CHAPTER 16

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CHAPTER 16

FIELD SURVEY DATA

16–01 GENERAL

The field survey data is obtained by the Field Survey Bureau. This Office performs the necessary field work by means of field parties. All the field information should be obtained from control points or establishing a base line that normally is the center line of the future highway. The field information consist basically in the location of structures, utilities, waterways and property boundaries, profile and cross sections of the center line.

All measurement are obtained using the metric system with a 30 meter metalic tape and the instrument most used is the "Transit".

All the field information is recorded in field notebooks which are send together with the field drawings to the Design Bureau.

The selection of alignment and the extend to which it may be chosen to fit the ground economically, depends on the geometric design standards adopted for the construction. These standards, in turn depend on the amount and type of transportation usage expected.

Standards may range from the criteria for widths, curvature, grades and sight distances sufficient to accommodate sparse rural traffic at moderate speeds, to those criteria necessary for large volumes of heavy traffic at high speeds.

With the classification of service established and the appropiate standards of alignment fixed thereby, ordinarily the combination of tangents and horizontal curvature is sought that will best fit the surface of the ground within theimit of the criteria.

This chapter will cover detailed information about the field procedures to be perform in working a project mentioned as follows: Reconnaissance, Control Surveys, Monumentation, Location Survey and others.

16–02 RECONNAISSANCE SURVEY

Reconnaissance Survey is the process of evaluating the feasibility of one or more possible routes for a highway between specific points, which may be many kilometers apart.

Service requirements of the termini and intermediate points are determined in advance by traffic studies. Consistent with proper service selection of an approximate route involves consideration of roadway design standards, topography, geology and land use.

Good reconnaissance can be the largest single money-saving phase in the construction of a new road.

16–02.01 STUDY OF AVAILABLE DATA

Reconnaissance begins with a "paper study" (topographic map) of an area 30% to 50% as wide as the distance between the termini. Ridges, water courses and land use are examined first. Low points or passes in the ridges, become potential fixed points in the location, as do stream-crossing sites that afford suitable topography for approaches. Thickly settled areas, as well as swamps and other ground unsuited to economical construction, should be avoided. Utility-relocation problems should be anticipated. Photographs, also, suplement the map, to a greater or lesser extended depending on its quality.

16–02.02 FIELD INSPECTION

Next, cognizant of the questions generated by the map study, the reconnaissance Engineer goes to the field. The best way to get a first look at key points and intervening alignments is to fly over them. Much of the engineers aerial-visual data will be sufficient to accomplish his appraisal of the terrain. The engineer then can restrict his ground study to considerations of unusual topographic features, hydrology, the nature of some manmade works and subsurface conditions.

The engineer should utilize all available survey control as the reconnaissance is executed. Bench marks, triangulation and traverse points may be tied to points that will be distinguishable in aerial photographs.

16–03 CONTROL SURVEYS

The purpose of the primary control survey shall be to provide permanent monuments with accurate horizontal and vertical coordinates throughout the entire length of the project. These points shall be used as control for all other surveys connected with the project.

The primary control survey shall be performed prior to other surveys and prior to the beginning of construction on the project.

The primary control survey shall be a closed survey or tied at each end and at such intermediate points as may be available, to one of the following:

a. USC & GS Control point.
b. Other primary control survey point.
c. Other survey point of known accuracy at least equal to that specified for the primary control survey itself.

Methods, procedures and equipment used for primary horizontal and vertical control survey shall be sufficiently precise to insure second order accuracy. If a survey fails to conform to second order standards prior to adjustment, a re-survey shall be made.

The survey shall be adjusted by an approved method prior to computing coordinates, bearings or distances.

All level lines, loops or nets shall be adjusted prior to computing elevations of points on the survey.

Elevations of all points shall be based on the Mean Sea Level Datum and all subsequent level surveys shall be adjusted to the primary vertical control survey.

16–04 MONUMENTATION

The monumentation of control survey points is an important part of a highway project. A monument is a fixed object on the ground, whether natural or artificial, serving as a permanent mark of the survey. Thousands of dollars in surveying work are lost annually because surveys were not properly monumented or the monuments were subsequently destroyed. A control survey monument should posses stability, positive identity and protection against destruction.

The variety in monuments depends on the type of survey, the local terrain conditions and the requirement of the survey project.

In highway engineering practice there are three types of monuments: standard tablets set in concrete, survey caps and marks placed in existing structures. References for each of the above described monuments should be made in the field either to permanent natural objects or to additional points set nearby. A witness post to each monuments should be placed above the ground and it serve as a warning to construction and maintenance personnel.

16- 05 LOCATION SURVEY

The location survey fixes the proposed highway's center line on the ground and includes the procurement of field data necessary for design and the acquisition of right of way. In a normal location survey, the alignment determined by the reconnaissance survey is staked out and a sufficient number of selected points on the center line are referenced so that it can be re-established when necessary.

The staked base line is used as a reference line for profile, cross sections, topography, the location of existing property lines and utilities and other information that will be needed.

16-05.01 STAKING CENTER LINE

The center line established on the ground shall follow as closely as practical the final line projected on the preliminary survey map conforming to the mayor and minor control points and the alignment prescribed. Minor alterations and adjustments are permissible and desirable in best fitting the line to the terrain during the staking-out process.

Center line tangents are established on the ground, the intersection of each pair of adjacent tangents is determined and the deflection angle from the back tangent to the forward is measured and checked for approximate agreement with the angle previously obtained in projecting the final line on the preliminary survey map. The measured deflection angles and the degrees of curve specified in the preliminary design are used to compute the data necessary for running the curves as the staking of the center line progresses. Where the intersection of tangents is inaccessible, the usual methods for determining the deflection angle are used.

The location surveys must be referenced to the State Plane Coordinate System so that the final line can be established on the ground by using the coordinates of P.I.'s and the azimuths of tangent together with ties to the control points. With reasonable care, third-order accuracy should be obtainable.

Center line stakes are placed at intervals of not more than 20 meter and where there is any significant change in the slope of the ground and should be alined in with a transit. Stationing is carried forward continuously through curves and tangents with provision for station equations if and where they occur. All points of curvature, points of tangency and points at discrete intervals on long tangents should be carefully referenced to permit easy relocation of the line during all phases of construction.

16-05.02 LEVELS

Location survey bench marks should be established as many as necessary to provide them at a maximum spacing of 300 meters along the alignment of the highway and at a distance from the center line sufficient to insure against disturbance during construction operations. In addition, at least one bench mark should be established within a reasonable distance (30 to 50 meters) of each proposed structure. The elevation and a complete description of each bench mark should be recorded.

Profile levels are taken along the center line to obtain the elevation of the ground at each station and at all intermediate points where there is any significant change in the slope of the ground, in order to obtain a profile truly representative of the ground. For the design of adequate transition grades for connecting with existing roads or proposed improvements, the profile should extend at least 200 meters beyond the beginning and end points of the projects.

When conventional ground methods are used in taking the profile, checks should be made on each bench mark as it is reached along the line with a permissible tolerance of 0.005 meter.

16 05.03 **CROSS SECTIONS**

Cross section should be taken at each station of the center line. Each cross section should be alined carefully at right angles to the center line and should extend far enough on both sides of the center line to provide adequate ground-surface information for the designer and for quantity computations.

Cross sections on flat terrain shall be taken using a level instrument and on rough terrain could be use a 3 meter long wooden board with a small carpenter level attached and shall be properly recorded in field books as a permanent record.

16- 05.04 **UTILITIES**

The nature and location of all utilities within the area of the proposed improvement should be determined and recorded both above and below the ground surface. These will include the mayor utilities in Puerto Rico that are the following:

P.R. Water Resources Authority	(PRWRA)
P.R. Aqueduct and Sewer Authority	(PRASA)
P.R. Telephone Company	(PRTC)
P.R. Communications Authority	(PRCA)
Pipelines of Puerto Rico Inc.	(PLPR)
San Juan Gas Company	(SJGCO)

Complete information on utilities is important so that provision can be made for their rearrangement or relocation where necessary. The responsible unit shall contact the various utilities to complete the data on types, sizes, etc. of the utility facilities located by the survey crew and to determine the location, types and sizes of any other underground utility facilities that may exist within the survey area but were not readily apparent to the surveyors.

16-05.05 **PROPERTY LINES**

The position of all property corners, property lines, fences, buildings and other improvements must be accurately determined and recorded. This information provides the basis for determining right-of-way requirements, for writing deed descriptions, for appraisal and for negotiating for right-of-way acquisition or easements.

The names of all property owners where right-of-way acquisition or easement may be involved should also be obtained.

All property lines should be referenced to stations on the center line.

16—05.06 **INTERSECTING ROADS**

The direction of all intersecting roads, with respect to the staked center line, should be measured and recorded. In addition profiles and cross sections of the intersecting roads should be taken for some distance on both sides of the center line of the project.

