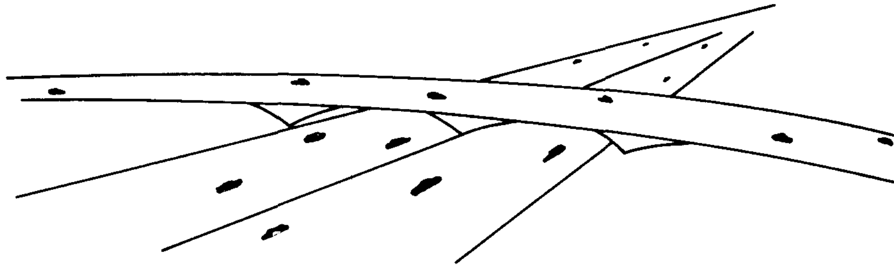

DEPARTMENTAL RESEARCH

Report Number: 28 - 1F

DETERMINATION OF CAPABILITIES OF ELECTRONIC EQUIPMENT FOR USE IN PHOTOGRAMMETRY

TEXAS HIGHWAY DEPARTMENT

DETERMINATION OF CAPABILITIES OF
ELECTRONIC EQUIPMENT FOR USE IN PHOTOGRAMMETRY

By

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Research Report Number 28-1F

Determination of Capabilities of Electronic Equipment
For Use in Photogrammetry 1 - 8 - 62 - 28

Conducted by

Division of Automation
The Texas Highway Department
In Cooperation with the
U. S. Department of Commerce, Bureau of Public Roads

September 1966

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ABSTRACT

The capabilities of the Electrotape Model DM-20 and the Auto-trol Scaler Model 3900 are reported. Both of these devices were used and evaluated by the Texas Highway Department on actual projects. The Electrotape was used to establish second-order control for mapping, bridge location, and as a check on baselines chained by field personnel. Measurements made by the Electrotape were also compared to a precisely chained baseline. Approximately 1,000 miles of control was established during this project and the average position closure was 1/23,000. The Auto-trol was used to establish cross-sections from aerial photography through the use of a stereo-plotter. These cross-sections were used to determine earthwork quantities, to establish hydraulic gradients for streams, and to establish hydraulic data for large bridge structure designs.

Both of these instruments delivered satisfactory results, required little maintenance, and offered considerable economic advantages over normal field methods.

I

INTRODUCTION

Background

The research study of the capabilities of the Electrotape (Cubic Corporation Model DM-20) and Auto-trol Scaler Model 3900 has been completed. This project was conducted by the Texas Highway Department in cooperation with the U. S. Department of Commerce, Bureau of Public Roads.

The aims of the study were as follows:

1. To state the methods used, problems encountered, accuracies, and limitations involved in the manipulation of each device under varying conditions.
2. To provide a reference guide of recommended procedures to be used as a training instrument and as a medium of disseminating information.

The Photogrammetry Section of the Division of Automation of the Texas Highway Department was charged with the responsibility for conducting the reported research which has been active since January, 1962.

Purpose

The purpose of this report is as follows:

1. To present the operativity of the two electronic devices as to their speed, efficiency, accuracy, constancy, and duration of

continuous action, response to mismanipulations, and frequencies of malfunctions.

2. To illustrate operational programs which have been developed for use with these devices.

Scope

This report is intended to be a general guide as to what may be expected of each of these devices as to accuracy, possible applications, and efficiency of operation. However, this report is not intended to cover every procedural detail of the project.

Organization

This report will be divided into two parts, one dealing with the Electrotape and the other with the Auto-trol. These sections are followed by conclusions on the accuracy, limitations, speed, efficiency, and reliability of each piece of equipment. An appendix which includes examples and tables follows the written text.

II

ELECTROTAPE

BACKGROUND INFORMATION

Types of Horizontal Control Surveys

There are three generally accepted field methods currently in use for the establishment and extension of horizontal control. They are *traverse, triangulation, and *trilateration, and for this report they are defined as follows:

Traverse is a method of surveying in which the stations are points on the ground at which the angles connecting the points are measured and between which the distances are measured. The distances and directions so obtained are used to compute the plane rectangular coordinates (State Plane or otherwise) of the points.

Triangulation is a method of surveying in which the stations are points on the ground at the vertices of a chain or network of triangles, whose angles are measured and whose sides are calculated (using the Law of Sines) from selected triangle sides called baselines, the length of which are measured on the ground. The directions and distances so obtained are used to compute the plane rectangular coordinates (State Plane or otherwise) of the points.

*A detailed example of an Electrotape traverse and an Electrotape trilateration network is illustrated in the Appendix.

Trilateration is a method of surveying in which the stations are points on the ground at the vertices of a chain of triangles whose sides are measured and whose angles are calculated (using the Law of Cosines). The directions and distances obtained are used to compute the plane rectangular coordinates (State Plane or otherwise) of the points.

General Specifications for Horizontal Control Surveys

By and large, the Photogrammetry Section of the Texas Highway Department uses the same general specifications for determining the quality of field work for horizontal control as do other agencies *i.e.* some modification of the "Requirements for Horizontal Control" used by the Coast and Geodetic Survey, U. S. Department of Commerce. The specification used is illustrated in Table 1.[1]

Equipment

Distance Measuring Equipment: The Electrotape (Cubic Corporation, Model DM-20) was used to measure all distances for the first and second-order traverses involved with this Project. A standardized surveyor's chain was used for most of the short distances (less than 1500 feet) or third-order traverses; the Electrotape was used on the longer distances (greater than 1500 feet). In urban areas, shorter distances were measured with the Electrotape because traffic and other obstructions usually restricted chaining.

Table 1. Horizontal Position Specifications

TRAVERSE

	First Order	Second Order	Third Order
Azimuth closure at Azimuth check not to exceed.....	2 sec$\sqrt{N}$, or 1 sec per station*	6 sec$\sqrt{N}$, or 3 sec per station	30 sec$\sqrt{N}$, or 8 sec per station
Distance measurement accurate to within.................	1 in 35,000	1 in 15,000	1 in 7,500
After Azimuth adjustment, closure error in position not to exceed..................	1 in 25,000	1 in 10,000	1 in 5,000

*N = Number of Stations

TRILATERATION

	First Order	Second Order	Third Order**
Distance measurement accurate to within.................	1 in 35,000	1 in 15,000	1 in 7,500
Position closure after Azimuth adjustment not to exceed....	1 in 25,000	1 in 10,000	1 in 5,000

**The Photogrammetry Section does not expect any of its Trilateration to fall below the Second-Order range.

Angle Measuring Equipment: Four different optical-reading theodolites were used to measure horizontal angles for this project. They are the Wild T-2 (1.0 sec.), Wild T-3 (0.1 sec.), Keuffel and Esser 2e (1.0 sec.), and the Dietzgen-Watts (1.0 sec.). All of these theodolites are capable of extremely accurate angle measurement.

TABLE 2

ELECTROTAPE DM-20 SPECIFICATIONS[2]

Equipment Description	The standard Electrotape precision electronic distance-measuring system is composed of two units, Model DM-20, complete with fiberglass case, self-contained antenna and powerpack, headset, field data sheets, 12-volt cable, accessory bag, velocity calculator, transport case, and instruction manual. Accessory equipment that is available includes tripod, psychrometer, altimeter and battery for internal use in DM-20 unit.
Dimensions	Height, 15 inches; width, 14 inches; depth, 11.5 inches. Weight, 33 pounds with battery. Case has 5/8 - 11 threaded baseplate to receive tripod mounting screw.

Table 2 (Continued)

Electronic Circuitry	All transistorized; no vacuum tubes except klystron. Plug-in printed circuitry. Built-in powerpack. Built-in check-out capability.
Carrier	10.0 to 10.5 Kmc
Frequency	Automatic frequency control
Temperature Range	-40° to + 125° Fahrenheit
Distance	100 feet to 30 miles
Resolution	1 centimeter
Communication	Self-contained two-way FM radio
Power Consumption	Maximum 5 amps at 12 volts; 2 amps at 24 volts
Accuracy	$\pm$ 1 centimeter $\pm$ 1 part in 300,000
Battery Life	Internal battery, 2 hours External battery (automobile), 10 hours

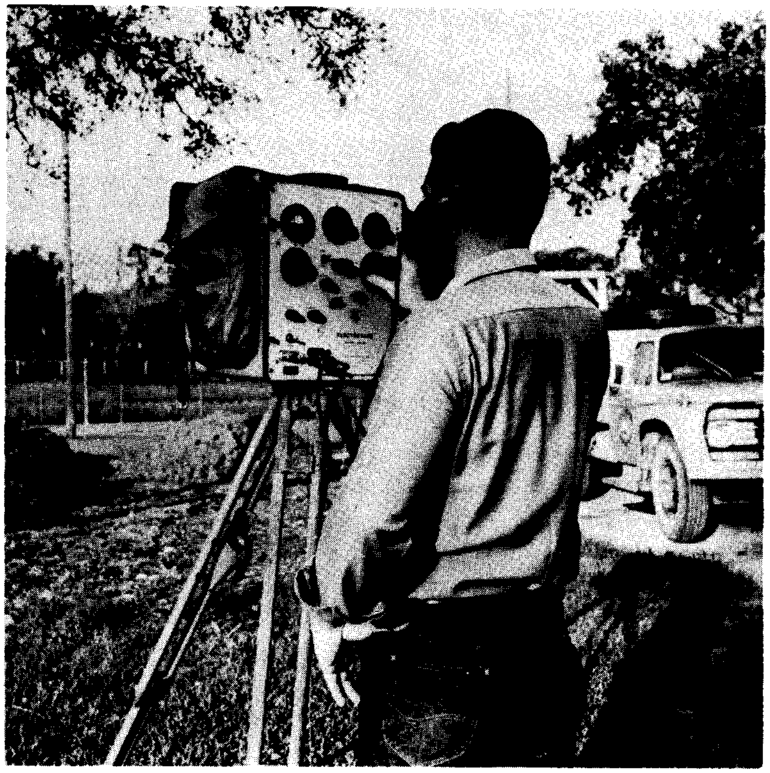


Figure I. Electrotape Model DM-20

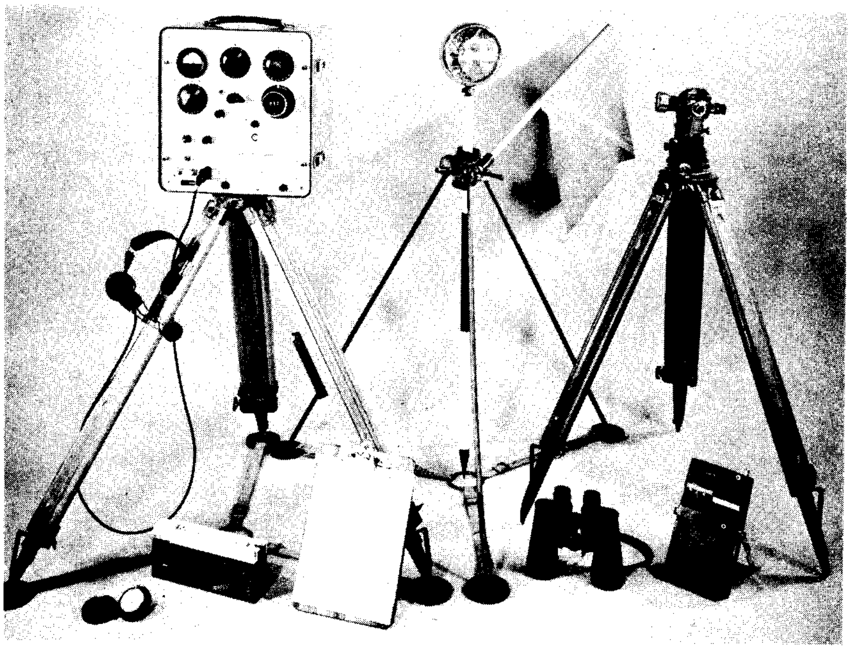


Figure 2. Survey Equipment

HORIZONTAL CONTROL BY ELECTROTAPE FOR PHOTOGRAMMETRIC MAPS

Specifications

The horizontal control for photogrammetric maps should be consistent with the accuracy that can be achieved on the available plotting devices. Although third-order horizontal ground control is consistent with the accuracy of the projection type plotting equipment available for mapping, it is felt that third-order horizontal control allows excessive errors to accumulate over the length (average 10 miles) of most photogrammetric mapping projects. Second-order horizontal control reduces the possibility of excessive errors in horizontal position accumulating over the length of the project and is desired for Right-of-Way acquisition and highway design using photogrammetric maps.

