PUBLIC ROADS

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UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

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A Sand-Clay Road in Georgia

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BUREAU OF PUBLIC ROADS

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A STUDY OF GRAVEL, TOPSOIL, AND SAND-CLAY ROADS IN GEORGIA

Report on Cooperative Research by the State Highway Board of Georgia and the U. S. Bureau of Public Roads

By Dr. C. M. STRAHAN, Acting as Special Director of Research for the State Highway Board of Georgia

IN 1922 the State Highway Board of Georgia and the United States Bureau of Public Roads entered into a cooperative agreement for the study of local gravel, chert, semigravel, topsoil, and sand-clay roads in Georgia. The investigation was directed to a determination of the scientific combination of soil ingredients, traffic behavior, and economic life.

Twenty-nine projects on the State system constructed by the State highway department with Federal aid were selected for study. These projects represented typical topographic, climatic, and subgrade conditions and comprised a total length of 247 miles. All of the projects had been completed between 1919 and 1921 and had been maintained by county authorities, and in 1922 were in process of transfer to the State highway board for future upkeep. The opportunity was at hand for keeping complete records of maintenance costs, instituting traffic counts, and pursuing systematic laboratory and field research in relation to the projects chosen.

The list selected comprised the following:

Two chert roads in northwest Georgia, where liberal deposits of chert are found amid prevailing surface soils of limestone and clay origin.

Three projects in west central and southwest Georgia built from the abundant local red pebble or iron-silica road soils.

Two roads built from local clay-gravel material; one in Richmond and the other in Quitman County.

One gravel road built from imported gravel on a subgrade of fine sand in Charlton County, where no local road soils were available.

Two projects largely built with artificial sand-clay mixtures using the existing red clay subgrade material into which coarse sand was incorporated.

Two semigravel roads in northeast Georgia built from local deposits running high in natural quartz material coarser than No. 10 sieve.

The remaining 17 projects were built from local sand-clay and topsoil deposits found near the road site.

The range of materials embraced by the individual samples reaches from the best semigravel and class A soils (see classification on page 118) down to a few weak class C materials. The majority of the road soil projects show the presence of class A and class B soil mortar associated with coarse material varying from zero to 30 per cent.

For economy in construction the deposits sought for and used were those within short haul of the work. An average haul of 1 mile or less was thus obtained. In consequence various deposits were utilized on long projects, resulting in notable variations in composition and behavior for different sections of the same project. In studying the detailed analytical data, this fact must be borne in mind.

RESEARCH PROGRAM CAREFULLY OUTLINED

The research was carried out according to the following program:

1. Careful inspection trips were made each spring and fall on which notes were taken and photographs made. One hundred and eighty sample points were carefully located and samples were taken on each for analysis and laboratory study.

On the spring inspection a record was made by notes and photographs of any weakness developed by winter and wet spring weather and of maintenance results.

2. Systematic traffic counts were made on each project. A daylight count during eight days of each month in alternate years was begun, using two days of each week thus: Sunday and Monday of the first week, Tuesday and Wednesday of the second week, and so on. This plan was used for two years, after which it was found that the average figures for spring, summer, fall, and winter, computed for all months in each season, practically coincided with the 8-day seasonal count in February, May, August, and November. Thereafter, 8-day seasonal counts were taken.

3. Maintenance cost records were instituted and systematically kept.

4. Laboratory studies covered the several soil ingredients (coarse material, sand, silt, and clay) in their various physical and capillary interactions, and incidental tests were tried out.

5. Depths of surfacing at the sample points were recorded each year as a factor bearing upon the loss of material and upon the influences of maintenance operations.

The broader aims of the research were twofold. First, to determine construction and maintenance costs, residual surface thickness, traffic burden, and salvage value at a given time as a basis for conclusions as to the economic worth, and life efficiency. Thus, a measure of traffic capacity and cost relations could be quantitatively determined.

The second objective was to determine the causes of surface strength and weakness, to develop tests and standards, and to improve traffic service for such abundant and low cost road materials.

This program has been steadily followed for five years, extending from July, 1922, to July, 1927. Incidental to field inspection of the 29 widely separated projects, some 1,800 miles of State highways were traversed twice each year. Most of this large mileage is of road-soil type. Observation and notes have thus been greatly extended as to the general behavior of road soils on the State system. The research, while in progress, has been useful in relation to current maintenance methods, drainage needs, and reconstruction problems to be anticipated.

Perhaps the broadest bearing of this research is in connection with the future of secondary and light traffic roads which require better utilization of natural soils and deposits for improved service. Main roads will ultimately be paved. The 90 per cent or more of secondary roads which comprise the immediate agricultural traffic outlet can not hope for such large investment of public funds.

The investigation is of importance in connection with paved roads, as road soil surfaces have high stability when utilized as the subgrade of pavements.

Serving as the first stage of betterment for the important roads, immediately upon grading and during settlement of the roadbed, road soil surfaces bring a substantial support and increased life to the pavement that later rests upon them.

ROAD SOILS ANALYZED AND CLASSIFIED

The research invaded a complex field bristling with queries and partially known facts. Methods of constructing these roads have grown out of large scale experience. Scientific explanation of their behavior and laboratory tests rest upon a similar empirical basis established by experience. The attempt is made in this research to submit certain quantitative results which at least are more specific than the knowledge hitherto available from general experience.

In other directions, the best which could be done was to record the judgment of a trained observer, applied twice each year, to short sections of each project, and to express that record in words or figures which might carry a more definite significance to the mind of the reader. Hence the report must be read in the light of special definitions and special meanings of terms subsequently presented.

The mechanical analyses of all road surface samples were carried out in duplicate, using methods approved by the Bureau of Public Roads.[1] Under these methods the following definitions apply:

Clay.—Material separated by subsidence through water and possessing plastic or adhesive properties, generally below 0.02 millimeter in diameter.

Silt.—Fine material, other than clay, which passes a No. 200 standard sieve, generally from 0.07 to 0.02 millimeter in diameter, having little or no plasticity.

Sand.—Hard material, usually siliceous, which passes a No. 10 standard sieve, generally from 1.85 to 0.07 millimeter in diameter.

Coarse material.—Hard material of gravelly nature, retained on a No. 10 sieve, i. e., more than 1.85 millimeters in diameter.

Soil mortar.—Mixtures of clay, sand and silt as defined above, i. e., all material in the sample which passes a No. 10 sieve.

The coarse material is determined as a percentage of the whole sample.

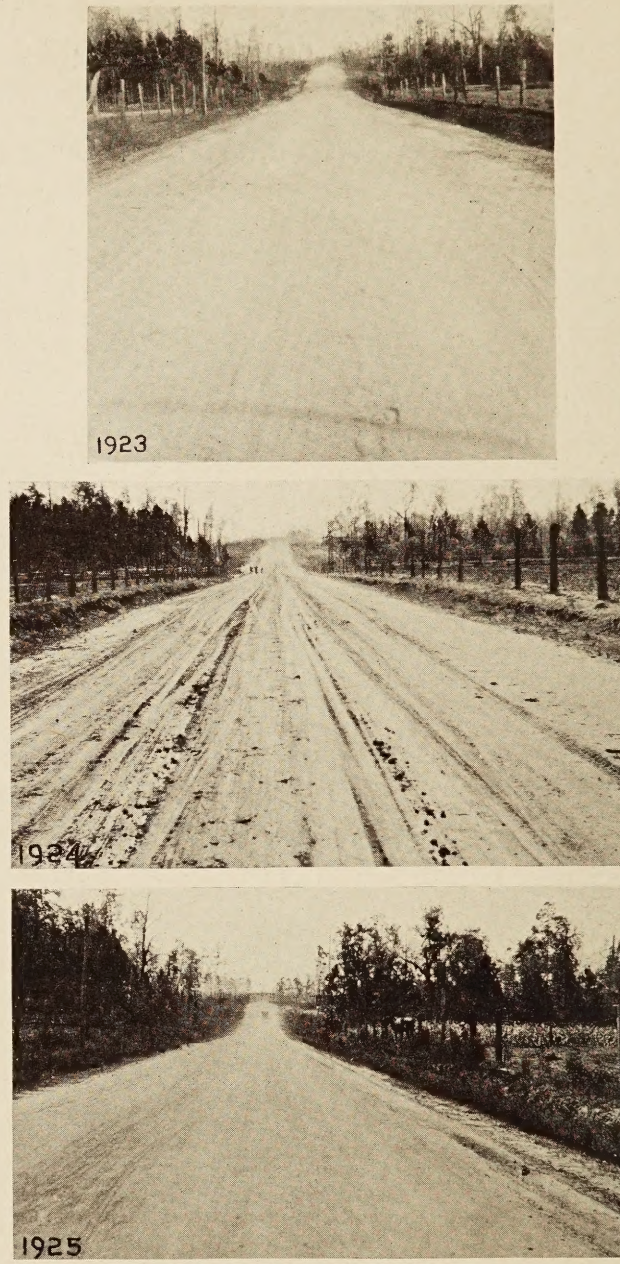
The soil mortars are the starting point of a percentage analysis of material below the No. 10 sieve and are classified and limited as shown below:

	Hard, or class A	Medium, or class B	Soft, or class C
	Per cent	*Per cent*	*Per cent*
Clay	10 to 18	15 to 25	10 to 25
Silt	5 to 15	10 to 20	10 to 20
Total sand	65 to 80	60 to 70	55 to 80
Total	100	100	100
Sand retained on No. 60 sieve	45 to 60	30 to 45	15 to 30

The last item representing the coarser sand is an important element in the stability of the surface, especially during wet weather.

Samples containing 10 per cent or more of hard, coarse material in well-graded sizes below 1.5 inches diameter have an increased hardness and durability roughly proportional to the amount present.

The program of analysis included successive annual samples taken from each of the carefully located points on each project. Typical tabulations of the results of analyses and field observations are shown in Tables 1 to 3.



PROJECT NO. 5, IN BACON COUNTY. SAMPLE POINT NO. 2

Those results must be considered in the light of the possible causes of changes in composition to which such surfaces are exposed.

1. The original surfacing is not strictly uniform. Samples taken from the same place in the road may be expected to show normal variations of 2 to 5 per cent in the sand or clay items.

2. The original surfacing was 18 feet wide with 4-foot shoulders of unselected local dirt. It is to be expected that maintenance of the surface by road machines, drags, and scarifiers would incorporate some of this poor shoulder material with the surfacing material.

3. When the surface is not frequently machined, it may become so much displaced as to need scarifying and addition of new material for reshaping. If the design thickness, normally 6 to 8 inches, was not put

[1] These methods described in bulletin of the University of Georgia, June 1922, vol. 22, No. 5a

Table 1.—*Project data sheet typical of north Georgia experiments* [1]

[Federal-aid project No. 4 in Walton County; top-soil surface; 9.42 miles long; completed July, 1920; red clay subsoil; top-soil shoulders]

Year	Depth of slab	Coarse material	Sand: Passing No. 10 retained on No. 20	Sand: Passing No. 20 retained on No. 60	Sand: Total retained on No. 60	Sand: Passing No. 60 retained on No. 200	Sand: Total	Silt	Clay	Grade of soil	Service quality	Surface condition
SAMPLE POINT NO. 1, 1.4 MILES—ON CURVE RIGHT, OVER CULVERT, ON 5-FOOT FILL												
	Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Per cent*	
1922	6	22	23.1	29.4	52.5	16.1	68.6	10.3	21.1	A	95	Excellent.
1923	6	20	17.0	28.2	45.2	13.3	56.5	9.4	32.1	A	95	Do.
1924	5.5	25	16.8	26.0	42.8	16.9	59.7	12.7	27.6	A	90	Excellent; slightly sandy.
1925	5	40	22.8	29.6	52.5	16.4	68.9	10.6	20.5	A	80	Very good to excellent; slightly sandy; potholes.
1926	5	34	16.8	30.0	46.8	14.9	61.7	12.2	26.1	A	60	Good to excellent; heavy corrugation.
1927	4.5	------	------	------	------	------	------	------	------	------	60	Very good to excellent.
Average	------	------	------	------	------	------	------	------	------	------	80	
SAMPLE POINT NO. 2, 1.8 MILES—20-FOOT CUT ON RIGHT, 9-FOOT CUT ON LEFT												
1922	4	25	15.1	27.2	42.3	26.9	69.2	12.3	18.5	B	95	Excellent.
1923	4	28	12.0	30.6	42.6	23.7	66.3	13.9	19.8	B	95	Do.
1924	4.5	39	13.2	27.7	40.9	26.5	67.4	12.1	20.5	B	80	Very good to excellent; slight potholes.
1925	6	12	11.2	40.0	51.1	33.9	85.0	7.0	8.8	A	80	Very good to excellent; slightly sandy; potholes.
1926	3	40	10.3	28.3	38.6	24.9	63.5	14.3	22.2	B	60	Good to excellent; heavy corrugation.
1927	------	------	------	------	------	------	------	------	------	------	70	New material.
Average	------	------	------	------	------	------	------	------	------	------	78.3	
SAMPLE POINT NO. 3, 3.1 MILES—20 FEET BEFORE BOX CULVERT AND ON A −2½ PER CENT GRADE												
1922	14	14	10.6	37.6	48.2	28.1	76.3	9.4	14.3	A	95	Excellent.
1923	13	20	9.8	40.2	49.7	24.0	74.2	9.4	16.4	A	95	Do.
1924	12	22	8.9	38.2	47.1	22.5	68.6	10.9	19.5	A	90	Very good to excellent; slightly sandy; potholes.
1925	5	15	9.6	39.1	48.7	24.6	73.3	10.5	16.2	A	85	Very good; patched.
1926	13.5	15	7.7	39.7	47.4	26.2	73.6	10.5	15.9	A	55	Fair; slightly sandy; potholes.
1927		------	------	------	------	------	------	------	------	------	60	New material.
Average	------	------	------	------	------	------	------	------	------	------	80	
SAMPLE POINT NO. 4, 3.8 MILES—WOODS ON BOTH SIDES, 2 PINES ON LEFT, −2 PER CENT GRADE, 3-FOOT CUT ON RIGHT, 5-FOOT CUT ON LEFT												
1922	7	11	11.4	35.4	46.8	21.8	68.6	11.0	20.4	A	90	Excellent.
1923	6	18	9.3	38.8	48.1	20.1	68.2	11.1	20.7	A	92	Do.
1924	6.5	15	10.3	32.6	42.9	17.1	60.0	11.2	28.8	B	93	Do.
1925	6.5	11	9.5	39.2	48.7	23.7	92.5	9.9	17.6	A	70	Very good to excellent, slightly sandy, potholes.
1926	5.5	20	11.0	37.8	48.8	22.8	71.6	9.5	18.9	A	45	Good to excellent; corrugated.
1927	6	------	------	------	------	------	------	------	------	------	75	New material.
Average	------	------	------	------	------	------	------	------	------	------	77.5	
SAMPLE POINT NO. 5, 4.9 MILES—OVER CULVERT, +2 PER CENT GRADE, P. C. 150 FEET BACK ON RIGHT, HOUSE ON LEFT 250 FEET AHEAD												
1922	13	7	11.8	42.8	54.6	16.0	70.6	11.6	17.8	A	90	Excellent.
1923	11	10	10.8	46.1	56.8	18.2	75.0	9.5	15.5	A	92	Do.
1924	12.5	15	12.2	39.2	51.4	19.0	79.4	10.5	19.0	A	93	Do.
1925	12.5	10	13.4	42.3	55.8	19.9	75.7	9.7	14.6	A	60	Good to very good, very sandy, potholes.
1926	11.5	15	11.4	44.0	55.4	21.8	77.2	9.0	13.8	A	50	Good, potholes, slightly sandy.
1927	4	------	------	------	------	------	------	------	------	------	75	New material.
Average	------	------	------	------	------	------	------	------	------	------	76.6	
SAMPLE POINT NO. 6, 6.2 MILES—TOP OF RISE, WOODS LEFT, 500 FEET AHEAD; 1-FOOT CUT RIGHT, 2-FOOT CUT LEFT, 2 PER CENT GRADE ON EACH SIDE												
1922	6	9	9.4	37.2	46.6	26.7	73.3	11.7	15.0	A	90	Excellent.
1923	8	10	10.7	40.1	50.8	23.5	74.3	9.9	15.8	A	92	Do.
1924	7.5	9	9.5	41.4	50.9	24.5	75.4	9.3	15.3	A	85	Nearly excellent; slightly bumpy and sandy.
1925	6.5	12	13.4	36.5	49.9	20.9	70.8	11.0	18.2	A	70	Very good; sandy; potholes.
1926	5.5	10	9.1	40.5	49.6	22.8	72.4	9.7	17.9	A	50	Fair, large potholes.
1927	6.5	------	------	------	------	------	------	------	------	------	75	New material, loose.
Average	------	------	------	------	------	------	------	------	------	------	77.0	

