinates, that is, the elevation of a point on the ground at a specified horizontal distance from a reference line. The profile is then plotted at a convenient scale using the distances and elevations as X and Y coordinates. Between each coordinate point the profile is assumed to be a straight line. Coordinate points are chosen by the field survey crew, using their best judgment.

Some of the errors made in obtaining the data for cross-sections in the field are as follows:

1. Significant breaks in the grade are not selected.
2. A sufficient number of points are not obtained.
3. Cross-sections are not taken perpendicular to the highway centerline.
4. Horizontal distances are not obtained in a precise manner.
5. Cross-sections are not taken at significant points along the highway centerline.

Since the computation of volumes by the computer is a mathematical procedure common to all methods of obtaining original data, differences in volumetric quantities are reflected in the original data. The approach taken in this study was to try and eliminate some of the more obvious errors in normal field methods by obtaining a set of "precise" cross-section data for each project. This "precise data" became the basis for comparing both the photogrammetric information and normal field data. Specifications for the three different data collection procedures are listed separately.

Precise Cross-Sections

Precise data to be used as a basis for comparison was obtained in the following manner:

1. Distances were measured with a steel chain.
2. Right angles were turned with a transit and hubs were set every 25 feet for maintaining cross-section alignment.
3. Plus stations (other than even 100 ft stations) were chosen carefully.
4. Breaks were chosen carefully.
5. Speed in obtaining the data was discouraged.
6. The field party was told that the data was to be used for research.

Normal Field Cross-Sections

Normal field data reflected current operational field procedures.

1. The field party was unaware that the data was to be used in research.
2. Normal field practices were followed.

Photogrammetric Cross-Sections

Photogrammetric data was taken using the following specifications:

1. The photography negative scale was 1"=200'.
2. Cross-sections were digitized from a 1"=40' image.
3. No special operational procedures were used.
4. Equipment:
   a. Kelsh stereoplotter
   b. Auto-Trol Scaler Model 3900
   c. Camera - Wild RC-8, 6" focal length
5. Vertical control panels were set every 300' along the center-line and the right-of-way lines.

IV. DATA COLLECTION AND EVALUATION PROCEDURES

Classifying Data by Terrain Type

One object of this research project was to determine the accuracy relationships of earthwork computations using photogrammetric methods in various types of terrain. Classifying the test sections into terrain types was based primarily on the appearance of the stereoscopic model as shown by the photography. Each project was listed under one of the following terrain categories: (1) flat, (2) rolling, or (3) rough. Table I indicates the length of each test section and the category given to the terrain. The terms used to describe the terrain for each of the test projects are relative. By looking at the oblique photographs and the centerline profiles of each of the various test sections, one is able to see the implied relationships between flat, rolling, and rough. The centerline profiles are in the Appendix.

Erroneous Points

For this study, a $\pm$ 0.5 ft difference in elevation was considered a blunder since this approaches the accuracy that could be obtained by contour interpolation. Distances which were out of order or instrument heights and elevations which were obviously incorrect were considered erroneous points. These were usually recording errors and were larger than what had been termed a blunder.

The erroneous points were corrected before any computations were made. On the Kendall County test section, the erroneous points were tabulated. The normal and precise field readings each had 3 elevation errors and 15 distance errors. The photogrammetric cross-sections had none.

TABLE I

CLASSIFICATION OF TEST SECTIONS

HIGHWAY AND STATIONS	LENGTH IN MILES	TERRAIN DESCRIPTION
Tarrant (SH 360) 488+00 - 511+00	0.44 Mi.	Gently Rolling
Crosby (US 82) 408+00 - 432+00	0.41 Mi.	Flat
Crosby (US 82) 622+00 - 640+00	0.34 Mi.	Very Rough
Crosby (US 82) 716+00 - 746+00	0.57 Mi.	Flat
Kendall (IH 10) (Before Clearing) 434+00 - 540+00	2.00 Mi.	Rolling
Kendall (IH 10) (After Clearing) 434+00 - 540+00	2.00 Mi.	Rolling
Travis (Loop 360) 645+00 - 836+00	3.62 Mi.	Rough

Methods of Evaluating Data

The evaluation process was divided into three general categories:

1. An arithmetic comparison of elevation differences for the three sets of original cross-section data (photogrammetric, normal field, and precise field)
2. Visual inspection and analysis of the plotted original cross-sections
3. A comparison of the volumetric earthwork quantities computed using the three different sets of data.

Arithmetic Comparison. The arithmetic comparison of the data included determining differences in elevations at selected profile distances, plotting percentage error curves, and computing standard deviations. To obtain the data necessary for an error analysis, a computer program was written to calculate the differences in elevations of the selected profile points between the precise cross-section data, normal field cross-section data, and the photogrammetric cross-section data.

Profile distances left and right of the centerline were chosen at the same intervals on all three sets of data. Since the distances to the rod readings on each set were not necessarily the same, an interpolation process was used. For example, on the Tarrant County test section, profile elevations were obtained at 80, 55, 50, 40, and 25 feet left and right of the centerline and at the centerline for each station at which data was collected. This profile information was used as entry data into the computer program written to compare the elevations. The computer program then subtracted one elevation from the other to obtain the difference and counted the number of differences that were 0.1, 0.2, 0.3, 0.4, and 0.5 foot. It also counted the number of errors that exceeded 0.5 foot. The program was written so that positive errors were counted separately from negative errors. It also produced the number and magnitude of the errors according to the profile distance; that is, it would indicate the number of +0.4 foot errors and the number of -0.4 foot errors encountered at the various profile distances. The same procedure was followed on all sets of original cross-section data. Typical output sheets from this program are in the Appendix.

Visual Analysis of Plotted Sections. Visual analysis of the plotted cross-sections was made easier by writing a computer program to drive an incremental plotter. The program was written so that the scale of the plots could be varied at will and the necessary annotation could be included such as station number and centerline elevation. Figure 5 shows an example of the plotting which has the precise cross-section data plotted along with the photogrammetric data for the same station. With this program it was possible to plot all three sets of original cross-section data at a given station for a visual inspection.

Visual inspection of the plotted cross-sections revealed horizontal displacement of the break points in the cross-section data. The plots comparing the original ground as depicted by the field data and by the photogrammetric data indicated that there was as much as 5 to 7 feet difference in horizontal location of sharp breaks in the ground and 2 feet was common. On sloping ground the two plots were parallel but often separated by an elevation difference of 0.5 to 0.75 foot. Figure 6 shows the effect of horizontal displacement on elevation.

