Developing Tools and Techniques for Geometric Design of Highways

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• PASSAGE of the Federal Aid Highway Act of 1956 initiated a tremendous engineering endeavor, unprecedented in the history of the United States. It loomed as a gigantic undertaking to design and construct the 41,000-mi system of Interstate and Defense Highways — highways having freeway characteristics in a network incorporating "all known features of safety and utility" — by the year 1970. This seemed particularly so because the highway engineering profession and the construction industry were not completely geared for the program. The challenge is being met, however, and the problem of shortages has been or is being resolved.

This paper brings out one facet in overcoming the lack of highway design engineers by means of stepping up engineering productivity. Specifically, the discussion deals with research and development of special tools and techniques for use in geometric design of highways, with particular emphasis on interchange design. This is an experience of one highway department in obtaining a three-fold objective, as follows:

1. To increase production per man-day.
2. To obtain effective utilization of young and inexperienced engineers.
3. At the same time, to improve on the quality of design.

SIMPLIFICATION OF DESIGN PROCEDURES

Developing plans for these high-type facilities posed many new problems for highway and traffic engineers. Photogrammetry and electronic computation were employed, but these were not enough. Need was recognized for simplification and standardization of design methods and procedures. After considerable study, some of the old methods gave way to simple, standard means of accomplishing many design operations.

Much of this was done with the aid of specially prepared material and instructions, coupled with a training program. Efficiency was gained by using newly developed standard forms for certain solutions and computations; by utilizing varieties of design tables prepared to minimize calculations; by using graphics in several areas of design in lieu of long, drawn-out procedures; and by employing many varieties of newly developed design templates to improve efficiency and quality of work.

Most of the effort in attaining engineering productivity was directed to interchange design because of its complex nature. Nearly 9,000 interchanges are contemplated on the Interstate system in rural areas, and an additional 3,000 to 4,000 in urban areas. The design effort required for these is about equal to that for the remaining elements of the system outside the interchange areas. The techniques evolved to facilitate geometric design, therefore, have been directed primarily to layout of interchanges. These techniques, their development and their application, are discussed herein with respect to the principal elements of interchange design.

INTERCHANGE DESIGN — CHANNELIZED RAMP TERMINALS

At-grade ramp terminals involving channelization comprise a significant part of interchange design. Layouts of these are based on design criteria for intersection curves, turning roadways, islands, etc., contained in the AASHO design policies. These elements and their correlation are predicated largely on the turning characteristics of design vehicles included therein. Even with the use of the AASHO criteria, which are quite complete and conveniently set up, the design of channelized intersections requires considerable skill and experience.

Turning Vehicle Templates

To facilitate the layout of intersections and to insure proper design, a set of templates for turning vehicle paths was developed. The set, consisting of 27 transparencies, provides for a variety of design conditions, including three types of trucks,[1] three turning radii, and three scales. Trucks represented are the SU, single-unit; C43, intermediate semitrailer combination; and C50, large semitrailer combination. Turning radii, described by the outer-front wheel, are 45 ft (or less), 60 ft, and 75 ft.[2] Scales used to fit the usual range and size of layouts are 1 in. = 50 ft, 1 in. = 40 ft, and 1 in. = 20 ft. Each transparency includes paths for a variety of turning angles (30°, 60°, 90°, 120°, 150°, and 180°).

A typical turning vehicle template is shown in Figure 1. For the type of vehicle and scale shown, it is one of a set of three illustrated in Figure 2. The grouping of templates in Figure 2 is the same as that contained in the bottom, middle section of the wall box shown in Figure 3. A total of nine such groupings for the three design vehicles and three scales are filed in this rack.

For ready reference, each template is edged with a thin band of color across the top. All templates having a minimum turning radius are edged red, R = 60 ft green, and R = 75 ft blue. For instance, in Figure 2 the top edging, from left to right, is blue, green, and red, respectively.

Holes at close intervals are provided along the wheel paths of each template. By placing pencil dots through these perforations, the turning paths may be transferred to a plan layout. The center hole, when used as a pivot, permits the paths to be adapted to any odd angle of turn. Right-turning paths are on the front of the template as shown in Figure 1 (arrows indicate direction of travel). The same templates apply to left-turning movements by using the reverse side. Minimum paths (red-band templates) usually apply to acute-angle turns, whereas the larger turning radii (green- and blue-band templates) generally apply to obtuse-angle turns.

The first step in development of the templates was the derivation of a series of intermediate paths to the basic 90° and 180° turning paths of the AASHO design vehicles. Initially, these paths were traced on acetate and used in checking intersection layouts. Later, they were found convenient as guides in design. Finally, the templates were adapted as direct aids in design of channelized intersections. This was made possible after the turning paths were expanded to include other than minimum turning conditions, and were printed on heavy film transparencies and perforated along the described paths. In design, the appropriate templates are laid over a skeleton or base of the intersection plan and the wheel paths, when located in a desired position, are transferred to the layout. The design is then sketched in, fitting these paths.

Illustrative Problem

The technique of using these templates is demonstrated in the following design problem, shown in sequence in Figures 4, 5, and 6.

The basic condition of the intersection is illustrated in Figure 4A. Here a 26-ft, two-way road is intercepted by a divided highway having two 12-ft lanes in one direction and three 12-ft lanes in the other direction, separated by a 16-ft median. The intersection angle is 68°. A divisional island, about 8 ft wide, is desired on the intercepted road. Also a small directional (triangular) island is called for in the acute-angle quadrant.

With the approximate position of the

[1] See "A Policy on Geometric Design of Rural Highways," AASHO, pages 429 and 432.

[2] The 45-ft turning radius is the minimum for the SU vehicle; for the C43 and C50 vehicles, minimum radii are 40 and 44 ft, respectively. Minimum turning radii, or near-minimum (60 to 75 ft), are normally employed in intersection design.

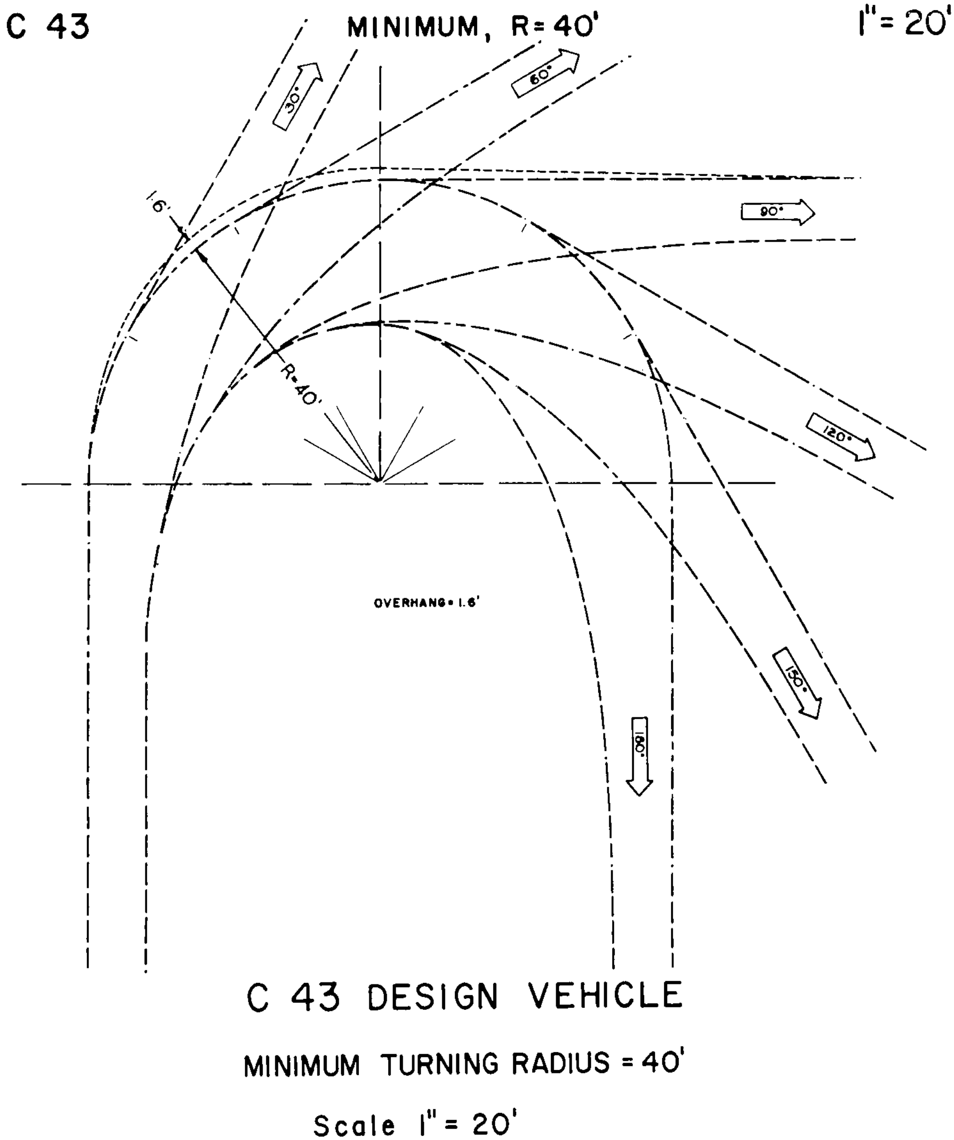


Figure 1. Typical turning vehicle template.

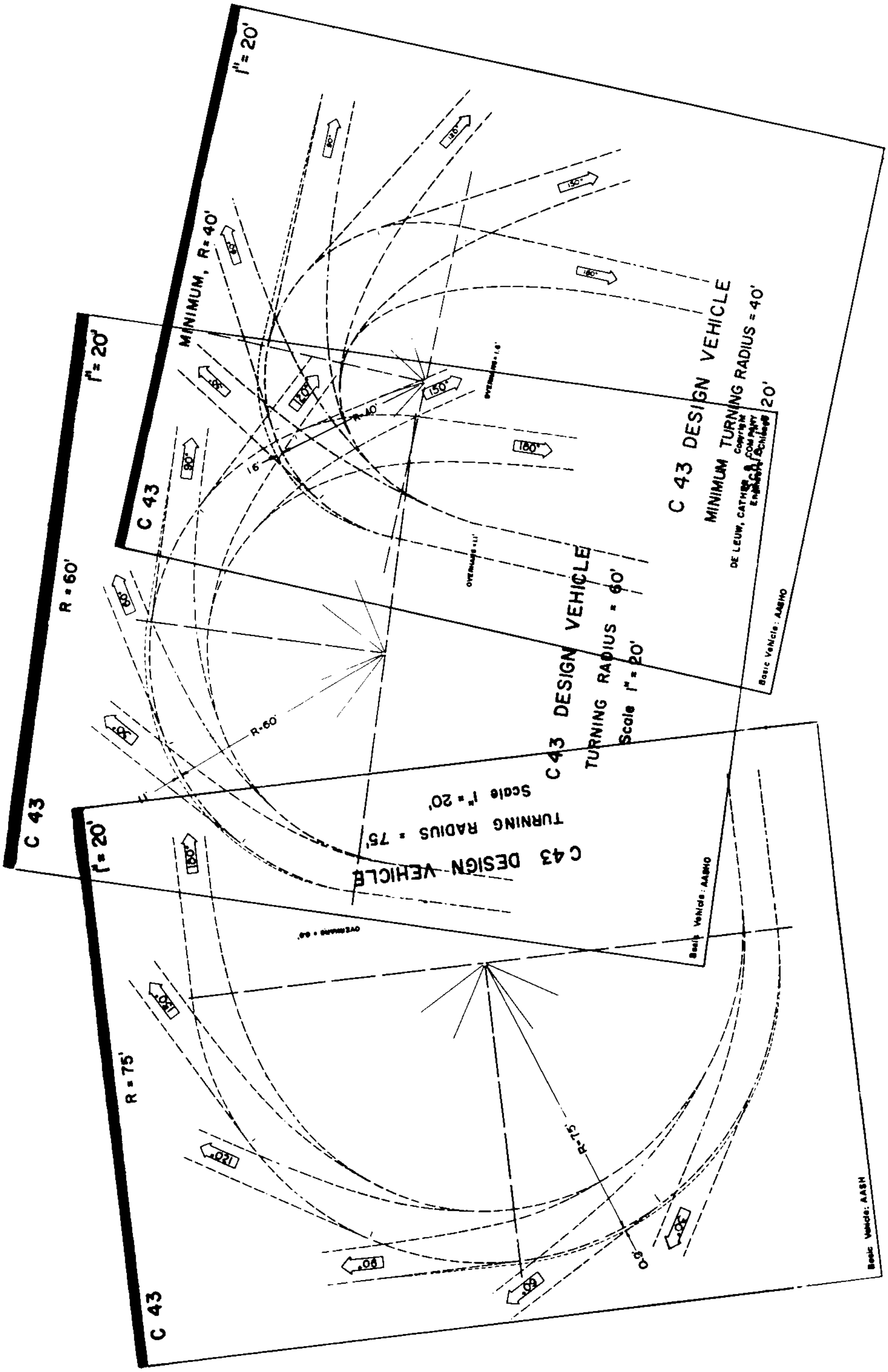


Figure 2. Typical set of turning vehicle templates; one of nine sets representing three vehicle types and three different scales.

