TRANSITIONAL GRADING OF HIGHWAY SLOPES

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Safety, stability, economy and improved appearance are all promoted by the use of slope transitions during the construction of highway cuts and fills. These benefits are sufficiently great that it is thought desirable to review some of the considerations for using such transitions.

Where there is considerable rainfall in the temperate zone, natural ground surfaces have a flowing rounded form composed of ogee curves concave at the bottom, convex above.

Since the form of the terrain has resulted from the action of the forces of nature, it demonstrates what roadsides tend to become. When a roadside is left angular and harsh, weathering eventually would recreate a flowing form. By shaping the roadsides in a natural manner, the amount of erosion is decreased materially, stable slopes are created promptly, thus abbreviating the period of major erosion, and prompt establishment of ground cover is facilitated.

The use of transitions when shaping the roadsides is based on sound economic principles. They make a road more stable, more economical of maintenance and safer to use.

Fortunately, well rounded roadsides are also attractive in appearance. This is because they seem natural, and man is, through evolution, attuned to like the natural. Motorists base their opinion of a highway on only a few features, such as width, crown and adequacy of pavement surface, alignment and grade, and the roadsides. So far as is practicable, all highways should be pleasant ways. Roadsides which are in harmony with the terrain offer a restful effect. The continuous variation decreases monotony and distraction.

The term 'Sunday Road' is sometimes used to refer to a road deliberately chosen for purely recreational purposes, one to be enjoyed. The Mount Vernon Memorial Highway south of Alexandria, Virginia, is such a road. One feels a loosening of tension and a satisfaction when driving over it. The alignment and grades are good, but not exceptional. The pavement is satisfactory, but not superior. The difference between it and most other roads is in the roadside treatment, the naturalizing of the roadsides.

Where the natural terrain is generally rounded, the landscape has few straight lines, and truly plane surfaces are rare. When straight lines and planes are used in highway construction, they appear artificial. If used for long distances, a driver's interest is not refreshed through variation, and he loses some of his alertness through monotony.

An 'open' section with flat, well rounded slopes appears 'rideable.' The driver is relieved of some of the strain arising from anticipation of what might occur.

Rounded slopes are more stable than slopes with angles and planes. Stability and economy in maintenance march side by side. Stability reduces the labor of cleaning out the ditches and the correction of slope gullying and other erosion. The removal of material by maintenance methods is usually more costly than its removal during the original construction, even where machine methods can be used in maintenance.

The proportion of highway funds devoted to maintenance is rising, and highway organizations are giving more attention to construction procedures which are less apt to require considerable maintenance later. 'Building-in' stability appears to be a fruitful source for ultimate economy.

'All-Prism' Construction - Highway engineers commonly use the term 'Highway Prism.' This is an inheritance from the days when railroads were being rushed to completion, when all cut and fill slopes were single planes, and when $1\frac{1}{2}$ to 1 slopes were accepted as stable.

Many materials have an angle of repose of $1\frac{1}{2}$ to 1. They are stable in the sense that they should be free from slips and landslides. However, roadside scars, the gullying of slopes, and the filling up or washing out of ditches show that wind, frost and water are moving the material and eroding the surface. Frequently the erosion is too rapid for vegetation to become established and so promote stability.

Many slopes originally constructed with a plane surface have eroded away on the face. A grass and tree root layer at the top has proved resistant. As a result, the upper part of the slope, sometimes for several feet in depth, has eroded away so that the surface is often vertical in the upper portion and overhangs some inches at the top where the root stratum occurs.

In these cases, the original raw slopes created by construction continue to remain raw year after year, because of progression erosion, causing a continuing maintenance cost and presenting a roadside scar that does not heal over.

Eventually, the slope will become flattened to such a degree that vegetation becomes established, slowing down erosion. The cornice of root growth will then disappear and the top of the cut will take on a rounded form. However, this process generally requires a period of many years.

On the steeper slopes, turf can be established by careful effort, but in the course of a year or two it is apt to give way in places and permit erosion and gullying to begin. The flattening of slopes is of material assistance in permitting vegetation to come in and establish itself on a self-perpetuating basis. It also greatly assists the seedlings of seeded areas to take root and to become established. The growth of grass, vines and other material on the slopes reduces erosion and maintenance, and helps to eliminate scars.

In typical 'all-prism'construction, a particular slope ratio is used on all earth cuts and fills throughout a project.

There has been a growing trend toward the use of flatter slopes on the lower cuts and fills, and at the ends of the higher cuts and fills. This practice improves the conditions and appearance, and is not particularly expensive if the yardage involved is taken into consideration when the alignment and grade are designed.

The tabulation below shows slope ratio variations that are in use in earth on particular roads now under construction.

TABLE 1

Variations in Slope Ratios with Height of Slopes, in Earth

Height of Cut or Fill	Rolling Terrain	Moderately Steep Terrain	Steep Terrain
0'- 4'	4:1	4:1	4:1
4'-10'	4:1	3:1	2:1
10'-15'	3:1	$2\frac{1}{2}$:1	1-3/4:1
15'-20'	2:1	2:1	$1\frac{1}{2}$:1
over 20	2:1	$1\frac{1}{2}$:1	$1\frac{1}{2}$:1

Variations of the slope ratios with height, as shown above, breaks up into facets the single plane face used in regular 'all-prism' construction. It is a desirable type of grading transition.

