HIGHWAY GRADING
AND
DRAINAGE

A Thesis
Submitted for the Degree of
CIVIL ENGINEER

By
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B. S. in C. E., 1925
Georgia School of Technology

Approved by ..................................................
Professor of Civil Engineering

Date .................................................

May 20, 1925
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INTRODUCTION

The purpose of this paper is to discuss that phase of road construction known as Grading and Drainage from the standpoint of the engineer in direct supervision of the work.

Within the subject come actual grading, construction of drainage structures (except bridges), and the several subsidiary items incidental to the construction and maintenance of a road in preparation for, and up to the point of, paving. Perhaps more engineering is involved in grading than in any other form of highway construction, for here the foundation of the road is laid and here the drainage is determined more or less permanently, so that mistakes made during the grading often can never be rectified.

Little theoretical analysis has been attempted, but an effort made to bring out every day problems encountered on the job, the solutions to some of them, and to discuss and describe up to date methods of road building and equipment. Much of the information contained is more or less elementary, and some is given in the Georgia Highway Specifications, but, in general, the attempt has been to point out facts not ordinarily found in text books.
All of the writer's experience has been gained in the service of the State Highway Department of Georgia, by whom he has been employed since June, 1925. For the past four years he has been in charge, almost entirely, of Emergency Relief and Regular Federal Aid Highway Projects located in Fulton, DeKalb, Clayton, Fayette and Laurens counties. All pictures submitted were taken on these projects.
The first task of the engineer in charge of a grading project is to set the stakes by which the job will be constructed, and to keep a record of all measurements taken.

My field experience shows me that one of the most important requisites of an engineer is the ability to take good notes. These must be neat, clear, accurate and complete. A man should bear in mind that others beside himself will have to use his note books, and therefore their contents should be intelligible and concise. Quite often a change in engineering personnel is made during the course of a project; for this reason an engineer owes it both to his own reputation and to the man who may succeed him to maintain clear and well-kept records.

(See sample page of notes.)

A separate note book should be used for each of the important items connected with the work, such as alignment, slope stakes, drainage structures, finishing grades, and miscellaneous items that require few notes, namely, clearing and grubbing, ditch excavation, grassing of slopes, right of way markers, and so forth. When enough cross-section notes are taken for grading, they should be transferred from time to time to a special note book for earthwork quantities.
### Sample Page Alignment Notes

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<th>Sta</th>
<th>4'50'</th>
<th>4°05'</th>
<th>RI - 239+61.2</th>
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<td>0°00'</td>
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<td>238</td>
<td>2°55'</td>
<td>L - 660.0'</td>
<td>T - 333.3'</td>
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<td>1°50'</td>
<td>E - 28.81'</td>
<td>R - 1910.1'</td>
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<td>1°05'</td>
<td></td>
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<tr>
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<td>P.C.</td>
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<tr>
<td>+32° = +40° Fwd</td>
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<td>Equality: 235 +32 = 235+40.3 Forward</td>
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</table>
CENTRE LINE AND REFERENCE POINTS

In the field, the engineer's initial task is to re-run his center line. While the line is always run on location, the case is more frequently than not, that many months elapse between the time the original survey is made and the time actual construction begins. That, of course, means that most of the original stakes are out. The engineer on construction should first go over the line, and find the references set on location. Using these, he can re-locate the necessary P.O.'s, P.T.'s, P.I.'s, and P.O.T.'s to run his line.

Center stakes should be set at each fifty-foot station, and at all intermediate points where there is a break in the profile of the ground. Center points should also be set at all culvert sites to facilitate the staking of these structures later.

When the line has been run, key points should be accurately referenced. In general, at least two points on each curve, and enough P.O.T.'s as will be necessary to re-establish the line after grading will require referencing. Where possible, two references for each point are advisable, as the objects may be removed or the stakes set destroyed.
The following methods of referencing a point may be used:

(a).

This method is perhaps, the most satisfactory. Care should be taken to select references in such directions that horizontal measuring, after cuts are taken out or embankments made, is possible. An inexperienced instrument man can easily fail to take this precaution.

(b) A point may be referenced by intersection:
This method does not require measuring, but it is not as safe as method "a". It is obvious that if any one of the four objects is lost, the reference is of no value. The angle between the two reference lines should be large, as nearly 90 degrees as possible, to insure accuracy of intersection. When the point happens to be in a very deep cut the method of intersection is almost necessary. In such a case, the hubs should be set fairly close to the edge of the banks in order that the road-bed may be seen, and the objects can be set on the opposite side of the road from the hubs, thus:

![Diagram](image-url)
(c) A method sometimes used for referencing P.C.'s, P.T.'s, and P.O.T.'s is to drive an iron pin into the ground a certain number of feet on either side of the point at right angles with the center line.

This method has the advantage of easy application, as no instrument is necessary. A steel tape and plumb bob are all that are needed to re-establish the point. On the other hand, iron pins alone in fields are difficult to find, and the loss of one will destroy the efficacy of the reference. Besides, as these points are always set at right angles, horizontal measurement is often difficult on account of high banks. This of course, increases inaccuracy.
(d) A fourth method is termed "hog-tying" :

No hubs are set, only distances to two or more points taken and recorded. Arcs swung with the distances as radii will intersect at the required point. While this type of reference is easy both to set and apply, its accuracy is questionable.

On references "a" and "b" iron pins, or better still, small size iron pipes, can be substituted for the hubs marked in the diagram. These are to be preferred, as wooden stakes, even of oak, will rot in the ground after a few months. Concrete posts with a cross mark on top, when used as right of way markers, make excellent reference points. These may be used exactly as described in "c" above.
CULVERTS

The length of a culvert will, of course, depend on the slope and height of fill above it.

From years of experience I have learned that in staking out pipe and box culverts plenty of length should be allowed; especially is this true in the case of culverts under high fills, and where the embankment slope is one and one-half to one. While this is the natural angle of repose of earth material, clods, rocks, etc., will roll to the bottom of the fill, making the culvert appear short. Then, too, possible grade changes must be allowed for. Furthermore, excess material in cuts is quite common; this material should be used to widen the fill uniformly. In such a case, unless the culvert under the fill has a little extra length, the shoulder directly
above the culvert will have to be narrowed, destroying the uniformity of road-bed width. Finally, it should be borne in mind that a culvert a little too long is better than one a little too short.

When the culvert is at right angles, all the stakes needed by the contractor for its construction will be a line along the center of the culvert and one at each end at right angles to the culvert center line, or parallel to the center line of the road. A grade stake to flow line at each end of the structure should also be given. When the culvert is skewed, each of the four wing walls should be staked by the engineer.
The fall to be given will depend largely on
the general slope of the ground at the site. About a
two per cent grade is ideal, while in flat sections a
grade of one-half of one per cent will suffice to drain
the water.

Actual construction lengths of drainage
structures should be checked early in order that ample
time may be given the contractor to place accurate
orders for the necessary materials, such as pipe
lengths, reinforcing steel for concrete culverts, sand,
stone, cement, etc.

As soon as these materials arrive representa-
tive samples should be taken by the engineer and sent to
the testing laboratory. The Georgia Highway Department
tests its materials at its own laboratory, located in the
State Highway Building in Atlanta. Where samples are sent
to the laboratory direct from the plants, as is the case
with certain materials, it is not unwise for check
samples to be sent in from shipments actually received
on the job. The Federal Bureau of Public Roads requires
that only materials with satisfactory test reports shall
be used.

While the sizes of all drainage structures
are determined on location and shown on the plans, it
is well for the construction engineer to check the
drainage areas before proceeding any further with stak-
ing out the culverts, ordering materials, etc. By so
doing he may prevent some serious blunder.

The openings necessary for various drainage areas on hilly, mountainous, rolling or flat land are given in tables computed from Talbot's formula.