[1] Has given notably good service under light traffic for 7.5 years. New material added recently has not been well chosen, being too sandy and giving a loose surface in spots.

Table 1.—*Project data sheet typical of north Georgia experiments* —Continued

Year	Depth of slab	Coarse material	Sand: Passing No. 10 retained on No. 20	Sand: Passing No. 20 retained on No. 60	Sand: Total retained on No. 60	Sand: Passing No. 60 retained on No. 200	Sand: Total	Silt	Clay	Grade of soil	Service quality	Surface condition
SAMPLE POINT NO. 7, 7.4 MILES—20 FEET BEFORE CULVERT, CARITHERS STORE 1,500 FEET AHEAD; PLUS AND MINUS 2½ PER CENT GRADE												
	Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Per cent*	
1922	6	6	9.7	39.5	49.2	21.5	70.7	12.0	17.3	A	93	Excellent.
1923	4	6	8.7	10.2	48.9	22.1	71.0	10.9	18.1	A	92	Excellent; slightly sandy.
1924	4.5	6	10.4	35.9	46.3	19.7	66.0	11.4	22.6	A	80	Very good to excellent; slightly sandy, potholes.
1925	13	10	11.1	37.6	48.7	23.1	71.8	10.4	17.8	A	65	Do.
1926	8	15	5.3	31.4	36.7	26.5	63.2	14.2	22.6	B	50	Fair; large potholes.
1927											70	New material.
Average											75.0	
SAMPLE POINT NO. 8, 8.4 MILES—4-FOOT CUT ON RIGHT, 2-FOOT CUT ON LEFT, JUST BEYOND CURVE LEFT AND HILL; HOUSE ON LEFT 150 FEET BACK												
1922	10	8	11.7	37.6	49.3	26.4	75.7	11.2	12.1	A	92	Excellent.
1923	10	8	9.8	38.9	52.4	25.0	73.7	10.5	15.8	A	90	Excellent; slightly sandy.
1924	7	12	14.5	37.8	52.3	25.7	78.0	10.2	11.8	A	93	Excellent.
1925	2	11	13.5	37.0	50.5	23.1	73.6	11.6	14.8	A	60	Very good to excellent; slightly sandy, potholes.
1926	8	15	14.6	39.6	54.2	26.8	81.0	8.3	10.7	A	60	Fair; rutted; potholes.
1927											75	New material.
Average											78.3	
SAMPLE POINT NO. 9, 9.7 MILES—AROUND CURVE LEFT, 7-FOOT CUT ON RIGHT, 3-FOOT CUT ON LEFT; CURVE TO RIVER 1,500 FEET AHEAD, WOODS LEFT												
1922	4	8	13.2	34.2	47.4	19.3	66.7	13.1	20.2	A	92	Excellent.
1923	12	25	16.5	35.0	51.5	19.1	70.6	12.1	17.3	A	90	Do.
1924	12	22	16.1	33.9	50.0	20.1	70.1	10.7	19.2	A	90	Do.
1925	5.5	22	15.4	36.0	51.4	22.7	74.1	9.0	16.9	A	80	Very good to excellent; slightly sandy; potholes.
1926	12	17	15.9	38.4	54.3	20.9	75.2	10.9	13.9	A	60	Good to excellent.
1927											70	New material.
Average											80.3	
Project average											78.1	

on or has been lost under weather and traffic, scarifying the surface may easily incorporate some of the subgrade earth in the surface.

4. Other sources of change exist, such as the tracking in of clay from private farm roads and the removal of sand or clay from the surface by washing rains or heavy winds.

The successive analyses of samples taken from the same points in the road reveal the total effects of all causes affecting surface composition. It is of interest to study the detailed analyses from this viewpoint and to find that so many of them have maintained an adequate composition during the 5-year period. The tables record the class of soil mortar year by year.

No previous record has been made on this phase of road soil behavior and the results are surprising in the constancy of composition maintained in spite of the many adverse agencies at work.

The exceptional and sudden changes found are relatively few and in most cases are explainable by known causes, chiefly the addition of new material, the scarifying of thin surfaces, or careless scraping of shoulder and side ditch material on to the surface. Two or three individual analyses showed sudden changes from previous analyses which were not explainable by field operations. Probably they represent errors in marking the sample or recording the analysis.

SURFACE DEPTHS AND LOSS OF MATERIAL STUDIED

Tables 1 to 3 record the successive annual surface thicknesses taken at the sample points. Such records were designed to throw light on the loss or gain of material under traffic, weather, and maintenance operations. It is to be expected that these variable influences would very seriously affect the measurements and possibly invalidate any real significance in the results.

An important advantage with road soil surfaces is that, granting a reasonable stability and durability, the minor displacements and roughnesses of the surface can be quickly and cheaply repaired by machines. But these maintenance operations are constantly loosening and reshaping a portion of the surface and increasing or decreasing the depth by transfer of material from high to low points in the immediate area. The effect on depth of surfacing at a particular point can not be predicted. The skill and care of the operator and the kind of drag or machine are always uncertain factors in the result.

Weather condition at the time of machining the surface is an important variable. Preferably such work should be done immediately after rains, so that the loosened material can promptly rebind with the undisturbed material below. If heavy washing rains

Table 2.—*Project data sheet typical of middle Georgia experiments* [1]

[Federal-aid project No. 124 in Washington County, topsoil surface; 5.93 miles long; completed January, 1921; sand-clay subsoil and shoulders]

Year	Depth of slab	Coarse material	Sand					Silt	Clay	Grade of soil	Service quality	Surface condition
			Passing No. 10 retained on No. 20	Passing No. 20 retained on No. 60	Total retained on No. 60	Passing No. 60 retained on No. 200	Total					
	Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Per cent*	
SAMPLE POINT NO. 1, 1.2 MILES—4½-FOOT CUT, ROAD LEFT, 175 FEET BACK; CURVE RIGHT, 150 FEET AHEAD; HOUSE RIGHT, 250 FEET AHEAD												
1922	7	2	2.3	31.3	33.6	40.1	73.7	11.8	14.5	B	70	Very good, rough.
1923	7	3	2.1	38.6	40.7	26.2	66.9	13.6	19.5	B	72	Very good; sandy.
1924	8	4	3.7	30.3	34.0	41.5	75.5	11.0	13.5	B	78	Very good to excellent; slightly sandy and worn.
1925	9	3	2.6	27.3	29.9	43.7	73.6	13.4	13.0	B	78	Excellent.
1926	7.5	2	3.1	31.6	34.7	40.6	75.3	14.5	10.2	B	78	Excellent; slightly sandy and rutty.
1927	7.5	0	2.6	27.9	30.5	46.1	76.6	11.7	11.7	B	60	Excellent, smooth.
Average											72.7	
SAMPLE POINT NO. 2, 1.9 MILES—2-FOOT CUT, LEFT; GRADE RIGHT, HOUSE 100 FEET AHEAD, GRAPE ARBOR 30 FEET BACK ON RIGHT												
1922	5	2	1.4	33.6	35.0	30.2	65.2	7.0	27.8	B	75	Excellent.
1923	6	2	1.0	28.5	29.5	29.2	58.7	8.7	32.6	B	60	Very good to excellent.
1924	6	6	1.7	33.6	35.3	36.8	72.1	5.9	22.0	B	75	Excellent.
1925	4.5	2	1.6	35.1	36.7	34.2	70.9	6.4	22.7	B	75	Very good to excellent.
1926	4.5	0	1.4	30.4	31.8	30.3	62.1	9.5	28.4	B	70	Excellent; slightly sandy on sides.
Average											75	Excellent.
SAMPLE POINT NO. 3, 3 MILES—6-FOOT CUT ON RIGHT, 2-FOOT CUT ON LEFT; ROAD ON LEFT 20 FEET BACK; CROSSROADS ON TOP OF HILL 200 FEET AHEAD												
1922	6	4	2.2	44.0	46.2	26.2	72.4	6.5	21.1	A	90	Excellent.
1923	6	4	2.0	49.4	51.4	21.4	72.8	6.9	20.3	A	90	Do.
1924	5.5	5	3.5	42.2	45.7	25.2	70.9	6.2	22.9	A	85	Do.
1925	5.5	5	2.8	44.9	47.7	25.2	72.9	6.2	20.9	A	85	Do.
1926	4	0	2.4	44.5	46.9	26.6	73.5	7.5	19.0	A	85	Do.
1927	3	2	2.8	37.7	40.5	34.0	74.5	6.0	19.5	B	81	Do.
Average											86	
SAMPLE POINT NO. 4, 4.4 MILES—20 FEET BEFORE SECOND CONCRETE BRIDGE, 7-FOOT FILL; ROADHOUSE ON LEFT, 700 FEET AHEAD												
1922	6	3	3.2	35.0	38.2	35.8	74.0	13.8	12.2	B	85	Excellent.
1923	5	2	3.8	36.9	40.7	32.5	73.2	9.1	17.7	B	75	Very good to excellent, slightly sandy.
1924	5	7	5.8	33.3	38.1	34.2	72.3	10.8	16.9	B	70	Excellent.
1925	5.5	8	3.7	34.4	38.1	32.3	70.4	11.0	18.6	B	70	Very good to excellent, sandy.
1926	4	2	3.5	35.7	39.2	33.5	72.7	13.0	14.3	B	65	Very good to excellent, sandy and corrugated.
1927											60	Excellent.
Average											70.7	
SAMPLE POINT NO. 5, 5.7 MILES—BARN ON LEFT, HOUSE ON LEFT, 150 FEET BACK; CONCRETE BRIDGE 100 FEET AHEAD												
1922	10	16	14.4	42.6	57.0	20.8	77.8	6.0	16.2	A	92	Excellent.
1923	9	16	11.4	45.2	56.6	19.1	75.7	8.3	16.0	A	85	Very good to excellent, slightly sandy.
1924	9	12	22.9	37.4	60.3	17.5	77.8	5.7	16.5	A	85	Excellent.
1925	9	12	13.6	42.9	56.5	21.5	78.0	5.4	16.6	A	83	Do.
1926	7.5	15	17.4	39.3	56.7	21.0	77.7	7.7	14.6	A	83	Excellent, slightly sandy.
1927	7	11	10.5	37.6	48.1	32.4	80.5	6.2	13.3	A	80	Excellent.
Average											84.7	
Project average											77.8	

[1] This project has given very good service for 6.4 years to an average daily traffic of 328 vehicles and has weakened little. The surface composition has been quite constant, with a gradual loss of clay.

occur immediately after fresh work, a larger amount of the loose material is permanently lost. This is particularly true on steep grades.

When class C surfaces are dressed in dry weather, the loose material does not rebind until it rains. Heavy winds will remove an appreciable amount of material under such condition.

The more serious operation of scarifying a rough surface and adding new material in weak places affects surface depth to a marked degree.

As a measure of lost material, it would have been much better to have had the test points closer together. On project No. 179 in Greene County—tabulation not shown—the test points were located about one-fourth mile apart, and the record on that project is the most consistent of those studied. In spite of all these uncertainties, it was found that many of the projects showed a continuous loss of depth and that the record as a whole is of value as bearing upon the efficient life period and the residual value of the surfaces at the time of last inspection. It has further significance in the case of thin surfaces and the observed action of failure and breaking down of the surface. Such observed conditions are commented upon in discussing the respective projects.

