Horizontal Control Staking by Triangulation With Computations by Computer

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This paper describes the development and use of a method for establishing a horizontal control system for staking complicated geometrics on the ground. Major control points were established overlooking the project. Construction stakes could then be "cut in" from at least two control points by using directional theodolites. The data for each control point, including clockwise angles from an established reference point to desired construction stakes, were predetermined. Calculations based on coordinates were made by using various geometric programs designed for the IBM 650 computer. The output information for each control point was printed and bound into a convenient field book size volume, thus completely eliminating the need for field computations.

The Austin project is nearing completion and this method of staking has proved effective in obtaining information necessary for plan preparation, adjustments of utility lines, and the most important phase—that of translating the geometric design of the plans to construction stakes in the field.

• HIGHWAY ENGINEERS are constantly faced with the problem of setting construction stakes for complicated intersections, structures, and expressway geometrics. Translating the design and layout information of the plans to construction stakes in the field is frequently a difficult task. This is especially true where physical features, obstructions, and heavy traffic congestion prevent laying out reference lines or centerlines in the field. In most cases, the modern urban highway is constructed along an existing alignment or amid a network of streets where it is virtually impossible to interrupt the flow of traffic and to provide the necessary safety to field surveying personnel. This danger and difficulty interferes with all surveying operations for gathering design data and setting stakes for the construction of the project.

This paper describes how the writer, in conjunction with the Texas Highway Department's Computer Section, solved many of these problems and established a new set of staking procedures for a project in Austin, Texas. These procedures constituted a method whereby construction stakes for horizontal control were set by being "cut in" from control points outside the limits of the construction area.

Interstate 35, from 19th Street to the Colorado River, is a new six-lane freeway under construction along old East Avenue, a main north-south artery through Austin. Approximately 30,000 vehicles each day used the avenue and heavy traffic congestion existed at all the cross-streets. This heavy traffic, combined with rough terrain, poor sight distance, and a lack of alternate routes available to detour traffic made conventional staking procedures a real hazard to field personnel. Chaining across the flow of heavy traffic was almost impossible.

The IBM 650 computer was used to calculate and tabulate all the necessary coordinates, angles, and distances in a form that could be readily used in the field by construction personnel. These predetermined data, geared to a field survey procedure, were used to set desired construction stakes quickly and accurately. The purpose of this paper is to acquaint the reader with the basic computer programs used. Then there is a discussion to show how these programs were combined to develop the triangulation method of horizontal control staking as used on Interstate 35 in the City of Austin.

COMPUTER PROGRAMS

The programs described are primarily basic geometric programs designed to solve any combinations of straight lines and curves. The rectangular coordinate system forms the basis for these programs, and the system may be either a recognized coordinate system such as the Texas coordinate system (Lambert) or a coordinate system selected arbitrarily for the problem. The Lambert scale factor can be incorporated where the Texas coordinate system is chosen. For the computer to calculate correct bearings, an arbitrary coordinate system should be so selected that the entire problem, including distant reference points, will always remain in the first quadrant (positive), and that the Y-axis of the system be due north and the X-axis be due east.

These programs are so designed that they may be used separately or, with the exception of the "traverse," may all be combined to extend calculations from one program into that of another.

This discussion is concerned only with a brief description of each program as it is used in the construction staking, without discussing the mathematics or the details involved in programing these problems. Additional information can be obtained from the Operations Division of the Texas Highway Department in Austin, Texas. The sample problem used on the Austin project, described later, will best illustrate the use of these programs and allow the reader to observe the input and output data for each program.

Interdependent Traverse Program

The interdependent traverse program, developed by the California Highway Department and modified by the Texas Highway Department (1), calculates unknown sides and unknown bearings, determines the area, and provides as output a systematic listing of courses with their computed or known factors. The traverse program, with coordinates furnished for the beginning point, will calculate coordinates for each subsequent points traversed. The program also provides for some interdependency of traverses. The interdependency feature allows data from specified courses to be stored for later use and permits a subsequent traverse to call for stored data.

One traverse problem will handle up to 90 courses. A maximum of 25 unknowns may be kept in storage at any given time to be used in subsequent problems.

B-10 Program

The B-10 program (2, Pt. I) computes two separate types of calculations as follows:

1. The coordinates of a point when the centerline station and offset are known. The centerline may be either a straight or curved line.
2. The centerline station and offset when the coordinates of the point are known.

Coordinates for all points computed in the B-10 program may be stored for future use in other programs. This is a very important feature in that this eliminates manual listing of coordinates on the input data sheet of subsequent programs. Coordinates of a desired point on a particular centerline can be computed and coded for re-use as reference coordinates for the line. This feature makes it possible to start with only one point of known coordinates and traverse through a series of straight or curved lines.

One B-10 program has a capacity of 10 reference or station lines and will compute the answers for 99 points. If more points are needed, another problem with a different part number must be run.

B-11 Program

If coordinates of any two points are known, the B-11 program (2, Pt. III) will compute the distance and bearing between them (the distance and bearing defines a straight line). Rather than having to manually write out the coordinates for each point on the B-11 input form, coordinates previously determined by the B-10 program, for one or both points may be called for by inserting the point number from the appropriate problem. Here again, this stored problem feature plays an important part in that writing out all the coordinates necessary for the input would be time consuming, costly, and a source of many human errors.