(See attached blue print.)

However, the experienced highway engineer knows that he must employ a special application of this formula. In the case of a well-drained highway, the road ditches and the outside surface ditches will catch the water and rapidly run it to the culvert. This will result in a greater concentration of water at the culvert than would be the case if the water flowed merely through vegetated areas or cultivated fields. The effect is to increase the constant "C" in Talbot's formula. Thus, if the slope of the land is such as to class it under 0.4, it will be more accurate (and safer) to use 0.6 for the same area in determining the size of culvert needed.
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<th>Mountainous Land</th>
<th>Hilly Land</th>
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<td>C=60</td>
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**Notes:**
- **Highway Department of Texas**
Before excavating operations can begin the engineer must set the necessary grade or "slope" stakes. These stakes mark the intersection of the plane of the slope (be it cut or fill) with the natural ground.

Thus, in the figure above, points "a" and "b" are the points at which slope stakes are set. On the stake the following information should be marked: the Station number, the "cut" or "fill", the distance from center line, the slope used, and the depth of the ditch in cuts.

Readings should also be taken, and co-ordinates recorded at all points on the section that will affect the grading quantities (points c,d,e,f,g and h in diagram above). These points are known as "breaks". (Points "x" and "y" are readings taken at the limits of the right of way, though outside of actual construction.)
With this information taken, the entire cross-section can be reconstructed. Cross-sections should be taken, and slope stakes set at every fifty-foot station and at all breaks in the slope of the ground between stations.

The quantities of excavation and embankment can be easily computed by determining the cross-sectional areas at each station, and the volume of earth between any two stations (consecutive ones) found by averaging the two areas and multiplying the distance between them. This method, known as the Average End Area Method, is used entirely by the Highway Department of Georgia, and while it is not quite as accurate as the Prismatical formula, it is much faster. Furthermore, it is entirely fair, as it is standard under the specifications, and bids are made on that basis.

In calculating the end areas, the engineer may use either some simple mathematical method, such as latitudes and departures or cross-multiplication, or he may plot the sections on co-ordinate paper, and obtain the quantities with the use of a planimeter. The latter method is faster as the instrument can be set to read cubic yards directly.

In the preparation of notes for setting grade stakes, a careful study of the plans is advisable. All grades should be checked for any errors, and the elevation of every station noted in the field book. Also to be noted are: variations in right of way widths, slope
used for each fill or cut, depth of ditch in cut sections, curves with rate of super-elevation and length of transition tangents (distance on tangents back of P.C. and ahead of P.T. in which super-elevation is run out), widening if any, description of bench marks with elevations, and any special feature that will affect the grading.

(See sample page of notes.)

While some engineers use a hand level for setting slope stakes, it is generally best to set them with a vye or dumpy level. While the latter method is slower, it is more accurate. Levels can be carried forward and the bench marks that were set on location checked in the process. Enough additional bench marks should be set so that they will come at intervals not to exceed five hundred (500) feet. This distance should be three hundred (300) to four hundred (400) feet on steep grades. To the field engineer it is obvious that closely spaced bench marks will prove exceedingly convenient during the course of construction of a project.

The longest way in the beginning often proves to be the shortest in the end. My experience has shown me that it is good practice to cross-section the entire right of way width at the time slope stakes are set. Then, if borrow, that is, excavation material in addition to that which is obtained from the normal cut section, is required to complete an embankment, it may be obtained on the right of way at a moment's notice, and at any desirable place
### Sample Page Slope Stake Notes

#### (Left Page)

<table>
<thead>
<tr>
<th>Sta.</th>
<th>H.I.</th>
<th>4:1 Fill, 2:1 Cut Slope</th>
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<td>128</td>
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<td>Superl. 0.08</td>
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</table>

#### (Right Page)

| Nail in root 30" oak, 75' at Sta. 126+60 |
| F24 F18 F12 18 | F25 F20 F16 F12 24 18 | C13 14 | C27 354 |
| 50 23 9 | 50 28 24 23 14 | 0 0 | 0 |

| Nail in Twin Poplar 60' Left Sta. 130+00 |
| F21 F26 F20 24 | C12 14 | C25 350 |
| 50 30 | 17 0 | 50 |

| Note: Readings enclosed in circles are Slope Stakes |
without the necessity of re-running a line and taking cross-sections. Sometimes the natural formation is such as not to afford a satisfactory base for the pavement. In such cases the excavation should be taken, or the embankment left, below grade, and then brought up to the proper elevation with good material that must be "borrowed". (This is known as "back-filling.") Of course, the kind of excavation obtained can be determined with certainty only when a cut has been opened and its face exposed. If the right of way has already been cross-sectioned, the engineer can select any nearby cut that is suitable to widen for borrow material to be used in back-filling without having to delay construction until readings have been taken.

There is another reason why it is wise to take cross-sections across the entire right of way width, even though construction may not extend to its limits. In rock cuts that require the use of explosives, overbreakage (the unavoidable blasting of masses outside the regular slopes), frequently occurs, in which case a certain amount of the excess rock moved must be paid for under the specifications; or in deep cuts slides of insecure masses may occur while the job is still under construction, necessitating the removal of the material from the roadway by the contractor. These quantities can be easily determined by the engineer if he has already taken readings to the limits of the right of way.
If time permits, it is advisable to re-calculate and re-distribute the excavation and embankment quantities on the basis of construction measurements before any actual work is done, the purpose being to make any necessary changes ahead of the grading. The quantities given on the plans are for bidding purposes only, payment being made for the excavation and borrow as determined by the engineer on construction.

After the road has been roughly graded, finishing or fine-grading stakes should be set, so that the road may be brought to the correct lines and elevations as shown on the typical section and profile. The center line must be re-run and the stakes set every fifty (50) feet on each shoulder. As much measuring, checking and itemizing will be done later on, it will prove very convenient to the engineer if at this time he will offset the center stakes outside of the construction lines, marking the station number and distance from center line on each stake. Grades are then given by means of stakes that have been set on the shoulder lines. The best results will be obtained by running bench mark levels and driving these stakes to the proper elevation, marking the tops with lumber crayon. By the use of these finishing stakes, or "blue heads", the road-bed and side ditches can be brought to the correct grades and lines. It is good practice for the engineer to require the contractor to preserve these stakes during his fine grading operations by working
within them, so that when the work has been completed, these stakes will be there to prove whether or not the road is true to line and grade.
CONTROLLING BALANCE
OF EARTHWORK

During the actual grading operations the distribution and balancing of the earthwork quantities is of the utmost importance. Many factors affect the degree of shrinkage of embankments. Different kinds of clay, sand, loam, rock, etc. have different shrinkage factors. As it is not always possible to accurately estimate the percent of shrinkage or swellage that will take place in an embankment, the resident engineer must watch the distribution closely and make such changes as will be necessary to bring about correct balancing of cuts and fills.

If he has the time, it will be well worth the effort, for the engineer to take cross-sections of the job and re-compute and re-distribute his quantities before the contractor begins grading. He will then be in a better position to size up his job and he will have an idea where to expect variations from the plans. For example, if a fill is to be built in a swamp with material from a certain cut, he will know that more material than is ordinarily needed for a fill of the given size will be required for this particular embankment. He can then plan where to obtain the extra excavation that will be needed. Such details cannot always be taken into consideration by a draughting force working up a set of plans in an office.
When the engineer sees that the quantities will not work out as anticipated on the plans, he must make a change somewhere. It is here that experience and good judgement come into play. Good engineering consists of doing the most economical thing consistent with good results.