Variation of the slope ratio with the height of cut or fill automatically provides variation in appearance generally. It also causes the use of one slope on one side of a road, and of another slope on the other side of the road, in a case where the road passes in through cut across a ridge of which the crest pitches sharply. Since these locations are frequently visible against the skyline, such variation adds to the appearance.

Where a crest pitches so steeply that only a small residual hillock would remain on the lower side, daylighting or flattening to permit roadside utilization is advantageous.

Figure 1 is a contour plan of a cut through a ridge with a level crest, and across an adjacent fill, where all-prism construction is used. Each slope face has been shown as a single plane.

The flattening of slopes, while beneficial, is not in itself sufficient to naturalize the work. It will be harsh and angular, and have an artificial appearance. The moving of small additional quantities of material will improve the results greatly. This can be accomplished by transition treatments such as the rounding of the tops of cuts and of the toes of fills, the blending out of the slopes in the zones where the road passes from cut to fill, and sometimes, the widening of cuts to provide space for the concave lower portion of ogee slope faces and for broad shallow gutters rather than V-shaped ditches.

Each of these is a simulation of the shaping produced by nature. While appearance is greatly improved, particularly when they are well done, economy and soundness of the construction are the major justifications for doing the work.

The fact that roundings and ogee surfaces are so prevalent in nature is conclusive proof that the operation of nature's forces tend to produce them. If the construction does not provide such features, Nature will, sooner or later. Since the slopes exposed by construction are raw slopes, and frequently unconsolidated, changes are apparent after each severe rain and after each winter. It is not necessary to wait for a geologic era to pass, to note the changes.

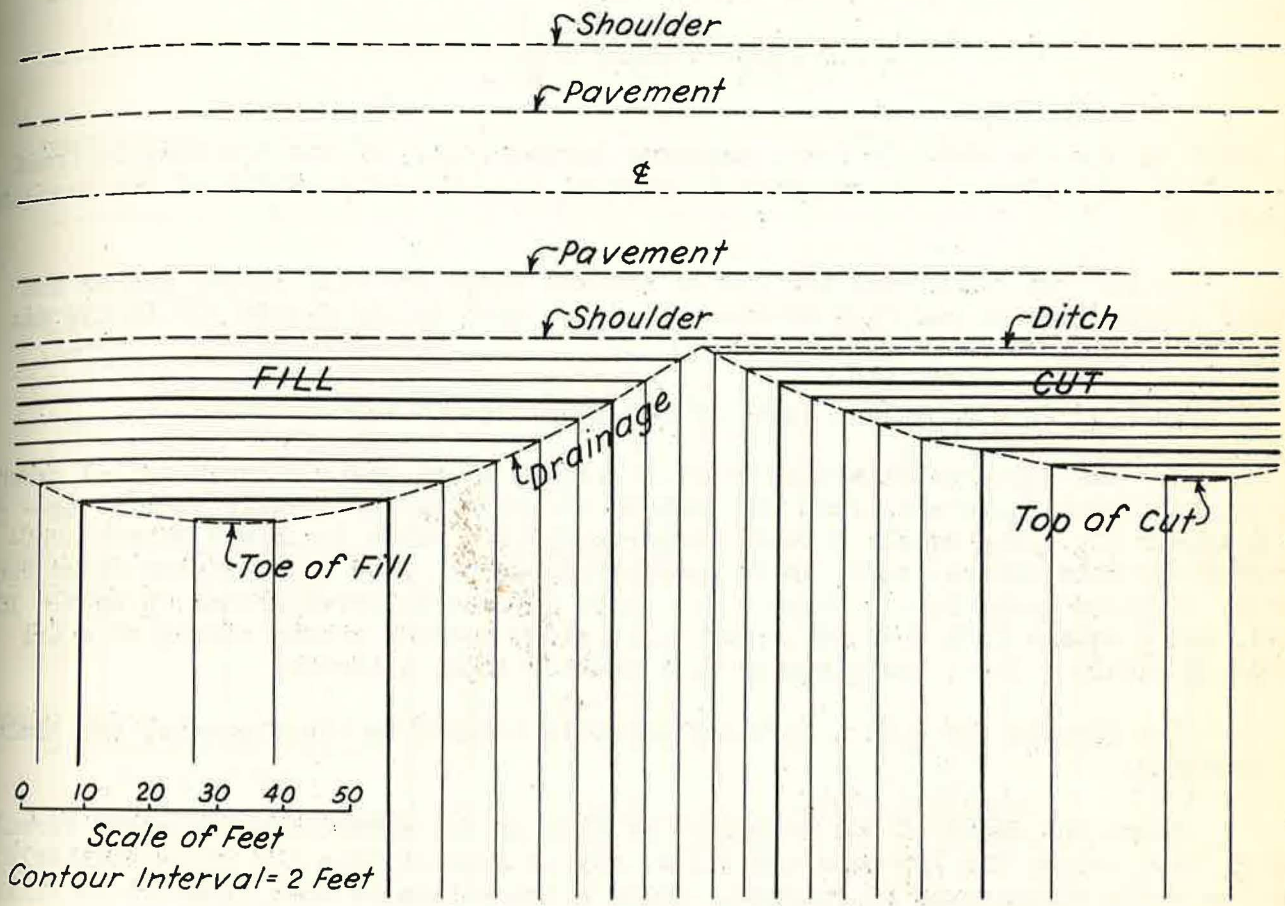

Figure 1. Contour Plan of 'All-Prism' Construction

The rounding of the top of a cut often reduces the gullying of the face. Water coming onto the cut face from the hillside above has a tendency to be better distributed, and to trickle or flow as a sheet rather than as a stream jetting onto the surface or dropping onto it from an overhanging root end. The rounding also assists plant growth to creep forward onto the slope, perhaps because there is less continual erosion. Since nature tends to round unprotected corners eventually, the erosion at corners is obviously greater than elsewhere, and it is a deterrent to plant establishment.