B-11A Program

The B-11A program (2, Pt. IV) is used in conjunction with the B-11 program. The purpose of this program is to define a straight line and when used with the B-11 program it computes the clockwise angle between the line defined by the B-11A and the line or lines defined by the B-11 program. This program furnishes the terminal data for the triangulation staking; i.e., the clockwise angles the instrumentmen must turn in the field to locate and establish the desired point for a construction stake.

TRIANGULATION STAKING FOR INTERSTATE 35 IN AUSTIN

As mentioned earlier, Interstate 35, from 19th Street to the Colorado River, followed East Avenue, an old established north-south artery through Austin. The traffic on East Avenue was very heavy and there was no way to detour or relieve the congestion of traffic within the project area. The rough terrain further complicated the traffic problem, making it almost impossible to establish conventional centerline control in the field for the purpose of gathering design information and for construction purposes.

A study of the various programs available from the Computer Section of the Operations Division, Texas Highway Department, indicated that coordinates could easily be obtained for any predetermined point within the project by using the B-10 program and that, with the addition of the B-11A program to the available B-11 program, additional information could be secured to simplify staking these points in the field.

A topographic map, prepared from recorded subdivision plats, was field checked against the old monument line of East Avenue. This map was then used for design

TEXAS HIGHWAY DEPARTMENT

TRAVERSE SHEET

PROBLEM TYPE	DISTRICT	I P S. NO.	TRAVERSE NO.
2	14	828	1

COUNTY Travis		CODE NO.
CONTROL	SECTION	JOB
15	13	

STATION POINTS	COURSE NO	DISTANCE	BEARING N/S DEGREE MIN SEC E/W	FUNCTIONS COSINE	FUNCTIONS SINE	COORDINATES NORTH *"Y"	COORDINATES EAST *"X"
21	00					231264.05	821510.41
21→15	01	55.000	N733342W				
15→47	02	468.900	S162618W				
47→48	03	54.470	S162618W				
48→51	04	54.470	S685920E				
51→53	05	23.900	S685920E				
53→52	06	23.900	S812700E				
52→49	07	99.120	S812700E				
49→43	08	99.120	N 64250E				
43→℄	09	———	N763935W				
℄→21	10	———	N132025E				
21	99					231264.05	821510.41

* SOUTH AND WEST COORDINATES MUST BE SHOWN AS NEGATIVE NUMBERS IN THE NORTH AND EAST COORDINATE POSITIONS RESPECTIVELY

PUNCHED VERIFIED

PROBLEM TYPE
0 TWO BEARINGS UNKNOWN
1 ALL SIDES & BEARINGS KNOWN
2 TWO SIDES UNKNOWN
3 1 SIDE & 1 BEARING UNKNOWN
4 TYPE NO 1 WITH AREA
5 TYPE NO. 2 WITH AREA
6 1 SIDE & ITS BEARING UNKNOWN
7 TYPE NO 3 WITH AREA
8 TYPE NO. 6 WITH AREA
9 TYPE NO 0 WITH AREA

SUBMITTED BY DATE
CALCULATED BY DATE
CHECKED BY DATE

Figure 1. Typical traverse—input form.

studies and as a base to prepare the project schematic layout. From the approved schematic layout, a project reference line or centerline was developed on the map for the entire length of the project. Reference lines were established for each frontage street and for each throughway lane in those sections of the project where they maintained separate alignments. Had photogrammetric methods been used to provide controlled topographic maps, this phase of development would have been much easier.

The centerline and one point on the north end of the project was oriented to the Texas coordinate system. This was a simple matter since this point was in sight of four USC & GS intersection stations and one USC & GS triangulation station. With the project centerline oriented with the Texas coordinate system, the interdependent traverse program was used to calculate distances, as well as tie together and check the various reference lines.

Traverses were run either to calculate or to check the geometric layouts for all ramps, connections, turnouts, and all transitions and channelized street connections. The traverse program, from the input (Fig. 1), calculated the coordinates (Fig. 2) for every point included in each traverse.

With the various reference lines set and the geometric layouts of the project established, a series of B-10 problems were prepared to calculate coordinates when either the station and offset were given or to calculate the station and offset with respect to the reference line when coordinates were furnished.

First, an attempt was made to predetermine all the points needed to control the project reference line or centerline and to establish sufficient offset points to this reference line for taking cross-section data and setting points to be used during construction as reference hubs. It was desirable to have several offset points on each side of the project reference line in order to eliminate chaining across the lanes of traffic within the project. A print of the project schematic showing the reference line and cross-section lines was prepared and all the desired points for control of these lines were plotted on this map. Points were chosen for each station and half-station along the project centerline and the P.C., P.I., and P.T. of each curve. Adequate offset points were also included. A second layout (Fig. 3), similar to the one used to control the project reference line, was prepared to show points required to stake frontage roads, ramps, connections, turnouts, transitions, inlets, and other miscellaneous points

