FOREST ROAD ENGINEERING

FE 346

FOREST ROAD DESIGN METHODOLOGIES

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I. PREDESIGN

A. Introduction

Before the roadway designer can become actively involved in the manipulation of the data in the design process he or she must start by developing the analytical model discussed earlier. At this stage this work involves taking the field survey data and converting it to a graphical model of how the land surface is naturally shaped. In the process of establishing this model, the preliminary or "P" line is plotted. This line is the locator's best estimate of how the proposed road should occupy the land.

Of the four plots that will go to make up the complete design package, three will be begun during the predesign phase.

(**This manual has been written primarily as a teaching aid in the Basic Road Design Short Course. The coursework includes the design of a section of forest road. With the constraint of time and the length of the design section in-mind, some of the steps in the design procedures can be eliminated in the course. The double asterisk • * Indicates such steps. For the professional production design, these steps should be completed. Each has its own reason for being which will become apparent as the design progresses.)

B. **Plan**

The plan is the map or the "bird's eye" view of the terrain. Four different plots of the horizontal data can be considered. The first three are suggested as aids to the designer in his or her work at gaining an understanding of the ground. The fourth plot is required for the design process.

First, if air photos of known scale are available, the designer can learn a great deal from plotting the "P" line on the photos. (**)

The second alternative (if photos are not available) is to plot the "P" line data on any available map of known sca3.e. These two alternatives provide the designer with information on the location of the roadway with respect to the land forms. (**)

The designer may be able to acquire either air photos or maps from the locator with the desired information already plotted or sketched. The drafting work is not needed in this case, but the work of understanding the road location has just begun.

On projects over about one mile in length, the designer is well advised to prepare a one inch to one thousand feet plot of the data. Such an area map will assist all of those individuals concerned with the plans. The relationship of the various sections of the project is easily determined. (**)

The fourth and necessary plot is usually made at a one inch equals one hundred feet scale. This will become both one of the basic tools and one of the basic products of the design process.

1. Cross hatched paper with spacing of ten divisions per inch both directions is recommended. If paper with non-reproducible lines is used, the design plot can be photo-transferred to mylar Federal Aid sheets with ease.
2. Plot tic marks every one thousand feet in either direction.
3. Plot the "P" line after computing the coordinates of each PI.
4. Check the plotted coordinates by using the bearing and distance information and a protractor and engineer's scale.
5. Identify the PI's with the small (.1 inch) diameter circle.
6. For clarity and neatness, do not letter the bearing or distance of the lines on the plot.
7. Because the "P" line is unchanged during the design, it can be drawn in *ink.* This eliminates having to redraw a penciled line repeatedly.
8. Establish the stationing of the "P" line by scaling from each PI. Each full station should be identified by a small but identifiable tic mark.
9. Plot and ink cross-section stations. The cross-section line should extend the same scale distance either side of centerline as the cross sections were taken. This will allow the designer to better visualize the available data. Care should be exercised that the cross-section lines are plotted with the correct relationship to the centerline. For example, a cross section taken along the centerline of a drainage may intersect the roadway centerline at some angle other than 90°. Cross-section lines should be plotted in ink. They are base data and will not change during the design.

10. Plot, in ink, all of the natural features that are reported in the field notes or that can be observed in air photos. These items should be drawn in sufficient detail that any reasonably knowledgeable individual could identify the feature. On the other hand, since the designer will be doing a considerable amount of additional work on the plan, excessive detail that would clutter or.confuse the drawing should be avoided. Typical naturally occurring features include:

    a. creeks, bogs, marsh and swamp areas
    b. rock outcroppings, abutments, and cliffs

11. Following the same guidelines as above, plot all of the manmade or cultural features. These include:

    a. section lines, corners or other land survey data
    b. property boundaries, rights of way, mining claims, sale units, resource management units
    c. existing or planned roads, powerlines or other utilities, rights of way

12. A brief title block is often desirable.

    a. road name or number
    b. district, zone, division, etc.
    c. forest
    d. date box
    e. designer
    f. approval

The above data is required in order to carry out an efficient design. Depending on available space, personal preference and other factors, designers will often add other information for their convenience.