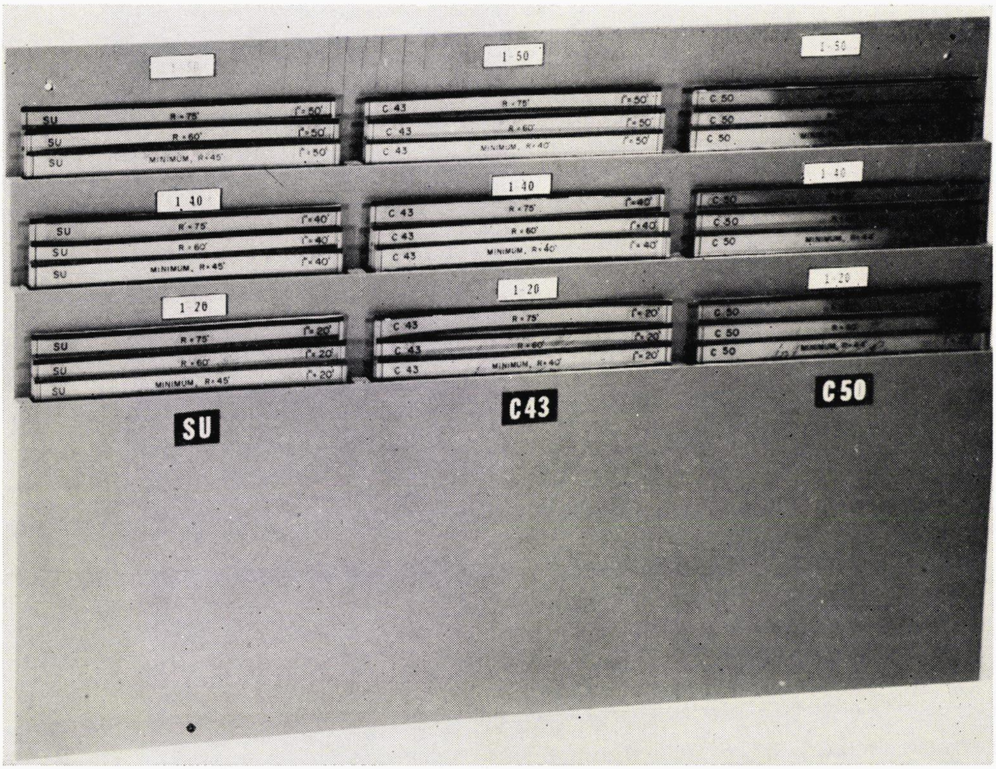


Figure 3. Set of turning vehicle templates in wall rack.

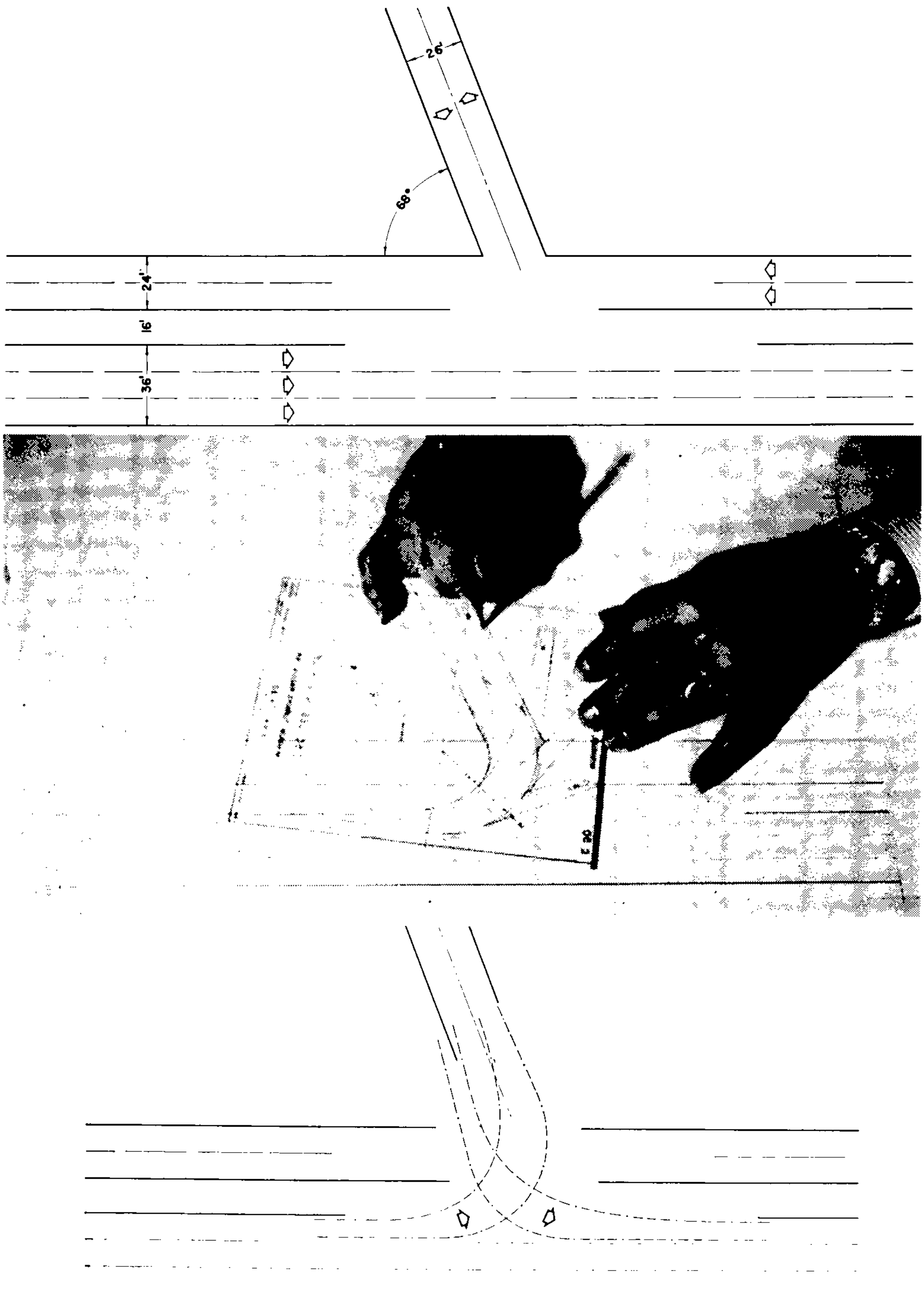


Figure 4. Illustrative problem for at-grade terminal: transfer of turning paths from templates to plan.

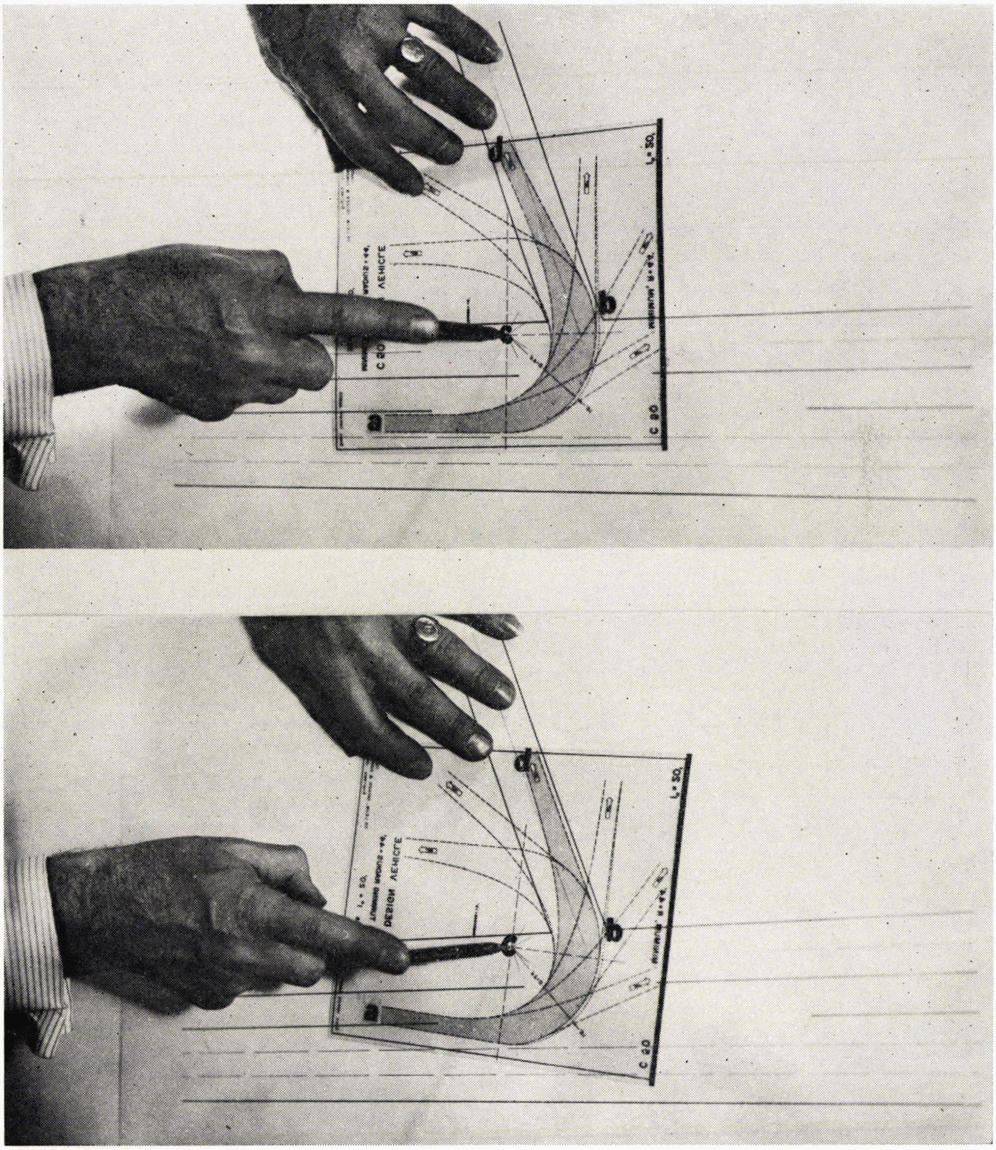


Figure 5. Illustrative problem for at-grade terminal: use of turning vehicle templates for odd angles of turn.

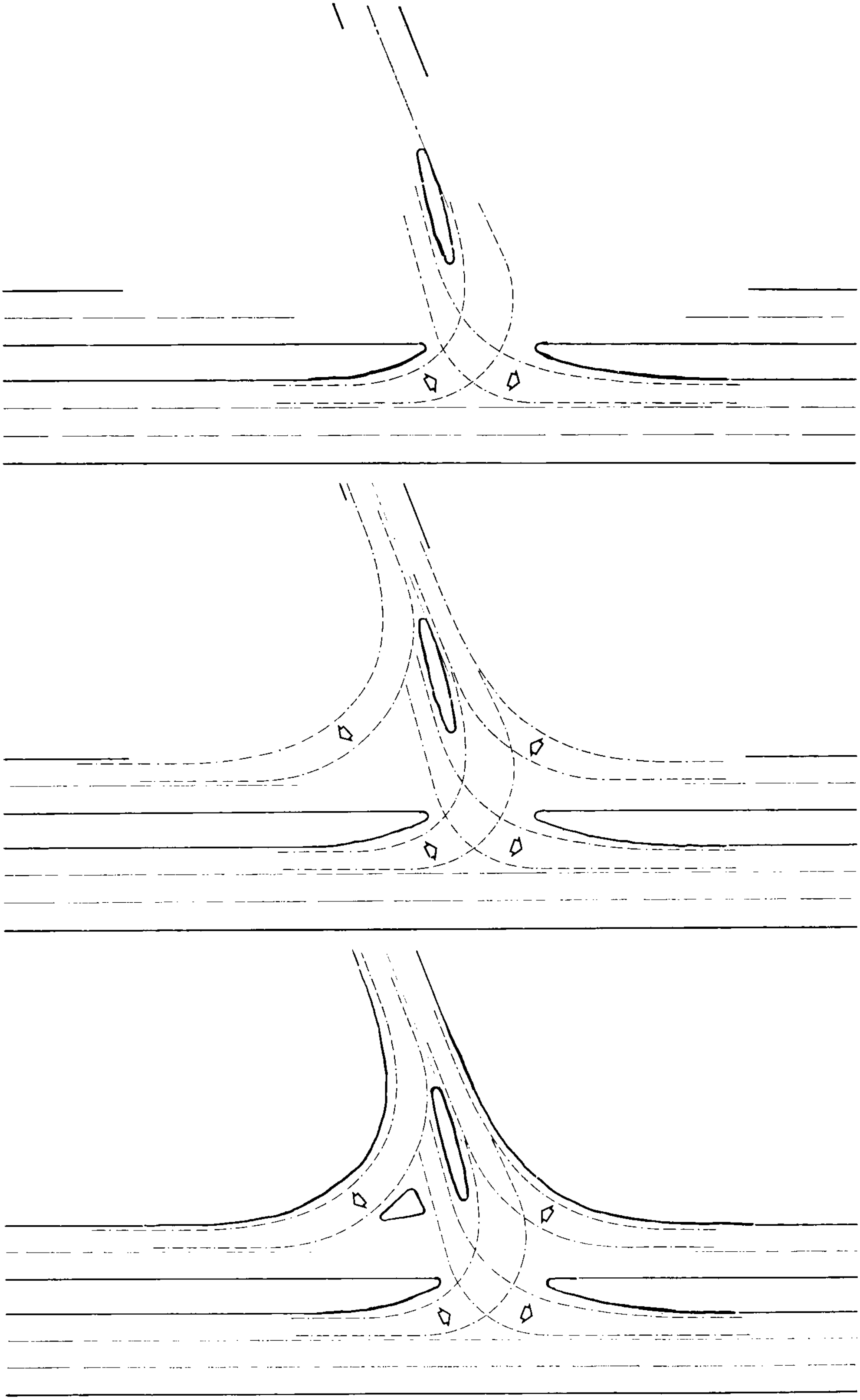


Figure 6. Illustrative problem for at-grade terminal: development of channelization to fit paths of turning vehicles.

divisional island assumed adjacent to and on the left of the centerline of the minor road, left-turning paths are established. This is accomplished by placing appropriate templates in the desired position and making pencil dots through the perforations (Fig. 4B). By this method the two left turns are transferred to the plan (dotted lines, Fig. 4C).

The 30° increments of turning paths do not fit closely enough the angles of intersection on the plan (in this case 68° and 112° in the two quadrants). The desired path for the 112° turning angle falls between the 90° and 120° angles available on the template. The sharper of the two, the stippled path indicated on the template in Figure 5, is used as a guide.

The method of adapting these turns to the exact angles of turn (68° and 112°) is illustrated in the two views of Figure 5. The template (Fig. 5A) is first placed with the beginning portion of the path (a) in proper position and with the outermost part of the path, point (b) placed so as to permit proper entry into the intercepted road. Then, with a sharp pencil held firmly in center hole (c), the far end of the path (d) is swung into position by revolving the template (Fig. 5B).

When the template is in its initial position (Fig. 5A) the beginning portion of the path is transferred to the layout by marking through the perforations, as previously illustrated in Figure 4B. The remainder of the path is transferred after the template is swung into the latter position (Fig. 5B). Thus, the effect produced is a described path for the specific or the odd angle of turn required.