TYPE	DISTRICT	I P E NO	TRAV NO
2	14	828	01

TEXAS HIGHWAY DEPARTMENT

TRAVERSE SHEET

MONTH	DAY	YEAR
11	07	61

COURSE NO	DISTANCE	N/S	DEG	MIN	SEC	E/W	COSINE	SINE	LATITUDE	DEPARTURE	* COORDINATES NORTH	EAST	–
											231264.050	821510.410	
1	55.000	N	73	33	42.0	W	.282983215	.959124857	15.564	52.752-	231279.614	821457.658	
2	468.900	S	16	26	18.0	W	.959124857	.282983211	449.734-	132.691-	230829.880	821324.967	
3	54.470	S	16	26	18.0	W	.959124857	.282983211	52.244-	15.414-	230777.636	821309.553	
4	54.470	S	68	59	20.0	E	.358548986	.933510909	19.530-	50.848	230758.106	821360.401	
5	23.900	S	68	59	20.0	E	.358548986	.933510909	8.569-	22.311	230749.537	821382.712	
6	23.900	S	81	27	00.0	E	.148672432	.988886495	3.553-	23.634	230745.984	821406.346	
7	99.120	S	81	27	00.0	E	.148672432	.988886495	14.736-	98.018	230731.248	821504.364	
8	99.120	N	06	42	50.0	E	.993142336	.116911482	98.440	11.588	230829.688	821515.952	
9	105.614	N	76	39	35.0	W	.230733803	.973016909	24.369	102.764-	230854.057	821413.188	-
10	421.363	N	13	20	25.0	E	.973016909	.230733801	409.993	97.223	231264.050	821510.411	-
99											231264.050	821510.410	

PROBLEM TYPE					ERROR OF CLOSURE LATITUDE	DEPARTURE	
0 Two Bearings Unknown	2 Two Sides Unknown	4 Type No 1 With Area	6 1 Side & Its Bearing Unknown	8 Type No 6 With Area			* NEGATIVE INDICATES SOUTH
1 All Sides & Bearings Known	3 1 Side & 1 Bearing Unknown	5 Type No 2 With Area	7 Type No 3 With Area	9 Type No 0 With Area		.001	AND WEST RESPECTIVELY

Figure 2. Typical traverse—output form.

needed during construction. These points were assigned numbers beginning with point No. 1 at the beginning of the project and numbered consecutively until all the desired points were identified.

Separate B-10 program input sheets were than prepared for points on each layout with the point number on the B-10 corresponding to the same point number on the layout. The B-10 input sheet (Fig. 4) is self-explanatory regarding the form. It might be pointed out that because only 99 points can be written for each B-10 problem, new B-10 problems with a change in part number were prepared and a notation made in the remarks column indicating the hundred series belonging to the point number.

Where coordinates for a particular point were found in a traverse program, these were entered in the X- and Y-columns of the B-10; thus, in addition to calculating the station and offset, it stored the coordinates of that point for future use.

The output information for all these predetermined points submitted on the B-10 problems was listed (Fig. 5) and the data stored for future use in subsequent problems. To establish terminology, all points listed on the B-10, either as a centerline point or as an offset point, were designated as station points.

Because the B-10 program had calculated the coordinates for all station points desired for construction, a method was needed to set quickly and safely these points in the field. It was thought that these station points could conceivably be set in the field if they could be "cut in" from two control points outside the area of construction. In other words, the station point became the intersection point of two lines whose bearing could be calculated.

A study of the B-11 program (Figs. 6 and 7) showed that from a control point of known coordinates, the distance and bearing to all desired station points could be accurately determined. The preparation of the input data sheet (Fig. 6) did not require coordinates for each station point to be manually written, but only the point number