1. Indication of soil classifications and location of various soil zones.
2. Special design considerations and field notations.
3. Particularly good or bad timber stands.
4. Possible equipment landings, cold decks, turnarounds, or other timber harvest information.
5. Hydrologic or streamflow data.

C. Profile

If the plan view is the bird's eye view of the roadway, the profile view is the worm's eye view. If a loaf of bread were cut vertically from end to end rather than from side to side, a profile view would result.

Only one profile view is prepared. Unlike the plan view, different scales are used for the vertical and horizontal dimensioning. 'This is done to exaggerate the change in elevation aspects of the design. Different designers and experienced engineers will recommend the use of different scale combinations depending on their experience.

For roads in relatively flat, even terrain with low grades and generally moderate design conditions, tradition has it that the scales are one inch equals one hundred feet horizontally and one inch equals ten feet vertically. For the common forest road with high grades and often undulating terrain, this level of exaggeration is excessive.

Some engineers recommend a 1" = 50' horizontal scale with a 1" = 20' vertical scale. This combination provides a more easily grasped profile.

For a variety of reasons, there are advantages in maintaining the horizontal scale the same as that used in 'the plan. Scales of 1" = 100' horizontally and 1" = 40' or 1' = 50' could be recommended in this case.

For the purposes of the basic road design course, the student is welcome to pick a scale that he or she (1) is comfortable with, (2) knows to be the standard in his or her home office, (3) feels gives the best representation of the design situation, or (4) wishes to experiment with. In any case the scale must be well documented on the profile drawing.

1. Select a scale.
2. Plot the elevations at each known station.
3. Connect the plotted points with a series of inked straight lines.
4. If because of space limitations the profile must be broken, overlap the matchline by a minimum of 500'. If the ground line is particularly broken, an overlap of 1000' or more may be required.
5. Plot, in ink, all of the natural features that are pertinent to the profile.
    a. rock outcroppings or other geologic structures
    b. stream and drainage channels including bogs or other poorly drained zones
6. Plot manmade or cultural features.
    a. existing culverts, bridges, or fords
    b. overhead transmission lines
    c. underground utilities
    d. known mining operations

In some cases the design work is done on plan/profile paper which allows for the plotting of both views on a single sheet. When two separate sheets are used, many experienced designers will reproduce many of the special design notes from the plan to the profile. While this is redundant and time-consuming, the time is, usually recovered by avoiding searches from one sheet to another for design information.

D. Cross Sections

Cross sections are the third major type of drawing the designer will produce. Returning to the analogy of a loaf of bread, the cross-section drawings are comparable to looking at each individual slice of bread.

The process of developing the numerous *cross sections* needed for the design process is tedious at best. The importance of accurate cross section work both in the field and in the office is understated. As will be seen, the cross sections are closely related to the earthwork computations which, in turn, determine some of the major cost elements of the project.

1. The most commonly used scale for the cross section is 1" = 10' both horizontally and vertically.
2. Using 10x10 cross-section paper, carefully plot the ground line points from the field survey notes. Connect the points with inked lines.
3. Where several cross sections are to be drawn on each sheet start at the bottom of the page and work up. When viewing the finished work, the designer will be better able to view the cross sections and develop a *mental* image *of* looking down the roadway.

4. Plot the centerline elevation at the proper elevation.

5. Plot all of the available cross-section information. For the typical forest road design, a corridor 100' wide is sufficient; Field data that extends past 50 feet on either side of centerline needs only to be noted on the cross section. If the designer needs to go beyond the plotted corridor, the data should be readily available.

6. Each cross section must be identified by its "P" line station. The centerline elevation should also be noted on the cross sections.