Following establishment of the two left-turning paths, the median opening and the crossroad divisional island are sketched in to fit the left-turning paths. As shown in Figure 6A, this is done freehand, setting the edges of pavements and islands at approximately 3 ft outside the wheel paths. Approach ends of islands, however, are offset slightly more.

In Figure 6B, the right-turning paths are added to the plan by the use of appropriate templates. The remainder of the plan is sketched in (Fig. 6C) by adding the triangular island and the outer edges of pavement along the paths of right-turning vehicles.

At this point the plan is complete except for refining the layout and, where required, fitting calculated lines to it. To facilitate this operation, a special technique, which was developed in the course of study to improve design methods, is used. This consists of using alignment templates correlated with design tables, and graphics coupled with slide-rule calculations to establish islands, tapers, median openings, etc. By this procedure, computations are substantially reduced or completely eliminated.

Alignment templates were developed using curve combinations for turning roadways in accordance with AASHO criteria. A three-centered curve template representative of this group is shown in Figure 7. This is one of a set of ten 11- by 9-in. transparencies to a scale of 1 in. = 20 ft, ranging from 100-20-100-ft to 180-90-180-ft radii curves. Another group consists of twelve transparencies to a scale of 1 in. = 50 ft, ranging from 100-20-100-ft to 460-230-260-ft radii curves. A third set to a scale of 1 in. = 50 ft, expressed in degrees of curve rather than in radii, also is available. As shown in Figure 8, the various sets of templates are filed for ready reference in book folders and wall racks.

Accompanying these templates are two sets of tables (Fig. 9), one for radii and the other for degrees of curves. The tables furnish complete properties of three-centered curves for the large number of curve combinations represented on the templates. For example, the tabulation shown in Figure 10 is a companion to the template illustrated in Figure 7. The great variety of conditions for which this template may be used is represented in the table, with curve data completely furnished.

In developing the plan, the templates are used as testing devices to determine what three-centered curve combinations fit the layout. This is illustrated by Figure 11, in which the problem solution of Figures 4, 5 and 6 is continued. The

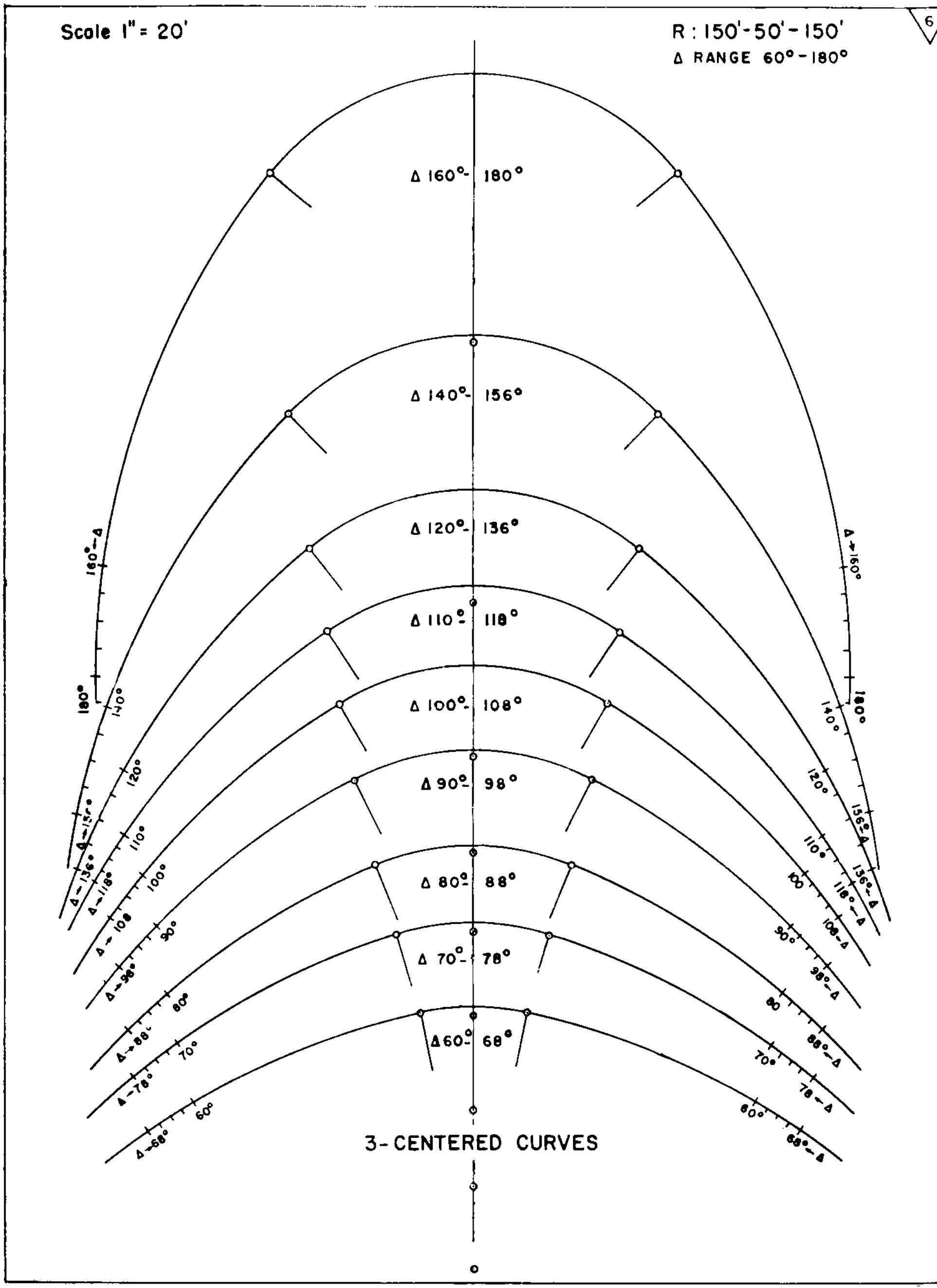


Figure 7. A typical three-centered curve template.

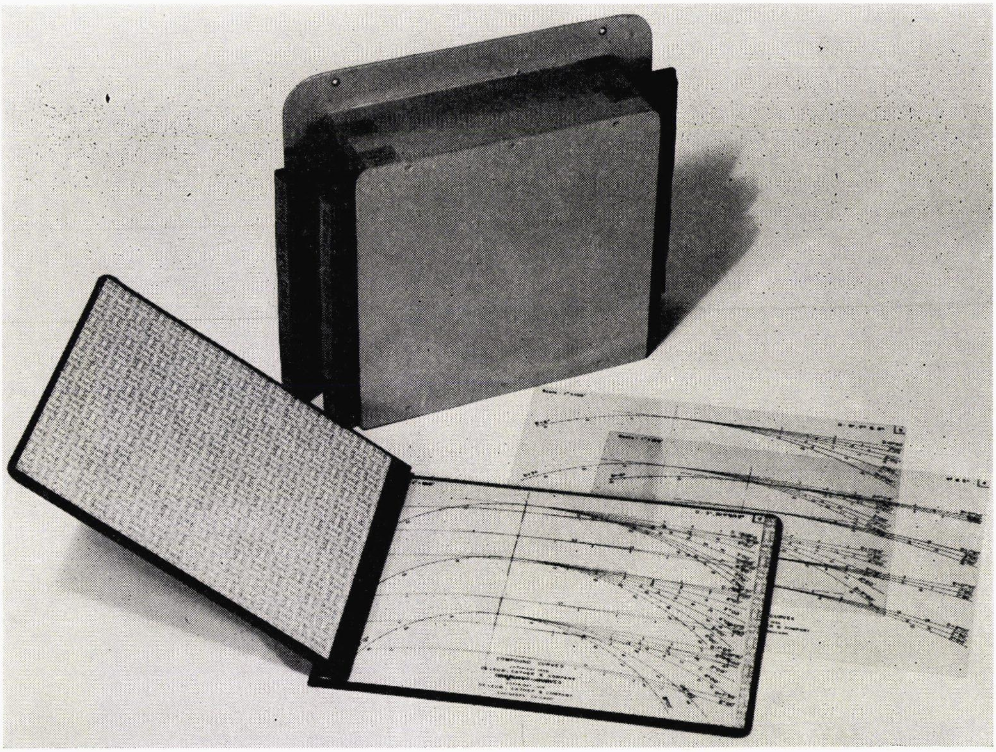


Figure 8. Sets of three-centered curve templates to various scales are kept in folders and wall rack.

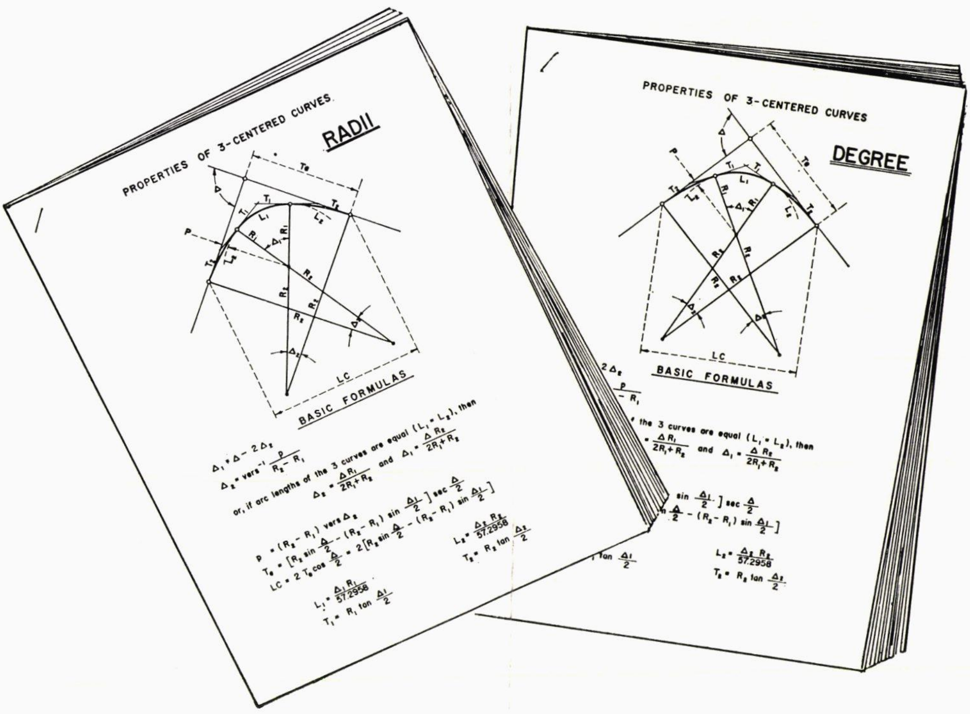


Figure 9. Design tables in terms of radii and degrees for three-centered curves.

R:150'-50'-150'
ΔRANGE 60°-180°

PROPERTIES OF 3-CENTERED CURVES

Δ	$Δ_1$	T_1	L_1	$Δ_2$	T_2	L_2	Te	p
60				18	23.76	47.12	62.59	4.9
62				19	25.10	49.74	65.87	↓
64				20	26.45	52.36	69.21	
66				21	27.80	54.98	72.62	
[illegible]				[illegible]	29.16	57.60	[illegible]	[illegible]
70				18	23.76	47.12	69.34	4.9
72				19	25.10	49.74	72.84	↓
74	34	15.29	29.67	20	26.45	52.36	77.42	
76				21	27.80	54.98	80.09	
78				22	29.16	57.60	83.85	7.3
80				18	23.76	47.12	76.96	4.9
82				19	25.10	49.74	80.75	↓
84	44	20.20	38.40	20	26.45	52.36	84.65	
86				21	27.80	54.98	88.66	
88				22	29.16	57.60	92.77	7.3
90				18	23.76	47.12	85.80	4.9
92				19	25.10	49.74	89.97	↓
94	54	25.48	47.12	20	26.45	52.36	94.28	
96				21	27.80	54.98	98.74	
98				22	29.16	57.60	103.35	7.3
100				19	25.10	49.74	98.63	5.4
102				20	26.45	52.36	103.39	↓
104	62	30.04	54.10	21	27.80	54.98	108.34	
106				22	29.16	57.60	113.48	
108				23	30.52	60.21	119.84	8.0
110				21	27.80	54.98	116.73	6.6
[illegible]				22	29.16	57.60	[illegible]	
114	[illegible]	33.73	59.34	23	30.52	60.21	128.31	↓
116				24	31.88	62.83	134.52	
118				25	33.25	65.45	141.07	9.4
120				21	27.80	54.98	133.95	6.6
124				23	30.52	60.21	148.06	↓
128	78	40.49	68.07	25	33.25	65.45	163.99	
132				27	36.01	70.69	182.17	
136				29	38.79	75.92	203.26	12.5
140				25	33.25	65.45	205.38	9.4
144				27	36.01	70.69	232.82	↓
148	90	50.0	78.54	29	38.79	75.92	266.57	
152				31	41.60	81.16	309.33	
156				33	44.43	86.39	365.59	16.1
160				29	38.79	75.92	*140.02	12.5
164				31	41.60	81.16	*141.66	
168	102	61.74	89.01	33	44.43	86.39	*142.94	↓
172				35	47.29	91.63	*143.84	
176				37	50.19	96.87	*144.40	
180				39	53.12	102.10	*144.58	22.3

NOTE: * IN COLUMN FOR Te INDICATE LENGTHS OF LONG CHORD.

Figure 10. Typical design table for properties of three-centered curves.