Table 3.—*Project data sheet typical of south Georgia experiments* [1]

[Federal-aid project No. 5, in Bacon County; sand-clay surface; 17.6 miles; completed September, 1921; sandy loam subsoil and shoulders]

SAMPLE POINT NO. 1, 1.3 MILES—40 FEET BEFORE CULVERT, WOODS BOTH SIDES, 4-FOOT FILLS

Year	Depth of slab	Coarse material	Sand: Passing No. 10 retained on No. 20	Sand: Passing No. 20 retained on No. 60	Sand: Total retained on No. 60	Sand: Passing No. 60 retained on No. 200	Sand: Total	Silt	Clay	Grade of soil	Service quality	Surface condition
	Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Per cent*	
1922	7	3	2.5	44.4	46.9	28.2	25.1	5.8	19.1	A	85	Excellent.
1923	7	6	3.1	46.1	49.2	24.3	73.5	5.2	21.3	A	85	Do.
1924	4	2	6.8	55.3	62.1	12.7	74.8	2.5	22.6	A	70	Very good to excellent, soft and rutted.
1925	2.5	5	4.0	52.0	56.0	30.4	86.4	4.1	9.5	A	75	Very good to excellent, soft and potty.
1926	1.5	5	7.5	44.8	52.3	23.8	75.8	7.4	15.5	A	65	Very good, potty and worn.
1927	2	8	4.6	46.3	50.9	35.1	86.0	5.0	9.0	B	50	Worn, loose, sand, corrugated.
Average											71.7	

SAMPLE POINT NO. 2, 2.1 MILES—40 FEET BEYOND CULVERT; ALL WOODS, 3-FOOT FILL; WOOD BRANCH 1,000 FEET BACK

1922	4	2	7.1	56.9	64.0	14.3	78.3	2.8	18.9	A	85	Excellent.
1923	6	3	4.2	57.5	61.7	15.3	77.0	3.7	19.3	A	90	Do.
1924	3.5	10	28.7	46.6	75.3	8.8	84.1	1.8	14.1	A	75	Very good to excellent; soft and worn.
1925	4	8	10.9	52.2	63.1	22.1	85.2	3.8	11.0	A	70	Do.
1926	5	2	9.9	52.6	62.5	25.0	87.8	4.8	7.4	A	65	Very hard under loose sand.
1927	5	5									50	
Average											72.5	

SAMPLE POINT NO. 3, 2.3 MILES—CULVERT 500 FEET AHEAD; OPEN WOODS, SMALL BORROW PIT ON RIGHT

1922	7	7	22.9	43.1	73.0	6.7	79.7	3.1	17.2	A	90	Excellent.
1923	5	30	7.6	44.8	52.4	20.4	72.8	7.6	19.6	A	85	Do.
1924	4.5	15	13.6	49.8	63.4	20.3	83.7	7.2	9.1	A	80	Do.
1925	5	12	6.6	56.3	52.9	24.7	87.6	5.8	6.6	A	70	Very good; sandy and potty.
1926	1.5	10	8.1	46.7	54.8	34.1	88.8	8.3	2.8	A	60	Sandy; new material.
1927	2										40	
Average											70.8	

SAMPLE POINT NO. 4, 4.4 MILES—CULVERT 50 FEET BACK; HOUSE ON LEFT, 175 FEET AHEAD AND 1,000 FEET BACK; 2-FOOT FILL

1922	5	6	8.8	53.3	62.1	12.2	74.3	4.8	20.9	A	90	Excellent.
1923	5	6	8.0	53.8	61.8	11.2	73.0	4.3	22.7	A	85	Do.
1924	4.5	13	7.5	44.7	52.2	19.9	72.1	5.4	22.5	A	65	Very good; rutted and worn.
1925	4	10	9.4	57.0	66.4	10.7	77.1	4.1	18.8	A	70	Very good; sandy and potty.
1926	2	9	9.5	48.7	56.2	28.3	84.5	5.7	9.8	A	60	Sandy and loose.
1927	2.5										30	2 inches of sand.
Average											66.7	

SAMPLE POINT NO. 5, 5.3 MILES—+1½ PER CENT GRADE, HOUSE ON RIGHT 60 FEET AHEAD; CLAY PIT OPPOSITE ON RIGHT

1922	3	5	12.1	60.5	72.6	5.3	77.9	2.9	19.2	A	90	Excellent.
1923	3	6	12.0	61.4	73.4	4.4	77.8	1.6	20.6	A	90	Do.
1924	2	3	13.0	59.5	72.5	8.4	80.9	2.0	17.1	A	85	Do.
1925	3	5	9.4	62.7	72.1	12.8	84.9	2.3	12.8	A	80	Do.
1926	4.25	5	11.8	60.4	72.2	11.0	83.2	2.2	14.6	A	65	New material, very good; slightly ribbed.
1927	4.5	20	7.4	41.8	49.2	20.2	69.2	5.6	25.0	A	50	New; very hard; excellent.
Average											76.6	

SAMPLE POINT NO. 6, 6 MILES, 8-FOOT FILL MIDWAY BETWEEN BRANCHES, 400 FEET APART

1922	3	10	10.0	51.2	61.2	17.4	78.6	6.3	15.1	A	85	Excellent.
1923	2	10	10.1	51.2	61.3	18.0	79.3	5.0	15.7	A	85	Do.
1924	5	14	13.1	47.6	60.7	20.1	80.8	6.6	12.6	A	75	Do.
1925	5	8	9.9	59.0	68.9	14.9	83.6	2.8	13.6	A	65	Very good to excellent; potty slightly sandy.
1926	3	7	11.1	56.4	57.5	16.7	84.2	3.8	12.0	A	60	Very good; part slightly ribbed.
1927	1.25										60	
Average											71.7	

SAMPLE POINT NO. 7, 7.5 MILES, 40 FEET BEYOND CULVERT, BORROW PIT ON RIGHT 25 FEET AHEAD, 2½-FOOT FILL, CURVE LEFT 1,000 FEET AHEAD

1922	4	6	16.9	57.0	73.9	5.2	79.1	2.0	18.9	A	90	Excellent.
1923	4	8	18.5	54.9	73.4	5.9	79.3	1.7	19.0	A	90	Do.
1924	3.5	5	26.0	49.4	75.4	3.9	79.3	.7	20.0	A	90	Do.
1925	5.5	12	13.0	48.6	61.6	10.4	72.0	4.3	24.7	A	70	Do.
1926	3.25	10	12.3	53.8	66.1	14.6	80.7	3.0	16.3	A	80	Excellent; slightly ribbed.
1927	4										70	Excellent.
Average											81.7	

See footnote at end of table.

TABLE 3.—*Project data sheet typical of south Georgia experiments*—Continued

SAMPLE POINT NO. 8, 8.7 MILES, FENCE ON RIGHT ENDS 175 FEET BACK, CURVE RIGHT 400 FEET AHEAD, 2-FOOT FILL

Year	Depth of slab	Coarse material	Sand: Passing No. 10 retained on No. 20	Sand: Passing No. 20 retained on No. 60	Sand: Total retained on No. 60	Sand: Passing No. 60 retained on No. 200	Sand: Total	Silt	Clay	Grade of soil	Service quality	Surface condition
	Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Per cent*	
1922	6	10	9.0	53.6	62.6	21.7	84.3	4.8	11.4	A	82	Excellent.
1923	6	4	13.5	52.8	66.3	10.3	76.6	2.4	21.0	A	80	Do.
1924	3.5	7	18.1	50.0	68.1	7.0	75.1	1.9	23.0	A	75	Do.
1925	5	6	13.2	58.6	71.8	11.7	83.5	2.9	13.6	A	70	Very good to excellent; slightly potty.
1926	4.5	5	15.0	53.4	68.4	14.5	82.9	4.0	13.1	A	65	Very good to excellent; slightly sandy.
1927	2										39	
Average											67.0	

SAMPLE POINT NO. 9, 9.9 MILES, 20 FEET BEYOND HOUSE ON RIGHT, COUNTY LINE 700 FEET AHEAD AROUND CURVE TO LEFT

Year	Depth of slab	Coarse material	Sand: Passing No. 10 retained on No. 20	Sand: Passing No. 20 retained on No. 60	Sand: Total retained on No. 60	Sand: Passing No. 60 retained on No. 200	Sand: Total	Silt	Clay	Grade of soil	Service quality	Surface condition
1922	5	13	9.5	51.3	60.8	18.4	79.2	7.1	13.7	A	90	Excellent.
1923	4	8	6.1	39.0	45.1	16.5	61.6	8.2	30.2	A	80	Do.
1924	5	12	10.5	38.9	49.4	14.4	63.8	6.7	29.5	A	82	Do.
1925	2	14	9.0	48.9	57.9	23.4	81.3	5.9	12.8	A	70	Very good; soft and potty.
1926	1	14	7.9	49.5	57.4	25.6	83.0	6.8	10.2	A	60	Very good; potty and sandy.
1927											40	
Average											70.3	
Project average											72.1	

[1] This project has given excellent service for 4 years to a heavy tourist traffic, but has weakened considerably in the past 18 months. The loss of material has been rather heavy and maintenance work has made the surface too sandy in recent years. It should be rebuilt. The daylight count is believed to be entirely too low for a true 24-hour duty. Probably 1,000 vehicles per day is the present average.

PHYSICAL CONDITION OF THE SURFACE AND QUALITY OF TRAFFIC SERVICE EVALUATED AS CLOSELY AS POSSIBLE

In seeking to record the physical condition of the surface adjacent to the several sample points, at the time of the semiannual inspections the terms listed below were used in the sense indicated.

Excellent.—This term implies that, when dry, the roadbed is strong, hard, free from noticeable ruts, holes, or corrugations, possesses a well-shaped crown and freely draining into the side ditches. A thin layer of loose, sandy material is sometimes present, but not in sufficient amount to impede traffic speed. During heavy rains or after long wet spells the surface is not noticeably softened, remains practically nonslippery, and is free from appreciable mud. Driving speed may be slightly but not seriously reduced.

Very good.—This term describes a hard and reasonably smooth surface which at weaker points shows incipient holes, corrugations, or worn wheel tracks, but which do not seriously affect speed or cause jolting. In wet weather there may be a slight amount of sloppiness while rain is falling, and following the rain a light skim coat of mud, not seriously slippery, but requiring some care in driving.

Good.—This term is used to describe a surface which is hard and firm when dry, with noticeable surface displacements affecting high-speed driving, but with no serious jolting at moderate speeds. The condition indicates the need of more frequent machining. In some cases the crown has become considerably warped, with an evident need of scarifying and reshaping. In wet weather a pronounced degree of sloppiness is manifest, with some softening and mud formation at the weakest points and some increase in slipperiness if the original material was high in clay content or has had clay brought in by wheels from unimproved side roads or from clay shoulders. No condition of deep mud has yet developed and there is no serious interruption of traffic during the worst weather.

Fair.—This term implies a distinct presence of rough sections or pronounced layers of loose material during dry weather and a liability to softening, slipperiness, and mud holes during continuous wet weather, especially when clay shoulders and clay subsoils exist. Such a condition usually indicates an immediate need of scarifying and reshaping with the addition of new material.

So many factors enter the problem that it is difficult to fully define the foregoing terms and, since the inspections were six months apart, for the inspector to make a perfectly uniform and consistent record. However, the attempt secures a more ordered judgment on a very complex matter than could be had if no effort to define the words had been made in advance.

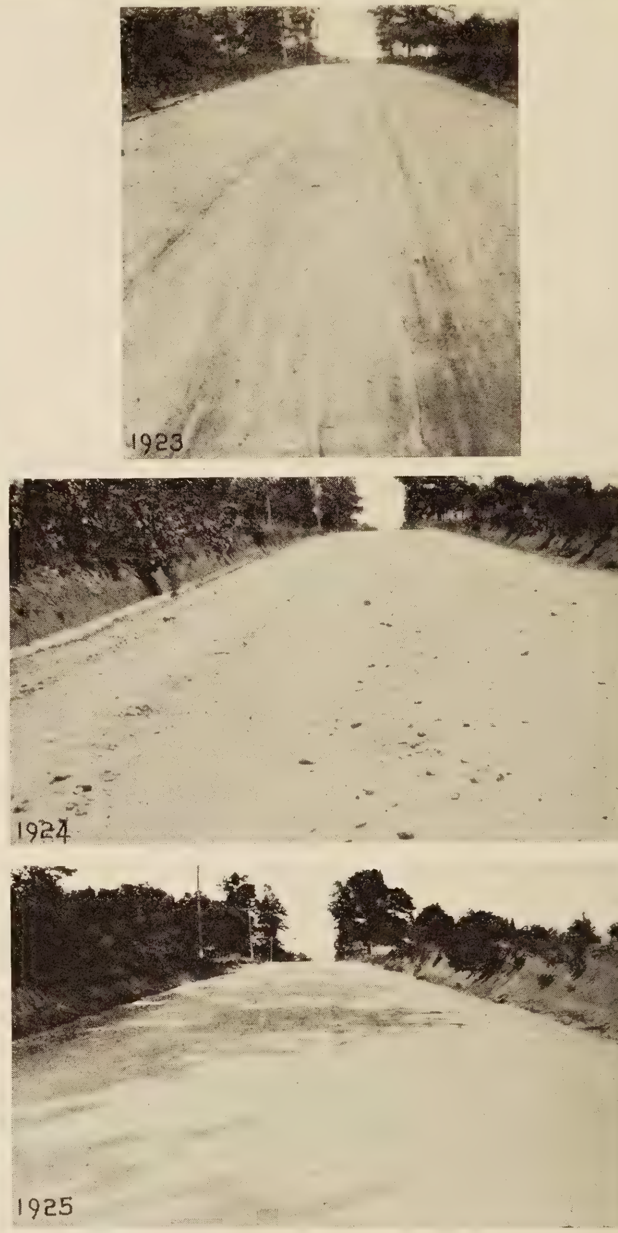
In addition to the verbal entries, a photograph was made to show the appearance of the road at each inspection. The pictures were taken at the same places in successive years.

It is clearly apparent that surface condition for this class of road reflects very directly the diligence and skill of the patrol maintenance force and the adequacy of the machine and tractor equipment used. In the earlier years of the research the State's patrol force was newly organized, untrained, and lacked proper equipment. The inspections have shown a steady general improvement in maintenance activities not only on these projects but over the whole State system.

QUALITY OF TRAFFIC SERVICE RENDERED

Since the inspection records made at 6-month intervals were so directly influenced by the length of time since the surface had been machined, it was felt that an effort should be made to evaluate in some way the general quality of traffic service furnished by the road throughout the year as distinguished from the physical surface conditions recorded during inspections. The plan adopted has been to interpret the inspection record in the light of comment on service from residents on the road, maintenance men, and division engineers as far as they could easily be obtained and were deemed sufficiently specific. For the projects under study these

Project No. 60, in Stephens County. Sample Point No. 1



Project No. 41, in Douglas County. Sample Point No. 2

reports were encouraging. They showed that the service, while variable, was highly acceptable and satisfactory and at all times free from serious interruption. The State highway department has been diligent in making investigation where newspapers report impassability on the State routes. None of them were valid on the projects studied.