7. All natural and manmade features that may lie along or near a particular cross section should be noted on that section. If appropriate the feature should be added to the drawing and elevations, if available, should be included.

   a. existing culverts, bridges, or other drainage structures including rock drains and similar earth or rockwork structures

   b. utility crossings above or below ground

   c. existing roads

   d. geologic features such as rock outcroppings, bogs, marshes, or problem soils

   e. if a centerline has been taken along a stream or drainage line, it should be so noted.

8. Again, many experienced designers will add notes concerning soils, hydrology or other field data that is pertinent to the particular cross section. These notes serve as flags during the design

process. They remind the designer of a design consideration that may otherwise be inadvertently overlooked.

E. Summary

At this stage, the designer has completed the foundation upon which the road design will be built. Before moving forward with the design process, the designer should review the drawings. Are they correct to this point? Are there any obvious discrepancies or discontinuities that may reveal bad field data? Is the data complete? Are there sufficient cross sections along the horizontal plan?

II. DESIGN

A. Introduction

With the "P" line plan, profile, and the groundline cross sections prepared, the designer is ready to begin the design process. As mentioned earlier, it is neither possible nor desirable to provide an all-inclusive design process in a step-by-step approach.

The procedures that will be outlined in this section will provide a skeleton structure. The designer must take the skeleton and flesh it out with his or her own expertise. The final design reflects the thinking and understanding of the designer. Triple crown winner Secretariat and a glue factory reject have the same skeletal structure.

Continuing the equine analogy, design is always a horse trading effort. The designer wants long tangents for visibility and to reduce the number of needed turnouts. At the same time, long tangents create more earthwork, do not have a minimum impact, create speed problems, etc. Steep grades gain elevation faster and can result in a shorter road and, therefore, less expense. Steep grades slow the travel speed and in some materials can create drainage and erosion problems. The designer's judgment is the only tool that can select the best design.

All of the rules, procedures, etc., that will be provided are, by necessity, generalizations. Mark Twain once wrote, "No generalization is worth a damn, including this one."

In short, using judgment as a guide, the designer must pick his or her pathway through a pasture full of rules, policies, procedures, standards, and specifications toward the best design for field situation. All of this must be done without stepping in anything.

B. Determine the Control Points*

Control points are those considerations, both natural and manmade, that put constraintsor controls on the design. For example, a lake provides an obstacle that, for the forest road, forces the designer to go around rather than over. A high traffic count could force the use of two lanes.

When a point limits how much the designer can move the "P" line on the plan drawing, this is referred to as a horizontal control point. The location of a highly desirable landing would be an example.

Similarly, a point where the grade of the roadway cannot be altered is a vertical control point. The elevation at a stream crossing would be an example.

There are points that are constrained both horizontally and vertically, such as at the intersection of existing roads.

control points result in the elimination of some of the alternatives open to the designer. This, in turn, usually forces the designer into options that increase the roadway cost. The decision making techniques to select the least'cost design alternative are beyond the scope of this manual.

1. Natural control points usually involve geologic or soil materials related problems.

   a. Surface water; bogs, swamps, marshes, lakes, rivers.

   b. Subsurface; groundwater flow.

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*Many engineers and surveyors have another definition of control points. This definition deals with precisely determined point on the surface of the earth. Such points are used to "control" other surveys.

c. Advantageous terrain; saddles, meadows or flatlands, desirable rock sources for paving materials, natural benches, ridges.

d. Soil materials; desirable stable materials, unstable materials.

2. Social or political control points are those often referred to as man-made.

a. Resource and land management; roadless area boundaries, campground or other proposed public use areas.

b. Existing facilities; roads, bridges, buildings, drainage structures.

c. Ownership; mining claims, private property, other agency public land boundaries.

d. Historical features; indian sites, logging railroad facilities, flumes.

3. Engineering considerations control the design to a large extent.

a. Traffic characteristics; type and volume.

b. Intersections with both existing and future roads.

c. Beginning and end points of the project.

d. bogging systems to be used.

The designer must spend the necessary time to identify the control points on the design. All of the available information on each control point should be collected, studied, and noted on the plans as needed.

