ROADSIDE GRADING AND DRAINAGE DESIGN

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ROADSIDE GRADING AND DRAINAGE DESIGN

A preliminary report of the Committee on Roadside Development presented at the 29th Annual Meeting of the Highway Research Board, December 13 and 14, 1949

H. J. Neale, Chairman

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INTRODUCTION

Without complete topographic and land use information on a given highway project it is not practicable to formulate detailed rules regarding roadside grading and drainage. In fact, it is doubtful whether detailed standardization will ever be desirable in roadside development since variety and change are the essence of the economic values of roadside improvement and of scenic highway interest.

Because of the fact that grading and drainage and erosion control practices are all subject to the variations inherent in natural materials and existing conditions of soil, topography, and climate, grading design procedures are not susceptible to the precise standardization and specification uniformity which can be achieved with manufactured or processed products like concrete pavements, curbs and gutters, or other structural materials. Hence it becomes necessary to classify roadside grading and drainage in flexible terms of "climatic ranges", with appropriately organized subdivisions, rather than in fixed terms of specific values. If we accept the concept that the "range" in climatic conditions controls the engineering design, it becomes possible to provide the engineer with a means of classifying, evaluating, and adjusting the design of graded cross sections for the positive protection of roadside slopes and drainageways.

Working on this premise, the Committee on Roadside Development has initiated this preliminary report as an advance outline of the basic principles and elements of grading and drainage design and practice that have evolved through experience of the States in the various regions. A correlated classification of topographic regions and of types of precipitation in relation to plant growth regions is suggested by the Committee as a guide for further regional and more localized study by roadside engineers.

Typical State highway cross-section grading designs now in use in the various regions are included for comparison and analysis. These sections reflect the influence of climate, topography, and soil on highway design and practice in the general regions outlined. It is urged that the States in the different regions design and adopt typical cross-sections to fit each class of topography and type of soil. In this way, there would be made available a series of typical sections more nearly fitting the requirements of existing local conditions for efficient machine economy in highway construction and maintenance.

Note: The preliminary report which follows covers the first step in preparation for the final report in the five-year program of the Committee. Some reference is made to material in other reports in order that the Coordinators may have basic information available for discussion of the many problems involved in the various phases of roadside operations. This is not intended to be a technical, finished product but a focusing toward all the phases of roadside grading and drainage for final presentation in 1953. The Committee has not endorsed the material but offers it for exploration and looks for final conclusions to be reached and reported upon in subsequent annual meetings. The illustrations in this preliminary report exemplify varying conditions and are not included as perfect examples.

The Committee on Roadside Development presents, this year, a preliminary analysis of the problem of highway grading and drainage. This is the first of five annual reports aimed toward summarizing the experience of the State highway departments of all regions of the United States in roadside improvement. This work is an essential part of complete development of highways, not within the traveled way alone, but from right-of-way line to right-of-way line.

In preparing this analysis of roadside grading and drainage design the Committee has drawn upon field observation and photography by its members. It has studied recent typical grading cross sections and plans submitted by the various States. Finally, it has read and abstracted engineering literature on the subject of grading and drainage including reports, papers, articles and text books dealing with the subject. This report is offered with the following purposes in mind:

(1) To outline certain basic principles of grading and drainage design evolved through experience in States of the various regions.

(2) To describe and compare the high points of typical grading and drainage design practices now to be observed in construction of primary highways in open country of all regions outside built-up urban areas.

(3) To recommend certain types of field study and research aimed toward improving roadside grading and drainage design practices.

Elements of Grading and Drainage Design

Mr. Carl Izzard in the report of our subcommittee on Drainage and Drainage Structures in the 1943 Proceedings of the Highway Research Board, summarized certain basic drainage design principles of great interest and value.

His report brings out the following points among others, upon which this year's report by the Committee as a whole is based.

First, to solve the highway drainage problem the highway designer must "visualize the path of all . . . water reaching the highway from the skies and from adjacent land above the highway. He must follow the water through in his design until it passes off the highway and eventually reaches natural drainage channels below the road."

Secondly, the drainage design problem is to a great extent governed by the character and amount of precipitation that may be expected to occur in the locality where a highway is constructed.

Third, effective drainage design in humid regions will be based on encouragement of free flow of surface water from adjacent lands to, and across highway slopes and drainage channels. Establishment of turf and other ground cover will then be relied upon to control surface water and prevent slope erosion.

By contrast, in dry regions where rapid establishment of vegetative cover is not usually possible, drainage design should aim toward diverting surface water into natural drainage channels before such water reaches the highway, wherever possible.

Expressing this thought in other words, it may be said that successful highway grading and drainage design will be based upon study and understanding of three basic factors by the highway designer:

1. The character of land relief, land surface cover and land use of watershed areas draining to the highway and below the highway.

2. The amount and character of annual and seasonal precipitation to be expected in the locality.

3. The design of highway slopes and drainageways as effected by surface and subsurface water flow derived from lands above the road or from rain or snow falling upon the highway itself.

LAND RELIEF

Figure 1 "Major Physical Divisions of the United States," shows regions of predominant typical low, moderate,* strong and high* relief and is based upon the U. S. Geological Survey map entitled "Physical Divisions of the United States."

In each of the general topographic regions shown, typical highway grading cross sections and drainage channels and drainage structure designs are being developed by the State highway departments to meet prevailing conditions of land relief and surface water run-off.

As experience in all regions has now demonstrated, graded cross section design in built-up urban areas is usually subject to severe restrictions by right-of-way and land use considerations. On primary highways in open country, the designer is relatively free of these restrictions and can flatten and round slope and drainage channels and adjust their design and subsequent protection against erosion, to meet existing topography, soil and climatic conditions.

TYPES OF PRECIPITATION

The Committee has prepared Figure 2 "Major Types of Precipitation in the United States" as a supplement to Figure 1. It will be noted that precipitation type regions are not as sharply defined as are corresponding areas of topography and land relief. A physical region may be defined by the dividing line between two watersheds such as the crest of the Sierra Nevada mountain range. The weather is influenced by such physical barriers but is seldom rigidly confined

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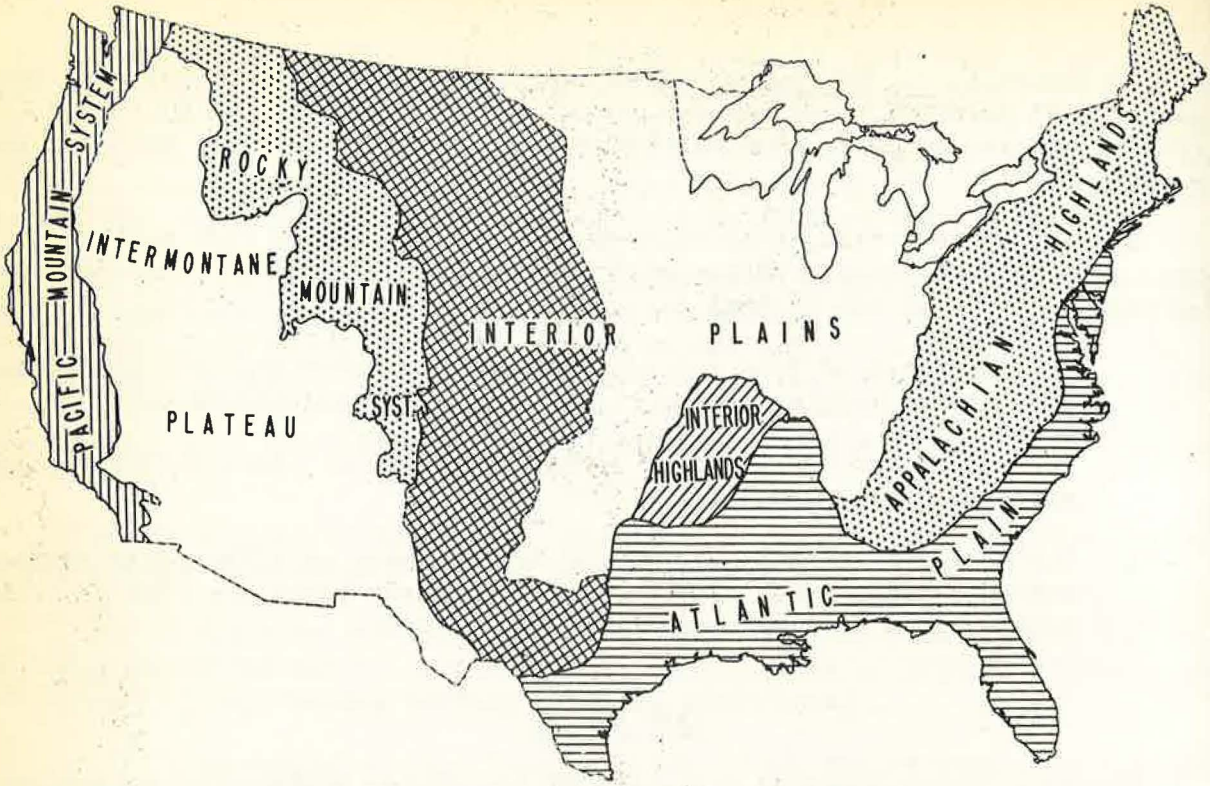
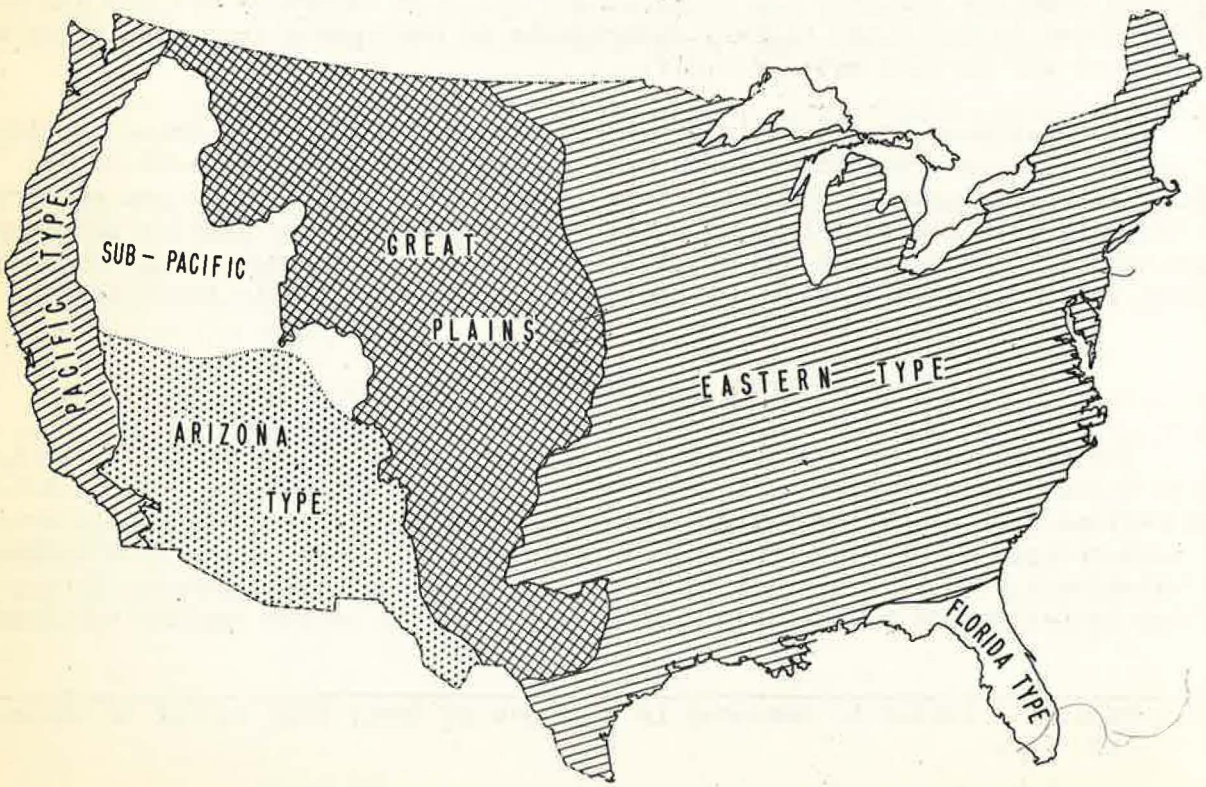
Note - *Moderate relief is measured in hundreds of feet; high relief in thousands of feet.



