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PAVEMENT PERFORMANCE CORRELATED WITH SOIL AREAS

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SYNOPSIS

This paper is a continuance of one entitled "Analysis of Spring Break-up Data in Virginia", presented by Messrs T E. Shelburne and A W Maner at the Twenty-Eighth annual meeting of the Highway Research Board The original paper considered data only from the Culpeper District of the Virginia Department of Highways, whereas this paper includes an analysis of performance of 18,000 miles of roads throughout the State—nearly 8500 miles of primary and 9500 miles of hard-surface secondary roads

Road performance surveys were conducted during the spring break-up of 1948 and uniform ratings were originated These ratings, five in all, which were dependent upon the degree of pavement distress, depicted road conditions when lowest support characteristics prevailed. During the survey, maps of each county, showing performance ratings of primary and secondary roads were prepared. These data were summarized and a map of primary routes was developed for each of the eight districts By combining these district maps a composite for the State was prepared

An expedient method of digesting the maze of information collected was to tabulate all data according to several categories Since non-hard-surface secondary roads vary so extensively, only primary and hard-surface secondary roads were considered under each category Road performance first was studied according to twelve general soil areas, established by grouping soils on a basis of physiography, geology and pedology. Further study of performance was made by grouping according to base and surface types

Studying pavement performance on a soil-area basis was a valid approach, for the percentage of total mileage in any one soil area was about equal to the percentage of the State within that soil area Based upon the 1948 spring break-up data, pavements were found to perform best in three soil areas—sandstone and

[1] An agency sponsored jointly by the University of Virginia and the Virginia Department of Highways.

shale, Triassic sandstone, and Coastal Plain sediments Likewise, poorest performance was observed where pavements were placed upon soils derived from sandstones-and-shales-with-coal and Triassic "red beds". While these ratings represent the conditions of pavements as they existed during the survey, some factors are not immediately apparent. To provide against undesirable characteristics of soils in several areas, roads had been built to higher types than elsewhere. For example, most roads built upon organic-clay soils were concrete with high-level profiles. Also, 63 percent of all primary roads built upon Coastal Plain sediments had bases constructed of local materials. In contrast, only 41 percent of comparable roads in the sandstone-and-shale area had bases of so-called stabilized, selected materials—59 percent were macadam.

During the break-up, primary roads fared better than secondaries despite the fact that 80 percent of all traffic uses these arterial highways (most heavy trucks use only the primaries). Only 43 percent of all hard-surface secondary roads were rated as performing good, compared to 58 percent of all primaries Structural design influences ultimate performance, for 51 percent of all primaries and only 12 percent of all hard-surface secondaries had macadam or other high-type bases

Climate is an important variable affecting pavement performance Although engineers cannot control this factor, they at least should recognize the controlling conditions In this way maintenance crews can anticipate a severe break-up and prepare their campaign. For this study, weather data for the past 31 years was reviewed. As a summary, freezing index values and precipitation (from 12 weather stations) were determined for four years to represent the two worst winters in 31 years and two other winters which were followed by light distress. These four seasons show that a combination of base and subgrade saturation followed by extensive freezing causes considerable destruction If one factor is diminished, distress usually is mild.

A few of the most significant facts brought out by this survey are as follows:

1. Climate will contribute to the deterioration of pavements if a certain combination of precipitation and temperature occurs

2 Adequate surface and sub-surface drainage are prerequisites for satisfactory road performance

3 Bituminous concrete and other high-type plant mixes give better service than other bituminous surfaces

4 Low-type bases of local and so-called stabilized, selected materials are adequate only if subgrade soils have favorable support characteristics

5 For economy, pavements and bases should be designed on an areal soil basis. Designs can be minified to take full advantage of soils with desirable support characteristics and, in other areas, augmented to provide against detrimental conditions

Engineers should be cognizant of the above factors and utilize this knowledge in planning both for construction of new and maintenance of existing highways

Highway engineers are continually striving to design, construct and maintain better pavements. In order to do this it is necessary that the various factors responsible for pavement performance be thoroughly understood and evaluated. Performance surveys made at the time of a severe spring break-up can be very helpful in determining not only the type but also the extent of failures It has often been stated that the highway system of a state constitutes one of the largest laboratories for conducting highway research on a full-scale basis While such an approach may have certain limitations, comprehensive road condition surveys can serve a very useful purpose if they are made at the time of a severe spring break-up Such a survey was made of the entire highway system in Virginia during the Spring of 1948. The methods of conducting the survey and rating the pavements have been described (*1*)[2]. Also results of the survey in the Culpeper District were reported last year (*2*).

This paper is a continuance of the work previously reported and includes an analysis of data on the performance of 18,000 mi. of roads throughout the state—about 8500 mi. of primary roads and 9500 of hard-surface secondary roads. A description of the State is

[2] Italicized figures in parentheses refer to list of references at the end of the paper.

presented with regards to such items as physiography, soils, climate, traffic and other factors influencing pavement performance together with an analysis of the ratings of the various types of base and surface courses.

GENERAL DESCRIPTION OF THE COMMONWEALTH OF VIRGINIA

Location—The Commonwealth of Virginia, one of the Middle Atlantic States, lies between Latitude 36° 30′ and 39° 30′ N. and Longitude 75° 30′ and 83° 30′ W. Virginia is bounded on the north by Maryland, the District of Columbia, and West Virginia; on the west by West Virginia and Kentucky; on the south by Tennessee and North Carolina; and on the east by Maryland and the Atlantic Ocean. The geographical center of the state is Latitude 37° 20′ N. by Longitude 78° 50′ W. Along the Atlantic Ocean Virginia's coastal plain lies within the embayed section of the Coastal Plain Province. This fact accounts for the ideal harbor facilities such as are found at Norfolk, Newport News and other cities to the north. In fact, the natural harbor facilities account for the location and growth of many of our most important cities.

Area—Once included within the boundaries of Virginia were the present states of Illinois, Indiana, Ohio, Kentucky and West Virginia. Of the United States Virginia now ranks 35th in area with 40,815 sq. mi., including inland waterways (*3*). Within the States are vast reserves of timber—about 65 per cent of the total land area is forested. Several large national forests cover a total of 6443 sq. mi. and State Parks and Forests include another 41 sq. mi. One hundred counties subdivide the State into smaller units of area. Serving these 100 counties, and 40,815 sq. mi. which comprise Virginia, are more than 47,000 mi. of primary and secondary highways. Stated another way, there are nearly $1\frac{1}{8}$ mi. of road per square mile or about 470 miles of roads per county.

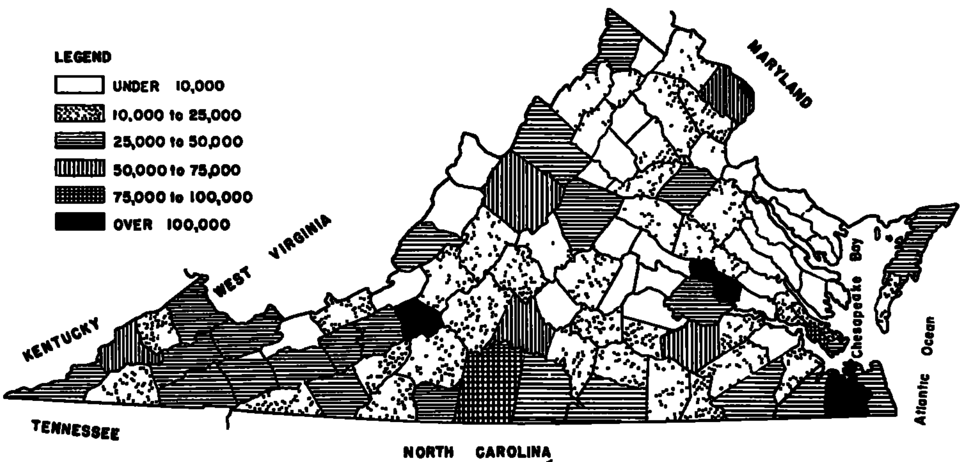

Figure 1. Population by Counties—July 1, 1947 Estimate by the Bureau of Population and Economic Research (Includes Independent Cities).