Let us suppose that an excavator is in a large cut in which more rock was found than was expected, and that the swellage of the rock, and the fact that it would have to be taken below grade would produce an excess of material which would have to be wasted. Let us further suppose that this cut is on a steep grade, and that at the time of consideration, approximately one-half of it has been removed. To make the quantities balance out, either the excavation must be decreased or the embankment increased. By taking readings in the cut the engineer can estimate how much material remains. He can then parallel the grade in the cut by an amount that will correct the distribution. Had the grade been a comparatively flat one, he could have chosen to steepen it slightly to reduce his excavation, but since it was already steep, he raised it parallel to the grade on the plans.

Sometimes it is better to raise the grade of a fill with excess material rather than eliminate this excess by reducing the excavation. When there is a steep, rising grade ahead of a long, flat one, the appearance from a distance is one of a very abrupt
break unless the two grades are connected by an unusually long vertical curve. Lengthening vertical curves in such locations with excess material is well worth the cost.

(See attached profile sketch for example both of paralleling steep grade in rock cut and increasing length of vertical curve at bottom of hill, made by writer on Federal Aid Project NRH 258-c, DeKalb County, Georgia, November 1934.)

It is well to remember that long vertical curves are very desirable from the point of view of both safety and appearance. Therefore, when a change in grade is necessary to balance the earthwork, the experienced engineer will, in effecting it, also lengthen any vertical curves within the change, if it is possible to do so. It is obvious that longer vertical curves, especially over the tops of hills, will afford longer sight distances ahead to motorists.

Let us now suppose that excavated material is to be hauled in both directions from two or more successive cuts located fairly close together, and that the distribution is running a little ahead; that is, that more earthwork is hauled forward than estimated. This means that less will be needed to be hauled back from the cut ahead to complete the connecting fill. If the material is of such a nature that it will not slide, the slope can be steepened in this
(the second) cut (before excavation on it is begun) to reduce the quantities back to a state of balance. Solid rock will stand on slopes of one-half or even one-fourth to one. But deep cuts in clay, shale, or boulder formation had better be left on slopes of at least one to one, or slides may ensue.

When the excavation is running short, either a borrow pit (see below) or a lowered grade will be necessary to bring about a balance. In the interest of economy, a lowered grade that will reduce the embankment rather than increase the excavation is preferable, if such a change can be made without adversely affecting the grade and the drainage of the road.

(See attached example of such change made by writer on Federal Aid Project NRH 104-c, Fayette County, Georgia, in spring of 1936.)

If the earthwork is only slightly out of balance, especially if it is running short, correction can be made by flattening the back slopes of one or more cuts uniformly to obtain the necessary excavation. At the same time both the appearance and stability of the back slope will be improved, and if the slope happens to be on the inside of a curve, the sight distance will be increased.
ACTUAL CONSTRUCTION

CLEARING AND GRUBBING

A contractor usually begins actual operation on a grading contract by clearing and grubbing when it is required. Where this item is paid for by the acre, the engineer should, of course, take measurements at once.

In general, it is advisable, and usually called for on the plans or specifications, that the entire right of way width be cleared and grubbed. However, the engineer should use his judgement. Quite often, trees may be out of the limits of construction but in the right of way. If these trees will not interfere with the drainage of the road it may be worth while to spare them. There is no question that shade trees on the side of a road lend beauty to it. If they happen to be on the inside of curves, however, or at such other locations that they will obstruct the view of the road ahead, they should be removed. Sometimes the amputation of a branch or two from a tree will give a clear vision ahead.

(See picture.)

The clearing and grubbing always should be kept at least one thousand (1000) feet, and preferably one-half mile ahead of the grading. If this is not done and the grading is allowed to creep up on the clearing
VIEW OF ROAD WITH SHADE TREES ON RIGHT OF WAY.
LOWER LIMBS WHICH WERE OBSTRUCTING
VISION HAVE BEEN REMOVED.
and grubbing, trouble may ensue. Enough labor to do extra work is not always on hand, and it may be necessary to slow down the grading to get stumps, roots, weeds, and other debris out of the roadway before a fill can be made.

Stumps under high fills should either be grubbed or cut off close to the ground. Large stump holes require as much as three cubic yards or more of earth to be filled. In dense forests, particularly in stumps, the cost to fill these holes will be considerable. At present, the Georgia State Highway Specifications require that, under fills three feet or more in height, stumps shall be cut off within six inches of the ground. Stumps under light fills must be grubbed.

All stumps on the right of way and outside of actual construction should be removed and the holes filled back. Weeds and other vegetable matter should also be cleaned off and disposed of. As stumps will not easily burn alone, it is good practice to save brush piles until the stumps have dried sufficiently to burn, and then burn brush and stumps together. Stumps may be dragged off and thrown into some nearby ditch or gully, to help arrest erosion if the contractor prefers, and the property owner consents. In no case, however, should they be allowed to remain on or beside the right of way, as they are most unsightly.

No vegetable matter should be allowed to go into embankments. Grass, weeds, pine needles, etc.
can either be cleared off the road by hand, or by being pushed out of construction with a road-machine and then disposed of.
Among the most essential features of a road are its drainage structures, and too much attention cannot be given to their selection and installation.

Pipe culverts may be of concrete, vitrified clay, cast iron, or any of the different types of corrugated metal. Each type has its advantages and disadvantages. Local conditions should be studied, and the kind of pipe best meeting these conditions is the kind of pipe to be preferred. Concrete has probably the lowest first cost, but is heavy and breakable. Vitrified clay, while it makes a very pretty line, is not used so extensively under roads due to its comparatively low crushing strength. Corrugated pipe of approved metal is light, comes in lengths up to approximately twenty (20) feet, and is easy to lay. The paved bottom type is to be preferred, the asphalt coating resisting both wear and rust.

Under high fills, however, the rigid types mentioned above (concrete and clay) are likely to crush. The light metal pipes, too, are inadequate to hold up heavy loads. Under such conditions pipe made of cast iron should be used—especially if the pipe is twenty-four (24) inches in diameter, or larger.

Great care is necessary in the installation of a pipe culvert if good results are to be obtained.

A simple but good method is the following: Drive a
stake at each end of the trench in which the pipe is to be laid, some convenient height above grade—say twenty-four (24) inches. Pull a cord or wire taut across the tops of these two stakes. Then the grade may be checked at any point in the trench. (See picture.)

Pipes will deflect a little in the center under the load of a fill, particularly if the fill is jetted. For this reason a slight camber should be put in the grade of the culvert. One to two inches is sufficient in the case of rigid pipes, but from three to five inches should be used with large size corrugated metal culverts, under heavy embankments.

Careless installation usually results in a decided dip in the grade of the pipe line. This is not only evidence of poor workmanship, but it reduces the effective opening of the culvert as well.

If concrete or clay pipe is used, the joints should be sealed with mortar to prevent seepage. An open joint may cause a washout under the road.
CHECKING GRADE FOR LAYING OF
PIPE LINE
After a pipe line has been installed, and the joints sealed, it is ready for back-filling. Select material—good clay if available—is to be preferred for this purpose. The dirt should be deposited in thin layers and tamped in place. Particular care must be taken in tamping the dirt placed in the trench underneath the sides of the pipe line. If this is not done there will be danger of displacement of one or more of the joints when the fill is dumped in place next to the pipe.

If the trench in which a pipe line is to be laid is found to be of solid rock, the excavation should be taken at least six inches below grade, and then filled back up to the required elevation with clay or other suitable material. This layer will act as a cushion between the pipe and the rock bed.

Firm foundations of uniform bearing for all culverts, but especially concrete box culverts, are highly desirable. If the bearing capacity of the soil beneath is not uniform throughout the length of the structure, greater settlement will take place on the softer end, with cracks in the concrete resulting. For this reason, while an unyielding foundation is, of course, to be preferred, it will be better to have a foundation that is all soft, rather than one which is hard for part of its length.