The Texas Highway Department has recently acquired a Zeiss C-8 Stereo Planigraph which is used to extend horizontal control between stations established by the Electrotape on projects in which intermediate control is difficult to obtain. This device requires at least second-order control. Therefore, it is required that the field crews establish basic second-order horizontal control throughout the project. Any supplemental horizontal control established in the field must be at least third-order.

Procedure

The horizontal control for photogrammetric maps compiled by the Photogrammetry Section is generally accomplished by the following procedure:

1. A second-order traverse (using Electrotape and theodolite) is originated from a USC & GS control point near the beginning of the job, is advanced through the project using stations 1200 to 2500 feet apart, and is terminated at a USC & GS control station near the end of the job.
2. Intermediate panel points, which are spaced appropriately for the scale of the map (e.g., at 300 feet for 1"=40' maps), are controlled by running a third-order traverse (using chain and transit) through them and "tying to" the second-order traverse. This operation may be omitted if stereo-bridging is to be used.

The practice of spacing the Electrotape-theodolite traverse stations at 1200 to 2500 feet for the basic-control traverse is dictated by the nature of the horizontal control projects. The three considerations governing the spacing of Electrotape stations are as follows:

1. Photogrammetric Considerations: The spacing of intermediate control points is dictated by the scale of the map to be

compiled (e.g., points would be spaced at 300 feet for a 1"=40' map). The intermediate points are on tangent between the Electrotape stations. A spacing of 1500 feet for Electrotape stations is considered to be the optimum spacing for ease in measuring the intermediate points to the required accuracy. If the project is to be stereo-bridged then the spacing is not as critical.

2. Economic Considerations: A field party can chain 800 to 1500 feet (and maintain the required accuracy) in the same time it takes to make an Electrotape measurement (10 to 15 minutes). Therefore, the minimum distance between Electrotape stations should be at least 1500 feet for economic reasons.

3. Future Use of Basic Control: The basic control for the photogrammetric project should be established in such a way that it is readily available for use during, or prior to, construction of the design facility.

In light of the above considerations the optimum spacing for Electrotape stations should be between 1500 and 2500 feet.

Results

The accuracy obtained, using the Electrotape for distance measurements and the theodolite for angle measurements, results in second-order traverse closures (i.e., horizontal position closures between 1/10,000 and 1/25,000 after adjustment of the azimuth traverse). These closures satisfy the accuracy requirements for horizontal control of photogrammetric maps. There has not been an instance during this project that the Electrotape has failed to measure distances that satisfied these accuracy requirements. A tabulation of some of the traverses run during the project, their error of closure, their relative accuracy, and their length is found in Table 3 on page 14. A complete list is included in the Appendix.

Remarks

It should be recognized that the speed with which horizontal control can be extended with the Electrotape and theodolite is not only a direct function of the number of lines, the number of angles, or the lengths of the lines, but it is also a direct function of the accessibility (the time involved in proceeding from point to point) of the traverse. Because the time spent in actually measuring distances and angles can be accurately estimated, the accuracy of the estimate of time needed to complete the field work for a horizontal control project is largely a function of how well the accessibility can be estimated. The accessibility of the project often has a more pronounced effect upon the time needed to complete the field work than actual measurement times.

Table 3

Traverse Closures

Name of Traverse	Length (ft.)	Position Closure (ft.)	Relative Accuracy
Eastland Co. SH 206			
POT #1 to PI 7	20,000	0.75	1/27,000
PI 7 to PI 8	30,000	1.37	1/22,000
PI 13 to PI 753+00	85,000	1.50	1/57,000
El Paso Co. Loop 375			
Fort to Frohtera	72,413	1.15	1/62,852
PI 24 to Saddle 1	57,613	5.33	1/24,042
Fayette-Gonzales Cos. I.H.10			
Botts to Waelder	127,980	5.33	1/24,042
BL POT to 133	72,024	4.19	1/17,196
Schlnbrg to Obar	78,375	2.40	1/32,623
Nueces Co. SH 44			
Rog 2 to Fairview	81,466	0.91	1/89,265
Harris-Galveston Co. SH 3			
HLP to Ellington	21,980	2.15	1/10,214

Table 3 Continued

POT 447 to Bkusn	57,360	1.57	1/36,630
Kerr Co. FM 1340			
Kinsel Loop	92,663	0.33	1/277,324
Pecos Co. IH 10			
Field to Miller	71,708	2.55	1/28,096
Field to Airport	29,383	0.58	1/50,580
Tarrant Co. IH 35W			
Seminary to Burleson	56,844	2.16	1/26,376
Loop 1 - GB - A - 1	9,843	0.14	1/72,471
Loop FM 1187	10,094	0.63	1/15,926
Loop South End	10,441	0.24	1/43,352
Grimes Co. SH 6			
Nelleva to Betts	71,671	3.41	1/21,038

EXTENSION OF HORIZONTAL CONTROL BY ELECTROTAPE TO THE MAPPING AREA

Specifications

Departmental policy requires that the horizontal control, extended through the mapping area be tied to horizontal control that meets the first-order specifications described by the Coast and Geodetic Survey, U. S. Department of Commerce.[3] This requirement may be fulfilled by either recovering stations already established by the Coast and Geodetic Survey, or by establishing first-order stations using first-order surveying techniques.

Procedure

In practice first-order control has been established by two different methods (1) traversing and (2) trilateration. To this date the Photogrammetry Section has not made use of triangulation to extend horizontal control because of the expense and time necessary to achieve first-order accuracy by this method. When the Electrotape and theodolite are used, first-order horizontal control can be quickly and efficiently extended to the mapping area without resorting to more inefficient triangulation. Trilateration has also been used for the extension of first-order horizontal control. Although detailed specifications are not currently available for extending horizontal control by this method, the limited experience reported in Table 4 indicates that the use of trilateration nets to date have resulted in first-order closures.

Results

Only a few projects have required horizontal control to be extended to the mapping area; therefore, this report includes limited information concerned with this particular type of control project. The results that are available may be found in Table 4 on page 18.

Remarks

In the past, it was not economically feasible to establish horizontal control for mapping unless easy access to U.S.C. & G.S. stations was available. With the Electrotape-theodolite traverse, it has become economically feasible to make rather long ties; hence, it has become a policy to tie the horizontal control for all mapping projects to the State Plane Coordinate System.

Trilateration was not used extensively in the past to extend horizontal control because of the laborious hand calculations that were necessary to reduce the data. A Computer Program has been developed that handles these routine calculations very economically. It is anticipated that in the future more first-order horizontal control will be extended by the method of trilateration.

TABLE 4

TRILATERATION NET CLOSURES

Project	Project Length	Position Closure	Relative Accuracy
Brazos River (CABFC)	2,200 ft.	0.01 ft.	1/220,000
Brazos River (CABEC)	1,700 ft.	0.02 ft.	1/85,000
Devil's River	6,300 ft.	0.01 ft.	1/630,000
San Angelo (Concho)	74,000 ft.	0.72 ft.	1/104,000
Kendleton (PI3, K4, K3, Pot 3)	30,000 ft.	0.08 ft.	1/400,000
Kendleton (Net Connection)	2,700 ft.	0.09 ft.	1/30,000

BEHAVIOR OF THE ELECTROTAPE

Accuracy

The Electrotape has proven to be capable of consistently measuring distances well within the accuracy required for Photogrammetric mapping projects. Examples of the accuracy that may be expected are shown in the Appendix. It has not been necessary to reestablish control because of failure of the Electrotape to function properly. There have been instances, however, when Electrotape-theodolite traverses had to be rerun because of angular problems.

In order to test the accuracy of the two Electrotapes, measurements were made on a first-order baseline which was established in the right-of-way on Farm to Market Road 1604 in Bexar County north of San Antonio. This baseline is one mile in length and consists of concrete monuments which were set in the bedrock at stations 0+00, 3+00, 9+00, 12+00, 26+00 and 52+00. Electrotape distances have been compared at all these stations and the results are in Table 5. These monuments were set originally with a transit and tape and then measured with an Invar tape using first-order methods. The baseline was chained a total of four times, twice in each direction. Figure 3 shows the Electrotape being used to measure this baseline.

The Electrotape has been used for locating major structures at various times. The normal method for locating bridge structures is to establish the location of the piers by triangulation. The Electrotape

Table 5

Mile Base Line Comparison

Distance	Chained (ft.)	Electrotape (ft.)
0+00 - 3+00	299.98	300.04
0+00 - 6+00	599.97	599.97
0+00 - 9+00	899.94	899.94
0+00 - 12+00	1199.96	1199.88
0+00 - 26+00	2599.91	2599.86
0+00 - 52+00	5199.86	5199.87

Differences in this table can be attributed to both the Electrotape and the chaining.

Figure 3. Electrotape Measuring On The Mile Baseline

eliminates this and saves considerable time. A sample problem in which the Electrotape was compared to triangulation as control on a bridge is included in the Appendix.

Limitations

Although the Electrotape is a very versatile distance measuring device, there are situations in which distance measuring is difficult. The following list illustrates some examples of these situations.

1. When measuring parallel and adjacent to dense, high-speed vehicular traffic, the measuring-signal is confused by the Doppler effect making it more difficult to make settings on the Electrotape. This in effect slows down measurement.
2. When measuring through dense, high-speed vehicular traffic, the measuring-signal is both confused by reflected waves and weakened by "scalping-off" part of conical signal pattern, and measuring is slowed down as in example 1.
3. When measuring through or against a background of dense wind-blown vegetation the measuring-signal is confused by reflected waves, and measuring is also slowed down.
4. Restricted radio-line-of-sight occurs when topographic features, vegetation, or other objects "scalp-off" a portion of the conical measuring signal. This can be avoided by proper point

location. The effect is to dispense or weaken the signal and make measuring difficult. However, it is possible to measure down narrow sinderas for short distances. (i.e. 1000 feet)

5. When distances less than 500 feet are measured, the ambiguous resonant frequencies become strong enough to be detected and to create difficulty in tuning the instrument. Also, there is an indication that the shorter distance measurements are of the poorest quality (See Table 5).
6. There are two additional limitations or operator complaints. The first complaint deals with the awkwardness of the catches and fastners for the lid and antenna-cover and especially the screw-in power-plug. The power-plug is extremely difficult to plug-in or remove in cold weather. The second deals with the need for a "safety" to prevent measuring distances with the antenna-cover on, which is a common operator error.

Speed and Efficiency

As has been brought out earlier in this report, approximately 10 to 15 minutes are required to make an Electrotape measurement. During the same time a good field party can chain between 800 and 1500 feet. However, it should be noted that the Electrotape can measure distances up to 30 miles in this same 15 minute interval. The Electrotape is easy to operate and the average operator can operate the machine as fast as a note keeper can record the data.

The Photogrammetry Section has found that the Electrotape field party is as expensive to maintain per day in the field as is a normal field party (about $125 per day). Since the Electrotape field party can do the work much faster, great savings accrue to total over-all project time and expense. For example, the Electrotape was used to check the distances measured by a field chaining crew. The field chaining crew (5 men) required 30 days to make the original measurements; the Electrotape crew (4 men) required only four days. This resulted in a savings of 20 to 25 days at a cost of approximately $50 per day.[4]

Reliability and Durability

The Electrotape was found to be a very reliable piece of surveying equipment. It has rarely failed and periodic maintenance has been performed on the Electrotape during slack times. All the maintenance and repair to the equipment has been done by Cubic Corporation at its San Diego, California plant. The maintenance and repair service received from Cubic Corporation has always been satisfactory. They have always returned the equipment from the plant on the date promised.

III

AUTO-TROL

BACKGROUND INFORMATION

Description of Cross-Sections

The transverse highway cross-section is extremely inportant in highway design. It is used by nearly all highway design organizations as the method of computing earthwork quantities. The Texas Highway Department uses the cross-section to determine earthwork quantities, to establish hydraulic gradients for streams, and to establish hydraulic data for large bridge structure designs. The examples in figure 4 on page 26 illustrate some typical highway cross-sections.

Physically, a cross-section is a graphic representation of the transverse profile of the ground at one station, on the centerline of the facility. It consists of straight lines which connect points at which the slope of the ground changes. The ground must be assumed to be regular between these changes of slope. Cross-sections are accurate representations of the ground if properly derived.

Description of the Auto-trol

The Auto-trol Scaler Model 3900 is an electronic analogue-to-digital converting scaler. The Auto-trol can be used with all types of photogrammetric equipment using the tracing table principle. The information obtained with this scaler is in a form suitable for use with electronic computers.