Population—In 1930, the total population of the Commonwealth was 2,421,774; but by 1940 this figure had increased to 2,680,593. Official census figures for 1948 are not available; however, the total population is estimated at nearly 3,100,000 (*4*). Of the State's 100 counties 61 have decreased in population since 1940, most of these being rural counties. Still other counties, particularly those of metropolitan areas, have gained in population—probably at the expense of rural and agricultural counties For example, the population of Arlington County, the county of smallest area in the State, more than doubled—increasing from 57,000 in 1940 to an estimated 122,000 in 1948 Figure 1 represents the estimated population, by counties, for the year of 1948 Four of the major cities of the State are Richmond, Norfolk, Roanoke, and Portsmouth with estimated 1948 populations of

225,837; 189,709; 74,154; and 74,010 respectively. In all there are 24 cities in Virginia with populations of 5000 or greater.

Resources and Industries—Much of the state is given to agriculture the nature of which varies with climate, topography and soils Truck farming, dairy cattle, melons, cotton and the raising of peanuts constitute the major agricultural pursuits in the Coastal Plain Dairy and beef cattle are raised throughout much of the Piedmont; well drained portions of the southern Piedmont have much of the cultivated land in tobacco and cotton. Orchards thrive on the well drained slopes of the mountains and ridges of northern and western Virginia. The great valley has long been famous for its agriculture, including dairy and beef cattle, poultry, orchards, and grain.

Many industries are found throughout the State. Of the most notable are tobacco, chemical, peanut, canning, textile, furniture, ship building, lumber and mineral Shipping and fishing assume major roles along the coastal areas. The development of water power in Virginia is an item of increasing importance. Virginia long has been a mecca for tourists and serving them has become a major industry throughout the State.

PHYSIOGRAPHY, GEOLOGY AND SOILS

Virginia is situated within five major physiographic provinces (Fig. 2)—Coastal Plain, Piedmont, Blue Ridge, Ridge and Valley, and Appalachian Plateaus (*5*) (*6*). Each of these provinces can be subdivided into smaller regions which have local prominence and significance Engineers involved in various types of transportation—highways, airports, and railroads—are interested both in physiography and in materials.

Within a given climatic belt, landform, stream systems, drainage characteristics, and soil types are dependent upon geologic age, geologic history, and parent materials. Mode of deposition and characteristics of the materials govern the ultimate soil development. Some materials disintegrate to produce plastic soils and the associated subdued topography. Other materials are conducive to rugged topography and may produce little residual soil. If, during the geologic history of the area, orogenic movement occurred there will be variations in the development of topography, and such movement might explain the location of certain soil areas. Since all these factors are interrelated one cannot consider one element without the others.

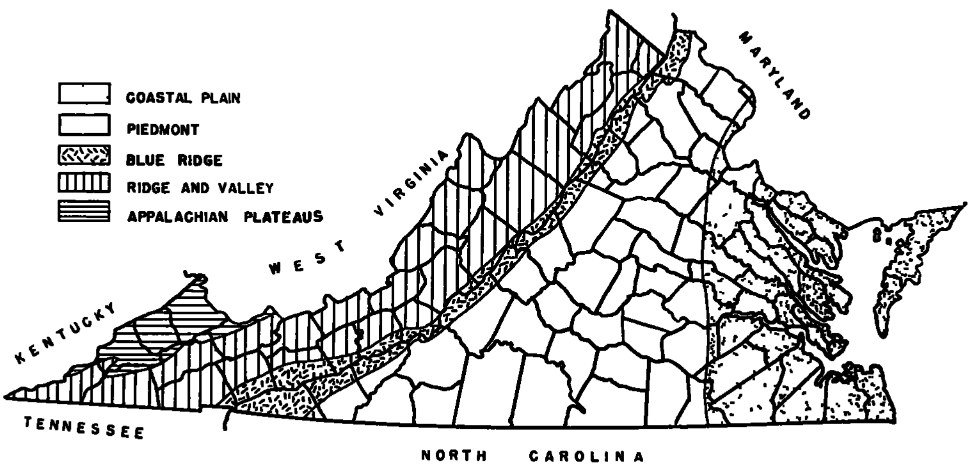

Figure 2. General Physiographic Provinces

Coastal Plain—The Coastal Plain province comprises a system of terraces extending from the Atlantic shore inland to the fall line at the Piedmont. The area is geologically young with each terrace representing a shore condition in the recession of the sea—the youngest terrace being adjacent to the present shore. Coastal deposits are Cretaceous, or younger, in age. Since these materials were deposited by moving water distinct gradation and sorting can be expected.

Some of the older deposits have been consolidated or cemented in varying degrees. The inner Coastal Plain, where oldest sediments are found, is somewhat dissected with some of the resistant formations displaying rather rugged topography. Outer Coastal Plain terraces generally are flat and swampy. Throughout the province good construction materials abound, ranging from sand clays to sand or sand gravels. Most of these soils will compact to high densities and provide stable subgrades. Some of the poorly-graded sands lack stability and present difficulties. Excellent internal drainage prevails for most of this soil area Locally one will find peat and muck deposits which are associated with the swamps of the lower terraces. These organic deposits are detrimental to construction; poor drainage, and waterlogged soils result in excessive settlements from consolidation of the subgrade. High ground water-table makes effective surface drainage difficult, necessitating the use of a high-level profile.

Piedmont—In a broad sense the Piedmont is said to be a submaturely dissected plain—that is, all the hill tops are about equal height and the stream systems have developed nearly to maturity. Of course, locally there are significant variations in the topography—often amounting to several hundred feet. The vast area comprising the major portion of the Piedmont consists of a complex system of hard crystalline rocks—largely Pre-Cambrian in age. Resistant rocks produce strong ridges or even low mountains and less resistant rocks result in subdued or low and rounded topography. Average elevations in the Piedmont range from about 800 ft. in Northern Virginia to 1500 ft at the North Carolina boundary.

Crystalline rocks of the Piedmont have been weathered to produce extremely deep soils, for geologically this region is very old These soils are as complex as the crystalline rocks from which they are derived; within a hundred feet one might encounter several soil types. Some of these soils are very plastic; others are highly micaceous and expansive, again the soils are quite granular and well-graded.

Probably the most contrasting of all variations in the Piedmont province are the Triassic lowlands. These lowlands, scattered throughout the Piedmont, resulted when numerous basins, formed by down-faulting, were filled with sediments ranging in texture from shales to conglomerates. Intruding the sedimentary strata in some of these lowland areas are found ridges of igneous rock—known as trap ridges. Naturally, topography of the Triassic lowlands will vary with material types. Soft shales develop low, rounded topography with prevalent poor drainage, sandstones, although soft, develop a stronger topography and dissection is apparent—topography of these sediments usually is lower than that of the surrounding Piedmont.

Since Triassic sediments have such wide textural ranges the resulting soils can be expected to vary accordingly. The clay-shales of the Red Beds develop very plastic soils which are poorly-drained Subsequent large changes in volume can be expected with changes in moisture content. Some of the Triassic formations have coal-measures and the associated plastic under-clays are problem soils similar to the residual shale soils. Well-graded, sandy soils usually develop from sandstone formations and problems are lessened. Conglomerates may develop sandy, plastic, or micaceous soils depending upon the matrix and the rocks involved.

Blue Ridge—Adjacent to the western edge of the Piedmont is a belt of mountains which comprise the Blue Ridge province. These mountains are remnants of a former highland which antedated lower peneplains on either side—Piedmont to the east and Ridge and Valley to the west. The Roanoke River divides the Blue Ridge roughly in two parts; north of this river the province seldom exceeds 14 mi. in width while south of this river the province widens to about 65 mi. The southern section is highest and its summits do not indicate a plane as much as do those of the northern section. Topography varies considerably along this province with the northern portion having long stretches which are 2000 to 3000 ft. in height and locally 4000 ft. The southern section ranges between 2000 and 3000 ft. with frequent expanses at nearly 5000 ft. Erosion and dissection have been instrumental in the formation of this province.

Structurally the Blue Ridge is closely allied to the Piedmont Similar rock formations comprise the two provinces—that is, hard, durable, resistant rock. Most of these rocks are of Pre-Cambrian igneous origin; however, the Cambrian quartzite contributes to the breadth of the southern portion.

Soil development on the Blue Ridge has been very slight; but the soils are as varied as the parent materials. Topography, erosion, and dissection account for the thin soil development along these mountains. Highway problems are confined mostly to grade, alignment, and rock excavation.