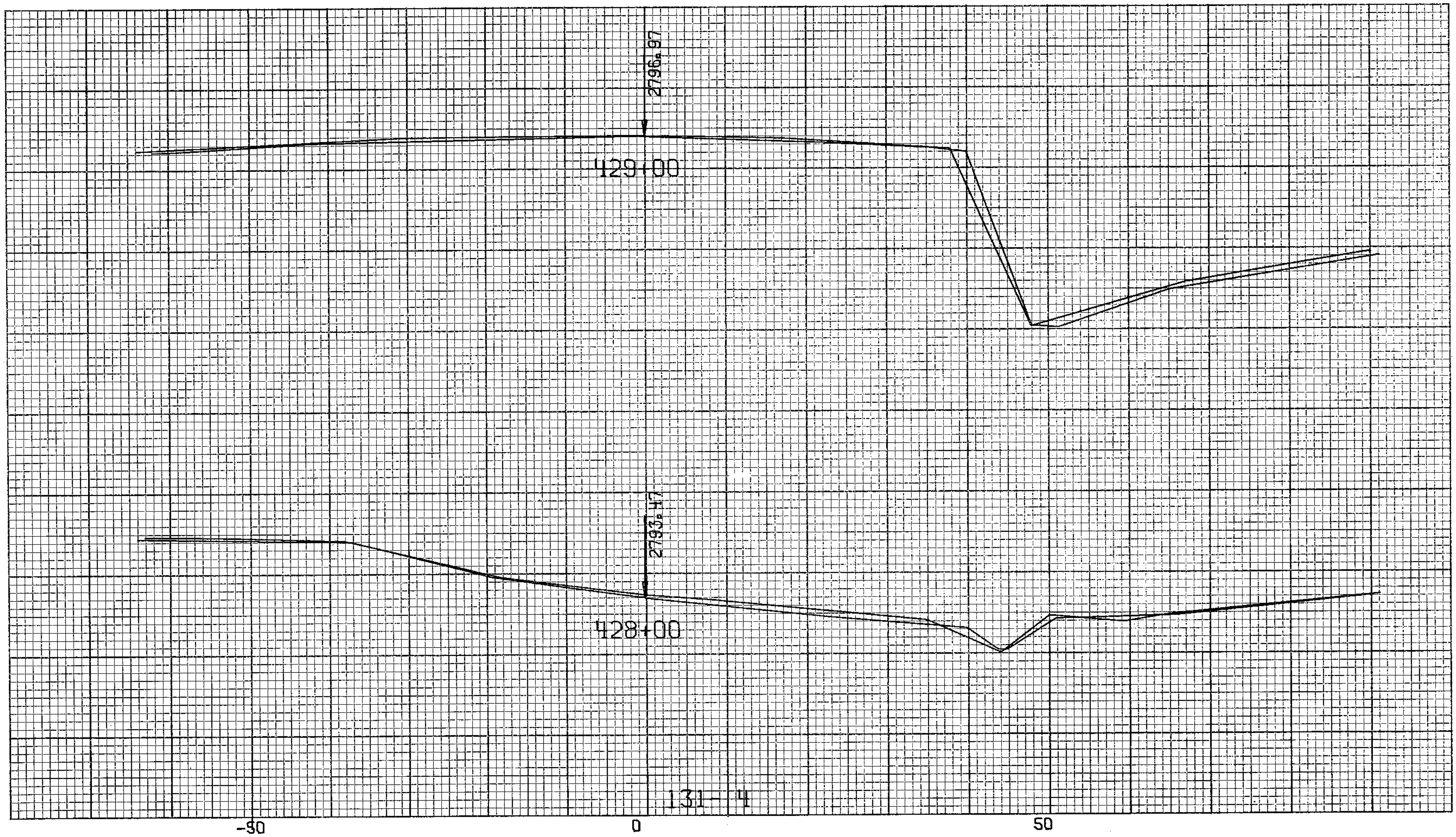

FIGURE 5. OVERLAY PLOT OF PRECISE AND PHOTOGRAMMETRIC ORIGINAL CROSS-SECTIONS

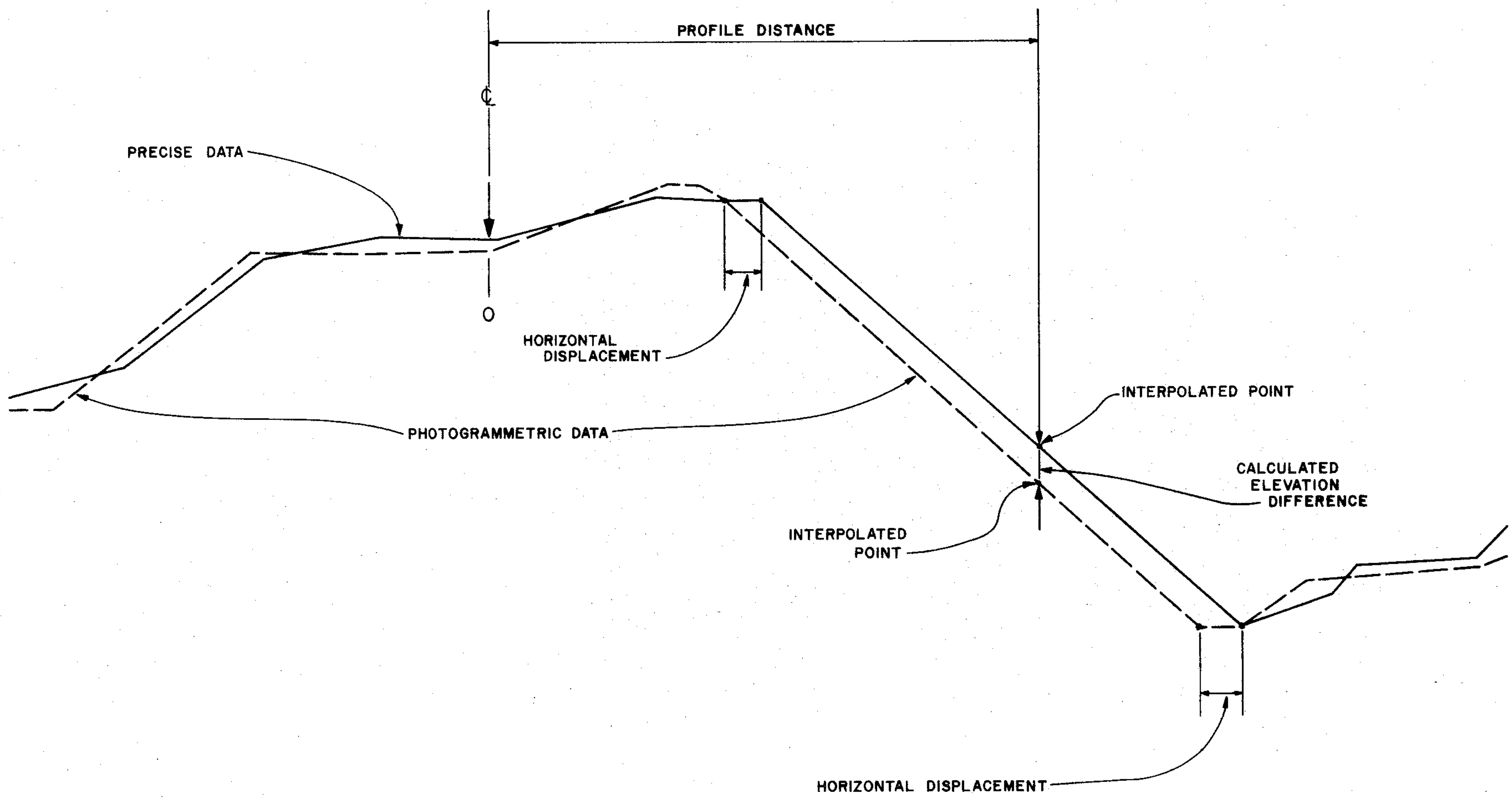

FIGURE 6. EFFECT OF HORIZONTAL DISPLACEMENT ON ELEVATION

Volumetric Comparison. Volumetric computations were made by using the Texas Highway Department earthwork computer program. This program uses the "average end area" method of volume computation. Two basic procedures were followed to obtain volumetric differences:

1. Two sets of original cross-sections were used.
2. Original cross-sections and field finals or design sections were used.

In the first case, illustrated in Figure 7, the precise cross-sections were used as original data and the photogrammetric and/or field cross-sections were applied as final templates. A volume difference was computed which indicated the relative difference between two sets of data. Table V (Page 28) contains the results.

In the second case, each set of original cross-sections was used with either the actual field finals or design templates. Table II summarizes the data used to obtain the volumetric information for each test section and Table VII (Page 31) gives the cut volume comparisons. In the volumetric comparisons, only cut volumes were used since cut volume is generally a direct pay item on most construction estimates.

Description of Data Obtained

Table II lists the actual types of data obtained on each test section. Although it was originally planned to obtain three sets of original cross-section data for each test section (photogrammetric, normal field, and precise field) construction schedules would not permit obtaining all three sets of data on all the projects. Loop 360, Travis County, developed at a later date and was included because it reflected rough terrain.

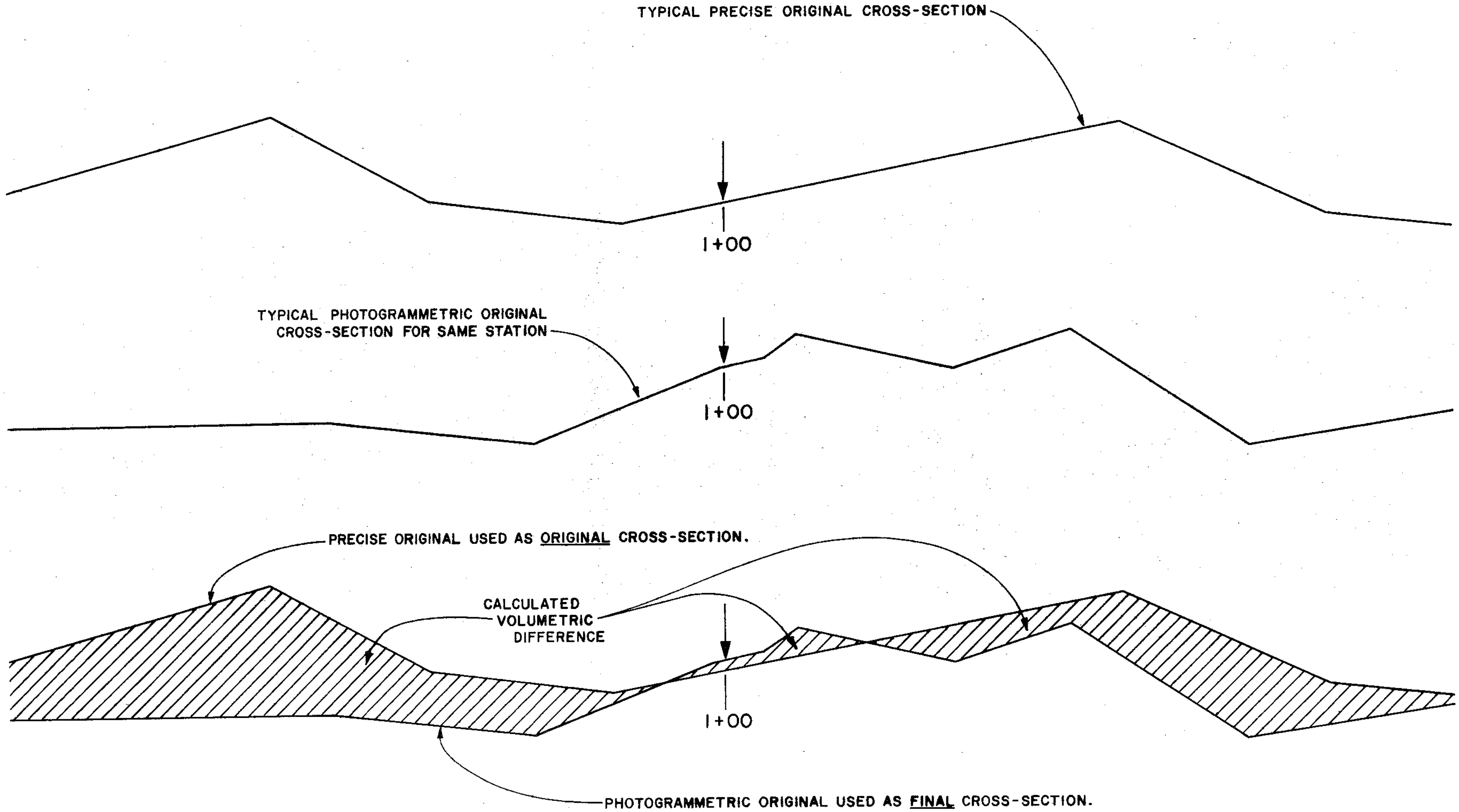

FIGURE 7. METHOD OF COMPUTING VOLUME DIFFERENCES BETWEEN TWO SETS OF ORIGINAL CROSS-SECTIONS

TABLE II

DATA AVAILABLE FOR VOLUMETRIC COMPUTATIONS

HIGHWAY AND STATIONS	ORIGINAL DATA PHOTOGRAMMETRIC	PRECISE	FIELD	FINAL DATA
Tarrant (SH 360) 488+00 - 511+00	x	x	x	Field Finals
Crosby (US 82) 408+00 - 432+00	x	x	x	Hypothetical Design
Crosby (US 82) 622+00 - 640+00	x	x		Hypothetical Design
Crosby (US 82) 716+00 - 746+00	x	x		Field Finals
Kendall (IH 10) (Before Clearing) 434+00 - 540+00	x		x	Field Finals
Kendall (IH 10) (After Clearing) 434+00 - 540+00	x	x	x	Field Finals
Travis (Loop 360) 645+00 - 836+00	x		x	Field Design

V. DISCUSSION OF RESULTS

Mathematical Analysis

The mathematical analysis of the data included calculation of standard deviations for each of the test sections and percentage distribution curves.

It should be pointed out again that elevations were interpolated at selected profile lines. These elevations were used to obtain the elevation differences. Therefore, the calculated difference in elevation may be due not only to vertical reading errors, but also to errors in horizontal displacement. Visual inspection of the plotted cross-sections reveals this to be true in numerous cases. Three examples in the Appendix illustrate this point. The interpolated profile differences, however, are considered valid for this project due to the assumption that a straight line exists between rod readings.

The percentage distribution curves in the Appendix were obtained using the precise cross-section data as a base. Where precise data was not available, the normal field information was used as a base.

Results of standard deviation calculations are shown in Table III. Elevation differences in excess of $\pm$ 0.5 foot were considered blunders and not included in the standard deviation calculations. Table IV gives the average centerline errors. These average centerline errors were computed since the centerline is a common point in all three types of original data. The centerline was staked on the ground and paneled for the photography in all the test sections except Kendall County. The details of the Kendall County test section are given under that heading.

TABLE III

STANDARD DEVIATIONS BASED ON SELECTED PROFILE ELEVATION DIFFERENCES

JOB	PRECISE/PHOTOGRAMMETRIC No. of Points	Arith. Mean	Std. Dev.	PRECISE/NORMAL FIELD No. of Points	Arith. Mean	Std. Dev.	PHOTOGRAMMETRIC/NORMAL FIELD No. of Points	Arith. Mean	Std. Dev.
TARRANT				286	0.01	0.11			
Photogrammetric (Set 1)	287	0.06	0.14				283	-0.04	0.15
Photogrammetric (Set 2)	288	-0.01	0.19				282	0.03	0.19
Photogrammetric (Set 3)	287	-0.06	0.14				285	0.07	0.17
CROSBY 400	225	-0.01	0.20	187	-0.02	0.16	191	0.00	0.20
CROSBY 700	346	0.12	0.18	-	-	-	-	-	-
AVERAGE		0.02	0.17		-0.01	0.14		0.02	0.18
KENDALL*									
Before Clearing	-	-	-	-	-	-	2,193	0.02	0.26
KENDALL*									
After Clearing	2,409	0.07	0.34	2,439	0.07	0.16	2,337	-0.01	0.22
AVERAGE FOR KENDALL COUNTY								0.01	0.24

*Photogrammetric cross-sections on the Kendall County project were taken from a reference line slightly different from the one used by the other two field parties. The calculated photogrammetric centerline lies within approximately ± 1.0 foot of the actual line.

TABLE IV

CENTERLINE ARITHMETIC AVERAGE

JOB	PRECISE/PHOTOGRAMMETRIC No. of Points	PRECISE/PHOTOGRAMMETRIC Centerline Average Difference in Feet	PRECISE/NORMAL FIELD No. of Points	PRECISE/NORMAL FIELD Centerline Average Difference in Feet
TARRANT			23	0.04
Photogrammetric (Set 1)	24	0.08		
Photogrammetric (Set 2)	24	0.01		
Photogrammetric (Set 3)	24	-0.01		
CROSBY 400	20	-0.06	20	-0.01
CROSBY 700	30	0.06	-	-
KENDALL				
After Clearing	110	0.10	113	0.08

The following paragraphs give the results on a project-to-project basis.

<u>U.S. 82, Crosby County (400 Series)</u>. The arithmetic mean difference in elevations for the normal field data is -0.02 ft with a standard deviation of 0.16 ft. For the photogrammetric data the mean is -0.01 ft with a standard deviation of 0.20 ft. There was sufficient data on this test section to compare normal field data with photogrammetric data. This comparison gives a mean of 0.00 ft and the standard deviation is 0.20 ft. The terrain in this section is relatively flat and the standard deviation of photogrammetric data is within 0.04 ft of that of the normal field procedures.

<u>U.S. 82, Crosby County (700 Series)</u>. No normal field sections were taken on this test section. The terrain is flat. Comparing the photogrammetric data with precise cross-section data yields an arithmetic mean of 0.12 ft and a standard deviation of 0.18 ft.

<u>U.S. 82, Crosby County (600 Series)</u>. No standard deviations were calculated on this section because of erroneous ground control elevations. There was not enough time to obtain corrected vertical control information before the contractor began work. Photogrammetric cross-sections were taken with the available control.