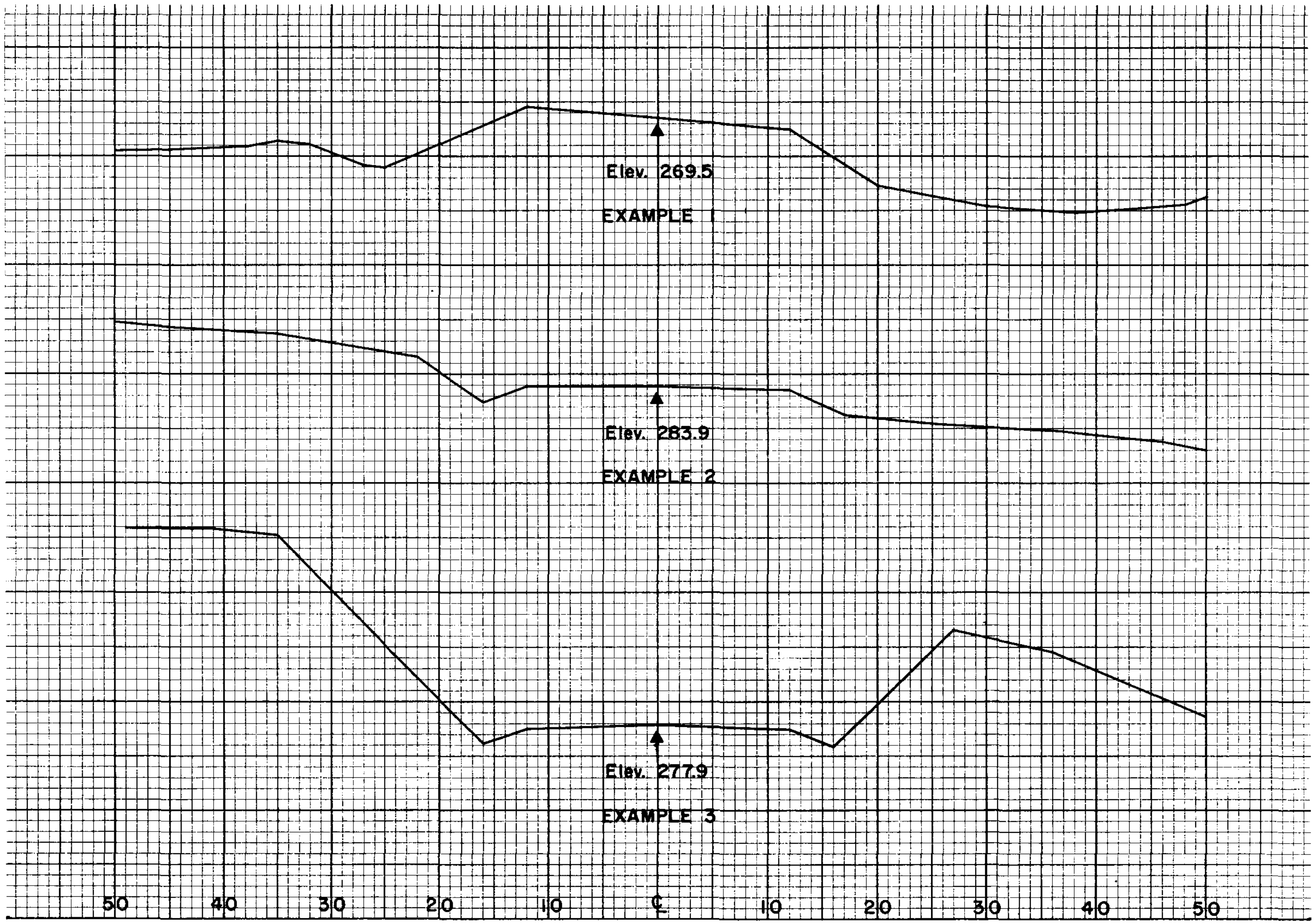


Figure 4. Typical Highway Cross-Sections

The Auto-trol Scaler consists of the main console, the horizontal unit, the vertical encoder, and the 80-column selector. In addition to this equipment an 024 or 026 IBM Keypunch Machine and a plotter with tracing table are required. All of these components are shown in figure 5 on page 28.

The main console is the portion of the Auto-trol in which the data is assimilated and digitized. The console unit signals to the keypunch machine which in turn places digitized analogue measurements on punch cards. Nixie tubes in the console show visual evidence of the data which is in the machine at any given time. The Nixie tubes show station number, horizontal distance, and elevation. The station can either be dialed into the console or into the "Easy-Reach". The "Easy-Reach" is merely an extension of the station dials of the console. The bias elevation or H.I. is dialed into the console unit. All elevations recorded will be relative to this bias elevation or H.I. In most of the work a bias elevation is used. The horizontal distance counter can be set to zero with a button which is attached directly to the tracing table. Physically the console is 24" by 15" by 15", contains over 175 electronic tubes, and has the ability to count 20,000 pulses per second in determination of analogue outputs.

The horizontal unit consists of two parts: the scaling bar and the base plate. The base plate is heavy enough to prevent accidental

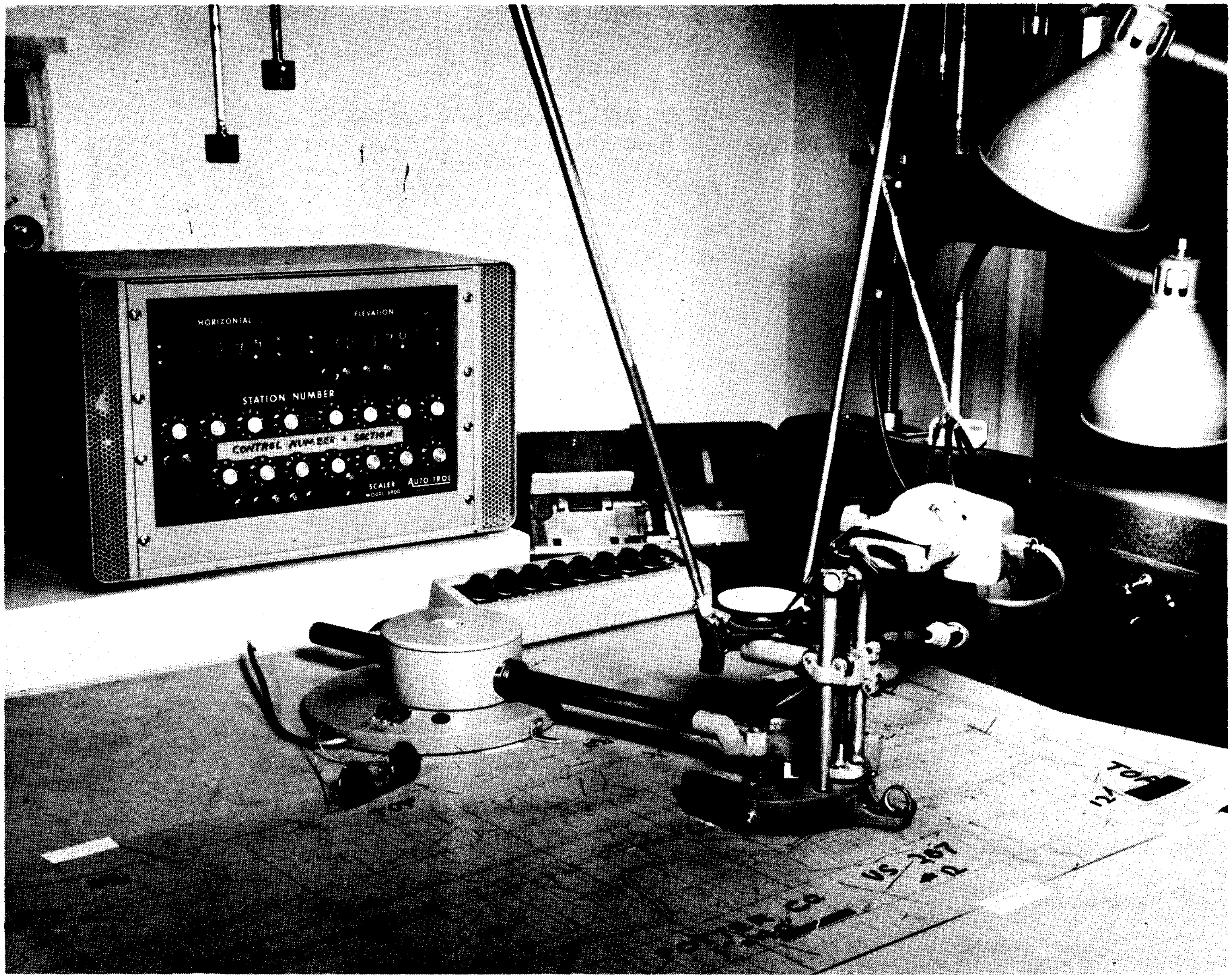


Figure 5. The Auto-Trol System

movement during the recording of a cross-section. It contains the gear reductions which allow for different scales. The scaling bar is a round bar of billet steel with gear teeth along one side. This bar attaches to the tracing table and passes through the base plate as shown in figure 6. The gears on the bar mesh with the driver gears in the base plate. The horizontal unit is aligned with the cross-section to be run and then any movement of the tracing table will be measured by the gear train in the base plate. These movements are transmitted electrically to the console. The horizontal unit is accurate to 0.001 inches.

The vertical encoder attaches directly to the tracing table and allows incremental elevation changes to be assimilated by the console. It is shown in figure 7 on page 30. When the record button which is attached to the bottom of the tracing table is pressed, the incremental elevation of the tracing table and the horizontal distance indicated by the horizontal scaling unit are punched on a card.

The 80-column selector is a device which attaches to the keypunch machine. It allows the keypunch machine to be driven by the Auto-trol system. The 80-column selector relays messages from the Auto-trol to the keypunch machine. It is shown in figure 8 on page 30.[5]

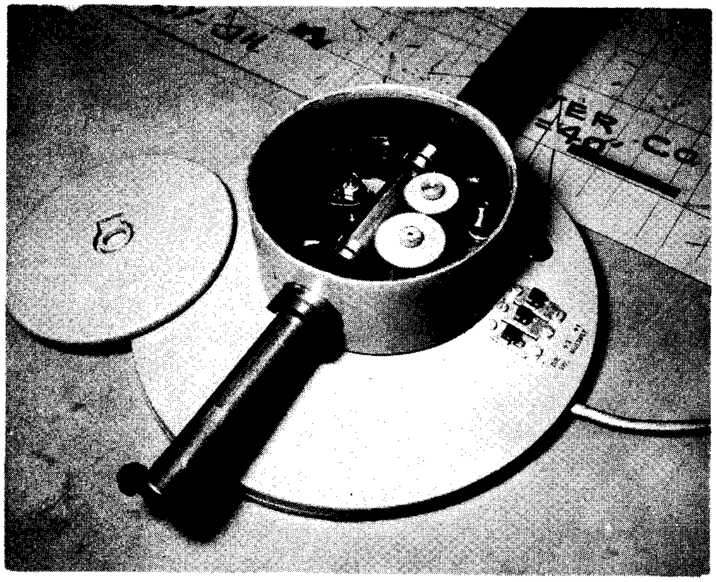
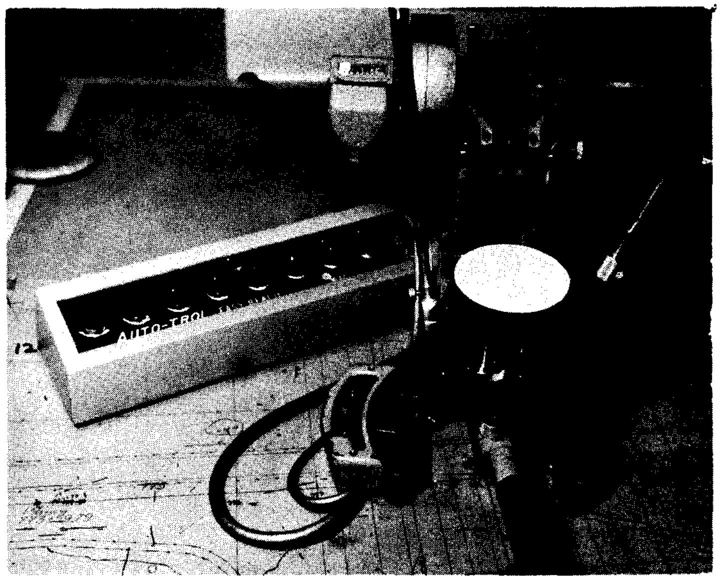


Figure 6.
The Horizontal Scaler

Figure 7.
The Vertical Encoder



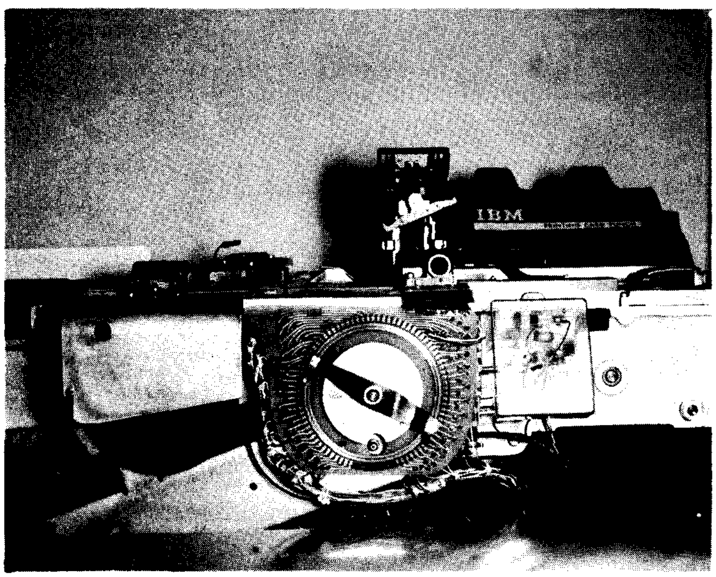


Figure 8.
The 80-Column Selector

Description of the Card Format

Digitized information from the Auto-trol is used in several computer programs and therefore must be placed on punch cards in proper form. The "Patch Board" which is furnished with the Auto-trol is used to achieve this proper form. Figure 9 on page 32 shows an 80-column computer card and figure 10 on page 32 shows a schematic of the "Patch Board".