Ridge and Valley—A long narrow belt of ridges and inter-mont valleys is situated west of, and parallel to, the Blue Ridge. This region, about 65 mi. in width, is aptly named the Ridge and Valley province. Most of the area in Virginia that lies west of the Blue Ridge falls within the Ridge and Valley province—the exception being a small portion of Appalachian Plateaus in the western extreme of the State. This area, extending diagonally across the State, must be considered as a major soil and economic region. Agriculturally, mineralogically, and industrially this province is important; here are located many of the important cities of the State.

This region owes its peculiar physiography first to the geological history and second to the erosional history of the area. As the name implies, the province is characterized by a series of almost parallel resistant ridges separated by broad level valleys. Ridges may range from 2000 to 3000 ft in elevation and valley floors about 400 to 1000 ft. Thus local differences in topography may be from 1000 to 2600 ft.

Materials that make up the formations in the Ridge and Valley Province are of sedimentary origin—Cambrian, Ordovician, Silurian, Devonian, and some Mississippian strata. These sediments include quartzite, conglomerate, sandstone, shale, dolomite, and limestone. They were deposited in horizontal strata which were subsequently folded and distorted while forming a geosyncline Subsequent planation, erosion, and dissection exposed the ends of strata differing in durability Limestones were soluble and quickly reduced to karst valleys. Shales weathering into clays, were eroded, and now form the valley portions in which the major streams are found. Sandstones, quartzites, and conglomerates—more durable materials—resisted the forces of nature to the extent that these strata form the ridges.

In the limestone valleys sinkholes abound and the soils are silty-clays. Generally, these residual soils are well drained in a natural state but become very plastic and impervious when remolded and compacted. Moisture content will affect greatly the degree of compaction and workability of the limestone soils. Alignment and impervious soils constitute the major construction problems in the limestone areas.

Shales, in general, produce plastic clay-like soils. These very plastic, poorly-drained soils suffer large changes in volume with changes in moisture content. Naturally, workability of these soils is impaired by high moisture contents. In addition to plasticity and workability the shale residual soils have relatively low-supporting capacity. When used for embankment material, frequent sloughs and settlements can be expected.

Residual soils derived from the quartzite, conglomerate and sandstone strata are usually well drained—sandy-silt or silty-sand. Of course soil development is retarded upon the ridges and erosion of the soil further decreases the accumulation. Highway construction problems of these ridges include alignment, grade, slides, and excavation of rock.

Appalachian Plateaus—The northerly extension of the extreme western end of Virginia lies within the Appalachian Plateaus province. Further subdivision, according to Fenneman, results in two separate divisions—the Kanawha and Cumberland Mountain sections. In areal extent this province includes a wedge-shaped section about 60 mi. long and a maximum of 25 mi wide. Its boundaries are Kentucky and West Virginia to the northwest and north and the Ridge and Valley province to the east and south. The average elevation is nearly 3000 ft. Dissection, which is the topography-forming agent throughout the province, has incised the uplifted region to produce local relief of over 1000 ft. in some instances. The entire province has been uplifted and dissected several, or more, times. In general, the Cumberland Mountain section is higher than any of the adjacent sections. This section depicts a high plateau where open or slight folds have been eroded. Strong relief and youthful dissection, illustrated by the New River Canyon, characterize the Kanawha section.

Several strata of the Carboniferous formations are exposed throughout the province mostly by dissection, for the sediments essentially are flat lying. During uplift these strata were warped locally so that occasional open folds were formed. Here are situated the major coal mines of Virginia. The Carboniferous strata are composed almost entirely of sandstones, shales, and coal. Soils are highly plastic, thus reflecting the influence of shales. Underclays, associated with the coal measures, are perhaps the most plastic soils to be found anywhere. Subgrade support, swelling and shrinkage, and slides combine to present most perplexing soil problems to the highway engineer. Securing satisfactory grade and alignment in this rugged topography is a challenge to the location and design engineer. In addition, heavy coal truck traffic causes severe pavement distress

General Soil Areas—For the purpose of analysing the state-wide road condition survey data the State of Virginia, and its five physiographic provinces, was considered as consisting of twelve general soil areas (Fig. 3). These areas were arbitrarily selected on the basis of geological formations and past experience These soil areas were arranged approximately in their order of suitability as construction materials Analysis of the data indicated further differentiation and rearrangement of the soil areas may be desirable. The arbitrarily selected areas are as follows:

1 Silts, sands, and gravels of the Coastal Plain.
2. Non-plastic granitoids of the southeastern Piedmont.
3. Soils derived from Triassic Sandstone formations in the Piedmont.
4 Soils of the sandstone-and-shale belt of northwest Virginia—a portion of the Ridge and Valley province
5. Quartzite and shale, a portion of the southern Blue Ridge province The soils developed from these parent materials are of medium plasticity.
6. High quartz granitoids which make up a major portion of the Piedmont. Locally these soils are micaceous.
7. Soils of the limestone-and-dolomite belt which extends throughout the great valley.
8. Low-quartz granitoids found in the southwestern portion of the Piedmont. These soils are highly micaceous and expansive.
9 Soils from extrusive igneous rock formations found in the central part of southern Virginia and Catoctin formation of the northern Blue Ridge. These soils are fairly plastic silty clays.
10. Sandstones-and-shales-with-coal, found in southwest Virginia in the Appalachian Plateaus province. These materials weather into very plastic soils.
11. Triassic "red beds" found in the Piedmont. Since the parent materials are predominantly shales they produce

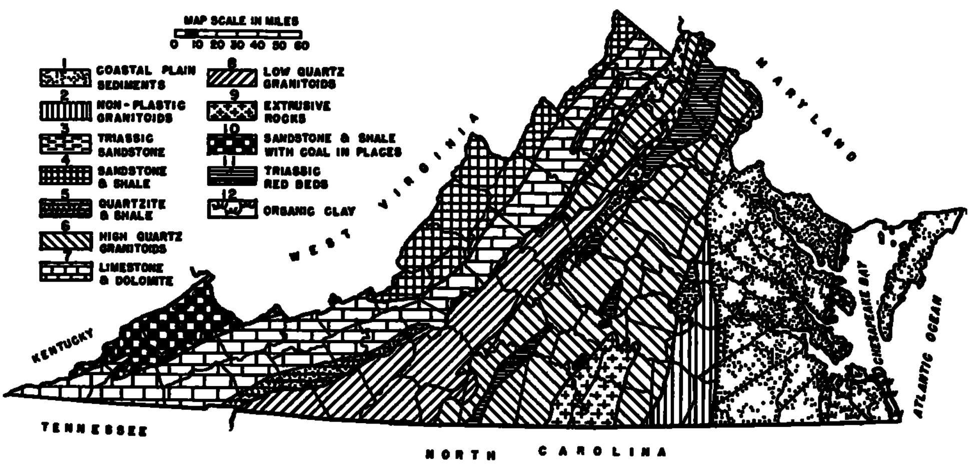

Figure 3. General Soil Areas

probably the most plastic soils in the state.

12. Organic clays of the lower and outer Coastal Plain These soils are capable of having extremely high moisture contents and are highly compressible

CLIMATE

Virginia is favored by a mild climate with infrequent deviations which produce an occasional unusual year The United States Weather Bureau records over the period from 1891 to date indicate the following: a yearly temperature range from an average high of about 85 F. to an average low of about 30 F., and the average annual total precipitation is about 42 in

Climatic variables influence the performance of highways in several ways, thus, knowledge of weather data adds much to any study of pavement performance. Probably the most trying time for maintenance engineers is that period in the spring when frost is leaving the subgrade and break-up occurs. In recent years engineers have become aware that certain combination of events cause a severe spring break-up. Two important factors influencing pavement break-up are precipitation in the fall and long periods of freezing weather during the winter.

High precipitation in October, November, and December will tend to saturate the subgrade soil and base. Subsequent long periods of freezing weather produce frost-heave and further saturation, particularly if some alternate freezing and thawing occurs. Thawing in the spring then leaves saturated, weak subgrades and under heavy traffic severe pavement damage results.

To examine further the correlation of pavement performance with climatic data a study was made of weather records from twelve representative weather stations for four typical seasons. The freezing index and total precipitation for the crucial period of November, December, January and February are presented in Table 1. Freezing Index charts strikingly present information on temperature.