<u>S.H. 360, Tarrant County</u>. The terrain on this test section is gently rolling. All three sets of original cross-section data were obtained, and the photogrammetric data was read three times. One operator read it twice on different days (Set 1 and Set 2) and a second operator read it once (Set 3). Set 2 was considered the best because of its error distribution.

Standard deviations were calculated on all sets. Comparing Set 2 photogrammetric data with the precise sections produces an arithmetic mean of -0.01 ft and a standard deviation of 0.19 ft. The normal field data has a mean of 0.01 ft and a standard deviation of 0.11 ft. Set 1 has a mean of 0.06 ft and Set 3 has a mean of -0.06 ft. It is interesting to note, however, that the standard deviation in both cases is the same, 0.14 ft.

I.H. 10, Kendall County. The centerline used by the two field parties was not paneled for photography. There was some difficulty in duplicating analytically the centerline in the photography exactly as it was staked on the ground because of inconsistent horizontal control information. This inconsistency was not discovered until after the photogrammetric cross-sections were obtained. Investigation shows that the reference line used for the photogrammetric cross-sections was removed from the reference line used by both field parties by as much as one foot or more in some places. The terrain is rolling. The horizontal displacement of the photogrammetric reference line for cross-sections caused more vertical error than should be expected. However, standard deviations were calculated and they appear at the bottom of Table III. The photogrammetric cross-sections after clearing have an arithmetic mean of 0.07 ft and a standard deviation of 0.34 ft. The effect of the displaced reference line for the photogrammetric cross-sections is reflected by the standard deviation of 0.34 ft and the average centerline difference of 0.10 ft.

Loop 360, Travis County. The normal field sections taken by the Resident Engineer on this project were not sufficiently accurate for use in the calculation of standard deviations. Because of the extremely thick vegetation and rough terrain, the Resident Engineer took rod readings approximately every 50 feet along each cross-section. This was sufficient for obtaining plan quantities but did not contain enough points to depict the shape of the section when compared to photogrammetric data. The field cross-sections were used as a basis of comparison for volumetric calculations since this data was used in determining the actual plan quantities.

Average Standard Deviations. For photogrammetric data the average mean of the distributions for Tarrant and Crosby Counties is approximately 0.02 ft; the average standard deviation is approximately 0.17 ft. The average mean of the distribution for the normal field cross-sections is -0.01 ft and the average standard deviation is 0.14 ft.

Volumetric Analysis

In analyzing the volumetric quantities, the following determinations were made:

1. The difference between two sets of original data with the precise cross-sections used as a base.
2. The average depth between two sets of original cross-sections using the data obtained above.
3. The difference between original cross-section data and actual final cross-sections or design templates.
4. The effect of plus stations on volumetric quantities.

Difference in Original Ground. The difference between two sets of original data was determined by computing the difference in their volumes. The precise cross-sections were used as a base. Figure 7, Page 19, illustrates the method employed and Table V gives the results.

As mentioned earlier, three sets of photogrammetric cross-sections were taken on the Tarrant County project. The difference in cut volumes obtained using the same photographs and the same equipment can, therefore, be compared. On each project the precise cross-section data was taken by a field party different from the party taking the normal field sections. Since the two field parties for Tarrant County differed by 636 cubic yards of cut volume, the spread of volumes indicated by the three sets of photogrammetric originals is not excessive.

Average Depth. The volumetric differences between two sets of original data as found in Table V were converted to a common parameter. The accumulated cut volume at each station was divided by the accumulated plane area. This calculation gave an average depth in yards which was termed a depth factor. The depth factors were averaged for each 5000 square yards of plane area. Table VI gives the results.

For photogrammetric data there is a difference in magnitude of the depth factors for each test section; however, the general trend is the same. The depth factor for normal field data is consistent. The overall average of the depth factors for photogrammetric data is near 0.03 yd, while the normal field data is 0.02 yd. The average depth factor of 0.03 yd multiplied by the number of square yards of disturbed plane area is an indication of the volumetric error an engineer can expect on a particular project by using photogrammetric methods.

TABLE V

ORIGINAL CUT VOLUME COMPARISONS IN CUBIC YARDS
(All Data is Original Terrain)

JOB	APPROXIMATE FINAL CUT QUANTITY CUBIC YARDS	PRECISE WITH PHOTOGRAMMETRIC AS TEMPLATE DIFFERENCE IN CUBIC YARDS	PRECISE WITH NORMAL FIELD AS TEMPLATE DIFFERENCE IN CUBIC YARDS
TARRANT			
Photogrammetric (Set 1)	11,000	1,333	636
Photogrammetric (Set 2)		962	
Photogrammetric (Set 3)		512	
CROSBY 400	12,000	965	874
CROSBY 700	12,000	2,578	-
CROSBY 600	63,000	5,908	-
KENDALL			
After Clearing	389,000	21,502	17,957

TABLE VI

DEPTH FACTORS

Accumulated Plane Area in Square Yards	Photogrammetric/Precise Difference in Yards: Tarrant Set 1	Tarrant Set 2	Tarrant Set 3	Crosby 400	Crosby 600	Crosby 700	Kendall After Clearing	Normal Field/Precise Difference in Yards: Tarrant	Crosby 400	Kendall After Clearing
0 - 5,000	.02	.03	.03	.02	.02	.03	.03	.02	.02	.02
5,000 - 10,000	.04	.04	.02	.02	.02	.04	.02	.02	.01	.02
10,000 - 15,000	.03	.03	.01	.02	.03	.05	.02	.02	.02	.02
15,000 - 20,000	.03	.03	.01	.02	.05	.05	.02	.02	.02	.02
20,000 - 25,000	.03	.02	.01	.03	.06	.05	.01	.02	.02	.02
25,000 - 30,000	.03	.02	.01	.03	.08	.04	.02	.02	.02	.02
30,000 - 35,000	.03	.02	.01	.03	.09	.05	.03	.02	.02	.02
35,000 - 40,000	.03	.02	.01	-	.09	.06	.03	.02	-	.02
Over 40,000	-	-	-	-	.12	.05	.05	-	-	.03
Average*	.03	.03	.01	.02	.06	.05	.04	.02	.02	.03
OVERALL AVERAGE				.03					.02	

*Average based on all stations in the test section.

Final Volumes. The volumetric quantities based on final cross-sections or design templates were examined for significant trends. Table VII shows the final cut volume comparisons and the percentage difference when the volume computed from the precise cross-section data is used as a base. At volumes less than approximately 15,000 cubic yards, the percentage difference from photogrammetric sections appears to be inconsistent. When volumes exceed approximately 50,000 cubic yards, the photogrammetric cross-section data produces differences near $\pm$ 1% of what was obtained by a field party.

The information in Table VII has been plotted and the graph is shown in Figure 8. The dashed line is an approximate curve based on the data in Table VII. Most Resident Engineers believe that duplication of volumetric quantities within plus or minus three per cent can be obtained from data taken by two different field parties. Figure 8 indicates that photogrammetric cross-section data averaged within these limits for project volumes greater than 15,000 cubic yards.

It should be noted that the project volumes shown in Table VII reflect differences which exist between the cross-sections obtained by the precise field party and those obtained by photogrammetric methods, and that these differences in cross-sections constitute the sole reason for the volume difference regardless of the project volume. A short project with heavy grading would be expected to have a lower percentage of volume error than a long project with light grading and an equivalent total project volume.

TABLE VII

FINAL CUT VOLUME COMPARISON IN CUBIC YARDS

JOB	ACCUMULATED CUT	PER CENT OF PRECISE
TARRANT		
Photogrammetric (Set 1)	10,529	4.9
Photogrammetric (Set 2)	11,095	-0.2
Photogrammetric (Set 3)	11,395	-2.9
Normal Field	10,919	1.4
Precise	11,073	-
CROSBY 400		
Photogrammetric	12,151	1.2
Normal Field	12,414	-1.0
Precise	12,294	-
CROSBY 700		
Photogrammetric	11,436	11.0
Normal Field	-	-
Precise	12,855	-
CROSBY 600		
Photogrammetric	63,158	0.6
Normal Field	-	-
Precise	63,563	-
KENDALL - Before Clearing		
Photogrammetric	390,859	0.7
Normal Field	393,464	-
Precise	-	-
KENDALL - After Clearing		
Photogrammetric	388,362	1.0
Normal Field	385,155	0.2
Precise	392,163	-
TRAVIS		
Photogrammetric	888,248	-1.1
Normal Field	878,613	-
Precise	-	-

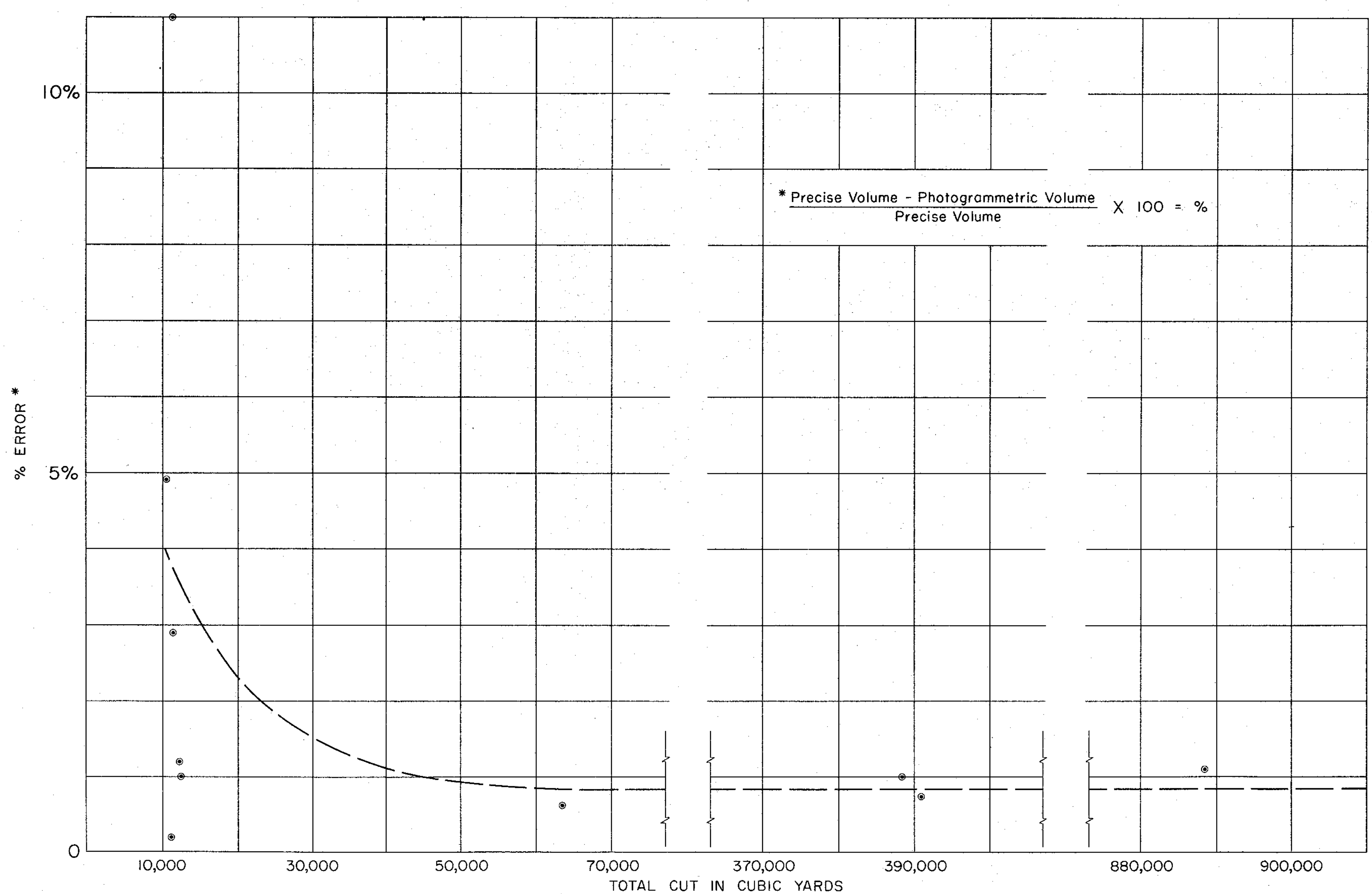

FIGURE 8. APPROXIMATE PHOTOGRAMMETRIC ERROR CURVE

The average depth factor was applied to the final volumes for the test sections, and the results compared favorably to the actual volumetric errors listed in Table VII. The depth factor indicates that the volumetric error one can expect is a function of two factors:

1. The size of area to be disturbed.
2. The depth of excavation.

Therefore, projects with high plane areas and shallow cuts will produce volumetric errors larger than smaller plane areas with much deeper cuts, even though their total volumetric quantities are the same.