The "Patch Board" controls the output information of the Auto-trol. The data can be placed on a computer card in any order depending on how the board is wired. This wiring is usually done by a factory representative so that the Auto-trol output is compatible with the customer's system.

The format used by the Division of Automation is as follows. The control and section number go in columns 1 through 6. The station number goes in columns 7 through 12 (to the nearest foot). The number which designates the type of card, i.e., Auto-trol, Field book, mark sense, etc., appears in column 13. The card number is in columns 14 and 15. The direction, left (L) or right (R) from the centerline, is in column 16. The next entry is the H.I. or bias elevation which is entered in columns 27 through 32. It has two decimal places. Rod readings and distances appear on the rest of the card. There are spaces for eight rod readings and distances on each card. The distance is taken to the nearest foot and the rod reading to the nearest tenth.

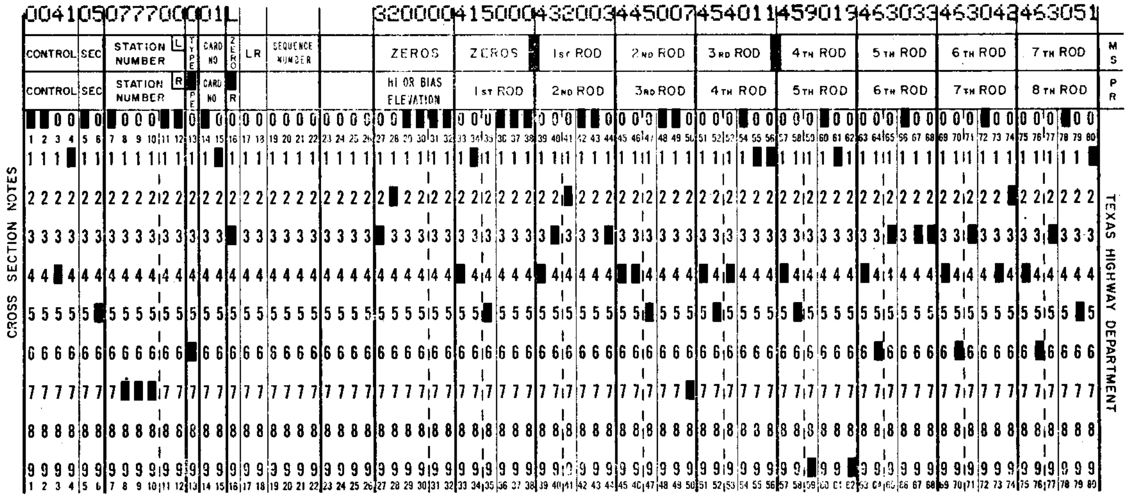


Figure 9. 80 Column Computer Card

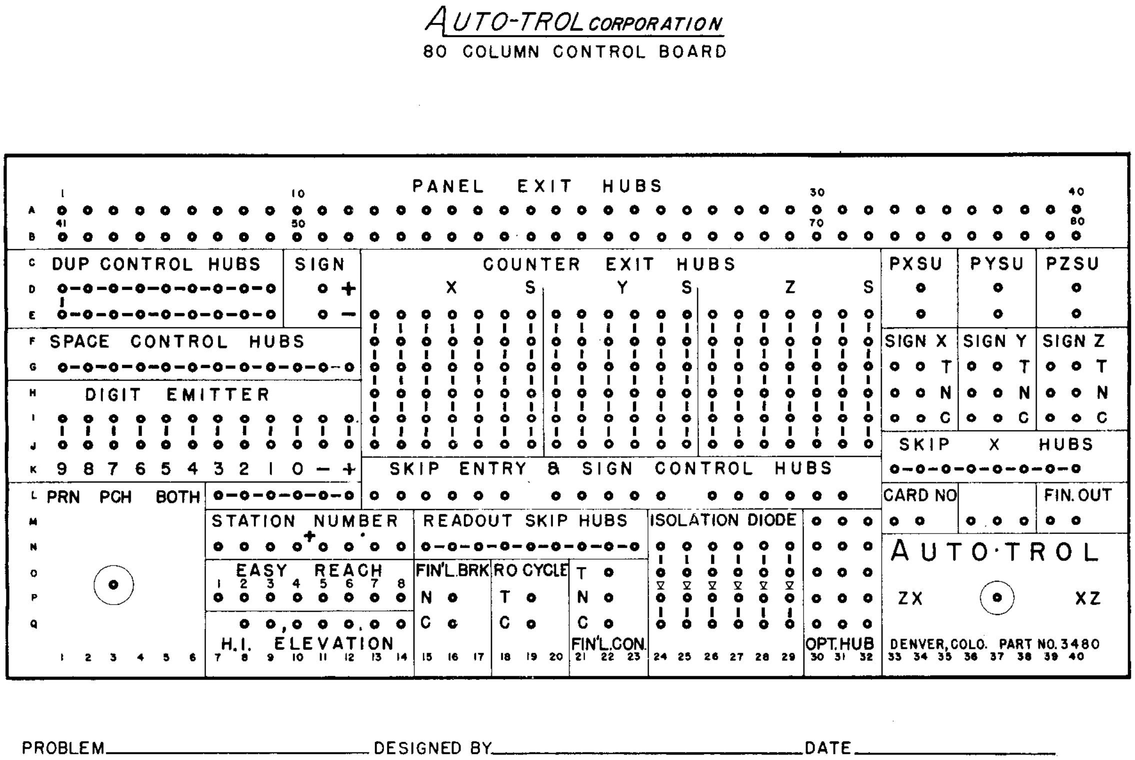


Figure 10. Patch Board Schematic

PHOTOGRAMMETRICALLY DEVELOPED CROSS-SECTIONS

Auto-trol Method of Compiling Cross-Sections

Nearly every highway department employs slightly different techniques in acquiring cross-sections. A brief explanation of the method used by the Texas Highway Department of compiling cross-sections using the Auto-trol follows. Photogrammetric cross-sections are usually established along a design centerline which is plotted on a photogrammetric map sheet. The coordinates of this centerline are calculated using data furnished by field personnel. The centerline for the cross-sections is plotted on a manuscript with a coordinatograph. After this has been done, the cross-section lines are established at right angles to the centerline of the design facility at even stations. The manuscript is then oriented to a stereoscopic model using a Kelsh Plotter. The terrain usually requires that cross-sections be taken at plus stations in addition to even stations. The plus stations are taken to the nearest foot. A normal stereoscopic model will have seven to eight stations (700' to 800') in addition to the selected plus stations. It is possible that there will be twenty or thirty cross-sections per model.

After the manuscript has been oriented, the vertical index is set into the counter on the tracing table and into the elevation counter of the Auto-trol. Before the Auto-trol is put into operation, the Nixie tubes must be zeroed by pressing the appropriate zero reset button. Next, the IBM Key Punch machine is turned on, the horizontal scaler connected to the tracing table, and the "Easy-Reach" placed on the slate of the plotter. The number of the station to be cross-sectioned is dialed into the "Easy-Reach". After this has been completed, the direction switch on the horizontal scaler, which controls the right and left readings, is properly oriented.

The first reading recorded is at the centerline (the left side of the section is always run first). The tracing table is oriented so that the dot appears to be on the ground, then the record button on the Auto-trol is pressed twice. The first operation takes the card through to column 7, the second takes it through to column 33. From then on as readings are taken, the button is pressed just one time for each reading. When the required distance is reached on the cross-section the final record button is pressed. This button records the last reading on the card and punches zeros in the remaining columns, so there are no blank spaces left. The right side is then done in a similar manner.

Uses of Photogrammetrically Developed Cross-Sections

The photogrammetrically developed cross-section is used by the Texas Highway Department in several ways. These cross-sections are used in determination of earthwork quantities, in hydraulic studies of rivers and streams, determination of volumes of borrow pits, etc.

After the cross-sections have been recorded on punched cards through the use of the Auto-trol, and punched cards, elevations can be found on the computer. In addition, the Division of Automation of the Texas Highway Department has developed a computer program by which cross-sections can be plotted on an automatic digital plotter using the data on these punched cards. There is another computer program by which earthwork quantities can be determined using this data with design profiles and design templates (for various typical cross-sections of the design facility). These cards can be used for any other earthwork program in the Division of Automation. They can also be used to determine water surface profiles with a program which has recently been developed.

Planimetric maps are usually developed on any project that is to be cross-sectioned. In this manner, the Resident Engineer of the project has at his disposal planimetric maps (which he uses to develop right-of-way) and cross-sections (which he uses to design his facility). It was found that this system offers very good results as the cross-sectioned area appears on a planimetric map.

BEHAVIOR OF THE AUTO-TROL

Accuracy

The accuracy of the cross-sections depends mainly on the ability of the operator to position the floating dot on the ground at the proper breaks. The vertical encoder of the Auto-trol is accurate to 1/10 of a foot at a scale of 1"=40'. The horizontal bar or counter is accurate to within 1/1000 of an inch, and it is believed that at the 1"=40' mapping scale there is almost no measurable error on the horizontal part of the Auto-trol. A vertical error of 1/10 of a foot is inherent in the Auto-trol since the method of determining incremental elevation involves a photo-electronic cell which shines through holes in a disc. Each hole represents 0.1 foot. If two of these holes are in range of the photo cell, the strongest signal is recorded. Therefore, if the operator misreads the ground by 0.25 foot and the Auto-trol is 0.1 foot in error, there can be an accumulation of error of 0.35 of a foot. However, it is felt that the average error is less than 0.25 foot at 1"=40' scale.

There are some distinct advantages which the Auto-trol has over field methods of cross-sectioning. The cross-section is at a true 90° from the centerline. More elevation shots are recorded than in the field to round out or shape the ground, i.e., the shape of a drain is given instead of just top bank, bottom of ditch, and opposite top bank. The width of the ditch and the lowest point are recorded, and if the top bank is rounded, it also will be shown.

Limitations of the Auto-trol

There are certain limitations of the Auto-trol, i.e., situations in which the Auto-trol cannot be used and situations in which it is awkward to use. These limitations are as follows:

1. Drain profiles are very hard to cross-section with the Auto-trol. A drainage area that runs nearly parallel to the centerline of the design facility has to be done manually because it is impossible to rotate the tracing table to this position. The elevations have to be picked along each break and written on the manuscript, then the manuscript has to be reoriented so that the horizontal scaler can function.
2. The horizontal bar in the horizontal unit is not long enough. Approximately $10\frac{1}{2}$ inches is all that can be scaled with this bar without reindexing. It should be noted, however, that the new Auto-trol which the Photogrammetry Section has purchased is equipped with a longer bar. The size of the base plate of the horizontal unit also limits the distance which can be

scaled as this base plate must be flat on the slate of the plotter.

There are some other limitations of the Auto-trol System. These are not limitations of the scaler but are limitations of the photogrammetric cross-section method. They are as follows:

1. Heavy wooded areas, tall grass, and water present problems. In these circumstances, it is difficult to see the ground due to shadows or actual physical obstructions. These problems may be alleviated by photographing the areas to be cross-sectioned during the winter when foliage is at a minimum.
2. Curbs and reverse slopes (i.e., cliffs which are undermined) cannot be shown accurately at present since distances must be in ascending order. There cannot be two elevations at the same distance, nor an elevation given with a distance less than the previous distance. Also, the smallest increment of horizontal distance is one foot.