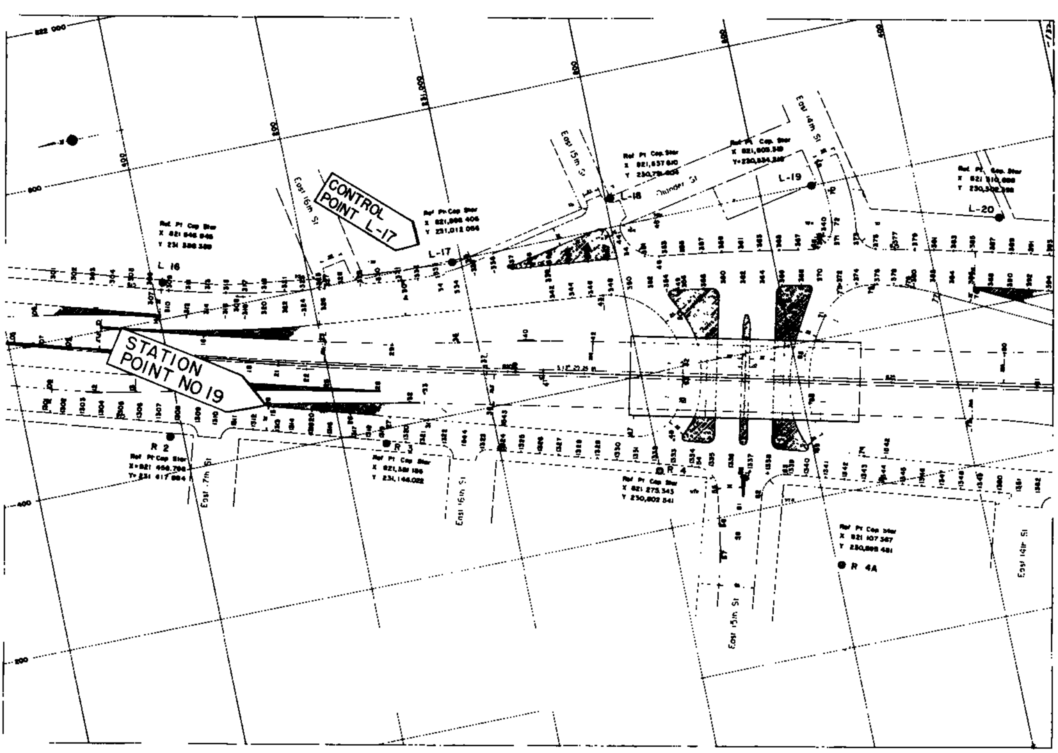

Figure 3. Station points for frontage roads, ramps, connections, etc.

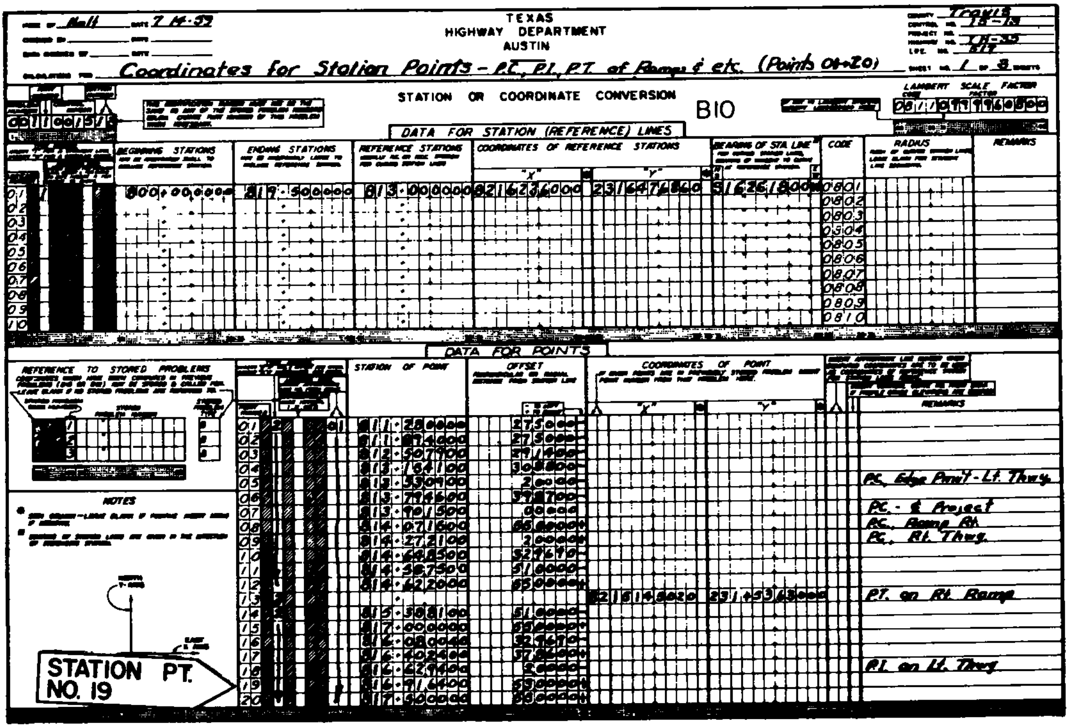

Figure 4. B-10 input form.

B 10

DATE 10 11 61 CODE	POINT NO	TYPE NO	STA. LINE NO	STATION	OFFSET	COORDINATES OF POINT X	Y	DIST. FROM POINT TO REF. STA.	BEARING FR PT TO REF. STA. DEG MIN SEC
11001513	01	2	1	811 28.0000	27.5000-	821698.6461	231804.8673	174.1845	S 25 31 19.61 W
	02	2	1	811 89.4000	27.5000-	821681.2716	231745.9793	113.9675	S 30 24 05.09 W
	03	2	1	812 50.7900	29.1400-	821665.4729	231686.6368	57.1905	S 47 04 14.15 W
	04	2	1	813 15.4100	30.8800-	821648.8560	231624.1683	34.5114	N 47 02 28.26 W
	05	2	1	813 53.0900	2.0000-	821610.4951	231596.2021	53.1276	N 14 16 51.60 E
	06	2	1	813 79.4600	39.8700-	821639.3539	231560.1948	88.9016	N 10 12 26.84 W
	07	2	1	813 90.1500	...	821598.0901	231561.2243	90.1499	N 16 26 17.95 E
	08	2	1	814 07.1500	55.0000	821540.5297	231560.4833	120.4413	N 43 36 35.16 E
	09	2	1	814 27.2100	2.0000	821585.6850	231526.2465	127.2256	N 17 20 20.55 E
	10	2	1	814 64.8500	32.9690-	821608.5722	231480.2512	168.1143	N 5 07 43.45 E
	11	2	1	814 58.7500	51.0000-	821627.5917	231480.9994	166.7409	N 1 22 18.54 W
	12	2	1	814 62.2000	55.0000	821524.9521	231507.6855	171.2713	N 35 10 10.14 E
	13	3	1	815 17.0053	49.7260	821514.5020	231453.6300	222.6297	N 29 20 40.67 E
	14	2	1	815 38.8100	51.0000-	821604.9369	231404.2149	244.1949	N 4 23 00.22 E
	15	2	1	817 00.0000	55.0000	821457.6613	231279.6146	403.7635	N 24 16 02.71 E
	16	2	1	816 08.0040	32.9690-	821568.0636	231342.9540	309.7634	N 10 19 43.01 E
	17	2	1	816 40.2400	37.8600	821491.0105	231332.0795	342.3399	N 22 47 15.98 E
	18	2	1	816 62.9400	2.0000-	821522.8162	231299.0288	362.9456	N 16 07 21.40 E
	19	2	1	816 91.6400	53.0000	821461.9452	231287.0665	395.2099	N 24 08 42.90 E
	20	2	1	817 50.0000	55.0000	821443.5128	231231.6602	453.3486	N 23 24 23.69 E
	21	2	1	817 00.0000		821510.4111	231264.0511	399.9999	N 16 26 18.03 E