MAJOR PHYSICAL DIVISIONS OF THE UNITED STATES

ADAPTED FROM A MAP ISSUED BY U.S. GEOLOGICAL SURVEY EDITION OF 1946

FIGURE 1.



MAJOR TYPES OF PRECIPITATION IN THE UNITED STATES

SOURCE: ATLAS OF AMERICAN AGRICULTURE

FIGURE 2.

by them. The following brief description of precipitation types will also serve to supplement previous maps included in Committee reports showing humid and dry regions of the United States. Regional types of precipitation are:

A Pacific Type: Pacific Coast States from the Sierra Nevada and Coast Range westward are characterized by concentration of rainfall during winter months and a typical dry period in summer. As much as 50 inches of rainfall may occur in winter on the Olympic Peninsula in Washington, for example. Fourteen inches is average winter precipitation near Santa Barbara in Southern California. By contrast during June, July, and August, northwest Washington receives an average of about ten inches of rainfall with the Santa Barbara region averaging about 0.1-inch.

A Sub-Pacific Type: The eastern portion of Washington and Oregon, and most of Idaho, Nevada, and Utah are characterized by precipitation that is fairly uniform during all but the summer months. Except for higher mountain areas total annual rain and snowfall is much less than in the Pacific region and it diminishes to the south. Thus, for example, annual winter precipitation in the area between Yakima and Spokane averages between four and eight inches with summer rainfall between one and four inches. Near Salt Lake City average winter precipitation is about four inches with summer rainfall between two and four inches.

Arizona Type: Southern Utah and Nevada, New Mexico, Arizona, and west Texas receive scattered heavy showers during July and August, with little rain during April, May, and June. During the fall and winter precipitation is sparse though fairly evenly distributed. During the winter months, for example, west Texas, Arizona and New Mexico at lower altitudes average some two inches of precipitation annually. During June, July, and August, thunder showers in west Texas may bring an average of six to eight inches of rainfall, with about four to six inches falling in central New Mexico and Arizona.

Plains Type: The plains region for purposes of this analysis includes the States from the Rocky Mountains eastward to the Great Lakes, thence south to Missouri and Oklahoma. Here there is typical generous rainfall in late spring and summer with very light fall and winter precipitation. Much rainfall is likely to occur during night hours, a distinct advantage from the standpoint of crop and grass growth. In parts of Montana and in certain areas in eastern Colorado and the Dakotas winter precipitation averages less than one inch. From western Texas north to Minnesota the Western Plains area receives an average of about two inches during an average December, January, and February period.

Eastern Type: This type of precipitation is found in the remainder of the country east of the Great Plains area with the exception of Florida. Rainfall in the South is subject to seasonal fluctuations with heavy torrential summer storms more frequent and more severe as the Florida region is approached. Average number of days during a single year when thunderstorms occurred in eastern Maine were about twenty. Along a line from central Iowa to central North Carolina this average increased to fifty days. The Gulf Coast from Louisiana to western Florida has an average of ninety days during which there may be thunderstorms. By contrast, the Northwest Pacific Coast rarely has as many as five days during a single year when thunderstorms occur.

Florida Type: In Florida and the nearby Gulf Coast areas to the west an average of two inches of rainfall per month or more may be expected from November to May. During each of the other five months particularly in July and August an average of about ten inches of rainfall is to be expected. Tropical storms during September and October bring heavy rainfall. The Florida type of rainfall merges with the Eastern type to the north and east and into the Plains type of precipitation in western Texas.

Snow: Precipitation in the form of snow is usually of minor importance south of a rough line on the map between central Virginia and northern Texas. Snow cover on the ground only occurs during an average ten days per year along this line. North of this area and west in high mountainous country the average annual days with snow cover increase to a possible maximum of 120 days per year. Here melting snow at spring seasons is an important factor in watershed run-off calculations.

PLANT GROWTH REGIONS

Figure 3, Plant Growth Regions of the United States, will also be found on page 68 of the 1941 Report of the Committee on Roadside Development. This map together with Figures 1 and 2 will serve to give the reader a broad picture of the widely variable conditions under which the highway designer must work in his drainage design. A study of these three maps should clearly indicate the reasons why typical highway grading cross sections designed for one State or one locality of a State may not provide the essential combination of adequate drainage and control of slope erosion needed in another State of the same general part of the country or in another locality.

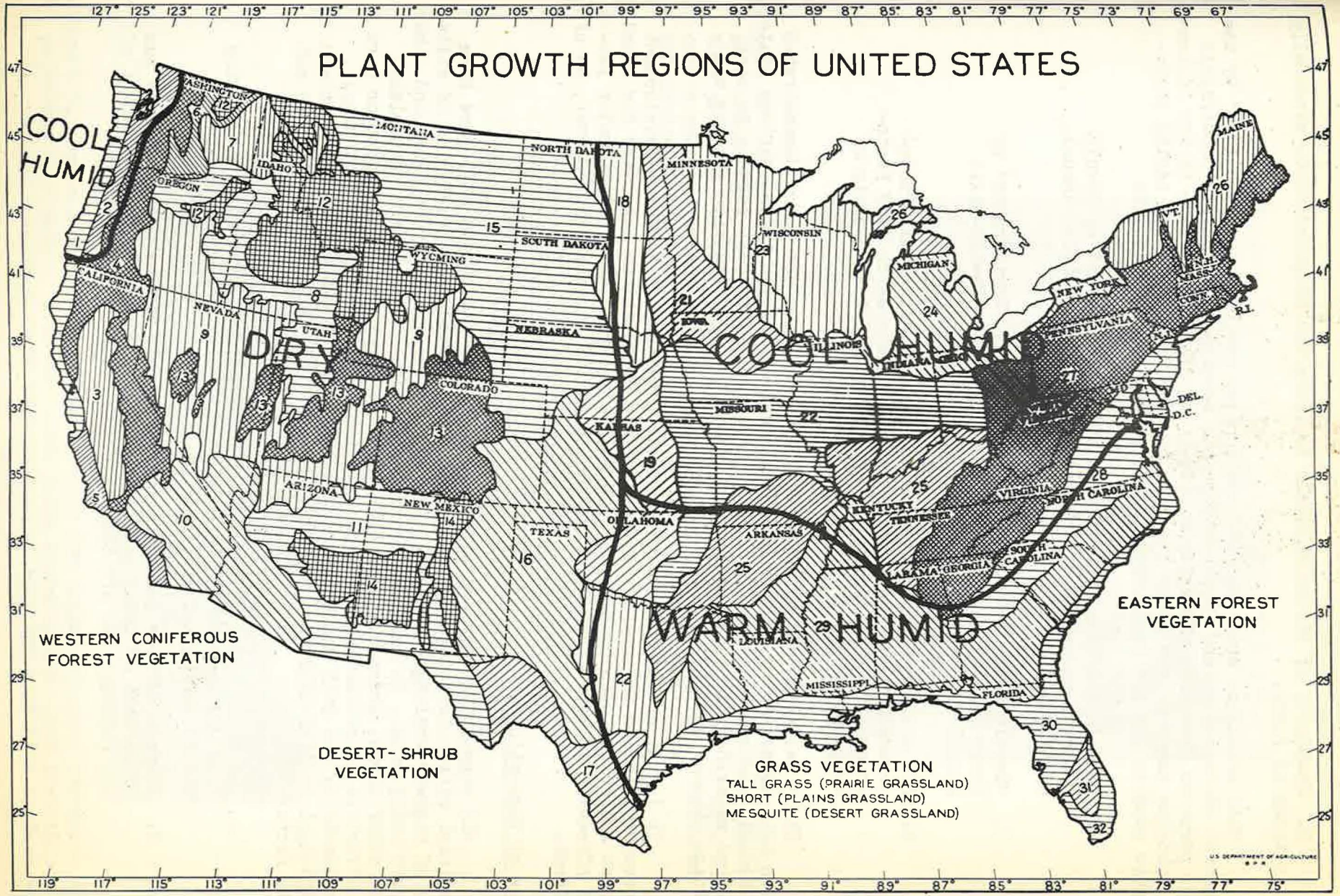
For example, it will be noted that the State of Colorado includes areas within both the "Sub-Pacific" rainfall area and the Great Plains precipitation type. The same State includes plant growth regions numbers 9, 13, 15 and 16. Topography in Colorado ranges from the high relief of the Rocky Mountains system to the low relief of the western Interior Plains. Colorado therefore requires at least two widely different types of cross sections, one to meet the requirements of a high rugged mountainous country with heavy snow and abundant rainfall to the west; the second to meet requirements of a flat plains country with light precipitation to the east.

CHARACTERISTICS OF WATERSHEDS

Having determined the character and probable amount of precipitation in the locality from available weather station records, the engineer may proceed to determine the following information regarding each of the watershed ares above the selected new highway location.

1. Degrees of slopes, sizes of watershed areas and total areas of forest, marshland, grassland, crop-land, or other types of land use.

2. Character of prevailing watershed soils, and rock, and other ground surface conditions influencing run-off.


PLANT GROWTH REGIONS OF UNITED STATES
COOL HUMID
DRY
COOL HUMID
WARM HUMID
WESTERN CONIFEROUS FOREST VEGETATION
DESERT- SHRUB VEGETATION
GRASS VEGETATION
TALL GRASS (PRAIRIE GRASSLAND)
SHORT (PLAINS GRASSLAND)
MESQUITE (DESERT GRASSLAND)
EASTERN FOREST VEGETATION
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
ARIZONA
COLORADO
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LOUISIANA
WISCONSIN
ILLINOIS
MICHIGAN
INDIANA
KENTUCKY
TENNESSEE
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
SOUTH CAROLINA
NORTH CAROLINA
VIRGINIA
PENNSYLVANIA
NEW YORK
VT.
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U.S. DEPARTMENT OF AGRICULTURE

FIG. 3

3. Stability of stream channels crossing the proposed road, especially during times of flood.

This essential watershed information can now be readily obtained by use of aerial photographs, and from photographic mosaics and accurate topographic maps, prepared from such photographs. Special reference is made to the following articles among others which indicate the many advantages of aerial photographic studies for use in determining watershed characteristics:

1. "The Engineering Significance of Soil Patterns" by Donald Belcher, page 569, Proceedings of the Twenty-third Annual Meeting of the Highway Research Board, 1943.

2. "Development of Drainage Maps from Aerial Photographs" by Merle Parvis, page 150, Proceedings of the Twenty-sixth Annual Meeting, Highway Research Board, 1946.

3. For stages in air survey methods, see "Symposium: Photogrammetry in Highway Engineering", in the March 1949 Photogrammetric Engineering journal of the American Society of Photogrammetry.