Speed and Efficiency of the Auto-trol

The speed of the Auto-trol depends on the ability of the operator, the terrain, and the vertical control. The authors find that cross-sectioning with "wing points" for vertical control is the fastest method.

Approximately 3,500 linear feet of cross-sections which extend 200' right and left of the centerline with accurate vertical control and fairly flat terrain can be done in one day. However, if the terrain is rough, plus stations are needed more often, and the sections run between four and five hundred feet right and left, about 1,200 linear feet per day is all that can be obtained. An average of between 2,500 and 3,000 feet of cross-sections can be recorded with the Auto-trol in one day. A field party in flat terrain performing work of comparable accuracy where there is relatively little cover can do 2,500' of cross-sections per day. In rough country where plus stations and turns are frequent, a thousand feet a day is excellent. The average four-man field party can do between 1,200' and 1,500' of cross-sections per day.

It should be noted that the Auto-trol operation can proceed as long as there is photography, whereas the field party cannot operate in inclement weather. The Auto-trol also does away with driving time to and from a job.

Durability and Reliability

Very little production time has been lost due to maintenance on the Auto-trol. The Auto-trol is in production about six hours a day five days a week and maintenance and down time is low. The 80-column selector on the Auto-trol has given some trouble because of poor contact between the rotor and the points. However, this was corrected by sending the Auto-trol to the factory where a few modifications were made to the rotor. The modified point and rotor system is working very efficiently. A wiring diagram came with the Auto-trol and with this diagram the State electronic repair shops have been able to maintain the machine. Auto-trol factory representatives have been called on several times and have shown efficiency in the work they performed. The Auto-trol Corporation has furnished customers with a punch card on which is recorded the different voltage readings, performance rating, and total hours the machine was used per week. This card is mailed to the Auto-trol factory where records are kept. If any voltages change, the customer is notified.

IV

CONCLUSION

The following conclusions have been drawn about the two instruments tested in this research study.

Electrotape

1. The Electrotape was found to be faster than normal field methods of measuring distances, if the distances measured are longer than 1500 feet.
2. The Electrotape has proven to be more accurate than normal field methods of chaining as shown in the body of the report.
3. The Electrotape has few limitations. The limitations that have been observed are noted in the body of the report.
4. The use of the Electrotape has been shown to save as much as $1,000 over conventional methods on a single project.
5. At no time has it been necessary to rerun the established control because of failure of the Electrotape to function properly.

Auto-trol

1. The Auto-trol is as accurate as normal field methods of cross-sectioning.
2. The Auto-trol is faster than normal field methods of cross-sectioning as shown in the body of the report.
3. The Auto-trol has few limitations. The limitations that have been observed are noted in the body of the report.
4. On an average project the Auto-trol will save between $500 and $600 per linear mile of cross-sections over normal field methods.
5. The down time of the Auto-trol has been found to be less than 2% of operating time and when maintenance was required it was performed in a swift and efficient manner.

FOOTNOTES

[1]Hugh C. Mitchell, Definitions of Terms Used in Geodetic and Other Surveys (Washington: U. S. Government Printing Office, 1948), p. 82-83

[2]Cubic Corporation, Cubic Model DM-20 Electrotape, p. 4

[3]U. S. Department of Commerce, prepared by the Photogrammetry for Highways Committee, Reference Guide Outline: Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways, (Washington: U. S. Government Printing Office, 1958) p. 74-76

[4]Letter from Mr. R. H. Lindholm, Jr., Senior Resident Engineer, to Mr. D. C. Greer, State Highway Engineer, Texas Highway Department.

[5]Auto-trol Corporation, Auto-trol 3900 Scaler, p. 01.01, 25.01, 30.01

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U. S. Department of Commerce, Coast and Geodetic Survey. Plane Coordinate Projection Tables, Texas (Lambert). Washington: U. S. Government Printing Office, 1950.

Books

Gosset, Captain F. R., Manual of Geodetic Triangulation. Washington: U. S. Government Printing Office, 1959.

Mitchell, Hugh C., Definitions of Terms Used in Geodetic and Other Surveys. Washington: U. S. Government Printing Office, 1948.

Mitchell, Hugh C. and Simmons, Lansing G., The State Coordinate Systems (A Manual for Surveyors). Washington: U. S. Government Printing Office, 1945.

____________________. Instruction Manual for Electrotape Model DM-20 Distance Measuring Equipment (Electronic). San Diego (5575 Kearny Villa Road, San Diego 11, California): Cubic Corporation, 1961.

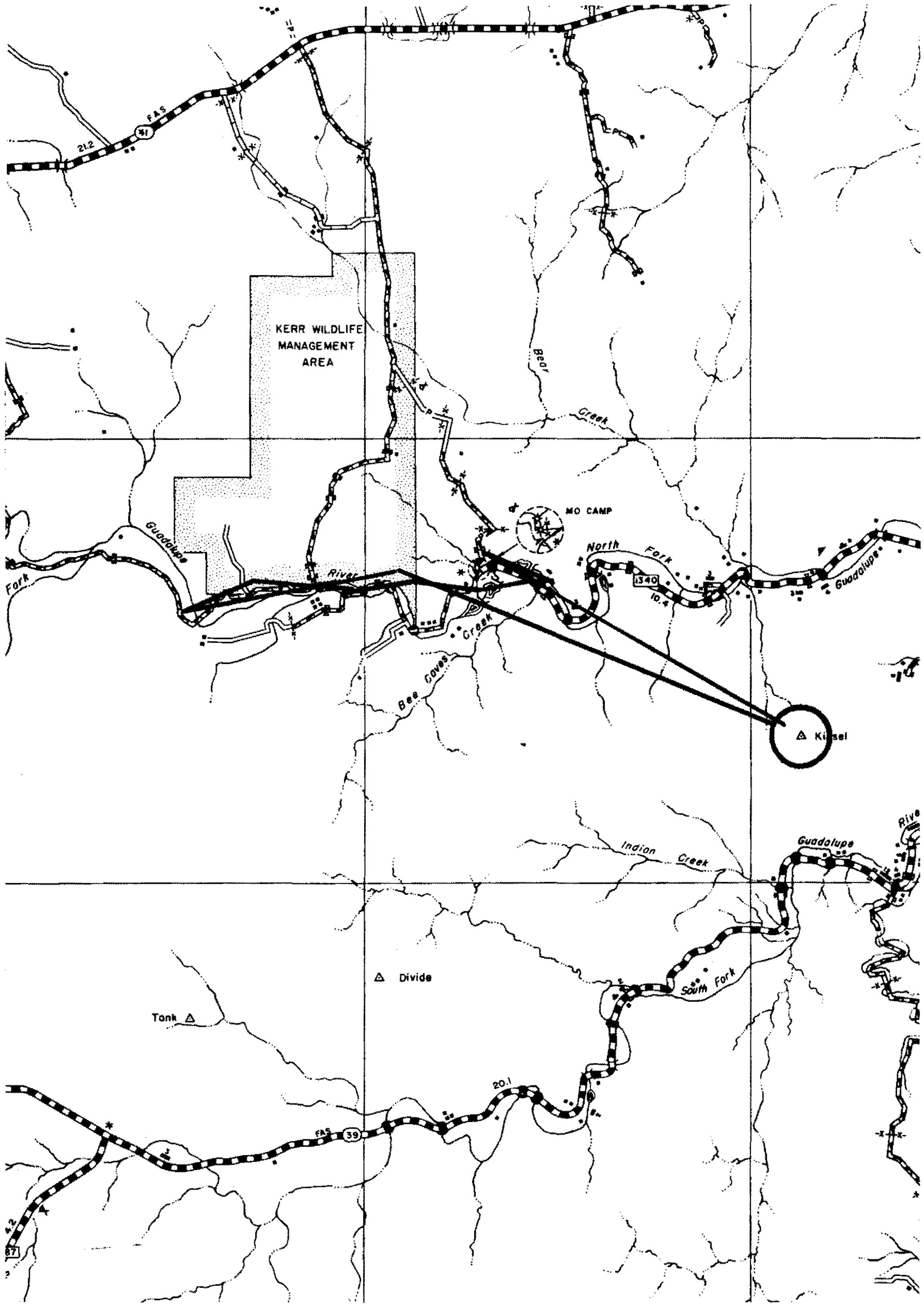
____________________. Auto-trol 3900 Scaler (Operation Manual). Denver (1355 Harlan, Denver 15, Colorado): Auto-trol Corporation.

APPENDIX

SAMPLE TRAVERSE

The following example serves to illustrate the procedure used by the Photogrammetry Section to establish second-order horizontal control for photogrammetric mapping projects. The example is an Electrotape-theodolite traverse. The step-by-step procedure is as follows:

1. The proposed traverse route is laid out on a County Road Map.
2. The field work (measuring the distances and angles) is completed.
3. The resulting data is reduced, and then recorded.
4. The coordinate and azimuth (Texas State Plane Coordinate System) information for the terminal control points is looked up and recorded.
5. The traverse is computed.
6. The resulting X & Y coordinates from the above step are tabulated and submitted to the map layout section.



FM 1340 Traverse In Kerr County
Scale 1" = 2 miles

TEXAS HIGHWAY DEPARTMENT

HIGHWAY DESIGN DIVISION

PHOTOGRAMMETRIC SECTION

ELECTROTAPE FIELD DATA SHEET

DATE 9/1/65 PAGE 17

DISTRICT 15 COUNTY Kerr

PROJECT FM 1340 LIMITS

CONTROL & SECTION

INST. NO. 210 TO INST. NO. 359

FROM STATION Tank (PI-C) TO STATION △ Kinsel

OPERATOR MARVIN RECORDER Don

METEOROLOGICAL DATA	TIME	T_{DB}	T_{WB}	P. ALT
LOCAL		82	70	1850
REMOTE		80	70	
LOCAL		82	70	1850
REMOTE		80	69	
SUM				
MEAN		81	70	1850

H.I. 2.0'

	6	5	4	3
	508	187	992	025
-1	431	431	431	431
	077	756	561	594

2	1	2-1	FREQ
335	431	904	1 HI
334	431	903	2 HI
333	433	900	3 HI
334	435	901	4 HI
335	433	902	5 HI
333	434	899	5 LO
335	433	902	6 LO
333	433	900	7 LO
332	433	899	8 LO
332	433	899	9 LO
SUM		9009	
MEAN		M2	

03
27
90

	6	5	4	3
	510	190	994	026
-1	433	433	433	433
	077	757	561	593
SUM				
MEAN	M6	M5	M4	M3

M6 077

M5 757

M4 561

M3 594

M2 9009

PRESET INDEX 320

ACTUAL INDEX 333

DIFFERENCE (−) 13

DISTANCE $X10^{-6}$ .756 ← DISTANCE 755900.9

PRODUCT 9.828 → MET. CORRECTION − 9.8

SLOPE DISTANCE (1) 755891.1

SLOPE DISTANCE (2) 755891.8

AVERAGE 755891.5

OPERATOR'S NOTES

SD = 7558.915 M.