Where an intersection or a grade separation is anticipated, a special survey (topography) of the area is made for the detailed studies necessary for design and plan preparation.

16- 05.07 **DITCHES AND STREAMS**

Ditches and streams within the area of the improvement should be carefully located with respect to the staked center line. In addition, stream-bed profiles should be taken for some distance up and down the stream; from 50 meters to 100 meters on ditches or small streams may be adequate, whereas for larger streams a more extensive profile is necessary. Also cross sections of the stream should be taken to provide information for use by the designer in making hydraulic studies.

Detailed information should be obtained for existing culverts or bridges including the type, size, number of openings or spans, elevation of culvert flow lines or stream-bed elevation under the bridge and high-water elevations. Also, the first structures up and down stream should be recorded since this information is important to the design engineer.

At any creek or river crossing along the staked center line where a large culvert or bridge may be needed, a special survey (topography) of the area is made to provide the detailed information needed for the design and preparation of plans.

16--06 DRAINAGE SURVEY

The application of hydraulic formulas in drainage structures design requires consideration of the following physical characteristics of the drainage area:

(a) The size of the area in acres
(b) The path of the stream bed or channel
(c) The slope of the stream bed or profile
(d) The average slope of the land within the drainage area
(e) The use of the land
(f) Topographical conditions

Generally, the surveys do not require a great amount of detail, but must be comprehensive enough so the above factors can be determined.

16--06.01 SIZE OF DRAINAGE AREA

All drainage area which are crossed by the survey line shall be taken from topographical maps. If these are not available, all areas will be run by stadia method. Areas will be classified as to the nature of the terrain, (flat, very flat and steep). The source of drainage area shall be indicated.

16--06.02 DRAINAGE PATH

Survey the horizontal alignment of the existing stream bed by running angle base line for a convenient distance left and right of survey center line, then measure from base line to center of stream bed at all angle points. A well-drawn sketch should show the stream alignment.

16--06.03 STREAM PROFILE

Information to establish the stream profile can be taken simultaneously or by a separate operation from the stream alignment. Shots shall be taken at every points where there is a change in the slope of the stream bed.

16--06.04 TOPOGRAPHICAL CONDITIONS

Record any topographical features, natural or man made, within the drainage area that would affect the run off. Record any high water marks observed and exact location taken. Also record any pertinent information relative to the area and date as obtained from persons familiar with the area. Recommendations should be made by the Supervisor if a particular placement of culvert seems desirable. Is a skewed structure is recommended give the skew angle. If a channel change seems necessary, run the centerline of the proposed channel change and take necessary cross sections to cover the new location and the old channel, so that proper location for necessary channel blocks can be determined.

16–07 FORMULAS

16–07.01 SIMPLE CIRCULAR CURVE

Simple circular curves elements are obtained by using the trigonometric tables of M.J. Gaunin for the lay out of curves for roads, railroads, and channels.

If the angle of the tangents and the radious are known, it will be information enough to calculate the length of the curve and to establish the points T, T' and M on the ground (PC, MC, PT.)

According to Figure 16–A, the elements of a simple curve are:

Tangent = ST = ST' = R tang $\Delta/2$

External = MS = OS-OM = R sec $\Delta/2$-R = R (Sec $\Delta/2$-1)

1/2 Length = 1/2L = Length of Arc TM = $\frac{\pi R \Delta/2}{180} = \frac{R (\pi \Delta/2}{180}$

L = Length of ARC TMT' = $\frac{2R (\pi \Delta/2)}{180}$

Examples:

Known: semiangle at center ($\Delta/2$) = 28 $^{\circ}$ 32' — 30"

Radius (R) = 800 Mts.

When $\Delta/2 < 45^{\circ}$, superior headings of the table are used.

Curve elements for a radius of one (1) meter will be found on Table 16—1. All curve elements obtained are multiplied by 800 except for the length of the curve that should be multiplied twice the radius.

Results

T	=	(0.543898)	R	=	(.543898)	(800)	=	435.118 Mts.
E	=	(1.138343-1)	R	=	(.138343)	(800)	=	110.674 Mts.
L	=	(.498146)	2R	=	(.498146)	(1600)	=	797.034 Mts.

When $\Delta/2 > 45^{\circ}$, inferior headings of the table are used.

All cases developed are based in the theory involved in Figure 16-A. Every time that two of the elements are known, the others can be obtained.

16–07.02 DEFLECTION ANGLES

The table most used in staking the center line is the "Gaunin Table" (Principles of Tables Construction).

Having obtained the elements, the curve can be laid out on its P. C., M. C. and P. T. If detailed monumentation is necessary to specify intermediate stationing, the curve has to be deflectioned as needed.

GAUNIN TABLE ILLUSTRATION FOR CURVE ELEMENTS

TABLE 16—1

Angulo de las tan gentes	Semi-ángulo al centro en segundos	Semi-ángulo al centro en grados, minutos y segundos	Seno Semi-cuerda Abscisa sobre la tangente	Seno-Verso Flecha Ordenada sobre la tangente	Tangente	Secante	Desarrollo del arco del semi-ángulo al centro
60′	102.600	30′ ″	0.477 159	0.121 183	0.542 956	1.137 893	0.497 419
59	102.630	30.30″	0.477 287	0.121 252	0.543 144	1.137 983	0.497 564
58	102.660	31. ″	0.477 414	0.121 322	0.543 332	1.138 075	0.497 710
57	102.690	31.30	0.477 542	0.121 391	0.543 521	1.138 163	0.497 855
56	102.720	32. ″	0.477 670	0.121 461	0.543 709	1.138 253	0.498 001
55	102.750	32.30	0.477 798	0.121 530	0.543 898	1.138 543	0.498 146
54	102.780	33. ″	0.477 925	0.121 600	0.544 086	1.138 433	0.498 292
53	102.810	33.30	0.478 053	0.121 669	0.544 275	1.138 523	0.498 437
52	102.840	34. ″	0.478 181	0.121 739	0.544 463	1.138 613	0.498 582
51	102.870	34.30	0.478 309	0.121 808	0.544 652	1.138 704	0.498 728
50	102.900	35. ″	0.478 436	0.121 878	0.544 840	1.138 794	0.498 873
49	102.930	35.30	0.478 564	0.121 947	0.545 029	1.138 884	0.499 019
48	102.960	36. ″	0.478 692	0.122 017	0.545 218	1.138 974	0.499 164
47	102.990	36.30	0.478 820	0.122 087	0.545 406	1.139 065	0.499 310
46	103.020	37. ″	0.478 947	0.122 156	0.545 595	1.139 155	0.499 455
45	103.050	37.30	0.479 075	0.122 226	0.545 784	1.139 245	0.499 600
44	103.080	38. ″	0.479 203	0.122 296	0.545 975	1.139 336	0.499 746
43	103.110	38.30	0.479 330	0.122 365	0.546 161	1.139 426	0.499 891
42	103.140	39. ″	0.479 458	0.122 435	0.516 350	1.139 517	0.500 037
41	103.170	39.30	0.479 586	0.122 505	0.546 539	1.139 608	0.500 182
40	103.200	40. ″	0.479 713	0.122 575	0.546 728	1.139 698	0.500 528
39	103.230	40.30	0.479 841	0.122 644	0.546 917	1.139 789	0.500 473
38	103.260	41. ″	0.479 968	0.122 714	0.547 106	1.139 879	0.500 619
37	103.290	41.30	0.480 096	0.122 784	0.547 295	1.139 970	0.500 764
36	103.320	42. ″	0.480 225	0.122 854	0.547 484	1.140 061	0.500 909
35	103.350	42.30	0.480 351	0.122 924	0.547 673	1.140 152	0.501 055
34	103.380	43. ″	0.480 479	0.122 994	0.547 862	1.140 242	0.501 200
33	103.410	43.30	0.480 606	0.123 063	0.548 051	1.140 353	0.501 346
32	103.440	44. ″	0.480 734	0.123 133	0.548 240	1.140 424	0.501 491
31	103.470	44.30	0.480 861	0.123 203	0.548 430	1.140 515	0.501 637
30	103.500	45. ″	0.480 989	0.123 273	0.548 619	1.140 606	0.501 782
29	103.530	45.30	0.481 116	0.123 343	0.548 808	1.140 697	0.501 928
28	103.560	46. ″	0.481 244	0.123 413	0.548 997	1.140 788	0.502 073
27	103.590	46.30	0.481 371	0.123 483	0.549 187	1.140 879	0.502 218
26	103 620	47. ″	0.481 499	0.123 553	0.549 376	1.140 971	0.502 364
25	103.650	47.30	0.481 626	0.123 623	0.549 565	1.141 062	0.502 509
24	103.680	48. ″	0.481 754	0.123 693	0.549 755	1.141 153	0.502 655
23	103.710	48.30	0.481 881	0.123 763	0.549 944	1.141 244	0.502 800
22	103.740	49. ″	0.482 009	0.123 834	0.550 133	1.141 336	0.502 946
21	103.770	49.30	0.482 136	0.123 904	0.550 323	1.141 427	0.503 091
20	103.800	50. ″	0.482 263	0.123 974	0.550 512	1.141 518	0.503 237
19	103.830	50.30	0.482 391	0.124 044	0.550 702	1.141 610	0.503 382
18	103.860	51. ″	0.482 518	0.124 114	0.550 892	1.141 701	0.503 527
17	103.890	51.30	0.482 646	0.124 184	0.551 081	1.141 793	0.503 673
16	103.920	52. ″	0.482 773	0.124 255	0.551 271	1.141 884	0.503 818
15	103.950	52.30	0.482 900	0.124 325	0.551 461	1.141 976	0.503 964
14	103.980	53. ″	0.483 028	0.124 395	0.551 650	1.142 067	0.504 109
13	104.010	53.30	0.483 155	0.124 465	0.551 840	1.142 159	0.504 255
12	104.040	54. ″	0.483 282	0.124 536	0.552 030	1.142 251	0.504 400
11	104.070	54.30	0.483 410	0.124 606	0.552 220	1.142 342	0.504 546
10	104.100	55. ″	0.483 537	0.124 676	0.552 409	1.142 434	0.504 691
9	104.130	55.30	0.483 664	0.124 746	0.552 599	1.142 526	0.504 836
8	104.160	56. ″	0.483 792	0.124 817	0.552 789	1.142 618	0.504 982
7	104.190	56.30	0.483 919	0.124 887	0.552 979	1.142 710	0.505 127
6	104.220	57. ″	0.484 046	0.124 958	0.553 169	1.142 802	0.505 273
5	104.250	57.30	0.484 173	0.125 028	0.553 359	1.142 894	0.505 418
4	104.280	58. ″	0.484 501	0.125 098	0.553 549	1.142 986	0.505 564
3	104.310	58.30	0.484 428	0.125 169	0.553 739	1.143 078	0.505 709
2	104.340	59. ″	0.484 555	0.125 239	0.553 929	1.143 170	0.505 855
1′	104.370	59.30″	0.484 682	0.125 310	0.554 119	1.143 262	0.506 000
122*	104.400	60. ″	0.484 810	0.125 380	0.554 309	1.143 354	0.506 145
Angulo al centro	Semi-angulo de las tangentes en segundos	Semi-angulo de las tangentes en grados, minutos y segundos	Coseno	Coseno-verso	Cotangente	Cosecante	Complemento del arco