It is believed that by making use of techniques now being demonstrated by the Soil Conservation Service and by engineers employed by the various State and Federal highway organizations, it is possible to forecast answers to most of these watershed drainage problems in terms of proper roadside grading and drainage channel design.

It is not within the province of the Committee on Roadside Development to present detailed information concerning the calculations necessary for sound culvert and bridge opening design. The following brief analysis of major factors affecting run-off from land surfaces above the highway may, however, be of interest.

Types of Vegetation

All vegetative cover on watershed lands above highways will have some beneficial effect in retarding run-off of surface water and prevention of siltation of highway drainage channels. Degree of slope, porosity of soil, and other factors being equal, it has been found that mature forest growth, brushland, dense cover crops, grass or other turf, and row crops such as potatoes or corn are effective in preventing rapid run-off in about that order. For example, experiments by the Soil Conservation Service during flood periods in northern Mississippi in 1931-1932 when some 130 inches of rainfall occurred, bring out these facts.

1. The above total rainfall fell in 103 storms with rainfall varying from .03 to 5.32 inches per storm; 28 percent of this rainfall was of torrential character.

2. Average surface run-off from a cornfield within the study area was 58 percent of total precipitation. In extreme cases 96 percent of all rainfall ran off the field.

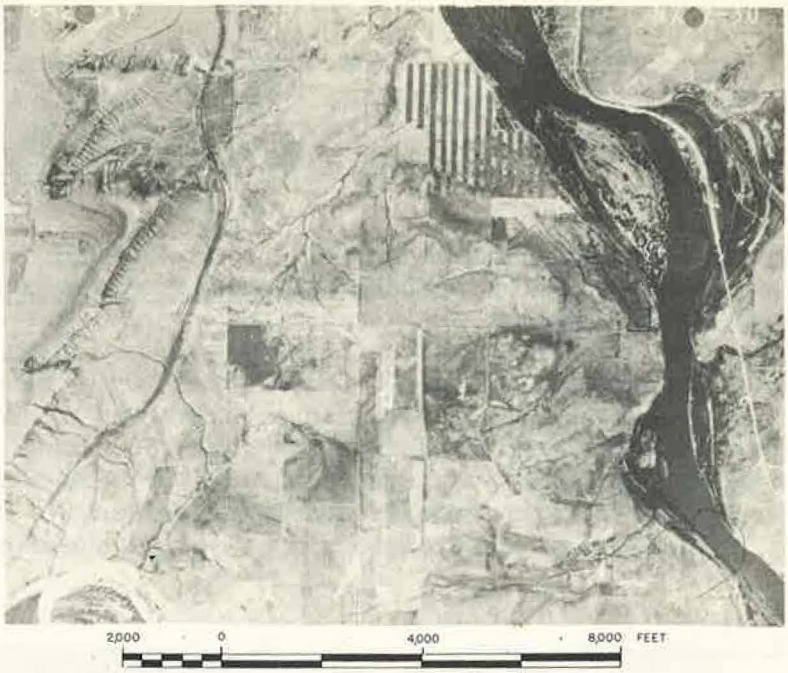

Figure 4. Aerial Photograph in the Interior Plains Region. Note how clearly each watershed area draining across highways to right and left, appears in this picture. By enlarging this photo to a known scale, areas of watershed can be measured with sufficient accuracy for effective design of culverts and drainage channels.

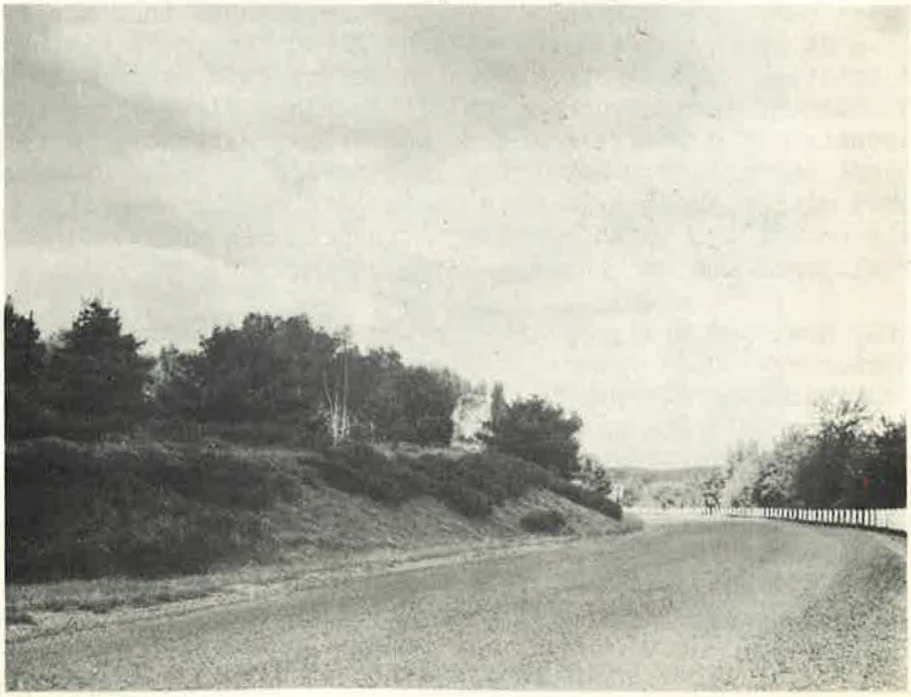

Figure 5. Typical Graded Cross Section on a New England Highway (Northern Appalachian Highlands). Note excellent slope rounding and slope protection, left. Wooded watershed above this section of road has held back surface water.

3. From barren plots on an adjacent partly weed covered old field, run-off averaged about 48 percent of rainfall.

4. From adjacent broom-sedge fields run-off was slightly more than 1 percent of total rainfall.

5. Run-off from nearby oak forest plots was less than 1 percent of total rainfall.

6. The cornfield lost an average of 195 tons of soil per acre of plot under above conditions. There was no measurable loss of soil from the oak forest area.

It will be evident from the above that surface water from forested slopes above a highway will rarely result in erosion or siltation of highway slopes or drainage channels. Intercepting channels below forested slopes, in other words, will rarely be needed. By contrast where cultivated or bare abandoned fields exist above a highway intercepting channels and other protective measures will, in regions of heavy rainfall, be essential to proper drainage and protection of the highway.

Changes in Types of Land Use

Closely related to the above is the need for anticipation of probable changes of land use following highway construction, in watershed run-off study and comparison. Serious changes in land use, as experience now indicates, have in some cases nullified the effectiveness of highway drainage channel and drainage structural design and seriously damaged such structures in the space of a single heavy rainstorm. Removal of timber and changes of watershed area from grassland to suburban housing development for example, are frequent on many important highways near our largest cities. These changes increase run-off from watershed areas at once, sometimes producing flood damage in highway drainage channels and existing natural streams which before such changes in watershed land use had adequate capacity to carry off overland flow of surface waters. Definite overdesign of drainage channels and bridge waterways is required on highways subject to intensive bordering land development. Many of our primary highways routed within about a 10-mile distance of major population centers will unquestionably be subject to sharp changes in land use where no housing or other intensive development now exists.

Highway drainage design in past years has been largely concerned with drainage structures. Until recent years drainage of surface water has been considered of importance by highway designers mainly where such waters were confined within drainage channels and passed through drainage structures or crossed the highway in the form of running streams. It is now evident that control and disposal of surface water passing across shoulders and slopes before such water has been concentrated in drainage channels is a problem deserving much more study than it has received.

Types of Highway Drainage

Three general types of highway drainage design are in use on primary highways in this country. They are:

1. A "closed system" of drainage design featuring curbs and gutters with all surface water carried away from inlets through storm sewers. All typical urban streets and most urban parkways and freeways use this system of drainage.

2. A modified partly "closed" and partly open system with storm sewers draining part of the roadbed, and part of it drained by open gutters, culverts and surface channels. Many divided highways of latest design are drained in this manner.

3. An open type of drainage, with surface water draining across road shoulders and down slopes into gutters, with the gutters leading to culverts. Culverts in turn drain away surface water onto the land below the highway. Storm sewers are used only in special areas as at intersections, in connection with bridges or grade separation structures, or larger traffic islands.

Comments in this report are concerned mainly with this third type, the "open drainage system" because on the large percentage of mileage of primary highways in open country, this is the only practicable and feasible method of drainage within the funds usually available.

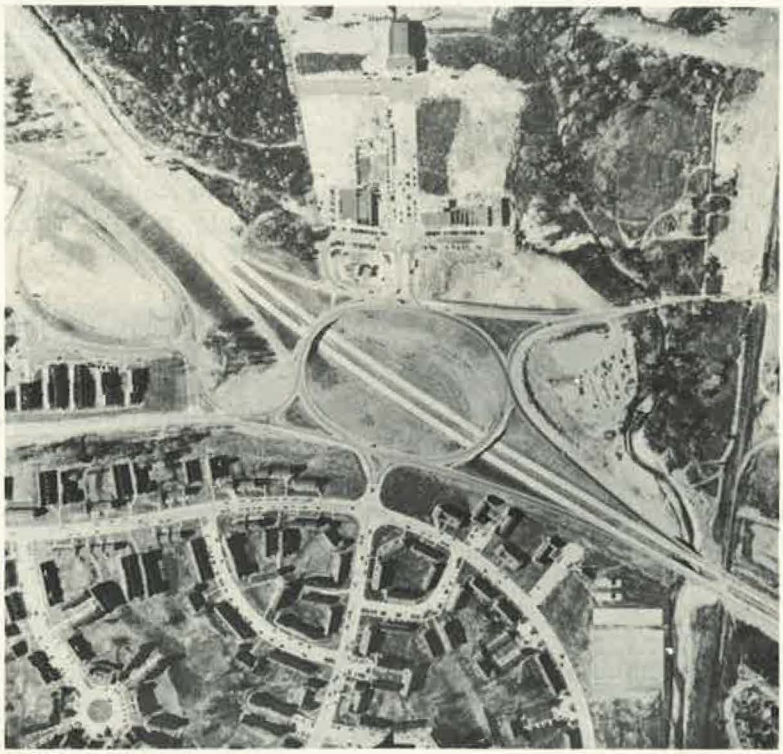

Figure 6. Aerial Photograph of a Watershed and Highway near Washington, D. C. Area shown now occupied by housing may have 70 to 80 percent runoff after storms because of extensive roof and road surface areas. Before housing was developed runoff may have been 10 percent or less on a heavily timbered watershed then existing. Allowance must be made for such changes in land use and runoff, particularly in suburban areas.

THE DESIGN OF GRADED HIGHWAY CROSS SECTIONS

Roadside drainage as distinct from roadbed drainage is largely dependent upon the proper design of graded highway cross sections. The rounded or "streamlined" type of cross section first developed as a part of roadside improvement operations by the States of all regions is, in fact, the first stage of adequate roadside drainage. Such "streamlined" grading design is also essential if free drainage is to be accompanied by complete control of erosion and siltation.

Objectives of Rounded Slope and Channel Design

The Committee on Roadside Development has emphasized the objectives of "streamlined" cross section grading in past years. It may be well, however, to repeat these here.