For this report it has been assumed that quality of traffic service might be expressed at a percentage, assuming the maximum satisfactory use which the best of these roads have given under the best conditions as 100 per cent. A quality of service ranging from 80 to 100 per cent was taken as corresponding to excellent. Lower grades of service corresponding to surface conditions of "very good," "good," and "fair" were assumed for ranges of 60 to 80 per cent, 40 to 60 per cent, and below 40 per cent, respectively. Such service quality percentages were reported for each road section adjacent to the sample points as illustrated in Tables 1 to 3. Thus expressed, it has been possible to average these figures and arrive at a fairly reasonable judgment concerning the service rendered.

Under this standard of judgment, as herein used, a quality of service of 50 per cent indicates a fairly acceptable service with progressive satisfaction attaching to higher figures. Eighty per cent or above represents a highly dependable and thoroughly satisfactory service in all weathers and for truck traffic up to 5-ton vehicles. The records include some truck traffic as high as 20 per cent of the total.

The writer recognizes that we have here only an approximate measure of judgment not to be used dogmatically nor as a mathematical certainty, but at least significant and clarifying in the premises.

TRAFFIC COUNTS LIMITED IN EXTENT

Traffic counts on these projects were begun in 1922, making a daylight count of all vehicles on eight days of each month. It was not practicable to weigh vehicles or to extend the count through night periods.

Project No. 189, in Hart County. Sample Point No. 2

Project No. 151, in Floyd County. Sample Point No. 3

At first no distinction was made between passenger cars, trucks, and horse drawn vehicles, but this distinction has been made in the past three years.

It was found after two years' trial that cost could be reduced by replacing the original 8-day count in each month for the whole year by an 8-day count in each season during the months of February, May, August, and November. By taking averages for the 3-month groups from the figures collected during the first two years and comparing these averages with the respective counts in February, May, August, and November, the figures were practically identical and hence the shorter and less expensive counts have since been taken.

It is difficult to take a traffic count which is entirely satisfactory with a somewhat restricted expenditure. To determine the exact effect of traffic on the road would require information as to both the number and weight of all vehicles for the full 24 hours. This research was restricted to the partial plan as outlined.

It does not seem practicable to evaluate the existing traffic except in terms of the entire number of vehicles. That figure is reported in Tables 4 and 5.

The counts were taken on a daylight basis, and were less than a 24-hour count would show. Just what allowance for early evening and night traffic should be made is problematical. Hence the figures given are in fact less than the actual performance in all cases. It is quite certain that many of these projects are carrying traffic which is 20 to 40 per cent higher than the counts shown. This is especially true on projects lying on Florida tourist routes, of which No. 5 in Bacon County is an example. A stream of tourist traffic flows night and day over such routes in fall and spring.

For roads of this type, where the construction and maintenance costs are so low, it is better that the showing should be made, not on the absolute minimum basis, but with an assured knowledge that the service rendered is liberally in excess of the costs shown.

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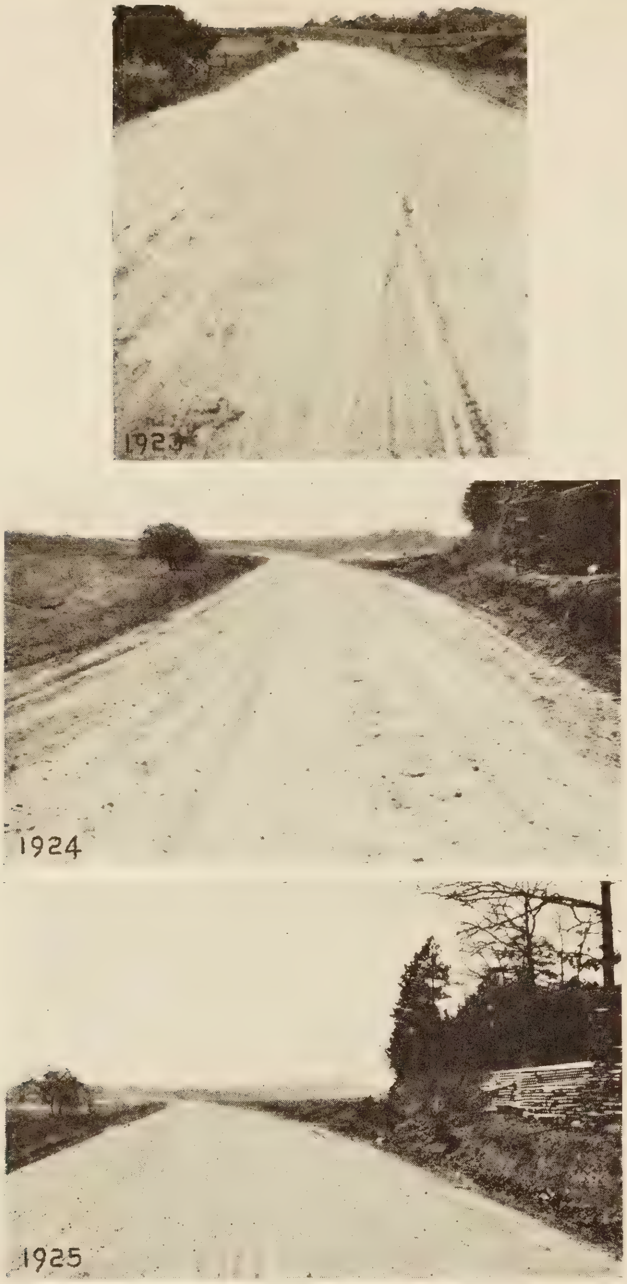


PROJECT NO. 22, IN MILTON COUNTY. SAMPLE POINT NO. 1

TABLE 4.—*Showing quality of soil mortar, percentage of coarse material, quality of traffic service, traffic, life period, initial depth of surface, annual loss from surface and number of sample points*

Project No. and county	Average class of soil mortar	Average percentage of coarse material	Average quality of traffic service during life period	Average number of vehicles per day	Life period	Average initial depth of surface	Average annual loss from surface	Number sample points
			Per cent		*Years*	*Inches*	*Inches*	
151, Floyd	C+	50	85	250	6.16	6.0	0.4	5
178, Murray	C−	45	75	218	4.50	8.5	[1].7	6
22, Milton	B−	20–40	60	720	6.00	6.0	[1].75	5
179, Greene	A	22	80	279	6.00	10.0	1.0	8
4, Walton	A	17	80	212	7.50	8.0	------	9
68, Walton	A	8	80	353	6.25	10.0	[1].5	6
6A, Hall	B+	10–30	65	220	7.16	5.0	.6	4
41, Douglas	B+	4–15	55	597	6.75	4.5	.7	4
59, Jackson	A−	8–20	80	321	7.00	7.0	[1].5	4
131, Jackson	A	15–20	70	321	6.00	6.5	[1].7	5
60, Stephens	B	5–15	65	435	6.33	6.5	[1].7	12
189, Hart	A	20	80	674	4.50	9.5	[1].7	7
1B, Henry	B+	------	70	1,015	6.00	8.0	[1].7	5
19, Bleckley	B+	5–15	65	94	4.85	6.0	[1].7	7
76, Wheeler	B+	4–15	75	170	5.25	9.0	.5	8
124, Washington	B+	6	80	255	6.42	7.0	[1].4	5
134, Coweta	B+	5	80	227	6.00	8.5	.5	8
144, Macon	C+	4	50	355	6.25	6.5	[1].8	4
197, Bulloch	B+	13	70	291	6.33	8.0	------	4
S-10-14, Richmond	A	35	85	650	5.25	6.3	[1].5	3
18, Dooly	B	3–5	60	198	5.91	4.0	------	9
5, Bacon	A	5–20	70	557	5.75	5.0	.6	9
196, Early	B+	6	80	318	6.00	8.0	[1].5	6
205, Effingham	C+	10	40	367	4.00	8.0	------	4
49, Mitchell	B	30	75	253	4.00	8.0	.5	12
145, Montgomery	B+	16	80	183	5.25	7.0	.45	9
146, Tift	B	20	80	540	4.75	4.0	.3	3
77, Charlton	A	30–50	90	800	3.00	8.0	[1]1.0	5
199, Quitman	B+	25	75	175	6.00	5.6	[1].6	4

[1] These projects show the more consistent losses in slab depth. Average loss on 25 projects, 0.6 inch.

COST DATA AND INVESTMENT OF PUBLIC FUNDS STUDIED

Table 5 is designed to present the financial investment which the public has made in these roads in relation to quantity and quality of traffic service. The basic economic figures are the first cost of the surfacing, the interest on the investment during the life period studied taken at 5 per cent properly amortized, the annual average expenditure for maintenance during that period, and the residual salvage value of the surfaces at the time of final inspection just prior to July 1, 1927, or the corresponding annual depreciation.

The first costs of the surfacing exclude the costs of grading and drainage structures which are a common expense for any type of road surface.

The expenditures for maintenance from 1922 to 1926 were taken from the systematic cost records of the State highway department and reduced to an average annual rate per mile. This average figure is applied in the tables to the entire life period shown for each project.

With machine methods of maintenance it is difficult to separate the expenditures upon the surface itself from concurrent work upon the adjacent earth shoulders. The records were not kept so that a clear distinction could be made. Hence, the figures include the upkeep of shoulders as well as of the road surface. Since work on the shoulders is a necessary incident to keeping the crown in good shape and maintaining free surface drainage into the side ditches, such shoulder costs are in general a legitimate part of operating expense. The figures do not include repairs to drainage structures and bridges, cleaning side ditches, mowing of weeds and bushes, or other items incurred in the care of the right of way.

Interest on the investment is computed at a rate of 5 per cent in the belief that it represents a full average rate for money obtained on county bonds in this State. Much of the money invested in these projects was obtained from county bonds, and all other money used may be properly accorded an equal earning power from the investment standpoint. In arriving at the total sum invested by the public in these and other types of roads for a given period of life, the interest-bearing value of the money should be included.

With the decision to make a final report on this research as of July 1, 1927, the writer made a careful inspection of the projects in the latter part of June. Notes were taken upon existing thickness of surfaces, condition of the surfacing, evidences of cutting through into the subgrade or other weaknesses with a view to forming a judgment of the remaining service or salvage

TABLE 5.—*Showing economic data on 29 Georgia Federal-aid projects, arranged in order of traffic density*

[Total length of projects, 246.7 miles]

Federal aid project No.	County	Section of State in which located	Material	Prevailing subsoil	Length	Service period to July 1, 1927	Depreciation per mile during service period: On percentage basis	Depreciation: Total	Depreciation: Annual	Initial cost of road surface per mile	Estimated life based on depreciation during service period	Average annual interest during life period at 5 per cent	Average annual maintenance of surface and shoulders per mile	Annual distributed cost per mile, (sum of columns 10, 13, and 14)	Vehicles per day, daylight hours: Average for February, 1927	Vehicles per day: Average for service period	Index of operating efficiency or annual distributed cost per average daily vehicle mile	Class of soil mortar	Average quality of traffic service during service period on basis of best service of these slabs as 100 per cent: First half	Second half	Whole period
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
					Miles	*Years*	*P. ct.*				*Years*										
19	Bleckley	Middle	Topsoil	Sand-clay	9.1	4.85	70	$746	$154	$1,065	7	$30	$106	$290	97	94	3.09	B+	65	70	65
76	Wheeler	do	do	do	9.9	5.25	65	2,029	387	3,122	8	88	145	620	221	170	3.65	B+	85	70	75
199	Quitman	South	Local gravel	do	5.0	6.00	65	1,078	180	1,658	9	46	174	400	200	175	2.29	B+	80	---	75
145	Montgomery	do	Red pebble soil	do	12.4	5.25	50	744	142	1,487	10	41	157	340	221	183	1.86	B+	85	75	80
18	Dooly	do	Variable, sand-clay	do	10.4	5.91	80	617	104	771	7	22	154	280	215	198	1.41	B	65	52	60
4	Walton	North	Topsoil	Clay	9.4	7.50	75	1,145	153	1,526	10	42	162	357	302	212	1.68	A	90	---	80
178	Murray	Northwest	Chert	do	6.3	4.50	40	1,222	272	3,055	11	83	147	502	(1)	218	2.30	C−	80	70	75
6A	Hall	North Georgia mountains.	Topsoil	do	5.7	7.16	90	1,475	206	1,639	8	46	228	480	254	220	2.18	B+	75	55	65
134	Coweta	Middle	do	do	19.9	6.00	60	1,204	201	2,007	10	55	150	406	238	227	1.79	B+	85	75	80
151	Floyd	Northwest	Chert	do	7.3	6.16	25	695	113	2,781	25	72	146	331	306	250	1.32	C+	90	80	85
49	Mitchell	South	Red pebble soil	Sand-clay	13.4	4.00	40	446	112	1,116	10	31	158	301	(2)	253	1.19	B	75	80	75
124	Washington	Middle	Sand-clay	do	5.9	6.42	50	586	91	1,172	13	32	200	323	339	255	1.27	B+	80	75	80
179	Greene	Northeast	Semi-gravel	Clay	2.7	6.00	40	491	82	1,227	15	33	146	261	215	279	.94	A	90	75	80
[3]197	Bullock	Middle	Sand-clay	Sand-clay	2.3	6.33	65	774	122	1,190	10	33	170	325	381	291	1.12	B+	---	---	70
196	Early	South	do	Sandy loam	8.9	6.00	75	1,625	271	2,167	8	61	142	474	---	318	1.49	B+	85	---	80
59	Jackson	Northeast	Topsoil	Clay	4.3	7.00	80	1,567	224	1,959	9	54	265	543	209	321	1.69	A−	85	70	80
131	do	do	do	do	7.1	6.00	85	2,106	351	2,478	7	71	180	602	209	321	1.88	A	80	60	70
68	Walton	North	do	do	9.1	6.25	65	1,496	239	2,302	10	63	173	475	438	353	1.35	A	85	70	80
144	Macon	Middle	Sand-clay	Sandy loam	3.8	6.25	85	659	105	775	7	22	165	292	389	355	.82	C+	60	45	50
[3]205	Effingham	South	Poor sand-clay	do	4.2	4.00	95	2,079	520	2,188	4	68	218	806	(4)	367	2.20	C+	---	---	40
60	Stephens	Northeast	Topsoil	Clay	11.0	6.33	85	1,499	237	1,763	7	50	177	464	468	435	1.07	B	70	60	65
[3]146	Tift	South	Red pebble soil	Sand-clay	6.0	4.75	75	1,838	387	2,451	6	71	209	667	(5)	540	1.24	B	80	80	80
5	Bacon	do	Sand-clay	Sandy loam	17.6	5.75	85	1,492	259	1,755	7	50	200	509	812	557	.91	A	85	60	70
41	Douglas	North Central	Topsoil	Clay	6.6	6.75	85	1,760	261	2,071	8	58	180	499	591	597	.84	B+	60	55	55
S-10-14	Richmond	Middle	Local gravel	Sand-clay	8.4	5.25	60	1,848	352	3,080	9	86	150	588	1286	650	.90	A	90	---	85
189	Hart	Northeast	Topsoil	Clay	3.8	4.50	60	1,190	264	1,983	8	56	205	525	(6)	674	.78	A	85	---	80
22	Milton	North Central	Semigravel	do	10.0	6.00	85	1,566	261	1,842	7	53	154	468	872	720	.65	B−	70	50	60
[3]77	Charlton	South	Gravel	Sandy loam	19.2	3.00	60	7,547	2,516	12,578	5	377	177	3,070	(7)	800	3.84	A	90	90	90
1B	Henry	Middle	Topsoil	Clay	7.0	6.00	100	1,427	238	1,427	6	42	298	578	(8)	1,015	.57	B+	70	65	70
Weighted averages					215.0	5.81	68	---	214	1,854	9	52	170	435	---	355	1.54	---	---	---	73
Weighted averages for service period for sections with less than 300 daily vehicles.					117.4	5.66	58	---	174	1,735	10	48	156	377	---	207	1.94	---	---	---	75
Weighted averages for service period for sections with 300 or more daily vehicles.					97.6	6.00	80	---	262	1,998	8	56	187	505	---	532	1.06	---	---	---	71