61°

SIMPLE CIRCULAR CURVE

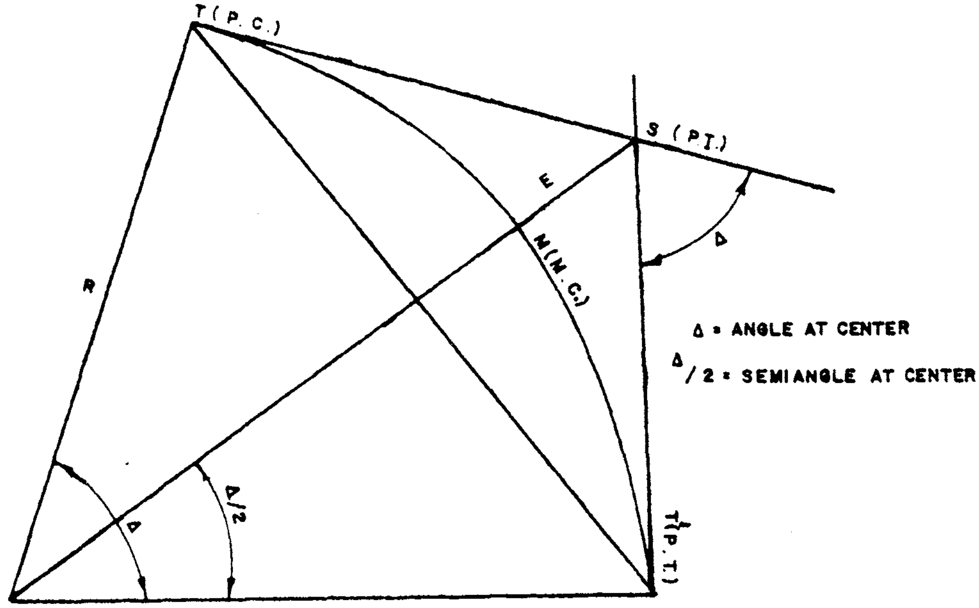


FIGURE 16-A

To obtain the values of the deflection angles, Table 16—2 from the Gauning book is used. This table gives values of the angles in function of the arcs. The corresponding angle at center for the curve of the radius given on the heading.

Remembering that from Figure 16—A, we obtained.

$$L = 2R \frac{(\pi \ \Delta/2)}{180}$$

where : L = total length of arc

R = Radius

$\Delta/2$ = Semiangle at center = total deflection angle from P.C. to P.T.

So, if we want to obtain the deflection angle for any section of arc in the curve (L), it is necessary to refer to Table 16—2 with radius = 2R (according to formula above). Then the angle obtained in the Table 16—2, corresponds to the angle $\Delta/2$ when the formula is solved. For examples of this case, refer to Figure 16—B.

Examples:

a) Known: R = 450 Mts.

L = 653.43 Mts.

Using Table 16—2 for R = 900

	Partial Arc.		Deflection Angle
	600		38°— 11′ — 49.8708″
	50		3°— 10′ — 59.1559″
	3		— 11′ — 27.5494″
	.40		1′ — 31.6632″
	.03		6.3755″
L =	600.43	$\Delta/2$ =	41°— 35′ — 54.6148″

b) For a specific point at 217.54 Mts. from the P.C.

	Partial Arc (Mts.)		Deflection Angle
	200		12°— 43′ — 56.6236″
	10		38′ — 11.8312″
	7		26′ — 44.2818″
	.50		1′ — 54.5816″
	.04		09.1673″
L =	217.54	$\Delta/2$ =	13°— 50′ — 56.4855″