The first objective of rounded cross section grading should be to fit cuts, fills, embankments, and rounded drainage channels and gutters smoothly into adjacent undisturbed ground surfaces. This fitting process is essential if surface water is to flow over roadside slopes and through drainage channels without serious erosion damage where soils are of erodible types. In broken topography with short steep hillsides, well-graded road slopes in sections of heavy cut will normally be relatively steep (2:1 or steeper) with relatively short, sharp rounding or vertical curvature at crest of cuts and toe of fills. By contrast well-graded slope sections in easy or flat topography will have flat slope ratios (3:1 or flatter) and long easy curvature at tops of cuts and toe fills. Thus, for example, on roadside areas where average natural hillsides slope at 1:1 or 2:1 it may be a mistake to grade deep cuts to 3:1 or flatter ratios. By the same reasoning, in plains or plateau topography with usual cuts and fills less than about 5 to 10 feet in height, there is usually no justification (other than first cost) for cuts and fills steeper than about 4:1 to 6:1.

Another objective of well-rounded slope and channel grading is the encouragement of use of heavy self-loading types of excavation equipment. Heavy types of blade graders and self-loading excavating equipment cannot be used to advantage on slopes steeper than about 3:1. Such equipment when operated at normal speeds will round and warp cuts and fill slope intersections with the long easy curvature desirable from standpoints both of slope stability and good appearance.

A third purpose of easy well-rounded cut and embankment slopes is to encourage rapid establishment of grasses and other ground covers which will prevent sheet and gully erosion. Experience now indicates that seeded or planted vegetation can be readily established in humid climatic regions on easy 3:1 or flatter slopes and on 2:1 cuts and fill slopes that have been liberally rounded at crest and toe. On slopes steeper than about 2:1, without liberal intersection rounding, serious gully formation may occur in erodible types of soils. Such gullies not only discourage quick establishment of vegetation on cuts and fills, but also tend to rapidly silt-up highway gutters and other drainage channels, and thus interfere with proper longitudinal drainage of the highway and its subgrade.

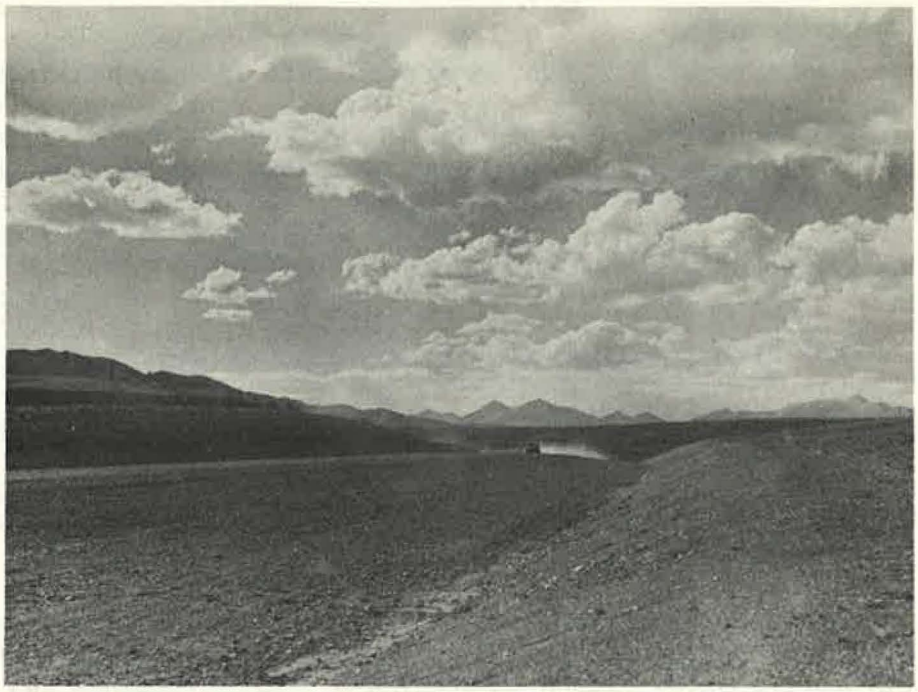

Figure 7. Well Graded Cross Section on a Colorado Highway. (Rocky Mountain System.) Note broad rounded drainageways and slopes. This cross section is designed to avoid snow drifts by permitting drifting snow to be blown clear of the roadway. All finish grading done with blade grader equipment - not hand labor.

Figure 8. Well Designed Cross Section in Mississippi (Atlantic Plain Region). Note excellent rounding, broad drainageway, and good turf slope protection. A safe highway maintainable at low cost.

A fourth objective of liberally rounded cross section grading is to provide slope ratios, flat enough to prevent normal slides* and sloughing. It is a known fact that some fine textured clays and silty soils will sometimes "stand" at almost vertical slope ratios. Some coarse, sandy, and gravelly soils, by contrast, require slope ratios of 2:1, 3:1, or even flatter ratios, if slides and serious gully erosion are to be avoided. Again certain "adobe" types of fine grained soils stand at about $1\frac{1}{2}$:1 when dry but slump immediately following saturation by hard rain. This slumping of steep high fills has been particularly disastrous in southern California for example. Experience, however, also demonstrates that vegetative ground cover cannot readily be established on slopes steeper than about $1\frac{1}{2}$ or 2:1 on any soil in any climatic region.

SPECIAL GRADING DESIGN PROBLEMS

As traffic densities have increased, particularly on primary highways near our larger cities, new forms of highway design have been necessary. Divided highways, for example, are more difficult to design for adequate drainage than the two-lanes undivided highways that preceded them. Divided highways present new problems in drainage design and they also increase the need for skill in the solution of old drainage design problems that have always existed on all highways. Grade separation structures sometimes involve two or three levels of interesting highways and corresponding difficulty in drainage. Median strips of divided highways present special drainage problems. Traffic islands and circles bordered by traffic lanes are another, though a closely related problem. Parking spaces and turnout areas and wayside parks also complicate the drainage of the whole strip of land we call a highway.

Embankments at Grade Separations, and Other Major Structures

Many special grading and drainage design problems occur in connection with "earthwork" at bridges and other important structures. The warping and fitting of slopes above and below ramps, and at ground lines where embankments meet piers and wing walls requires much more care than the grading of usual sections of roadway, if adequate drainage is to be obtained. Experience indicates that these problems are best solved in the drafting room where grading plans can be prepared showing the following details:

Contours of natural ground surfaces to a one-foot interval of the whole area affected by the structure.
Contours of finished embankments, roadways, slopes and drainageways as these merge into (a) groundlines of structures, and (b) contours of existing undisturbed ground surfaces above. Location of pavements, sidewalks, curbs, gutters, drainageways, culverts, and catch-basin inlets and outlets, etc.
Location of proposed subsurface drainage structures, public utilities, etc.
Location of surface public utility lines, lighting standards, etc., to be considered in the grading and shaping of finished slope and ground surfaces.

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*Note: Special local conditions causing earth slides such as "slip planes" in underlying rock are outside the scope of this report.

Median Strips of Divided Highways

A study of typical cross sections of divided highways in all regions brings out the following facts, regarding drainage design of medians in divided highways. Two methods of cross-section grading design have been developed:

1. Highways with relatively narrow median strips have been graded with a crowned median area designed to cause surface water to drain outward into a curb and gutter system.

2. Highways with wide median strips have featured a drainageway or gutter at the center of the median. Road shoulders drain to the center of the median. Surface water is carried away in a central median gutter to storm drain or culvert inlets.

The first of these drainage design methods has the disadvantages of the "closed system" of curb and gutter drainage previously discussed under "Types of Highway Drainage," page 22. The second type of median drainage design meets the requirements of the open drainage system now widely used on main highways in open country.

Figure 9. Special Care Must be Given to Drainage Design and Protection Against Erosion, on Areas Near Major Highway Structures like This. Note erosion beginning in drainageway, indicating need for stabilizing gutter by either solid sodding, paving, or other treatment during construction.

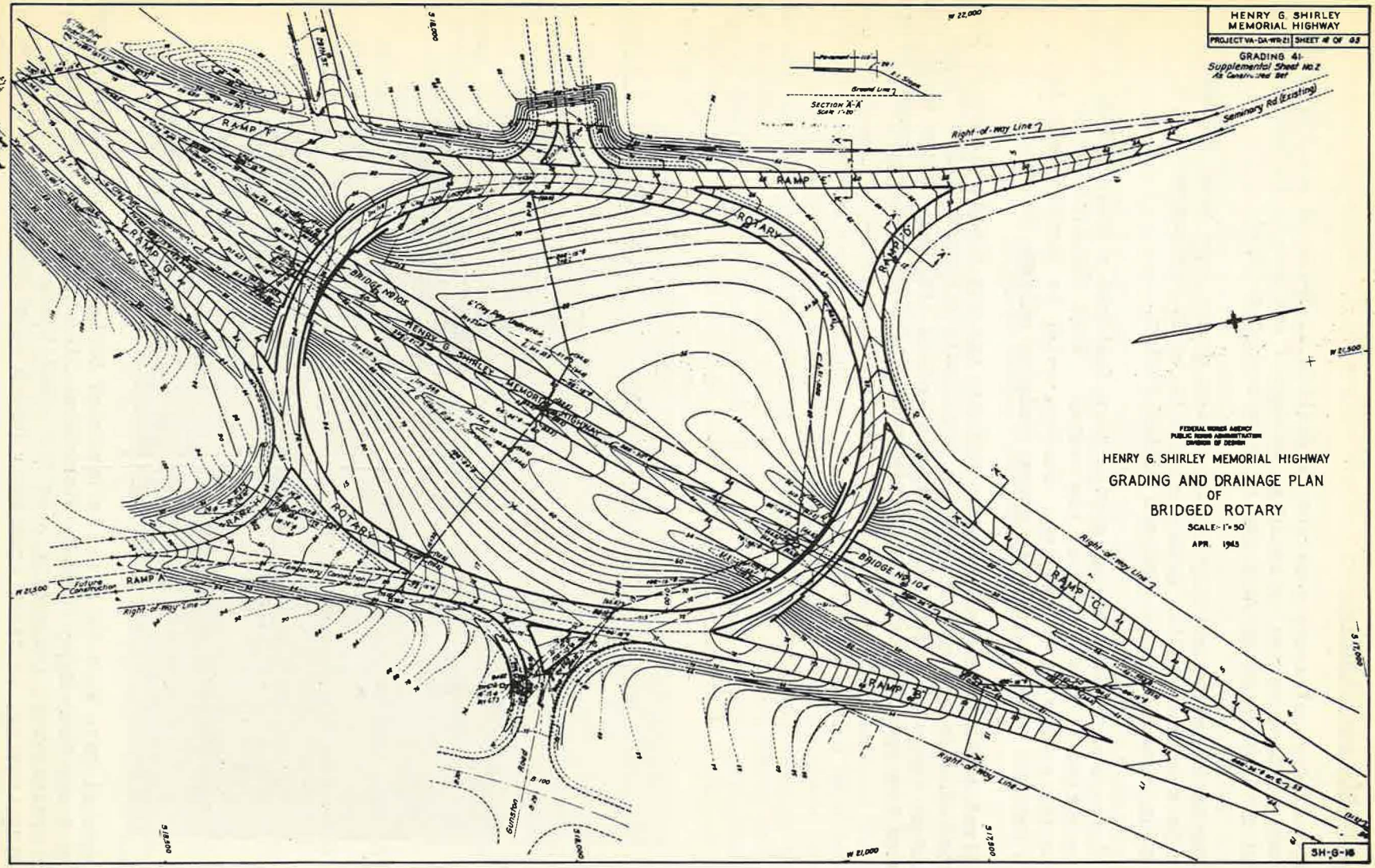

Figure 10. Grading Plan for Area Shown Within Traffic Circle in Photograph No. 45-2344. Grading and drainage problems can be solved on such plans before construction begins--an important saving in construction time and expenditure.