Plus Stations. The relative influence of plus stations on volumetric computations was examined since observation reveals that as a general practice photogrammetry obtains significantly more plus stations than those taken by normal field procedures. On the Kendall County project, volumetric quantities were obtained for a one-mile segment using the original field data and final cross-sections. The plus stations were then removed and the volumes recomputed. The identical procedure was followed with precise data and the results are shown in Table VIII. The difference in volumes in both cases was less than one per cent.

TABLE VIII

KENDALL COUNTY ACCUMULATED CUT VOLUMES
WITH AND WITHOUT PLUS STATIONS

	NORMAL FIELD			PRECISE FIELD		
STATION	Acc. Cut Without Plus Sta.	Acc. Cut With Plus Sta.	No. of Plus Sta.	Acc. Cut Without Plus Sta.	Acc. Cut With Plus Sta.	No. of Plus Sta.
434+00	-	-	-	-	-	-
435+00	38	50	2	37	37	0
436+00	89	94	5	87	87	0
437+00	122	127	0	122	122	0
438+00	138	143	0	140	140	0
439+00	152	157	0	155	155	0
440+00	164	175	2	168	175	2
441+00	171	184	1	178	187	1
442+00	224	237	0	230	239	0
443+00	291	364	1	295	364	1
444+00	473	546	0	492	561	0
445+00	983	1,056	0	1,025	1,094	0
446+00	1,784	1,865	3	1,841	1,916	1
447+00	2,790	2,871	0	2,871	2,946	0
448+00	3,765	3,859	4	3,904	3,979	0
449+00	4,812	4,906	0	4,991	5,066	0
450+00	5,977	6,071	0	6,148	6,223	0
451+00	7,088	7,182	0	7,302	7,377	0
452+00	8,110	8,307	1	8,409	8.484	0
453+00	8,830	9,219	2	9,169	9,244	0
454+00	9,179	9,568	0	9,520	9,595	0
455+00	9,316	9,705	0	9,662	9,737	0
456+00	9,464	9,853	0	9,792	9,867	0
457+00	9,598	9,997	2	9,913	9,988	0
458+00	9,638	10,037	0	9,966	10,041	0
459+00	9,638	10,037	2	9,966	10,041	0
460+00	9,638	10,037	0	9,966	10,041	0
461+00	9,638	10,037	0	9,966	10,041	0
462+00	9,638	10,037	4	9,966	10,041	0
463+00	9,638	10,037	0	9,966	10,041	0
464+00	9,638	10,037	1	9,966	10,041	1
465+00	10,157	10,511	2	10,516	10,532	2
466+00	11,401	11,981	3	11,809	11,912	1
467+00	12,403	12,942	1	12,842	12,945	0
468+00	12,807	13,259	1	13,268	13,371	0
469+00	12,973	13,421	1	13,450	13,553	0
470+00	13,013	13,450	2	13,497	13,600	0
471+00	13,014	13,451	2	13,498	13,601	0
472+00	13,015	13,452	5	13,500	13,606	1
473+00	13,017	13,454	0	13,503	13,609	0
474+00	13,023	13,464	1	13,522	13,628	0
475+00	13,210	13,641	0	13,721	13,827	0
476+00	14,113	14,486	2	14,668	14,774	0
477+00	16,191	16,425	2	16,793	16,899	0
478+00	19,378	19,569	1	19,956	20,062	0
479+00	23,442	23,576	2	24,063	24,169	0
480+00	28,684	28,818	0	29,406	29,512	0
481+00	35,436	35,558	1	36,311	36,391	1
482+00	44,398	44,509	1	45,409	45,489	0
483+00	55,766	55,877	0	56,907	56,987	0
484+00	69,532	69,511	2	70,813	70,749	1
485+00	85,520	85,499	0	86,948	86,884	0
486+00	103,170	103,208	2	104,762	104,755	2
487+00	121,211	121,488	2	123,011	123,004	0

VI. CONCLUSIONS

The following conclusions are based on the data used in this research project.

1. The average standard deviation between precise field and photogrammetric measurements (exclusive of Kendall County) is $\pm$ 0.17 ft. The average arithmetic mean is 0.02 ft. The average standard deviation between the precise field and normal field measurements (exclusive of Kendall County) is $\pm$ 0.14 ft. The average arithmetic mean is -0.01 ft. These values approximate the current specifications for photogrammetric cross-section accuracy at the Texas Highway Department.
2. Photogrammetric cross-sections have fewer points that are obviously in error than field measurements.
3. The difference in horizontal placement of cross-section points between photogrammetric methods and field methods affects the general shape of the cross-sections more than the difference in elevation placement does. Because of the ease and accuracy of making measurements, overall photogrammetric horizontal displacement is less than by field methods in rough terrain. (The horizontal unit of the Auto-Trol is accurate to 0.001 inch.[3])
4. The errors in volumetric quantities computed from photogrammetric data are a function of the size of the plane area disturbed and the depth of cut.

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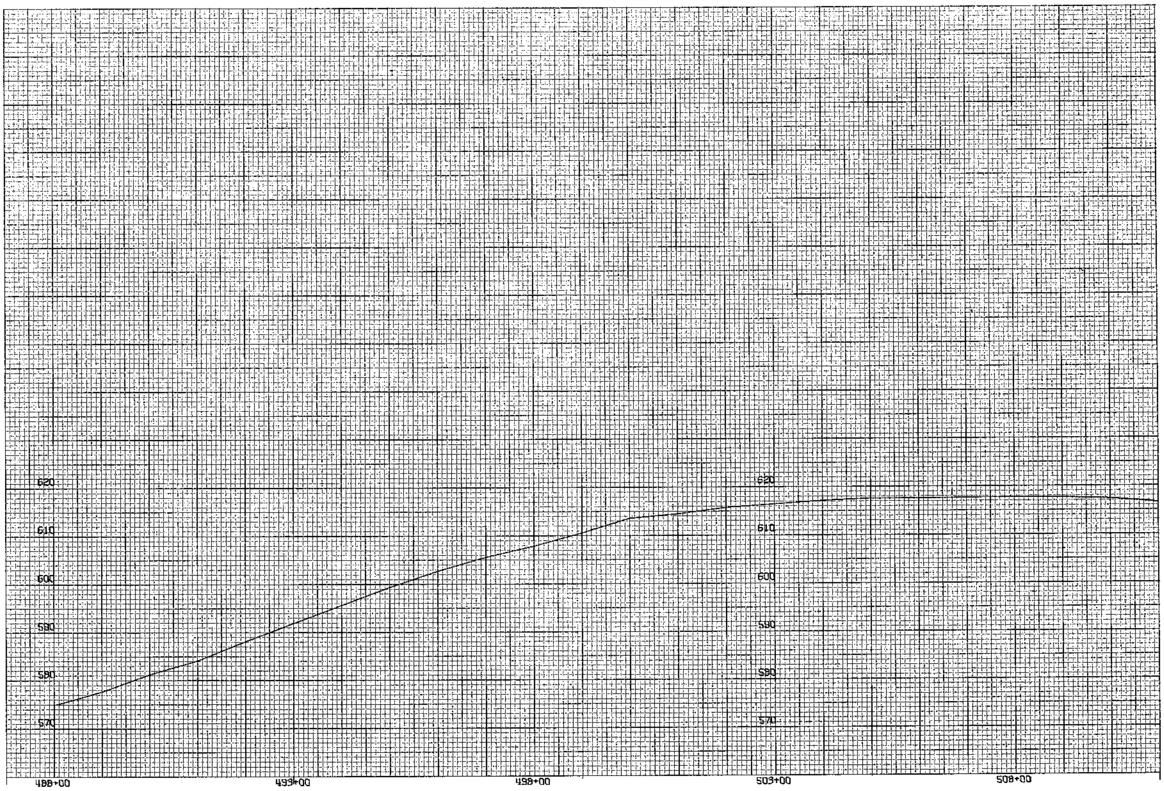
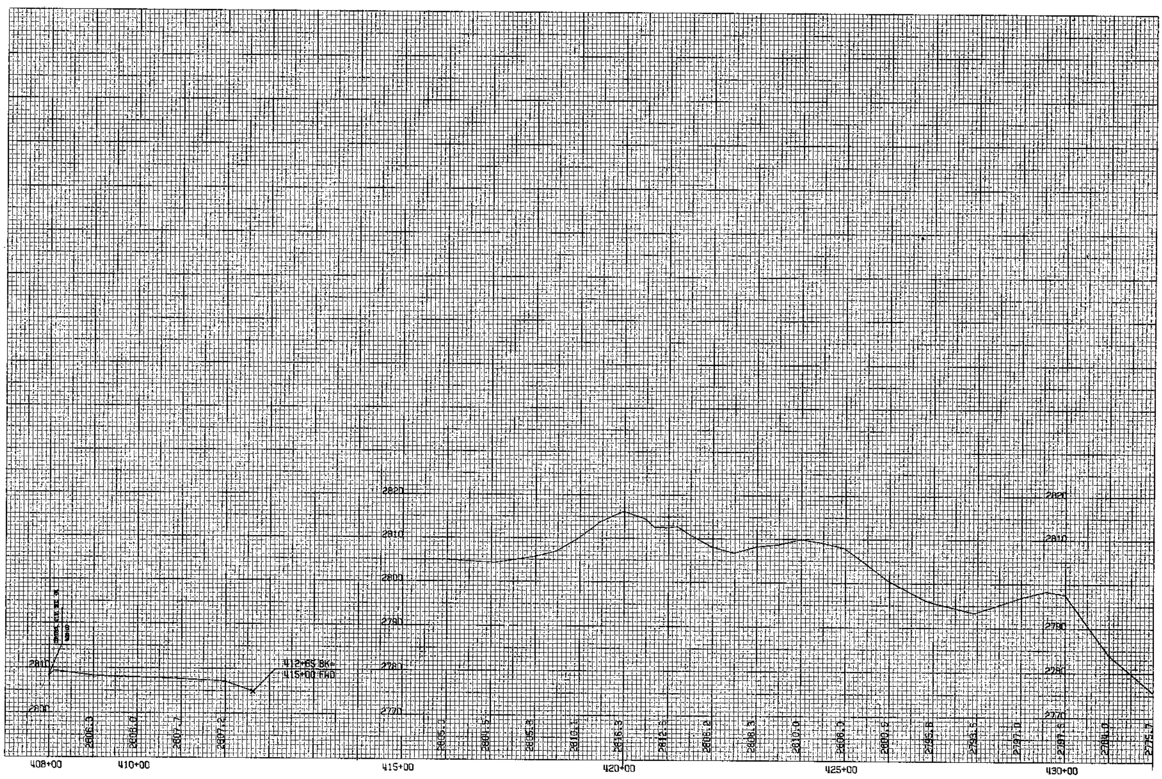
[3] Mangum, p. 30.

5. When photogrammetric data is used, the probable maximum volumetric error can be estimated by multiplying the depth factor of 0.03 yd by the approximate square yards of earth movement on a project. The result is the volume difference in cubic yards.
6. When photogrammetric methods are used, projects with large plane areas and light grading produce volumetric errors larger than projects with smaller plane areas and heavy grading.
7. Volumetric quantities determined from photogrammetric data are sufficiently accurate for contractual payment and design. The differences in volume for the various types of data are inconsistent when quantities are less than 15,000 cubic yards. On projects involving 50,000 cubic yards or more, there is a volumetric difference of approximately ± 1%.
8. On large volumetric projects additional plus stations do not significantly affect the volumetric computations.