TABLE 1
FREEZING INDEX AND PRECIPITATION

Weather Station		Norfolk City	Richmond	Washington National Airport	Lawrenceville	Charlottesville	Lynchburg	Chatham	Winchester	Roanoke	Hot Springs	Burkes Garden	Dante	Average	Minimum	Maximum
Soil Areas		Coastal Plain Sediments	Coastal Plain Sediments Non-Plastic Granites	Schist, Gneiss, Slate and Granite Coastal Plain Sediments	Non-Plastic Granite	High mica Schist and Granite	High Mica Schist and Granite Schist, Gneiss, Slate and Granite	Schist Gneiss Slate Granite	Limestone and Dolomite	Limestone and Dolomite	Sandstone and Shale	Limestone and Dolomite	Sandstone and shale with coal in Places			
'48 '49	FI[a] P[b]	17 15 49	17 15 30	25 18 45	18 Not Available	24 20 81	22 18 55	20 17 32	30 14 77	28 19 75	55 18 63	49 14 50	20 17 01	27 17.33	17 14 50	55 20 81
'47 '48	FI P	28 16 61	85 13.94	61 13 60	86 14 98	161 12 55	117 12 01	104 11 97	272 8 03	89 10 82	351 11 05	294 11 83	281 16 75[c]	161 12 84	28 8 03	351 16 75
'39 '40	FI P	71 9 02	115 9 81	159 8 49	173 12 87[d]	252 11 29	122 9 88	173 11 38	300 9 12	160 8 61	541 8 00	491 8 04	261 8 16	235 9 56	71 8 00	541 12 87
'35 '36	FI P	95 16 63	164 16 99	298 15 79	208 19 08	201 19 35	182 21.10	177 18 81	445 11 71	187 17 67	382 17 16	339 17.71	264 16 38	245 17 36	95 11 71	445 21 10
Avg	FI P	53 14 44	95 14 01	136 14 08	121 15 64	160 16 00	111 15 38	118 14 87	262 10 91	116 14 21	332 13 71	293 13 02	206 14 58	167 14 27		

Data is for 4 month period (November, December, January, February)
[a] Freezing Index
[b] Precipitation
[c] Value for Pennington Gap, no data for Dante available
[d] Value for Callaville, no data for Lawrenceville available

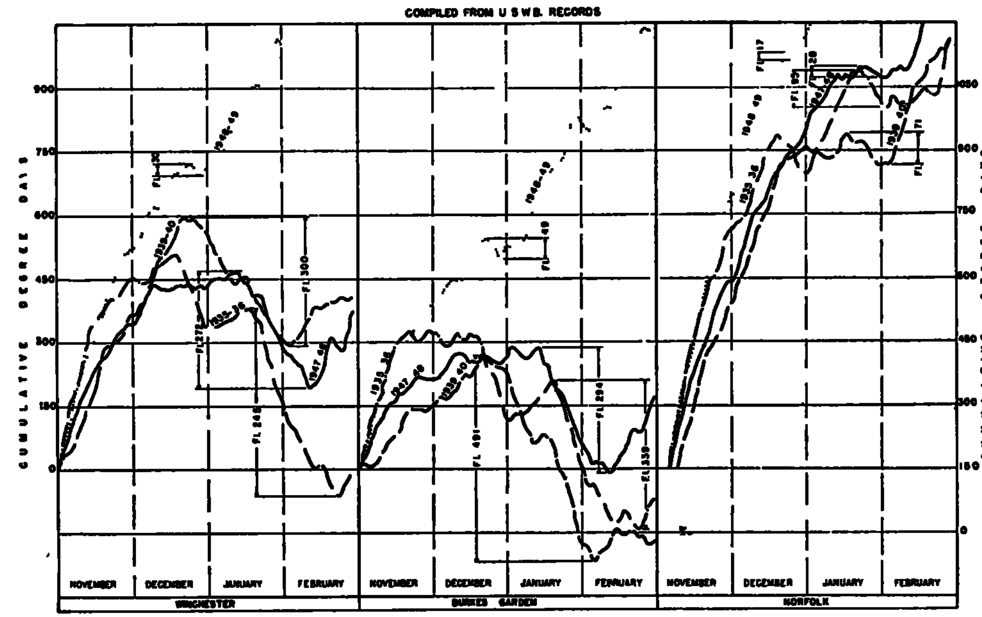

Figure 4. Determination of Freezing Index

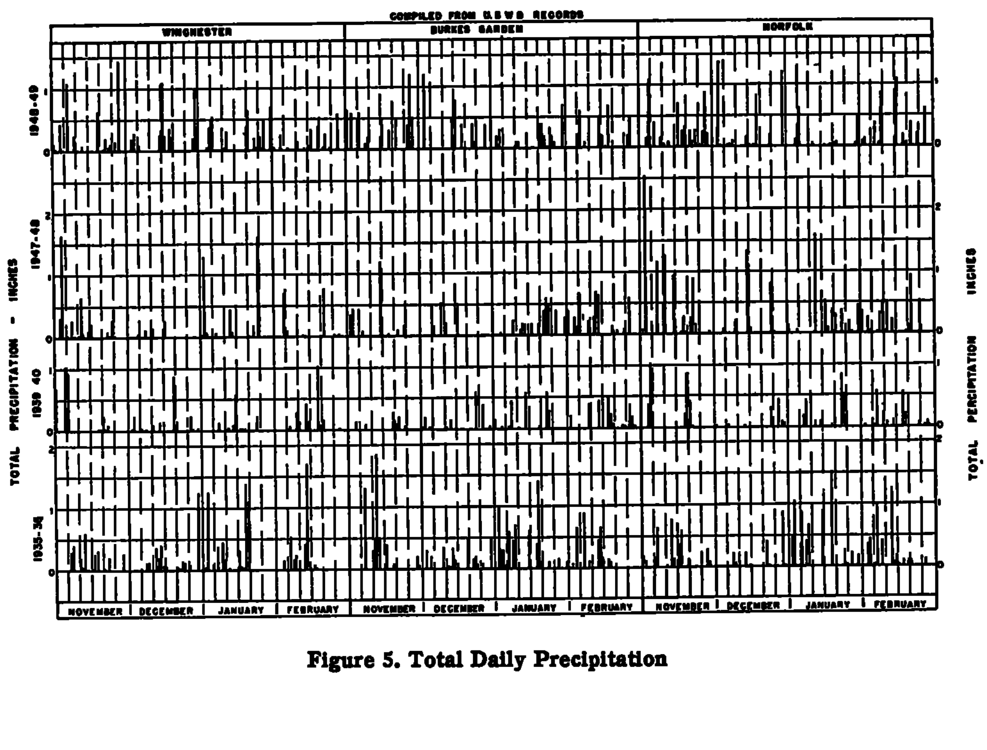

Figure 5. Total Daily Precipitation

Typical charts (Fig. 4) are shown for three weather stations representing extremes of the State. The Freezing Index is prepared by plotting deviations from freezing against time—deviations are represented by degree days, and are accumulative Thus, inflections of the curve indicate sustained periods of temperature change. The index is the algebraic difference between the maximum and minimum points of inflection of the curve. The precipitation data is shown simply by plotting inches of precipitation day by day (Fig. 5).

Highway engineers well remember that the Spring of 1936 was noted for the worst break-up in recent years. The preceding fall and winter were marked by high precipitation and long periods of freezing Likewise, in Virginia a similar condition existed in 1947–48; however, precipitation was less and the freezing index was smaller. As a result of these conditions a break-up occurred which approached the severity of that in 1935–36 in most locations throughout the State.

The freezing index for the 1939–40 season throughout the State was comparable to that of 1935–36 in severity, but average precipitation was only about one-half as high. The past season, 1948–49, was noted for its unusually high precipitation, yet temperatures were mild, as indicated by the freezing index. Pavement break-up was very slight in the Spring of 1940 and again in 1949.

Thus, it can be shown that spring break-up of pavements is influenced by a combination of two important climatic variables—precipitation and temperature. Past experience correlated with weather records indicates that break-up is most severe when high precipitation is followed closely by long periods of freezing weather This condition is further aggravated by high precipitation during the thawing period. Merely an extremely cold winter alone, or one with high precipitation only, does not result in severe pavement damage.

HIGHWAY SYSTEM AND TRAFFIC

The Virginia State Highway Department was first organized July 1, 1906, but this date does not represent a true beginning of road building and planning First roadways were planned during early colonization when the seat of government was situated in Jamestown. In compliance with the 1916 Federal Road Act a state highway system was established in 1918, consisting of 4000 mi of primary highways Then, in 1932, roads of 97 counties were taken into the state system, thus adding 37,462 mi to be maintained Previously these roads had been directly under the jurisdiction of county supervisors Arlington, Henrico and Warwick Counties continue to supervise their own secondary road systems The 1948 highway system consisted of 9,000 mi. of primary and 38,000 mi of secondary roads—a total of 47,000 mi.