Traffic Islands and Rotaries

Small traffic islands, less than 10 to 15 feet wide, are usually graded to drain toward the adjoining traffic lanes. Wide islands and major traffic rotaries are usually graded to drain to inner catch-basin inlets. The use of grading plans as previously described under grade separation structures has proven advantageous in the development of complex interchange and rotary designs as in New Jersey, for example.

Parking Space, Turnouts, and Wayside Parks

Existing topography of the site largely determines the design of grading and drainage on turnouts and wayside areas. Wherever topography permits it is probably advisable to grade such areas so that they will drain away from the traveled way toward existing natural drainage channels. Large wayside park areas, of an acre or more, may require subdrainage with catch basins, inlets, and storm sewer installations. On large waysides of an acre or more the use of grading plans as described under "Embankments at Grade Separation Structures, etc.," is generally advisable.

In all grading and drainage work on the above-described special areas the following basic principles of grading should be considered.

1. Whenever possible grading and drainage design of larger intersection and median areas should be studied on grading plans showing all relationships between finished contours of graded areas and contours of natural undisturbed adjacent areas.

Figure 11. Wide Medians on Divided Highways are Usually Drained to a Central Gutter, with Sodding or Paving to Stop Channel Erosion.

2. Whenever possible in humid climates, water falling on surfaced traffic lanes should be permitted to drain freely to sodded or surfaced gutter areas off the shoulder edge. Surface water falling on traffic islands, medians or other roadside areas should drain to sodded or surfaced drainage channels or to inlets within the island or median.

3. Particularly in regions of snow and heavy frost, drainage from roadside areas over curbs or inward to traffic lane surface edges may cause trouble with icing. Such drainage design may also fail to provide effective drainage in freezing weather.

TYPICAL ROADSIDE CROSS SECTION GRADING DESIGN

Study and analysis of the typical grading cross sections for various regions shown in Figures 24 to 28 brings out the following summary of observations regarding the special role of each part of highway cross sections in drainage of the highway as a whole.

The Road Shoulder and Drainage of the Roadbed

Mr. Harold Allen in a report on "Pumping Action of Slabs" in the 1948 Proceedings of the Highway Research Board* makes this significant observation: "It has been observed that shoulders sloped to drain storm water to the pavement instead of to the ditches, or shoulders that are badly rutted, contribute to pumping (of concrete road slabs). Therefore the maintenance of smooth shoulders sloping toward the ditch will help to eliminate pumping." Briefly summarizing what we can learn from various authentic sources, the essentials of good road shoulder drainage appear to be:

Adequate shoulder cross drainage by means of a pitch of not less than one-half inch per foot of shoulder width on bituminous or other "hard surfaced" shoulders, or about one inch per foot on shoulders with a truf cover.

Construction of earth shoulders of a mixture of granular soils or aggregates in studied proportions with existing clays or other fine textured soils. In localities with sandy and gravelly soils, clay binder materials may be necessary in combination with such coarse granular soils. Such studied combinations of soil materials will result in a shoulder capable of supporting occasional traffic in all weather, and not subject to serious rutting at any season. Ruts, of course, seriously interfere with cross drainage of surface water.

Proper consolidation of turf-covered shoulders by means of rollers may be necessary following periods of prolonged rains or following the emergence of frost in spring. Blading may correct drainage difficulties at the cost of shoulder erosion after turf has been removed.

Regular mowing is desirable during the turf growing season to facilitate rapid run-off of water from surfaced traffic lanes.

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*Page 299 - Paragraph on "Shoulders and Drainage"

Careful removal of sand or cinders used to cover icy traffic surfaces in winter is necessary for free run-off of surface water across shoulders.

Repair of rutted or rough earth shoulders when damaged by vehicles should be made by filling holes with selected granular soil materials. This is necessary to maintain a smooth well-drained shoulder surface.

Gutters, Channels, Dikes and Other Drainageways

Existing trends in regional cross-section grading of road gutters and channels are shown in Figures 24 to 28 showing prevailing types of slope and channel design in various regions. Among the types of drainageways commonly encountered in highway design are (1) intercepting channels and dikes above cut slopes and below fills, (2) flumes carrying water down the slopes of cuts and fills, (3) road gutters, (4) relocated stream channels, (5) terrace outlets and agricultural drainage channels leading downward to road gutters, or away from culvert outlets.

Intercepting Channels and Dikes

Some of the intercepting channels and dikes constructed at the crest of highway cut slopes in past years particularly in Western regions have increased rather than controlled erosion--see Figure 13. Intercepting channels and dikes can be effective if their design is based on certain simple principles evolved by the Soil Conservation Service over many years. These are summarized on page 648 of the yearbook of the U. S. Department of Agriculture for 1938, as follows:

Intercepting and diversion ditches are practical and desirable on steep or unusually long slopes.

Use of diversion channels is dependent on locations affording suitable places for outlets. Unsuitable outlets may do more damage than if (water were) allowed to flow across the slope.

Broad flat channels are constructed to reduce velocity (of surface water) and facilitate crossing with farm implements (or highway maintenance equipment).

Gradient of channels should be such that non-erosive velocities are maintained under maximum flow conditions. Capacity should accommodate run-off from the heaviest rains to be expected in a ten-year period under normal conditions.

To avoid blocking of diversion channels by eroded material from the area above it is desirable that each channel be located immediately below a well-vegetated area. This implies the assumption that one of the first stages of effective highway drainage is the restoration of vegetative cover on cut and fill slopes.

All channels illustrated in the above reference are protected with turf. Bare unprotected earth channels on agricultural land (or on highways) may be damaged by surface water to the point where they are no longer effective.

Figure 12. Drainage Channels of Broad Rounded Form With a Protective Cover of Turf or Bituminous or Stone Paving will Altogether Control Erosion. This type of gutter provides effective drainage with maximum traffic safety.

Figure 13. Intercepting Gutters Should be Designed on a Profile Grade that Will Prevent Damaging Velocity in Drainage Water Flow. Here the intercepting drainage channel is destroying a cut it was designed to protect.

Figure 12. Drainage Channels of Broad Rounded Form With a Protective Cover of Turf or Bituminous or Stone Paving will Altogether Control Erosion. This type of gutter provides effective drainage with maximum traffic safety.

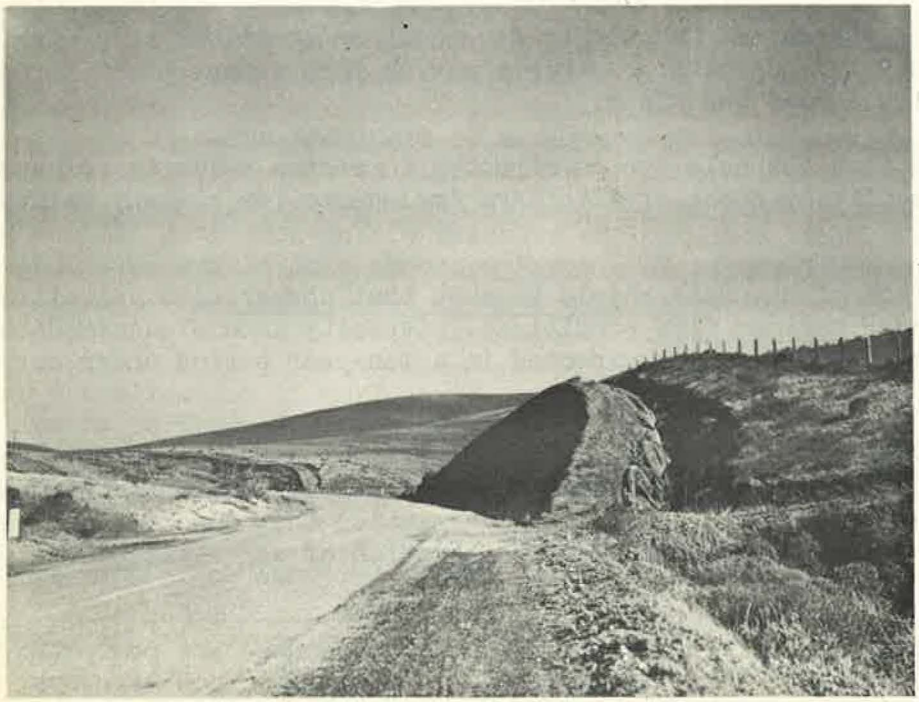

Figure 13. Intercepting Gutters Should be Designed on a Profile Grade that Will Prevent Damaging Velocity in Drainage Water Flow. Here the intercepting drainage channel is destroying a cut it was designed to protect.

Flumes and Pipe Drains

Use of metal flumes and pipe to carry surface water across fill slopes is standard practice in certain Western States. These metal structures are often combined with bituminous surfaced dikes or gutters collecting and retaining water at the outer edge of road shoulders at the top of fills. Observations of pipes and flumes in the West and in northeastern areas would indicate the following:

Sodded flumes are effective in areas with adequate rainfall where good solid sodding can be done. Sodded flumes have been observed to be practicable where gradient of flumes may be kept at slope ratios of about 3:1 or flatter.

Stone-paved flumes or those with bituminous surfaces have been effective provided they have sufficient capacity to prevent side overflow. Stone or bituminous surfaced flumes with inadequate capacity have been frequently damaged by overflow along the line where surfacing and ground join.

Solid sodding is usually desirable in humid localities to protect edges of stone or bituminous surfaced flumes.

Pipe flumes must be oversized to capacity of more than usual heavy rainstorm. Pipe or open flumes across new unconsolidated fills tend to be washed out in short order where serious overflow occurs at inlets.

In very alkaline soils, serious corrosion of metal pipe drains has been observed. Even asphalt-lined pipe flumes are sometimes rapidly destroyed under such conditions because surface water carrying gravel and coarse sand at high velocities (usual on road fills in hill country)quickly cuts away asphalt coatings in such metal flumes or pipes.

Both paved and metal-pipe flumes may require special energy dissipating devices to prevent excessive erosion of adjoining lands or of natural and artificial drainage channels below the highway.

Road Gutters

Various types of gutter cross sections are illustrated in typical regional highway cross sections, Figures 24 to 28 in Appendix. Much research is still needed in the field but the following principles appear to apply to gutter design under unusual roadside conditions in the various climatic regions.

1. The slope between outer edge of shoulder and the gutter should be 4:1 or flatter to permit safe crossing by vehicles forced to leave the highways in emergencies and effective use of motor-operated maintenance equipment.

2. The gutter cross section should be of such a broad well-rounded slope as to permit ready operation of mowing or other maintenance equipment.

3. The gutter surfaces should be completely protected against erosion, either by sod in humid localities or by surfacing or paving where required on steep profile grades and in dry regions.

Figure 14. Bituminous Surfaced Dike Used to Control Surface Water Flowing Downward Across Highway Fill in California. Metal flumes are often used to prevent erosion in connection with these dikes.