Where muck or similar material is encountered, it should be taken below grade approximately twelve (12) inches, and back-filled with field stone up to about
six inches in size, placing the larger pieces at the bottom and the smaller ones above. Then the entire foundation may be topped with a two inch layer of crushed aggregate on which the bottom slab of the culvert may be poured. (In the case of a pipe culvert a light layer of clay should be placed on the stone to act as a cushion, as above.)

Concrete should never be placed on a soft or sloppy foundation as the mucky material will work up into the concrete. As a substitute for the method of back-filling with rock, a wooden floor may be built. This can be done by nailing boards on timbers laid longitudinally in the ditch. The footing of the culvert is then poured on the floor. Since the foundation is of uniform strength in such a case, no uneven settlement is likely to take place.

Whenever possible, the engineer should locate the culvert outside the stream bed and at right angles to the center of the road. If there is sufficient fall above the culvert, the structure may well be placed in the hillside. Here the foundation is likely to be firmer, and while more excavation will be necessary, the extra cost will be compensated by a saving in concrete, affected by the higher flow line, which will decrease the height of fill above the culvert, and hence its length.

Quite often, when an old road bed is being widened, the culvert in place may be in good condition,
but too short for the new, wider road. In such a case, rather than throw the old structure away, lengthening is desirable. The parapet and wing walls of the culvert in place must be removed and forms built to meet the line and grade of the barrel. The exposed reinforcing steel should be allowed to extend into the new concrete to tie it with the old structure. Of course, new wings and parapets will be built at the ends of the necessary extensions to catch the new fill. (See picture.)

Occasionally, where the old structure is only slightly too short, instead of extending the culvert, it will be more economical only to raise the parapet walls and wing walls to meet the new embankment. This is easily done by drilling holes for dowels in the top of the old walls at approximately twelve (12) inch centers, setting the new forms and steel, and pouring the concrete to the required elevation.

Section Showing Raising of Parapet or Wing Wall
END VIEW OF EXTENDED CULVERT BEFORE
WIDENING AND DRESSING OF OLD
EMBANKMENT
At the ends of pipe culverts under the road, concrete end walls or "head walls" are built, the purpose being to keep the fill back out from the opening of the pipe, and to protect the ends of the structure (which would otherwise be exposed) from breakage.

Several types of end walls are used, each designed to meet certain drainage conditions. (See picture.) On the upper end, if the water approaches the structure from both directions, that is, if the inlet is lower than the ditch grade on either side, the straight wall is used. On the other hand, if the inlet is on a grade, a wall with an L type wing is desirable, to prevent the water from running past the culvert. The L type end wall may also be built on the lower end if it is needed to force the water in a particular direction. In general the wall with U type wings is to be preferred on the outlet end of pipe lines, since the paved floor between the wings prevents the water from undermining the foundation at the end of the structure. In the case of large pipes, as in the thirty-six (36) inch line shown in picture, end walls with 45 degree wings may be used.

On mountain roads, if enough flat stone is locally available, the head walls may be built of grout ed masonry. Under such conditions, not only is there likely to be a considerable saving in cost, but the rustic appearance of the stone walls will be more in keeping with the natural surroundings.
U TYPE END WALL

L TYPE END WALL
END WALL WITH 45 DEGREE WINGS

STRAIGHT END WALL ON DOUBLE LINE OF PIPE
It is not the purpose of this paper to go at any length into the design and control of reinforced concrete, but inasmuch as in the construction of graded roads concrete is necessarily used, it will be well to discuss this subject briefly, as it affects concrete culverts.

Having obtained a satisfactory foundation for the structure as discussed above, we proceed with the construction of the bottom slab. Before permitting any pouring, the outside forms of the side walls and wing walls must be set and the upright steel placed in position so that it will bond the footing and walls together. It is essential that the steel be set, and securely fastened in the positions of the maximum stresses, which are the inside of the side walls, the bottom of the top slab, and the top of the bottom slab. The steel should be wired together at all the points where bars cross, and held in its proper place by pre-cast concrete blocks or other supports during the pouring and spading of the concrete within the forms. If displacement of the steel is allowed to take place it is obvious that it will not serve its purpose. Only deformed bars should be used.

It is necessary that the forms be of dressed lumber, constructed to the proper dimensions and securely braced. The lines and chamfer strips must be straight after all wiring, bracing, and strutting has been done, the forms painted with a light, colorless
oil, and all dirt, saw-dust, and other debris washed clean from within the structure. The engineer or inspector should satisfy himself completely, by personal checking, that all of the above details have been taken care of before he permits pouring to begin; otherwise confusion and poor work are likely to result. It is much easier to correct a faulty form than to attempt to rub out a bad line from concrete that has hardened, and nothing shows up the quality of workmanship so much as the lines and chamfer edges.

Of course, the concrete should be mixed as dry as possible and still be consistent with good results. A two to three inch slump in slabs, and a three to four inch slump in thin sections will probably give the proper consistency. It is necessary that enough men be employed to thoroughly spade the concrete, otherwise "honey-comb" may result.

After the footing and the side walls have been poured, the forms for the top slab may be built, the steel laid, and the top slab poured. Since the culvert will be covered with earth it is not essential to have a good finish on the top and on the outside of the walls. However, the floor of the culvert should be reasonably smooth.

FINISHING

After the concrete has set approximately twenty-four (24) hours, it will be safe to remove
the forms from the wing walls, parapet walls, and outside the barrel, since these parts will not be subjected to stresses until after the fill has been placed on and around the culvert. Care must be taken in removing the forms not to injure the still fresh concrete. However, the forms inside the barrel, and particularly those supporting the under side of the top slab should remain in place from ten days for short spans to twenty-one (21) days for the longer ones.

Of course the object for early removal of the forms is to finish the exposed surface before the concrete becomes too hard. All form marks, minor projections, and other irregularities can be easily removed with a carborundum stone, and holes, depressions and "honey-comb" pointed with mortar, and the entire surface rubbed until smooth. The lines and chamfer edges of the wings and parapets especially need attention as they constitute the ornamental portions of the structure. A second rubbing of the concrete, several days after the first, will give it a smoother surface and a white, almost marble-like effect. It is to be remembered, however, that this last rubbing is intended only to produce a fine finish, and that all irregularities must be corrected on the first rubbing when the concrete is not yet very hard.
Curing

Concrete, in order to attain its full, potential strength, must be properly cured—that is, kept moist in its early stages. Even while pouring, rapid drying out may cause hair cracks, and therefore it is essential to frequently sprinkle a slab as it approaches its initial set if the day is hot and the sun is striking the surface of the concrete.

For good results a curing period of about seven (7) days is recommended. The top slab may be covered with dirt and kept wet during the curing period. In the case of the wing walls and parapet walls where discoloration must be avoided, wet burlap is commonly used.

Back-filling

Since concrete must be of considerable age before it has attained sufficient strength to withstand heavy loads, a period of twenty-one (21) days should elapse before filling over and around the culvert (especially behind the wing walls where the action is of a cantilever effect) is permitted. Close inspection is required here, with only select material used, deposited in thin layers and tamped in place. Only after the back-filled material is at least a foot above the top of the culvert will it be safe to permit vehicles to cross it. Flooding with water may be substituted for tamping, to insure compaction.
Most heavy work under the above head is done today with power shovels. Not only can earth be excavated more rapidly with this kind of equipment, but it has the advantage of faster hauling, especially over long distances when used with trucks. Furthermore, if the material encountered happens to be some sort of soft or loose rock, the power excavator can readily dig it. Where the haul is short, and no appreciable amount of rock encountered, tractor-pulled earth-moving equipment, such as the "ball-wagon", "Le Tourneau", etc. may be used to advantage. This latter type does leave both the cut slope and the grade in better condition than the shovel, and therefore less work will be required later on when the job is dressed up.