Expenditures have amounted to about $700,000,000 during the past 40 yr, and annual expenditures now exceed $50,000,000. With all this gigantic expenditure Virginia has operated on a "pay-as-you-go" basis Although available funds cannot be stretched to provide all the attention that each mile of road deserves, the State Highway Department strives to keep every road passable throughout the year.

In reviewing growth and development of the present highway system, many inborn faults or deficiencies can be accounted for. Sight distances, grade crossings of railroads, intersections, and narrow pavements which did not cause appreciable alarm twenty years ago are now as out-dated as buck-boards and draught horses. The Highway Department is cognizant of these dificiencies and, where feasible, corrective measures are undertaken with celerity. In 1945, a comprehensive plan was prepared and submitted to the General Assembly for development of the system during the coming 20-yr. period (*7*). This future program of modernization probably will cost more than $500,000,000. For these expenditures, as before, funds will accrue on a "pay-as-you-go" basis. Primary roads, comprising 20 percent of all road mileage, bring in 80 percent of all gasoline tax. Thus, these arteries of transportation must bear some costs of secondary road construction and maintenance.

Except during the recent war, traffic throughout the state system has increased continually year by year. During the past few years increase has been on a scale never before observed. This fact can be realized from the following traffic data: (*8*)

Fiscal year ending July 1, 1949 compared to previous years.

(a) 71.42 percent over 1939
(b) 41 52 percent over 1941

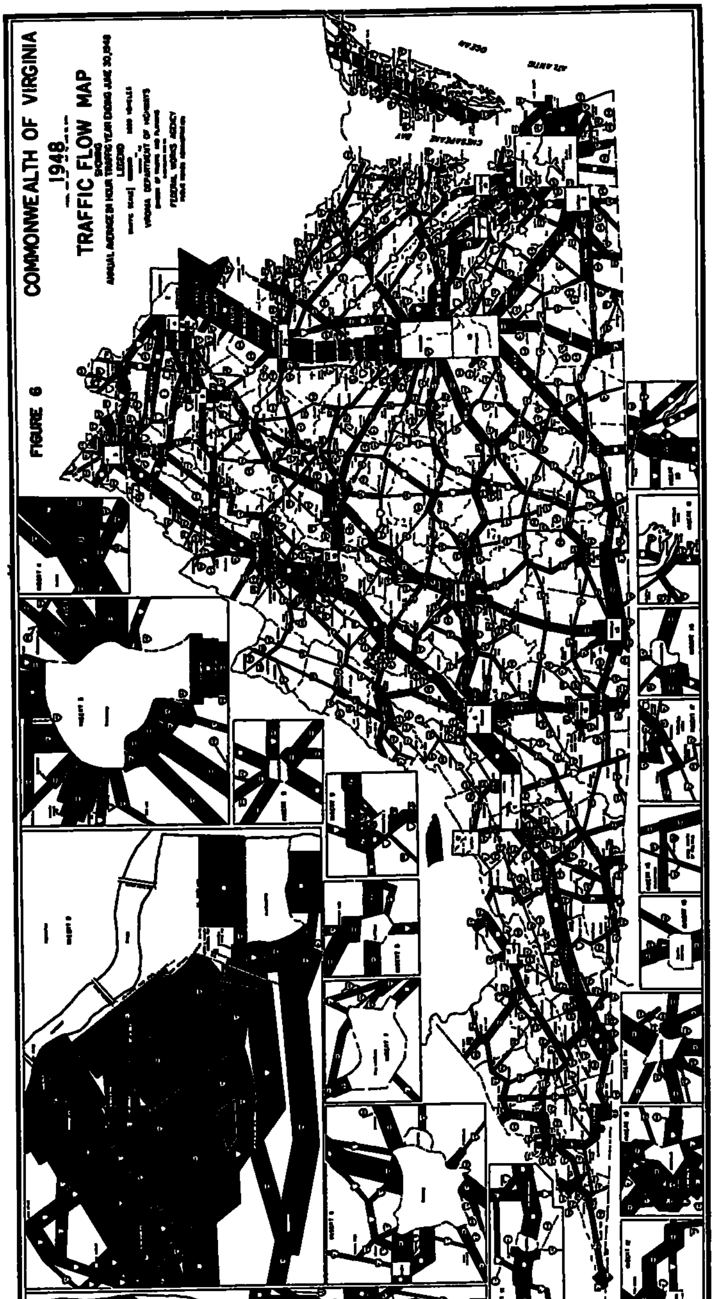
COMMONWEALTH OF VIRGINIA
1948
TRAFFIC FLOW MAP
SHOWING
ANNUAL AVERAGE 24 HOUR TRAFFIC YEAR ENDING JUNE 30,1948
LEGEND
VIRGINIA DEPARTMENT OF HIGHWAYS
FEDERAL WORKS AGENCY
FIGURE 6
HAMPTON
ROADS

Figure 6

(c) 115.50 percent over 1943
(d) 9.48 percent over 1948.

Thus in each 24-hr. period vehicles travel some 12,565,503 vehicle miles

Of great interest to highway engineers is the composition of this traffic, particularly the volume of heavy trucks. Vehicle-miles traveled by large and heavy units has increased more rapidly than for lighter units as shown by this table of comparison for the years of 1939, 1941, and 1948.

Class of Vehicle	*Percentage Increase* 1939–1949	1941–1949	1948–1949
Virginia Passenger Cars	+74.39	+42.57	+9 03
Foreign Passenger Cars	+50.85	+24 01	+13 40
Light and Medium Trucks	+73 00	+53.01	+6 72
Tractor-Trailer and Buses	+117.49	+66 15	+10 30

Considering all traffic since 1939, the rate of increase of passenger cars has diminished in proportion to that of heavy trucks. Where this trend will level off, if at all, no one knows. However, the highways of today must carry about 1 7 times the volume of traffic that existed in 1939. To summarize these facts and to show which routes accomodate most of this traffic Figure 6 is presented. This traffic flow map is reproduced from an original map prepared by the Traffic and Planning Division.

CONDITION SURVEY RESULTS

After completion of the survey, results were summarized into tables by counties for each of the eight districts, listing total miles of road and percentages in each performance rating. Separate tabulations were prepared for primary and secondary roads. The data for secondary roads were further divided into hard- and non-hard-surface roads. These tables permitted a comparison, not only of road mileage by counties and districts, but also according to performance. Because of their bulk, the 18 tables so prepared are not included in this report. A summary of the data by districts is shown in Table 2 for the entire State.

For purposes of analysis, this report contains only data on primary and hard-surface secondary roads. While road performance data according to counties and districts are helpful to field engineers and those responsible for establishing construction programs and maintenance schedules, it was desired to study the data further and to determine if pavement performance could be related to other factors.

Pavement performance is affected by many variables One major item is the type of soil (together with its drainage characteristics) upon which a pavement is placed. Other variables include· climate, base type, surface type, depth of base, age of pavement, and amount and type of traffic, to name a few. For lack of data, no attempt has been made to analyze all variables. Considerable data was available on base and surface types and a study was made of pavement performance in the twelve general soil areas. Information is discussed separately for primary roads and hard-surface secondary roads.

Primary Roads—Results of the condition survey of 8439 mi. of primary roads have been summarized in Table 3 according to ratings for each of twelve soil areas. The summary includes not only total mileage but also the percentage in each rating. Data indicate that about 4870 mi. (58 percent) of primary roads were giving good performance while 1572 mi. (19 percent) were rated as giving poor performance. The remaining 1996 mi. (23 percent) were in fair condition. Figure 7 presents these data graphically.

A map of primary highways was prepared showing the condition rating of each road section (Figure 8). The map shows that roads with the poorest ratings are, in general, grouped in certain areas. Upon further investigation, and by comparing the performance map with the soil area map, importance of the soil area as a major variable is evident. Typical performance pictures of both primary and hard-surface secondary roads are presented in Figures 9 through 24.