STATION PT. NO. 19

Figure 5. B-10 output data sheet.

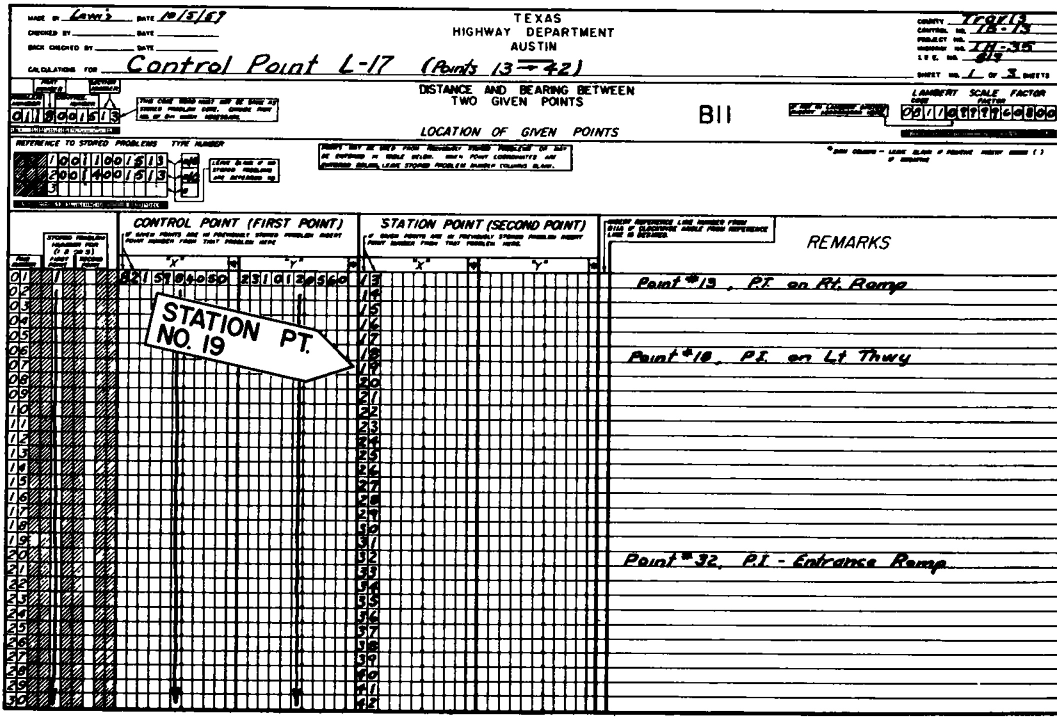

Figure 6. B-11 input form.

B 11

DATE 10 11 61 CODE	...LINE NO	1ST PT PROB # & PT #	2ND PT PROB # PT #	COORDINATE OF FIRST POINT X	COORDINATE OF FIRST POINT Y	COORDINATE OF SECOND POINT X	COORDINATE OF SECOND POINT Y	DISTANCE BETWEEN POINTS	BEARING 1ST PT TO 2ND PT DEG MIN SEC
118001513	01	1	13	821598.4050	231012.0560	821514.5020	231453.6300	449.4921	N 10 45 30.46 W
	02	1	14	821598.4050	231012.0560	821604.9369	231404.2149	392.2286	N 57 15.28 E
	03	1	15	821598.4050	231012.0560	821457.6613	231279.6146	302.3302	N 27 44 44.48 W
	[illegible]	1	16	821598.4050	231012.0560	821568.0636	231342.9540	332.2992	N 5 14 20.53 W
	[illegible]	1	17	821598.4050	231012.0560	821491.0105	231332.0795	337.5760	N 18 33 03.18 W
	[illegible]	[illegible]	18	821598.4050	231012.0560	821522.8162	231299.0288	296.7725	N 14 45 23.64 W
	07	[illegible]	19	821598.4050	231012.0560	821461.9452	231287.0465	307.0170	N 26 23 25.95 W
	08	1	20	821598.4050	231012.0560	821443.5128	231231.6402	268.7438	N 35 11 46.51 W
	09	1	21	821598.4050	231012.0560	821510.4111	231264.0511	266.9270	N 19 14 55.08 W
	10	1	22	821598.4050	231012.0560	821498.0061	231229.0733	239.1253	N 24 49 36.17 W
	11	1	23	821598.4050	231012.0560	821529.0711	231197.6460	198.1259	N 20 29 06.03 W
	12	1	24	821598.4050	231012.0560	821449.4459	231211.8624	249.2313	N 36 42 18.59 W
	13	1	25	821598.4050	231012.0560	821466.9195	231207.4104	235.4912	N 33 56 34.71 W
	14	1	26	821598.4050	231012.0560	821429.3641	231183.7059	240.9212	N 44 33 40.49 W
	15	1	27	821598.4050	231012.0560	821415.2195	231135.7515	221.0493	N 55 58 17.43 W
	16	1	28	821598.4050	231012.0560	821451.0604	231139.6232	194.9020	N 49 06 53.37 W
	17	1	29	821598.4050	231012.0560	821508.9825	231119.4339	139.7423	N 39 47 13.04 W
	18	1	30	821598.4050	231012.0560	821588.8782	231089.9333	78.4608	N 6 58 27.83 W
	19	1	31	821598.4050	231012.0560	821401.0670	231087.7972	211.3823	N 69 00 08.89 W
	20	1	32	821598.4050	231012.0560	821428.7867	231104.9302	193.3918	N 61 17 42.35 W
	21	1	33	821598.4050	231012.0560	821435.9622	231084.2757	177.7802	N 66 01 50.76 W