Before any actual excavation is begun, the foreman in charge may save himself considerable trouble by taking several precautions. First, he must thoroughly familiarize himself with the proportionate distribution of the earthwork, and the slope, roadway section, ditch, and superelevation, if any. Of course, he will obtain this information from the engineer or inspector. Then he must make provisions for preserving his slope stakes and for cutting the correct slope, ditch, and shoulders. He can save the stakes with all the information on them by off-setting them a safe distance out, let us say ten (10) feet. Then, since the point of their original location will, in the course of the work, be covered up with loose
earth, etc., he should drive another stake some twelve (12) or eighteen (18) inches into the ground so that he may at all times have the point of intersection of the original ground with the slope at each fifty (50) foot station. Then, as the shovel approaches a section of the cut, he may guide the operator by setting rows of stakes two or three feet high and spaced about five feet apart on line between the slope stakes at each station, another row for the ditch line, and a third row for the shoulder line.

Since the teeth of the dipper will leave marks in the slope it is well to cut about six inches short of the desired surface, so that when the bank is dressed to eliminate holes, bumps, and irregularities, no extra material will have been removed from the slope.
In taking out a cut, it is essential that the sides be cut uniformly and to the true slope to which the stakes were set.

(See picture of cut on Federal Aid Project 435-D, Laurens County, Georgia, December 1937.)

If the operator of an excavator is careless, or incompetent, or hurries his work too much, an unsightly slope and a very poor ditch line will be had when grade is reached. It will then be necessary to widen the entire cut in order to get a uniform line at the bottom.

The booms and dipper sticks of most excavators are not long enough to cut a straight slope of more than about eight feet. At a greater height than that the dipper will describe an arc, with a concave slope resulting. To avoid this, deep cuts should be taken out in layers of about eight feet each. Modern road-machines are so constructed that the blade may be raised cut and up, to trim banks. Since these blades are only ten or twelve (12) feet long, it will, of course, be necessary to blade each layer of a cut, before excavation on the one below it is begun. Otherwise, the road-machine will be of use in planing only the lower part of a cut, and the upper portion will have to be dressed by hand.

(See picture.)

During the course of the work it is highly advisable to frequently check the slope, as it is being
POWER SHOVEL AT WORK IN DEEP CUT, BUILDING FILL APPROACHES TO BRIDGE IN BACKGROUND, (ALSO UNDER CONSTRUCTION)
COMPLETED CUT,
SHOWING UNIFORMITY OF SLOPE
AND DITCH LINE

DRESSING SLOPE OF CUT WITH ROAD-MACHINE
cut, to determine whether or not it is true, and to make the necessary adjustments if it is not. This can be done either with a hand level and tape, or by the use of a wooden "templet" equipped with spirit level. The templet can be constructed so that it may be adjusted for any particular slope.

By setting this templet to the required slope and placing the hypotenuse of the triangle against the bank, the spirit level will at once indicate whether the slope is correct or not.

It is easily apparent that considerable saving in excavation, as well as a neater appearance of the work may be effected by exercising some care in excavating so as not to cut beyond the true lines and slopes.
Where the excavation is in solid rock, explosives of course must be used. Most men, experienced in this sort of work, drill a great number of holes—as high as one hundred (100)—to a depth of about two feet below grade so as to be certain that the rock will be shattered low enough. Then all the holes are loaded with explosives, connected with wire to a battery placed a safe distance away, and touched off together. A competent dynamite man will have very little rock thrown to any great height or distance, even on a very heavy blast.

Immediately after the blast the excavator can set to work dislodging the shattered rock and loading it on the vehicles to be hauled to the fill. It is likely that further drilling and blasting will be found necessary to break up fragments of rock too large to be handled by the shovel and trucks.

Of course, a rock cut cannot be cut smooth and true to slope as one in clay, but large irregularities and overhanging masses should be removed. Any insecure rock left in the bank presents a hazard and must be taken out to solid matter.
**Borrow**

When enough earthwork is not obtained from the regular roadway excavation to complete a given fill, the additional excavation which must be obtained for this purpose is known as "borrow".

Under ordinary conditions, a borrow pit, even when called for on the plans, should not be gone into until all the material has been removed from the available cut or cuts. Arrangements may then be made for borrowing the necessary amount to complete the fill. If the borrow is estimated and removed before the roadway excavation, waste may result.

It is usually best to obtain borrow within the right of way—if suitable material within an economical hauling distance is available—by widening some cut. It is readily apparent that by widening the ditches the road drainage will be improved. If practicable, the widening should be done on the inside of curves to increase the sight distance. The borrow pit should parallel the shoulder of the road with regard both to alignment and grade.
The dotted line in the preceding sketch represents the widened cut section produced by borrowning.

A convenient method is to set the shovel in the ditch and simply cut the width of its tracks; or, if a tractor-pulled scraper of some sort is being used, to cut the width of the pen. When enough material has been obtained, with the widening carried through only a part of the cut, the borrow pit should not be abruptly cut off but should be gradually tapered off into the normal section of the cut.

When the quality of the material necessary, or the quantity needed, is such that borrow must be resorted to outside the limits of the right of way, the engineer will of course have to take the necessary cross section elevations before any excavation can begin in the borrow pit. He must run a reference line that can always be re-established. Particular attention should be paid to taking the cross sections at right angles to the reference line. It is very easy to get off line if the direction is estimated by eye, and in hilly country this will result in failure of the final section to close with the original grade line when plotted up on cross-section paper, and therefore in great inaccuracy in the earthwork computations. When the borrow pit is large, it is best to turn ninety degrees at each section with a transit. Of course, the reference line and cross section readings are not necessary if the borrow is made by widening a cut within the right of way limits if the procedure as outlined
under "Trading Stakes" above, has been followed.

It is quite important that borrow pits be left in a slightly condition. The banks should be cut on a minimum slope of one to one, and the bottom taken to a uniform grade so that no water will stand. After all material needed has been removed, the appearance of the borrow pit may be greatly improved by blading with a road machine and dressing the slopes to a reasonably neat surface.

In selecting a borrow pit, the engineer, by the use of good judgement may not only improve the appearance and drainage of the road, but also exercise some fairness towards the contractor. For example, borrow in rock should never be made unless unavoidable. Again, it is unnecessary to require work in a pit containing trees, stumps, roots, etc., if another pit, relatively clean, is available close by.

Subgrade Excavations

The quality of the material forming the top foot or eighteen (18) inches is of great importance, as this layer forms the base on which the pavement is to be laid.

Where there is likelihood of rock close to the surface, the graded section to be tested may be scarified to the desired depth with a road ripper to reveal the presence, if any, of rock or boulders. If rock is encountered, it should be removed to a depth of one foot below
grade and back-filled with clay or other suitable material available. At first thought it may appear that no better foundation for a pavement than solid rock could be had, but the surfacing, if resting directly on rock, would soon be broken by the force of the vehicles striking it from above, while a layer of dirt will act as a cushion between the solid bed and the pavement.

Any soft, flaky, or unstable subgrade, that will not serve as a satisfactory base for the surface contemplated, should also be removed a foot or more below grade, and replaced with suitable material. Sometimes, where "gumbo" or muck, is encountered, instead of excavating below grade and back-filling, better results at less cost may be attained by raising the grade with good borrow material.

When the location is in woods, in a thicket, or in pasture land, a layer of decayed vegetable matter is usually found on the surface of the ground from six inches to a foot in depth. As this material will not compact, or "set up", under traffic, it is advisable to remove it at the "grade point" (that section in the grade where the cut ends and the fill begins) for a distance of from fifty (50) to one hundred (100) feet, and replace it with suitable material from the excavation. Otherwise there will be a bad spot in the subgrade at each "grade point".
Typical Ditch Section in Cuts

Few things have as much bearing on the appearance of a new road as the lines and slopes on the shoulders and side ditches. The latter must be parallel to the roadbed in line, and, where drainage permits, also in grade.