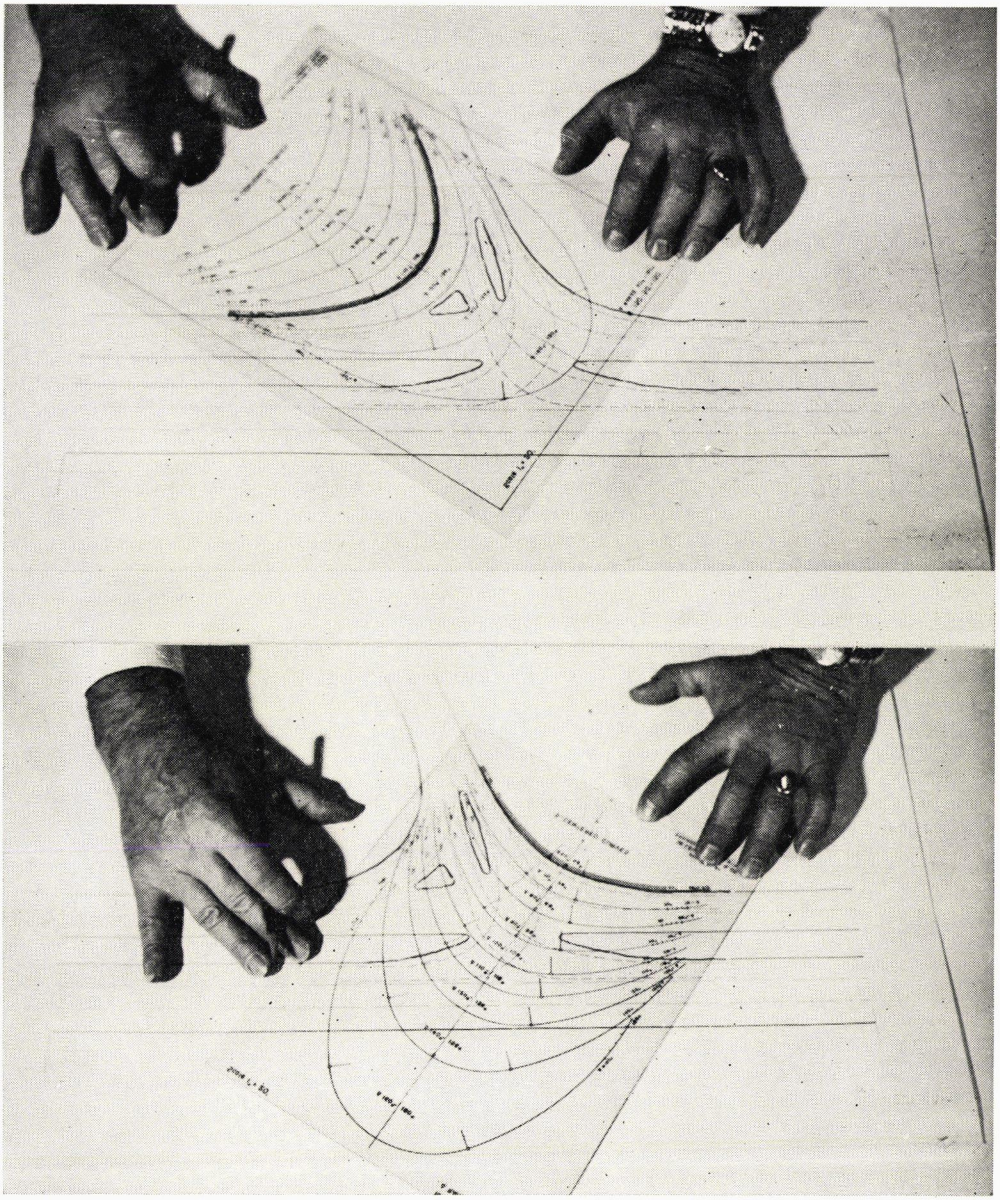


Figure 11. Illustrative problem for at-grade terminal: use of three-centered curve templates to test out and determine the curves that fit the plan.

curve combinations fitting the curb returns (having central angles of 68° and 112°) are found quickly, as shown by the shaded curve on the transparency in each view of Figure 11. With this information, appropriate tables are entered, in which are given complete curve data for the three-centered curves selected. The two sets of values for this problem are shown by shaded bands on Figure 10.

The three-centered curve templates may be used for any intersection angle, no matter how odd. The companion tables, however, are set up in terms of even delta angles. Still, the tables can be used in most cases and calculations avoided by adhering to a design policy of using even azimuths and, thus, even intersection angles. Where an effort is made to do so in design, bearings and angles established in terms of degrees, without minutes and seconds, are found to be practicable in nearly all cases. Occasionally, where an odd angle cannot be avoided, the required curve data can be computed by the use of formulas summarized on the cover of each table (see Fig. 9).

Having the preliminary layout of Figure 6C and the data for the three-centered curve combinations of the two curb returns, the final plan is carefully constructed as an overlay of the preliminary plan (Fig. 12). The median opening, islands, and tapers are transferred from the preliminary plan and are positioned graphically as follows. Using the selected 2.0-ft radii, median and island ends are fixed and referenced from scaled dimensions to the centerline of the two roads. The remaining shapes, of median-end tapers and the elongated island, are established by intermediate offsets based on parabolic distribution. The offsets, using the relations indicated in the upper left corner of Figure 12, are obtained by slide rule. These are plotted and tabulated on the plan, verifying the shapes assumed on the preliminary layout. Thus, the plan is completed without calculation.

This technique was ultimately adopted throughout the department. Designs of channelized intersections and ramp terminals which used to take days now can be done in a matter of hours. Moreover, the quality of design has been improved, even when performed by less experienced engineers.

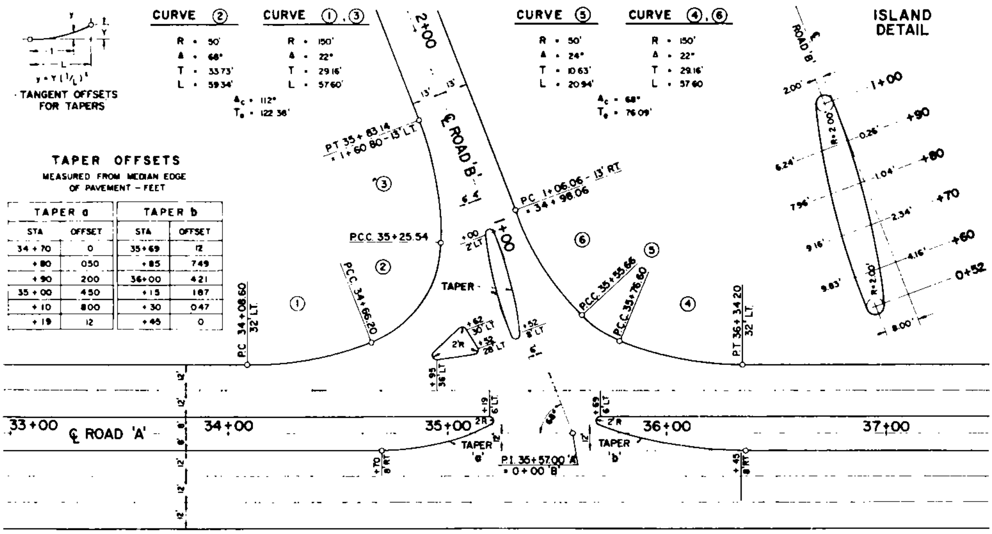
INTERCHANGE DESIGN—RAMP ALIGNMENT

Development of Design Techniques

Establishing the ramp alignment of interchanges (that is, producing a fully computed and integrated layout) generally is a time-consuming, detailed procedure. Before discussing the new techniques, it would be well to describe briefly the steps that are normally taken for this phase of design.

In starting the final design, there is generally available a preliminary plan of the interchange (a graphical layout) to a scale of 1 in. = 100 ft or 1 in. = 200 ft. Upon verification of profiles, right-of-way, and requirements for handling traffic, the preliminary plan (over-all configuration, as well as shapes of individual ramps) is followed fairly closely in development of the ultimate plan. The final layout is started by reproducing and refining graphically the preliminary plan to a larger scale, generally 1 in. = 50 ft or 1 in. = 40 ft. Each ramp is carefully constructed, using certain combinations of radii, measured angles, and distances. This information is then used to calculate each ramp, producing mathematically closed figures on a coordinate system.

The procedure described is unduly detailed and drawn-out. Analyzing the various steps, it became evident that there were ways of stepping up design efficiency. These were gradually introduced. First, ramps were classified as to types for calculation purposes. Then, the ways or methods of calculation to attain a solution were narrowed down to relatively few. Thus, for each ramp type there was a preferred way, and one or two alternate ways, of effecting a solution. Standard procedure and calculation forms were set up for this purpose. Included in the procedure was the adoption, where feasible, of even degrees of curvature, coupled with the use of even bearings and, thus, even degrees of central angles. Later, such practice led to the



LAYOUT PLAN

SCALE 1" = 20'

Figure 12. Illustrative problem for at-grade terminal: final design resulting from use of templates, design tables, and graphics.

development of design tables, eliminating in large measure the calculations required for curve data. All of this was used effectively to cut design time and permitted inexperienced engineers to grasp the technique quickly. Ultimately programs were developed for some of these procedures on the electronic computer, so that calculation time was further reduced.

However, the step that still appeared to take too much time was that of graphically constructing the interchange on a relatively large scale as a prerequisite to calculation. Further study revealed that this phase of the work could be facilitated by using adjustable tracing paper overlays of portions of ramp alignment. That is, parts of desired ramp alignments, involving compound curves, were constructed to the required scale in two or more sections with overlapping curves on separate pieces of tracing paper. These were used as overlays of the base map, and by matching and joining the separate pieces of alignment plottings, the desired ramp shapes could be formed. After the alignment was transferred from the overlays to the base map, measurements from it were used to set up the calculations. It became obvious, after a while, that if enough shapes of ramp alignments were set up permanently on transparent material and used as templates, the process could be further simplified.

Ramp Alignment Templates

A series of templates was finally developed, representing sections of alignment which, when joined, could form practically any shape of ramp. This was accomplished by devising sections of alignment consisting of three major forms of curves, as follows:

1. Compound curves.
2. Three-centered curves.
3. Multi-centered curves.

Each form was made up of families of curves. Even-degree curves and combinations of curves popularly used in accordance with AASHO criteria were employed to produce a great variety of configurations. These were printed photographically on heavy film transparencies to be used as overlays. Typical templates to a scale of 1 in. = 100 ft are shown in Figures 13, 14, and 15. These,

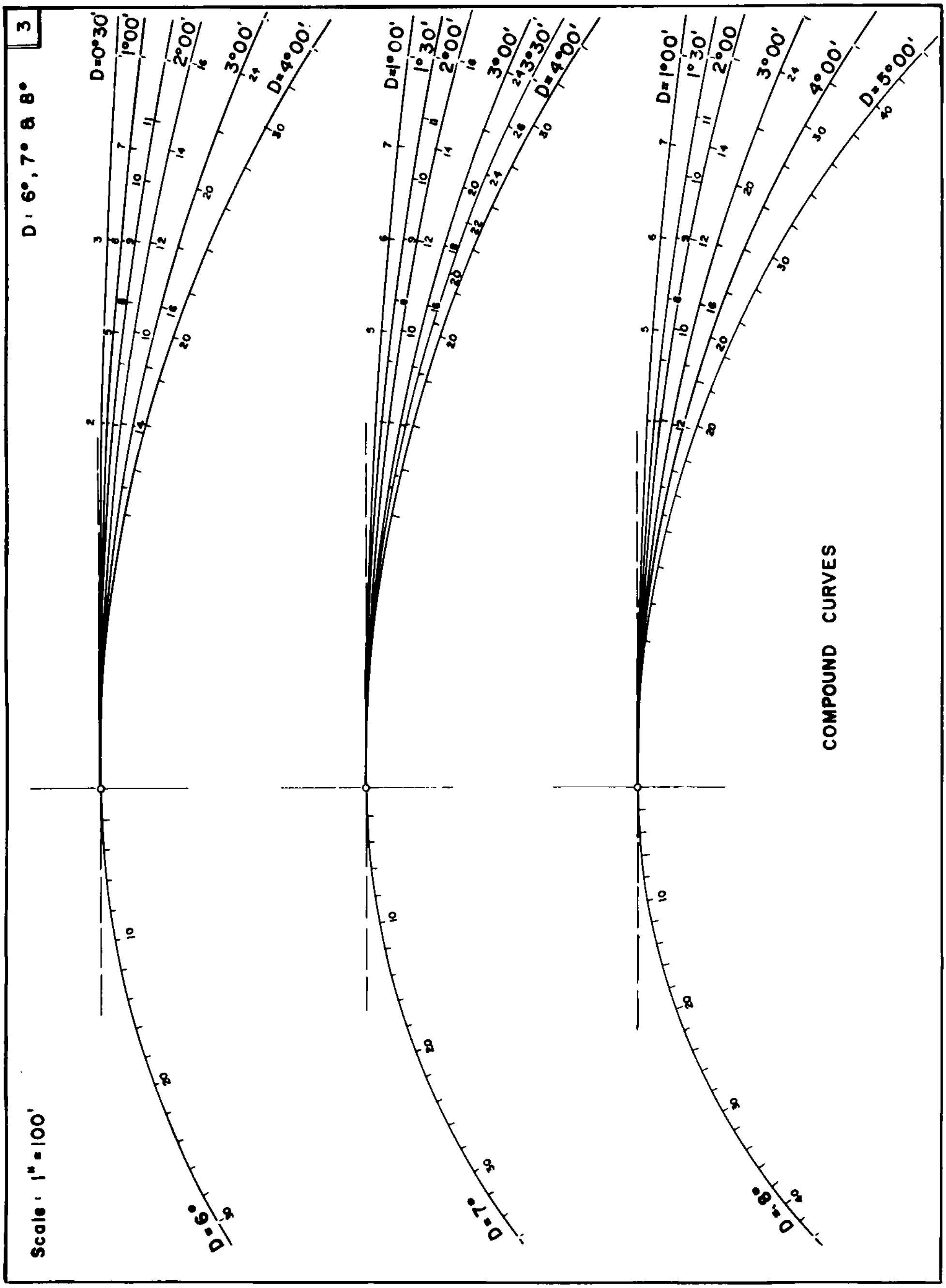


Figure 13. Typical compound-curve template.