Secondary Roads (*Hard surface*)—Results of the survey of 9500 mi. of hard-surface secondary roads have been summarized also according to soil area and are shown in Table 4 (See Figure 7 for a graphic presentation of the data). A comparison of data revealed that the break-up of hard-surface secondary roads was more extensive than that of primary roads. Approximately 43 percent (4068 mi) of these secondary roads were giving good performance and nearly 28 percent (2634 mi.) were poor. It should be pointed out, however, that few secondary roads have been built to standards ability and it was not suprising to find road damage more extensive here than in other soil areas. In the Triassic "red beds" primary roads were rated 28.0 percent good and 56 3 percent poor. Only 16.4 percent of road mileage in the sandstones-and-shales-with-coal soil area was rated good while 59 2 percent was considered giving poor performance.

Secondary Roads (*Hard-surface*)—Considering all areas, best performance was found in the Triassic sandstone and the sandstone-and-shale areas; poorest performance was noted in the Triassic "red beds" and sandstones-and-shales-with-coal areas. For example, in these last two areas 56.8 and 61.0 percent respectively were rated poor and only 18 1 and 12 7 percent were classified as good.

The same three soil areas (Coastal Plain sediments, high-quartz granitoids, and limestone and dolomite) that had the largest primary mileage also contained most hard-surface secondary roads (70.5 percent, Table 4). Of pavements placed upon limestone-and-dolomite soils 64.7 percent rated good and 16.3 percent poor; however, 35 percent were high type (macadam). Coastal Plain sediments, with only 6 percent of hard-surface secondary roads built to high types (macadam or concrete), had 43 9 percent giving good and 24.8 percent poor performance. High-quartz granitoids, with but 3 percent of the pavements built to high types, had slightly more mileage (32.8 percent) in poor ratings than in good ratings (31.6 percent)

Summarizing the discussion on soil areas, certain facts are apparent. First, it was found that in any given soil area the ratio of mileage to total state mileage (either primary or secondary hard-surface roads) corresponds closely to the ratio of the area of that soil region to the total state area Since this relationship exists, survey data represents the true picture of existing conditions Second, although a variety of pavement and base types were available a definite correlation was established between performance and soils. For example, in two soil areas performance of both primary and hard-surface secondary roads was best. Likewise, in two other areas performance was poorest.

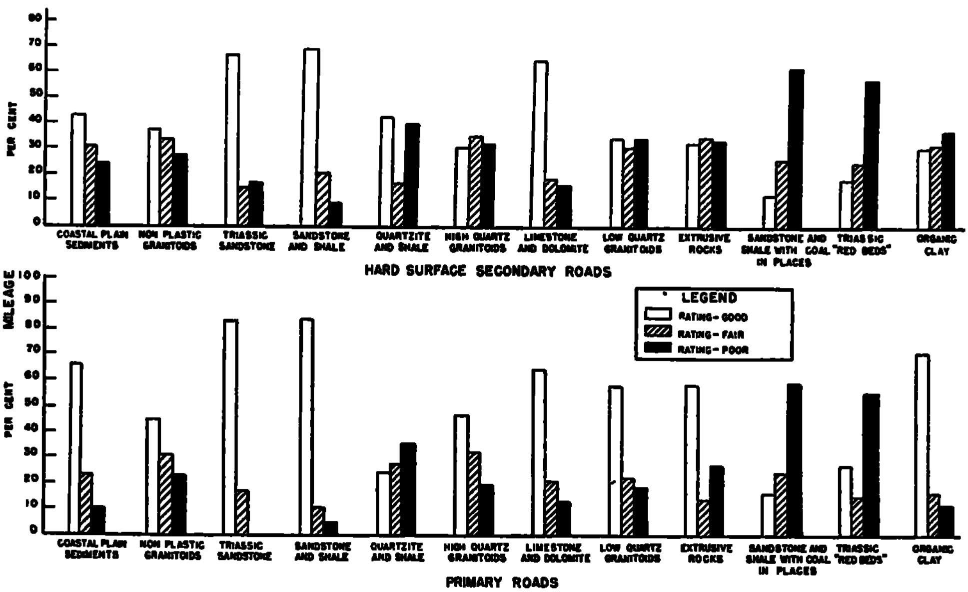

Figure 7. Road Performance by Soil Type

PAVEMENT PERFORMANCE ACCORDING TO BASE TYPES

Primary Roads—Primary road bases had been classified previously by the Division of Traffic and Planning according to type (See Table 5.) Two types predominated—stabilized, se-

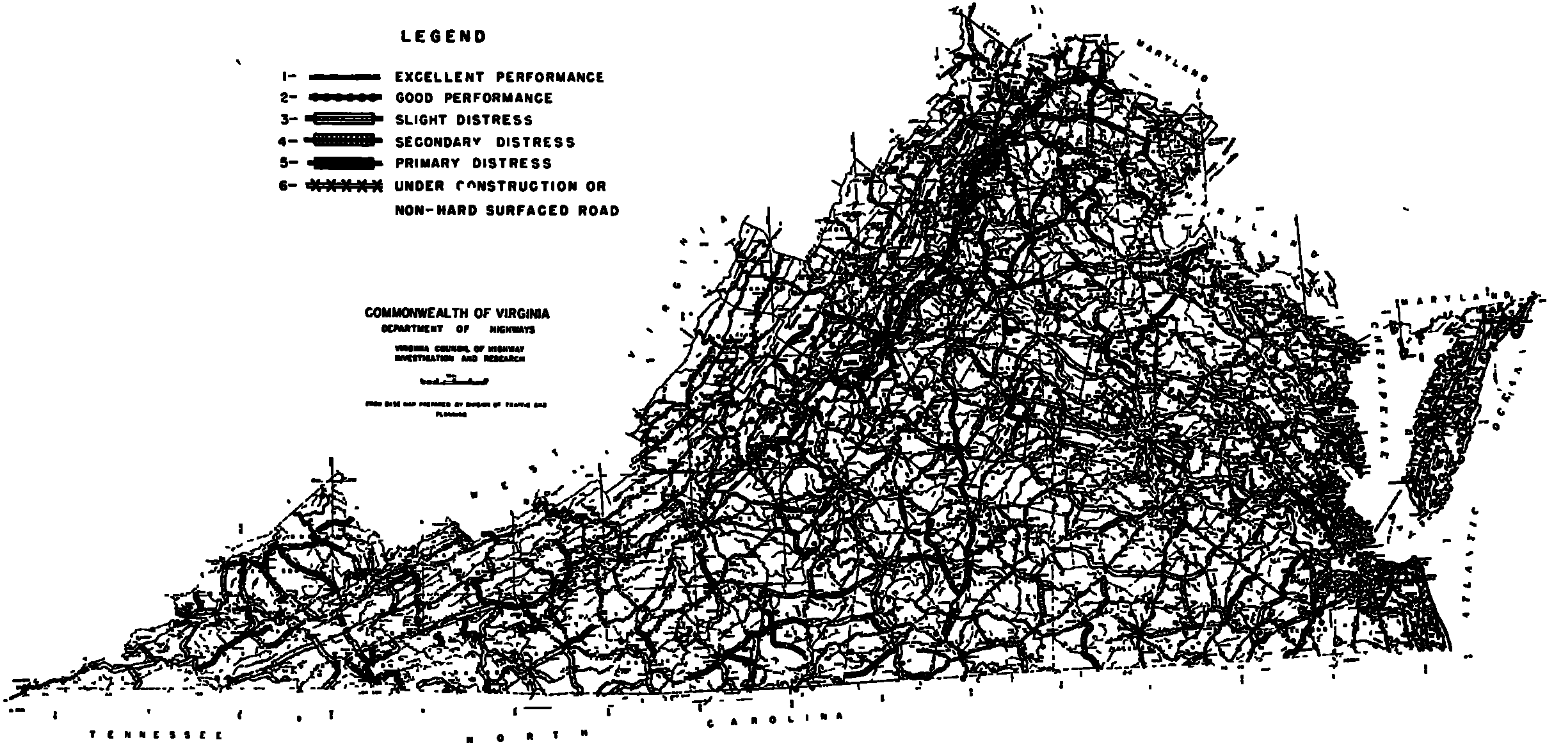

Figure 8. Spring 1948—Road Condition Survey Ratings of Primary Roads

lected materials and macadam. These two comprised 76 per cent of all primary road bases in the State, with macadam totaling 40 percent and stabilized selected materials 36 percent.

Organic clay soils are thought to be the worst in Virginia with regards to subgrade support, but survey results indicate that 71.0 percent of primary roads in this area gave good performance. Data showed, however, that 48 percent of the roads in the organic clays were built of concrete, which undoubtedly had adequate bases and high-level profiles.