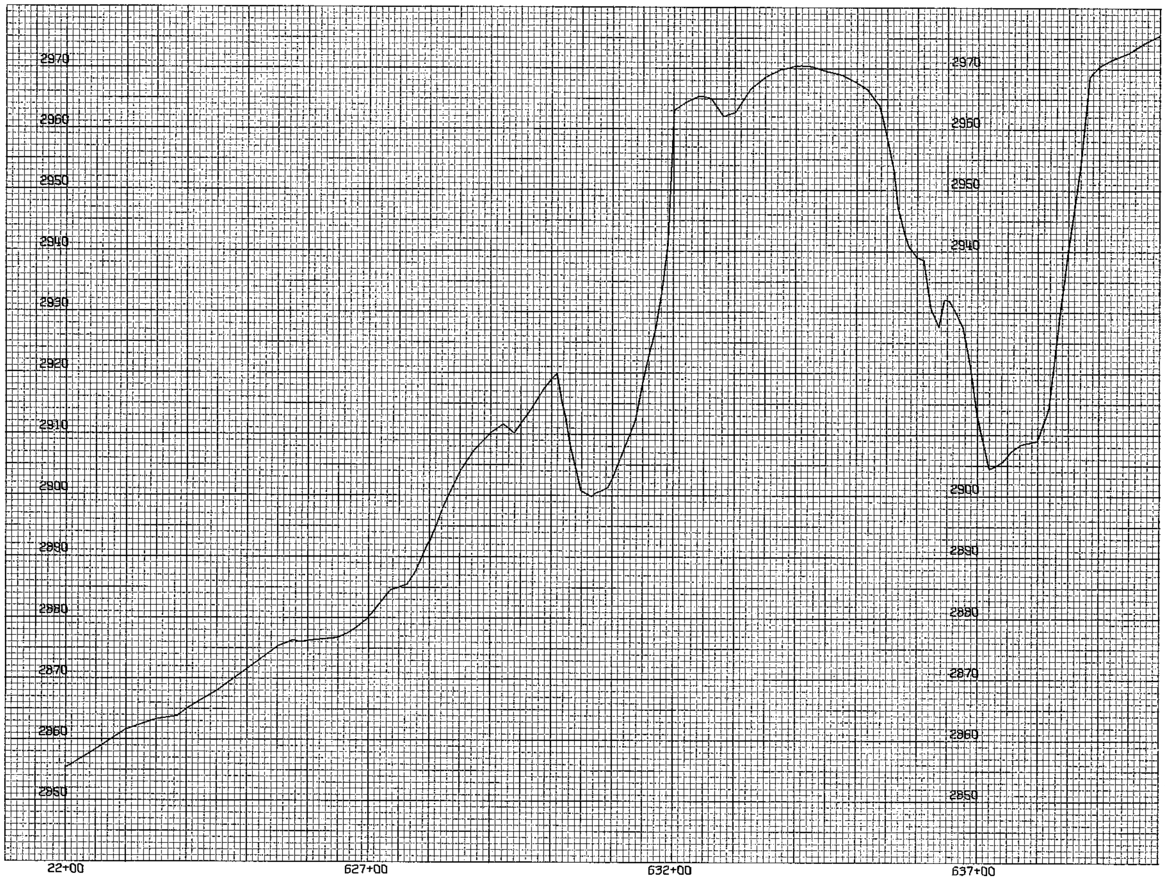
APPENDIX



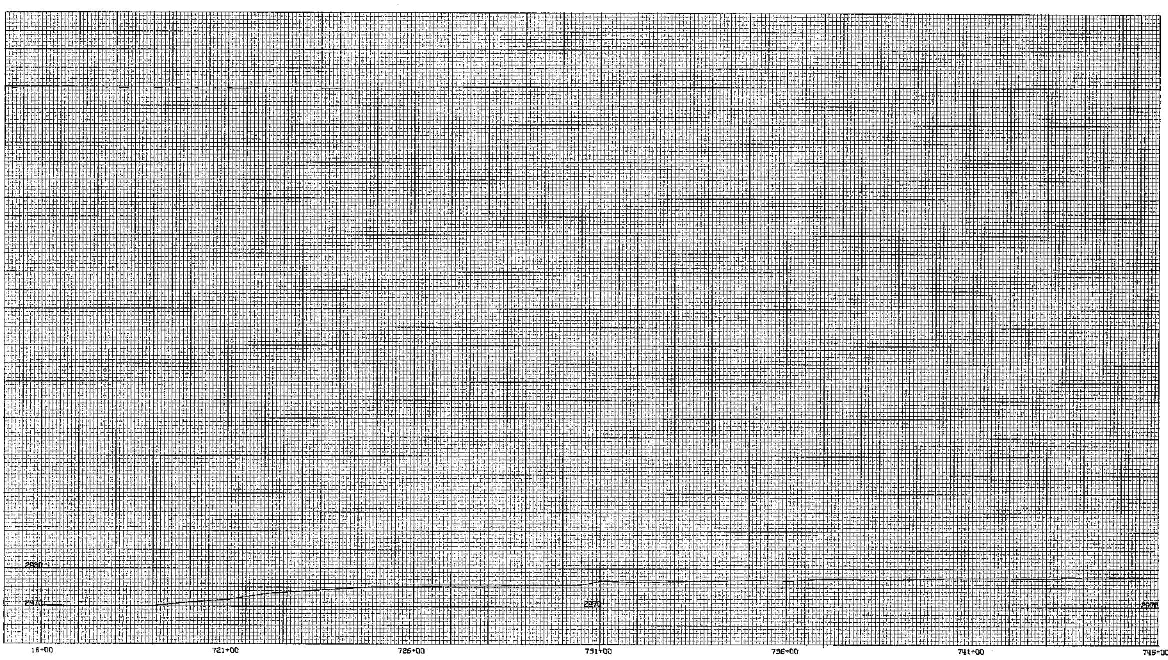
TARRANT CENTERLINE PROFILE



CROSBY 400 CENTERLINE PROFILE



CROSBY 600 CENTERLINE PROFILE



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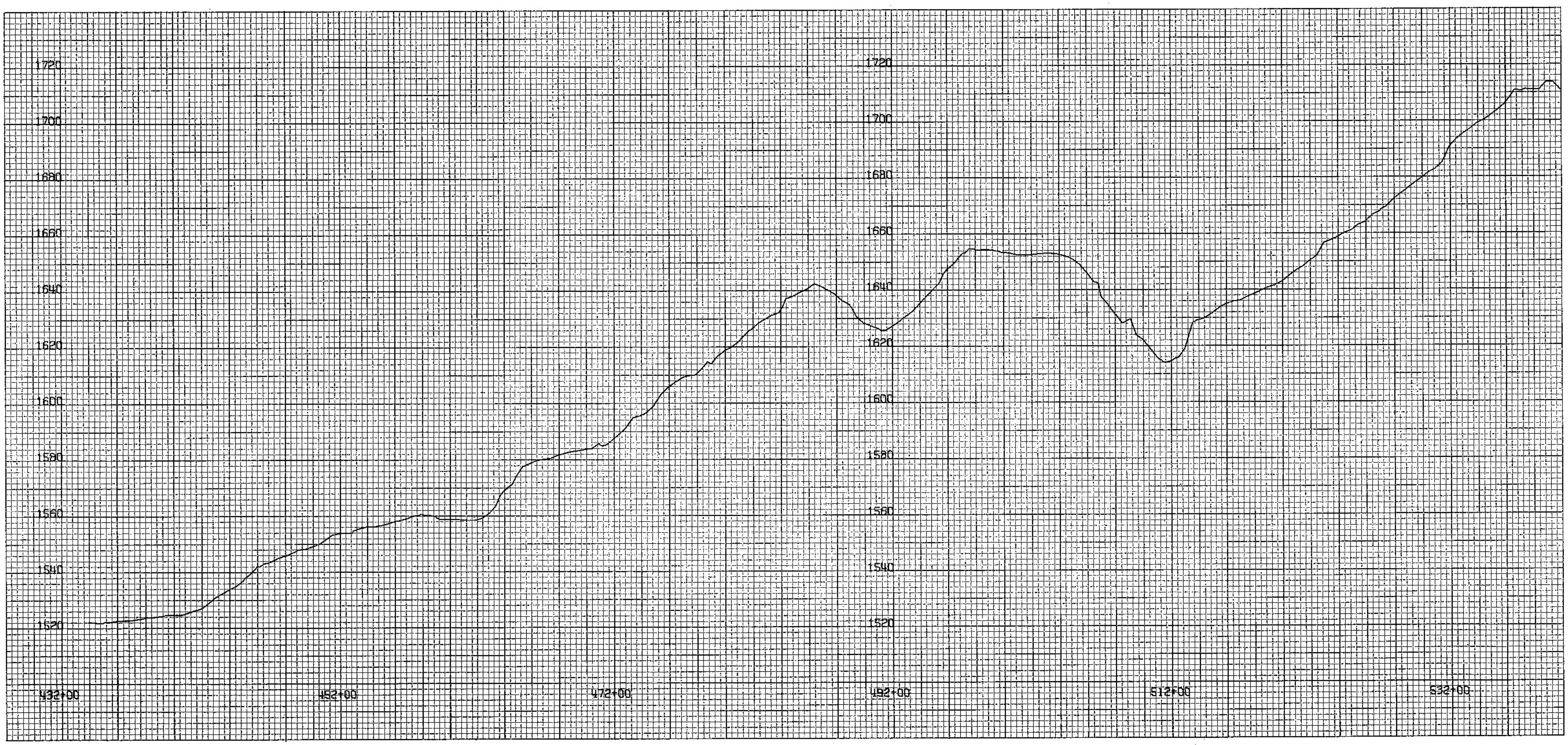
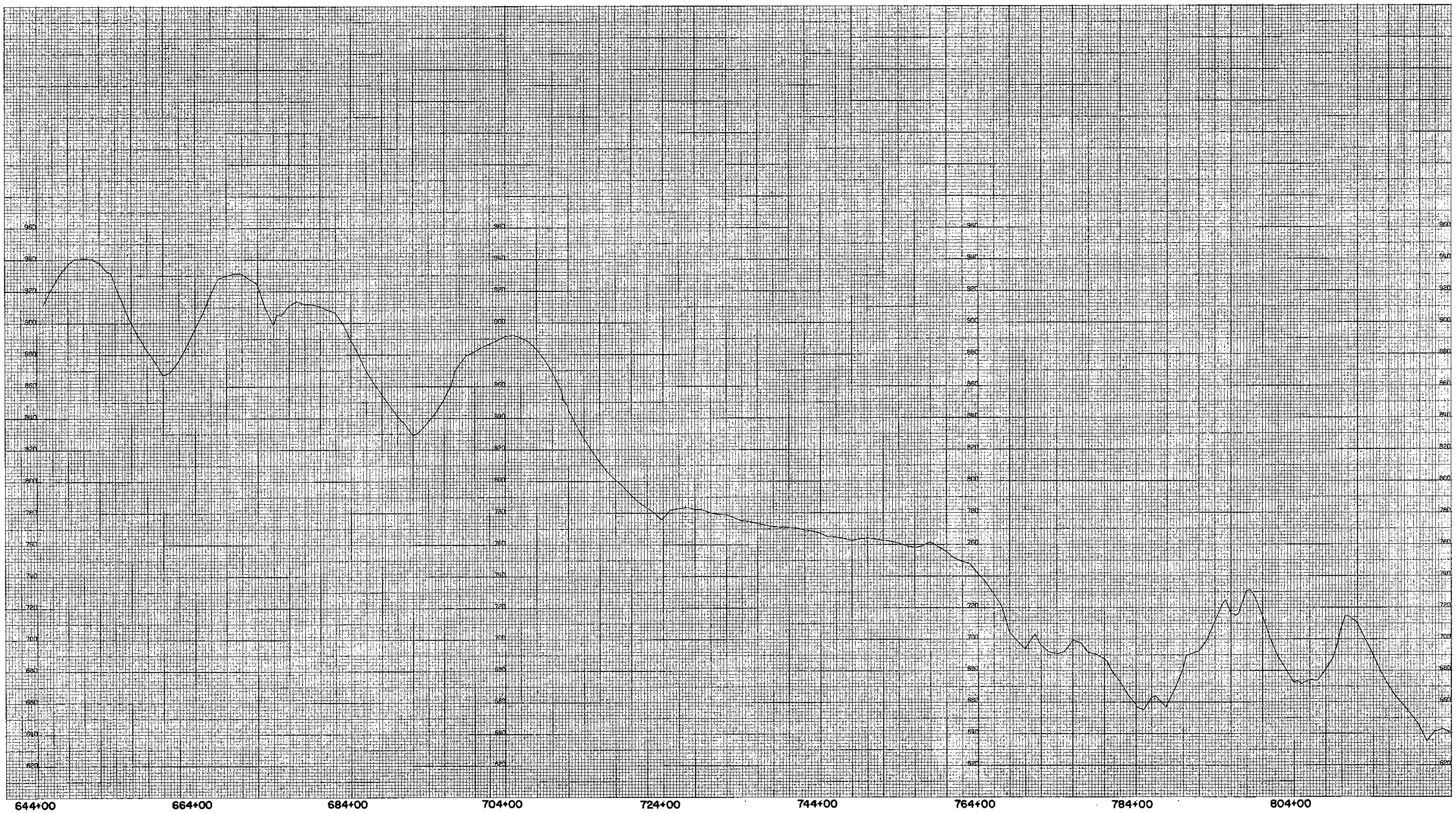