[1] Surface treated in 1926.
[2] Paved in 1925–26.
[3] Project omitted in computing weighted averages.
[4] Rebuilt with gravel in 1925–26.
[5] Paved in 1926.
[6] Paved in 1926–27.
[7] Surface treated in 1925.
[8] Paved in 1925–26.

worth of each section of road adjacent to sample points. A number of representative samples were taken for final analysis.

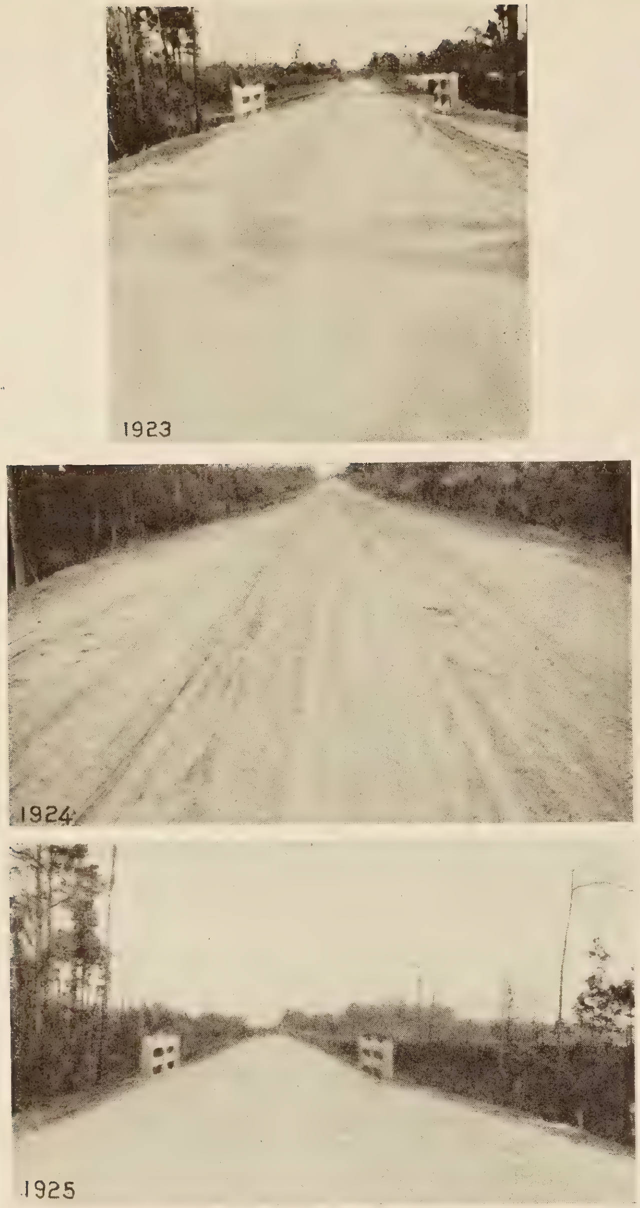
The judgment arrived at was expressed as a percentage of the first cost of the surfacing. The data were not sufficient to estimate satisfactorily the quantity of original surfacing material still present on the road owing to the distance between sample points, and the variable conditions noted between such points in the final inspection. Judgment was based on the depth losses recorded, physical condition of the surface, evidence of cutting where such existed, and recent reports of dependable service in wet weather. From the salvage estimate, the complementary total depreciation is easily derived. This figure appears in column 8 of Table 5 and is reduced to annual dollars per mile in column 10.

It has been thought useful to combine the foregoing financial items into the figures shown in column 15 of Table 5 to represent the total investment per mile per year expended at a uniform rate to furnish traffic service. The total depreciation of surface divided by the life period used gives the annual depreciation per mile per year. If we add the average annual expenditure for maintenance, the average annual interest (see column 13) on the first cost of the surface and the average depreciation per year expressed in dollars, the sum constitutes the distributed annual cost per mile.

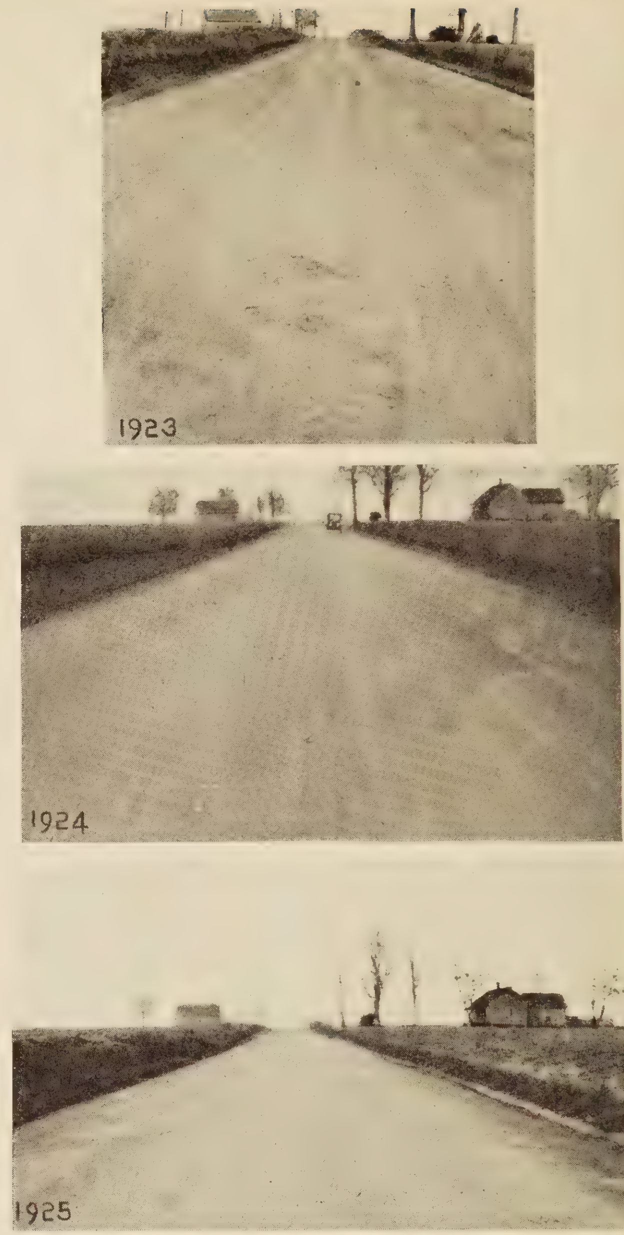
Such figures are useful and significant in comparing the several road soil projects with each other and in a further comparison with types of paved roads where similar data covering the life history have been kept.

Column 18 of Table 5 shows the quotient of the annual distributed cost per mile when divided by the average daily traffic for each project. This quotient may be regarded as an operative efficiency index. So long as the index decreases as traffic increases and the quality of service is substantially maintained, the economic status is improving. This index thus becomes a measure of traffic capacity when related to the quality of service rendered.

Another important significance is found when a road of this type has worn down and must be rebuilt. Comparing the vehicle-mile cost for this type with the same figure at the same traffic density for a more costly type of surface becomes a valuable basis of



Project No. 76, in Wheeler County. Sample Point No. 3



Project No. 196, in Early County

decision between replacement with the same road soil material or with a more expensive surface.

AVERAGE QUALITY OF SERVICE

Columns 20 to 22 of Table 5 show the average quality of traffic service by periods for use in interpreting the financial results. The figures are derived from the detailed project data tables. An average quality of service below 50 per cent is to be regarded as weak and unsatisfactory. From 60 to 70 per cent should be considered quite satisfactory, from 70 to 80 per cent as very good, and above 80 per cent as excellent and dependable service in all weathers and under 5-ton trucks. The percentages in the table represent the repeated judgments of the inspectors.

At the bottom of Table 5 weighted averages are shown which are thought to have significance. These generalizations are of importance in giving a picture of what may reasonably be expected in the matter of cost, service, and traffic carrying capacity of this class of roads. They draw the picture in darker colors, however, than it deserves since the list of projects contains a number of weak soils which can and should be eliminated in future construction of this type. It should be said that such elimination has been made already by the State highway department, and that on road soil projects built since 1922 better materials have been used and more attention has been given to details during construction than on many of the older projects included in this research.

Throughout the research the observed and the computed data have been handled from the following viewpoint:

We are dealing with a material of low cost and relatively large variations in composition acted upon by varying weather conditions and traffic burdens of uncertain amounts. Some of the important data is arrived at as a matter of judgment. In presenting a

Project No. 179, in Greene County. Sample Point No. 1

report it is desirable to so handle the data that the resultant conclusions shall be on the side of conservatism. It is much better to understate than to overstate the possibilities inherent in the use of this class of materials as revealed by the quantitative evidence adduced.

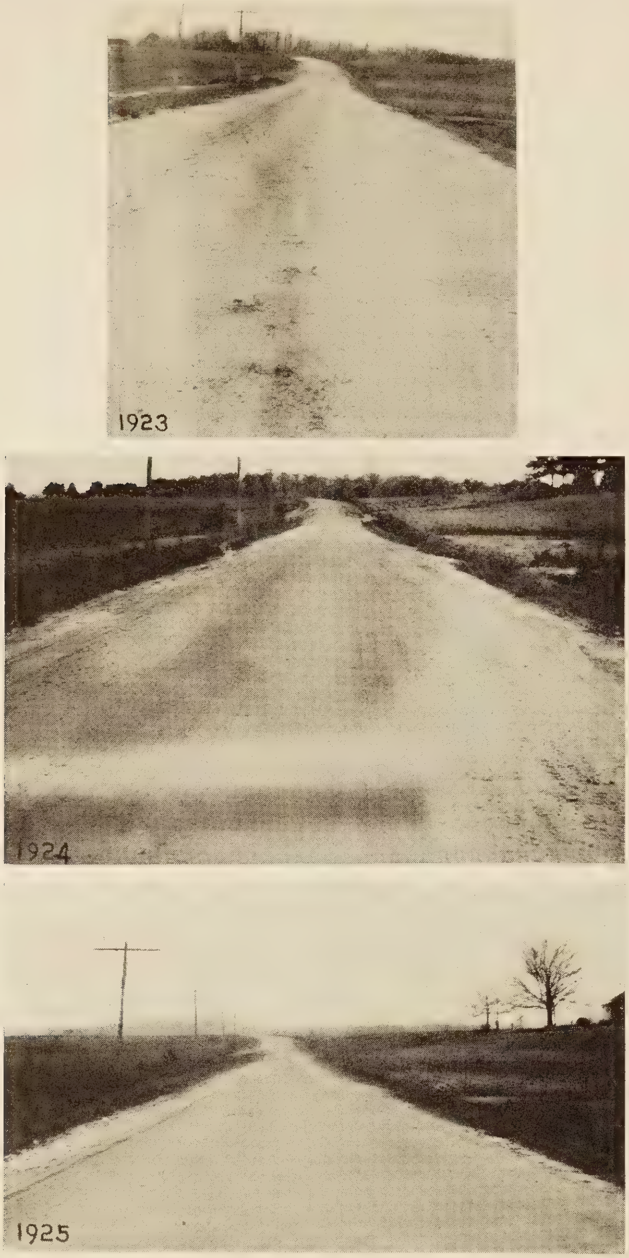
It should be said, on the other hand, that these road soils have many substantial merits and occupy an assured place in the future of highway betterment. The casual reader must not be misled on this point by the candor with which the report points out the adverse factors. Their known results are notable and worth while.

LACK OF KNOWLEDGE OF CLAY CHARACTERISTICS HAMPERS INTERPRETATION OF DATA ON SOIL COMPOSITION

The complete records representing the 180 sample points (illustrated by Tables 1, 2, and 3) are not presented here, but conspicuous facts resulting from their study will be presented. These records were examined for changes in surface composition. The most significant items are those showing the amounts of clay and the coarser sand above No. 60 sieve. A number of cases were noted where sudden clay increases or losses are attributable to admixture of shoulder material because of lack of care in machining the roadbed. On project No. 60, in Stephens County, all the sample points showed a 5 to 8 per cent increase in clay between 1922 and 1923. Likewise on project No. 144, in Macon County, where sandy shoulders exist, the opposite effect of decrease in percentage of clay was noted at all the sample points due to incorporation of fine sand in 1924. If only one sample point on a project shows sudden change, the cause is probably local such as tracking in of clay from a side road or careless shoveling of some ditch material onto the surface. In reviewing the analyses at all of the 180 sample points, it was found that 113 of that number showed very consistent composition, and that the grade of soil mortar remained notably constant or normal during the life period.

