REPORT OF INVESTIGATION OF LOW COST IMPROVED ROADS

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INTRODUCTION

This investigation was conducted more in the nature of a survey of the low cost road situation than as a detailed and scrutinizing research This procedure appeared advisable because of the immediate need of a large mileage of low cost roads. The subject must receive study and attention if highway service is to keep pace with motor vehicle registration and the increasing radius of travel by motorists, for it has been truly said, "We pay for roads whether we have them or not." The loss sustained by not having roads has not been calculated nor can all the benefits of adequate road service be stated in dollars and cents The public at large is interested only in improved road service, while the road builder is concerned with furnishing this service at as low a cost as possible

The selection of type for these roads may be affected by character and intensity of traffic, interest on investment, cost of replacement, maintenance cost and that somewhat intangible item, cost of vehicle operation. Calculations based on all of these items have indicated to some that genuine maximum economy lies in the selection of a high type surfacing

However, in many of the Western, Middle Western and Southern states, advantage cannot be taken of the absolute and theoretical economics of the situation if transitory or even temporary service is to be given These sections of the country represent a tremendous area, they contain a small population per unit of area and they need at once a large mileage of serviceable roads. Some of these states have no treated surfaces and less than 10 miles of pavement, whereas some of the North Eastern states have no untreated surfaces and several thousand miles of pavement in their state highway systems.

Within a few years many highway departments have constructed and are maintaining thousands of miles of low cost roads, which furnish continuous service between objectives Over them the public is traveling in safety and comfort, and at high rates of speed. This has been made possible by the extensive use of local materials, intelligent maintenance, and surface treatments

The successful low cost surface is on a light traffic road, carrying not more than 1500 vehicles per day with an average of 600 or less This may be mixed traffic with a fair percentage of light trucks and an occasional heavy truck Low cost roads of this type will adequately meet the needs of a large area of the country for many years to come, provided intelligent maintenance methods are perpetuated

In order to determine which types of surfacing and what points of interest on them would be useful to road builders, a canvass was made which showed the points of interest to be

1 First Cost
2 Maintenance Cost
3 Traffic and Service

Other points included conditions of climate, salvage, soil and subgrade, construction and maintenance methods, typical cross section and topography.

Preference for types to be investigated was affected somewhat by the local conditions surrounding the highway officials questioned, but the majority favored the following order of importance.

1 Bituminous surface treatments of gravel, stone, slag and miscellaneous materials
2. Bituminous macadam and various types of bituminous concrete
3 Untreated surfaces of traffic bound stone or gravel, water-bound macadam, earth and sand clay.
4 Nonbituminous surface treatments of gravel, earth and sand clay

It was felt that all of these types and the factors affecting them should be considered in a survey of this character, but it was early recognized during the investigation that nearly every type and each of the factors affecting the respective types could well be made the subject of a separate investigation This survey has therefore been confined to those types which are considered as serviceable investments by those responsible for their existence Although the data are not always complete it is the purpose to retell the facts, as obtained, through field observations, conferences, and published information

The report is condensed to as brief a form as is consistent with clarity and consists of:

Introduction. Outline of the object, procedure and scope of the investigation.

Chapter 1 Summary statement of conclusions.
Chapter 2 Practical application of findings.
Chapter 3. Digest of findings.
Chapter 4. Presentation of findings.
Chapter 5. Supplementary discussions.

A summarized outline was presented on November 1, 1927, to the Executive Committee of the Highway Research Board through the Director, Charles Upham. This was read at the seventh annual meeting held on December 2, 1927.

The final report was presented to Director R. W. Crum on April 15, 1928. It was then reviewed by Professor Thomas R. Agg, member executive committee, Highway Research Board, and was approved for publication by the executive committee of the Highway Research Board on October 15, 1928.

Valuable assistance and cooperation were offered and given by the Bureau of Public Roads, Weather Bureau, Forest Service, Patent Office, practically all State Highway Departments and several counties.

Comment and suggestions were requested and received from representatives of the following industries: Asphalt, Tar, Calcium Chloride, Lime rock, Asphalt, Crushed Stone, Sand and Gravel, Machinery and Equipment.

In fact the possibilities for usefulness of the entire report were greatly increased by the assistance and information furnished without charge by all of these organizations.