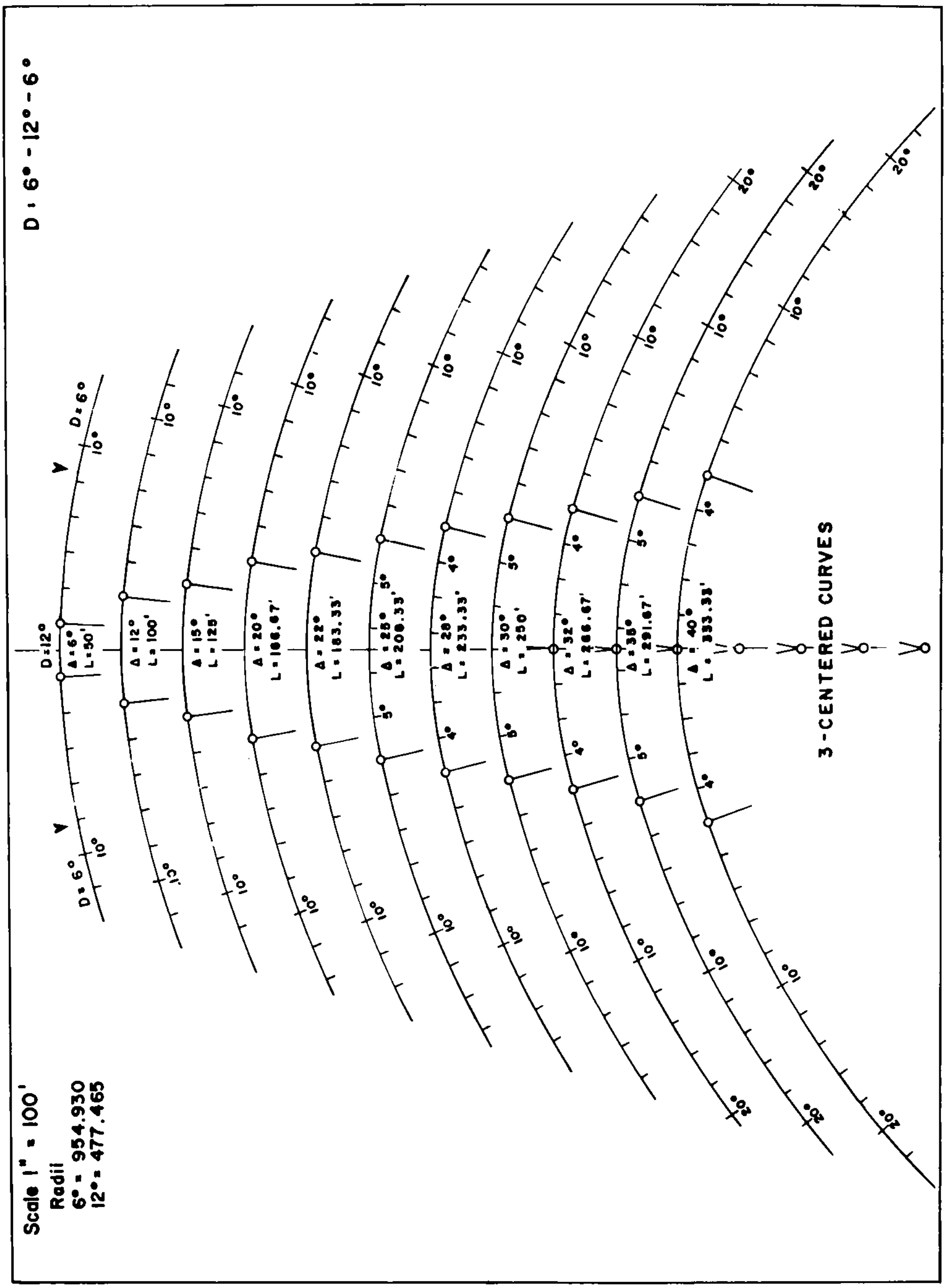


Figure 14. Typical three-centered curve template.

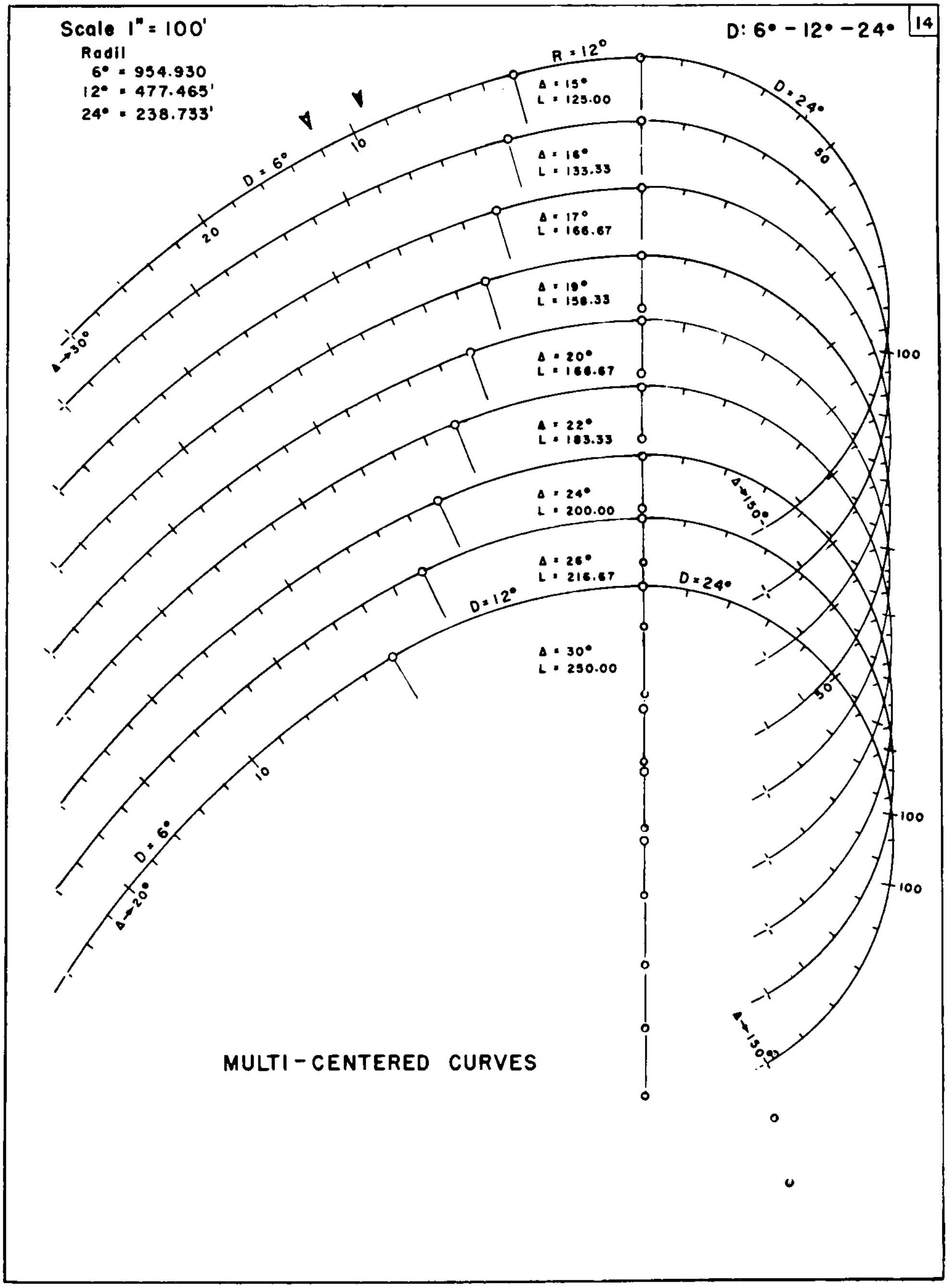


Figure 15. Typical multi-centered curve template.

too, are filed in folders and in a wall rack as in Figure 8.

Compound-curve templates consist of many curve combinations, such as a given degree of curve compounded with a number of flatter curves; for example, an initial 3° curve compounded with 2°, 1°-30′, 1°, 0°-45′, 0°-30′, and 0°-15′ curves; or, at the other extreme, an initial 12° curve compounded with 10°, 9°, 8°, 6°, 5°, and 4° curves. Four 11- by 14-in. template sheets, cover the entire range between initial 3° and initial 12° curves with their families of compound curves. The example in Figure 13 is typical of these series. The templates of compound curves are designed primarily for establishing high-speed exit and entrance ramp terminals. Other configurations, however, may be produced by combining two or more of these templates. Examples are multi-centered curves as 8°-6°-4°, 12°-6°-3°, etc. Three-centered curve combinations with a variety of angles also may be formed by two duplicate templates, as 8°-12°-8°, 3°-6°-3°, etc.

Three-centered curve templates are made up of many variations in which the middle arc ranges from a 12° to a 38° curve, or from about 500- to 150-ft radius. The two terminal arcs in each case have radii twice that of the middle arc. This fits normal ramp design practice of doubling the radius in compounding curves. A typical three-centered curve template is illustrated in Figure 14. Twelve templates of 9- by 11-in. transparencies make up the series. In cases where curve combinations flatter than 6°-12°-6° are called for, they can be produced by using two duplicate compound-curve templates as described in the preceding paragraph.

Multi-centered curve templates combine three curves of different radii to produce a transitional effect in curvature. The radius of each succeeding curve is made twice that of the preceding curve in accordance with AASHO criteria. For any one combination a family of curves is introduced by varying the arc length of the intermediate curve. The example in Figure 15 is typical of a set of 14 templates. The controlling or sharpest curve on each 9- by 11-in. transparency varies from an 18° to a 64° curve, and from a 300- to a 50-ft radius. The three-centered curve templates are particularly adaptable to design of loop ramps by overlapping curves from duplicate transparencies. Many other configurations may be produced for any type or shape of ramp by combining parts of one template with parts of another, or with compound-curve or three-centered curve templates previously described.

In the early stages of development, templates were experimented with as tools to facilitate graphics in layout of interchanges on a scale of 1 in. = 50 ft preparatory to calculation. Although the templates proved to be of great aid in this operation, further study showed that practically all graphics, as a step in forming the final plan, could be eliminated. This was accomplished by using the templates as devices to test alignment on a preliminary plan of an interchange, rather than as direct construction elements for the final plan layout. (The preliminary plan of any interchange is a design requirement and is normally available prior to final design. It is prepared quickly to a relatively small scale, 1 in. = 200 ft or 1 in. = 100 ft.) By applying appropriate templates to a preliminary plan on a scale of 1 in. = 100 ft, the information needed for ramp alignment calculations can be readily obtained. Upon completion of calculations, the ramps are plotted (by coordinates) for the first time on a base of the final plan, using a scale of 1 in. = 50 ft or larger.

This technique proved successful. As a result, all templates for ramp alignment design were standardized to a scale of 1 in. = 100 ft. To further facilitate this design process, central angles of arcs are appropriately marked along the curves of the templates, so that the combination of radius, R, of any curve and its central angle, Δ, could be immediately spotted (see Figs. 13-15). As required, minimum and desirable-minimum lengths of arcs, in accordance with AASHO criteria, are noted for ready reference by solid and open arrowheads, respectively. To facilitate matching and manipulating of templates, holes are provided on points of compounding, on central-angle ticks, and on curve centers.

Although the primary purpose of the templates is to evolve the alignment for the final layout, they may also be used as devices for the construction of preliminary plans. This is done by transferring the desired configurations, by means of the template holes, to the base of the preliminary plan. Using templates for both the preliminary and final plans permits a high degree of correlation and efficiency between them.

How the templates are used to form a certain ramp shape is shown in the several views of Figure 16. The upper and middle pictures show duplicate multi-centered curve templates representing the series, D: 6°-12°-24°. These are two copies of the template depicted in Figure 15. Only the upper and lower curves are shown; the rest have been removed to make the demonstration clear. In Figure 16A a loop ramp is formed between intersecting roads (dash lines) by using the upper curve of each template. Note that this is accomplished by reversing one of the templates and joining the centers of the sharpest curve. A pencil point passing through the center hole permits the two parts to be matched quickly and to be manipulated into place.

In Figure 16B a somewhat different shape of loop ramp is formed by using the same two transparencies. This time, however, the bottom curve is employed on the template closer to the camera. The shape of the previous curve is shown dotted for comparison.

Looking back at Figure 15, it may be noted that the family of D: 6°-12°-24° curves consists of nine configurations. Any one curve on this template may be matched with any one of nine curves of a duplicate template. This makes 81 possible variations of ramp shapes employing the same degree of curves. Further variations using the same templates may be effected by varying the relationship between the lengths of the two terminal curves utilized.

A large number of additional shapes may be formed by combining different templates. This is shown in Figure 16C, where a template of the series D: 9.5°-19°-38° is substituted in place of one of the transparencies used in the preceding demonstrations. The two previous shapes are retained by dotted lines on the base for comparison.

By this process of combining templates, any desired shape and size of ramp can be established, and its entire alignment preselected. That is, all the radii or degrees of curves, together with their central angles, are chosen; straight portions and reverse curves, if any, are included.

Computer Program

After the alignment of the ramp is completely selected, it is injected, by computation, into proper position with respect to the intersecting roads. The general method of solution is indicated in Figure 17. For example, the selected alignment B′CDEA′, shown dotted for a loop ramp in the upper and for a direct connection in the lower diagram, is slid into place between the intersecting roads. A special method of solution resolves the points of tangency A and B and, hence, distances m and n, which provide the necessary mathematical closure. This procedure is programmed on an electronic computer to give rapid results.

Illustrative Problem

To comprehend fully how this over-all technique is applied in design of interchanges, an example is presented here and explained through a sequence of illustrations (Figs. 18-27).

A preliminary plan of the northeast quadrant of a cloverleaf interchange is shown in Figure 18. This 100-ft scale layout has been checked and approved for final design and preparation of construction plans.