One hundred and fifty sample points show a fairly normal or constant figure for coarse sand. The variations in clay content are the widest. This is to be expected; yet 116 sample points give a fairly consistent clay percentage. If the last two years of service are omitted, when quite a large number of surfaces had worn thin and were scarified and frequently new material added, the number of surfaces with consistent composition becomes larger. It was observed that several of the projects, notably No. 179 in Greene County and No. 189 in Hart County, were somewhat

Project No. 19, in Bleckley County. Sample Point No. 1



Project No. 59, in Jackson County. Sample Point No. 2

low in original clay and high in coarse material or gravel. These projects while free from mud are subject to more rapid loss in dry weather. Such surfaces need from 20 to 30 per cent clay in the mortar to bind the coarse material properly.

Project No. 179, in Greene County, had an average gravel content of 22 per cent, and an average clay content in the mortar of 14 per cent. The latter figure is but 11 per cent of the whole material. While furnishing an excellent quality of service for traffic of 279 vehicles per day, this project has undergone an annual loss of depth of nearly 1 inch per year.

Project No. 189, in Hart County, with a traffic of 674 vehicles per day and clay and gravel limits similar to project No. 179, was very difficult to keep smooth and free from holes during its four and one-half years of service before a concrete pavement was laid.

An exact interpretation of variations in composition is seriously hampered by lack of knowledge of the quality of the clay ingredients. Certain clays are more adhesive and effective than others, but the quantitative degree of variations in clay characteristics is yet to be fully determined.

SURFACE LOSSES RARELY EXCEED 1 INCH PER YEAR

In the matter of depth losses, there are 16 projects where two-thirds or more of the individual sample points show a consistent loss of material not seriously affected by maintenance or addition of new material. The average annual losses on these projects range from 0.5 inch to 1 inch per year, with a general average of 0.67 inch. Taking the record for all the projects, the general average loss per year is 0.6 inch. Making allowance for any doubtful factors, it seems conservative to say that for this type of surface and within reasonable traffic limits the annual loss of material will rarely exceed 1 inch per year. Certainly for the first five years of service a much lower loss is shown on the projects studied.

It was observed that surface losses, while progressive, do not accumulate uniformly, nor are they dependent solely on the amount of traffic. Comparing project No. 19, in Bleckley County, carrying the extremely light traffic of 94 vehicles per day, with project No. 76, in Wheeler County, carrying 170 vehicles, we find the former has a yearly loss of 0.7 inch as against 0.5 inch for the latter. Both surfaces are comparable in composition and both projects are similar as to subgrade material and general topography.

Likewise project No. 124, in Washington County, which is closely adjacent to the Wheeler County project, has been carrying a traffic of 255 vehicles per day with a loss of only 0.4 inch per year. Project No. 60, in north Georgia, has a composition similar to project No. 19, in Bleckley County, but rests on a clay subsoil and with clay shoulders, and has borne 435 vehicles per day with a 0.7 inch loss, which is just equal to that of project No. 19.

No hard and fast decision is warranted regarding surface losses, but it is undoubtedly true that a large part of them accrue from weather influences, grade conditions, and machining, and it may be tentatively suggested that this portion of the loss will reach 0.3 inch or more per year, regardless of traffic density. Up to a certain point, traffic helps to maintain the surface by packing the loose material which is formed when machining and smoothing the surface.

The two chert projects—No. 151, in Floyd County, and No. 178, in Murray County—are quite different from soils with true clay binder. The large percentage of fine material is recorded as clay, but it is in fact amorphous silica. It has good binding value and is nonswelling with moisture. The Floyd County project has proven much the better of the two. The Murray County project lost material so fast that it was surface treated with asphalt in 1926.

Of the other original projects, No. 77 in Charlton County, No. 146 in Tift County, No. 49 in Mitchell County, No. 1B in Henry County, and No. 189 in Hart County have been surface treated or paved since the research study began, and No. 205 in Effingham County has been rebuilt with a gravel surfacing.

Table 4, on page 126, gives comparative data which may be of interest, but the reader is cautioned against arbitrary conclusions therefrom, especially in regard to depth and loss of surface material. The traffic wears each section of road as it finds it, and is no respecter of averages. However, the table does generalize and compare certain results in a tentative way that may awaken thought, and furnish possible illustrations.

COST OF PROVIDING TRAFFIC SERVICE ON VARIOUS PROJECTS DISCUSSED

Attention is now directed to the more significant items in Table 5, on page 127.

The depreciations in column 8 are necessarily the result of judgment and careful estimate as previously explained. In most cases the period of study has covered about 75 per cent of the prospective total life. Thus the evidences of depreciation were well advanced and in a number of cases the necessity of early replacement was clear. In other cases the thickness of material still remaining in place and the condition of the surface indicated at least 2 or more years of satisfactory service. Project No. 151, in Floyd County, built of high grade chert, and the exceptionally good semi-gravel project No. 179, in Greene County, are in notably good condition and deserve the high estimate given. On the latter project, the underlying subgrade is itself an excellent quality of adhesive clay containing a large percentage of coarse sand.

The purpose of Table 5 is to arrive at the significant annual distributed cost per mile (column 15) and the related index of operating efficiency (column 18). Thus an estimated total life period as shown in column 12 is needed. The assumption of a straight-line depreciation is made in arriving at the figures given. This assumption is possibly too favorable. The actual rate of depreciation of all kinds of road surfaces involves many complex factors. This is especially true of the road soil surfaces. Theoretically the rate of depreciation of these surfaces should increase progressively owing to loss of material and growth of traffic density. If the ultra assumption were made that all of the projects were entirely worn out the effect on the average distributed cost per mile would be to raise it about 30 per cent. The effect of the assumption of a straight-line depreciation is to increase the average life of all the projects by about three years. In the writer's judgment, an average 2-year increment will be borne out in their actual history.

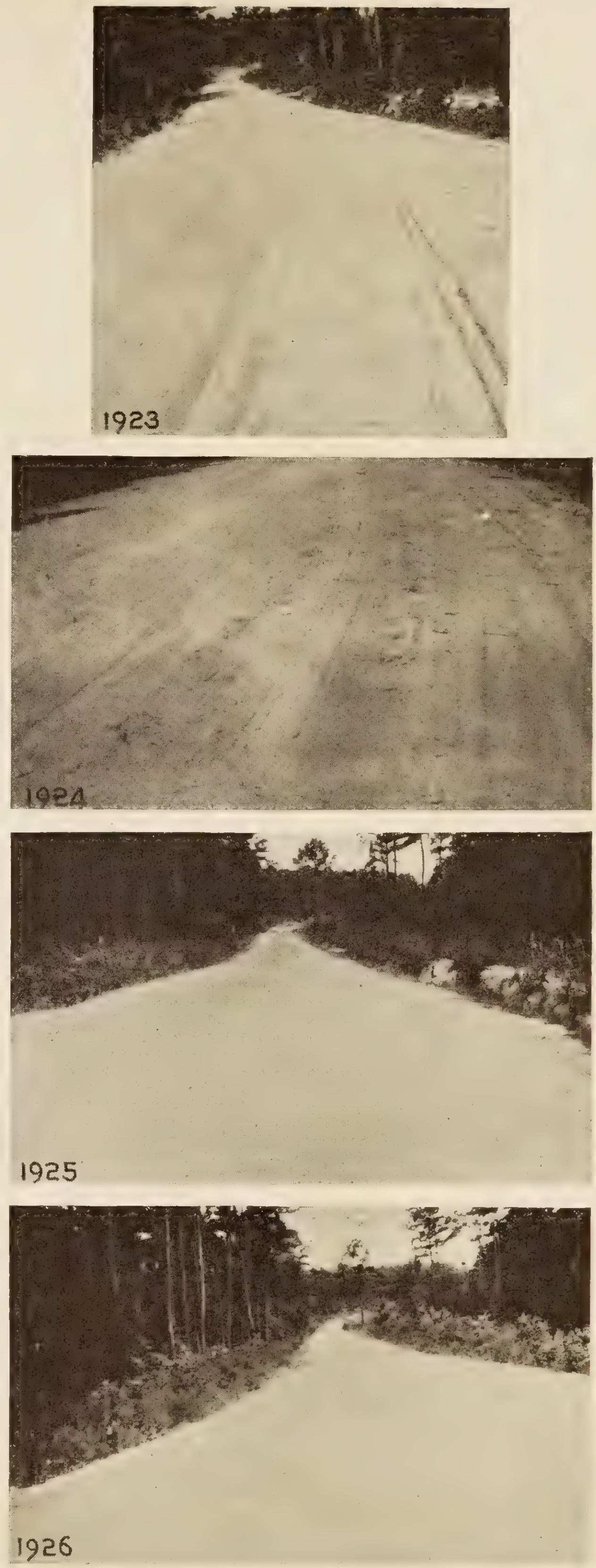
Interest is allowed on the money invested at the rate of 5 per cent. The investment in the original surface decreases year by year as depreciation accrues and the average annual interest charge is amortized by the following formula:

$$\text{Average annual interest} = \frac{A\ I}{N}\left(\frac{N+1}{2}\right)$$

Where A = initial cost,
I = interest rate,
and N = years of total life.

The sum of the annual depreciation (column 10), the average annual interest charges (column 13), and the average maintenance expense (column 14) compose the annual distributed cost per mile. This may be regarded as the measure of the actual outlay, uniformly disbursed, which the public treasury pays to furnish this transportation facility.

If the annual distributed cost per mile on each project be divided by the average traffic count in column 17, the result is the annual vehicle-mile cost (column 18); i. e., the amount of public money which was used



Project No. 124, in Washington County. Sample Point No. 3

Project No. 4, in Walton County. Sample Point No. 1

to supply 365 miles of travel to each vehicle which used the road on an average day.

The relation between the transportation mileage furnished and the quality of that service is of interest. Columns 20, 21, and 22, seek to express the quality of service as explained on page 123.

Four of the 29 projects are omitted from the computation of weighted averages owing to various uncertainties in the record, to short service, or marked difference in material.

Computations of weighted averages omitting the two chert projects were made separately, and another set omitted the semigravel projects, etc. The results varied so slightly that one set of averages can include the 25 projects considered.

It will be noted that the annual distributed cost per mile ranges from $280 to $620, with the weighted average at $435. Variations from this average are due largely to initial cost and depreciation.

The annual maintenance figures do not vary widely from the weighted average of $170; not so much, perhaps, as the current needs of the several projects warranted. The highway laws of Georgia have a clause providing for uniform distribution of maintenance funds which is embarrassing at times and which can be escaped only to a limited degree through a small emergency fund. Thus, on project No. 22, in Milton County, with a traffic count of 720 vehicles, including 15 per cent trucks, the maintenance figure is $154, which is less than the average. From the outset, this project has shown a lower quality of service than would have been the case had the maintenance been fully adequate. It is felt that the normal yearly maintenance figure for these types should be from $200 to $250 per mile for best efficiency in quality of service with the probability of some increase in the life of the surface.

AVERAGE COSTS, LIFE PERIOD, AND SERVICE QUALITY OF ROAD SOIL SURFACES INDICATED

The general weight of the detailed evidence carried by Table 5 may be summed up as follows: The 25 projects comprise 215 miles of road which are widely distributed and satisfactorily representative of subgrade, topographic, and traffic conditions in the State. The weighted averages give direct evidence that with a traffic count of 355 vehicles and an initial cost of $1,854 per mile the projects have served for an average life of 6 years—5.81 years—with a quality of service represented by 73 per cent. This rating corresponds to a very satisfactory and reliable service.

The corresponding annual distributed cost per mile is $435 and the vehicle index is $1.54.

The indicated service quality during the first half of the life periods observed was better than during the later years. Eighteen of the 29 projects show 80 per cent or better during the first half of their life periods and 17 show 75 per cent or better for the entire period of observation. The figure of 80 per cent means entirely dependable uninterrupted service in all weathers for passenger cars and trucks (5-ton maximum).

Interpreted in terms of speed, 80 per cent quality of service implies safe movement of passenger cars at 50 miles per hour in dry weather and 30 to 35 miles per hour when heavy rain is falling. Similar limits for trucks are 35 and 20 miles per hour, respectively. The figure of 75 per cent implies substantial satisfaction in all weathers, but with reduced speeds in wet weather, less smoothness, and more care in driving. It does not imply soft mudholes or serious slipping in wet weather.

INVESTIGATION SHOWS TRAFFIC LIMITS AND REPLACEMENT DATA FOR ROAD SOIL TYPES

A study of Table 5 together with the related research data makes it pertinent to include here certain details and suggestions with regard to traffic limits and replacement which seem to be valid and helpful.

In place of the 18-foot width of surface which these projects represent, it is evidently wise to make the surface 26 feet wide for a 30-foot road (includes ditches 2 feet wide). This eliminates the present 4-foot shoulders of poor grade local dirt and provides a freer drainage from the bottom of the surface into the side ditches. The compacted surface should have an average depth of 7.5 inches (8 inches for the central 18 feet, reducing to 4 inches at the ditch margins). This is the present practice of the Georgia State Highway Department and results in more effective machine maintenance without danger of incorporating poor shoulder material into the road surface.

Such construction requires 3,400 cubic yards of material per mile and costs, at present contract prices, about $1,700 in place under average conditions and with an average haul of 2 miles.

The field observations and the tabulated data indicate that when traffic density exceeds 600 vehicles per day, the economic working capacity of these surfaces has, in general, probably been reached.

To date, 15 of the 29 projects have carried a traffic ranging from 318 up to 1,015. Of these, three have been paved since 1922, mainly on account of dense traffic—No. 1B, in Henry County, with a 1,015 count; No. 189, in Hart County, with 674 count; and No. 146, in Tift County, with 540 count. Project No. 77, in Charlton County, was originally built with gravel. Because of rapid loss of material, it was surface treated with asphalt. The traffic count of 800 is deemed to be lower than the actual 24-hour burden on this tourist route to Florida.

Project No. 49, in Mitchell County, was paved in 1925–26. At that time the traffic count was 253 and the surface was in excellent condition. The replacement was due to causes other than traffic density.

Project No. 205, in Effingham County, was originally surfaced with a manifestly inadequate local soil and gave such poor surface that it was rebuilt with gravel as soon as practicable. The average traffic was 367 vehicles daily.