If decisions by others need to be made concerning control point items, these decisions should also be obtained at this point in the design. The designer should stand ready to seek advice from the various specialists available as to how best handle the control points.

C. Isolate the Control Points

By carefully studying each of the control points the designer can determine a zone of the roadway over which each he or she is limited in design alternatives. These should be temporarily marked on the plan and profile. When this has been completed, the designer will find that the project has has been broken down into zones of difficult design connected by zones of comparatively easy design.

On an informal basis, the designer can determine which of the "controlled" zones is most difficult, which is next in difficulty, etc.

D. A Design Philosophy

The design philosophy that is recommended in this manual is to attack each of the difficult zones individually. Determine a workable design for that zone. The zones which contain no control points will be used to transition between the controlled zones.

In order to minimize earthwork and, therefore, excavation costs, the designer should attempt to create a "balanced section" wherever possible. A balanced section is not justified where it results in unacceptable grades or alignment.

(A balanced section is one where the amount of excavated material equals the fill embankment material plus the amount lost due to the various elements of the compaction factor.)

E. A Design Procedure

Refer to the design flow diagram as an overall guide to the following design procedure.

Taking one zone the designer is at the point in the flow chart where an assumption must be made as to whether to adjust grade or alignment. Once this assumption has been made, a more or less mechanical process follows.

ROAD DESIGN FLOW DIAGRAM

FIELD NOTES

TRAVERSE TOPOG AND
CLASSIFICATION

PLANIMETRIC MAP

CONTAINS SOIL AND
DRAINAGE PROBLEMS
% SIDE SLOPES
ROCK OUTCROPS

OR CONTOUR MAP

CROSS SECTIONS

PROFILE

ASSUMPTION
GRADE OR ALIGNMENT

GRADEWHEN:

1. "P" LINE AT MAX. GRADE OR
2. UNIFORM SIDE SLOPES OVER 30% OR
3. SECTION HAS GRADE CONTROL POINTS OR
4. ALIGNMENT CAN BE IMPROVED BY ROLLING WITHIN MAX. GRADES

MARK GRADE ON EACH
"P" CROSS SECTION

MOVE TEMPLATE HORIZONTALLY TO
GET CROSS SECTION BALANCE POINTS

MARK POINTS ON PLAN

LAY IN ALIGNMENT

LAY IN GRADELINE

ALIGNMENT WHEN:

1. SIDE SLOPES LESS THAN 30% OR
2. THERE ARE ALIGNMENT CONTROL POINTS SUCH AS ROCK BLUFFS, SWAMPS OR TOWERS

LAY IN ALIGNMENT

SCALE OFFSET FROM PLAN

MOVE TEMPLATE VERTICALLY
TO GET CROSS SECTION
BALANCE POINTS

LAY IN GRADELINE

COMPUTE EARTHWORK

PLOT MASS DIAGRAM

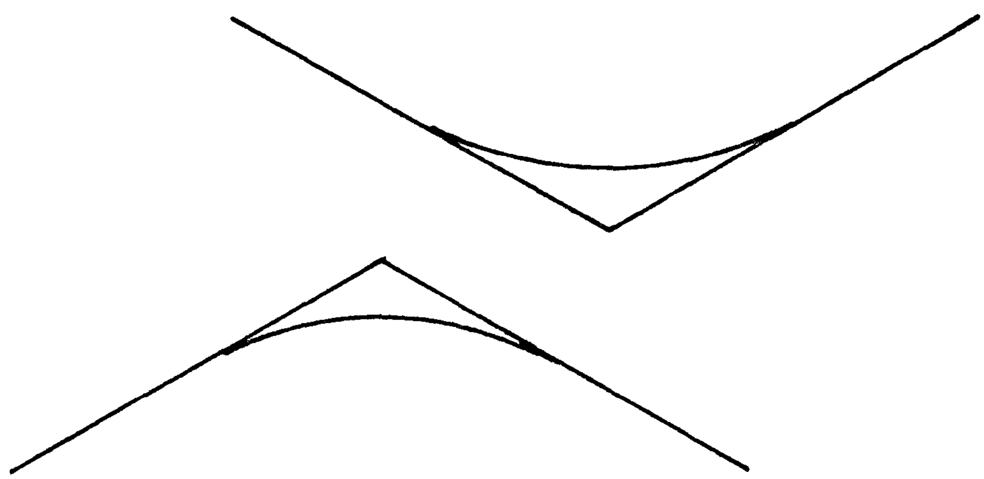
REDESIGN IF NECESSARY

COST ESTIMATE
FINAL PLANS &
SPECIFICATIONS

DESIGN FOR VERTICAL CONTROL POINTS

Consider, first, taking the left hand branch of the ROAD DESIGN FLOW DIAGRAM. That is where vertical control points will control the design of this zone of the project. Construction limitations such as full bench sections, or full fill sections are not always control points.

I. Draw a grade line between the vertical control points. Keep in mind that on the sag curve, the roadway actually passes above the grade line. Similarly, on the crest curve, the roadway passes below the grade line.



Do not be concerned with trying to balance the cut and fill at this time. The profile is not a reliable indicator of the earthwork that will be involved. The grade line that is selected should satisfy the criteria specified for the class of road, its use and its users.

There are occasions where a designer should consider exceeding the specified grade in the essence of good engineering. For example, a short pitch of grade in excess of that specified may allow the road to reach a bench, a saddle, ridge or other desirable terrain. The effect is often to shorten the total road, provide for a better side slope condition, or eliminate earthwork. The designer should be ready and willing to consider non-traditional solutions to the road design problems. As part of this consideration, the designer must be ready to document the reasoning and engineering behind his or her decision to utilize the non-standard design technique.

connect the profile grade lines with vertical curves. The vertical curve can be one of the designer's most valuable tools. The length of a curve can be adjusted to provide a particular elevation at a sag or crest point. Even more flexibility is available to the designer who wishes to apply unbalanced or unsymmetrical vertical curves to the design. These curves provide a great deal of ability to control the earthwork along the alignment by controlling the cut or fill through the change in grades. Refer to the appendix discussion on vertical curves for more detail.

Design philosophies often state that a roadway should not have a vertical curve located on a horizontal curve. For arterial roads and forest highways, this is a reasonable goal. Often the designer is unable to satisfy this criteria on the end-of-system haul road and on occasion on the collector roads. Due to the relatively low volume and low speed of these roads, it is reasonable to allow the superposition of the horizontal and vertical curves. Each case must be considered individually.

II. The designer must always be considering the effects *on the entire* design of any one design action or decision. At this time the designer should be considering what effect the vertical grade will have on possible horizontal alignments. The individual cross sections covered by the grade line should be examined. can this grade line be constructed to the right or left of the established "P" line location? Will this result in a horizontal control point?

III. Turnouts should also be considered at this time. Study the horizontal "P" line alignment to establish the turnout locations that appear to be needed.

Refer to the design standards and specifications for the road classification to determine the characteristics of the turnouts. Study the vertical "P" line alignment to establish turnout locations needed for crest curve safety considerations. Finally, the designer must consider the interaction of the horizontal and vertical alignments to determine if turnouts are needed as a result of the combination of the two alignments.

When the designer is considering the cross sections, he or she should recall that the turnout results in a considerable widening of the roadway. In a similar fashion, extra widening may be needed for curves and for slough widening on fill sections.

Where long adverse grades are encountered, the designer should consider the need for a double track typical section. This, in effect, provides a passing lane. (The length of this double track must be considered in terms of the passing sight distance.)

IV. Drainage must be given a preliminary consideration at this time. Tentative location for all culverts and drainage structures must be determined.

V. Refer to the ROAD DESIGN FORM. Record on the form the "P" line stations where cross sections were taken. See item A. Using the "P" line profile, determine the elevation of the grade.at each "P" line station. Record this information on the ROAD DESIGN FORM. See item B. This is the elevation of the proposed grade, not the ground line elevation. This same grade elevation should be plotted on the cross section. Utilize a short horizontal line drawn at the "P" line centerline to denote this elevation.