GAUNIN TABLE ILLUSTRATION FOR DEFLECTION ANGLES

TABLE 16–2

"ARC" ARCOS	R 600 1^m 343' 774.677.078.494	R 700 1^m 294' 664.008.924.423	R 800 1^m 257' 831.007.808.870	R = 900 7^m = 229' 183.118.052.329	R = 1.000 1^m = 206' 264.806.247.096	ARCOS
m.						
0.01	0°00'03'4377	0°00'02'9466	0°00'02'5783	0°00'02'2918	0°00'02'0626	0.01
0.02	0.00.06.8755	0.00.05.8933	0.00.05.1565	0.00.04.5837	0.00.04.1253	0.02
0.03	0.00.10.3132	0.00.08.8399	0.00.07.7349	0.00.06.8755	0.00.06.1879	0.03
0.04	0.00.13.7510	0.00.11.7866	0.00.10.3132	0.00.09.1673	0.00.08.2506	0.04
0.05	0.00.17.1887	0.00.14.7332	0.00.12.8910	0.00.11.4592	0.00.10.3132	0.05
0.06	0.00.20.6265	0.00.17.6792	0.00.15.4699	0.00.13.7510	0.00.12.3759	0.06
0.07	0.00.24.0642	0.00.20.6265	0.00.18.0482	0.00.16.0428	0.00.14.4385	0.07
0.08	0.00.27.5020	0.00.23.5731	0.00.20.6265	0.00.18.3346	0.00.16.5012	0.08
0.09	0.00.30.9397	0.00.26.5198	0.00.23.2048	0.00.20.6265	0.00.18.5638	0.09
0.10	0.00.34.3775	0.00.29.4664	0.00.25.7831	0.00.22.9183	0.00.20.6265	0.10
0.20	0.01.08.7549	0.00.58.9328	0.00.51.5662	0.00.45.8366	0.00.41.2530	0.20
0.30	0.01.43.1324	0.01.28.3992	0.01.17.3493	0.01.08.7549	0.01.01.8794	0.30
0.40	0.02.17.5099	0.01.57.8656	0.01.43.1324	0.01.31.6632	0.01.22.5059	0.40
0.50	0.02.51.8873	0.02.27.3320	0.02.08.9155	0.01.54.5816	0.01.43.1324	0.50
0.60	0.03.26.2648	0.02.56.7984	0.02.34.6986	0.02.17.4999	0.02.03.7589	0.60
0.70	0.04.00.6423	0.03.26.2648	0.03.00.4817	0.02.40.4182	0.02.24.3854	0.70
0.80	0.04.35.0197	0.03.55.7312	0.03.26.2648	0.03.03.3365	0.02.45.0118	0.80
0.90	0.05.09.3272	0.04.25.1976	0.03.52.0479	0.03.26.2648	0.03.05.6383	0.90
1	0.05.43.7747	0.04.54.6640	0.04.17.8310	0.03.49.1831	0.03.26.2643	1
2	0.11.27.5494	0.09.49.3280	0.08.35.6620	0.07.38.3662	0.06.52.5296	2
3	0.17.11.3240	0.14.43.9920	0.12.53.4930	0.11.27.5494	0.10.18.7944	3
4	0.22.55.0987	0.19.38.6560	0.17.11.3240	0.15.16.7325	0.13.45.0592	4
5	0.28.38.8734	0.24.33.3200	0.21.29.1550	0.19.05.9156	0.17.11.3240	5
6	0.34.22.6481	0.29.27.9841	0.25.46.9860	0.22.55.0987	0.20.37.5888	6
7	0.40.06.4227	0.34.22.6481	0.30.04.8171	0.26.44.2818	0.24.03.8536	7
8	0.45.50.1974	0.39.17.3121	0.34.22.6481	0.30.33.4649	0.27.30.1184	8
9	0.51.33.9721	0.44.11.9761	0.38.40.4791	0.34.22.6481	0.30.56.3833	9
10	0.57.17.7468	0.49.06.6401	0.42.58.3101	0.38.11.8312	0.34.22.6481	10
20	1.54.35.4935	1.38.13.2802	1.25.56.6202	1.16.23.6624	1.08.45.2961	20
30	2.51.53.2403	2.27.19.9203	2.08.54.9302	1.54.35.4935	1.43.07.9442	30
40	3.49.10.9871	3.16.26.5604	2.51.53.2403	2.32.47.3247	2.17.30.5922	40
50	4.46.28.7339	4.05.33.2004	3.34.51.5504	3.10.59.1559	2.51.53.2403	50
60	5.43.46.4806	4.54.39.8405	4.17.49.8605	3.49.10.9871	3.26.15.8884	60
70	6.41.04.2274	5.43.46.4806	5.00.48.1705	4.27.22.8183	4.00.38.5364	70
80	7.38.21.9742	6.32.53.1207	5.43.46.4806	5.05.34.6494	4.35.01.1845	80
90	8.35.39.7209	7.21.59.7608	6.26.44.7907	5.43.46.4806	5.09.23.8326	90
100	9.32.57.4677	8.11.06.4009	7.09.43.1003	6.21.58.3118	5.43.46.4806	100
200	19.05.54.9354	16.22.12.8018	14.19.26.2016	12.43.56.6236	11.27.32.9612	200
300	28.38.52.4031	24.33.19.2027	21.29.09.3023	19.05.54.9354	17.11.19.4419	300
400	38.11.49.8708	32.44.25.6036	28.38.52.4031	25.27.53.2472	22.55.05.9225	400
500	47.44.47.3385	40.55.32.0045	35.48.35.5039	31.49.51.5590	28.38.52.4031	500
600	57.17.44.8062	49.06.38.4054	42.58.18.6047	38.11.49.8708	34.22.38.8837	600
700	66.50.42.2740	57.17.44.8062	50.08.01.7055	44.33.48.1826	40.06.25.3644	700
800	76.23.39.7417	65.28.51.2071	57.17.44.8062	50.55.46.4944	45.50.11.8450	800
900	85.56.37.2094	73.39.57.6080	64.27.27.9070	57.17.44.8062	51.33.58.3256	900
1.000	95.29.34.6771	81.51.04.0089	71.37.11.0078	63.39.43.1181	57.17.44.8062	1.000

DEFLECTION ANGLES

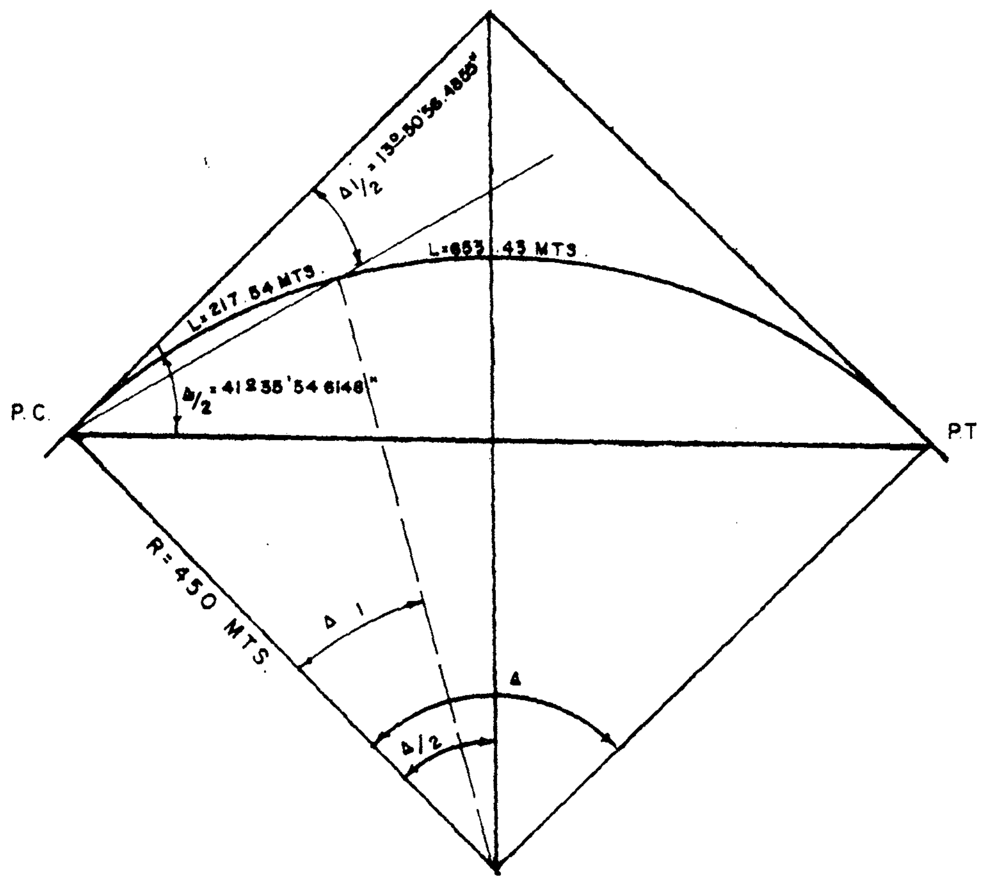
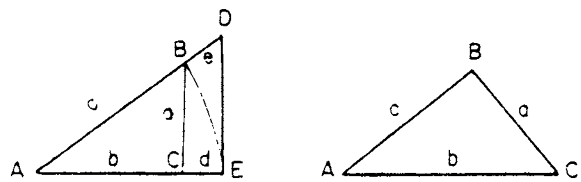


FIGURE 16-B

16.07-03

TRIGONOMETRIC FORMULAS



Right Triangle   Oblique Triangle

RIGHT TRIANGLES

$\sin A = \frac{a}{c} = \cos B$ $\sec A = \frac{c}{b} = \operatorname{cosec} B$

$\cos A = \frac{b}{c} = \sin B$ $\operatorname{cosec} A = \frac{c}{a} = \sec B$

$\tan A = \frac{a}{b} = \cot B$ $\operatorname{vers} A = \frac{c - b}{c} = \frac{d}{c} = 1 - \cos A$

$\cot A = \frac{b}{a} = \tan B$ $\operatorname{exsec} A = \frac{e}{c} = \sec A - 1$

$a = c \sin A = c \cos B = b \tan A = b \cot B = \sqrt{c^2 - b^2}$

$b = c \cos A = c \sin B = a \cot A = a \tan B = \sqrt{c^2 - a^2}$

$c = \sqrt{a^2 + b^2}$ $d = c \operatorname{vers} A$ $e = c \operatorname{exsec} A$

OBLIQUE TRIANGLES: $A + B + C = 180°$ $s = \frac{1}{2}(a + b + c)$

Given	Sought	Formulas
A, B, a	b, c	$b = \frac{a}{\sin A} \cdot \sin B \quad c = \frac{a}{\sin A} \cdot \sin(A + B)$
A, a, b	B, c	$\sin B = \frac{\sin A}{a} \cdot b \quad c = \frac{a}{\sin A} \cdot \sin C$
C, a, b	A, c, B	$\tan A = \frac{a \sin C}{b - a \cos C} \quad c = \frac{a \sin C}{\sin A} \quad b > a$
C, b, a	B c A	$\tan B = \frac{b \sin C}{a - b \cos C} \quad c = \frac{b \sin C}{\sin B} \quad a > b$
A, b, c	a	$a^2 = b^2 + c^2 - 2bc \cos A$
B, a, c	b	$b^2 = a^2 + c^2 - 2ac \cos B$
G, a, b	c	$c^2 = a^2 + b^2 - 2ab \cos C$
a, b, c	A, B, C	$\sin^2 \frac{1}{2} A = \frac{s - b}{b} \cdot \frac{s - c}{c}$
		$\sin^2 \frac{1}{2} B = \frac{s - a}{a} \cdot \frac{s - c}{c}$
		$\sin^2 \frac{1}{2} C = \frac{s - a}{a} \cdot \frac{s - b}{b}$
a, b, c	A, B, C	$\cos A = \frac{b^2 + c^2 - a^2}{2bc}$
		$\cos B = \frac{a^2 + c^2 - b^2}{2ac}$
		$\cos C = \frac{a^2 + b^2 - c^2}{2ab}$