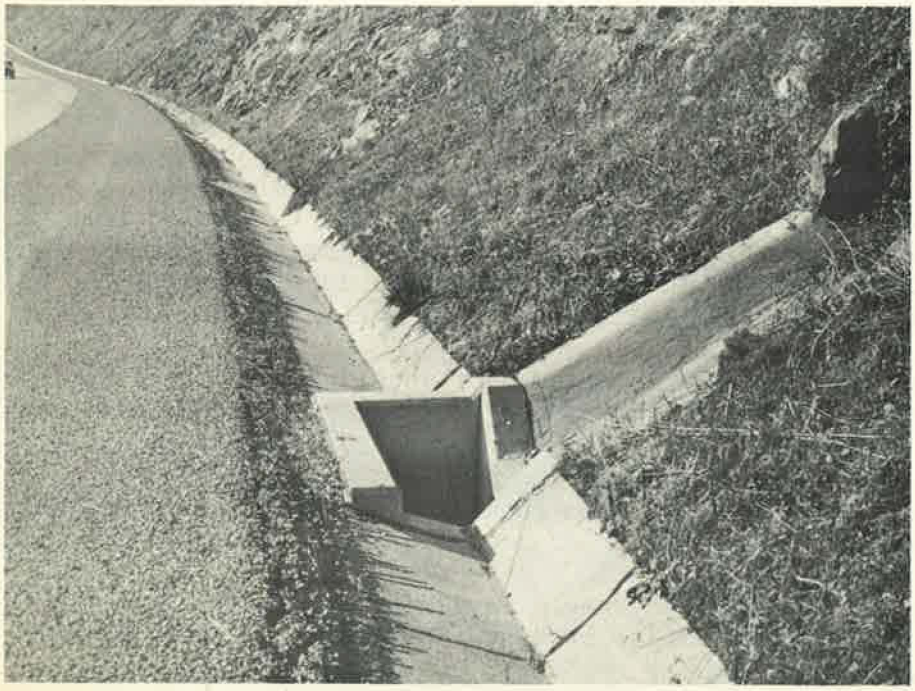

Figure 15. All Drainage Structures Must Consider Traffic Safety. This inlet with its concrete gutter hardly appears to have adequate capacity at the foot of a long mountain slope. This inlet is a hazard to motorists especially during night and storm conditions.

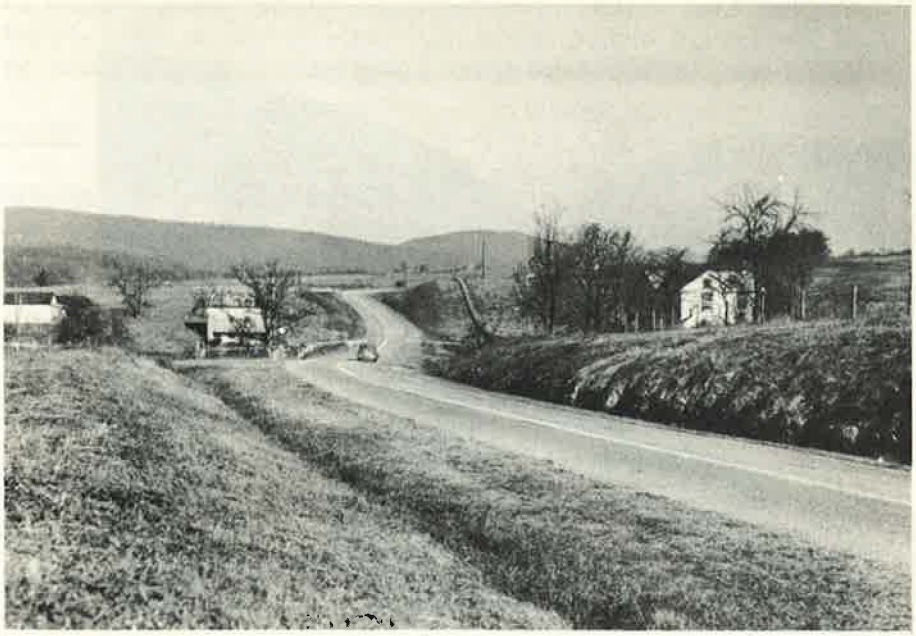

Figure 16. A Highway in the Middle Appalachian Highlands Region. Note angular dangerous V-ditches, and narrow right-of-way. Seeding and mulching of slope and gutter has, however, largely stopped erosion.

Figure 17. A New Highway in the Appalachian Highland Region One Year After Construction. Note heavy slope erosion and clogged drainage. Reshaping of slope and drainage ways will cost several hundreds of dollars per mile on this section of roadside. Mulching immediately following slope and gutter grading is essential if drainage is to be maintained and erosion controlled.

Figure 18. Special Protection is Required in Drainage Gutters on Grades Like This. Note concrete gutters, inadequate rounding of cut slopes, and the beginning of erosion on steep slopes in spite of mulching that followed finish grading.

Figure 19. Ditch Checks are Sometimes Used to Slow the Velocity of Surface Water Flow. Note siltation occurring here because cut slope and drainage channel were not protected by sodding or mulch and seed. Erosion control and drainage design must go together. They cannot be considered as separate problems.

Typical broad well-rounded gutters illustrated for the Central Low Lands, Figure 26, for example, have ample capacity for the heaviest rainfall. Equivalent run-off capacity is rarely required under usual New England conditions, for another example. Space in the drainage area in the North and northeastern States of the heavy snow belt must, however, be provided for snow storage.

Stream Channels

Existing streams tend to have ample capacity to drain their watersheds as long as there are no changes in stream channel alinement and no destruction of vegetative cover or other major changes in watershed land use. Construction of a wide primary highway parallel to a stream in undeveloped rural areas is usually followed by such major changes in watershed vegetation as to render stream bank erosion likely. Forests usually are cut down, brush and pastureland is frequently plowed, towns may even be built where open fields existed before highway construction. Under such conditions, existing streams became in effect artificial rather than natural drainage channels. As such the following basic requirements of channel design and channel protection must be met:

Stream channels must be cleared of all natural or artificial obstructions and if necessary widened and deepened until they have adequate capacity to handle possible increased run-off.

Stream channels can be kept open by protecting both banks and bed of stream against erosion. Willow planting, sodding, stone riprapping and other measures should be used where each method is considered most effective and economical.

Above all, highway culvert outlet channels leading to natural streams, and the earth embankments at bridges, will require sodding, riprapping or other special protection under these changed stream watershed conditions. Surface channels, pipe drains and storm sewers leading from watershed areas denuded of original forest or grassland vegetation following new highway construction are another special problem. Such structures under intensively developed watershed conditions may carry water in heavy volume at high velocities. Their outlets at junctures with natural streambeds must often be provided with energy dissipating and stilling basin devices.

Highway Drainage on Lands Below the Right-of-Way

Once surface water has crossed the highway through culverts or under bridges, it flows downward across lands below the right-of-way. Overland flow from the right-of-way and watershed areas above it will now be found in these forms:

1. Water flowing down fill slopes not yet concentrated in channels;

2. Water concentrated in channels at culvert outlets; and

3. Water already channelized in streams or other natural channels before it crosses the highway center line.

The first of these types of surface water flowing from highway slopes protected by a well-established growth of seeded, sodded or planted ground cover, rarely causes serious damage by either erosion or siltation to land below the highway. The second and third types of drainage water often cause such damage unless protective measures are taken. For example, it will often be necessary for the highway designer to provide adequate protected waterways leading from culvert outlets to natural channels or flowing streams below the highway. It will also be desirable during highway construction to provide necessary walls, riprap, sod, or willow or other bank planting at stream crossings under the roadway to protect waterways, road and bridge embankments, and private lands downstream, from damage by erosion or siltation.

Drainage from Culverts and Highway Drainage Channels

It has been found in localities where soil conserving methods such as terracing and contour cultivation are practiced that sodded outlet channels are necessary to conduct water away from ends of terraces or contour furrows. Without such protected channels soil erosion may be as great as though no terracing or contour cultivation were done.

These field and terrace outlet channels have in some cases done serious damage to highway fills and embankments. To avoid such damage it has been necessary to provide adequate sodded or surfaced highway gutters or intercepting channels conducting water from outlet channels to highway culvert inlets.

On the same principle, water discharged from highway culvert outlets must be provided with adequate sodded or otherwise protected channels or storm drains to conduct water across agricultural fields or other developed areas to streams or other natural drainage channels below the highway.

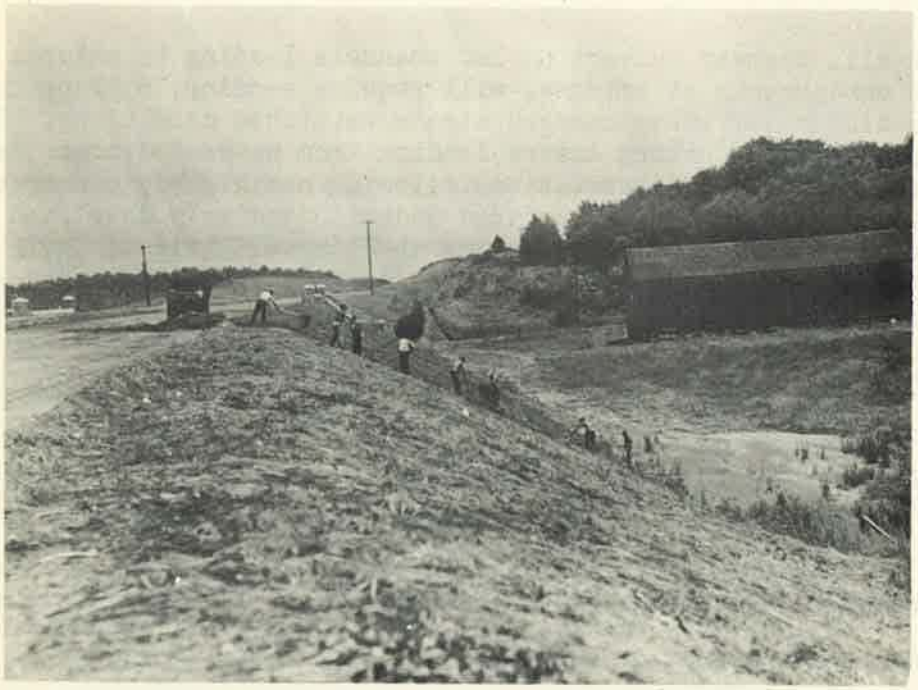

Figure 20. View of Slope Mulching Operations on an Eastern Highway. Note erosion on intercepting channel, centre background, and siltation of a farmer's field resulting from slope erosion, right foreground. Proper drainage must be combined with erosion control. Modern mulching equipment being developed to eliminate hand labor is reducing the cost of this basic operation. (See cut No. 16 - Report of Committee on Equipment).

PROTECTION OF STREAM CHANNELS

As outlined in previous reports by the Committee on Roadside Development, protection of bridge and road embankments and natural stream channels is necessary as a part of the highway drainage problem. Construction of primary highways usually lends to changes in watershed areas both above and below new highways. As forest cover is cut down, grasslands are replaced by plowed fields or fields are replaced by residential development on lands bordering the new road; run-off is certain to increase. Protection of stream channels at bridges and along road fills is likely to become essential as a result of this increased volume and velocity of stream flow.

Figure 22 shows an example of the need for stream channel protection on a highway near Washington, D. C. These relationships between the highway and streams crossing or running parallel to them are of extreme importance. In some cases where run-off and stream-flow factors have not been considered both in location of the road and protection of embankments and stream banks following construction, whole sections of highway have been seriously damaged or destroyed by stream erosion. Long experience in various topographic and climatic regions emphasizes the following principles.

1. New highway development in open country is usually followed by increased volume and velocity of overland flow on watersheds above and below the road. Any change in watershed vegetation or denudation of watershed ground surfaces tends to produce these results. Such changes should be expected and anticipated in highway location and design, as related to existing stream channels.