Many formulas have been proposed to define the rounding for the tops of cuts and the toes of fills. In general terms, liberal rounding is desirable, a parabolic curve is preferable to a circular curve, and the rounding should extend well down onto the face of the slope. It has been suggested that the rounding may well extend about one-third of the way down the cut face or up the fill slope, as an approximation of half of an ogee curve.

The following are particular examples of formulas for roundings which are in actual use.

A. <u>In Mountainous, Rocky Country</u>, (for application where earth is encountered):

$$R = 20 \left(\frac{1}{C.S.} - \frac{1}{G.S.} \right)$$

$$e = \frac{R}{4} \left(\frac{1}{C.S.} - \frac{1}{G.S.}\right) = \frac{R^2}{80}$$

in which 'R' is the width in feet, measured horizontally, of the rounding in front of the vertex, and also of the rounding in back of it. The total width of the rounding equals 2R,

'C.S.' and 'G.S.' are the run of the cut slope (or fill slope) and of the ground slope, in feet per foot of rise, that is, such as the figure '2' in the expression '2 to 1 slope',

and 'e' is the maximum depth of the rounding, in feet.

For the quite extreme case where a 2:1 cut slope meets a negative 2:1 ground slope, one which falls away from the vertex, the term in parenthesis becomes ($\frac{1}{2} + \frac{1}{2}$), so R equals 20, and e equals 5 feet. Apparently this value for R was chosen arbitrarily for this unusual case, as an appropriate value. For less extreme cases the values of R and e are less. Where a 2:1 slope intersects level ground, R equals 10 feet, and e equals 1.25 feet, while for a 2:1 slope meeting ground rising at a 4:1 slope, R equals 5 feet, and e equals 0.31 feet or about 4 inches.

The formula for e is a vertical parabola tangent to the slopes at the limits of rounding.

Since the depth of cut or height of fill do not enter into the above formula for R, that value, for low cuts and fills, may be greater than the width available, and the whole slope would be rounded. Where a transition is made from cut to fill, this often will include the portion of the face where such occurs.

Figure 2 is a contour plan of a cut and fill, where the slopes are varied with the height of the face, and with roundings of the top of the cut and the toe of the fill, but without transitioning of the zone between the cut and the fill. The slope variations and the roundings shown are base on the formulas for steep mountainous terrain.

B. <u>In Flat Terrain</u>, (where little or no rock encountered):

$$R = \frac{H \times C.S.}{3}$$

$$e = \frac{R}{4} \left(\frac{1}{C.S.} - \frac{1}{G.S.}\right)$$

In the above, H is the vertical height of the slope face, the other values being as before.

These formulas are for use in flat terrain. The variations in the slope of the ground surface have been disregarded, and the rounding begun 1/3 the way down the slope. Again, a parabolic curve is used for the rounding.