STATION PT. NO. 19

Figure 7. B-11 output data sheet.

from the appropriate B-10 program entered in the station point column was required. By using the B-11A program (Fig. 8) in conjunction with the B-11 program, the clockwise angle (Fig. 9) from some known reference point to each station point was determined. Then, from any two such control points, a station point within view could be set by intersection (Fig. 10). A station point could also be set by turning the prescribed angle and measuring the computed distance from a nearby control point.

On the Austin project, permanent markers designated as control points were set approximately 500 ft apart, along and just outside of the construction area. These control points, identified by number, were arbitrarily set to command a view over approximately 800 ft of the project length and with the idea that each station point to be set must also be within view of at least two and preferably three control points, except for those station points within convenient measuring distance of one control point. In addition, each control point was set in view of a known reference point. Because coordinates for the star on the top of the State Capitol dome were available and this point was visible from almost all parts of the project, this provided an excellent reference point for most of the control points. A control point located on high ground or on top of some adjacent building provided the best vantage point for observing the project area.

After control points were set, conventional triangulation and traverse methods of surveying were used to determine accurately the coordinates for each control point. These control points were then plotted on the strip maps with their identifying numbers so that their relation to the station points could be observed.

The B-11 and B-11A programs (Figs. 6 and 8) were then submitted for each control point. The coordinates for the control point and the reference point were entered as input data together with the appropriate B-10 problem for the stored station points. At the end of the B-11 input listing, it was found desirable to enter the coordinates of several adjacent control points or of any other secondary reference point in the station point column. This not only served as a check for the control points themselves, but it was thought that certain construction features or weather conditions may subsequently prevent the observer from seeing the primary designated reference point.

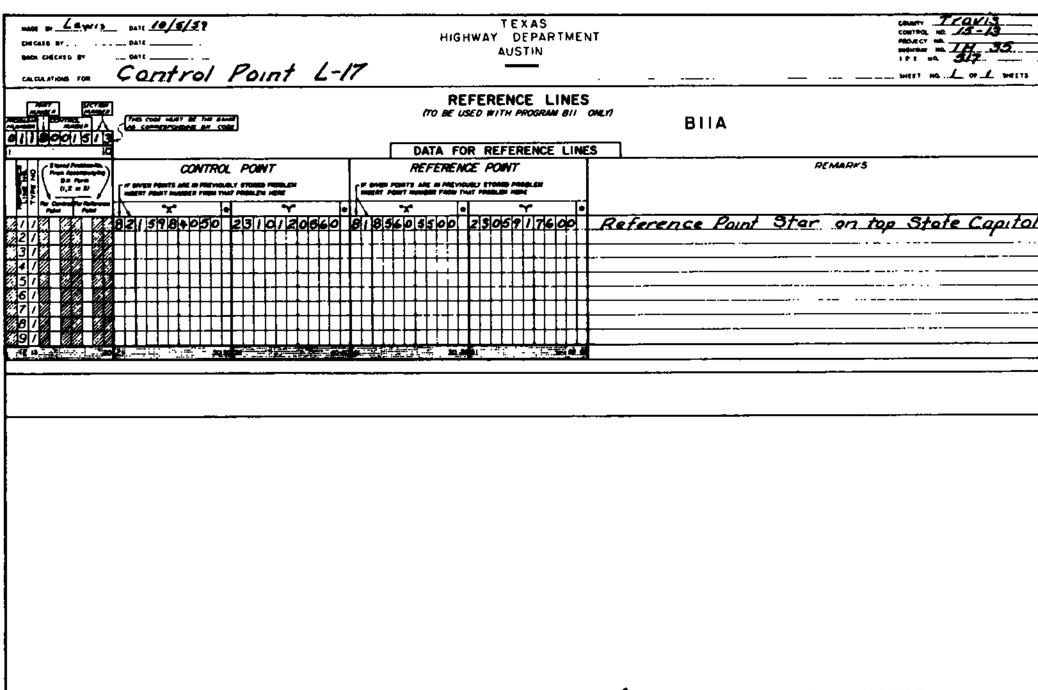

Figure 8. B-11A input form.