2. The Committee on Roadside Development has repeatedly emphasized in its reports the need for revegetation or other surface protection of all slopes, shoulders, and drainageways laid bare by highway construction equipment. It is equally vital that all road and bridge embankments subject to damage by stream flow be protected by revegetation, mowing or otherwise as a part of highway construction operations.

3. Straightening, widening, or deepening of existing stream channels in connection with road construction should not be done unless the following precautions are taken:

   a. Adequate knowledge obtained of local rainfall character and character of watershed run-off above such channel changes.

   b. Reasonably accurate estimates made of increase in stream velocity that will result from channel changes proposed.

   c. Effects of channel changes studied in highway design and plan stages as to:

Figure 21. Note dumping of stone on slopes to stop heavy stream channel erosion on watershed area shown in Figure 6. Excessive runoff following changes in watershed land use caused this damage. Heavy rip-rap or masonry wall protection should be provided to protect embankments of this divided highway structure pictured in lower left corner of Figure 6.

Figure 22. Road Embankments Bordering on Streams Must be Protected by Rip-rapping, or by Appropriate Willow Planting, or Otherwise. This protection should be provided in original construction of the highway, as it was here.

(1) Probable effects of channel changes on road and bridge embankments.

(2) Probable effects of proposed channel changes on stability of stream channels below the change.

(3) Probable rise of flood water levels downstream resulting from channel changes.

(4) Probable damage to biological and domestic water supply values downstream as a result of channel changes.

4. Stream channel changes should be avoided wherever possible when study of above factors in stream channel change indicates likelihood of serious damage to road structures, agricultural or other land developments, or biological and water supply values. In any case, the amount of probable land damage loss resulting from stream channel change should always be balanced against possible increased cost of road or bridge construction when no channel changes are to be made before decision is reached.

Summary and Conclusion

In summary, the Committee emphasizes the following points regarding the design of graded cross sections and subsequent protection of roadside slopes and drainageways.

1. Roadside drainage design should be concerned not with standardization of graded slope and drainageway cross sections but with the adjustment of such graded cross section design to:

a. Prevailing land relief, land use, and surface water run-off conditions in each locality.

b. Predictable annual rain and snowfall and amount of such precipitation and surface run-off to be expected in characteristic local storms of average 10-year occurrence in view of known watershed conditions above the road.

2. Proper streamlined grading cross section design with adequate surface drainage of roadside slopes and drainageways must be accompanied by establishment of vegetation or other appropriate means of preventing erosion, depending on particular local conditions.

3. Open types of highway cross section design--encouraging surface water to flow into broad well-rounded and protected drainageways are desirable on highways in open country, for drainage efficiency and economy in maintenance.

4. Well-rounded slope and gutter sections without sharp angles are necessary for proper roadside drainage. Such grading must be combined with protection against erosion, for stabilization of slope areas.

5. Special grading and drainage problems in connection with grade separation structures on divided highways are best solved in the drafting room before construction begins, through use of spline-line profile and grading plan procedures showing graphically in three dimensions the interrelationship of all features, existing and proposed.

6. Intercepting channels and dikes should be installed above cut slopes and below fills where local run-off conditions render them desirable. Care should be taken to provide suitable outlets for such channels, for positive protection from erosion.

7. Bridge and road embankments subject to stream erosion should be protected by appropriate riprapping or willow planting to be shown on original highway design and plans, and carried out during highway construction. Unnecessary stream channel changes should be avoided wherever possible unless positive protection from erosion based on watershed study can be provided for the new channel.

8. Lands below the road should be protected against erosion or siltation by flow from highway culverts and drainage channels by well designed drainage channels protected against erosion.

Suggested Research and Investigation

The coordinators in the various divisions of the Bureau of Public Roads are urged to consider field study and investigation of the following problems of roadside grading and drainage design.

1. Most effective and economical grading cross section design permitting finish grading and mowing and other machine maintenance by use of latest motored equipment, to meet land relief, precipitation and prevailing soil characteristics in States of each of the physical division of the United States.

2. Most effective, safe and readily maintained design of gutters, intercepting dikes and ditches, and channels at inlets and outlets of culverts.

3. Most effective grading design of bridge embankments, medians of divided highways, traffic islands, rotaries and intersections, and other special roadside areas by use of contoured grading plans.

4. Most effective and economical design of roadside drainage channels, and protection of channel and stream banks against flood damage caused by runoff resulting from changes in watershed land use.

5. Selection and development of sources of best seed, sod and plant and mulching materials for grassed surface protection in drainage channels, stream channels, bridge embankments and cut and fill slopes, in humid regions. Development of alternative measures as necessary in drier regions for protection from erosion, by wind or water.

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APPENDIX

TYPICAL STATE HIGHWAY CROSS SECTION GRADING DESIGN IN THE VARIOUS REGIONS OF THE UNITED STATES

The Committee recommends that:

1. Each State design and adopt, for each class of highway (i.e. primary, secondary, interstate) a typical section to fit each type of soil in the respective classes of topography in the State.

2. Well rounded cross sections (earthwork) be graded with efficient machine equipment during original highway construction to avoid the uneconomical practice of regrading highways as part of a mulching, seeding or sodding operation, and later costly upkeep.

3. Width of right-of-way taking be determined by the local conditions controlling the highway design. In other words, the typical cross section should be developed for the full width of right-of-way, and indicate also building setback lines and related right-of-way control necessary, where applicable.

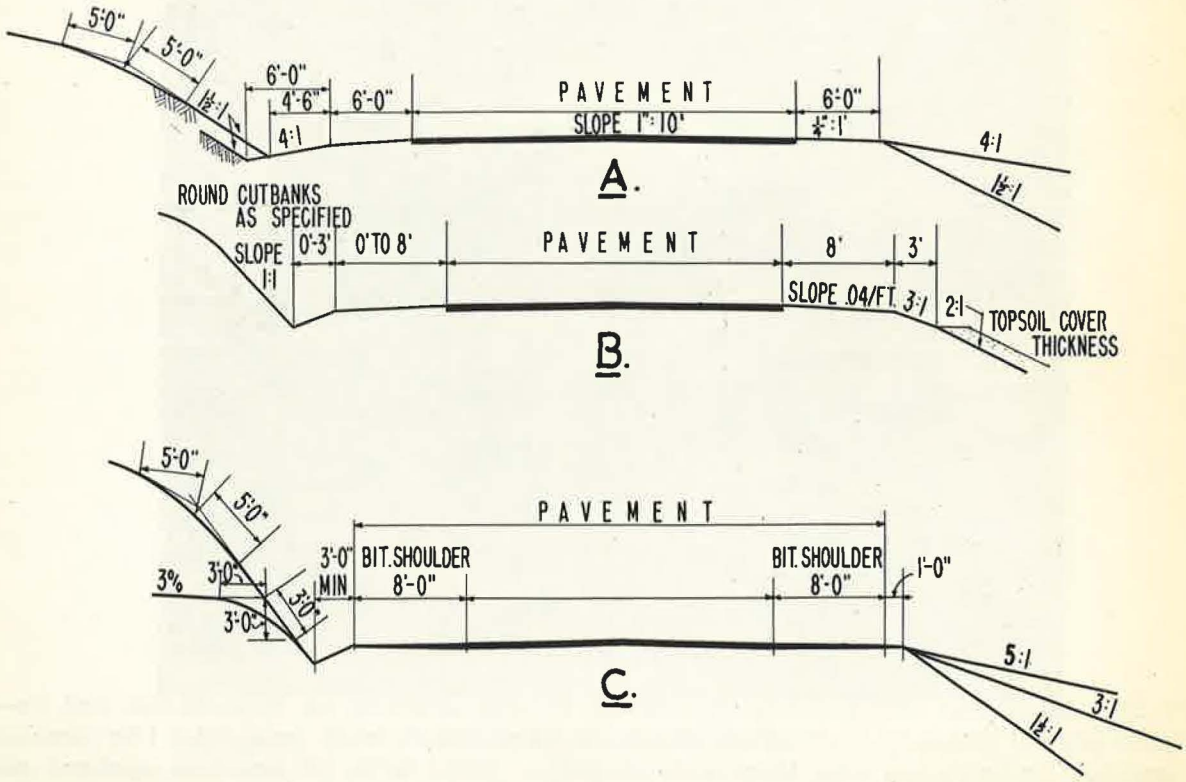

Figure 23. Pacific Mountain System - State Highway Cross Sections.

Figure 24. Typical Cross Section Grading Design - the Pacific Mountain System. (California). Note the dykes along fill at right--designed to keep water from flowing over fills except at points where flumes or paved channels are provided. Cut slopes are graded and rounded to fit adjacent topography.

Figure 25. Mulching Immediately Following Finish Grading is Economical and Desirable in all Regions. Seeding under or over mulch will complete the process of erosion control on this Maryland project. This type of erosion control has been effectively adapted to Pacific Coastal conditions by modifications to fit local climatic factors.

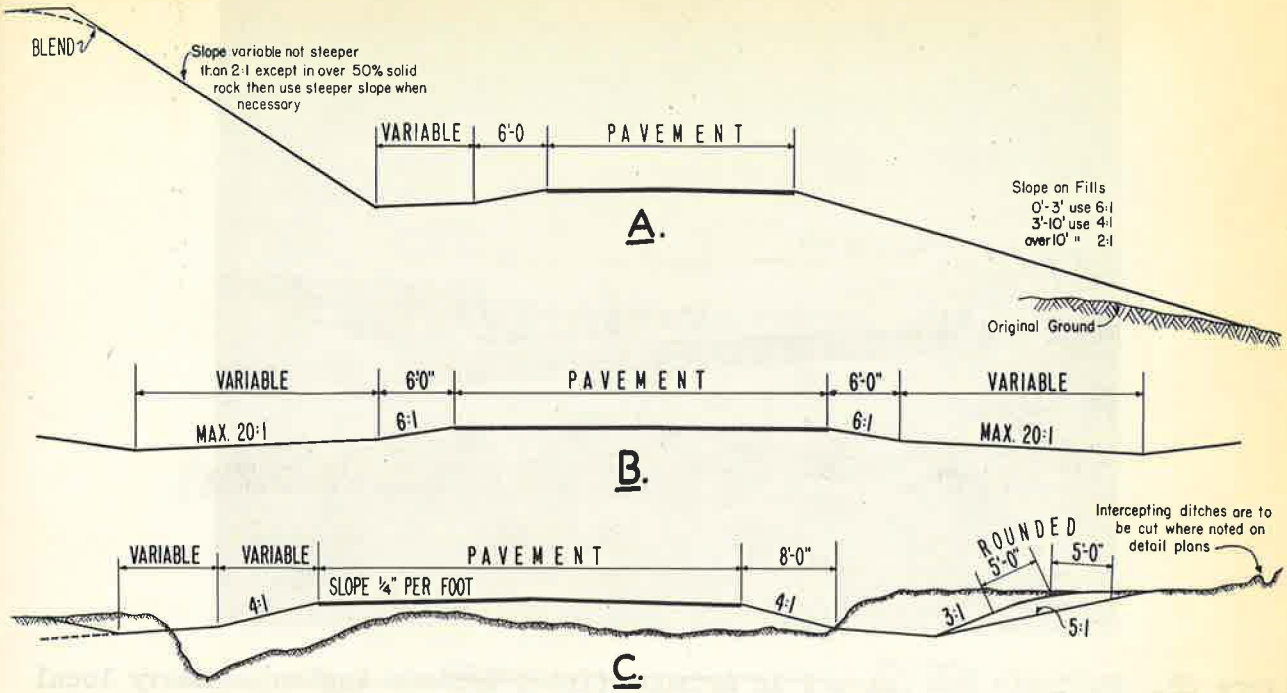

Figure 26. Rocky Mountain System - Interior Plains - State Highway Cross Sections.