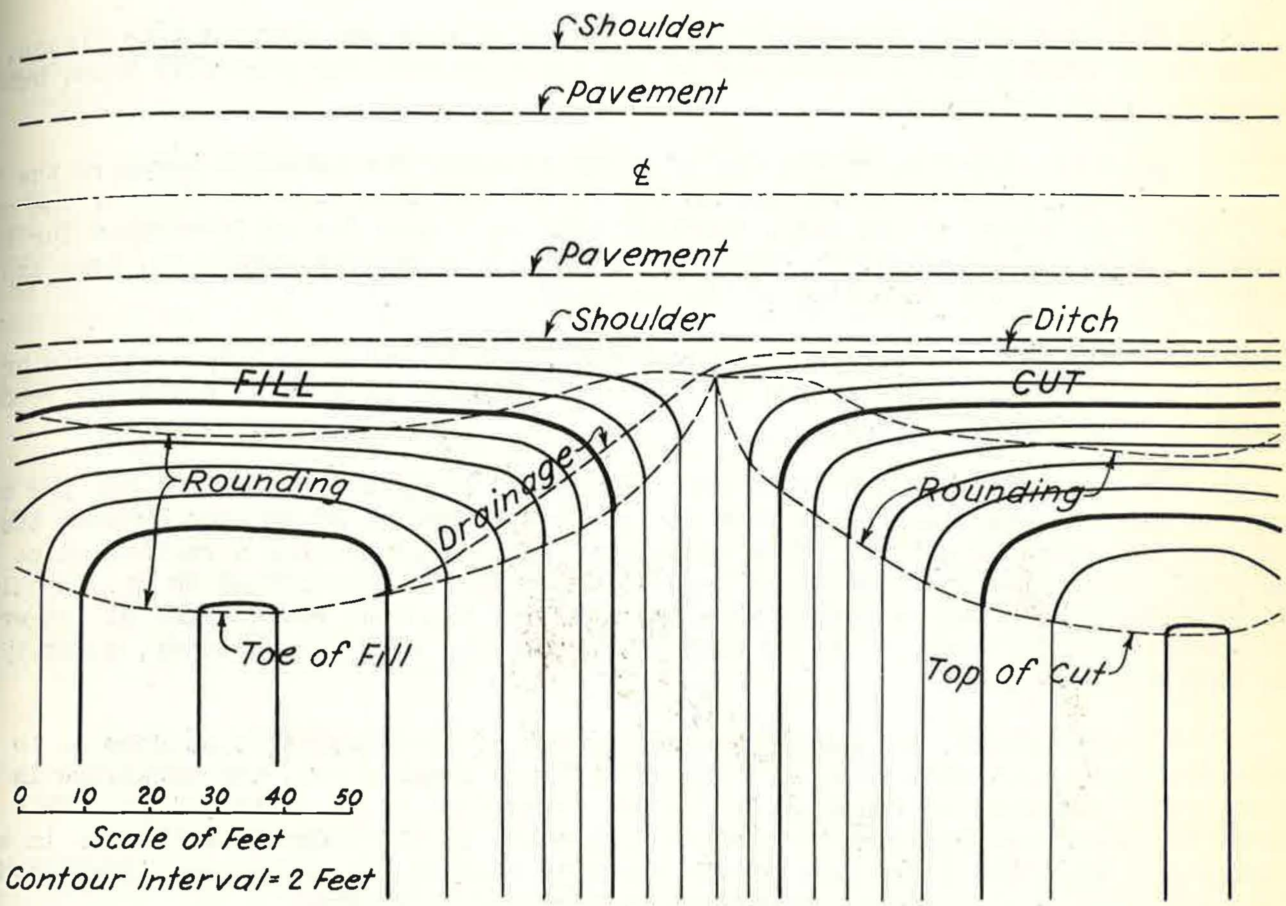

Figure 2. Contour Plan of Prism Construction with Rounding

Figure 3 shows graphically the definition of the terms in the foregoing formulas.

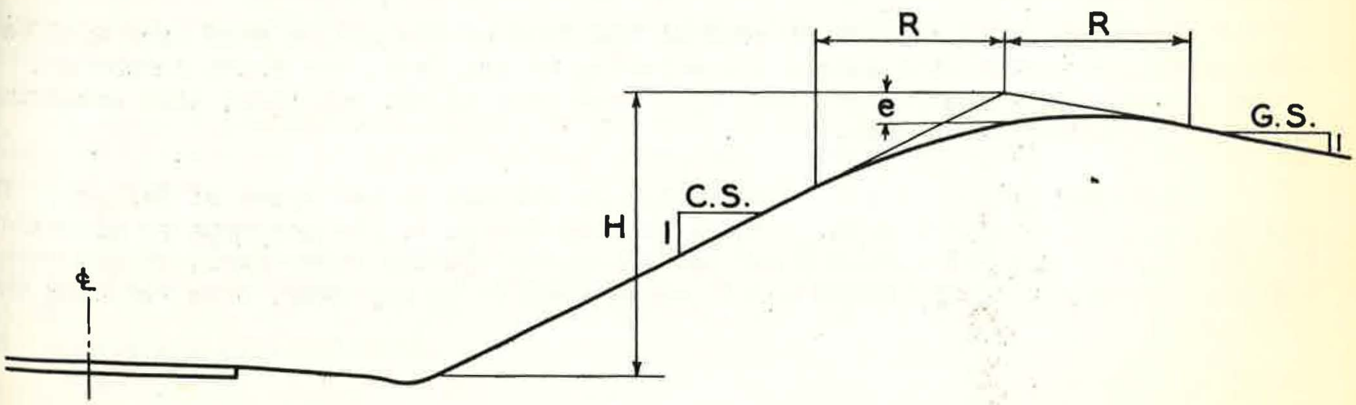

Figure 3. Terms in Formulas for Slope Rounding

It is rather immaterial whether the curve of a rounding be any particular mathematical curve, as long as it is tangent to the cut face and to the original hillside, and changes in radius progressively. Few, if any, terrain curves are precise parabolas or other mathematical curves. It is sufficient if the roundings seem natural to an observer.

The practice of 'sandpapering' the faces of cuts has dropped into disuse. Instead it is usually quite sufficient if the slope be machined generally true, but left somewhat rough and serrated.

When the rounding of the top of a cut is done, the material moved is the topsoil of the area. It is convenient to let it trickle down over the face of the cut. Much of it may lodge on the slope and thus provide a more favorable seedbed for later growth. When this is done, the rounding is largely a machine operation, less expensive than loading and disposing of the material.

If part of a face is a fresh rock cut, topsoil lodging in the crevices or coming to rest on the rock ledges will be of particular benefit in assisting seedlings to become established.

Unless cuts are high or in rock, it may be worth while to widen out the cut section sufficiently to provide room for the lower portion of an ogee between the cut and the ditch or gutter. This additional width will provide a resting place for material that comes down the slope before full cover is established on it. Should it be necessary to remove the material eventually, the need would arise at longer intervals than for ditches at the slope face, and, in addition, cheaper, quantity, methods could be used.

In many cases, the periodic cleaning out of the ditches is so done as to occasion subsequent bank erosion. When a ditch is cleaned out, the backslope is frequently steepened or 'undercut', for the lower foot or so of the slope. This tends to start more rapid erosion which progresses up the slope like the run in a stocking. Where the lower part of the slope is concave, there is less likelihood that the erosion will start, or that it will go far if started.