The output listing from the computer provided, for each control point, the distance and bearing to each station point (Fig. 7) and the clockwise angle from the reference point to each station point (Fig. 9). Two copies of these output data were bound in book

CONTROL POINT NO. L-17
REF. PT.: CAPITOL STAR

STATION PT. NO. 19

B11 A

DATE CODE	PR NO	REF LN	DEG	MIN	SEC	CODE FROM
11 14 61						B11
118001513	01	1	87	07	06.86	13
	2	1	98	49	52.60	14
	3	1	70	07	52.84	15
	4	1	92	38	16.79	16
	[illegible]	1	79	19	34.14	17
	[illegible]	[illegible]	83	07	13.67	18
	[illegible]	[illegible]	71	29	11.38	19
	8	1	62	40	50.80	20
	9	1	78	37	42.23	21
	10	1	73	03	01.14	22
	11	1	77	23	31.28	23
	12	1	61	10	18.73	24
	13	1	63	56	02.60	25
	14	1	53	18	56.82	26
	15	1	41	54	19.89	27
	16	1	48	45	43.95	28
	17	1	58	05	24.28	29
	18	1	90	54	09.49	30
	19	1	28	52	28.43	31
	20	1	36	34	54.97	32
	21	1	31	50	46.56	33

Figure 9. B-11A output data sheet.

form. With this information available, it was then possible to set any one of the preselected station points on the ground without having to make field calculations. The identifying number shown on the strip map (Fig. 3) for each station point corresponds to the same point number on the B-10 (Fig. 5), B-11 (Fig. 7), and B-11A (Fig. 9) programs. A typical station point (Point 19, Fig. 10) has been marked on the examples to indicate the steps through the various programs and to show that data for any desired point could be found quickly.

The following procedure was used in the field to set construction stakes. The survey crew consisted of a party chief, two instrumentmen, and a rodman. The party chief, using the strip map showing the numbered station points and the location of control points (Fig. 3), directed the instrumentmen to two chosen control points in command of the area to be staked. The party chief informed each instrumentman of the station point number to be set. Communications between members of the party were accomplished by hand signals. At times during construction, three two-way hand radio units were successfully used to improve communications. Each instrumentman using the data for his respective control point turned the computed clockwise angle to that station point. A rodman, obtaining line from each instrumentman, located and set the station point. The rodman, after a little experience, was able to find this point of intersection rapidly.

Two directional theodolites were used in the field to turn the required angles. These instruments read directly the clockwise angle and only that angle when the zero angle was observed on the reference point. This established a simple procedure for turning and checking angles because the clockwise angle calculated and printed by the computer was read and set directly in the theodolite. The instrumentmen, observing zero angles on the reference point, proceeded to "cut in" as many points as necessary to establish construction control. The instrumentmen, to check instrument orientation, turned

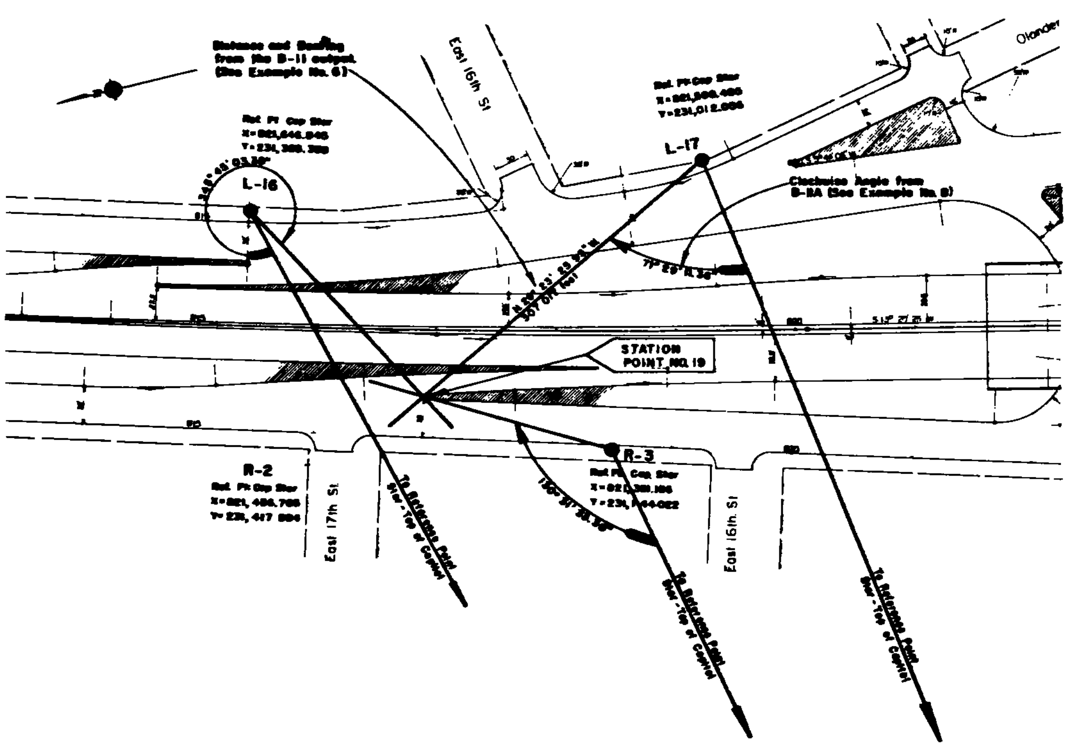

Figure 10. Typical station point set from control points.

calculated angles to other established points in the area. These points were adjacent control points, secondary reference points, or a station point previously set and checked.