KENDALL CENTERLINE PROFILE



TRAVIS CENTERLINE PROFILE

TEXAS HIGHWAY DEPARTMENT

PRECISE, AUTOTROL, AND FIELD DIFFERENCES

PRECISE CONTROL 2266 SEC 12   FIELD CONTROL 2266 SEC 22   AUTOTROL CONTROL 2266 SEC 98

STATION 488 + 00

PROF. DIST.	80.0 L	55.0 L	50.0 L	40.0 L	25.0 L	0.0 R	25.0 R	40.0 R	50.0 R	55.0 R	60.0 R	80.0 R
DATA SET 1 2												
P-A	0.2	0.3	0.3	0.2	0.2	0.1	0.1	0.2	0.4	0.0	0.3	0.1
P-F	-0.1	-0.0	-0.0	-0.0	-0.1	-0.7	-0.0	0.1	0.3	-0.1	0.2	0.0
A-F	-0.2	-0.4	-0.4	-0.3	-0.2	-0.7	-0.1	-0.1	-0.1	-0.1	-0.1	-0.0

STATION 489 + 00

PROF. DIST.	80.0 L	55.0 L	50.0 L	40.0 L	25.0 L	0.0 R	25.0 R	40.0 R	50.0 R	55.0 R	60.0 R	80.0 R
DATA SET 1 2												
P-A	-0.1	0.1	0.1	0.2	0.0	0.1	-0.1	-0.1	-0.2	-0.3	-0.3	-0.3
P-F	0.0	0.1	0.1	0.1	0.1	0.0	0.1	-0.0	-0.1	-0.1	-0.1	-0.1
A-F	0.2	-0.1	-0.1	-0.1	0.1	-0.0	0.2	0.1	0.1	0.2	0.2	0.3

STATION 490 + 00

PROF. DIST.	80.0 L	55.0 L	50.0 L	40.0 L	25.0 L	0.0 R	25.0 R	40.0 R	50.0 R	55.0 R	60.0 R	80.0 R
DATA SET 1 2												
P-A	-0.0	0.1	0.1	0.1	0.1	0.1	-0.0	-0.0	0.1	-0.3	-0.3	0.1
P-F	-0.0	-0.0	0.0	0.0	0.0	0.1	-0.0	0.1	0.1	-0.0	-0.0	0.1
A-F	-0.0	-0.1	-0.1	-0.1	-0.1	-0.0	-0.0	0.1	0.0	0.2	0.2	-0.0

STATION 491 + 00

PROF. DIST.	80.0 L	55.0 L	50.0 L	40.0 L	25.0 L	0.0 R	25.0 R	40.0 R	50.0 R	55.0 R	60.0 R	80.0 R
DATA SET 1 2												
P-A	-0.1	0.1	0.1	0.0	0.1	-0.0	0.3	-0.4	0.0	-0.0	-0.2	-0.7

***NOTE-IF SIGN OF RESULT IS A MINUS, VALUE OF DATA SET 2 WAS LARGER THAN DATA SET 1.
** INDICATES ONE OR BOTH READINGS WERE ZERO ELEVATION.

TYPICAL COMPUTER LISTING OF PROFILE DIFFERENCES FOR EACH STATION

TEXAS HIGHWAY DEPARTMENT

PRECISE, AUTOTROL, AND FIELD DIFFERENCES

PRECISE CONTROL 2266 SEC 12   FIELD CONTROL 2266 SEC 22   AUTOTROL CONTROL 2266 SEC 98

ERRORS BY PROFILE DISTANCE - CALCULATED BY COMPARISON TO PRECISE READINGS

	+0.5		+0.4		+0.3		+0.2		+0.1		0.0		-0.1		-0.2		-0.3		-0.4		-0.5		TOTALS	
	A	F	A	F	A	F	A	F	A	F	A	F	A	F	A	F	A	F	A	F	A	F	*A	*F
80.0 L	0	0	1	0	0	0	1	0	3	10	7	12	9	2	2	0	0	0	1	0	0	0	24	24
55.0 L	0	0	3	0	1	0	1	0	8	7	4	10	2	5	5	0	0	1	0	1	0	0	24	24
50.0 L	2	0	1	0	1	0	1	0	8	8	3	10	5	3	3	1	0	2	0	0	0	0	24	24
40.0 L	0	0	2	0	1	0	3	1	6	10	1	9	8	3	1	1	2	0	0	0	0	0	24	24
25.0 L	0	0	0	0	1	0	5	3	5	11	4	8	5	2	4	0	0	0	0	0	0	0	24	24
0.0 R	0	0	0	0	0	0	2	0	6	10	11	13	3	0	1	0	1	0	0	0	0	0	24	23
25.0 R	0	0	0	0	3	0	4	1	4	9	4	10	6	4	2	0	0	0	1	0	0	0	24	24
40.0 R	0	0	1	1	1	0	2	0	5	10	5	10	5	2	1	1	2	0	2	0	0	0	24	24
50.0 R	0	0	1	0	1	2	4	1	2	6	5	5	2	6	5	4	3	0	1	0	0	0	24	24
55.0 R	0	0	0	0	0	0	4	1	1	3	6	9	3	9	4	1	5	0	1	0	0	0	24	23
60.0 R	0	1	0	0	3	0	3	1	3	2	2	7	2	11	5	2	3	0	2	0	1	0	24	24
80.0 R	0	0	0	0	0	0	1	0	3	7	6	11	5	4	2	2	4	0	2	0	0	0	23	24
TOTALS	2	1	9	1	12	2	31	8	54	93	58	114	55	51	35	12	20	3	10	1	1	0		