Even where the terrain is generally rounded, rock cliffs often occur. Paradoxically, such a cliff is evidence of active erosion below. The cliff itself may have some of the permanence which advertisements have attributed to Gibraltar, but through the ages weathering would have masked the face with a talus slope and weathered material, if removal of the loosened material had not occurred.

Where there is sufficient room at the foot of the cut, a rock face will become partially masked with debris accumulating at the foot, and where shrubs and trees can establish themselves, they also mask part of the cut face, thus screening part of the construction scar.

<u>V-Shaped Ditches</u> - A V-shaped ditch is subject to two types of failure. It may fill up, blocking drainage, perhaps causing damage to the pavement or discomfort to traffic, and require cleaning out periodically. On the other hand, it may wash out and create a traffic hazard which causes traffic to shy away, thus reducing the

effective width of the adjacent traffic lane. In addition, the material washed out at times settles on and deteriorates usable land below. The repair of washouts may be rather expensive. Certainly a washed out ditch is not an attractive part of the roadside.

The flattening, mulching and seeding of slopes, and where practicable, the provision of space at the foot of the cut for talus material, will reduce the cleaning required.

Rounded Gutters - Erosion by running water depends upon the velocity at which the water flows. This is partly a function of the shape of the flowing stream. A broad stream flows more slowly than the same water in a narrower, deeper, smoother channel. If there can be space for an adequate broad shallow gutter, the tendency to erode will be reduced. The difference in velocity may be the deciding factor whether a sod gutter may suffice or whether more expensive gutter paving is required. If paving later proves necessary, the space available permits it to be broad and shallow, and thus it can be 'rideable'.

Because turf is usually cheaper than gutter paving, and also more attractive, it seems worthwhile to try out doubtful installations with turf, going to gutter pavement later if found necessary.

It is well to round the toes of fill slopes. Often, the rounding below fills occurs automatically, to some degree, due to the escape and lodgment of some of the material being placed above, or by the casting back of material excavated to form a shelf on which to found the lower part of the fill.

Cut-Fill Transitions - There is still another type of transition rounding meriting consideration. This is in the zone where the road passes from cut to fill.

In the old all-prism construction, the top of cut, in vertical projection, is crescent shaped, with the sharp top edges pointing toward the road at the ends. Such construction is shown in the 'All-Prism' model of Figure 4. If the tops of the cuts are rounded, these ends are softened materially, but they still 'point toward the road'. At the ends of cuts, and also at the ends of fills, where they are low, the width for rounding is narrow, and the rounding must be rather abrupt. Unfortunately, these are the portions most apparent to the traveller. For appearance, and also for other reasons, a further modification is desirable.

Perhaps the most natural results can be obtained in this transition zone by carrying out faithfully grading plans which have been worked out carefully for each location.

Such a procedure connects the contours of the face of the cut back to the faces of the natural hillsides, through sweeping curves. The same thing is done for the fill slopes.

However, it is not customary to use detail grading plans to control the work. The Mount Vernon Memorial Highway appears to have been done in this way and it seems to be the reason why the highway has an appearance that is more pleasing than that of perhaps any other highway.

When the grading plan method is carried out quite liberally on short cuts, the whole surface of the cut may be absorbed into the transitions at the two ends. Where the face of the cut is also a full ogee curve, rounded at the bottom as well as at the top, the result is a hill nose of natural appearance, even though it has been artificially constructed.

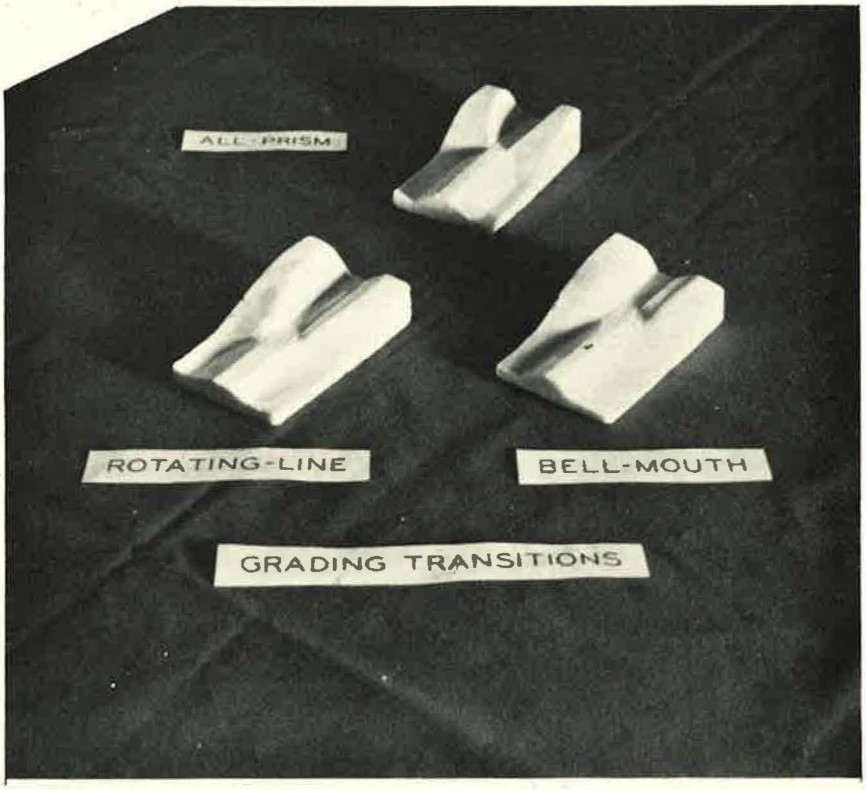

Figure 4. Models Illustrating Transitioning

The advantages in appearance obtained by the use of grading plans can be approximated by field control methods.