File 8.87

Electrotape Data Sheet

TEXAS HIGHWAY DEPARTMENT

HIGHWAY DESIGN DIVISION

PHOTOGRAMMETRIC SECTION

ELECTROTAPE FIELD DATA SHEET

DATE 1 sept 65 PAGE 17

DISTRICT 15 COUNTY Kerr

PROJECT FM 1340 LIMITS

CONTROL & SECTION

INST. NO. 359 TO INST. NO. 210

FROM STATION Kinsel △ TO STATION PI C (on tank)

OPERATOR Bill RECORDER Gene

METEOROLOGICAL DATA	TIME	T_{DB}	T_{WB}	P. ALT
LOCAL		80	70	
REMOTE				
LOCAL		80	69	
REMOTE				
SUM				
MEAN				

	6	5	4	3
	668	347	148	184
+100 −1	592	592	592	592
	056	755	556	592
	674	353	154	187
−1	597	597	597	597
	057	756	557	590
SUM				
MEAN	M6 056	M5 756	M4 556	M3 591

2	1	2−1	FREQ
496	592	904	1 HI
495	595	900	2 HI
495	594	901	3 HI
494	594	900	4 HI
494	597	897	5 HI
500	596	904	5 LO
499	598	901	6 LO
499	596	903	7 LO
501	598	903	8 LO
500	597	903	9 LO
SUM		9016	
MEAN		M2	

HI 4.4

M6 056

M5 756

M4 556

M3 591

M2 9016

PRESET INDEX 320

ACTUAL INDEX

DIFFERENCE

DISTANCE X10^{-6} ← DISTANCE 075590 1.6

PRODUCT → MET. CORRECTION −9.8

SLOPE DISTANCE (1)

SLOPE DISTANCE (2) 755891.8

AVERAGE

OPERATOR'S NOTES

File 8.87

Electrotape Data Sheet

TEXAS HIGHWAY DEPARTMENT
HIGHWAY DESIGN DIVISION
PHOTOGRAMMETRIC SECTION

THEODOLITE DATA SHEET

DATE 9-1-65 ANGLE TURNED P1-2+28.00
DISTRICT 15 COUNTY Kerr
PROJECT FM-1340 LIMITS

STATION		UPRIGHT	INVERTED	AVERAGE	AVE. ANGLE	ANGLE
B.S. P1-2 +15.00	1	00-12-02	180-12-10	00-12-06		
	2	45-02-56	225-03-05	45-03-00		
	3	90-03-21	270-03-30	90-03-25		
	4	135-09-33	315-09-39	135-09-36		
⊼ P1-2+28.00						
	1	180-12-46	0-12-52	180-12-49	180-00-43	
	2	225-03-41	45-03-49	225-03-45	180-00-45	
	3	270-04-08	90-04-14	270-04-11	180-00-46	
F.S. P1-3	4	315-10-18	135-10-25	315-10-21	180-00-45	180-00-45

♡ Marvin	⊼ Don	Φ Bean
WEATHER P C d [illegible] wind		

AH. VERTICAL ANGLE 91-21-10 (268-38-56)
BK. VERTICAL ANGLE 269-55-09 (90-04-52) ANGLE P1-2+28.00
File 8.160 PAGE 5

Theodolite Data Sheet

PROJECT - KERR CO FM 1340 PROJECT NUMBER - HPR 0028 IPE
TRAVERSE - KINSEL LOOP DATE - 09 03 65

BEGINNING		337 45 15	1871654.60	797969.80
ENDING		157 45 15	1871654.60	797969.80
.9999409	2000			
5INSEL	323 2 17	7558.91	-34	
PI C	338 56 30	1293.07	-237	
PI 1+200	339 47 14	640.17	33	
1+2300	179 56 56	720.35	2	
PI 2	225 22 58	523.22	84	
2+1500	179 59 30	396.31	1	
2+2800	180 0 45	274.33	22	
PI 3	117 22 46	518.51	57	
3+1700	179 49 39	935.21	-31	
PI A	359 31 42	259.59	-734	
3+3919	52 59 54	232.12	50	
3+4678	179 59 56	529.17	16	
3+6414	136 34 52	715.08	39	
3+8760	204 9 32	558.67	71	
3+10591	181 34 26	241.92	25	
3+11384	144 31 7	552.26	34	
3+13196	21 35 27	4224.99	-39	
PI B	216 13 46	8077.64	-27	
KINSEL	38 31 9	-0	-0	

PROJECT - KERR CO FM 1340 PROJECT NUMBER - HPR 0028 IPE
TRAVERSE - KINSEL LOOP DATE - 09 03 65

AZIMUTH TRAVERSE CLOSURE INFORMATION
THE UNADJUSTED AZIMUTH CLOSURE IS WITHIN SECOND ORDER LIMITS. AZIMUTH CLOSURE= 0 0-25
AFTER THE ANGLES RIGHT WERE ADJUSTED THE AZIMUTH CLOSURE WAS COMPUTED TO BE, 0 0 0

COMBINED ADJUSTMENT FACTOR, (ELEVATION FACTOR)X(SCALE RATIO)= .999845248

POINT	ANGLE RIGHT	AZIMUTH	DISTANCE	UNADJUSTED STATE PLANE COORDINATES EAST-WEST (X)	NORTH-SOUTH (Y)
GIVEN BEGINNING AZIMUTH		337 45 15			
5INSEL	323 2 16			1871654.60	797969.80
		120 47 31	24795.56		
PI C	338 56 29			1850354.40	810663.16
		279 43 59	4240.51		
PI 1+200	339 47 13			1854533.87	809946.26
		79 31 12	2099.69		
1+2300	179 56 55			1852469.21	809564.34
		79 28 7	2362.99		
PI 2	225 22 57			1850146.02	809132.44
		124 51 3	1714.26		
2+1500	179 59 29			1848739.23	810112.04
		124 50 32	1300.03		
2+2800	180 0 44			1847672.25	810854.77
		124 51 15	899.61		
PI 3	117 22 45			1846934.03	811368.89
		62 14 0	1699.93		
3+1700	179 49 38			1845429.84	810576.94
		62 3 38	3067.77		
PI A	359 31 41			1842719.64	809139.57
		241 35 18	849.23		
3+3919	52 59 53			1843466.58	809543.63
		114 35 11	759.79		
3+4678	179 59 55			1842775.67	809859.76
		114 35 6	1735.78		
3+6414	136 34 51			1841197.25	810581.91
		71 9 56	2345.35		
3+8760	204 9 31			1838977.47	809824.75
		95 19 27	1831.24		
3+10591	181 34 25			1837154.13	809994.67
		96 53 51	793.17		
3+11384	144 31 6			1836366.70	810089.93
		61 24 57	1811.28		
3+13196	21 35 26			1834776.19	809223.33
		263 0 23	13859.25		
PI B	216 13 45			1848532.32	810910.83
		299 14 7	26497.18		
KINSEL	38 31 8			1871654.31	797969.64
COMPUTED ENDING AZIMUTH		157 45 15			
		157 45 15 ENDING AZIMUTH		1871654.60 ENDING COORDINATES	797969.80

POSITION CLOSURE INFORMATION
THE ERROR IN POSITION CLOSURE IS LESS THAN 1/10,000
ERROR OF CLOSURE X= 2.94860840E-01 Y= 1.57165527E-01 RATIO OF PRECISION = 1/ 277324

PROJECT - KERR CO FM 1340 PROJECT NUMBER - HPR 0028 IPE
TRAVERSE - KINSEL LOOP DATE - 09 03 65

THE FOLLOWING DISTANCES, AZIMUTHS, AND COORDINATES
WERE COMPUTED FROM AN ADJUSTED SECOND ORDER TRAVERSE.

COMBINED ADJUSTMENT FACTOR, (ELEVATION FACTOR)X(SCALE RATIO)= .999845248

POINT	ANGLE RIGHT	AZIMUTH	DISTANCE	ADJUSTED STATE PLANE COORDINATES EAST-WEST (X)	NORTH-SOUTH (Y)
GIVEN BEGINNING AZIMUTH		337 45 15			
5INSEL	323 2 16			1871654.60	797969.80
		120 47 31	24795.52		
PI C	338 56 28			1850354.48	810663.21
		279 43 59	4240.52		
PI 1+200	339 47 13			1854533.96	809946.32
		79 31 12	2099.68		
1+2300	179 56 55			1852469.31	809564.40
		79 28 7	2362.98		
PI 2	225 22 57			1850146.13	809132.50
		124 51 4	1714.26		
2+1500	179 59 29			1848739.34	810112.11
		124 50 33	1300.03		
2+2800	180 0 44			1847672.37	810854.84
		124 51 16	899.61		
PI 3	117 22 44			1846934.14	811368.96
		62 14 0	1699.93		
3+1700	179 49 38			1845429.96	810577.02
		62 3 38	3067.76		
PI A	359 31 41			1842719.77	809139.65
		241 35 18	849.23		
3+3919	52 59 53			1843466.71	809543.72
		114 35 12	759.79		
3+4678	179 59 55			1842775.81	809859.84
		114 35 6	1735.78		
3+6414	136 34 50			1841197.39	810582.00
		71 9 56	2345.35		
3+8760	204 9 31			1838977.62	809824.84
		95 19 27	1831.23		
3+10591	181 34 25			1837154.29	809994.77
		96 53 52	793.17		
3+11384	144 31 6			1836366.86	810090.02
		61 24 57	1811.27		
3+13196	381 35 26			1834776.35	809223.42
		263 0 23	13859.30		
PI B	216 13 44			1848532.53	810910.93
		299 14 7	26497.22		
KINSEL	38 31 8			1871654.60	797969.80
COMPUTED ENDING AZIMUTH		157 45 15			
		157 45 15 ENDING AZIMUTH		1871654.60 ENDING COORDINATES	797969.80

PROJECT - KERR CO FM 1340
TRAVERSE - KINSEL LOOP

PROJECT NUMBER - HPR 0028 IPE
DATE - 09 03 65

THE FOLLOWING DISTANCES, AZIMUTHS, AND COORDINATES
WERE COMPUTED FROM AN ADJUSTED SECOND ORDER TRAVERSE.

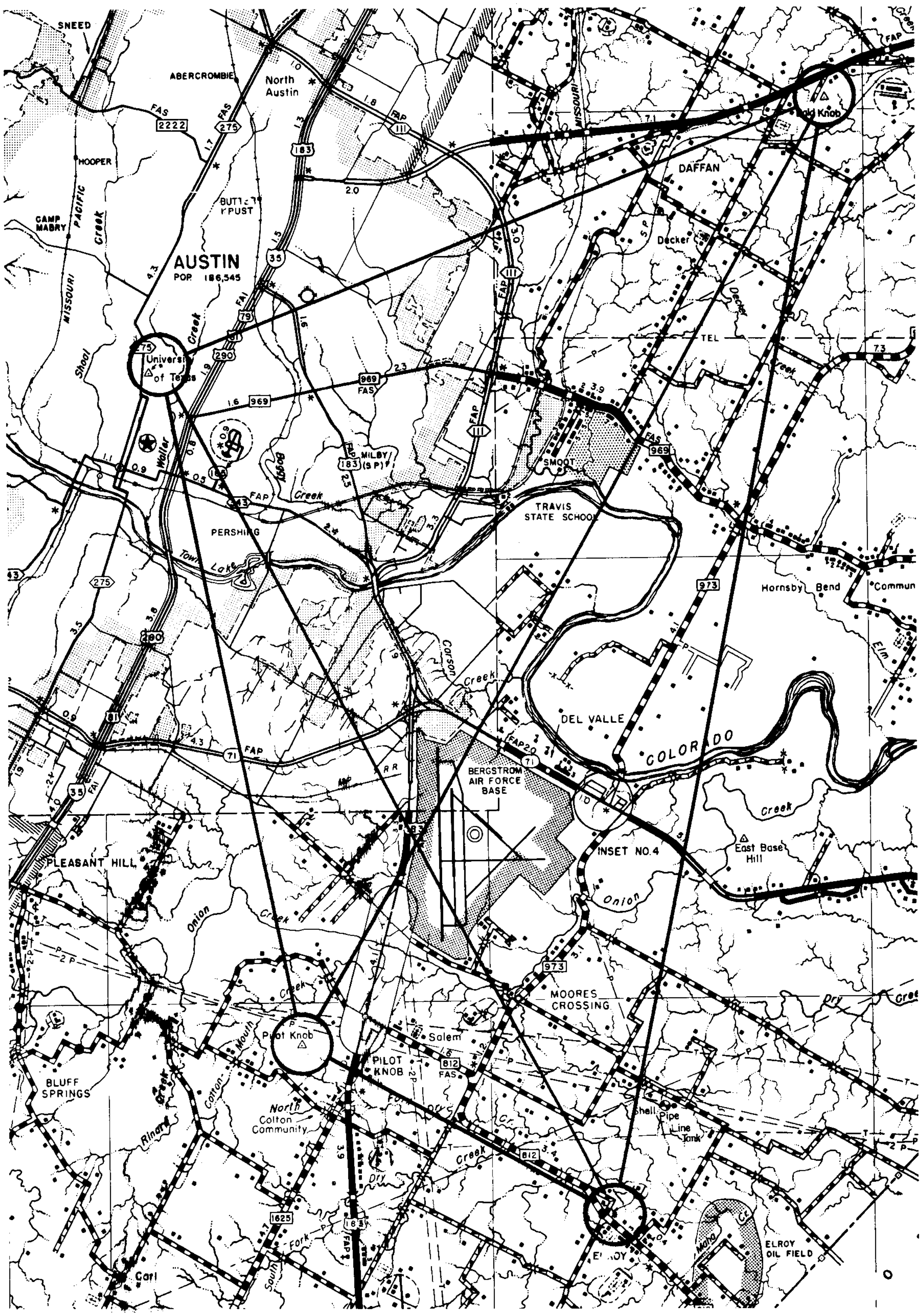
SURFACE ADJUSTMENT FACTOR, 1.0/(AVE. COMB. FACTOR) = 1.000154775

POINT	AZIMUTH	DISTANCE	ADJUSTED SURFACE COORDINATES EAST-WEST (X)	NORTH-SOUTH (Y)
5INSEL			1871944.29	798093.31
	120 47 31	24799.36		
PI C			1850640.87	810788.68
	279 43 59	4241.18		
PI 1+200			1854821.00	810071.68
	79 31 12	2100.01		
1+2300			1852756.02	809689.70
	79 28 7	2363.35		
PI 2			1850432.48	809257.74
	124 51 4	1714.52		
2+1500			1849025.48	810237.49
	124 50 33	1300.23		
2+2800			1847958.34	810980.34
	124 51 16	899.75		
PI 3			1847220.00	811494.54
	62 14 0	1700.19		
3+1700			1845715.59	810702.47
	62 3 38	3068.24		
PI A			1843004.98	809264.88
	241 35 18	849.36		
3+3919			1843752.04	809669.01
	114 35 12	759.91		
3+4678			1843061.03	809985.19
	114 35 6	1736.05		
3+6414			1841482.36	810707.46
	71 9 56	2345.71		
3+3760			1839262.25	809950.18
	95 19 27	1831.52		
3+10591			1837438.63	810120.13
	96 53 52	793.29		
3+11384			1836651.08	810215.40
	61 24 57	1811.55		
3+13196			1835060.33	809348.67
	263 0 23	13861.44		
PI B			1848818.64	811036.44
	299 14 7	26501.32		
KINSEL			1871944.29	798093.31