COMMENTS AND OBSERVATIONS

The Austin project is now nearing completion and this system of staking has proved very effective. Other than a few field tests to prove the practicability of setting up such a control for the Austin project, the first real test came in the design stage when it was necessary to obtain original cross-sections for earth work computations. Cross-sections every 50 ft along the 1.7-mi long project centerline were taken and the horizontal control for approximately 70,000 linear ft of these sections was staked in one week under adverse traffic conditions. The cross-section lines and points were obtained without having to chain across moving traffic lanes or without having to stake the project centerline. Also, this method was used extensively to set location stakes for the relocation of utility lines on this project.

In the beginning, the idea was to use this method to stake only roadway geometrics; however, during construction when proved an accurate, simple, and effective way to set points, the system was enlarged to include bridge construction points. This Austin project was constructed in segments or sections conforming to a planned sequence of work to allow traffic to pass through it uninterrupted. Without this method of staking, it would have been difficult to furnish the contractor with sufficient construction stakes.

How accurate were points set in the field using this method of triangulation staking? It must be realized that errors such as careless handling of the instrument, wind vibrations, heat from the sun, mistakes in reading the proper angle, and other errors common to angular measurements had to be considered in the field staking. The control points were set and coordinates determined to an accuracy greater than second order horizontal control as defined by the U.S. Coast and Geodetic Survey. However, because a number of station points were set from one control point, the position of each station point, relative to each other, depended primarily on the accuracy of the clockwise angle turned at the control point. The calculations and listing provided by the computer gave angles to the nearest 0.01 sec. With the instruments used on this project, angles were consistently measured within 5 sec of the desired angle. By using a long backsight on the reference point and observing a short foresight (500 ft or less), the error caused by the inability to turn the exact angle was minimized. Many points were set and checked in the field and the usual maximum variation amounted to approximately 0.01 ft. In staking an overpass structure, column points in a bent were staked by triangulation and then checked by chaining the prescribed distances between them. Only one column was out of position by about 0.02 ft and this error was corrected when the angles turned at the control points were rechecked. Accurate setting of station points

TABLE 1

THE ERROR RESULTING FROM VARIOUS ANGULAR ERRORS, (FT)

Angular Error (sec)	Distance From Control Point (ft)					
	100	200	300	400	500	1,000
1	0.0005	0.0010	0.0015	0.0019	0.0024	0.0049
2	0.0010	0.0019	0.0029	0.0039	0.0049	0.0097
3	0.0015	0.0029	0.0044	0.0058	0.0073	0.0145
4	0.0019	0.0039	0.0058	0.0078	0.0097	0.0194
5	0.0024	0.0048	0.0073	0.0097	0.0121	0.0242
6	0.0029	0.0058	0.0087	0.0116	0.0145	0.0291
7	0.0034	0.0068	0.0102	0.0136	0.0170	0.0339
8	0.0039	0.0078	0.0116	0.0155	0.0194	0.0388
9	0.0044	0.0087	0.0131	0.0175	0.0218	0.0436
10	0.0048	0.0097	0.0145	0.0194	0.0242	0.0485

for this type of construction depended on having strong angles of intersections in addition to repeating the angle measurement several times. Table 1 gives the reader an idea of the angle accuracy necessary to establish transit line within desired limits. This table indicates the errors resulting from various angular errors at given distances from a control point.

Although not directly concerned with horizontal control staking, other uses were made of the data furnished by the computer. The listed data from the B-10 was used to plot the various layouts required in plan preparation. These data were not only an aid to plotting, but furnished an excellent check on the geometric calculations. The B-10A program (2, Pt. II), a program used in conjunction with the B-10 program, was later submitted to obtain the profile grade elevations for points along the desired reference lines. The stored data from these B-10 problems were used later in conjunction with the B-12 program (2, Pt. V), program designed to find the coordinates of the intersection point of two straight lines, points of a straight line and circle, or points of two circles. This program was used to develop design sections for the multi-lane earthwork program by finding at each cross-section station, the perpendicular distance from the project centerline to other adjacent roadways.

The development and use of this staking procedure during the last two years on the Austin project has proved the practicability of using this method of staking on this and other future complicated projects. Intersections containing numerous compound curves, small radius curves, curved bridges, and other construction features that are normally difficult to stake could very well be adapted to this method of horizontal control. Because reference lines are normally developed for the design layouts, it is not necessary to replace completely the reference line method of staking with triangulation staking. They can complement each other and there may be times during construction or on certain portions of the project where it would be more desirable and convenient to set stakes from reference lines.

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The efforts of all who have contributed and encouraged the development of this report are greatly appreciated.

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