16-07.04 AREA AND VOLUME FORMULAS

AREA OF:

Trapezoid: 1/2 (Sum of parallel sides) X (perpendicular height)

Circle: πr^2, Where r = radius, π = 3.1416

Ellipse: πab = 3.1416 X Long diameter X short diameter

Parabola: Base X $\frac{2}{3}$ Perpendicular height

Sector of Circle: Arc X 1/2 radius = 1/2 r^2 X Central Angle (in radians) = 0.0087266 r^2 X Central Angle (in degrees)

Segment of Circle: $\frac{r^2}{2}\left(\frac{r\,\phi}{180} - \sin\phi\right)$ where ϕ is Central Angle in degrees

Triangle: 1/2 base X height

Rectangle: base x height

VOLUME OF:

Prism or Cylinder: Area of base X the perpendicular height = (A X h)

Pyramid or Cone: 1/3 (Area of base X height) = 1/3 (A X h)

Frustum of Pyramid or Cone: Sum of end Areas, A_1 and A_2, Plus the Square root of their products X 1/3 Perpendicular height h = $(A_1 + A_2 + \sqrt{(A_1 \times A_2)})\frac{h}{3}$

Sphere: $\frac{4}{3}\pi r^3$ = 4.1888 radius^3

Rectangle: Area base X height

Electronic Computer Programs for Highway Surveys

ICES COGO is a computer system designer to aid engineers and surveyors in the solution of geometric problems. The user of ICES COGO describes his problem to the computer programs of the COGO systems using a language and conventions which are made natural for the engineer solving a geometric problem, rather than being tailored to the computer.

Open and closed traverses curve elements and areas are checked by this system.

ROUTE LOCATION NOTES

STA.	PARTIAL DIST	TOTAL DIST	VERTEX	CURVE ELEMENTS	OBS BEARING	CALC BEARING	OBSERVATIONS
2+54 42	12 24	254 42					
2+42 18	13 17	242 18					
2+29·01	15·00	229·01					
2+14·01	16·93	214·01					
PT.1+97·08	11·00	197·08		A=127° 50'			
1+86·08	7 21	186 08		R=40 00			
MC.1+78·87	6 21	178 87	V-3-R	T=19 58	S 44° 15' W	S-44° 10' W	
1+72·66	8·00	172 66		E= 4 54			
1+64·66	4 00	164·66		L=36 42			
PC 1+60·66	5.65	160 66					
1+55·01	7·00	155·01					
1+48·01	8·81	148·01					
PT.1+39·20	9·00	139 20		A=155°00'			
1+30·20	7·36	130·20		R= 75 00			
MC 1+22·84	6·36	122·84	V-2-L	T= 16 63	S-7° 45' E	S-8° 00' E	
1+16 48	10 00	116 48		E= 1 82			
PC 1+06·48	11 47	106·48		L=32 72			
0+95 01	14 43	95·01					
PT 0+80 58	10 00	80 58		A=116°30'			
0+70·58	6 63	70 58		R=30 00			
MC 0+63 95	3 47	63 95	V-1-R	T=18·56	S-17° 00' W	S-17° 00' W	
0+60·48	13 15	60 48		E=5 28			
P.C.0+47·33	7 33	47·33		L=33·25			
0+40 00	20·00	40 00	0 51+ 38 00				
0+20·00	20 00	20 00	0 51+ 23 00				
0+00 00	051+00	00 OF PAVED ROAD					

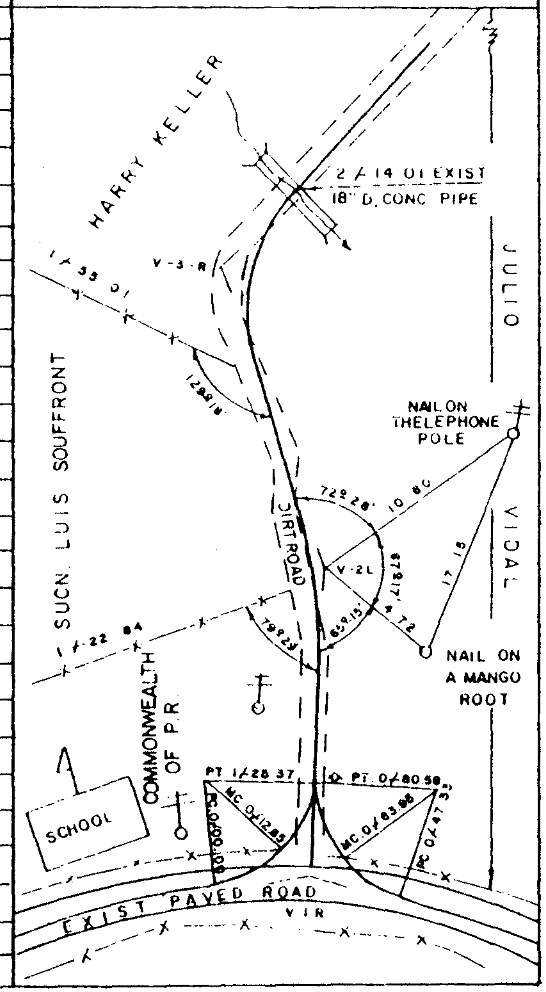


FIGURE 16-3

LEVELING NOTES

STA.	BACK SIGHT (+)	H - I	FORE SIGHT (−)	T. P. S.	ELEV. (MTS.)
BM # 10	3.168	335.769			332.601
0+00.00			1.75		334.019
0+20.00			1.81		333.959
T.P. # 1	3.768	339.465		0.072	335.697
0+30.00			3.09		336.375
0+40.00			3.03		336.435
0+55.00			2.75		336.715
T.P. # 2	3.234	342.597			339.323
0+65.00			2.98		339.617
0+80.00			2.45		340.147
1+00.00			2.43		340.149
T.P. # 3	2.657	345.020		0.234	342.363
1+10.00			3.65		341.370
1+25.00			2.98		342.040
1+35.00			2.02		343.000
BM # 1				1.058	343.962

LEVELING CHECK

BM. # 1	1.058	345.020			343.942
T.P. # 1	0.198	342.020		2.657	342.363
T.P. # 2	0.156	339.479		3.238	339.323
T.P. # 3	0.067	335.766		3.780	335.699
BM. #10	.			3.162	332.604

332.601
332.604

ERROR OF CLOSURE = ·003 MT.

TABLE 16-4

SURVEY LINE CROSS SECTIONS

PARTIAL DIST.	DIFF. IN ELEV.		TOTAL DIST.	TOTAL DIFF. IN ELEV.	OBS.	PARTIAL DIST.	DIFF. IN ELEV.		TOTAL DIST.	TOTAL DIFF. IN ELEV.	OBS.
		000	+ 20.00				ELEV.	333.	959		
3.0	+0.30		-03.0	+00.30		1.0	-0.60		01.0	-00.60	
3.0	+0.25		-06.0	+00.55		1.5	-0.20		02.0	-00.80	
3.0	+0.33		-09.0	+00.88		1.5	-0.90		04.0	-01.70	XXXX
3.0	+0.40		-12.0	+01.28		4.0	-0.80		08.0	-02.50	
3.0	+1.10		-15.0	+02.38		3.0	-1.10		11.0	-03.60	
3.0	+0.92		-18.0	+03.30	XXXX	3.0	-1.40		14.0	-05.00	
3.0	+0.30		-21.0	+03.60		3.0	-0.10		17.0	-04.90	
3.0	+0.20		-24.0	+03.80		3.0	-0.20		20.0	-05.10	
3.0	+0.20		-27.0	+04.00		3.0	-0.15		23.0	-04.95	
3.0	+0.10		-30.0	+04.10		3.0	-0.60		26.0	-05.55	
						3.0	-0.50		29.0	-06.05	
			IMPORTANT COLUMNS								

Notes:

1- All cross sections information must be filled like the illustrated form.