Formerly in Georgia a one foot V type ditch was used. At present, however, the practice is to cut ditches two feet deep (or even more), with a three to one or four to one front slope and a two foot flat bottom.

The larger ditch increases the excavation considerably, but it has obvious drainage advantages. More surface water can be taken care of, while any seepage water is kept farther away from the roadbed than in the case of the one
foot ditch.

Then, too, the larger ditch is easier to maintain. More or less material will slide into the ditch from most cuts during winter; of course, only a small amount of dirt will fill up the small ditch, stopping drainage, while the two foot flat bottom ditch, because of its much larger area, will hold several times as much dirt. This will give the maintenance forces time to clean the ditches out before drainage is stopped.

Another advantage of the larger ditch is the fact that it is deep enough for a fifteen (15) or eighteen (18) in drain pipe to be placed in it under cross roads or driveways and covered, without producing a bump.

Still another advantage of the large ditch section is that its greater width provides longer sight distance around the inside of curves.
With the possible exception of drainage, the most important single item involved in the construction of a graded road is the building of embankments. More failures in pavements are to be found over embankments than in excavated sections; and this is due largely to improper placing of the fill material, permitting settlement after paving.

In preparing the ground on which a fill is to be laid, it is advisable to remove all vegetable matter (except stumps, as discussed under "Clearing and grubbing"). Then the surface should be scarified, or harrowed if in a soft field, to insure bonding with the initial layer of embankment material to be deposited. If an old fill is to be widened, or if the original ground happens to be on a steep hillside, stepping is advisable to prevent sliding of the new embankment.

The outstanding essential that must be sought in the construction of embankments is compaction. Wherever possible, the fill should always be brought up in horizontal layers not exceeding twelve (12) inches. If the earth is hauled in trucks and dumped on the grade, uniformity in depth of the layers and smoothness of surface may be obtained by blading the loose material down with a road machine. Then the vehicles may run over the grade and thoroughly compact the layers. Instructions to the drivers should be given to cover the entire roadway width rather than for all
the trucks to follow one pair of tracks.

If the lowest part of the fill happens to be in a deep ravine, it will, of course, be impracticable to begin the light layer at once. But as soon as the embankment is high enough so that it is possible for the trucks to run over it, the thin layers should be begun.

Placement of the fill in layers is also impracticable if an old embankment of considerable height is being widened. Here, however, the new material will be out on the slopes where compaction is not essential, since the pavement will be laid on the old roadbed which has been settled by time and traffic. That part of the fill which will bear the pavement is the part that especially needs attention.

The material which goes into an embankment should be free of any material which is likely to decay. Many a failure in pavements has been traced to vegetable material which had rotted in the fill, permitting settlement. Where large earth handling equipment is being used to do the grading, it is very easy to get stumps, logs, roots, and other organic matter mixed in with the load and dumped on the grade. Then, of course, they must be thrown out. Here again, the thin layers prove advantageous; for when the dumped load is bladed down, the roots, etc., will be exposed, and can then be taken up and thrown out beyond the construction limits.

When the embankment is being built of shattered
rock, it is extremely important that the voids between the larger particles be filled with smaller particles and dirt. Otherwise settlement is likely to take place. If the upper portion of the fill contains sand or clay, particles will, in time, drop down between the interstices of the rock fragments below, with failures in the pavement resulting.

When early paving without previous hydraulic settlement is being contemplated, the embankment should be brought up in layers not more than eight inches thick, bladed with a road-machine or auto-patrol, and rolled with a three wheel roller weighing at least ten tons.

If one can be secured, a "sheep-foot" type roller will afford greater compaction.

(See picture.)

This type of roller is a relatively new development in road-building equipment. It consists of a cylindrical drum, the surface of which is studded with knob-like protrusions, or "feet", made of metal, and flat on the ends. The drum is filled with water to give it added weight, and is drawn over the grade with a tractor. The feet concentrate the load on small areas, producing greater compaction. The effect is similar to, and the inventor may have received the idea from, an old fashioned grading outfit of wheelers drawn by teams. Of course, several trips over the grade for each layer of embankment are necessary to cover the entire area. This type of roller can be drawn by a tractor over rough ground, it can be used in the ditches where an old road is
SHEEP-FOOT TYPE ROLLER
being widened, and may even roll a fill slope in side hill work if it is not too steep; whereas a three wheel steel roller is of use only where the grade is level and smooth. Another advantage of the "sheep-foot" roller is the fact that it roughens the surface of the grade so that the next layer will better bond to it.

If caution is taken in building up an embankment, little waste in earthwork will result. Poles equal in height to that of the fill may be cut and stuck into the ground at each station. Then the fill may be carried up, care being taken to maintain the slope correct at all times. The same templet described under "Excavation" may be used here. If one or two men with shovels are employed on the slope to keep it smooth, little dressing will be required afterwards. As grade is approached (and it may easily be checked by sighting to the top of the fill poles), the distance across the grade can be checked for width, and stakes driven into the fill at the shoulders so that the tops will be at the proper elevations for the last layer of the embankment.

In general, flat fill slopes are to be preferred. Not only do they present a more pleasing appearance, (See Picture,) but they are less subject to washing, and therefore will require less maintenance. Furthermore, flat fill slopes are less dangerous than steep ones. A car may run off a four-to one or six to one fill, and possibly not only not turn over, but even run back up to the road.
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VIEW OF LONG TANGENT SHOWING FLAT FILL SLOPES
IN BACKGROUND
Of course, the cost plays a large part in determining the slopes to be used. Hills of great height and length must be built with steeper slopes, or their cost will be prohibitive. Besides, in such cases, the slope is likely to carry beyond the right of way. The natural angle of repose of earth material is one and one-half to one, but, in general, no slope steeper than two to one should be used, except in mountainous sections or unusually high fills elsewhere. Hills under twelve (12) feet in height may be put on a three to one, and under six feet, on about a five to one slope. These figures are by no means fixed requirements, but only general recommendations to be followed where practicable.

Embankments that have been built in layers of twelve (12) inches or more should be left slightly higher than the correct elevation, to take care of shrinkage, if hydraulic settlement is contemplated (q.v.), or if paving is not expected for some time. An allowance of five per cent of the total height of the fill for shrinkage is generally sufficient.

Unless very light layers were used along with rolling, it is preferable to delay paving over high embankments for a year or two—at least over one winter—so, while many roads have been paved a very short time after the grading and have stood up, it has also been demonstrated that hydraulic settlement is not always satisfactory.
The cost of maintenance of roads will depend largely on the provisions made for taking care of the water. Therefore, the item of ditching is of great importance.

Berm or surface ditches, paralleling the road are intended to intercept the water before it can reach the roadway, and to carry it to some satisfactory point of discharge. They are needed, of course, only on the upper sides of cuts or fills where the ground slopes toward the road. If the quantity of water to be carried is not appreciable, a trapezoidal ditch about a foot deep, and a foot wide at the bottom, with its sides cut on a one to one slope, is generally satisfactory. Where the areas draining to these ditches are larger, correspondingly larger ditches will be required.

Ditches should be cut at the downhill ends of cuts so as to turn water away from the embankments. If the slope of the ground then is such that the water will tend to wash the toe of the fill, a ditch paralleling the fill can be cut to take the water to the nearest culvert.

Sometimes where two low points in the profile are close together, with only a slight rise between them, and a culvert called for at each, it may be possible to eliminate one of the structures by cutting a ditch from
the higher point to the inlet of the lower culvert. If the flow in the culverts happens to be in opposite directions, that is, if the water flows through one culvert and then back again through the other, both structures might be eliminated by means of a large ditch if a satisfactory point of discharge is near. In any such case where a large volume of water is to be carried beside the road, caution must be exercised to avoid washing the slopes. If there is any doubt of the advisability of eliminating a culvert by means of ditching the water, it will be safer to put in the culvert. This is a good rule to follow.