One method that is being used has been called the 'rotating-plane' method. The name 'rotating-line' is a more appropriate term.

Some schools have models of various geometric solids. One model, perhaps of a hyperboloid, can be formed by a succession of tightly drawn strings representing elements of the surface. The surface is composed of straight lines, but they form a surface rather sharply warped in three dimensions.

A cut-fill transition using a rotating line is somewhat similar. In Figure 4, the model showing it is labeled 'Rotating-Line'. Near the end of the cut, a point is selected where the top of the cut is somewhat above eye height, say 6 or 7 feet up. Another point is selected where the toe of fill is the same distance away from the road. At the first point, the line element up the cut slope is carried along the road and, simultaneously, it is rotated about the ditch line and the edge of the shoulder until it coincides with the fill slope at the second point. The slope flattens progressively while passing from cut to fill.

This procedure flares out the end of the cut and reduces the appearance of 'pointing toward the road'. The result is a shape passing continuously from cut to fill, without sudden angular change, and keeps the edge of the work well out from the shoulder line. This last is advantageous in appearance and is adapted to construction by machine methods.

Figure 5 is a picture of a cut transitioned in accordance with the 'Rotating-Line' method.

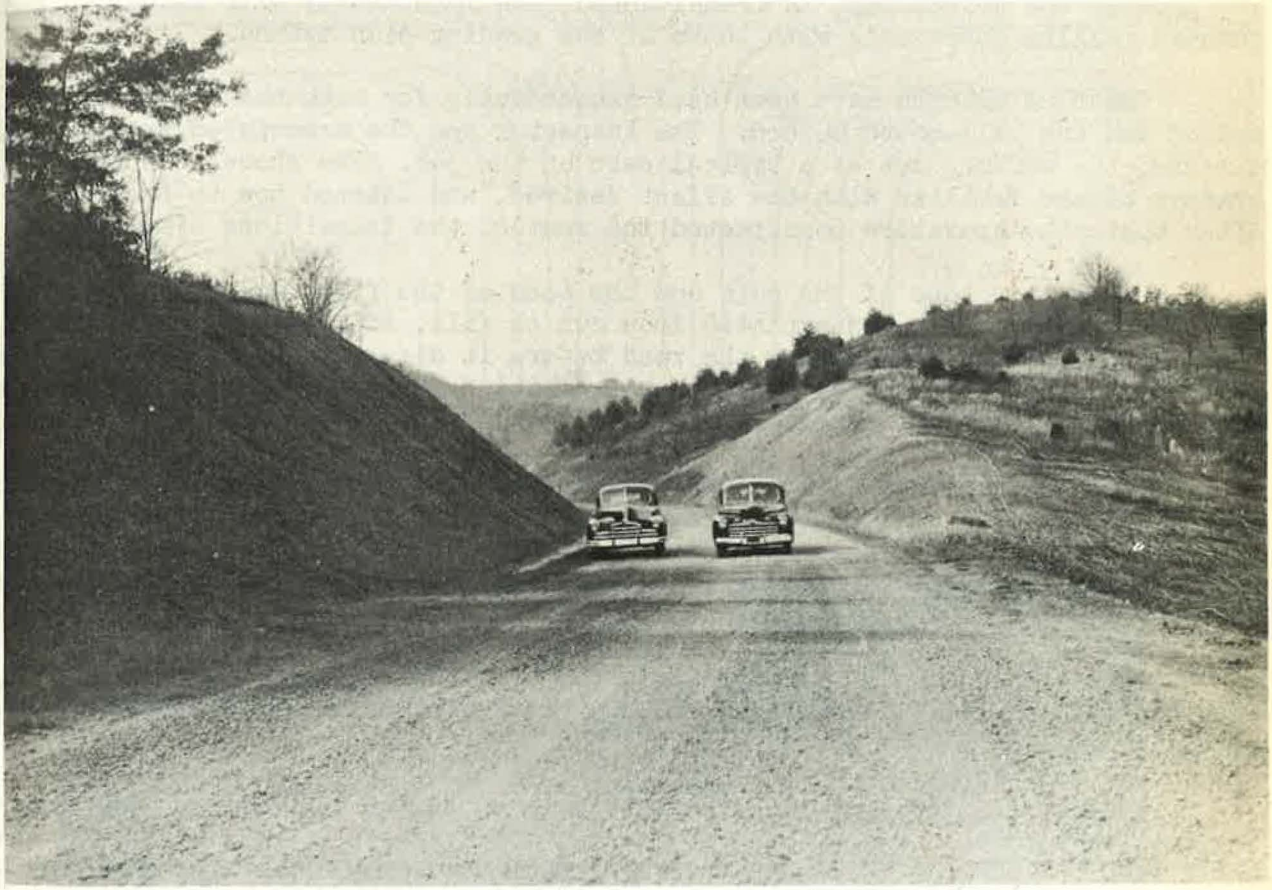

Figure 5. Cut with 'Rotating-Line' Transition

Another method can be called the 'bell-mouth' method.

In this method, a point is selected where the top of the cut is a suitable distance above the road. This point is considered the apex of a cone, and the end of the cut is coned back away from the road until it blends with the hillside. The term 'bell-mouth method' arises from the shape of the resultant contours. In approaching the end of the cut, each contour bends progressively further from the road. In a section through a bell, the lip of the bell is also further from the center than the main body of the bell.

