APPLICATION OF GEOMETRIC DESIGN PRINCIPLES TO ROUTE DESIGN

The fundamental objective in the highway geometric design process is the establishment of the new highway's centerline and cross sections in relation to the terminal points and to the topography through which the highway will pass. The vertical and horizontal alignment of the centerline determines the amount of cut and fill, cross section details, drainage design, construction and user costs, and environmental impacts.

PRELIMINARY ROUTE LAYOUT AND GEOMETRIC DESIGN

In selecting a preliminary, technically feasible route, the designer should attempt to envisage the topography in three dimensions. This may be difficult initially, but some practice will assist. The major activities may be divided into: defining design controls; establishing an initial alignment; balancing cut and fill; and, refining the design. These activities are described below.

Defining Design Controls -- The alignment of a highway is subject to design controls that ensure that it will provide suitable service for the traffic within the topography for which it is designed. As well as the controls noted earlier, it is necessary to specify several other variables that are inputs to establishing a preliminary route. These variables are described as follows:

1. <u>Minimum radius of horizontal curves</u>, based upon the design speed and the permissible super elevation.

2. <u>Minimum length of vertical curves,</u> based upon design speed and difference between intersecting grades.

3. <u>Maximum grade at any point on the highway</u>, determined from consideration of road classification, truck traffic, and terrain.

4. Maximum grade in proximity to existing intersections. The vertical alignment of the proposed route should allow for a minimum to moderate grade approaching the intersection with the existing highway in order to assist in safe stopping on downhills and improved sight distance on uphill approaches. Ideally, this grade should be no more than is required for adequate drainage. Because this approach grade may intersect with a vertical curve ascending or descending the hillside, a vertical curve may be required at this location. The length of this curve is determined by consideration of the design speed and intersecting grades. For preliminary design purposes, it is suggested that within a distance of about 30 m from the intersection's stop line, the grade be no more than 2%. This value will be used in the design projects presented later and will allow for any necessary modifications in the detailed design stage.

5. Minimum grade at any point on the highway to ensure adequate drainage. A minimum of 0.5% is suggested for preliminary design purposes.

6. Maximum horizontal approach angle at intersections. It is desirable to design the route to ensure that intersections with existing highways are of suitable alignment and configuration from a safety and capacity point of view. Therefore, the horizontal alignment should feature as nearly as possible a right-angled intersection with the existing highway (within, say, 90° ± 15°). It is suggested that for preliminary design purposes, the proposed approach to the intersection be a tangent section for a distance of at least 30 m to aid drivers' visibility at the approach.

7. Maximum depth of excavation and height of fill, a maximum depth of cut and height of embankment must be specified in order for the designer to establish an initial vertical alignment.

Establishing an Initial Alignment - Development of the alignment is a trial and error process involving defining a trial alignment, then checking to see if it complies with the horizontal and vertical controls, then modifying it in successive iterations until all the controls are complied with. One approach to this process is illustrated by the problem example shown in Figure 3-1. In addition to these steps, the following points may help to guide the process.

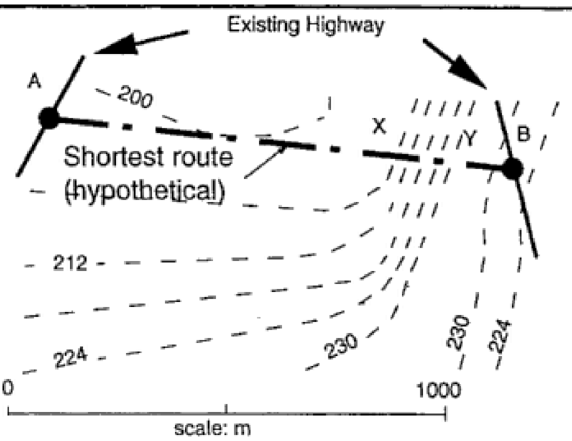
Horizontal Alignment. A first step is usually to determine if the shortest route possible will comply with the controls, because this is likely to be the least-cost solution. Examination of how this first trial route complies with the controls will suggest how the route may be modified for the next trial. The highway should be constructed as close to the existing ground (or slightly above it to assist adequate drainage) as possible, provided that the design controls are complied with. Thus, any horizontal centerline should be checked, first of all, **for its grade**. This may be done approximately by measuring the length of a given segment of highway and counting the **contour lines that are crossed**. The vertical distance covered, divided by the horizontal length, indicates the approximate grade. If this grade is significantly more than the specified amount, the alignment must be readjusted.

Where the rounded topography of a mountain or a hill must be negotiated in a transverse fashion, the curve of a highway should preferably conform approximately to the surface of the hill itself, or excessive cuts or fills are likely to result. At this point, the designer must sketch a curve that approximately conforms to the topography, by using compasses or templates. This curve must then be checked for conformity with the maximum allowable radius and also for the grade the highway negotiates throughout the curve. The latter must also conform with the maximum allowable grade requirement and be adjusted if necessary.