The solution is begun by testing and selecting the alignment for the loop ramp (Fig. 19). Appropriate multi-centered templates are found to be D: 9.5°-19°-

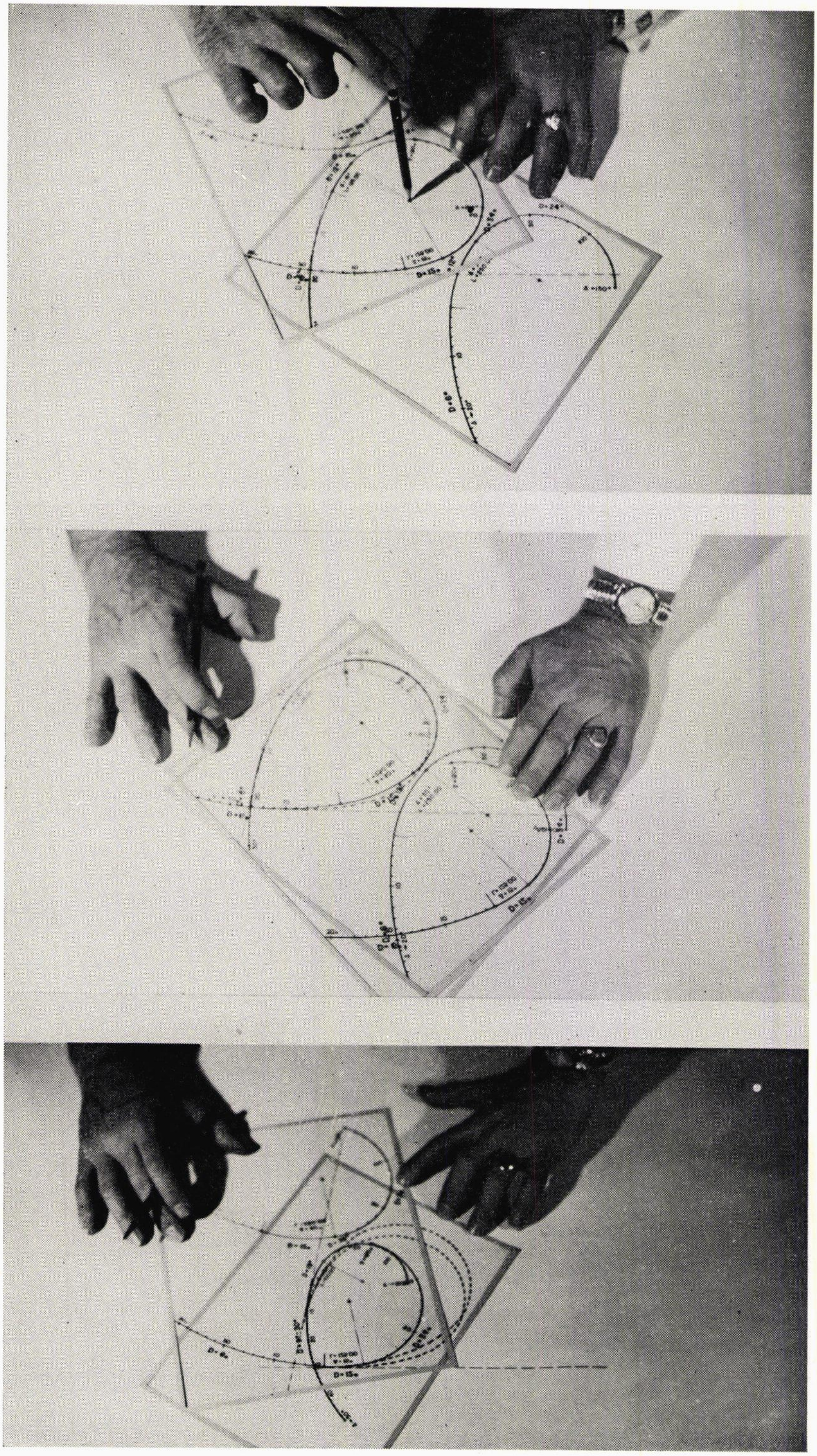
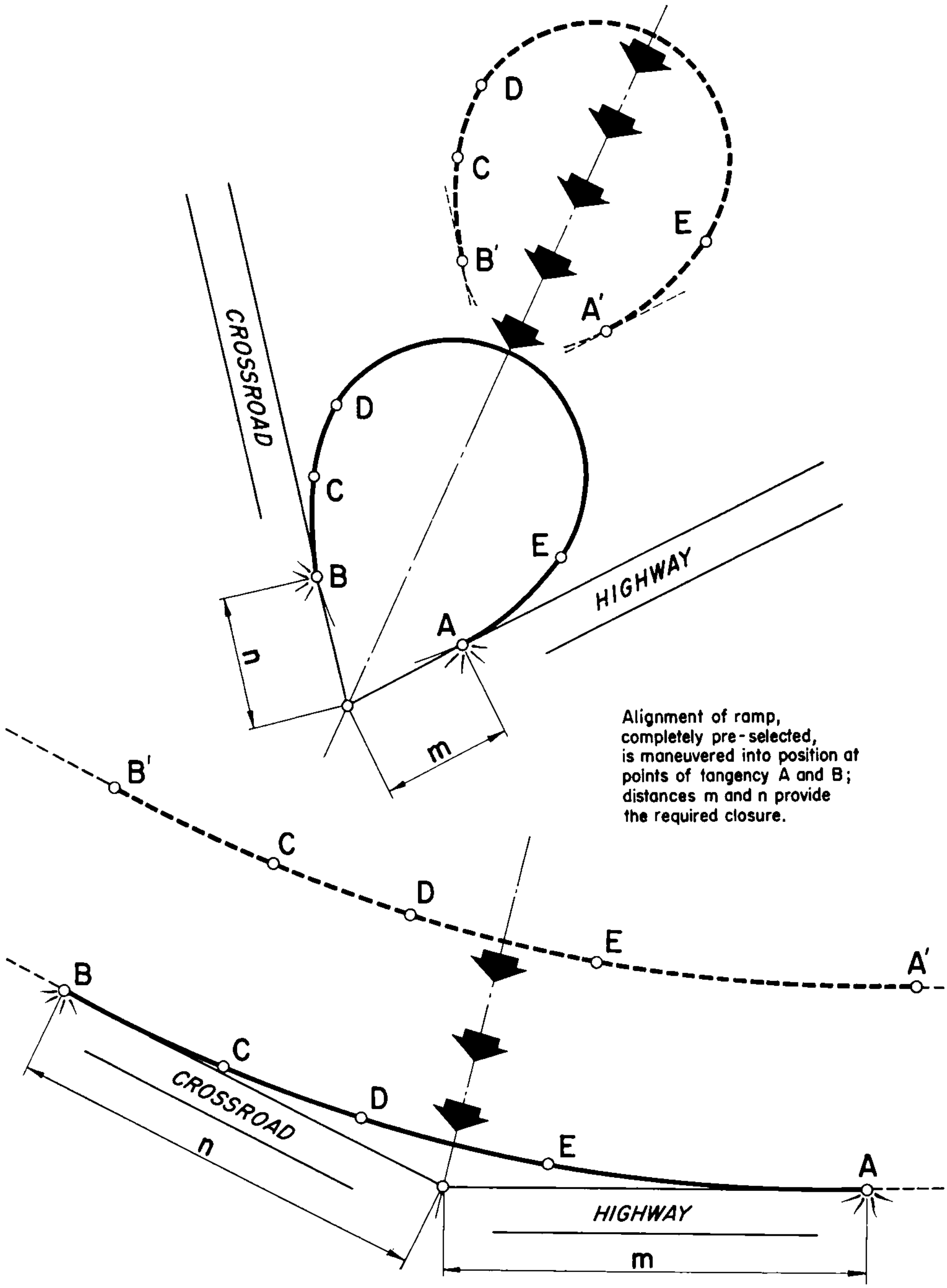


Figure 16. Forming ramp alignment by combining and overlapping of templates.



Alignment of ramp, completely pre-selected, is maneuvered into position at points of tangency A and B; distances m and n provide the required closure.

Figure 17. Method of computation for ramp alignment, programmed for solution by electronic computer.

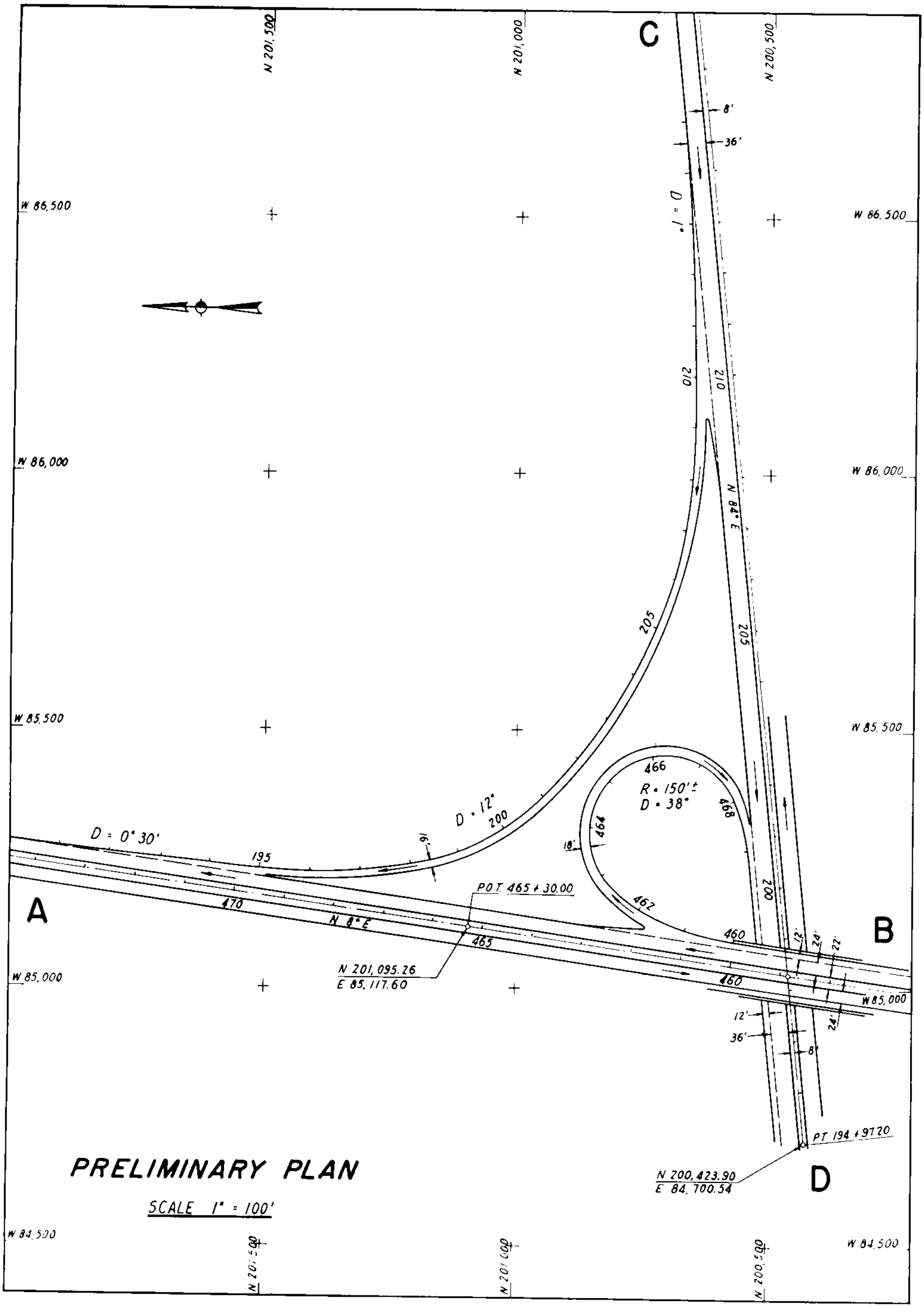


Figure 18. Illustrative problem for ramp alignment: preliminary plan of one quadrant of interchange used as base for final alignment determination.

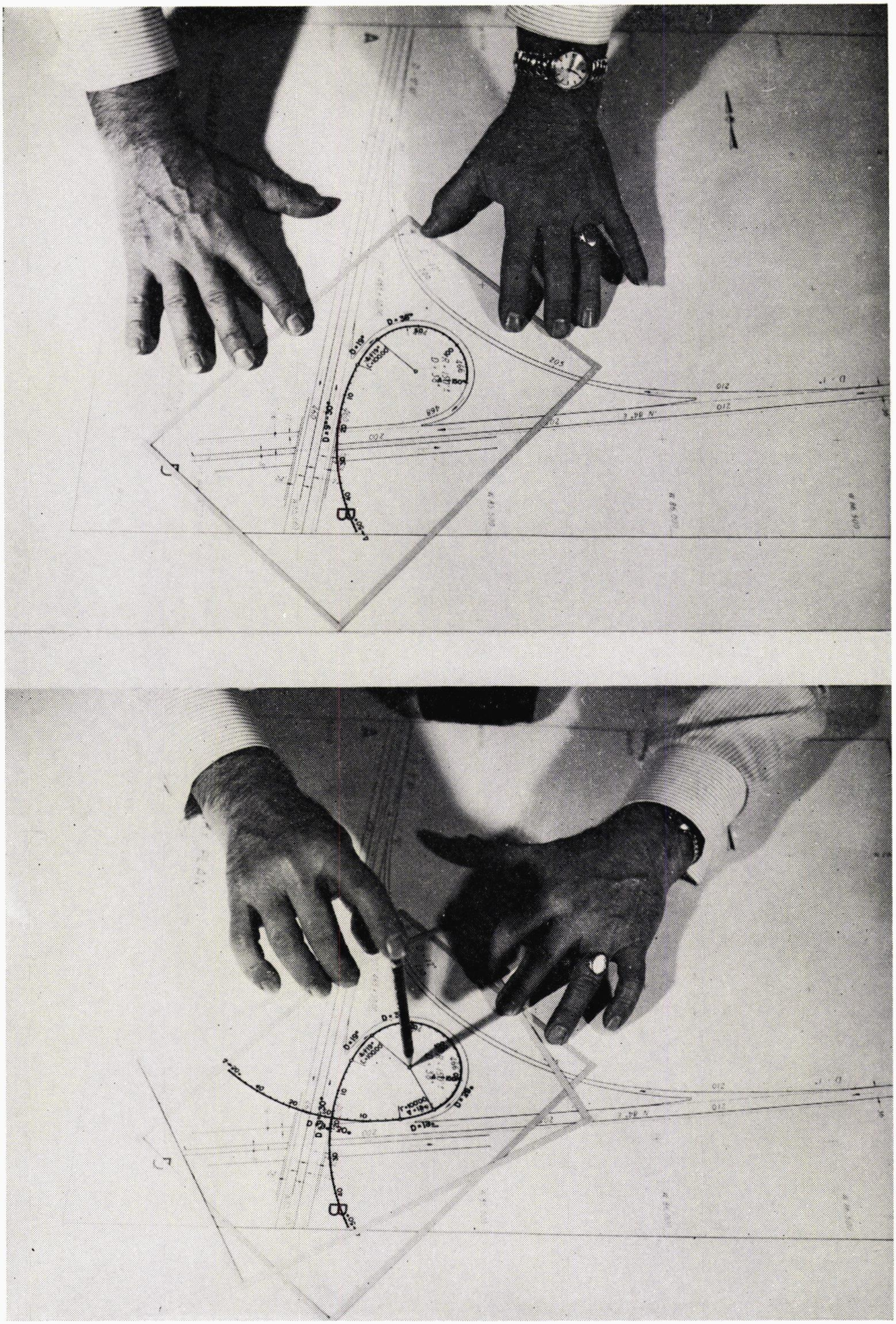


Figure 19. Illustrative problem for ramp alignment: placing of three-centered curve templates over preliminary plan to form the alignment for loop ramp.