Quite often it is necessary to change or straighten channels of streams, or to widen and deepen existing ones, at bridge or culvert sites to insure rapid run-off in high water.
Indeed, in the case of small structures, it is frequently necessary to cut ditches to the inlet and from the outlet so that the water may enter and leave the culvert. A new channel should be carried a sufficient distance upstream and downstream to make the change in the course of the stream effective. It is essential that the water be directed away from the embankment slopes.

(See picture.)

It will prove more convenient if the channel change at a bridge site is made before the structure is built, thereby permitting the shovel (if one is used to do the work) to cut the entire channel. On the other hand, if the ditching is delayed until the spans above the location of the new channel are built, the portion under the bridge will have to be cut by hand. Furthermore, if the fill approaches to the bridge have also been made, and the clearance is insufficient for the shovel to go under, (and this is usually the case), the shovel will have to be taken to the end of the fill to cross the road, and back down the other side to cut the remainder of the channel on the other side of the bridge. In long, swampy places this is inconvenient and expensive.

It is preferable to so locate the new channel that the middle span or spans of the bridge be symmetrical about the stream bed, and approximately at right angles to it. This plan will improve the appearance of the bridge and channel, and at the same time keep the water at the farthest possible distance from the
STRAIGHT TYPE END WALL ON PIPE CULVERT WITH INLET DITCHES

DRESSED SECTION OF ROAD
NOTE DITCH TURNING WATER AWAY FROM FILL SLOPE AT RIGHT
approach fills.

When the material from a channel change is satisfactory and the attending conditions permit, it may be used in the embankment, thereby saving excavation or borrow. If it has to be wasted, such disposition must be made as will leave the banks neat in appearance. In such a case, some of the material may be used to fill up the old stream bed. The remainder should be placed and dressed down neatly several feet from the edges of the banks; if deposited too close, it may soon wash back and fill up the channel.

Flat slopes on the sides of all ditches will decrease caving in. If the material is fairly substantial, a one to one slope will be satisfactory. In muck a two to one slope is preferable.

French Drains

When water is encountered in a cut, proper subdrains to convey the water out must be built or the subgrade will remain soft and unstable. These drains, known as "French Drains", may be constructed as shown in the diagram on the following page.
The bottom layer may be of stone or gravel spread to a uniform grade, and serves the purpose of a clean floor on which to lay the pipe. The tile is laid with the joints open so that the water may enter. Perforated tile may be used. The larger stones are carefully placed around and over the pipe taking care to keep all mud out so that the water may always have freedom of flow among the interstices of the stone. Smaller stone is placed above, to more or less fill the voids at the top of the layer of larger particles, and about a foot of dirt is used to bring the ditch...
up to grade. If the seepage is from the bank alone, a French Drain is needed only under the side ditch, but if springs are under the roadbed as well, lateral drains to carry the water to the drain at the side will also be required.

Sub-drains are expensive, but they should be put in, if they are necessary, during the grading of the road, and not just ahead of the pavement, so that ample time may be had for settlement and for the observation of the performance of the drains.

In my experience, French Drains, built as outlined above, collected enough water from springs within the roadway, to discharge steadily a continuous stream.
HYDRAULIC SETTLEMENT OF FILLS

When early paving of the road is contemplated, the embankment can be artificially settled in a short time by the method known as hydraulic settlement, or "jetting". Briefly, this consists simply of saturating the fill with water to make it settle at once, so as to prevent failures in the pavement after it is laid.

The method used on construction is as follows: The surface of the fill is first ploughed. A pipe line one inch in diameter is laid from some water supply to the embankment, and a hose connected to the end. Then a pipe one-half inch in diameter and approximately equal in length to the height of the fill is attached to the end of the hose forming a nozzle. Water under pressure is pumped thru the pipe. The jet is inverted and forced into the fill a depth of about two or three feet and held at this level until water comes out of the hole. Then the jet is lowered an additional two or three feet until the water again comes out of the hole. This process is continued until the jet reaches the bottom of the fill. Another hole is then jetted in a like manner, and so on, until the entire fill is saturated. The holes should be spaced about five feet center to center on the road-bed, with the outside holes about two feet from the edges of the fill. Two or more jets used simultaneously will speed up the operation if enough water is available. Jets often remain in the same holes for many hours if the material is dry and of such
a nature that it will hold much water.

During the process of jetting it will be well to throw up small earth dams at the edges and across the road at intervals of about twenty-five (25) feet, to pond up the excess water, so that instead of running off it will soak through the ploughed surface of the fill and further aid settlement.

Great care must be taken in jetting over culverts. The jets should be sunk so as to approach the culvert gradually from both directions. Then, when the distance from the structure on each side is about one and one-half times the height of the fill, a row of holes should be sunk directly over the culvert. That part of the fill immediately next to the culvert should be jetted last. The intent of the above method is to equalize the pressure on the sides of the structure. As earth saturated with water will act almost as a liquid, the side walls, or wing walls, may be cracked if the above precaution is not taken.

A period of from six to eight weeks should elapse after jetting before paving is permitted, to give the excess water time to seep out and the wet fill time to shrink.
Provisions must be made for taking care of traffic at all cross roads, and for property owners to enter and leave the driveways to their homes and fields.

When the side road or driveway is located on a grade and the water in the road ditch must get across, a pipe will be needed in the ditch parallel to the highway, and under the side road. This pipe is termed a "side drain" and the connection formed a "turnout".

Side drain pipes may be of concrete, vitrified clay, corrugated metal, etc., but the metal pipe is most often used on account of its light weight and its easy installation.

Turnouts to fields should be spotted, whenever possible, at the grade points so that little grading will have to be done. Of course, Talbot's formula for waterfall should be used to determine the size of pipe needed, as in the case of cross drains.

A great many side drains can be eliminated by building ramps to fields or driveways at points where the water can be made to flow in opposite directions, as at the top of a hill, or just below a point of discharge.
DITCH CHECKS

On steep grades of appreciable length through excavated sections, considerable water will collect in the ditches in spite of the surface ditch above. If the formation is anything but rock, scouring will take place, with the result that soon a deep ditch, which is both ugly and dangerous, will be on either side of the road.

To prevent this occurrence ditch checks, or baffle walls, are put in. These may be of concrete, of local stone, or of sod.

The checks are built to fit the shape of the ditch and are anchored into the front and back slopes. Sod ditch checks are put in with a board to help keep them in place until the grass takes hold.
Ditch checks are placed at close enough intervals to step down the fall in the ditch, decreasing the speed of the water, and thereby practically eliminating scouring action.
All slopes and shoulders are subject to more or less washing, and to protect them, Bermuda grass is planted.

The method is, briefly, as follows: First, the slopes are dressed to the desired lines and grades. Then furrows are ploughed for the grassing at about ten inch centers, and from four to six inches in depth. If the ground is not moist, it must be watered, and fertilizer is then sprinkled in the rows. Live sprigs of Bermuda grass are placed in the furrows at close spacing, and then covered with earth.

The surface of the slope is then smoothed back down with rakes, the clods that were ploughed up broken, and a hand roller pulled over the slope. From this point on for about two weeks, and especially for the first few days, frequent watering is essential. Best results will be obtained by watering at night.

As soon as the grass has reached the stage where it begins to spread, nitrate of soda is applied. Immediately after a rain or early in the morning after a heavy dew is the proper time for this application, so that the soda will dissolve. If applied before a rain it will be washed away. The soda will greatly accelerate the growth of the grass.
The slopes of fills and borrow pits should be grassed on the grading, while grassing on the shoulders and front slopes in cut sections may be done after the pavement has been laid. The section to be grassed in that case is shown in the accompanying sketch.