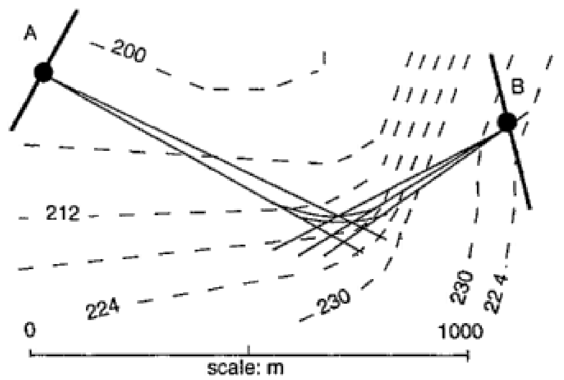
FIGURE 3-1
OUTLINE OF STEPS IN DETERMINING A POTENTIAL HORIZONTAL ALIGNMENT

PROBLEM: Connect points A and B below with a highway having a maximum grade of 6%, minimum grade (for drainage) of 0.5%, a minimum horizontal radius of 240 m, a minimum vertical curve length of 120 m, and maximum cut and fill depths of 10 m.

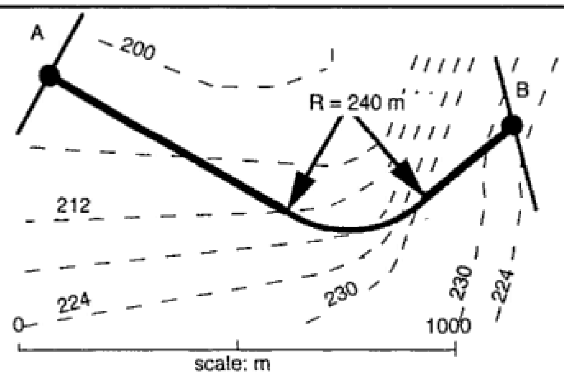
STEP 1. Examine the contours along the shortest possible route (hypothetical) and estimate the steepest ground slope along this route. The steepest slope is between points X and Y (from examination of contour lines) - a vertical rise of nearly 38 m in 240 m horizontally. This represents a slope of over 15%. This is more than twice the allowable maximum grade of 6% and would result in excessive depths of cut and heights of fill. Therefore a less steep route should be examined, as shown in Step 2, below.



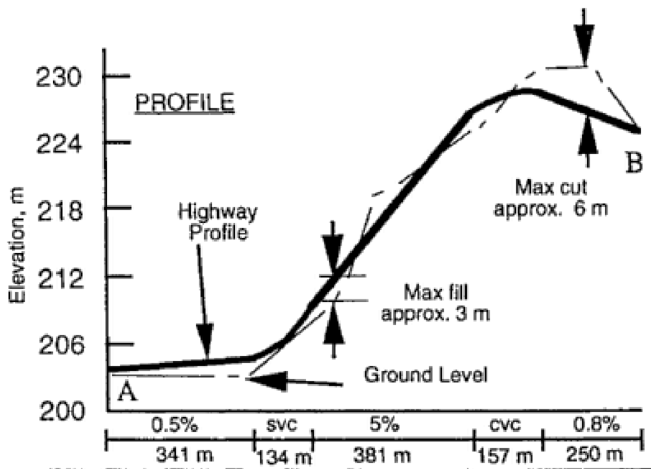
STEP 2: Sketch a new trial alignment with a reduced ground slope. The one shown here is sketched freehand and includes a curve, the radius of which is approximately the same or larger than the 240 m minimum specified. Notice the grade between points X and Y of Step 1 will be less steep because the horizontal alignement of the highway crosses the contour lines at a greater angle than in Step 1.



STEP 3: Convert the sketch of Step 2 into a dimensioned tangent and circular curve alignment by scaling and the use of compasses or a template for constructing and measuring the curve. It is also usually desirable to ensure that the intersection of the proposed highway with the existing road is within about 15 degrees of a right-angle in order to assist driver sight distance requirements.



STEP 4: Construct a profile of the ground levels as a basis for defining a profile of the highway pavement which does not exceed the 6% slope and the 10 m cut and fill requirements. This is usually done to balance the cut and fill amounts also, and an acceptable (though not necessarily unique) solution is shown here, for the alignment of Step 3 above. It is also usually desirable to ensure that the grade of the proposed road where it intersects the existing road is a maximum of about 2% to assist stopping and sight distance requirements. Note also that the minimum grade requirement of 0.5% has been complied with. The diagram indicates the combination of sag vertical curve, (svc) straight grades, and crest vertical curve (cvc) that together comprise the total length of the potential route. The total length of the route is 1261 m.