38°. With the templates positioned to fit the ramp, the degrees of curves and their central angles are read and jotted down on a standard form for ramp alignment input data shown in Figure 23.

The alignment of the outer connection is similarly tested by templates. In Figure 20 a compound-curve template is applied to the exit terminal. On this template, only the curve needed for the problem is shown; all other curves are excluded for clarity in presentation. (The actual complete template is pictured in Figure 13.) Another compound-curve template is used to fit the entrance terminal of this ramp, as shown in Figure 21. Finally, a three-centered curve template (selected from the actual template depicted in Figure 14) is used in Figure 22 to complete the alignment. The data taken from these templates and those required from the base map are placed on the input data sheet in Figure 24.

It may be noted on both input data sheets (Figs. 23 and 24) that little information is needed for the computer. The data required consist basically of two elements: the selected ramp alignment (degrees of curves and their central angles); and a bearing and one coordinated point on the centerline of each intersecting highway.

These data are fed into an electronic computer. The solution for each ramp is shown on computer output sheets (Figs. 25 and 26). The answer is automatically typed out, including stationing of all control points and their coordinates, distances and bearings of tangents, and complete properties of curves.

These results are plotted by coordinates directly on a 50-ft scale base, forming the final layout plan for the interchange, as shown in Figure 27.

CONCLUSION

The techniques and devices here demonstrated in the geometric design of high-

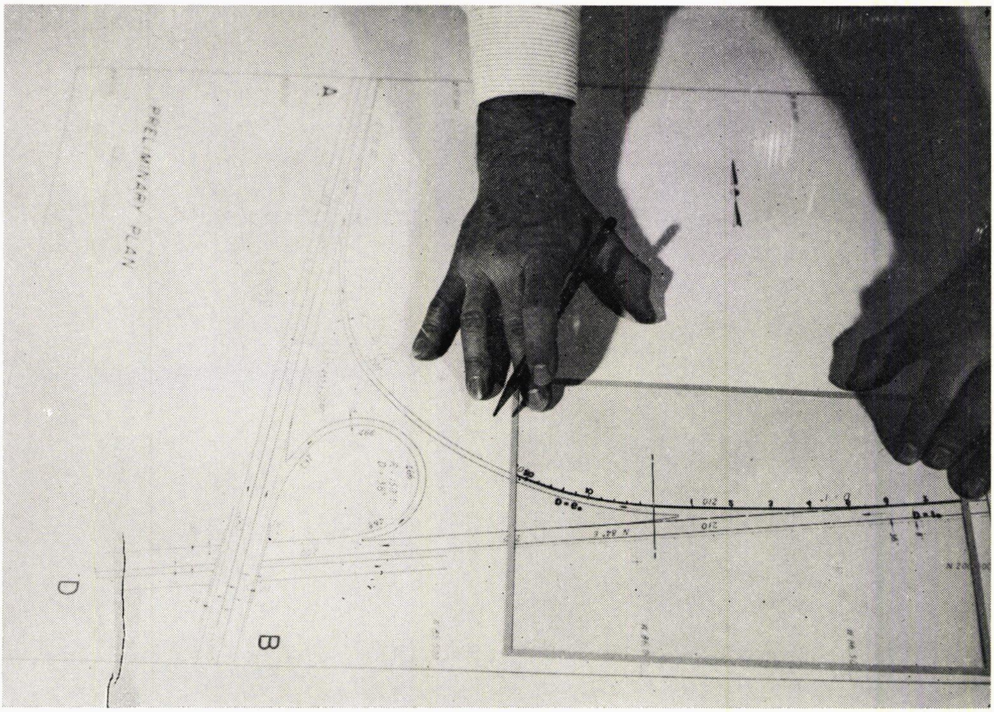


Figure 20. Illustrative problem for ramp alignment: placing of compound-curve template over preliminary plan to fit exit terminal of outer connection.

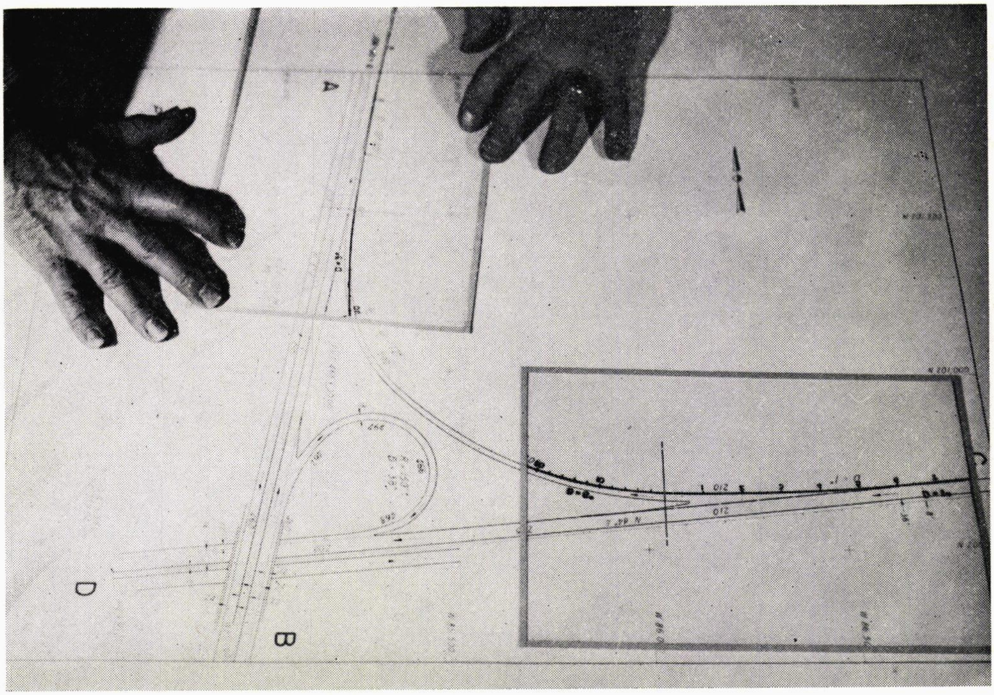


Figure 21. Illustrative problem for ramp alignment: placing of compound-curve template over preliminary plan to fit entrance terminal of outer connection.

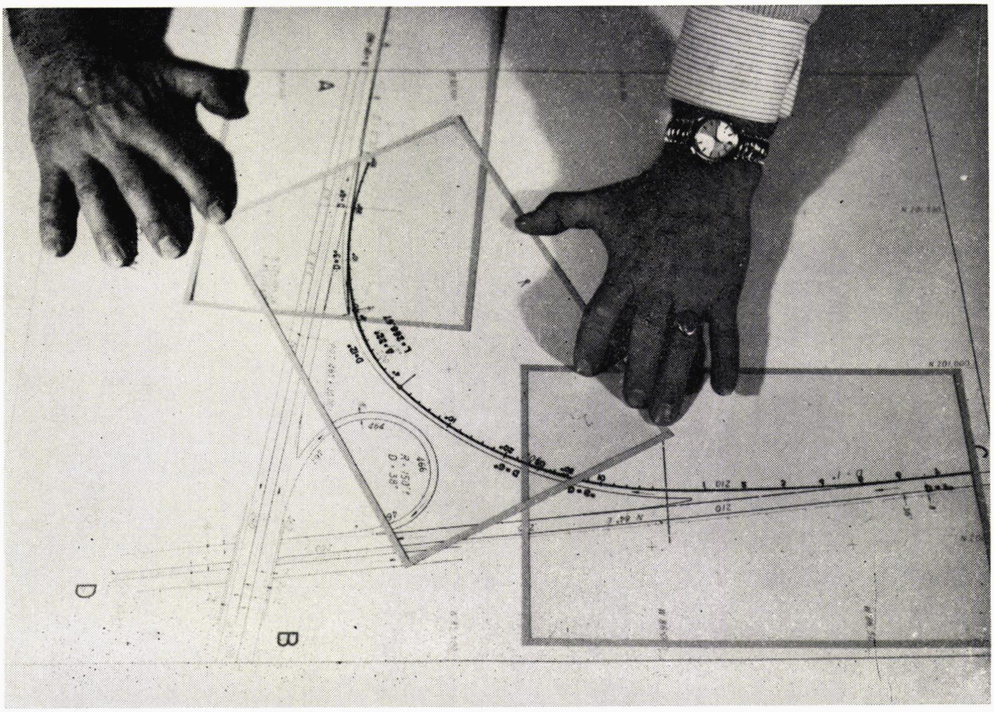


Figure 22. Illustrative problem for ramp alignment: adjusting final (three-centered curve) template to complete the configuration of outer connection.

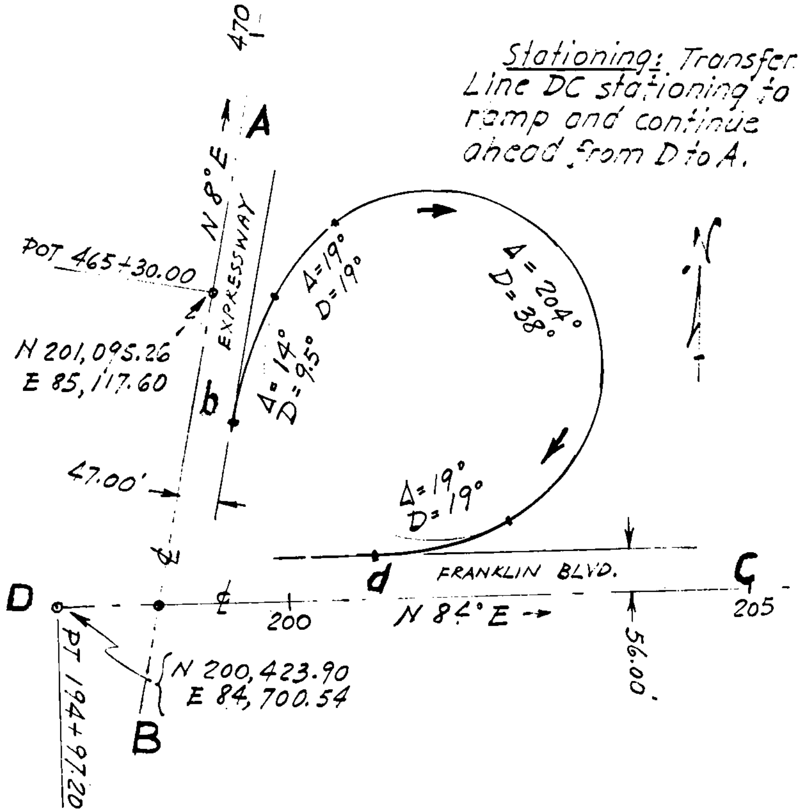
RAMP ALIGNMENT INPUT DATA

SOLUTION FORM I

Ramp BD
Interchange at:
Franklin Blvd

Project Northwest Expressw. Job No. 1042
By JEL Date 12-15-58 ch'd BG

SKETCH & DATA:



- INSTRUCTIONS -

1. Prepare sketch with predetermined alignment showing Δ angles and radii (or degrees of curves); if intersecting highways are on tangent the sum of Δ angles must equal intersection angle.
2. Show centerline bearing of each highway and coordinates of one point on each; indicate north direction.
3. Show width, centerline to edge pavement, and stationing on each highway.
4. Indicate method of stationing on ramp.

Figure 23. Illustrative problem for ramp alignment: input data for computer taken from templates and base map for solution of loop ramp.

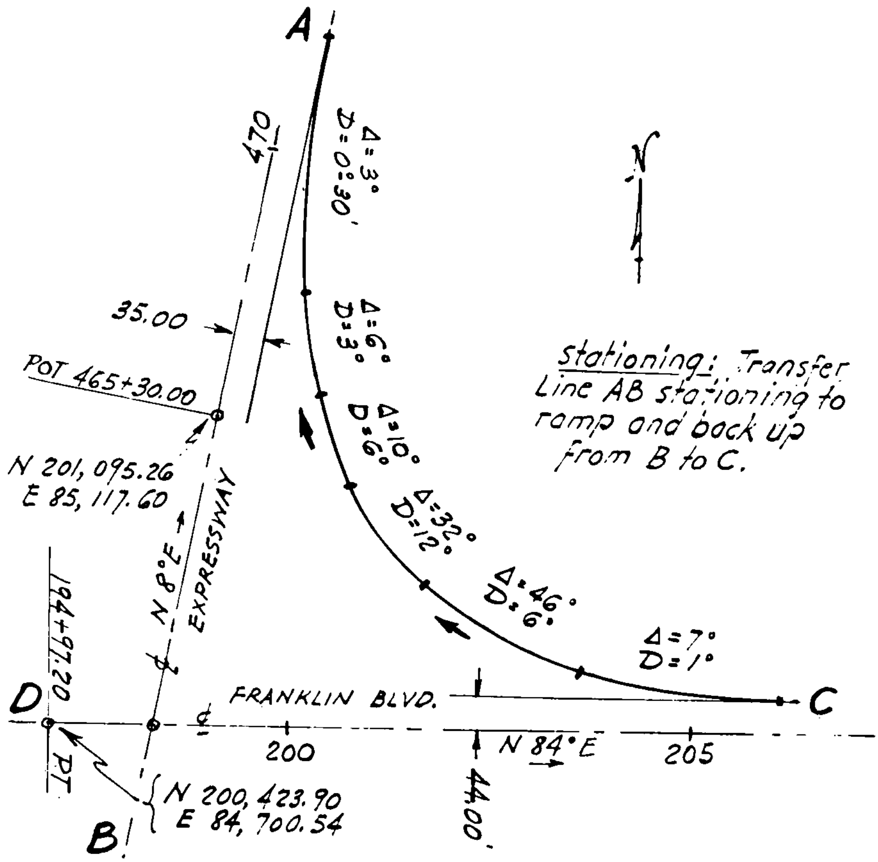
RAMP ALIGNMENT INPUT DATA

SOLUTION FORM I

Ramp CA
Interchange at:
Franklin Blvd

Project Northwest Expressw. Job No. 1040
By JEL Date 12-15-58 ch'd BE.