ERRORS EXCEEDING +0.5

AUTOTROL= 0
DISTRICT= 1

COMPLETE AUTOTROL TOTALS= 288

ERRORS EXCEEDING -0.5

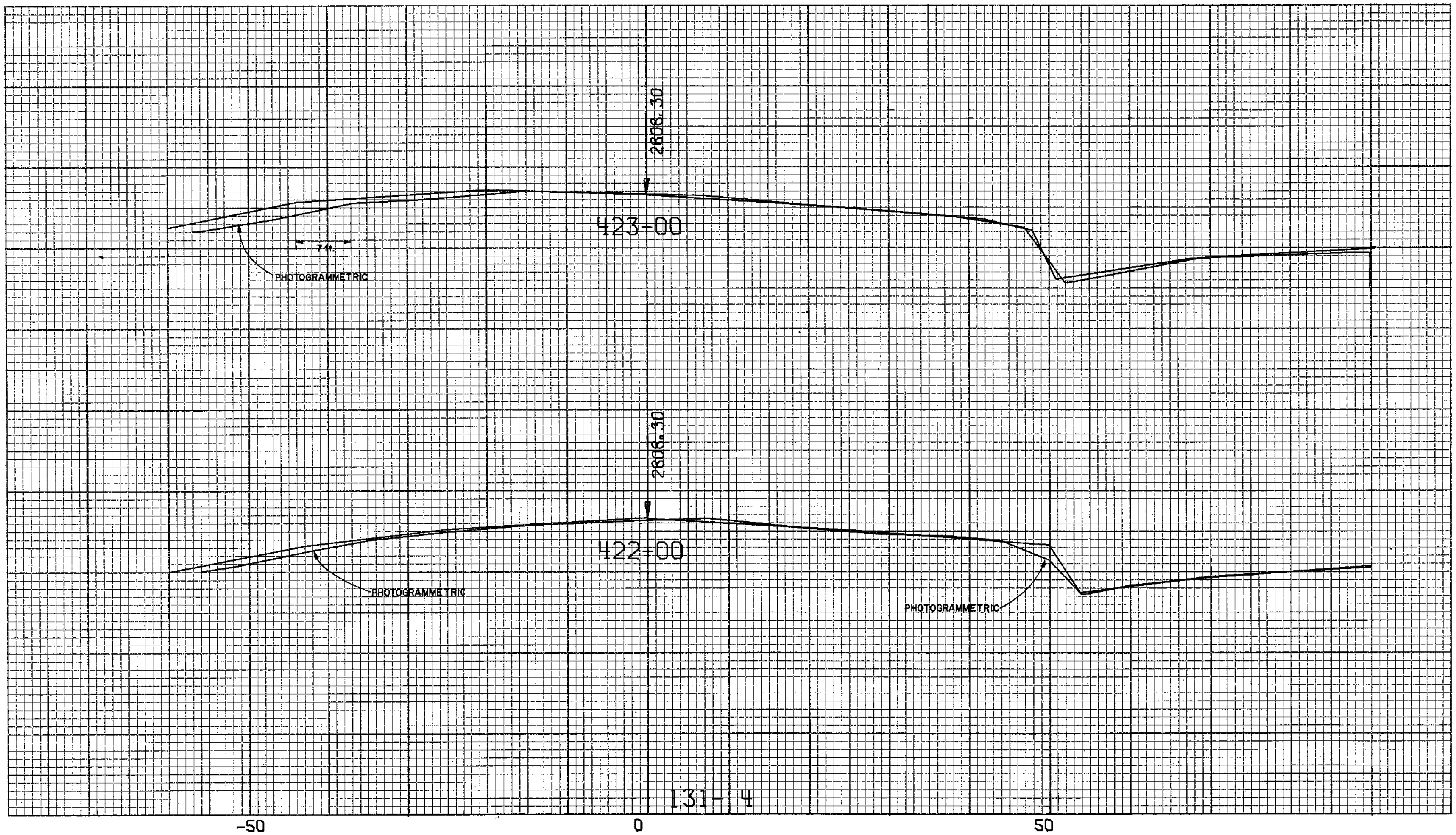
AUTOTROL= 1
DISTRICT= 1

COMPLETE DISTRICT TOTALS= 288

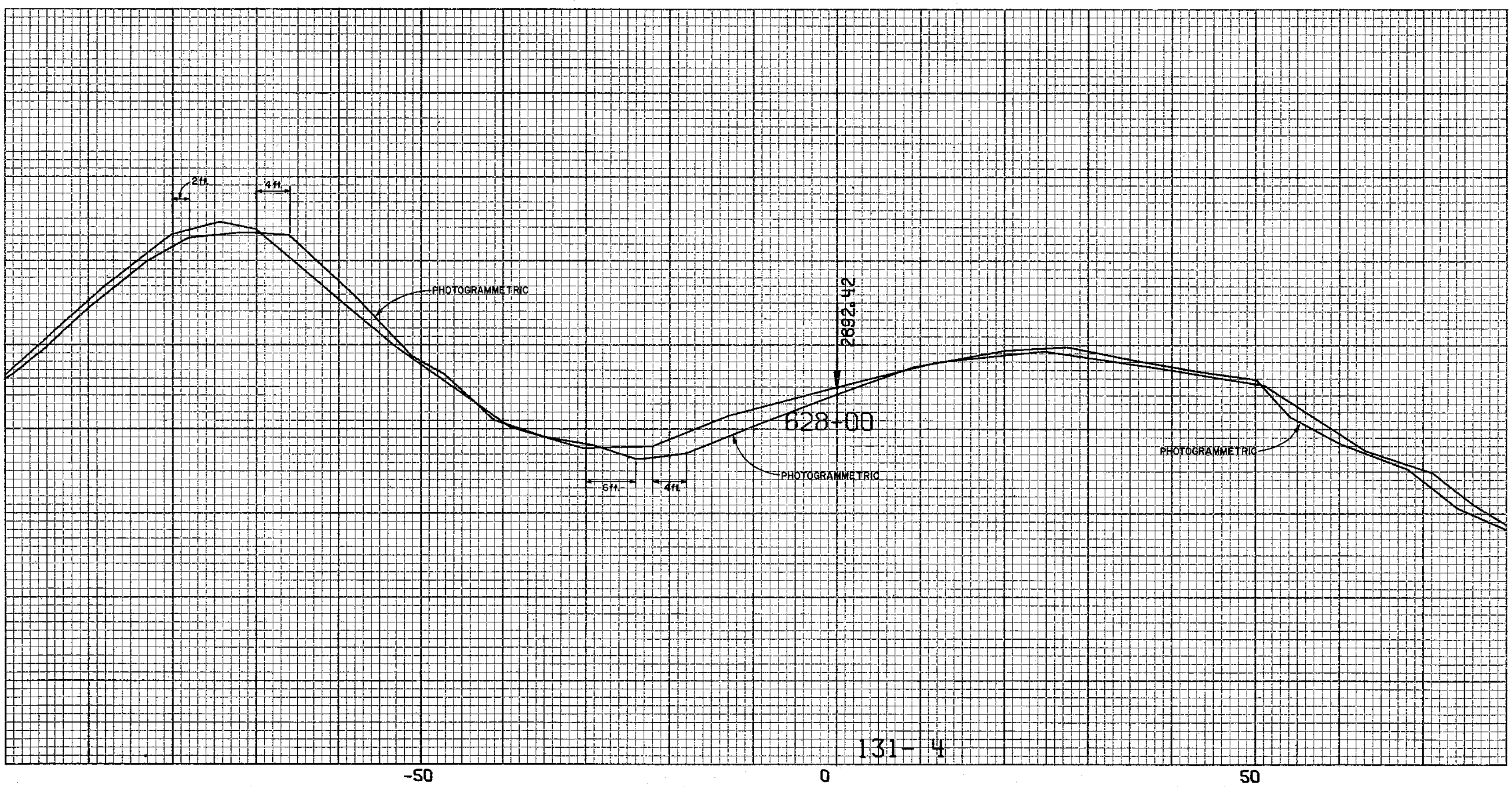
DEVIANCES OF AUTOTROL AND FIELD READINGS FROM PRECISE READINGS----FIGURED ACCORDING TO SIZE OF ERROR

	+0.5	+0.4	+0.3	+0.2	+0.1	0.0	-0.1	-0.2	-0.3	-0.4	-0.5
AUTO	2	9	12	31	54	58	55	35	20	10	1
FIELD	1	1	2	8	93	114	51	12	3	1	0

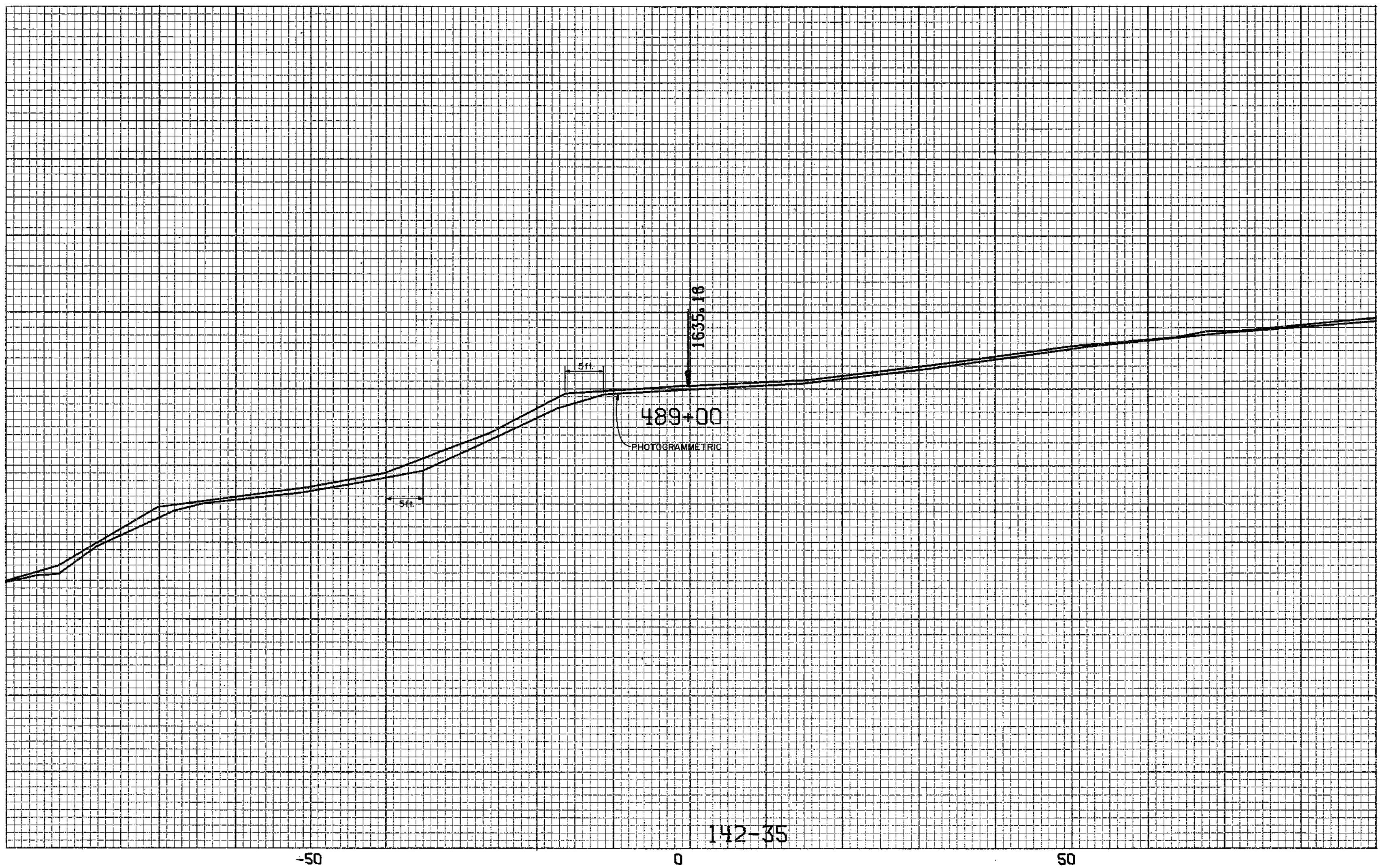
TYPICAL COMPUTER LISTING OF PROFILE DIFFERENCES ARRANGED BY ERROR SIZE AND PROFILE DISTANCE