Similarly, the ends of fills are also flared out so that contours have the shape of a bell mouth. Figure 4 has a model labeled 'Bell-Mouth' showing the effect created.

Figure 6 is a contour plan similar to Figure 2 except that the slopes and roundings are those for rolling terrain and except that a bell-mouth transition is added in the zone between cut and fill.

Figure 7 is a picture of a bell-mouthed cut.

The rotating-line and the bell-mouth methods differ in the concept of the method of attaining the transition. The results may however be somewhat similar. In practice, the rotating-line method has been applied to the lower 6 or 7 feet of a cut, while the bell-mouth method has been used on a considerably greater scale. The greater the height that is transitioned, the more nearly will either method furnish results comparable with those of the grading plan method.

Machine methods have been used successfully for both the rotating-line method and the bell-mouth method. The inspector and the associated architect have directed the working out of a typical case on the job. The shovel and machine operators became familiar with the effect desired, and learned how to produce it. After that, the operators constructed the rest of the transitions similarly.

Where the tops of the cuts and the toes of the fills are rounded, but no specific transition is contemplated from cut to fill, it sometimes is found advisable to turn the ditch away from the road before it discharges down the hillside. When this is done, a type of bell-mouth transition results. The machine methods used in such a case are equally applicable to all such locations.

When the toes of fill slopes are rounded, and particularly where the end of the fill is given a bell-mouth flare, a broad 'swale' is created running down the fill near the end. It is less subject to erosion than is the V-shaped valley of 'all-prism' construction. Paving of a flume down the end of the fill may not prove necessary.

The bell-mouth type of transition creates a widening of the shoulder, in both the cut and the fill portions. Where the shoulders are rather narrow, an opportunity is created for a car to be stopped off of the pavement.

<u>Built-In Stability</u> - If transitions in shape are constructed when the grading work is done, the quantities of material involved can be allowed for at the time the alignment and profile of the road are designed. Should the transitioning be done as a separate operation subsequently, it is more difficult to secure any borrow required or to dispose of any excess of material. It is therefore usually cheaper in earthwork cost to include the transitioning in the primary contract.

In addition to the reduction in cost of earthwork, a further factor is involved. Considerable erosion may occur before a cover of vegetation is established. Because of the need to correct these erosions, greater quantities of material might be required if transitioning is deferred to a later operation.

<u>Summary</u> - Transitions in forming cut and fill slopes offer opportunity for material reduction in the cost of subsequent maintenance. The transitions may be accomplished largely by machine methods, and involve relatively small yardages.