Sodding of back slopes in excavated sections that will be subject to washing, as well as fill slopes, has just been adopted in Georgia. Trenches four inches deep and six inches wide and spaced twelve inches apart, are cut in the bank, a two inch mat of top soil mixed with fertilizer is placed in the trench, and then the Bermuda turf with uninjured roots is cut into strips and placed in the trench.
During the grading a little foresight will often materially aid the growth of the grass. For example, if a light cut is in a field that is covered with a good layer of top soil, it will be well not to excavate here, until the embankment has been nearly completed with material from a deep cut, and then to flush the slopes lightly with the top soil. Of course, grass will grow and spread much more rapidly if planted in top soil rather than in sand or clay.

Where the exigencies of the work permit, and the grass is planted during the spring months, it will save the contractor much work during his maintenance period. Grassing greatly reduces erosion on slopes once a good stand has been obtained. On shoulders, the saving in maintenance cost will be practically one hundred per cent.

Considerable attention should be given to this item, for a good grassing job adds wonderfully to the appearance of a new road.

(See picture.)
GRASSING ON FILL SLOPE
CLOSE-UP OF SAND CEMENT
RIP RAP IN BAGS
SHOWING BROKEN JOINTS

SAND CEMENT RIP RAP IN BAGS. PICTURE TAKEN
DURING HIGH WATER.
RIP RAP OF ROUGH STONE

RIP RAP OF CUT STONE
to be reasonably close to a quarry, then the cut stone may be preferred. In regions quite distant from any source of stone, the sand-cement blocks or bags should, of course, be used.

In the case of the rough stone the Georgia Highway requirements are that the rip rap must be at least twelve inches thick at all points, and that 60 per cent of the rocks used shall weigh more than 150 pounds. When cut stone, sand-cement blocks, or sand-cement bags are used, the minimum thickness is ten inches and the blocks 12" X 12".

In all cases a trench at least two feet deep should be cut below the surface of the natural ground at the toe of the fill to prevent undermining of the rip rap.

The fill should first be dressed to insure a neat and smooth surface. Then the laying of the rip rap may begin at the bottom of the slope. The stone or blocks should be placed perpendicular to the slope, and great care taken to break the joints. If this is not done, and some
settlement takes place, failure in the rip rap is likely to result. On the other hand, close, broken joints will prevent sliding of the rocks above.

Care should also be taken to obtain as smooth and as neat a surface as possible. Of course, it is much easier to get a good looking job in the case of the poured blocks or bags than with the rough stone on account of the wide variations in size and shape of the latter. The larger rocks will have to be sunk deeper in the fill than the smaller ones in order to get a good surface, and it will require care in the selection of each rock to be laid in order to break the joints.

(See picture.)

When water is expected to run over the rip rap, as in the case of gutters, or aprons at the outlets of culverts, it is advisable to fill the joints with grout, consisting of one part cement and three parts of sand. This is known as "Grouted Rip Rap."

(See picture.)
RIP RAP SPILLWAY

OF

CONCRETE BLOCKS

WITH

GROUTED JOINTS
No close observer can have but noticed the great number of failures in pavements due to settlement of fills at the ends of bridges. There are two reasons for this. First, because of the fact that the bridge is on an unyielding foundation, even a minor settlement in the adjacent fill becomes apparent by contrast; then the little step which is formed, greatly increases the impact with which heavy vehicles strike the pavement as they come off the bridge, forcing the fill to go down still more.

Second, due to the exigencies of the work, either the bridge or the fill will usually be constructed first. Even if they are being built simultaneously and under the same contract, the circumstances will be fortuitous indeed, if the progress is such that the fill can be made around the end bents just after the columns are poured and before forms for the pier caps are set, so as to permit rolling. And even here the rolling can be carried only as high as the bottom of the cap. From this point to the top of the bridge, the embankment will have to be put in after completion of the structure.

(This did happen on Federal Aid Project 435-D, in Laurens County, Georgia, in December 1937. See picture. Work here was done by W. L. Cobb Construction Company.)
BUILDING AND ROLLING FILL WITH "SHEEP-FOOT" TYPE ROLLER AROUND COLUMNS OF END BENT OF BRIDGE BEFORE SETTING FORMS FOR PIER CAP.
Ordinarily the short and deep section of the fill next to the bridge will be deposited under conditions which make rolling impracticable. Tamping and jetting help considerably, but they are not enough to prevent some settlement in time under traffic.

The Georgia Highway Department, in recent years, has endeavored to take care of this condition by spanning the weak part of the fill with the reinforced concrete approach slab. This consists simply of a slab of concrete ten inches in thickness, reinforced with steel, the width of the bridge, and from ten to twenty (20) feet long. One end is placed against the bridge, supported by the paving rest, the other end lying on the compacted portion of the fill.

(See picture showing steel in approach slab before pouring.)

The approach slabs have proved very successful, greatly decreasing the per cent of pavement failures next to bridges on roads built since their adoption.
REINFORCED CONCRETE APPROACH SLAB

SHOWING STEEL IN PLACE BEFORE CONCRETE IS Poured
FINAL DRESSING

The quality of workmanship that has been put into a road, will be judged upon its completion, by its appearance. For this reason, the item of dressing assumes considerable importance.

After the job has been graded according to the grade stakes, much work yet remains to be done. In the first place, slightly high and low places will be found throughout the work, and though they may not be apparent to the eye, they must be taken out so that when the forms are set for surfacing, material will not have to be borrowed, wasted, or hauled, just ahead of the paving. This is the reason for setting the finishing grades, discussed under "Grading Stakes".

To do the fine grading, the contractor may employ teams with wheelers or drag pans, or do the work with tractor equipment of the scraper type, supplemented with a blade grader, or auto patrol. Any of this equipment can bring the grade very close to the elevations and lines designated by the finishing stakes. But, in spite of all, much work will have to be done by hand.

It will pay the contractor to employ large forces on his dressing, so that the entire job may be put into good shape before rains can have time to do much damage.
The shoulder lines should be straight, and the point sharp, to stand out. Rounded or irregular shoulders give a shoddy appearance to the whole job. Likewise, waves or depressions in the grade of the shoulder or slope detract from the looks of the work.

Hand work is necessary to correct all of the aforementioned errors. A string line is drawn on the shoulder between "blue tops", and strings are also needed on either side of the flat bottom ditch, so that the corners may be cut sharp, the width uniform, and the grade true.

The tops of cut slopes are rounded as shown in the accompanying sketch, improving the appearance, and decreasing the likelihood of the top caving in. The sodding is then carried to the back of the rounded slope.
ROUNDING TOP OF CUT SLOPE
Having rounded the top of a cut, the same crew of men is then put to work trimming the bank to remove unsightly bumps, marks left by the teeth of the dipper, or other irregularities.

To dressing up embankments, care must be taken to bring the slopes to a plane surface. All waves, rolls, or high spots must be removed, and any concave places brought up. If the degree of slope changes within an embankment the appearance can be improved by making the transition as gradual as possible. Any rocks or boulders that were not covered up but rolled away from the embankment, should be lined up at the toe of the fill.

Finally, the right of way should be cleared of all stumps, roots, piles of old timber, dilapidated structures, and any other undesirable debris. Weeds, tall grass, or bushes that have sprung up can be cut down and burned, stump holes filled, and the right of way bladed with a road machine.

In his final check-up before completion of the work, the engineer will note all the trees left on the right of way, retain the best ones and order the rest removed. He will inspect all culverts to see that the inlets and outlets are open, and check the performance of all ditches. If any portion of the work has become misplaced, or needs attention, he will order the necessary corrections to be made, always keeping in mind the fact that even a minor item over-looked or
necessarily done on construction, may become a source of constant trouble and expense on maintenance.