Figure 9. Sandstone-and-Shale-with-Coal—Buchanan County—Rt. 80—Slide on Side Hill Cut—Note Base Failure in Foreground—Applied Local Material Base with Heavy Bituminous Surface

Figure 10. Sandstone-and-Shale-with-Coal—Buchanan County—Rt. 83— Heavy Coal Traffic Over Insufficient Base in High Capillarity Soil Caused Complete Base and Surface Failure—Applied Local Material Base with Heavy Bituminous Surface

In comparing macadam with selected materials bases (Table 5) performance of the former was superior (66.9 percent good) to that of the latter (43.2 percent good). Condition of roads with macadam bases was found to be best in Coastal Plain sediments, non-plastic granitoids, Triassic sandstone, organic clay, and sandstone-and-shale soil areas. As might be expected, poorest performance of roads built with macadam bases was noted in the sandstones-and-shales-with-coal and Triassic "red beds" soils.

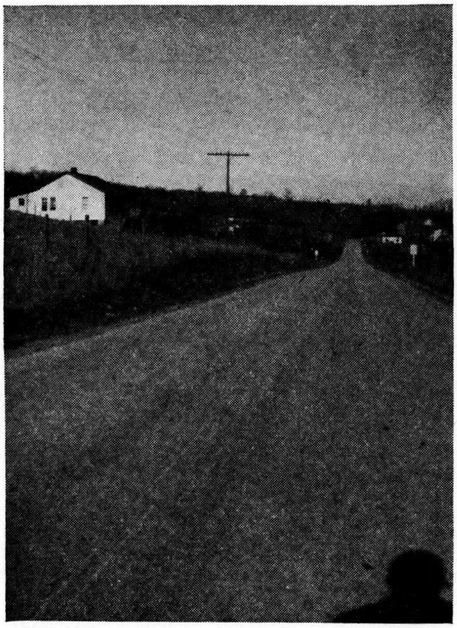

Figure 11. Limestone and Dolomite soil area—Bland County—Rt. 42—Excellent Performance of Macadam Base with Heavy Bituminous Surface Road

Figure 12. Limestone and Dolomite soil area—Pulaski County—Rt. 100—Surface and Base Failure—Macadam Base with Heavy Bituminous Surface

Secondary Roads (*Hard-surface*)—Bases of secondary hard-surface roads were of six types (shown in Table 6). Stabilized, selected materials and macadam comprised 99 percent of all mileage—88 percent stabilized, selected materials and 11 percent macadam. Thus, can be seen that very few bases for these roads have been constructed of a high type.

Macadam bases were superior in performance, for 64.7 percent of this mileage was giving good performance compared to only 39.8 percent for selected materials. Survey results showed that performance of all hard-surface secondary roads in certain soil areas was far from good. For example, only 12.7 percent of the mileage in the sandstones-and-shales-with-coal soils gave good performance.

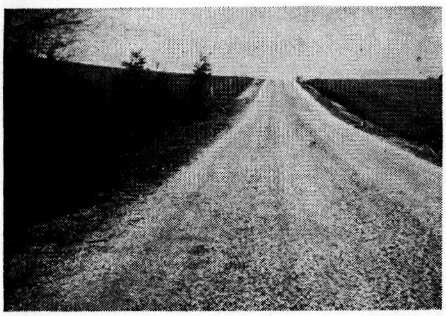

Figure 13. Low Quartz Granitoids soil area—Franklin County—Rt. 623—Excellent Performance of Selected Materials Base with Light Bituminous Surface—This Section Was Built in 1947

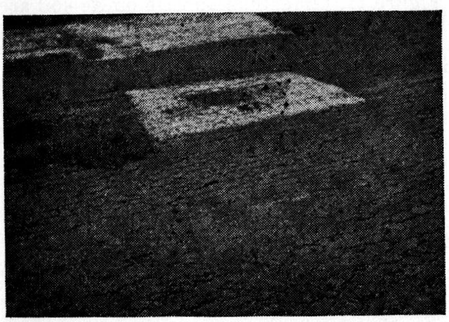

Figure 14. Low Quartz Granitoids soil area—Patrick County—Rt. 8—Complete Failure of Surface Treated Soil Road

An interesting fact brought out by the survey was that a larger percentage of roads in soil areas of low-support characteristics had been built to a high type than those in areas of high-support characteristics. For example, in the sand stones-and-shales-with-coal area 66 percent of the primary roads had been built of macadam or concrete. In con-

Figure 15. Low Quartz Granitoids Soil Area—Carroll and Floyd Counties—Rt. 221—Note Difference in Performance Beginning at County Line. The Base of the Road in Floyd County (Foreground) is 6-in. Field Stone. In Carroll County the Base is 5-in. Selected Materials.

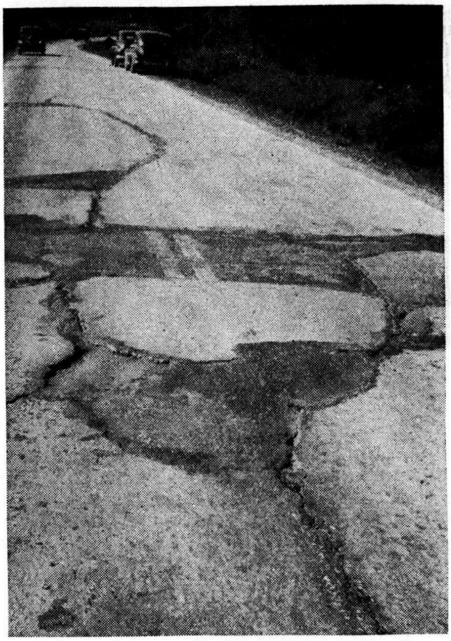

Figure 16. High Quartz Granitoids Soil Area—Henry County—Rt. 220—Break-up of Concrete Pavement—This Failure Was Probably a Result of Poor Subgrade and Age (20 yr.) of Pavement. Notice Absence of Joints.

trast only 33 percent of bases placed upon Coastal Plain sediments were built of macadam or concrete. This situation probably was not a planned procedure, but one evolved through performance experience in various soil areas.

PAVEMENT PERFORMANCE ACCORDING TO SURFACE TYPE

Primary Roads—Three of six surface types on primary roads accounted for 88 percent

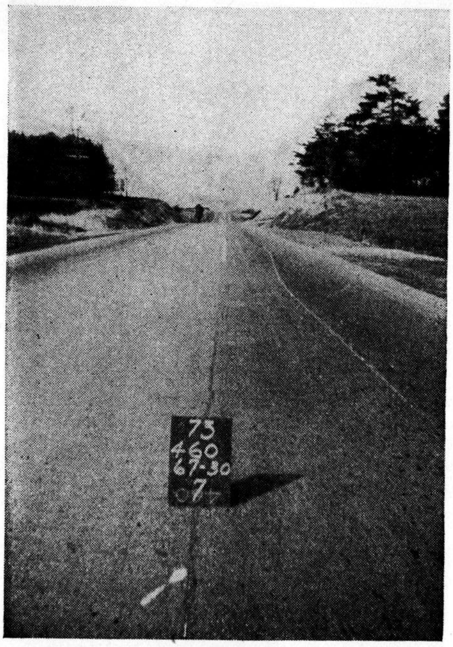

Figure 17. High Quartz Granitoids Soil Area—Prince Edward County—Rt. 460—Note excellent performance of macadam base, bituminous plant-mix surface road

of the mileage. These were: light bituminous treatments (22.2 percent), heavy bituminous treatments (49.8 percent) and bituminous plant mix (16.2 percent).

Data indicate that plant mix (bituminous concrete) and rock, sheet or sand asphalt were the best bituminous surfaces. Light bituminous treatments were better than the heavy bituminous treatments (considering total mileage). However, a negligible mileage of light treatment existed in weak soil areas.