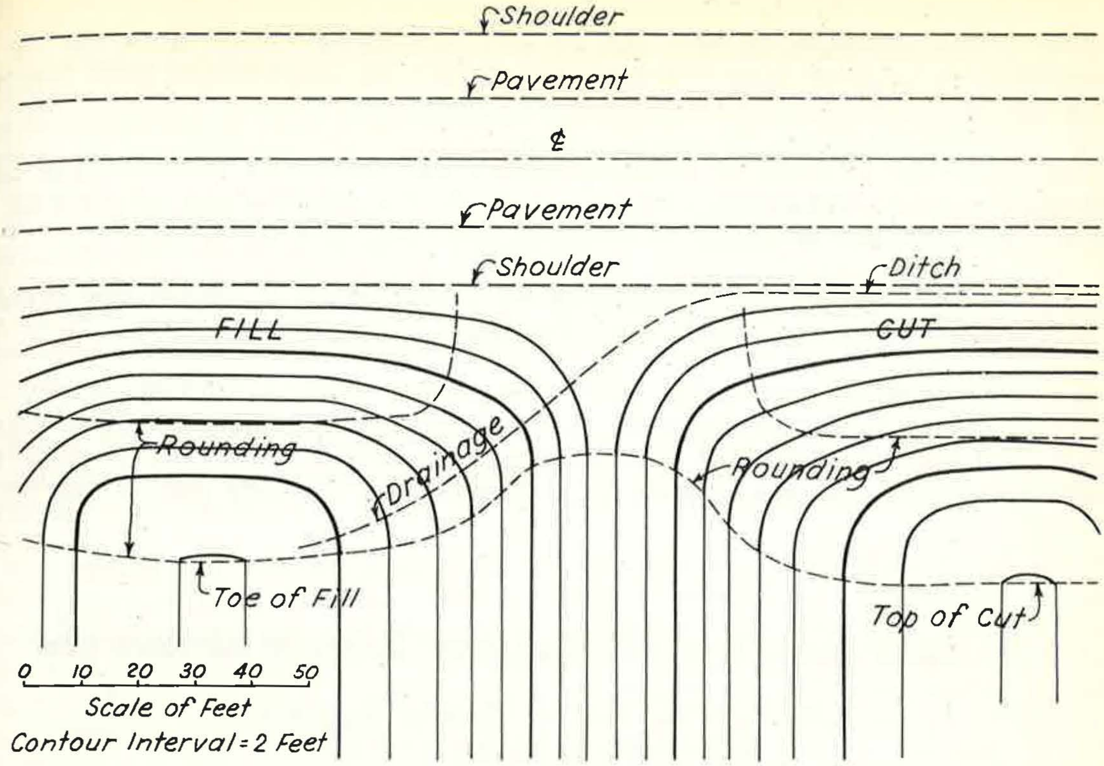

Figure 6. Contour Plan with Rounding and with 'Bell-Mouth' Transition

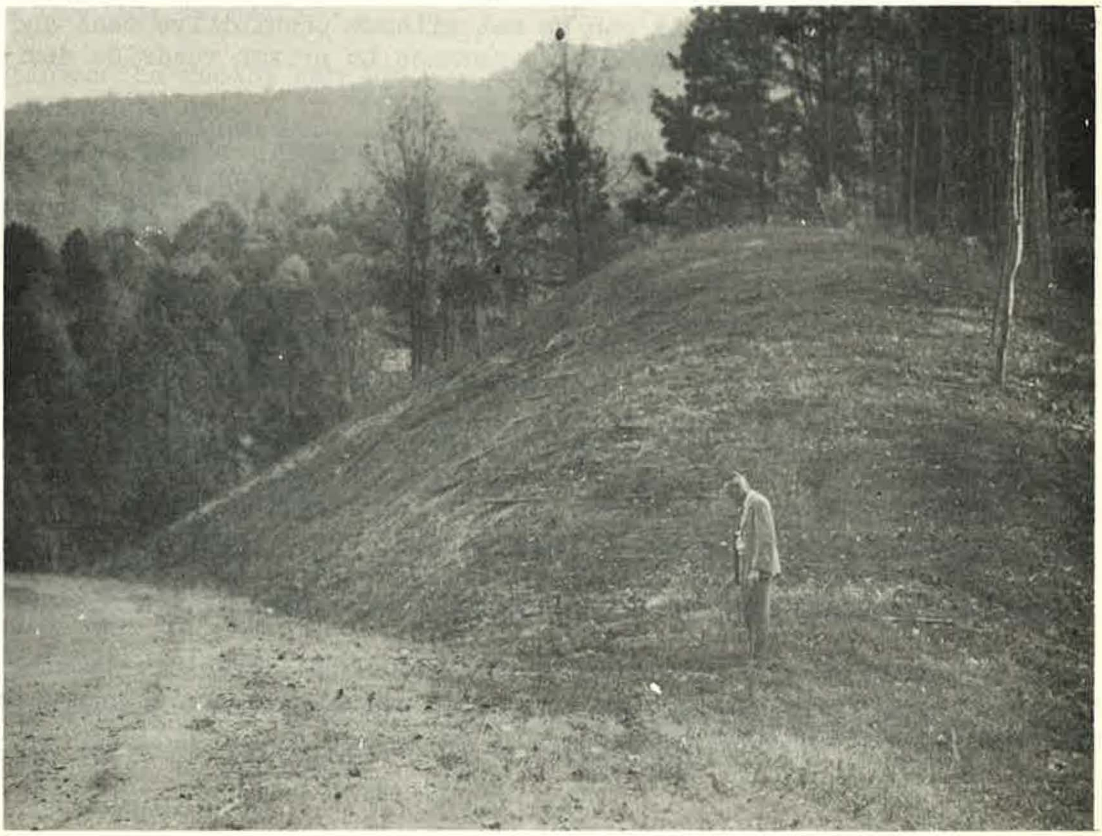

Figure 7. Cut with 'Bell-Mouth' Transition

In most cases, the increase in cost due to the forming of transitions during the initial construction is less than the continuing cost of maintenance were the work left harsh and angular.

The reduction in cost of maintenance is due primarily to reduction in erosion. There are other attendant savings, such as the elimination of some of the hand mowing, and greater facility in keeping the road open in winter.

Transitions improve the appearance of a road greatly, since the forms of natural hillsides are approximated more closely.

Broad shallow gutters and a flowing roadside promote 'rideability'. The psychological effect produced promotes safer operation of vehicles. The absence of angularities and artificialities makes the road more attractive, it satisfies the traveller better. Such a highway is a 'Sunday Road' every day in the week.

SLOPE DESIGN PRACTICE IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

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Good conservation policy requires that roads in National Parks shall be inconspicuous and create a minimum of scar and disfigurement of the landscape. The results of 16 years of road construction in the Great Smoky Mountains National Park demonstrate that these requirements can be met without prohibitive cost and without sacrifice of essential traffic service by adherence to proven roadside design and construction practices.

Most of the roads in this area lie in rough mountain terrain covered by dense forest. Plentiful rainfall insures rapid growth of vegetation but also presents serious erosion problems. Roadside use by the public is an important factor in the design of roads as great crowds of people flock to the Park on summer weekends.

Experience has shown that roadway slopes of $1\frac{1}{2}$ horizontal to one vertical, or flatter are quickly covered with volunteer vegetation, while steeper slopes remain naked for years due to erosion and ravelling under frost action. The natural mountain slopes usually range from $1\frac{1}{2}$ to 1, to $2\frac{1}{2}$ to 1, so that slope design is necessarily a compromise between the desirable and the practical. In steep terrain the desired maximum of $1\frac{1}{2}$ to 1 for earth cuts cannot always be attained economically and in these circumstances a steeper slope, usually 1 to 1, and, rarely, 3/4 to 1 must be used. In sound, solid rock a vertical cut slope is the ideal condition since it creates the least scar on the landscape when viewed from a distance.

With all materials so far encountered in the area structurally stable embankments can be made on slopes of $1\frac{1}{2}$ to 1; and these slopes are standard design for mixed materials in steep country.