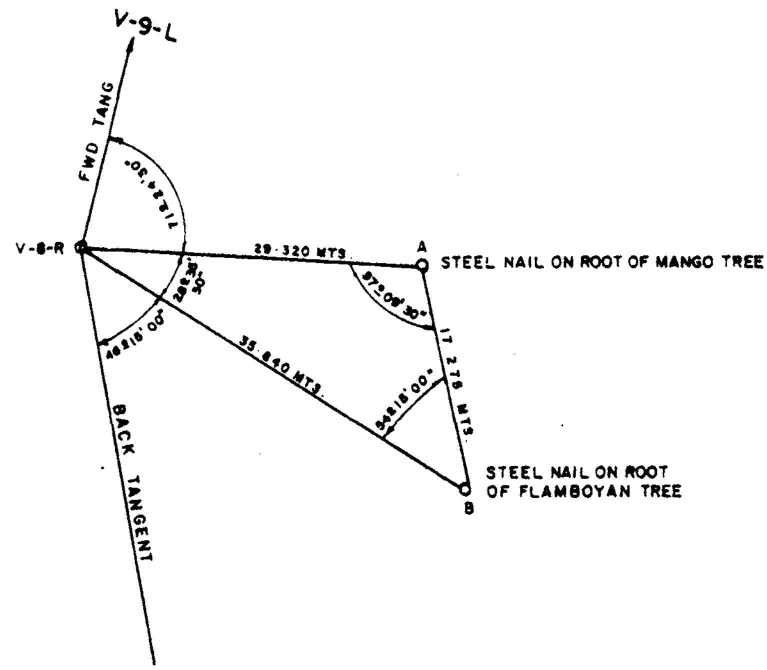
2- The indicated columns should have the correct number of digits, the decimal point, and the corresponding sign in the difference in elevation columns.

3- The reason for the specific details mentioned on 1 and 2 is that the information is going to be punched in IBM cards directly from the field book. Then it will be processed by the computer.

TABLE 16-5

SURVEY REFERENCE POINTS

THIS TYPE OF REFERENCE IS THE MOST COMMONLY USED



THIS TYPE OF REFERENCE IS ALSO ACCEPTED

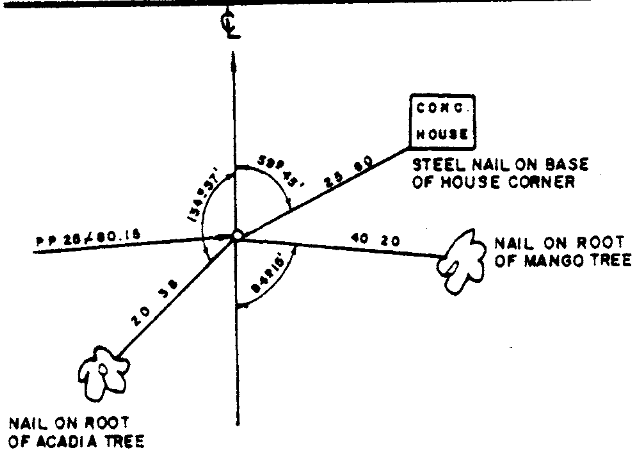
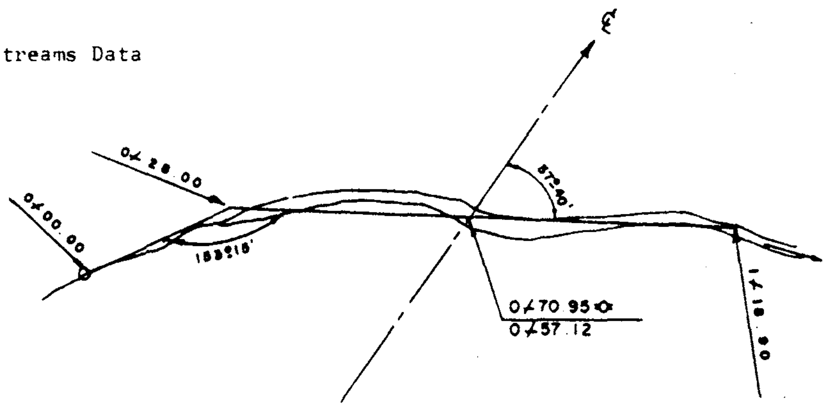


FIGURE 16-C

DRAINAGE SURVEY

1. Streams Data



Beside the ground plan, a profile and cross sections of the stream are drawn to be used in the design.

2. Bridge Replacement

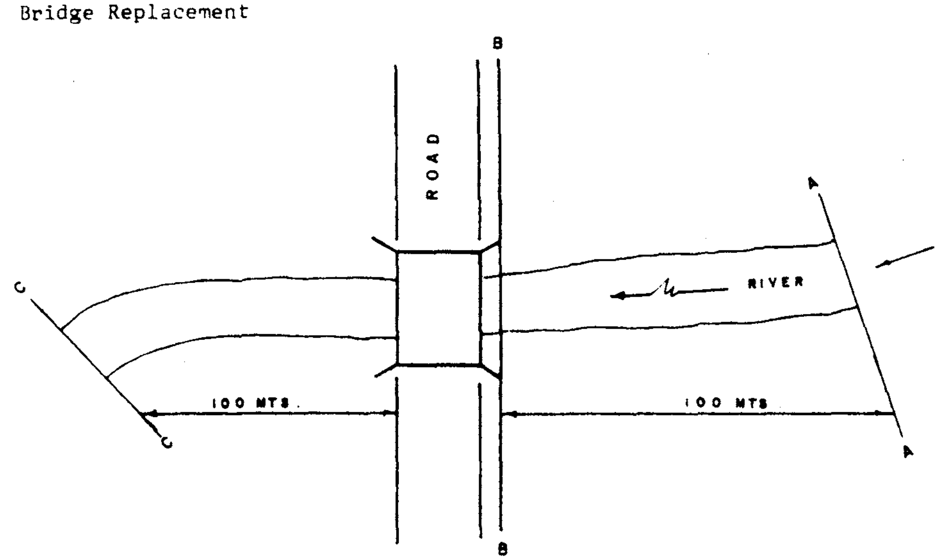
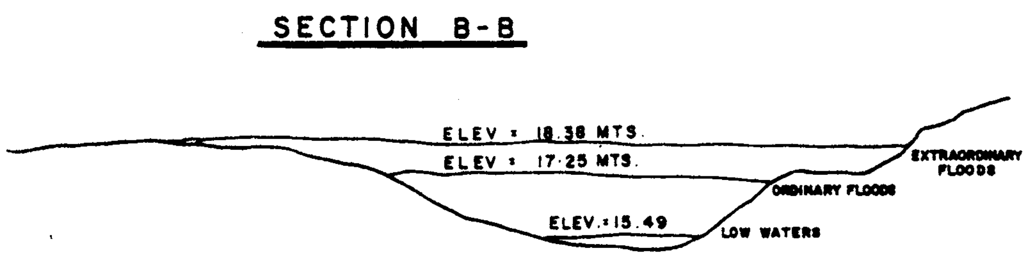


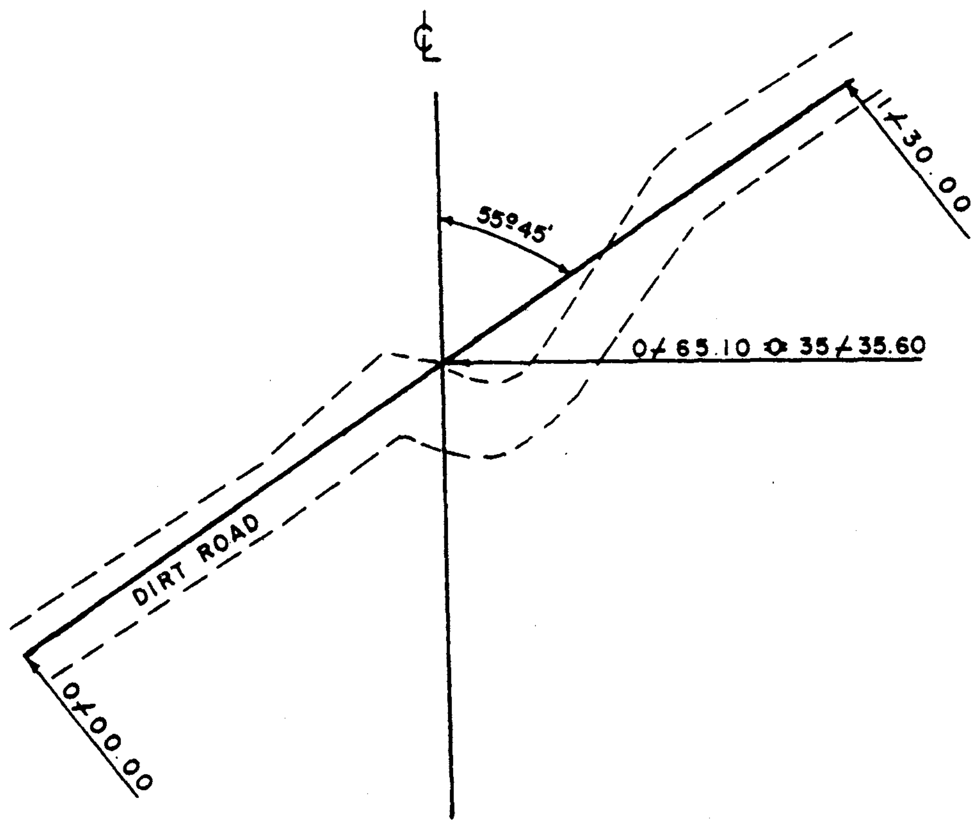
FIGURE 16-D

For bridge replacement, a topography is necessary. The size of the topography is determined after a joint field trip between the structural engineer in charged of the bridge design and the Survey Office Personnel.