SKETCH & DATA:



- INSTRUCTIONS -

1. Prepare sketch with predetermined alignment showing Δ angles and radii (or degrees of curves); if intersecting highways are on tangent the sum of Δ angles must equal intersection angle.
2. Show centerline bearing of each highway and coordinates of one point on each; indicate north direction.
3. Show width, centerline to edge pavement, and stationing on each highway.
4. Indicate method of stationing on ramp.

Figure 24. Illustrative problem for ramp alignment: input data for computer taken from templates and base map for solution of outer connection.

RAMP ALIGNMENT OUTPUT DATA

RAMP	INTERCHANGE AT	JOB NO.	BY	DATE
BD	Franklin Blvd.	1040	JEL	12-15-58

STATION	AZIMUTH OR BEARING	LENGTH	COORDINATES NORTH	COORDINATES EAST	
45886.8068353			200458326346	085028084811	INTERSECT.
1	008000000000	000124111689	000122903843	000017273009	
46010.9185247			200581230189	085045357820	"b"
2	082000000000	000047000000	- 000006541136	000046542599	
46010.9185247			200574689054	085091900419	PC 1
46010.9185247	= 46010.9185247	STATION EQUATION			
46010.9185247			200574689054	085091900419	PC 1
1	008000000000	000074053022	000073332343	000010306189	
46084.9715471			200648021397	085102206608	PI 1
1	022000000000	000074053022	000068660767	000027740750	
46158.2869458			200716682164	085129947359	POC 1-2
1	022000000000	000050463291	000046788748	000018903881	
46208.7502365			200763470912	085148851240	PI 2
1	041000000000	000050463291	000038085129	000033106897	
46258.2869458			200801556041	085181958138	PCC 2-3
2	049000000000	000150778367	- 000098919509	000113793878	
xxx			200702636532	085295752016	"O_3"
2	025000000000	000150778367	- 000136651608	000063721691	
46795.1290510			200565984923	085359473707	PCC 3-4
3	065000000000	000050463291	- 000021326708	- 000045735273	
46845.5923417			200544658216	085313738434	PI 4
3	084000000000	000050463291	- 000005274850	- 000050186848	
46895.1290510			200539383365	085263551586	PT 4
46895.1290510	20069.1986500	STATION EQUATION			
20069.1986500			200539383365	085263551586	PT 4
2	006000000000	000056000000	- 000055693226	000005853594	
20069.1986500			200483690139	085269405180	"d"
3	084000000000	000242649629	- 000025363793	- 000241320369	
19826.5490211			200458326346	085028084811	INTERSECT.

CURVE DATA

46010.9185247	46158.2869458	46258.2869458	46795.1290510	PC STA.
46158.2869458	46258.2869458	46795.1290510	46895.1290510	PT STA.
14.0000000000	19.0000000000	204.000000000	19.0000000000	Δ
9.30000000000	19.0000000000	38.0000000000	19.0000000000	D
603.113468558	301.556734278	150.778367138	301.556734278	R
74.0530224115	50.4632907003	xxx	50.4632907003	T
147.368421051	100.000000000	536.842105263	100.000000000	L
147.002084823	99.5424340480	294.966996120	99.5424340480	LC

Figure 25. Illustrative problem for ramp alignment: computer output of solution for loop ramp.

RAMP ALIGNMENT OUTPUT DATA

RAMP	INTERCHANGE AT	JOB NO.	BY	DATE
CA	Franklin Blvd.	1040	JEP.	12-15-58

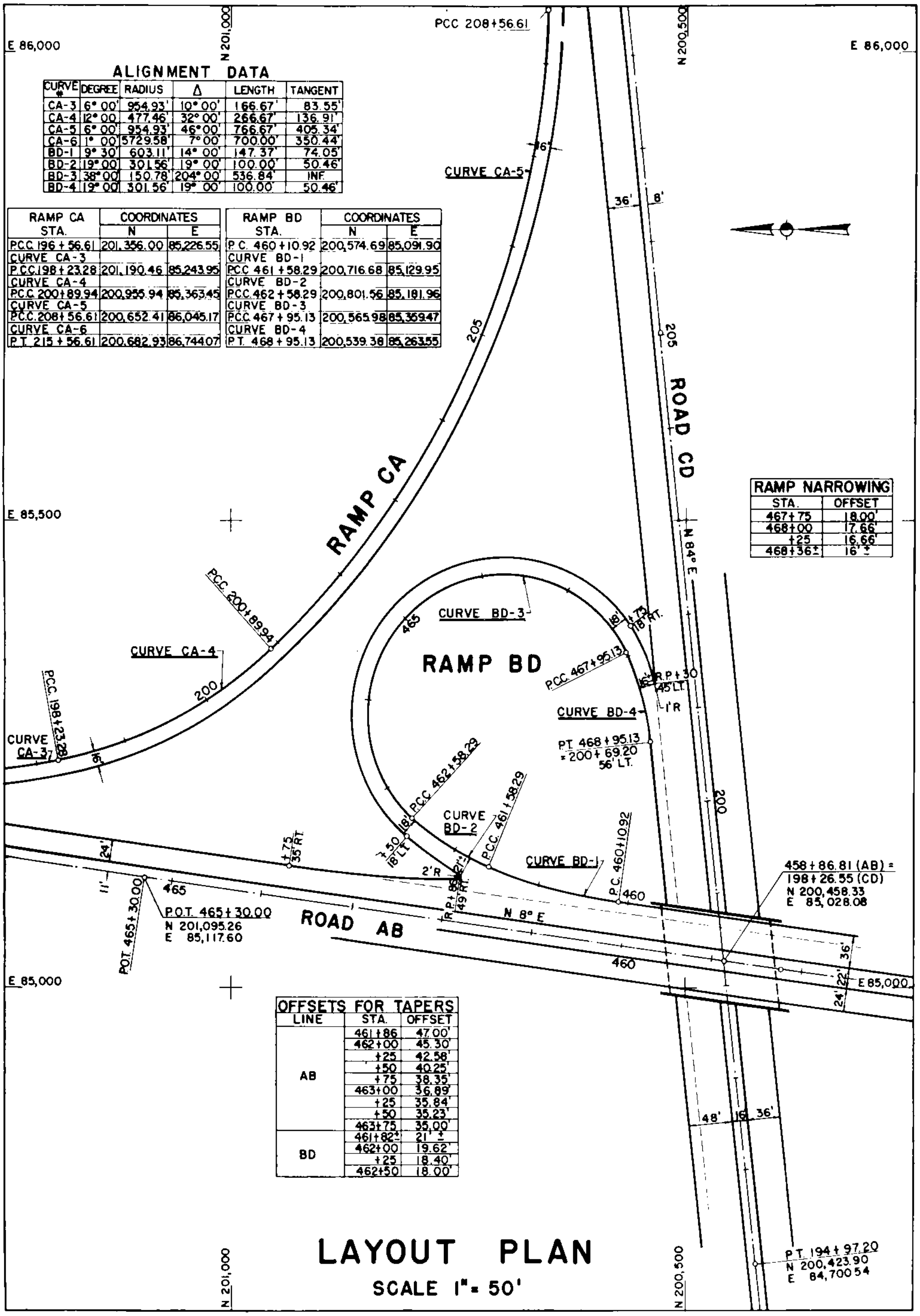
STATION	AZIMUTH OR BEARING	LENGTH		COORDINATES NORTH		COORDINATES EAST	
+	° ′ ″						
19826.5490211				200458326346		085028084811	INTERSECT.
1	084000000000	001730061793		000180840701		001720584334	
21556.6108143				200639167047		086748669145	"C"
4	006000000000	000044000000		000043758963	-	000004599252	
21556.6108143				200682926011		086744069893	PT 6
21556.6108143	= 21556.6108143	(STATION EQUATION)					
21556.6108143				200682926011		086744069893	PT 6
3	084000000000	000350436000	-	000036630537	-	000348516275	
21207.0468141				200646295474		086395553618	PI 6
4	089000000000	000350436000		000006115951	-	000350382627	
20856.6108143				200652411425		086045170991	PCC 5-6
4	089000000000	000405343591		000007074221	-	000405281856	
20495.2877389				200659485646		085639889136	PI 5
4	043000000000	000405343591		000296449536	-	000276443665	
20089.9441476				200955935183		085363445471	PCC 4-5
4	043000000000	000136910837		000100130247	-	000093372966	
19960.1883176				201056065430		085270072505	PI 4
4	011000000000	000136910837		000134395399	-	000026123819	
19823.2774809				201190460828		085243948686	PCC 3-4
4	011000000000	000083545520		000082010553	-	000015941237	
19740.1563338				201272471381		085228007449	PI 3
4	001000000000	000083545520		000083532795	-	000001458070	
19656.6108143				201356004177		085226549378	PCC 2-3
4	001000000000	000100091486		000100076241	-	000001746837	
19556.7022998				201456080418		085224802541	PI 2
1	005000000000	000100091486		000099710607		000008723548	
19456.6108143				201555791025		085233526089	PCC 1-2
1	005000000000	000300068558		000298926706		000026152698	
19156.6793720				201854717731		085259678787	PI 1
1	008000000000	000300068558		000297148311		000041761472	
18856.6108143				202151866043		085301440259	PT 1
18856.6108143	= 47601.9088449	(STATION EQUATION)					
47601.9088449				202151866043		085301440259	PC 1
4	082000000000	000035000000		000004871059	-	000034659382	
47601.9088449				202156737101		085266780876	"A"
3	.008000000000	001715102010	-	001698410755	-	000238696065	
45886.8068353				200458326346		085028084811	INTERSECT.

CURVE DATA:

21556.6108143	20856.6108143	20089.9441476	PT STA.
20856.6108143	20089.9441476	19823.2774809	PC STA.
7.00000000000	46.0000000000	32.0000000000	Δ
1.00000000000	6.00000000000	12.0000000000	D
5729.57795130	954.929658551	477.464829275	R
350.435999858	405.343591306	136.910836656	T
700.000000000	766.666666666	266.666666666	L
699.564732156	746.241486227	263.214286073	LC

19823.2774809	19656.6108143	19456.6108143	PT STA.
19656.6108143	19456.6108143	18856.6108143	PC STA.
10.0000000000	6.00000000000	3.00000000000	Δ
6.00000000000	3.00000000000	.300000000000	D
954.929658551	1909.85931710	11459.1559025	R
83.5455195878	100.091485551	300.068557714	T
166.666666666	200.000000000	600.000000000	L
166.455207325	199.908627300	599.931463429	LC

Figure 26. Illustrative problem for ramp alignment: computer output of solution for outer connection.



ALIGNMENT DATA

CURVE #	DEGREE	RADIUS	Δ	LENGTH	TANGENT
CA-3	6° 00'	954.93'	10° 00'	166.67'	83.55'
CA-4	12° 00	477.46'	32° 00'	266.67'	136.91'
CA-5	6° 00'	954.93'	46° 00'	766.67'	405.34'
CA-6	1° 00'	5729.58'	7° 00'	700.00'	350.44'
BD-1	9° 30'	603.11'	14° 00'	147.37'	74.05'
BD-2	19° 00'	301.56'	19° 00'	100.00'	50.46'
BD-3	38° 00'	150.78'	204° 00'	536.84'	INF.
BD-4	19° 00'	301.56'	19° 00'	100.00'	50.46'

RAMP CA STA.	COORDINATES N	E
P.C.C. 196 + 56.61	201,356.00	85,226.55
CURVE CA-3		
P.C.C. 198 + 23.28	201,190.46	85,243.95
CURVE CA-4		
P.C.C. 200 + 89.94	200,955.94	85,363.45
CURVE CA-5		
P.C.C. 208 + 56.61	200,652.41	86,045.17
CURVE CA-6		
P.T. 215 + 56.61	200,682.93	86,744.07

RAMP BD STA.	COORDINATES N	E
P.C. 460 + 10.92	200,574.69	85,091.90
CURVE BD-1		
PCC 461 + 58.29	200,716.68	85,129.95
CURVE BD-2		
PCC 462 + 58.29	200,801.56	85,181.96
CURVE BD-3		
PCC 467 + 95.13	200,565.98	85,359.47
CURVE BD-4		
P.T. 468 + 95.13	200,539.38	85,263.55

RAMP NARROWING

STA.	OFFSET
467+75	18.00'
468+00	17.66'
+25	16.66'
468+36±	16' ±

OFFSETS FOR TAPERS

LINE	STA.	OFFSET
AB	461+86	47.00'
	462+00	45.30'
	+25	42.58'
	+50	40.25'
	+75	38.35'
	463+00	36.89'
	+25	35.84'
	+50	35.23'
	463+75	35.00'
BD	461+82±	21' ±
	462+00	19.62'
	+25	18.40'
	462+50	18.00'

Figure 27. Illustrative problem for ramp alignment: final layout plan plotted from computer output to scale of 1 in. = 50 ft.

ways provide the means of stepping up engineering productivity, by:

1. Reducing manpower requirements.
2. Utilizing effectively young and inexperienced engineers.
3. Producing designs of higher quality.

In the case of channelization and at-grade ramp terminals, all guesswork as to position of islands, median openings, tapers, offsets, etc., is removed. The designer is able to approach a problem directly by applying turning vehicle templates which permit him to make the layout effectively and rapidly. Nearly all computations are eliminated by use of three-centered curve templates coupled with design tables and graphics, including slide rule determinations by parabolic distribution of flare and taper offsets. Thus, an intersection design which previously took days can now be done in a matter of hours.

Geometric design of interchanges also is greatly facilitated by the use of alignment templates. These preclude tedious graphical construction as a prerequisite to calculations. Data taken from templates are fed into an electronic computer to produce a complete solution. An alignment for most ramps can be selected in 15 or 20 min and solved on the computer in another 25 min. By this method, the alignment of a cloverleaf interchange, for example, can be completely worked out in one day, compared to a week or longer by the previous method without templates and electronic computer.

Although the results obtained through this endeavor have been gratifying, it is realized that the over-all effort in development of tools and techniques for geometric design of highways has been quite small. Many methods and procedures of design in use today are not compatible with modern requirements. There is much that can be done to simplify and streamline design by developing special techniques and various design aids. These possibilities should be explored on a broad scale to help expedite the Interstate highway program.