SAMPLE TRILATERATION-NET

The following example serves to illustrate the procedure used by the Photogrammetry Section to establish horizontal control for a photogrammetric mapping project by the Trilateration method. The step-by-step procedure is as follows:

1. The proposed net is laid out on available maps.
2. The field work (measuring the distances) is completed.
3. The resulting data is reduced and recorded.
4. The beginning and ending coordinate and azimuth information is determined.
5. The interior angles are computed by CDC 1604 computer.
6. A traverse through the points is selected and computed (using the measured distances and the computed distances).
7. The resulting X & Y coordinates from the above step are tabulated and submitted to the map layout section.



Trilateration Loop in Travis County
Scale 1" = 2 miles

TEXAS HIGHWAY DEPARTMENT

HIGHWAY DESIGN DIVISION

PHOTOGRAMMETRIC SECTION

ELECTROTAPE FIELD DATA SHEET

DATE 8/11/65 PAGE 4

DISTRICT 14 COUNTY TRAVIS

PROJECT RESEARCH LIMITS TRI. LAT

CONTROL & SECTION

INST. NO. 210 TO INST. NO. 209

FROM STATION BALD KNOB TO STATION PILOT KNOB

OPERATOR BEAR RECORDER STAN

METEOROLOGICAL DATA	TIME	T_{DB}	T_{WB}	P. ALT
LOCAL		98	81	500
REMOTE				
LOCAL				
REMOTE				
SUM				
MEAN		94	77.5	460

	6	5	4	3
	869	899	199	200
-1	644	644	644	644
	225	255	555	556

2	1	2-1	FREQ
212	644	568	1 HI
210	640	570	2 HI
211	640	571	3 HI
212	642	570	4 HI
212	640	572	5 HI
213	640	573	5 LO
211	642	569	6 LO
211	640	571	7 LO
212	640	572	8 LO
210	642	568	9 LO
SUM		5704	
MEAN	M2	570.4	

	6	5	4	3
	862	890	795	794
-1	642	642	642	642
	220	248	553	552
SUM				
MEAN	M6 223	M5 252	M4 554	M3 554

HJ - 4.0'

M6 2 2 3

M5 2 5 2

M4 5 5 4

M3 5 5 4

M2 5 7 0 4

PRESET INDEX 320

ACTUAL INDEX 354

DIFFERENCE -34

DISTANCE X10^{-6} 2.26 ← DISTANCE 22555704

PRODUCT 76.84 → MET. CORRECTION -76.8

SLOPE DISTANCE (1) 22554936

SLOPE DISTANCE (2) 22554972

AVERAGE 22554954

OPERATOR'S NOTES

SD = 22,554.954 M

SD = 73,999.045 ft

File 8.87

Electrotape Data Sheet

TEXAS HIGHWAY DEPARTMENT

HIGHWAY DESIGN DIVISION

PHOTOGRAMMETRIC SECTION

ELECTROTAPE FIELD DATA SHEET

DATE 8-11-65 PAGE 4
DISTRICT 14 COUNTY TRAVIS
PROJECT TRILAT LIMITS
CONTROL & SECTION
INST. NO. 209 TO INST. NO. 210
FROM STATION PILOT KNOB TO STATION BALD KNOB
OPERATOR DON RECORDER BILL

METEOROLOGICAL DATA

	TIME	T_{DB}	T_{WB}	P. ALT
LOCAL		90	73	625
REMOTE				
LOCAL				
REMOTE				
SUM				
MEAN				

4.1 = 4.1

	6	5	4	3
	084	109	412	414
-1	852	852	852	852
	232	257	560	562

2	1	2-1	FREQ
427	852	575	1 HI
426	854	572	2 HI
427	858	569	3 HI
426	853	573	4 HI
428	856	572	5 HI
429	855	574	5 LO
430	858	572	6 LO
435	852	583	7 LO
429	857	572	8 LO
433	855	578	9 LO
	SUM	5730	
	MEAN	5740	

	6	5	4	3
	862	713	412	417
-1	855	855	855	855
	221	258	557	562
SUM				
MEAN	M6	M5	M4	M3

M6 2 3 0
M5 2 5 7
M4 5 5 5
M3 5 6 2 4
M2 5 7 5 0

PRESET INDEX 320
ACTUAL INDEX
DIFFERENCE

DISTANCE X10^{-6} ← DISTANCE 2 2 5 5 5 7 4.0
PRODUCT → MET. CORRECTION -76.8
SLOPE DISTANCE (1) 2255497.2
SLOPE DISTANCE (2)
AVERAGE

OPERATOR'S NOTES

File 8.87

Electrotape Data Sheet

TEXAS HIGHWAY DEPARTMENT
HIGHWAY DESIGN DIVISION
PHOTOGRAMMETRIC SECTION

THEODOLITE DATA SHEET

DATE 8-11-65 ANGLE TURNED PILOT KNOB
DISTRICT 14 COUNTY TRAVIS
PROJECT TRI LAT LIMITS

STATION		UPRIGHT	INVERTED	AVERAGE	AVE. ANGLE	ANGLE
B.S. ST. EDWARDS	1	00-04-22	180-04-26	00-04-24		
	2	45-11-14	225-11-26	45-11-20		
	3	90-07-55	270-08-04	90-07-59		
	4	135-08-06	315-08-16	135-08-11		
⊼ PILOT KNOB						
	1	16-26-47	196-26-56	16-26-51	16-22-27	
	2	61-33-54	241-33-54	61-33-54	16-22-34	
	3	~~108~~ 106-30-24	286-30-30	106-30-27	16-22-28	
F.S. CAPITOL	4	151-30-38	331-30-38	151-30-38	16-22-27	16°-22'-29"

BILL	⊼ DON	Φ

WEATHER CLEAR - HOT - MANY HEAT WAVES

AH. VERTICAL ANGLE
BK. VERTICAL ANGLE ANGLE
File 8.160 PAGE 1

Theodolite Data Sheet

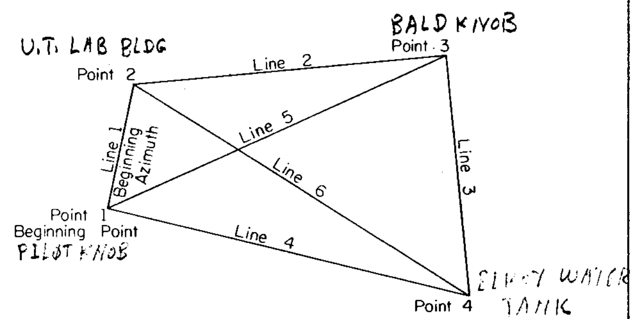
PROGRAM TRILAT

GEODETIC TRILATERATION PROGRAM (SECOND ORDER)

TEXAS HIGHWAY DEPARTMENT
DIVISION OF AUTOMATION

A	+01
B	11/22/65
C	+1
D	PLT, UT, BLD, ELRY
E	000
F	TRAVIS TRILAT
G	HPR 0028
H	PLT KNØB
I	168 18 09
J	2829739.04
K	188707.15
L	+0.9999709
M	+0711
N	+0580
O	+0674
P	+0600

	Q	R
1	- 47769.88	+0131
2	- 18359.38	+0099
3	- 77549.89	+0079
4	- 24599.28	+0111
5	- 73999.04	+0037
6	- 66049.98	+0020



A. Number of Courses
B. Date
C. Course Number
D. Quadrilateral Name
E. IPE
F. County and Highway
G. Project Number
H. Name of Beginning Point
I. Azimuth of Line 1
J. X Coordinate of Beginning Point
K. Y Coordinate of Beginning Point
L. Scale Factor
M. Elevation of Point 1
N. Elevation of Point 2
O. Elevation of Point 3
P. Elevation of Point 4
*Q. Distance
**R. Horizontal Adjustment Factor

NOTE:
* For Distances — Denotes Feet; + Denotes Meters
** For Horizontal Factor + Denotes Difference in Elevation; — Denotes Sine of the Vertical Angle

0 = Zero	1 = One	2 = Two
Ø = Alpha O	I = Alpha I	Ƶ = Alpha Z

This sketch is placed here for ease of coding this form. Actual point names can be written on this sketch for handy reference.

NOTE: (A) Point 1 is always the beginning point.
(B) The azimuth of line 1 is always the beginning azimuth.

File 19.1

PROJECT - TRAVIS TRILAT
QUADRILATERAL - PLT,UT,BLD,ELRY

PROJECT NUMBER - HPR 0028 IPE 000
DATE - 11/22/65

SIDE	SLOPE DISTANCE (ORIGINAL)	HORIZONTAL DISTANCE (FEET)	GRID DISTANCE (FEET)	HORIZ. FACTOR	SLOPE DISTANCE (ADJUSTED)
1	-47769.88	47769.88	47767.02	1.0000000	47769.58
2	-48359.38	48359.38	48356.52	1.0000000	48359.08
3	-77544.84	77544.84	77540.22	1.0000000	77544.54
4	-24599.28	24599.28	24597.79	1.0000000	24598.98
5	-73999.04	73999.04	73994.44	1.0000000	73998.74
6	-66049.98	66049.98	66046.19	1.0000000	66049.68

STATE PLANE DISTANCE REDUCTION INFORMATION,
COMBINED FACTOR= .999940241 SCALE FACTOR= .999970900 AVE. ELEV.= 641

COMPUTED INTERIOR ANGLES

	ORIGINAL SIDES		ADJUSTED SIDES	
	UNADJUSTED ANGLES	ADJUSTED ANGLES	UNADJUSTED ANGLES	ADJUSTED ANGLES
ANGLE 1	39 57 28	39 57 27	39 57 27	39 57 27
ANGLE 2	16 51 3	16 51 3	16 51 2	16 51 2
ANGLE 3	83 49 1	83 49 1	83 49 2	83 49 2
ANGLE 4	39 22 30	39 22 30	39 22 29	39 22 29
ANGLE 5	18 29 31	18 29 31	18 29 30	18 29 30
ANGLE 6	38 18 59	38 18 58	38 18 59	38 18 59
ANGLE 7	34 15 31	34 15 30	34 15 29	34 15 29
ANGLE 8	88 56 1	88 56 1	88 56 2	88 56 2
ANGLE 9	128 53 25	128 53 27	128 53 29	128 53 29
ANGLE 10	100 40 2	100 40 4	100 40 4	100 40 4
ANGLE 11	57 52 0	57 52 0	57 52 0	57 52 0
ANGLE 12	72 34 28	72 34 29	72 34 28	72 34 28

ERROR EQUATION COEFFECIENTS

CORNER CONDITIONS				OPPOSITE ANGLE CONDITIONS		ANGLE SUM CONDITIONS	
0 0 4	0 0 2	0 0 1	0 0 3	0 0 0	0 0 0	0 0 0	0 0 0
0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 C	0 0 C

APPARENT SYSTEMATIC ERROR IN SIDES,
ERROR= .30 FEET OR 9 CENTIMETERS

PROJECT - TRAVIS TRILAT
QUADRILATERAL - PLT,UT,BLD,ELRY

PROJECT NUMBER - HPR 0028 IPE 000
DATE - 11/22/65

THE FOLLOWING QUANTITIES WERE COMPUTED FROM
UNADJUSTED SIDES AND THE UNADJUSTED ANGLES

LINE	AZIMUTH	SLOPE DISTANCE (ORIGINAL)	GRID DISTANCE (FEET)	SURFACE DISTANCE (FEET)
1	168 18 4	-47769.88	47767.02	47769.87
2	247 38 2	-48359.38	48356.52	48359.41
3	9 46 2	-77544.84	77540.22	77544.85
4	117 11 34	-24599.28	24597.79	24599.26
5	208 15 32	-73999.04	73994.44	73998.86
6	331 27 1	-66049.98	66046.19	66050.14

DISTANCE AND COORDINATE CONVERSION FACTORS.
SCALE F.= .999970900 AVE. ELEV.= 641 COMB. F.= .999940241

THE FOLLOWING COORDINATES WERE COMPUTED BY PATH 1

POINT	APPROXIMATE ELEVATION (FEET)	STATE PLANE COORDINATES		GROUND COORDINATES	
		E-W	N-S	E-W	N-S
1	711	2829734.04	188707.15	2829903.15	188718.43
2	580	2820048.40	235481.89	2820216.94	235495.96
3	674	2864767.09	253882.78	2864938.29	253897.95
4	600	2851612.81	177466.48	2851783.23	177477.08

X-Y COORDINATE CALCULATION CLOSURE INFORMATION.