VI. A balanced roadway prism is desired. Using a template on the cross section, slide the template to the left or right until a balanced cross section is achieved. A balanced section is one where the amount of material to be cut or excavated (represented by the cut area) equals the amount of material to be filled (represented by the fill area). This is also referred to as a side-cast section. The designer must allow for the extra width that may be involved with turnouts, slough widening, and curve widening. In addition, allowance must be made for material that will be lost or gained as a result of the shrinkage or swell factor. When the template has been located at the balanced section location, the centerline of the roadway should be marked on the cross section with *a* short vertical line. The distance from the "P" line centerline to the proposed or "L" line centerline should be scaled off of the cross section sheet and recorded on the ROAD DESIGN FORM under the heading of TRIAL OFFSET. See item C. Note on the form

ROAD DESIGN FORM

›ject Manual No. ______ Section ______ Class ______ Page ______

rest ______ Designed by RH Date October 19 79

Line	Trial Grade Elev.	Trial Lt.	Offset Rt.	"L" Line	Offset Lt.	Rt.	Ground Elev. Projtd. Line	% Grade	Tangent Grade El.	Vertical Curve Dist.	Ord.	Elev.	Remarks
(A)	(B)	(C)	(C)	(D)	(E)	(E)	(F)		(G)	(H)		(I)	
-00	805	10		0+00	8		800	-4%	805				
-27	804	5		0+26	4		797	-4%	804				
+52	803			0+49		1	795	-4%	803				
+02	801		6	1+00		7	793	-4%	801				
+50	VPC (799)								799	0		799	
-75	798		12	1+74		12	790	-4%	798	25		799-	
+00	VPI (797)								797	50		798	
+10	797+		8	2+12		9	792	+5%		60		799-	
+50	VPT (799)								799	100		799	
r-80	801		4	2+84		5	796	+5%	801				
+25	805			3+30		2	801	+5%	805				

those cross sections where the ground line slope is steeper than the design fill slope. Those locations will require full bench sections design.

VII. Refer to the horizontal plan of the "P" line and the ROAD DESIGN FORM. Use the offsets recorded in the column TRIAL OFFSETS and plot these distances on the cross section lines on the plan drawing. When this is completed, if these points were connected, a minimum earthwork roadway would have been aligned. It is unlikely, however, that such an alignment would result in a smooth continuous curve or in any tangents.

A horizontal alignment that will fit both the offsets and the design criteria can now be designed. The horizontal alignment of a roadway should, of course, provide as direct a route as possible. The design should also provide for an alignment that fits the contours of the terrain as much as possible to eliminate earthwork.

The designer is often cautioned to avoid the use of the tightest curve for a given design speed, i.e., the maximum degree of curvature, or the minimum radius of curvature, avoid broken back curves, compound curves, reverse curves, and abrupt changes in the alignment. These considerations are both correct and valuable. However, for the low volume, low standard roadway, these considerations often must give way to the more pragmatic considerations of limited impact, and minimum cost. The designer's judgment is stretched to the limit, at times, in the decision making process.

The horizontal design must taken into consideration termainals, future expansion, intersections, the logging and transportation plans, and the vertical alignment.

Using a compass, radius guide, circle template, and a straight edge, lay in an alignment that satisfies the specified criteria for the horizontal alignment design. Along this alignment take into account the location of turnouts, culverts and drainage installations, both surface and subsurface, and all existing horizontal control points. One method for expediting the horizontal layoutprocedure is to draw straight line through the various tangent sections that exist on the plan. The points where these tangents intersect become the "PI's" for the "L" line. The exact location of these PI's can be either scaled off of the plan or designated at the nearest 10 foot coordinate line.