A comparison of the behavior of project No. 77, in Charlton County, and No. S–10–14, in Richmond County, gives instructive illustration regarding clay ingredients and gravel content. The latter project is built from a local gravel soil containing 35 per cent coarse material. It is bound by an excellent class A soil mortar containing a strongly adhesive kaolin type of clay. It has carried a heavy traffic burden (650 daily vehicles) on an important tourist route. It was laid in varying depths from 8 to 5 inches. After 5.25 years, it retains an average depth of 3.25 inches and has shown a quality service of 85 per cent. Its initial cost was $3,080 per mile, its annual distributed cost per mile is only $588, and its vehicle index is 90 cents. By contrast, No. 77, in Charlton County, was built with imported gravel containing 30 to 50 per cent coarse material. During three years' service it lost surface thickness at the rate of 1 inch per year and was surface treated with asphalt to preserve it. Its soil mortar was similar to the Richmond project in clay percentage, but evidently the quality of the clay was far less adhesive. Its initial cost was $12,578 per mile, its annual distributed cost per mile was $3,070, and its vehicle index $3.84. The comparison is made to show that a better knowledge of the characteristics of the clay ingredient in soil and gravel mixtures is vital to true economy in their use.

Project No. 134, in Coweta County. Sample Point No. 2

With reference to project 1B, in Henry County, it is felt that the average daily traffic of 1,015 vehicles was well beyond the limit of road-soil efficiency. Despite an annual maintenance expenditure of $298 and 2 miles built of virtually a gravel material (30 to 60 per cent coarse material), the service quality was not maintained above a 70 per cent figure. The traffic found this road rough from quickly forming holes and corrugations and loose on top from constant scraping. It had no deep mud or serious traffic interruptions. Its vehicle index is 57 cents. It appears from this project that when the vehicle index gets much below $1 it is probable that conditions are unsatisfactory and rebuilding with a higher type of material is necessary. The same indication is seen on project No. 5, in Bacon County, and No. 41, in Douglas County.

Observing the special counts for February, 1927, it appears that most of the roads have grown steadily in vehicular service. Three projects apparently have lost traffic density and five seem to have remained stationary. Project No. 19, in Bleckley County, is one of the latter, and has the lowest count of 94 vehicles per day. It is low in maintenance cost and in annual distributed cost per mile but very high in vehicle index. Project No. 76, in Wheeler County, has shown a slight growth in traffic. It was built when prices were very high, has a high annual distributed cost per mile, and with the exception of No. 77, in Charlton County, has the highest vehicle index recorded.

Taking the foregoing discussion into consideration, it is submitted that Table 5 is sufficiently representative in time, traffic records, and costs to establish a reasonable standard of expectancy for selected road soil surfaces, to wit: A 6 to 8 year life at 75 per cent quality of service for a traffic of 400 to 600 daily vehicles, with an annual distributed cost per mile not exceeding $500 and an operative vehicle index close to $1 per vehicle under the said traffic.

The accumulated data seem to give a useful basis of judgment to guide replacement programs. Roads with traffic counts below 400 and with no evidence of marked increase of traffic density may be wisely rebuilt with road-soil material. As the traffic conditions approach or exceed 600 vehicles and where conditions indicate rapid traffic growth, the use of a more durable type of surfacing should be considered.

MORE IMPORTANT CONCLUSIONS AND SUGGESTIONS SUMMARIZED

The life history of road-soil surfaces reflects the combined results of original surface composition, depth, cross section, and width used, methods of mixing and consolidation, and continuous attention and upkeep by road machines. If the road soils selected lie within certain recognized limits of composition and are subjected to a traffic of moderate intensity (400 to 600 vehicles per day), the average quality and length of service are highly satisfactory, the maintenance operations are quickly and easily performed, and the cost of both construction and maintenance is gratifyingly low.

These types have a large and permanent place in highway betterment in three directions:

(1) As the first stage of surfacing for newly graded main roads.

(2) As the chief dependence for surfacing secondary roads.

(3) As a valuable subgrade under higher types of surface.

COMPOSITION AND CLASSIFICATION OF ROAD SOILS

1. The mechanical analysis as at present used seems a satisfactory laboratory method in the premises and the definitions of coarse material, sand, silt, and clay are in the main acceptable.

2. Knowledge of the differences in adhesive values of clays is insufficient. The way has been opened to supply this deficiency in accord with tests suggested by Dr. Charles Terzaghi for the identification of clays.[1]

3. Until a more accurate knowledge of the clay ingredient is available, the present limits of composition for classes A, B, and C soil mortars may be allowed to stand.

4. In judging these materials, full emphasis should be placed upon the soil mortar—i. e., material below the No. 10 sieve. Weak soil mortars even with large amounts of "coarse material" often do not give proper stability under traffic. In general, class C mortars are not to be recommended except for very light traffic or when the surface is to be covered with a 2-inch layer of gravel, semigravel, or coarse screenings.

[1] Principles of Soil Mechanics, by Dr. Charles Terzaghi, Engineering News-Record, Nov. 5, 1925, et seq. (8 articles), vol. 95.

5. "Coarse material" above 10 per cent in amount distinctly increases the stability and durability of the surface, less with class C, and progressively more with class B and class A mortars.

6. "Coarse material" is most effective when present in graded sizes from 1 inch downward. Such material of micaceous, feldspathic, or slaty types is most commonly soft and soon becomes valueless.

7. Organic matter gives much initial adhesive strength, but is soon oxidized or blown away.

8. Of the total sand in a road soil mortar, that portion which lies above the No. 60 sieve is a most important factor in hardness, supporting value, and durability of the surface, especially under wet conditions. A soil mortar of this type will not give satisfactory service unless it contains a liberal percentage of sand coarser than the No. 60 sieve, except in the case of cherts.

MIXING, DEPOSITING, AND CONSOLIDATION

The natural deposits of these materials, whether surface or underground, are rarely of uniform composition. It is most important to secure fair uniformity before the road surface is consolidated.

1. Topsoil deposits are usually thin surface layers, 4 to 10 inches thick, and of limited area. They are loosened by plowing in one or more layers. Preferably, the loosened material should be intimately mixed by harrowing before loading and depositing. Care in plowing only to the limit of good material is an obvious precaution.

2. Subsurface deposits excavated from pits should be well mixed by repeated harrowings after deposit on the road bed.

3. Intimate mixing is the most profitable and at the same time the most frequently violated principle of construction with these types.

4. The loose material of these surfaces should be spread in one layer to the full depth of the surface. A 12-inch loose depth with an expected consolidated depth of 8 inches or more is advised.

5. Consolidation of the loose material from the bottom upward is most effective. At present, this is largely done by the wheels of construction teams and current traffic. Freshly placed surfacing which is reduced to a soft mud state by rain and is thoroughly puddled shows markedly greater strength than those which are packed with less moisture.

6. The packing process is accompanied by repeated shaping of the surface with road machines until the finished cross section is finally set up.

7. Lumpy consolidation in the early stages should be broken up by scarifying or plowing before final packing is permitted.

8. Current vehicle traffic need not be detoured. Its presence is an aid to consolidation but its passage over the loose surface should be guided and distributed.

9. Clay subgrades should preferably be rolled and crowned before the surfacing is deposited.

DEPTH AND WIDTH OF SURFACE

1. The surface material should extend from ditch to ditch. For a 30-foot road (includes ditches 2 feet wide) the main surface should be 18 feet wide with an average depth of 8 inches and with a 6-inch depth covering the two 4-foot shoulders.

2. The crown should be approximately one-quarter inch per foot. Heavier crowns frequently show ribs

made by water flowing to the side ditches. The light crown is more easily smoothed and maintained by road machines and drags.

STABILITY FACTORS DISCUSSED

Reliance for results is placed upon the properties and behavior of the several classes of ingredients (clay, silt, sand, coarse material), acting by virtue of mass and internal bond developed from interlocking grains and from the action of capillary moisture forces.

The functions of the several ingredients in relation to binding strength and resistance to traffic and weather are conceived as follows:

1. All the ingredients present contribute to a certain total of seating and embedment stability, and furnish mass and weight resistance to traffic impacts and pressures.

2. The very fine ingredients, notably the clay (when in other than the liquid state), supply an additional adhesive and cohesive bond which varies with the percentage of water and the capillary structure of the mass.

3. The coarser sizes of sand and the "coarse material" furnish the main hardness and supporting strength, especially in wet weather. They also give the chief seating bond which the finer sand and silt and clay supplement by an embedment bond.

4. In a rough sense, the integrity of the surface, during dry weather and with low moisture conditions, is largely maintained by the adhesive influence of the clay in preventing surface and internal displacement of the granular materials.

5. This adhesive and cohesive action of the clay continues through a wide range of internal moisture content, diminishing with the increase of the moisture. It becomes negligible if the surface is very wet, or, more accurately, when the clay reaches its lower liquid limit. Possibly, the silt plays a similar but less important part. As the cohesion, due to increasing moisture content in the road slab, approaches zero, the stability of the surface depends more and more on the mechanical bond of the sand, and especially of the coarser sizes.

6. The desirable composition of a suitably effective road soil may be stated as follows:

(*a*) Enough clay present to cement the sand and silt in dry or low moisture condition; but not so much clay that its expansion by water will dislocate the seating and embedment bond of the granular particles, viz, the surface should maintain a constant volume.

(*b*) A liberal amount of coarse sand grains to furnish an adequate seating or bearing bond, not materially affected by water content.

(*c*) Only moderate amounts of silt and very fine sand. A superabundance of silt, very fine sand, and especially of clay tend to reduce percolation after rains and to hold larger amounts of water in the surface whereby the lower liquid limits of the fine ingredients are more rapidly approached, and the stability of the surface more rapidly weakened.

7. When "coarse material" is present or is added to a good soil mortar in appreciable amount (10 per cent or more), the hardness and durability of the surface is increased, and continues to increase until the full gravel type of surface is reached.

8. Maintenance of a smooth surface and crown for prompt removal of surface water is obviously desirable. But regardless of this, rain water disappears with considerable rapidity from holes or depressions showing active percolation through the surface and rapid evaporation. The porosity of these surfaces when most densely packed is not less than 20 per cent. Thus permeability must be considered in relation to rate of gravity drainage and the attendant capillary retention in the clay and silt. Class A samples taken after long periods of rain always show high strength and no serious internal softening. The condition shown in wet weather is commonly a thin coat of sandy mud, nonslippery, one-quarter to one-half inch deep on a firm supporting surface.

9. The conclusion to be reached and its explanation are as follows:

For class A soils: When rain begins, the clay in the surface layers expands and tends to close the surface pores and make the surface less pervious. If a smooth crown exists water is largely discharged into the side ditches. The expansion of the clay into the sensible pores prevents dislocation of the coarser sand grains. Entrained air aids in moisture exclusion. Abrasion by the traffic creates a thin layer of nonslippery mud which rebinds to the surface on drying out. Water collects in depressions, and either percolates through the surface or evaporates from the surface. Some weakening occurs, but owing to the sensible size of the pores and small amount of clay it is not serious.

For soils high in clay: In wet weather the expansion of the clay loosens the mechanical bond of the sand grains. Absorbed water is retained by the clay in large amount. Layer by layer, the fine materials approach their lower liquid limit, and the wheels of traffic rapidly cut the surface into deep mud. This explains why it is desirable for surface material to extend from ditch to ditch, and why clay subgrades should be rolled and crowned. Both requirements provide better opportunity for prompt removal of percolating water to the side ditches.

10. It is found that when 15 per cent or more "coarse material" is present the allowable amount of clay in the mortar may be somewhat increased, limited by a maximum clay content of 25 per cent of the unseparated soil sample which includes the coarse material.

LOSS OF SURFACE MATERIAL UNDER TRAFFIC

Loss of material from soil surfaces is affected by several variable factors. The most important are machining, dragging, and scarifying the surface, when concurrent with high winds or washing rains.

1. The loss of surface depth is progressive but not at a uniform annual rate.

2. The loss is not consistently related to the volume of traffic.

3. Surfaces with 15 per cent or more of "coarse material" resist depth losses much better than surfaces with little or no "coarse material."

4. The observed data indicates that in general the annual loss of thickness will be between one-half inch and 1 inch under a traffic of 400 to 600 vehicles per day.

5. When surfaces are reduced to a depth of 2 inches or less, their behavior is directly influenced by the nature of the subsoil. Apparently, thin surfaces on subsoils high in clay content will cut through more easily in wet weather than those on sandy loam subsoils; but not much difference is noted between thin surfaces on clay and those on very fine sand subsoil. The integrity of the surface is rapidly destroyed in both cases with the production of mud on clay subsoil

during rains, and loose sand pockets and wheel ruts in dry weather on the fine sandy subsoil.

6. In general, when surfaces are worn to less than 3 inches it is wise to scarify and rebuild them to an 8-inch compacted depth.

LIMITS OF ACCEPTABILITY

1. This type of road surface is best adapted to light or moderate traffic densities which this research data places at 400 to 600 vehicles per day according to composition of the surface and to the provision for constant patrol maintenance. Adequate equipment for an intelligent execution of maintenance work has much to do with both the quality of service rendered and the efficient life of such roads.

2. The expectancy shown by Table 5 and other research results is an effective life of 6 to 8 years under 400 to 600 vehicles daily, with a quality of service of 75 per cent, an annual distributed cost per mile of $500, and an operating index of $1 per daily vehicle per mile per year.

ROAD SOIL SURFACES AS SUBGRADES FOR PAVED ROADS

As subgrades under pavements these surfaces have the following merits:

1. A well-established initial supporting value which is quite uniform.

2. A structure which is not easily softened by water or conducive to capillary rise of moisture from the subsoil below.

3. Not liable to damage from expansion under frost under the climatic conditions found in Georgia. Cases have been observed in winter where a firm, dry road soil surface was flanked by clay shoulders on which hoar frost stood several inches in height.

ECONOMIC ASPECTS

1. Road soils such as semigravel, top soil, natural sand-clay, artificial sand-clay mixtures, iron-silica pebble deposits and cherts are available over large areas of the State. Their normal cost at present contract prices may be estimated within limits of $1,800 to $2,500 per mile for a 26-foot surface, averaging 7½ inches compacted depth and requiring 3,400 cubic yards of loose material per mile.

2. The normal life expectancy of such surfaces with a traffic of 400 to 600 vehicles per day may be taken at 6 to 8 years before replacement.

3. The normal provision for maintenance should be at least $200 per mile per year.

4. The annual interest charges at 5 per cent will be $90 to $125 per mile for the initial cost limits suggested to be amortized as depreciation occurs.