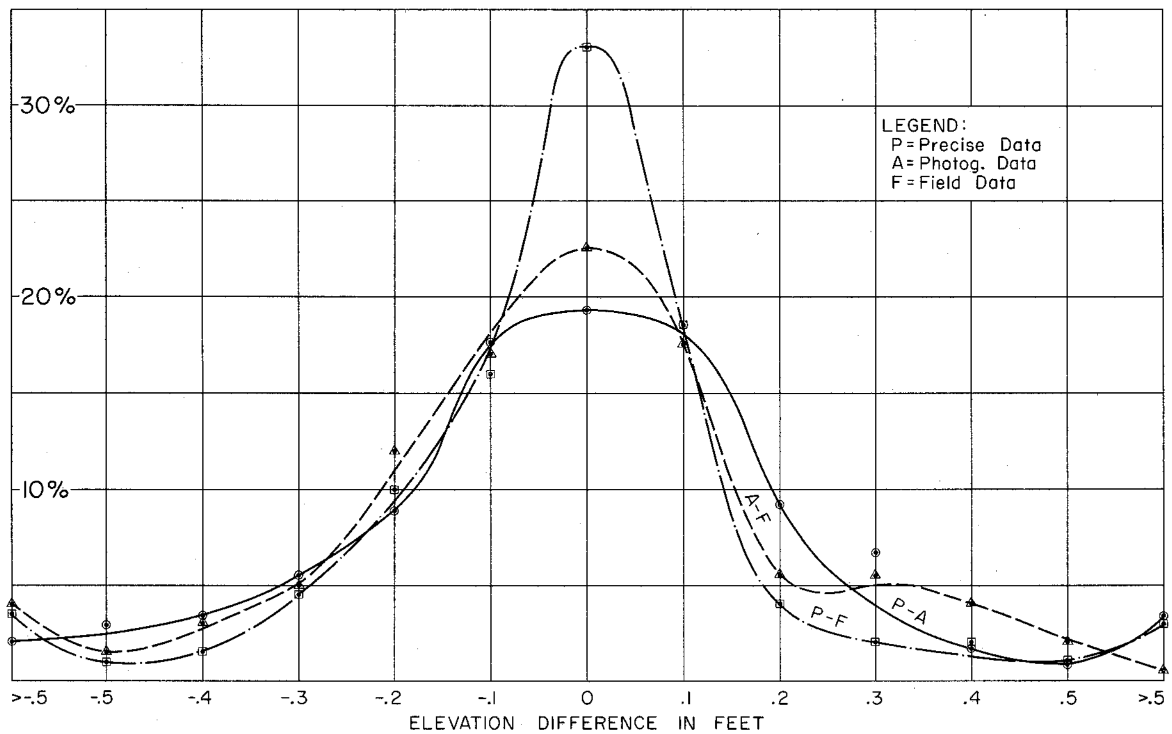
ACTUAL HORIZONTAL DISPLACEMENT - CROSBY COUNTY



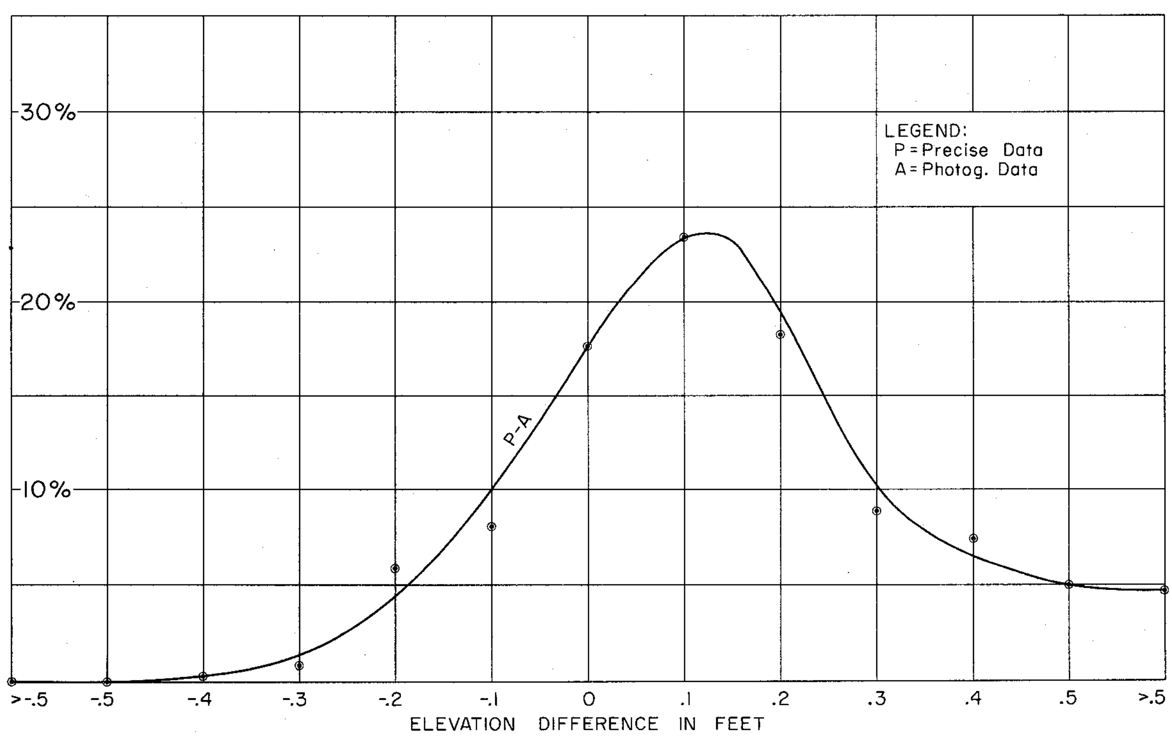
ACTUAL HORIZONTAL DISPLACEMENT - CROSBY COUNTY



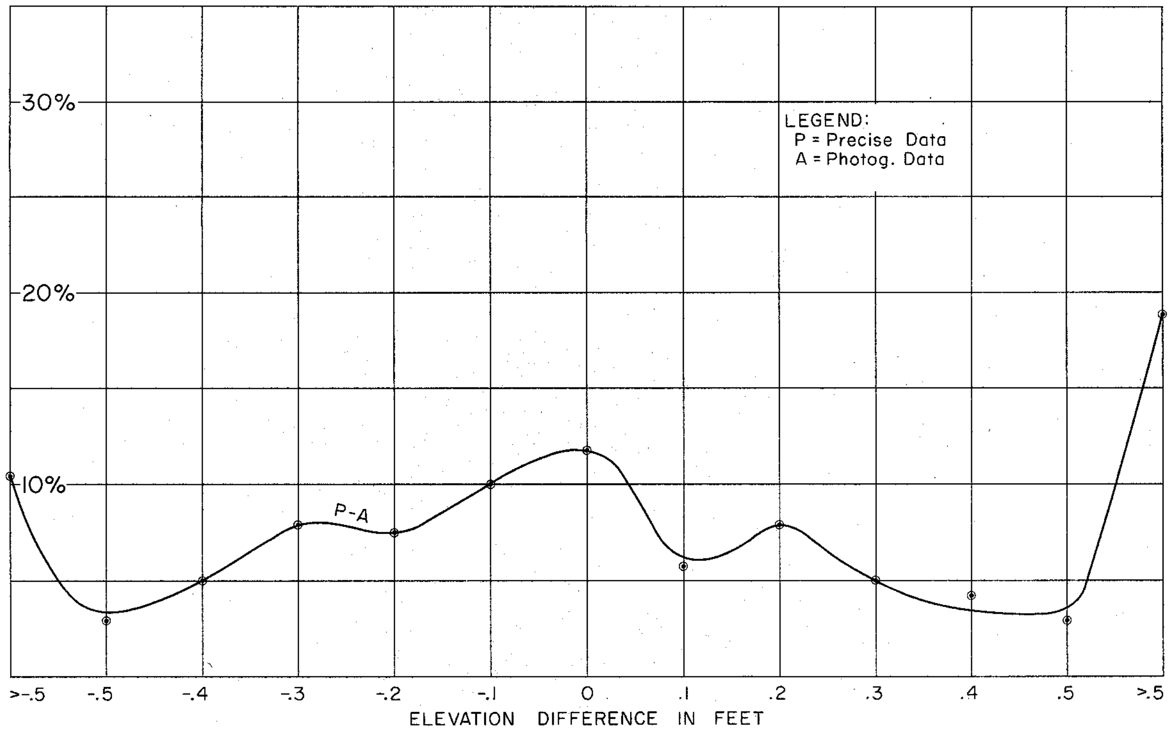
ACTUAL HORIZONTAL DISPLACEMENT - KENDALL COUNTY



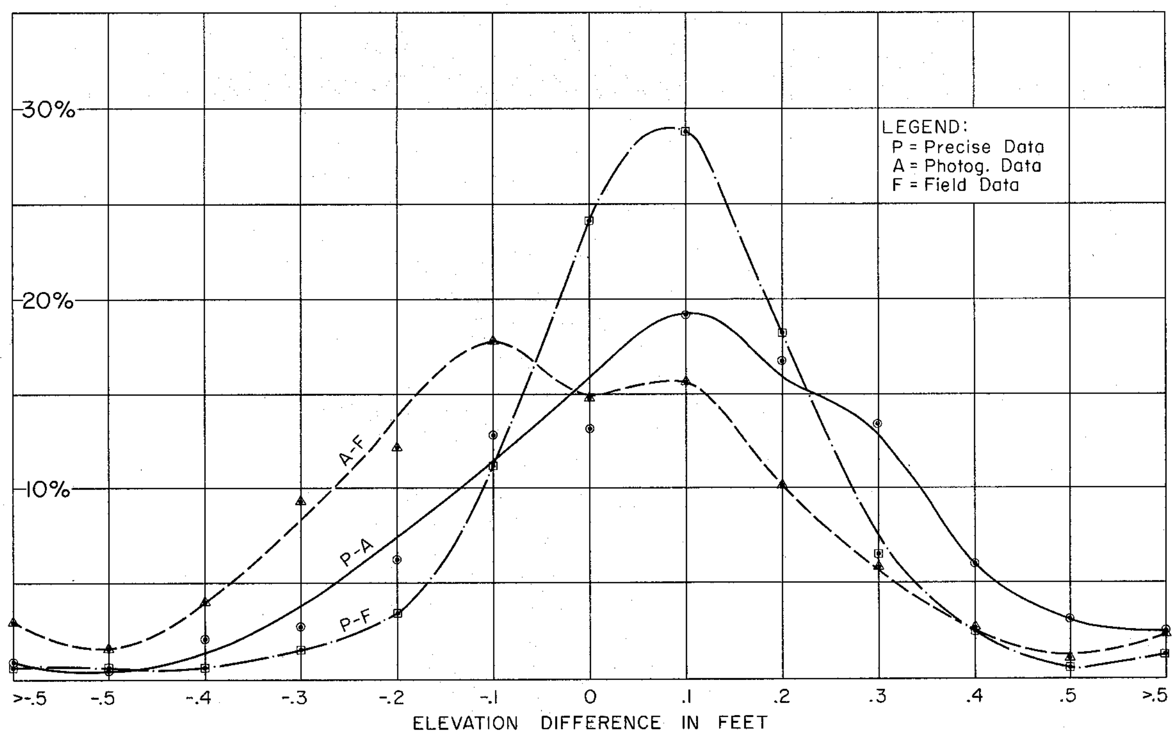
CROSBY 400 - PERCENTAGE DISTRIBUTION



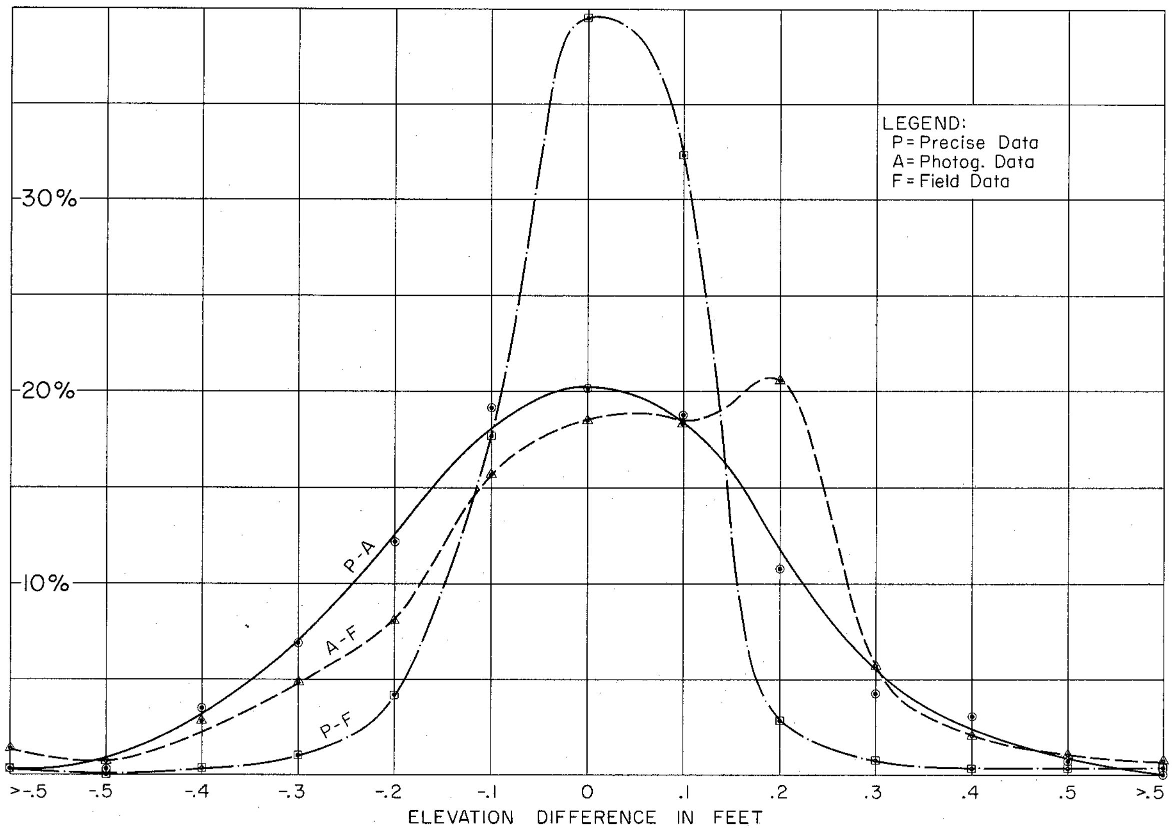
CROSBY 700 - PERCENTAGE DISTRIBUTION



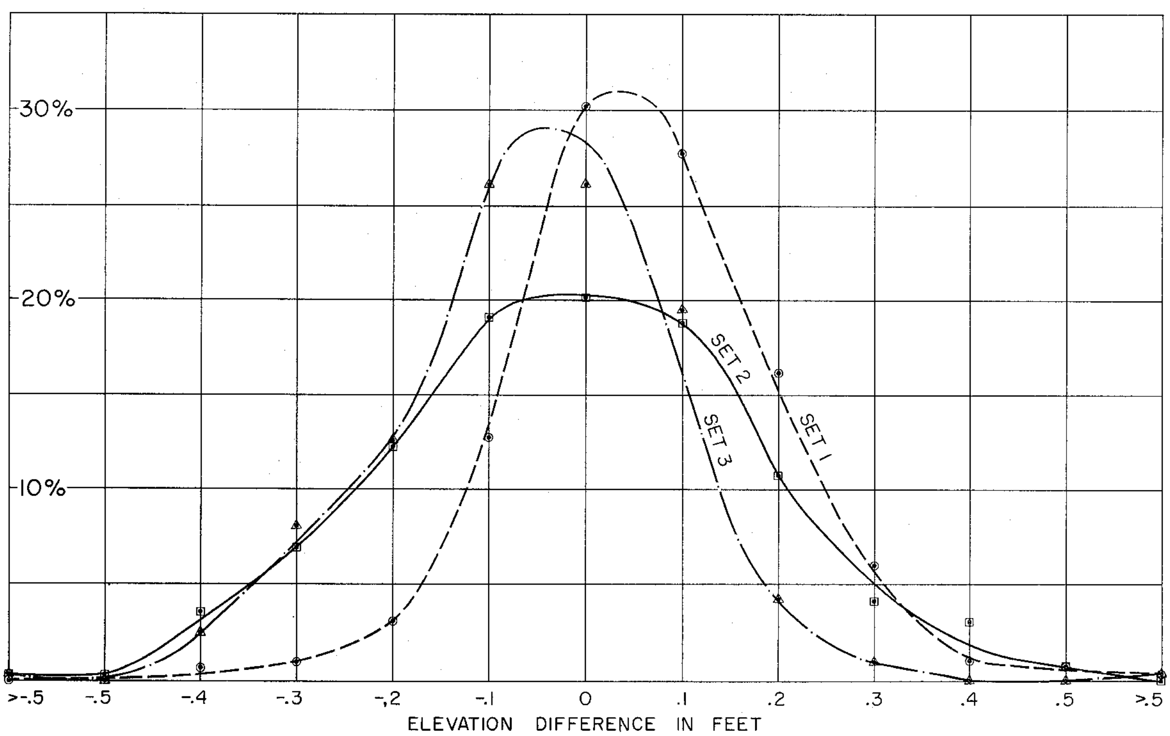
CROSBY 600 - PERCENTAGE DISTRIBUTION



KENDALL - PERCENTAGE DISTRIBUTION



TARRANT SET 2 AND FIELD-PERCENTAGE DISTRIBUTION



TARRANT-3 PHOTOGRAMMETRIC SETS-PERCENTAGE DISTRIBUTION