VIII. To insure that the horizontal and vertical alignments are well coordinated, it is advisable at this stage to prepare a profile of the proposed or "Trial" alignment or "L" line. Since the proposed alignment has been moved off of the "P" line, that profile is no longer valid.

In order to prepare the trial "L" line profile, it is necessary to determine the new stationing of the "L" line. Because the cross sections are the only source of the profile information, the designer must determine the "L" line station at each "P" line cross section.

Starting at the beginning of the design zone, scale along the center-line to determine the stationing of the "L" line. Because of the trial nature of the design at this point, it is acceptable to simply scale around the curves to determine the stationing.

Where the "L" line intersects a cross section, the "L" line stationing should be recorded, in pencil, on the ROAD DESIGN FORM opposite the "P" line stationing for that cross section. See item D on the form.

Although the offset from the "P" line to a possible "L" line was recorded earlier, it may no longer be valid. If the proposed "L" line alignment passes through the tic mark set off from the "P" line, the distance recorded in the column titled TRIAL OFFSET can be re-recorded in the column titled OFFSET. See item E. If, on the other hand, the proposed line does not go through the tic mark scale, the new offset distance from the "P" line and record that distance in the OFFSET column.

Referring to the cross section sheets, determine the ground line elevation under the "L" line centerline mark. Record this elevation under the appropriate column on the ROAD DESIGN FORM. See item F.

Using the "L" line stations and the ground line information, plot the "L" line profile. Since this line may be subject to adjustments, it should be drawn in pencil.

The designer now must superimpose the trial design grade and the vertical alignment upon the revised "L" line profile to determine if the horizontal adjustments that were made have a significant effect on the design; If significant problems have been introduced as a result of the trial design, the designer must attempt another trial design over the zone in question. Experience has shown that most neophyte designers complete a satisfactory design in no more than two cycles. Experienced designers usually have completed the vertical alignment at this stage.

If no significant problems have been introduced into the design, the designer is ready to prepare preliminary earthwork computations and a trial mass diagram. We will return to these topics after reviewing the other alternative to vertical control.

DESIGN FOR HORIZONTAL CONTROL POINTS

If the designer has determined that the most significant control problems over a particular design zone are those of the horizontal design, the process moves down the right side of the ROAD DESIGN FLOW DIAGRAM. Many of the design considerations are exactly the same. The major differences are in the order that the design processes are carried out.

I. On the plan, prepare a series of tangents that provide a satisfactory routing through or around the existing horizontal control points. These tangents need not connect existing "P" line points of intersection. Most inexperienced designers are reluctant to deviate too far from the "P" line. You are encouraged to locate new PI points anywhere along the design where they will provide you with a well engineered alignment with respect to the control points. New PI's can be picked at convenient points on the plan. The coordinates of these points can then be determined by scaling or by picking their coordinates off of the grid paper.

Using a radius guide, circle template, or compass, connect the tangents with curves that satisfy the design specifications. Consider sight distances, etc. The tangents and curves make up the trial "L" line.

II. Scale the "L" line to the "P" line cross sections to determine the "L" line stationing. Record this information on the ROAD DESIGN FORM. See items A and D on the form.

III. Scale from the "P" line to the "L" line on each section to determine the TRIAL OFFSET, item C on the example form.

IV. Plot the offset information on the cross section. Mark the "L" line centerline.

V. Determine and record the "L" line ground line elevation. This elevation should be determined at the centerline. See item F on the form.

VI. Place the roadway template on the cross section and slide it vertically until the cut and fill areas are approximately equal considering shrinkage and swelling of the material, turnouts, curve widening, slough widening and drainage. Record the elevation of the centerline under the heading of TRIAL GRADE ELEVATION.

VII. Referring to the ROAD DESIGN FORM, use the "L" line stationing and the "L" *line* groundline elevation plot the "L" line ground line profile. Using the same stationing, plot the "L" line TRIAL GRADE ELEVATION. Use tic marks to denote the TRIAL GRAD ELEVATION at each station.