Refinements to Selected Route - Once an initial, **technically feasible route**

has been defined and examined, the alignment may be adjusted to ensure that the relevant K values have been complied with, address coordination of horizontal and vertical curves, and explore other routes that involve, for example, less depth of cut or height of fill or reduce the proximity to sensitive features such as wetlands. The alignment selection process can now be followed for a number of alternatives. There are several reasons for doing this. For example, the shortest highway that is **feasible in a technical sense may not be the least expensive.** Detailed economic analysis will be needed to determine these relative costs. Also, in practice, the provision and estimation of several alternatives will provide information for decision makers who may favor certain alignments over that considered preferable by purely engineering evaluation. If possible, at least three alternatives should be initially defined, all of which are technically feasible and conform to the specified design controls.

DEPTH AND HEIGHT OF CUT AND FILL SECTIONS

In rolling or mountainous terrain, most highways will be constructed partially on cut and fill sections. In general, it is desirable to "balance" the amount of cut and fill over the length of the highway and to avoid excessive haul lengths during construction. This requires careful consideration of the depth and configurations of cut and fill segments of the highway. This section addresses some of the considerations that should be taken into account when deciding the maximum permissible depth of cuts and height of fills.

Highways Constructed in Cuts - Ingeneral, highways are constructed in cuts at locations near the high points in the highway profile. The design details of the cut will depend on the type of material excavated and upon the depth from the original grade level.

Although no guidelines have been established, in general, a maximum of 10 m should be about the greatest depth of cut for most highways, with 7 m being a more desirable maximum. Beyond this depth, problems of slope stability and excessive costs usually tend to outweigh the benefits derived from decreases in grades and horizontal alignments, unless the highway accommodates high traffic volumes. Deeper cuts may be necessary but the highway alignment should be investigated very carefully for alternatives before such action is taken.