PATH 1	DX= -.33	DY= .17	DXY= .37
PATH 2	DX= .58	DY= .31	DXY= .66
PATH 3	DX= .25	DY= .49	DXY= .55

PROJECT - TRAVIS TRILAT PROJECT NUMBER - HPR 0028 IPE 000
QUADRILATERAL - PLT,UT,BLD,ELRY DATE - 11/22/65

THE FOLLOWING QUANTITIES WERE COMPUTED FROM
THE UNADJUSTED SIDES AND THEIR ASSOCIATED ADJUSTED ANGLES.

LINE	AZIMUTH	SLOPE DISTANCE (ORIGINAL)	GRID DISTANCE (FEET)	SURFACE DISTANCE (FEET)
1	168 18 4	-47769.88	47767.02	47769.87
2	247 38 0	-48359.38	48356.52	48359.41
3	9 46 0	-77544.84	77540.22	77544.85
4	117 11 31	-24599.28	24597.79	24599.26
5	208 15 31	-73999.04	73994.44	73998.86
6	331 27 1	-66049.98	66046.19	66050.14

DISTANCE AND COORDINATE CONVERSION FACTORS.
SCALE F.= .999970900 AVE. ELEV.= 641 COMB. F.= .999940241

THE FOLLOWING COORDINATES WERE COMPUTED BY PATH 1

POINT	APPROXIMATE ELEVATION (FEET)	STATE PLANE COORDINATES		GROUND COORDINATES	
		E-W	N-S	E-W	N-S
1	711	2829734.04	188707.15	2829903.15	188718.43
2	580	2820048.40	235481.89	2820216.94	235495.96
3	674	2864766.98	253883.04	2864938.18	253898.21
4	600	2851613.39	177466.62	2851783.81	177477.23

X-Y COORDINATE CALCULATION CLOSURE INFORMATION.

PATH 1	DX= .09	DY= .01	DXY= .09
PATH 2	DX= .04	DY= .10	DXY= .11
PATH 3	DX= -.41	DY= -.01	DXY= .41

PROJECT - TRAVIS TRILAT PROJECT NUMBER - HPR 0028 IPE 000
QUADRILATERAL - PLT,UT,BLD,ELRY DATE - 11/22/65

THE FOLLOWING QUANTITIES WERE COMPUTED FROM
THE ADJUSTED SIDES AND THEIR ASSOCIATED ADJUSTED ANGLES.

LINE	AZIMUTH	SLOPE DISTANCE (ORIGINAL)	GRID DISTANCE (FEET)	SURFACE DISTANCE (FEET)
1	168 18 4	-47769.88	47766.72	47769.58
2	247 38 0	-48359.38	48356.23	48359.12
3	9 46 1	-77544.84	77539.93	77544.56
4	117 11 33	-24599.28	24597.50	24598.97
5	208 15 31	-73999.04	73994.14	73998.56
6	331 27 2	-66049.98	66045.90	66049.85

DISTANCE AND COORDINATE CONVERSION FACTORS.
SCALE F.= .999970900 AVE. ELEV.= 641 COMB. F.= .999940241

THE FOLLOWING COORDINATES WERE COMPUTED BY PATH 1

POINT	APPROXIMATE ELEVATION (FEET)	STATE PLANE COORDINATES		GROUND COORDINATES	
		E-W	N-S	E-W	N-S
1	711	2829734.04	188707.15	2829903.15	188718.43
2	580	2820048.46	235481.60	2820217.00	235495.67
3	674	2864766.77	253882.63	2864937.98	253897.80
4	600	2851612.94	177466.55	2851783.36	177477.16

X-Y COORDINATE CALCULATION CLOSURE INFORMATION.

PATH 1	DX= .01	DY= .00	DXY= .01
PATH 2	DX= .00	DY= .01	DXY= .01
PATH 3	DX= -.03	DY= -.00	DXY= .03

TRAVERSE CLOSURES

Name of Traverse	Length (ft.)	Position Closure (ft.)	Relative Accuracy (ft.)
Eastland Co., S.H. 206			
POT #1 to PI 7	20,000	0.75	1/27,000
PI 7 to PI 8	30,000	1.37	1/22,000
PI 13 to PI 753+00	85,000	1.50	1/57,000
El Paso Co., Loop 375			
Fort to Frontera	72,413	1.15	1/62,852
PI 24 to Saddle 1	57,613	1.76	1/32,797
El Paso Co., U.S. 54			
Park to PI 20	51,138	1.69	1/30,111
PI 24 to St. Line	138,189	9.14	1/15,119
El Paso Co., I.H. 10	15,623	1.45	1/10,723
Ft. Bend Co., U.S. 59			
K trig. sta. to H trig. sta.	35,000	3.14	1/11,000
K trig. sta. to L trig. sta.	85,000	0.95	1/90,000
Sugarland to State	56,000	3.30	1/17,000
Lane to PI 40	39,500	1.18	1/34,000
Fayette-Gonzales Cos., I.H. 10			
Botts to Waelder	127,980	5.33	1/24,042
BL POT to 133	72,024	4.19	1/17,196
Schlnbrg to Obar	78,375	2.40	1/32,623
Jefferson Co., U.S. 69			
Power to Beaument	30,208	2.82	1/11,000

Name of Traverse	Length (ft.)	Position Closure (ft.)	Relative Accuracy (ft.)
Harris Co., U.S. 290			
Hockley to Kulnack	72,000	2.60	1/36,000
Tom Green Co., U.S. 87	64,000	1.18	1/54,000
Nueces Co., S.H. 44			
Rog. 2 to Fairv.	81,466	0.91	1/89,265
Bell Co., I.H. 35			
Belton to Temple	86,264	2.15	1/40,091
Harris-Galveston Cos., S.H. 3			
HLP to Ellington	21,980	2.15	1/10,214
POT 447 to DKnsn	57,360	1.57	1/36,630
Harris-Galveston Cos., S.H. 146			
Hanson to GSB	88,711	5.53	1/16,049
Hanson to Moses	45,683	1.41	1/32,342
Cameron-Willacy Cos., U.S. 77			
Combes to Lyford	67,696	0.94	1/72,100
Lyford to Yturria	82,245	3.98	1/20,674
Harrison Co., Loop 390			
Marsh. to Sulli.	39,569	0.52	1/76,265
Harris-Brazoria Cos., S.H. 288			
Foster to S-5164	53,744	0.42	1/128,168
PI 25 to Arcola	35,532	1.55	1/22,861
PI 35 to Sandy Pt.	52,367	1.40	1/37,463
PI 53 to Lak Jak	141,016	7.25	1/19,450

Name of Traverse	Length (ft.)	Position Closure (ft.)	Relative Accuracy (ft.)
Wise-Tarrant Cos., S.H. 114			
Traverse #1	22,063	1.97	1/11,208
Traverse #2	34,798	0.37	1/94,424
Traverse #3	56,296	2.75	1/20,490
Kerr Co., F.M. 1340			
Kinsel Loop	92,663	0.33	1/277,324
Palo Pinto Co., S.H. 337			
Oaks to Rock	180,602	17.97	1/10,052
Palo Pinto Co., S.H. 254			
Kyle Loop	132,190	2.49	1/53,047
Crockett Co., I.H. 10			
Yates to University	168,937	15.74	1/10,732
845 to Air	96,684	2.16	1/44,796
Ozona to Gravel	55,422	2.06	1/26,933
Pecos Co., I.H. 10			
Field to Miller	71,708	2.55	1/28,096
Field to Airport	29,383	0.58	1/50,580
Reeves Co., I.H. 10			
Rice to Toyah	183,679	2.26	1/81,269
Parker Co., U.S. 180			
Gilbert to Rocky Kroll	102,036	3.11	1/32,834
PI 1 to PI 16	23,570	0.97	1/24,405
Victoria-Jackson Cos., U.S. 59			
Foster to Plainview	223,311	1.79	1/124,422

Name of Traverse	Length (ft.)	Position Closure (ft.)	Relative Accuracy (ft.)
Freestone Co., I.H. 45			
455+28 to Grindstone	86,157	5.95	1/14,457
Wichita Co.,U.S. 281			
PI 177+ to PI 188+	36,069	1.85	1/19,475
U.S. 79 X-flight	10,237	0.44	1/23,072
Dallas Co., I.H. 20			
PI 15 to Duncan	20,482	0.52	1/39,523
PI 28 to Rolett	39,462	3.58	1/11,015
Tarrant Co., I.H. 20			
Leatherman to Wisdom	66,590	2.07	1/32,204
POT PI 12 to PI 13	10,366	0.64	1/16,259
Brambleton to POT 39-B	74,375	4.65	1/15,994
Leatherman to PI 4	29,651	1.27	1/23,306
Traverse #1	13,812	0.95	1/14,608
Traverse #2	14,082	0.71	1/19,967
Tarrant Co., I.H. 35W			
Seminary to Burleson	56,844	2.16	1/26,376
Loop 1-C-B-A-1	9,843	0.14	1/72,471
Loop F.M. 1187	10,094	0.63	1/15,926
Loop South End	10,441	0.24	1/43,352
Crosby Co., U.S. 82			
Saunders to Ralls	46,327	0.64	1/72,841
Croen to S-1	62,043	4.92	1/12,618
Tarrant Co., I.H. 820			
Amsteader to IP 3	90,820	3.63	1/25,013

Name of Traverse	Length (ft.)	Position Closure (ft.)	Relative Accuracy (ft.)
San Patricio Co., I.H. 37			
Block to Corpus	58,536	1.71	1/34,168
Tarrant Co., S.H. 360			
PI 1 to PI ZN	45,635	2.77	1/16,467
Montague Co., U.S. 287			
Queen to Park	128,344	0.85	1/151,119
Jefferson Co., S.H. 87			
Port Arthur Bridge	60,703	1.06	1/57,169
Brazos Co., S.H. 6			
Benchley to A & M	94,693	5.47	1/17,311
PI 29 to A & M 1	52,063	1.54	1/33,722
PI 22 to PI 33 alt	14,959	0.41	1/36,807
Panola-Harrison Cos., U.S. 59			
M-10 to Martin	114,428	5.72	1/20,019
Gray-Donley Cos., I.H. 40			
Bailey to Alan	69,973	1.32	1/52,945
Alan to Reed	47,506	1.69	1/28,102
Reed to Jerico	49,768	1.03	1/48,436
Jerico to Groom	70,991	6.14	1/11,559
Fayette Co., S.H. 71			
LaGrange Loop	35,292	0.55	1/63,939
Smith Co., Tyler Loop			
Smith Co. Loop	82,045	1.86	1/44,204

Name of Traverse	Length (ft.)	Position Closure (ft.)	Relative Accuracy (ft.)
Grimes Co., S.H. 6			
Nelleva to Betts	71,671	3.41	1/21,038
Harris Co., U.S. 90			
Jacinto to Crosby	75,552	0.74	1/101,823
PI 53 to Crosby	45,401	0.49	1/91,978
Runnels Co., U.S. 83			
Winters to Mann	50,672	1.58	1/32,115
Williamson Co., Loop 427			
U.S. 79 Loop	44,966	0.85	1/52,760

COMPARISON OF THE ELECTROTAPE TO TRIANGULATION FOR CONTROL ON BRIDGE STRUCTURES

Distance	Triangulation (ft.)	Electrotape (ft.)
A - B	644.53	644.70
A - C	925.02	925.07
A - D	631.27	631.20
D - E	620.17	620.31
B - C	827.30	827.40