Figure 27. A Highway in the Inter-Mountain Plateau Region (Utah). Here little surface water can reach the highway in damaging volume because of low annual rainfall and heavy vegetative cover of watershed lands. Note wide cross sections with all surface water tending to be kept some thirty feet or more away from the surfaced traffic lanes.

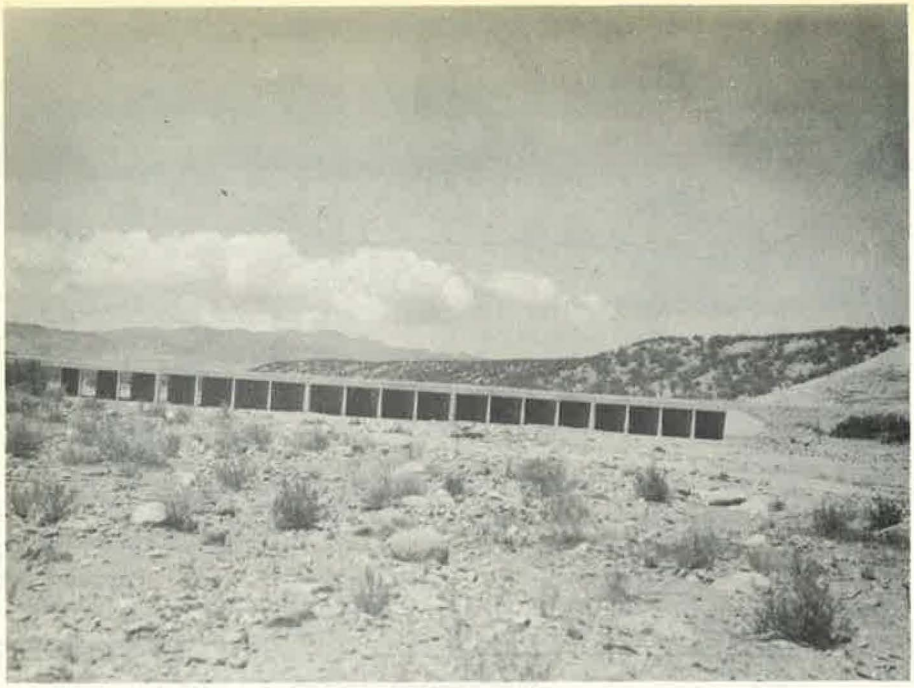

Figure 28. Multiple Box Culvert in Arizona (Inter-Montain Region). Heavy local storms at long intervals of time appear to make it well nigh impossible to calculate watershed runoff to be expected over a ten-year period in the Southwest. This safe culvert design keeps the whole natural drainageway open for flash flood runoff.

Figure 29. Typical Highway Cross Section Grading in Interior Plains Region. Designed to permit snow to blow clear of the roadway without drift formation. Vegetation is hard to establish on road slopes in this locality. Broad rounded cross section grading, as shown here, will largely prevent erosion that would be expected in V-types of drainage channels.

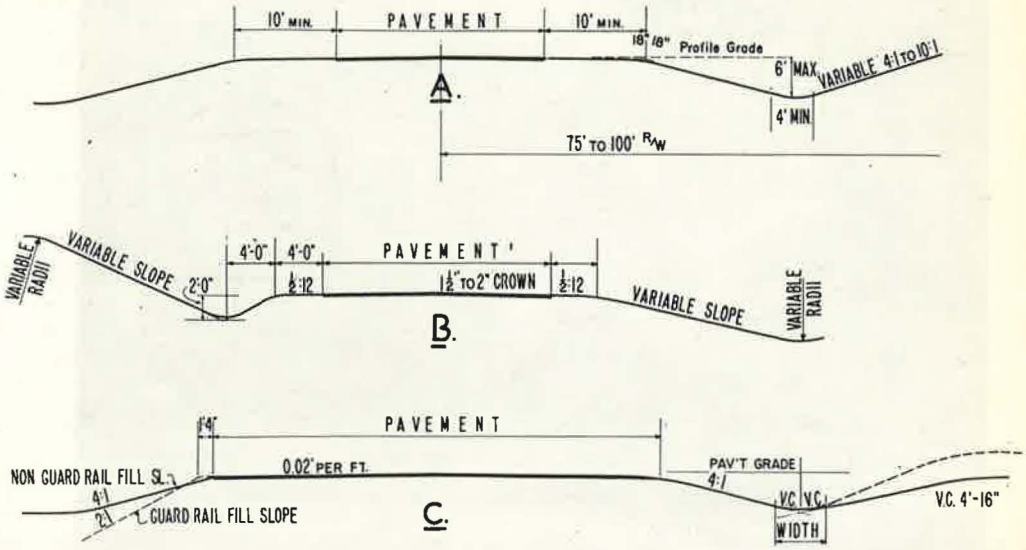

Figure 30. Central Low Lands - State Highway Cross Sections.

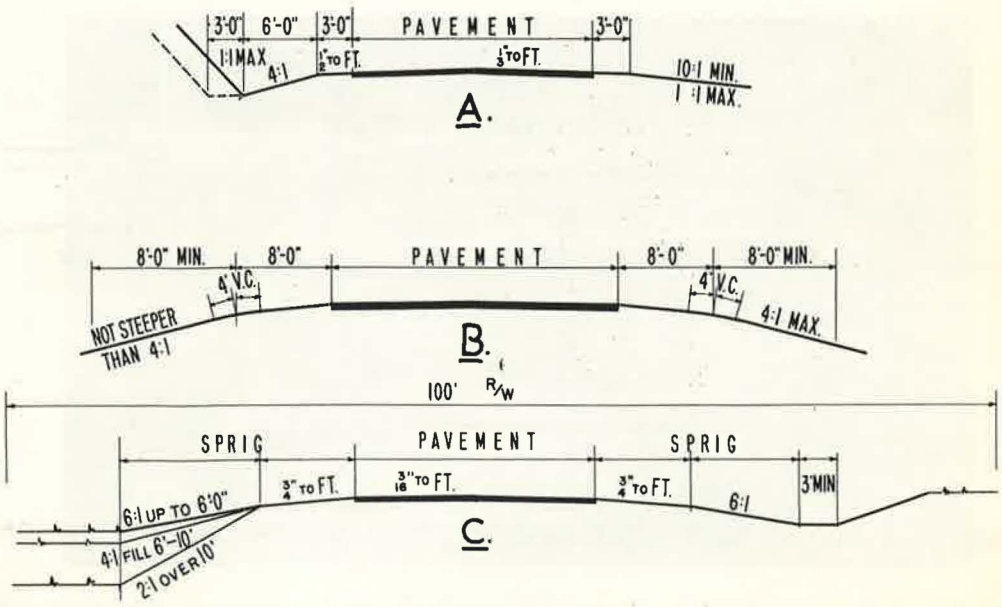

Figure 31. Atlantic Plain - State Highway Cross Sections.

Figure 32. Typical Graded Cross Section - Atlantic Plains Region.
Note - parabolic shoulder design - well rounded gutter - and excellent turf cover.

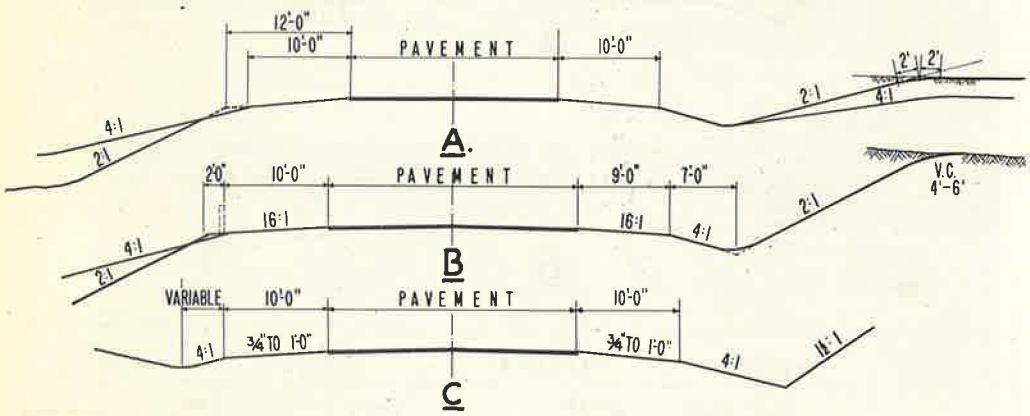

Figure 33. Appalachian Highlands - State Highway Cross Sections.

Figure 34. A Typical Appalachian Region Landscape (Virginia) Showing a Series of Small Watershed Areas Draining to the Highway. Good highway drainage is primarily a problem of so locating and designing the road that water will flow readily from lands above it to natural drainageways below it. This flow of water must be accomplished without erosion or siltation of either the roadway or private lands adjacent to it. Note gutters close to edge of traveled way.

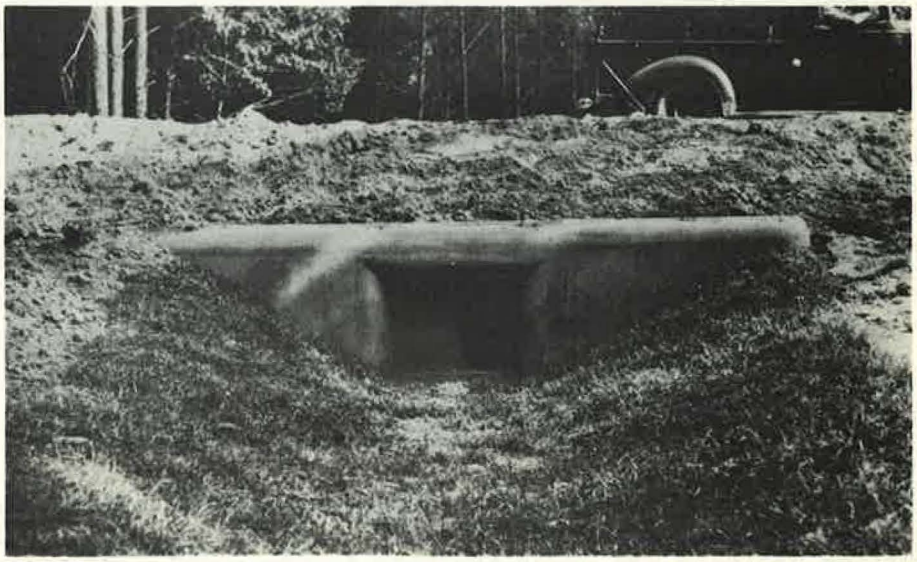

Figure 35. Culvert Design on an Eastern Highway. Heavily wooded watershed conditions hold back a large percentage of surface water here. Relatively small culvert openings are made possible by this watershed condition. Note smooth lines of culvert and sodding to protect waterway.

Figure 36. Note narrow V-type ditches which it appears may soon be clogged by erosion on cut slope, right foreground.

Figure 37. Wide right-of-way, careful fitting of the road to existing topography in cross section design and the least possible interference with existing natural land surface drainage are among the keys to the problem of better highway drainage. This parkway shows the results of such location, and cross section grading. Complete restoration of natural field turf on road border has prevented any interference with drainage by erosion here.