VIII. Draw vertical alignment tangents through the tic marks wherever possible. Connect these tangents with appropriate vertical curves that pass through as many tic marks as possible. By this method, prepare a vertical alignment that satisfies the design criteria. Remember to take into consideration all of the previous discussion on vertical alignments.

IX. Where there are significant differences between the TRIAL GRADE ELEVATIONS and the designed grade, return to the cross sections. Study, the cross sections to ensure that the change in centerline elevation does not change the cut *or* fill slopes in such a way that the horizontal design *is* unsatisfactory. Also, ensure that the slopes of the sections will catch in a manner appropriate for the control points.

X. If necessary, consider either horizontal alignment or vertical alignment adjustment to alter the side slope catch point locations in order to avoid horizontal and/or vertical control points. Again, with experience the designer will be able to make these adjustments with one iteration of the process.

XI. When both the horizontal and vertical alignments have been adjusted to satisfy the design criteria and to properly deal with the control points, preliminary earthwork computations can be completed and a trial mass diagram plotted. These topics are covered in the next section.

CROSS SECTION DESIGN

With reference to the ROAD DESIGN FORM, the grade elevations will be used to plot the typical roadway section on the groundline cross section.

In a fashion similar to the horizontal alignment, the Vertical Points of Intersection (VPI's) can and should be determined at the end of the tangent sections. The designer may select both the station and elevation for the VPI's. For example, the station can either be read graphically off of the profile *or* rounded up or down to the nearest full, half, or quarter station or any other desired station. The elevation can be read from the profile or rounded to a figure that may ease computations. The station and elevation of each VPI should be recorded on the ROAD DESIGN FORM. Once the VPI's have been established, the tangent elevations can be quickly computed via the following equation:

$$\text{Elevation}_{\text{station X}} = \text{Elevation}_{\text{VPI}} + (\text{Station X} - \text{Station}_{\text{VPI}})\ \text{Grade}(\%)$$

Record the computed elevations *on* the ROAD DESIGN FORM. See item G.

Refer to the appendix discussion of vertical curve computations for guidance in the computation of the grade elevations along the vertical curves. Record this information on the ROAD DESIGN FORMS, items H and I.

II. With the grade elevations established, the designer can begin drafting the roadway template onto the cross sections. The template is drawn at the elevation of the subgrade. That is the grade at which the primary earthwork is completed. Any surfacing must go on top of this grade. Allow for this feature in drawing the typical section. If the design roadway is to be ten feet wide, the subgrade may be on the order of twelve to fifteen feet in width depending on the surfacing. Since this must be constructed and paid for, it is important that it is included in the design.

The typical section must be drawn to include curve and slough widening, turnouts, and the widening required for drainage inlet of various types.

Drainage pipes or trench drains must also be considered when preparing the cross sections. The typical section (in concert with vertical alignment) must provide for adequate cover.

III. Where sliver fills, full bench sections or other difficult construction conditions show up on the cross sections, the designer is well advised to stop at the end of that particular design zone and revise the horizontal and/or the vertical alignments to eliminate or at least minimize the problems.

IV. As each cross section is drawn, refer to the plan to determine the angle of skew with respect to the "L" line centerline. Cross sections were taken for the "P" line perpendicular or at an angle of ninety degrees to the centerline. The alignment of the "L" line that results from the design process may not intersect the cross section at ninety degrees. If the cross section is skewed on the order of thirty degrees from the perpendicular note the skew angle in the remarks column on the ROAD DESIGN FORM.

V. On some occasions, the centerline of the "L" line may be moved in such a fashion that the skew is excessive, that cross sections cross one another or that the centerline runs off of one or more cross sections. The designer must exercise judgment in handling these situations. To fail to consider these situations or to ignore their effects will result in serious errors in the earthwork computations and the ensuing mass diagram.

It is not possible to outline the solution to all of the possible skewed cross section situations that the designer will encounter. Each situation will require that the designer carefully sketch and consider the situation. The goal is to make the most accurate estimate of the volume of earth material that will have to be excavated or placed.