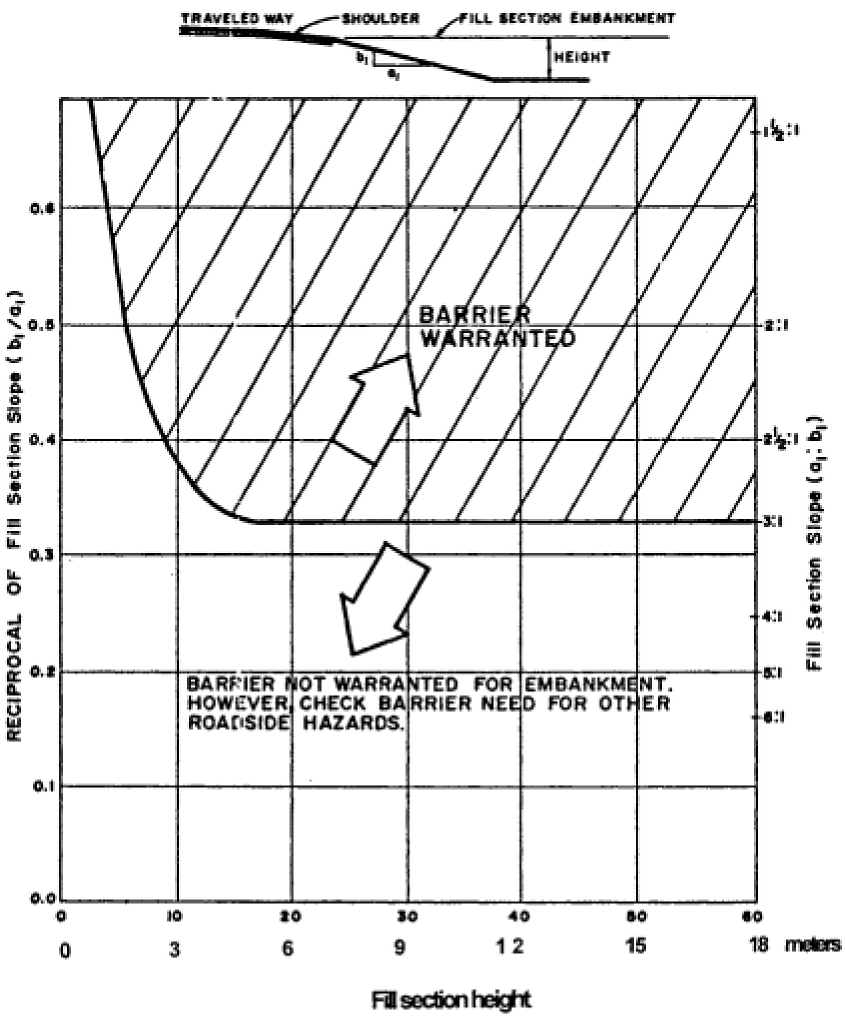


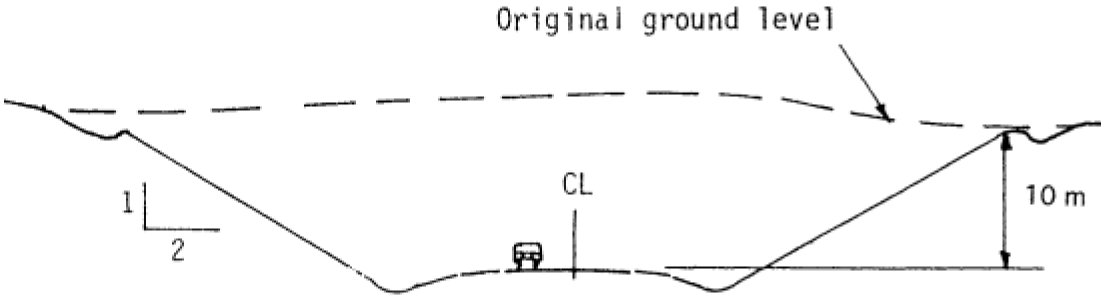
Figure 2-11. Comparative risk warrants for embankments
(Source: Ref. 5, Figure 5.1)

An example of selected characteristics of highways constructed in cuts is shown in Figure 2-12. Figure 2-12A shows a highway in a cut where the ground material is stable enough to be formed into self-supporting slopes. In general, slopes should conform to the values described and should be consistent with the provision of guardrail and other safety measures described earlier. The design of all slopes should be based upon detailed engineering soils analysis. In addition, to assist in slope stabilization, fabric and vegetation may be included. Selection of the appropriate materials, again, should be subject to detailed engineering analysis. It can be seen that the volume of excavation increases significantly as the depth of the cut increases. Thus, excessive depths of cuts should be avoided. Note that when the cut is located with an extensive slope above it, an interceptor ditch should be provided at the top of the cut section to reduce erosion of the cut slope by surface water runoff.

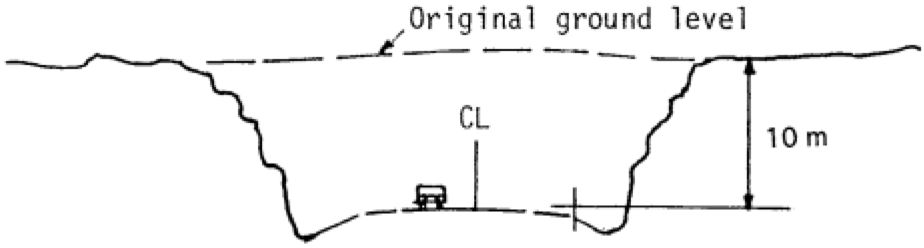
Figure 2-12B shows a cut section where the base material is rock. Again, the rock slope beyond the limits of the ditch and pavement structures should be the result of detailed engineering analysis. In some instances, the rock must be adequately stabilized and, if necessary, barriers at the base of the cut should be provided in order to prevent rock fragments from falling onto the highway. In instances where cuts are provided in rock, the expense of blasting quickly becomes extremely high. Again, such depths of cut should be minimized.

Highways Constructed on Embankments (Fill) -- Probably the greatest amount of highway construction in rural areas occurs on fill. Even in extremely flat topography, the highway pavement should be elevated several feet above the surrounding ground, thus assisting drainage. In order to obtain this fill, particularly where few cut segments are available, it is often necessary to obtain material from borrow pits along the highway route.

As with the cut section, it is usually desirable to keep the height of the fill section to 10 m or less, with 7 m being a preferred maximum. Above this height, depending upon the topography, the classification of the highway, and the affected land uses, it may be more economical to construct a bridge. This may be particularly true where the highway passes through rocky terrain or where the fill section is on a marsh, swamp, or any other location where unstable ground conditions occur.



A) Typical conditions with approximately 2:1 slope



B) Excavation conditions in rock

Note: Each of the above examples shows a 10 m deep cut. This is a considerable depth for a two-lane highway and will be close to the maximum practicable depth in most cases.

Figure 2-12. Highways in cut sections

Slopes for cuts and fills should be determined in accordance with the guidelines discussed earlier under Cross Section Elements, including the provision of guardrails or other safety devices. <u>Usually, the side slopes should be no steeper than 1 in 2 for regular fill material from soil stability, surface vegetation, and maintenance considerations.</u> This slope may be increased somewhat if rock or other more stable material is available for the purpose or if limited space or environmental factors dictate. **Again, the exact slope should be the result of detailed engineering analysis.**

Drainage of fill sections is particularly important to ensure that rainwater from the highway surface does not erode the slopes of the fill, resulting in possible eventual subsidence of the highway surface itself. Thus, curbing at the top of the fill, transverse flumes, and substantial ditches at the foot of the slope section may be major features of the drainage systems.