Three cross sections are necessary to show the river or stream bed and slope in the vicinity of the bridge location. Section B - B must show the water marks. See example:



ACCESS DETAILS



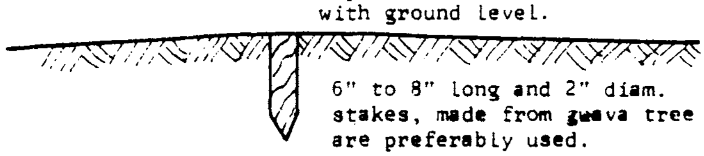
Beside the ground plan, a profile and cross sections of the access are drawn to be used in the design.

FIGURE 16-E

TYPES OF STAKES

1- AT GRADE STAKES (Center Line stakes)

Top of stake is set even with ground level.

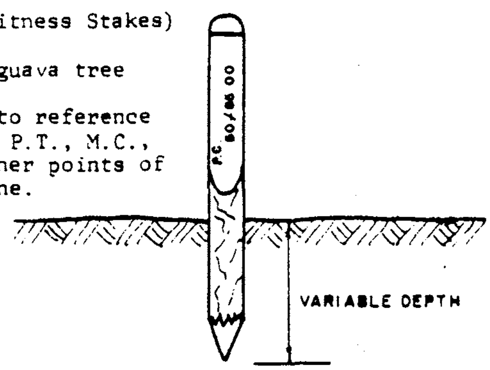


6" to 8" long and 2" diam. stakes, made from guava tree are preferably used.

2- REFERENCE STAKES (Witness Stakes)

18" long - made from guava tree

This stakes are used to reference points such as P. C., P.T., M.C., P.P., P.I. and all other points of the highway center line.