Hard-surface Secondary Roads—Since 97 percent of hard-surface secondary roads were surfaced with light bituminous treatments, a fair comparison cannot be made with other surface types. However, the data indicate

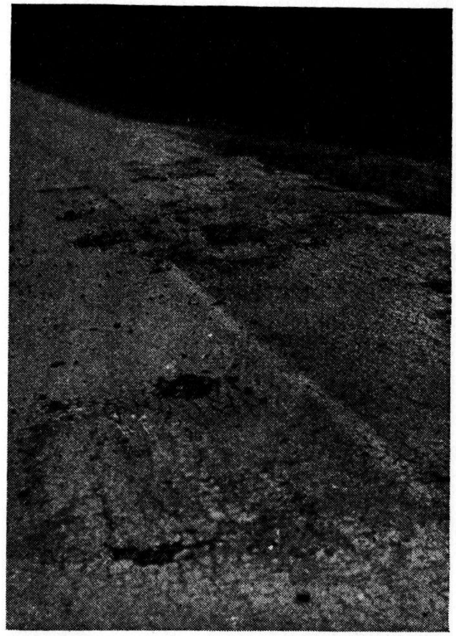

Figure 18. Non-Plastic Granitoids Soil Area —Dinwiddie County—Rt. 40—Selected Materials Base with Light Bituminous Surface

Figure 19. Organic Clays Soil Area—Nansemond County—Rt. 58—Pumping of Concrete Pavement in Dismal Swamp Area

that better performance results where higher type surfaces are employed.

SUMMARY OF RESULTS AND CONCLUSIONS

While it is not feasible in this paper to enumerate all of the benefits to be derived from a state-wide condition survey made at the time of a severe break-up, the most important findings have been summarized below. These results are based upon data secured on the performance of approximately 8500 mi. of primary roads and 9500 mi. of hard-surface secondary roads during February 15 to April 1, 1948. The findings also include information concerning an analysis of 30-yr. weather data for 16 stations throughout the Commonwealth.

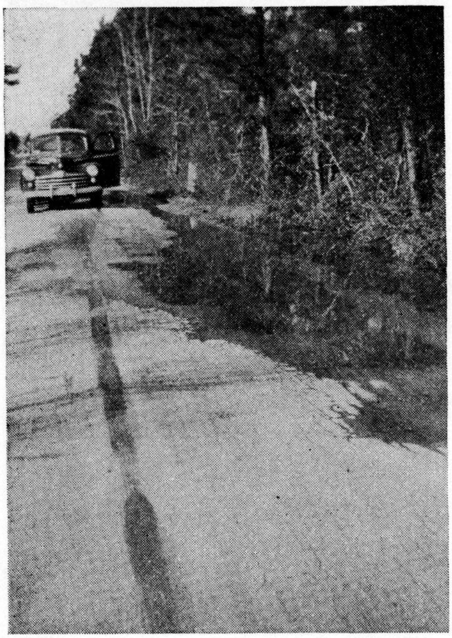

Figure 20. Organic Clays Soil Area—Mathews County—Rt. 617—Poor Drainage and Resulting Break-up of Selected Materials Base Road with Light Bituminous Surface

Soil Areas

1. The soil upon which a pavement is placed is a major item affecting performance.

2. Based upon 1948 spring break-up data, the three soil areas in Virginia giving best performance were the sandstone and shale, Triassic sandstone, and Coastal Plain sediments. Likewise, poorest performance was associated with soils derived from sandstones-and-shales-with-coal and Triassic "red beds". It should be emphasized that these ratings are influenced by construction practices. For example, 63 percent of the primary road bases in the Coastal Plain were constructed

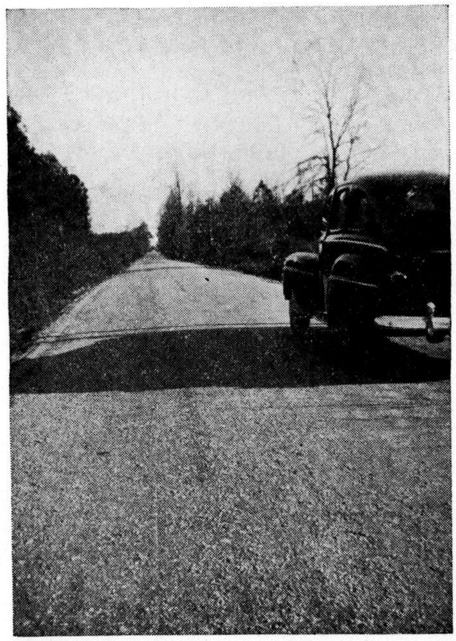

Figure 21. Coastal Plain Sediments Soil Area (Upper Terrace)—King William County—Rt. 600—Excellent Performance of Secondary Road—Selected Materials Base with Light Bituminous Treatment—Seal Treatment Applied in 1947

Figure 22. Coastal Plain Sediments Soil Area (Lower Terrace)—Sussex County—Rt. 648—High Water Table Resulting in Base and Surface Movement—Selected Materials Base with Light Bituminous Surface

of local materials; whereas, only 41 percent of comparable roads in the sandstone-and-shale area were built of so-called stabilized, selected materials—the remaining 59 percent being macadam.

3. These studies demonstrated the value of studying soils on an areal basis and indicated a need for further studies of this type. While not included in the scope of this investigation, the study of air photos constitutes one of the most promising methods of identifying and classifying soils on an areal basis.

Figure 23. Triassic "Red Beds" Soil Area—Culpeper County—Rt. 669—Complete Failure of Secondary Road—Macadam Base with Light Bituminous Treatment

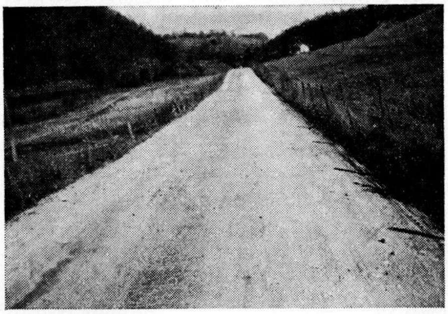

Figure 24. Quartzite and Shale Soil Area—Washington County—Rt. 58—Heavy Traffic, Poor Subgrade, and Improper Drainage Caused Base and Surface Failure. Macadam Base with Light Bituminous Surface

Pavement Design

4. Despite the fact that 80 percent of highway traffic is carried on primary roads their performance was better than that of secondaries. For example, 58 percent of all primary roads were rated good as compared to only 43 percent of the hard-surface secondary roads. These results reflect pavement design, since 51 percent of primary roads and only 12 percent of hard-surface secondary roads had macadam or other high-type bases.

5. Survey results emphasized the necessity of designing pavements on a soil-area basis, paying particular attention to those areas containing soils of low-supporting characteristics. While some roads in certain areas have been built to offset deficiencies of subgrade soils, performance experience was the governing factor rather than recognition of soil characteristics.

6. Bases constructed of local and so-called stabilized, selected materials were inferior to those of higher types; however, in areas of favorable support-characteristics, low type bases were adequate.

7. Bituminous concrete or other high type plant mixes performed best of all bituminous surfaces. Over 97 percent of surfaces included in the survey were bituminous.

Climate

8. Climate is one important variable affecting pavement performance. While this variable cannot be controlled it is important that the highway engineer recognize climatic factors affecting performance.

9. The freezing index is a feasible means of presenting and comparing temperature data for different locations or for the same location in different years.

10. Freezing index values and total precipitation, averaged for 16 stations throughout the state during November through February on each of four winters, indicate that a combination of high precipitation and a high freezing index result in pavement damage. These destructive combinations occurred in the Winter of 1935–36, and again in 1947–48.

General

11. Road condition surveys, if made at a time of a severe break-up are an excellent means of securing an over-all picture of pavement performance throughout a state, particularly as related to load-supporting characteristics.

12. Results of such a survey can be used in conjunction with the planning of construction and maintenance programs.

13. Conducting such surveys provides an excellent opportunity for training personnel to observe and relate various factors contributing to pavement performance.

14. Providing adequate drainage, both surface and subsurface, is essential if good pavement performance is to be secured. While not discussed in this analysis, men conducting the survey repeatedly called attention to this item.

ACKNOWLEDGEMENTS

Without the cooperation of nearly 200 people this paper could not have been written In the short period of six weeks over 47,000 mi. of roads in the State system were examined and rated with efficiency and thoroughness.

The writers wish to express their sincere appreciation to the large number of individuals who participated in the study Thanks are extended to Mr. C. S. Mullen, Chief Engineer, for his foresight in initiating the study. District engineers, resident engineers and their assistants, district materials engineers, various members of the field forces (superintendents, foremen, patrolmen, inspectors), and individuals of the Division of Tests are all to be commended for their part in making the study a success Thanks are also extended to the student employees of the Virginia Council of Highway Investigation and Research, who prepared most of the figures and tables, and to the secretarial staff, who typed the report.

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