5. A satisfactory annual distributed cost per mile range is from $450 to $650 per mile per year with a corresponding operating index close to $1 per year when a traffic density of 400 to 600 vehicles per day is reached. This gives a highly satisfactory service quality expressed as 75 to 80 per cent.

6. Traffic above 800 vehicles per day increases the maintenance cost and lowers the life expectancy to a marked extent except with semigravel surfaces containing more than25 per cent of "coarse material."

7. The data secured by the 5-year study of road soil surfaces is deemed sufficient to establish the economic basis suggested for these types.

ATTAINMENT OF BETTER RESULTS

Despite the many variables involved, knowledge and methods now available enable the engineer to secure very substantial road service from these road soil surfaces at a remarkably low cost. There is, however, the possibility of further improvement. Better results in service and durability can be reached mainly along the following lines:

1. Greater care in construction with regard to the details which affect uniformity of composition and intimate mixing before consolidation.

2. Improved types of machines for quickly and more uniformly packing the loose material from the bottom upward.

3. The abundant use of water during the consolidation stage, either by taking advantage of rains and scarifying or puddling the surface before its final consolidation is permitted, or by the most liberal use of sprinkling carts which circumstance and finances permit.

4. A more intelligent appreciation and specific knowledge on the part of both engineers and contractors of the possibilities attainable.

SUGGESTIONS FOR FURTHER RESEARCH

A prerequisite for substantial improvement in results with road soils is a more definite knowledge of the quality of the clay ingredients. As a result of the Terzaghi experiments the way has been opened to attain such knowledge. It will require patience, special apparatus, and specially trained men, but the effort will be fully repaid in applying such knowledge on the immense mileage of the low-traffic public roads yet to be improved.

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924.
Report of the Chief of the Bureau of Public Roads, 1925.
Report of the Chief of the Bureau of Public Roads, 1927.
Report of the Chief of the Bureau of Public Roads, 1928.

DEPARTMENT BULLETINS

No. *136D. Highway Bonds. 20c.
220D. Road Models.
257D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*314D. Methods for the Examination of Bituminous Road Materials. 10c.
*347D. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*370D. The Results of Physical Tests of Road-Building Rock. 15c.
386D. Public Road Mileage and Revenues in the Middle Atlantic States, 1914.
387D. Public Road Mileage and Revenues in the Southern States, 1914.
388D. Public Road Mileage and Revenues in the New England States, 1914.
390D. Public Road Mileage and Revenues in the United States, 1914. A Summary.
407D. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
463D. Earth, Sand-Clay, and Gravel Roads.
*532D. The Expansion and Contraction of Concrete and Concrete Roads. 10c.
*537D. The Results of Physical Tests of Road-Building Rock in 1916, Including all Compression Tests. 5c.
*583D. Reports on Experimental Convict Road Camp, Fulton County, Ga. 25c.
*660D. Highway Cost Keeping. 10c.
*670D. The Results of Physical Tests of Road-Building Rock in 1916 and 1917.
*691D. Typical Specifications for Bituminous Road Materials. 10c.
*724D. Drainage Methods and Foundations for County Roads. 20c.
1216D. Tentative Standard Methods of Sampling and Testing Highway Materials, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.
1259D. Standard Specifications for Steel Highway Bridges, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road work.

DEPARTMENT BULLETINS—Continued

No. 1279D. Rural Highway Mileage, Income, and Expenditures, 1921 and 1922.
1486D. Highway Bridge Location.

DEPARTMENT CIRCULARS

No. 94C. T. N. T. as a Blasting Explosive.
331C. Standard Specifications for Corrugated Metal Pipe Culverts.

TECHNICAL BULLETIN

No. 55. Highway Bridge Surveys.

MISCELLANEOUS CIRCULARS

No. 62M. Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects.
93M. Direct Production Costs of Broken Stone.
*109M. Federal Legislation and Regulations Relating to the Improvement of Federal-Aid Roads and National-Forest Roads and Trails. 10c.

SEPARATE REPRINTS FROM THE YEARBOOK

No. 914Y. Highways and Highway Transportation.
937Y. Miscellaneous Agricultural Statistics.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Connecticut.
Report of a Survey of Transportation on the State Highway System of Ohio.
Report of a Survey of Transportation on the State Highways of Vermont.
Report of a Survey of Transportation on the State Highways of New Hampshire.
Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio.
Report of a Survey of Transportation on the State Highways of Pennsylvania.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D- 2. Effect of Controllable Variables upon the Penetration Test for Asphalts and Asphalt Cements.
Vol. 5, No. 19, D- 3. Relation Between Properties of Hardness and Toughness of Road-Building Rock.
Vol. 5, No. 24, D- 6. A New Penetration Needle for Use in Testing Bituminous Materials.
Vol. 6, No. 6, D- 8. Tests of Three Large-Sized Reinforced-Concrete Slabs Under Concentrated Loading.
Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

* Department supply exhausted and can be secured only by purchase from the Superintendent of Documents.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

CURRENT STATUS OF FEDERAL AID ROAD CONSTRUCTION

AS OF

AUGUST 31, 1929

STATE	COMPLETED MILEAGE	UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FEDERAL-AID FUNDS AVAILABLE FOR NEW PROJECTS	STATE
		Estimated total cost	Federal aid allotted	MILEAGE			Estimated total cost	Federal aid allotted	MILEAGE				
				Initial	Stage[1]	Total			Initial	Stage[1]	Total		
Alabama	2,025.9	$ 3,027,294.13	$ 1,508,352.40	158.8	21.3	180.1	$ 522,062.11	$ 259,256.86	6.4	14.0	20.4	$ 1,969,823.58	Alabama
Arizona	654.9	2,618,092.77	2,178,504.27	100.5	63.1	163.6	495,398.84	372,985.31	15.3	37.9	53.2	2,133,114.66	Arizona
Arkansas	1,755.6	3,692,261.60	1,829,390.59	119.3	5.1	124.4	1,030,559.10	449,807.49	42.5	27.0	69.5	1,870,198.71	Arkansas
California	1,671.0	9,212,403.01	4,161,872.78	235.0	20.2	255.2	1,940,208.78	979,943.96	62.6		62.6	32,863.82	California
Colorado	1,136.7	3,967,705.26	2,130,214.11	139.0	35.6	174.6	325,736.93	182,933.83	10.5	6.6	17.1	1,649,473.51	Colorado
Connecticut	229.3	792,275.72	217,937.99	12.5		12.5	1,448,304.88	597,151.39	8.1		8.1	541,679.71	Connecticut
Delaware	212.9	1,282,731.90	563,525.96	46.2		46.2	66,905.00	28,121.00	6.8		6.8	22,619.12	Delaware
Florida	449.0	2,734,529.08	1,135,234.01	90.9	5.7	96.6	1,008,856.54	504,428.26	18.5		18.5	1,461,438.36	Florida
Georgia	2,569.0	3,517,718.38	1,556,798.10	159.2	29.3	188.5	70,659.77	34,958.17	6.2		6.2	2,023,798.56	Georgia
Idaho	1,154.6	1,096,080.01	657,019.90	83.8		83.8	271,000.00	163,000.00	9.3	24.2	33.5	661,442.22	Idaho
Illinois	1,918.0	18,338,480.92	8,284,697.86	545.8		545.8	648,000.00	324,000.00	22.5		22.5	2,606,225.00	Illinois
Indiana	1,294.1	8,984,554.11	4,231,647.36	274.1		274.1	318,800.00	146,900.00	9.1		9.1	167,425.69	Indiana
Iowa	2,974.4	5,290,953.08	2,299,485.57	68.9	122.0	190.9	504,545.69	196,028.95	.4	17.2	17.6	62,869.26	Iowa
Kansas	2,607.8	4,047,954.25	1,750,143.47	249.8	10.2	260.0	2,127,011.65	1,017,953.00	141.0	16.5	157.5	344,998.66	Kansas
Kentucky	1,312.9	5,257,094.91	2,519,289.64	283.3	5.1	288.4	629,329.99	311,541.03	52.6	30.4	83.0	356,777.47	Kentucky
Louisiana	1,321.4	3,623,495.55	1,803,989.15	151.8		151.8	222,531.67	84,738.17	12.2		12.2	1,171,119.61	Louisiana
Maine	495.7	2,531,479.51	921,071.91	63.2		63.2	302,384.56	136,942.41	11.9		11.9	1,048,640.31	Maine
Maryland	610.2	1,162,795.35	537,152.88	40.0	17.7	57.7	369,231.77	156,650.00	14.7		14.7	38,992.49	Maryland
Massachusetts	580.8	4,781,761.53	1,408,057.81	79.5	3.4	82.9	540,948.81	234,417.27	5.0		5.0	1,563,285.72	Massachusetts
Michigan	1,486.1	11,199,714.05	4,784,803.20	268.5	9.4	277.9	1,548,000.00	656,378.38	48.3	3.9	52.2	899,534.46	Michigan
Minnesota	3,854.0	6,375,744.24	2,098,916.23	299.2	112.0	411.2	573,504.87	79,000.00	27.4	9.0	36.4	320,000.00	Minnesota
Mississippi	1,710.1	3,892,670.93	1,709,018.52	156.3	17.4	173.7	79,957.35	30,000.00	.1		.1	1,309,292.99	Mississippi
Missouri	2,246.1	10,988,651.82	4,190,204.78	193.2	126.5	319.7	674,314.32	239,472.98	1.7	20.4	22.1	161,038.99	Missouri
Montana	1,557.7	5,847,335.38	3,620,886.70	408.6	7.6	416.2	2,341,528.73	1,299,016.67	210.3	11.5	221.8	2,724,032.48	Montana
Nebraska	3,559.4	4,380,894.47	2,127,862.38	286.0	135.3	420.3	3,216,176.94	1,499,919.68	97.4	114.1	211.5	1,060,264.65	Nebraska
Nevada	1,093.0	1,041,765.88	915,444.30	94.2	121.3	215.5	307,907.68	273,575.89	32.9	33.4	66.3	62,426.01	Nevada
New Hampshire	337.4	609,627.20	266,668.29	16.9	1.1	18.0						147,571.80	New Hampshire
New Jersey	465.2	5,319,502.78	1,005,490.00	67.0		67.0	348,376.53	84,225.00	5.6		5.6	441,540.08	New Jersey
New Mexico	1,890.0	2,506,955.85	1,586,811.66	140.8		140.8	660,866.17	421,302.16	36.7		36.7	699,123.79	New Mexico
New York	2,250.3	26,505,817.76	5,710,405.55	382.0		382.0	5,631,100.00	1,105,650.00	73.8		73.8	3,679,100.66	New York
North Carolina	1,734.0	1,249,817.70	624,908.83	71.1	7.2	78.3	524,276.67	257,215.84	25.3	13.0	38.3	1,519,154.27	North Carolina
North Dakota	3,835.5	2,723,444.02	1,067,752.76	439.0	122.6	561.6	991,820.35	417,842.18	114.5	173.7	288.2	701,307.89	North Dakota
Ohio	2,060.6	11,937,102.10	4,050,162.88	236.0	9.4	245.4	6,546,912.19	1,732,149.71	87.5	24.5	112.0	1,451,925.84	Ohio
Oklahoma	1,806.6	3,088,623.67	1,388,235.17	107.9	25.1	133.0	1,393,217.08	638,203.40	41.4	33.7	75.1	200,413.84	Oklahoma
Oregon	1,113.0	1,959,933.75	1,112,323.95	116.0	35.8	151.8	923,222.06	574,521.04	40.3	21.4	61.7	881,316.91	Oregon
Pennsylvania	2,094.2	15,390,627.68	4,034,023.96	245.8	14.1	259.9	4,617,116.97	1,244,294.71	78.2		78.2	902,474.68	Pennsylvania
Rhode Island	172.1	1,161,982.40	300,641.55	17.1		17.1	70,170.40	22,755.00	1.5		1.5	556,598.48	Rhode Island
South Carolina	1,854.8	3,617,865.95	818,392.22	121.0	37.3	158.3	19,353.44	4,000.00				787,144.96	South Carolina
South Dakota	3,329.2	3,972,635.27	2,143,361.51	486.6	59.5	546.1	304,774.29	157,585.31	36.5	14.9	51.4	318,103.51	South Dakota
Tennessee	1,174.0	3,567,176.89	1,642,033.58	114.7		114.7	609,436.85	304,218.33	22.4		22.4	724,521.35	Tennessee
Texas	6,141.1	19,654,818.47	8,310,432.05	664.2	301.8	966.0	2,557,572.97	1,092,280.83	51.0	71.1	122.1	139,274.84	Texas
Utah	921.2	1,927,305.85	1,313,396.69	82.9		82.9	332,936.11	188,632.72	8.0	.3	8.3	185,248.13	Utah
Vermont	240.9	1,324,835.05	494,989.54	26.3		26.3						62,872.48	Vermont
Virginia	1,362.3	2,332,293.22	1,025,772.33	98.2	14.6	112.8	574,453.96	265,662.33	22.0		22.0	510,429.16	Virginia
Washington	865.2	4,333,558.37	1,595,400.00	93.5	18.1	111.6	1,300,102.18	383,000.00	15.6	22.2	37.8	507,657.65	Washington
West Virginia	670.1	3,787,063.98	1,571,948.45	90.8	27.6	118.4	321,462.29	100,058.71	1.6	7.1	8.7	82,709.19	West Virginia
Wisconsin	2,099.4	8,985,093.12	4,079,181.94	303.7	24.5	328.2	696,160.67	223,974.41	10.7	4.5	15.2	7,972.18	Wisconsin
Wyoming	1,670.4	3,447,205.88	1,192,239.69	189.7	30.5	220.2	174,491.39	114,553.57	7.8	24.4	32.2	34,077.51	Wyoming
Hawaii	39.5	402,261.10	137,426.82	6.6		6.6	562,688.38	247,259.61	16.6		16.6	1,072,664.16	Hawaii
TOTALS	78,797.6	259,691,965.90	104,613,910.33	8,724.4	1,597.3	10,321.7	50,731,365.23	19,839,505.36	1,570.7	776.9	2,347.6	41,566,632.59	TOTALS

[1] The term stage construction refers to additional work done on projects previously improved with Federal aid. In general, such additional work consists of the construction of a surface of higher type than was provided in the initial improvement.

U. S. GOVERNMENT PRINTING OFFICE: 1929