3- BENCH MARKS

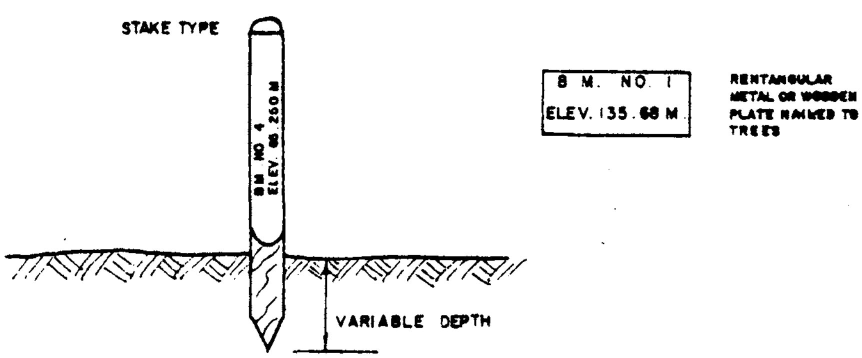


FIGURE 16-F

CONVENTIONAL SIGNS

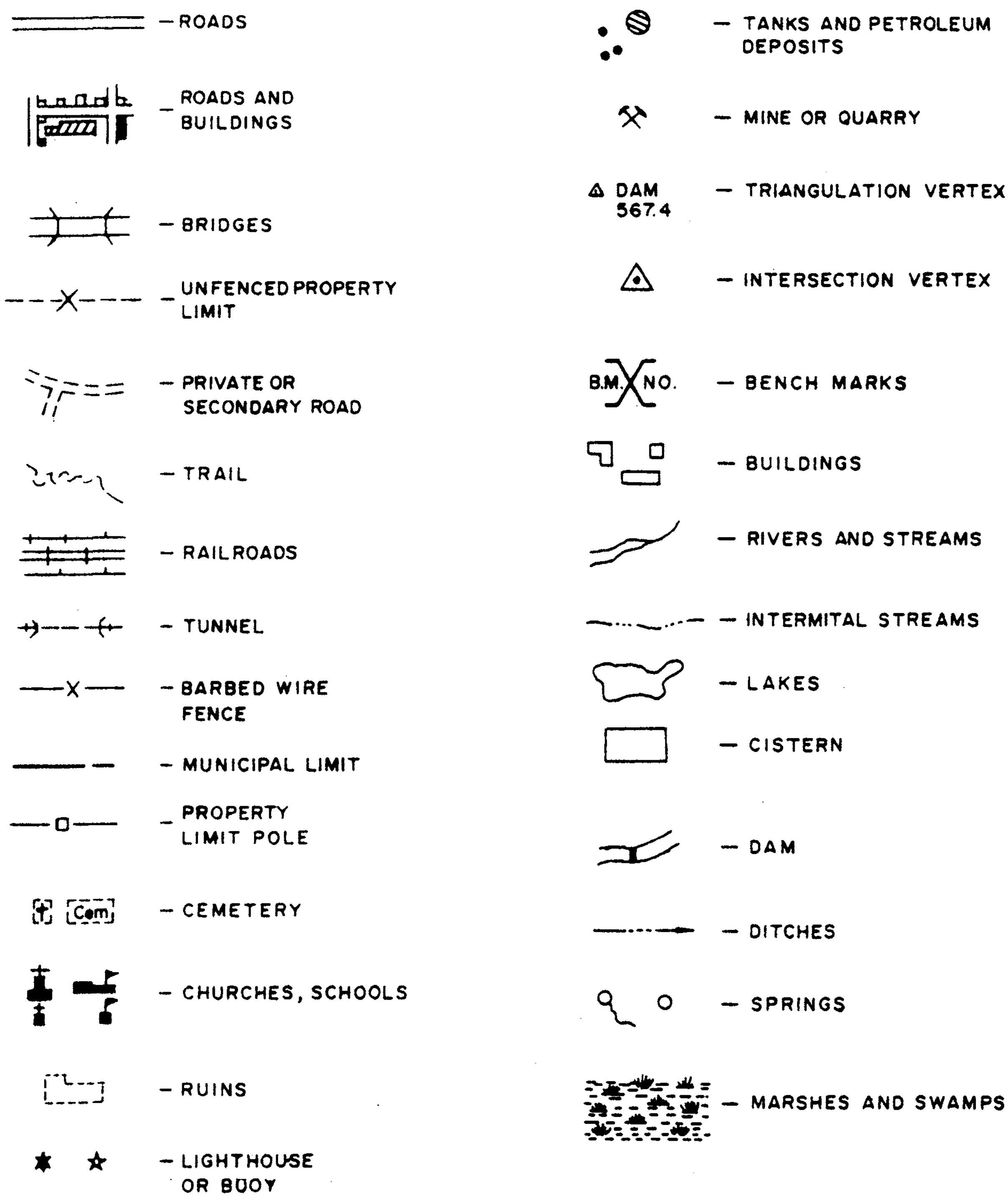


FIGURE 16-G

UTILITIES SYMBOLS

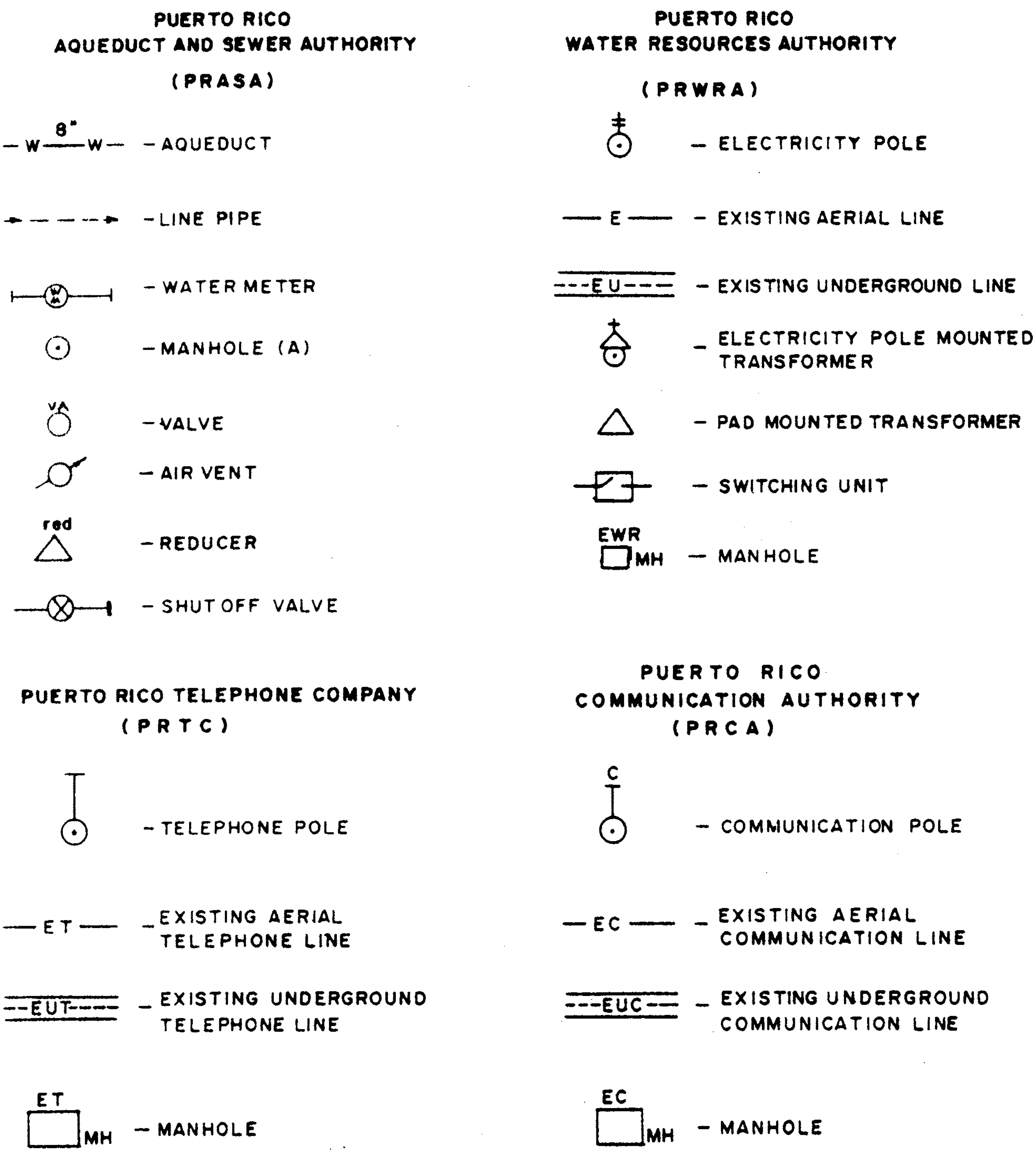


FIGURE 16-H

Application of Photogrammetric Methods to the Different Stages of Highway Design

16–12 INTRODUCTION

The development of the technique of highway design during recent decades has implied that the requirements on the information regarding the topography and geology of the terrain have increased. One of the reasons is the introduction of more advanced elements of road alignment. Another is the fact that the requirements on the fitting of the road into the surrounding terrain or landscape from the points of view of environments, of aesthetics and traffic safety have increased.

The process of highway design can generally be divided into three different stages, namely Route Location, Preliminary Design and Final Design. This division is, from the point of view of photogrammetry, a practical division as there is a relation between each of the different design stages and the requirements of the geometrical accuracy of the terrain information for that stage. In the first two stages interest is concentrated upon requirements on less accurate topographic information over wide areas. While in the final stage accurate detailed information is required over limited areas. The requirements of geological-geotechnical information follow the same principles in the design process.

16–13 ROUTE LOCATION

The main considerations of the highway network of the single road are defined in this stage. Therefore a preliminary fitting of the requirements of the forecasted traffic to the topographical and geological conditions of the terrain is needed in order to optimize the total cost function. The actual cost function is principally divided into construction cost and cost of vehicle operation. These two cost functions are correlated with the alignment of the road in the terrain.

One of the main tasks of the analysis of the terrain in the location stage is to delimit areas, that because of their geological conditions are evidently unsuitable for highway construction. Areas, where geotechnical problems may play a determining influence upon the construction cost are also of interest. The geological-geotechnical photointerpretation therefore is an important aid in this design stage.

A summation of the delimitations of terrain areas that are complicated from point of view of highway construction gives an indication of the location of possible terrain corridors.

Aerial photographs from flying heights between 5,000′ and 10,000′ are generally used for the photogrammetric study of the terrain. Photo interpretation studies of these photographs ordinarily give a satisfactory survey of the loading capacity and other geological-geotechnical parameters of the terrain from the road construction point of view. Airphoto-interpretation may be very valuable for the choice of the route for a road and for information of soil conditions and materials, areas of poor drainage, marshy areas, landslides and unstable ground, mining subsidence, swallow holes, and rock outcrops. Man-made features of interest include any changes since the last map revision, e.g. new roads of buildings, demolition of buildings, extensions to quarries and gravel-pits, removal or changes in field boundaries, pipelines and movement of mining spoil heaps.

The application of airphoto-interpretation relate mainly to the route location and preliminary stages of Highway Design.

Investigation of possible alignments of different fundamental centerlines can be made photogrammetrically. The Kelsh Plotter may be mentioned as an instrument suitable for producing and efficient and convenient overall view of the entire photogrammetric model or set of models including preliminary measurements of the longitudinal profiles along the fundamental alternative centerlines.

Complete horizontal and vertical control for the different photogrammetric models is generally not required. And arbitrarily located baseline, measured in the field can by satisfactory for the scaling of the model. Vertical control can be achieved by simple measurements, barometric, etc, if is is not already available.

The control points for the evaluation of the models can also be achieved by aerial triangulation. This method is mainly used when the result of the evaluation consists of a map with contours. The scale of the map is generally 1:10, 000 to 1:2, 000 and the contour interval 5m or 2m. Second order photogrammetric equipments as Kelsh Plotter are mainly used for the mapping.

16--14 PRELIMINARY DESIGN

The first part of this design stage consists of a systematization and actualization of the result from the route. location stage concerning the actual terrain corridor. The result of the design work of this stage is a centerline, analized in such detail, that it is ready for setting out in the terrain. This means that the actual alternative centerlines within the terrain corridor are investigated concerning their preliminary horizontal and vertical alignment, so that their cost functions, construction and vehicle operations, can be analized together with their effects upon the development of the community. Therefore, in this design stage the requirements on a survey over wideareas within the terrain corridors must be combined with requirements on geometrical quality of the terrain data, that are adapted to the real needs.

Aereal photographs from 5,000′ to 10,000′ flying heights are generally used in the preliminary design stage, depending on the information requirements. These image scales are more related to the requirements on an overall view of wide areas than to the requirements of geometric accuracy. Experience has up to now, shown that these photographs, evaluated in suitable equipment, using a suitable technique, give an acceptable compromise between an overall view and geometrical accuracy.

The terrain corridors generally have a long and narrow form and planimetric control points can thus be arranged in the form of a traverse through the corridor. The traverse points are signalized before the photography. The advantage of terrestrially measured control points compared to photogrammetrically triangulated control points consists of the possibilities of using the control points as both reference and control points for the staking out of the centerline in the terrain.

The required vertical control is procured in a conventional way using levelling, trigonometric or phototrigonometric height measurement, depending on topography and vegetation.

It can thus be stated that the recent development in the field of aerial triangulation means a good step forward in improving the practical application of photogrammetry to highway design, as the combination of geodetic methods and photogrammetric triangulation can be organized in a more efficient way than before for the horizontal and particularly and for the vertical control.

The detail maps are generally made at the scale of 1:2, 000 and the contour interval is 1m or 2m depending on the topography. The maps are made in a conventional photogrammetric way but as the flying height for the photographs mainly is estimated by a compromise between the requirements on good topographic information over the entire terrain corridor for the evaluation of alternatives and the requirements of geometrical accuracy for the detail mapping, great attention must be paid to the geometrical quality of the photographs and of the evaluation equipments.

16–15 FINAL DESIGN

In the first step an analysis is made concerning the method of procuring the detailed terrain information that is needed for the final design of the body of the road, hereinafter reffered to as the roadbody, along the centerline, that is determined in the previous stage. Terrain topographic data can be obtained by terrestrial or by photogrammetric methods or by a combination of the two methods. The choice of methods generally depends on the ground vegetation, the size of the project and the topography of the terrain. A traverse with a side-length of approx. 200 m is record noted, marked and signalized along the centerline before the photography in order to serve as planimetric control for the photogrammetric evaluation. The traverse points are located in such a way that they can also be used as control points for the setting out of the centerline. Terrain details, identified in the photographs after the photography, are mainly used for the vertical control.

The aerial photographs are taken from a flying height of 1250′ to 2500′.

The evaluation of the photographs consists of measurements of longitudinal and transverse profiles and of preparing detail maps at the scale of 1:500 to 1:1000 with contours at an interval of 0.5 to 1m. The maps are used for the final design of interchanges, bridges etc.

The photogrammetric measurements of longitudinal and transverse profiles, the model coordinates, are automatically registered on punch cards by a registering device, connected to the evaluation equipment. The model coordinates are first transformed into the ground system of coordinates and then into the system of the centerline before they are shown in the form o longitudinal and transverse profiles. The computer programs generally allow the insertion of terrestrial measurement in cases, where gaps occur due to vegetation etc.

Ordinarily the topographic data must also be complemented by geological-geotechnical data from borings, etc, as the design of the roadbody also depends on soil conditions.