The National Research Council through the Highway Research Board has aided with clerical assistance. Mr. E. J. Preisler, a highway engineer from North Carolina, has assisted in the preparation of exhibits and filing of data

The investigations and report were originally made financially possible by contributions from General T. Coleman Dupont and the American Road Builders' Association. Additional financial support was given by: Various members of the Asphalt Association, the American Tar Products Company, the Highway Research Board, the Barrett Company, the Texas Company, the National Crushed Stone Association, and the Calcium Chloride Co-operative Publicity Committee.

OBJECT OF THE SURVEY

The object of this survey was to collect and correlate available information on the various types of low cost improved roads.

Analysis of each type and comparisons between types have been made wherever sufficient information could be secured. In some instances this was not possible, since:

1 Maintenance costs and traffic counts were not available.
2. Few low cost test roads have been built. Conclusions on these apply to local conditions.
3. Authentic records of salvage values have not been kept.
4. Detailed condition surveys on satisfactory and unsatisfactory types would have required a considerable force of investigators over a period of several years

The investigation is confined principally to roadway surfaces which are rendering a reasonable service under the field conditions which govern their construction and operation

PURPOSE OF THE SURVEY

The purpose of this report is to assist those interested in low cost roads to improve and increase mileage of this type by furnishing information on:

1. The use of local materials and foreign admixtures.
2. Methods of construction and maintenance.
3. Details which affect cost, traffic, capacity, selection of type, and service.

PROCEDURE

Necessarily some data obtained were not sufficiently complete for inclusion yet the procedure of obtaining whatever information was available was followed throughout and consisted of:

1. Study of typical cross section, specifications, patents, official reports of state and county highway commissions, construction and maintenance cost information, articles by highway engineers in the technical press and proceedings of various associations.
2. Conferences with highway engineers and officials in both the technical and industrial field.
3. Field surveys of low cost roads under service and construction conditions.

4. Inspection of machinery, equipment and materials
5. Correlation of the results of this survey with those of previous and current investigations

SCOPE AND LIMITS

The survey consisted of:

1 Study of typical cross sections from 28 states, Canada and Mexico, Bureau of Public Roads and Forest Service
2 Study of 43 sets of specifications
3. Study of 64 sets of patents
4. Study of 40 annual or biennial reports of state and county highway commissions
5. Study of construction and maintenance cost information from 39 different states.
6 Study of leading technical articles, highway text books, and proceedings published during the past 5 years
7. Conferences with highway engineers of 25 state departments and 20 industrial organizations.
8 Field inspections in 24 states and Mexico of construction, maintenance and equipment.

The survey was limited in general to untreated surfaces which cost less than $10,000.00 per mile, and to surface treatments and surface courses which cost less than $6,000.00 per mile

It was advisable to investigate other types whose cost exceeded these amounts This was done on some which had been successful under particular local conditions, on others to show their relative position in cost and service compared with lower cost types

PRESENTATION OF DATA

The data consist of information on:

1 Materials of construction and maintenance
2 Methods of construction
3 Methods of maintenance.
4. Costs of construction and maintenance.
5 Selection of type.
6 Selection of typical cross section
7 Effect of climate and soil upon type.

8. Service, traffic and costs.
9. Equipment for construction and maintenance.

The types included are:

UNTREATED SURFACES

1 Sand-clay surfaces.
2. Chert, shale and disintegrated granite surfaces.
3. Gravel surfacing.
4 Traffic bound surfaces of gravel, slag and stone.
5. Macadam.
6 Lime rock, marl, caliche, base and surface
7 Miscellaneous untreated surfaces.

SURFACE TREATMENTS AND SURFACE COURSES

8 Nonbituminous dust preventives.
9 Single bituminous surface treatments.
10. Dual bituminous surface treatments.
11. Mixed-in-place bituminous surface, fine aggregate type.
12 Mixed-in-place bituminous surface, coarse aggregate Type I
13 Mixed-in-place bituminous surface, coarse aggregate Type II
14 Pre-mixed bituminous surface, laid cold
15 Natural rock asphalt surfaces.
16. Modified or "puddle" bituminous macadam.
17 Bituminous macadam, hot penetration method
18 Pre-mixed bituminous surfaces, laid hot
19. Miscellaneous surfaces, principally lime treatments of clay.

The practical application of findings is based on the foregoing information.

The findings of the investigation are summarized under three principal headings

1 Conclusions
2 Strong indications
3 Further suggested research.

CHAPTER 1

SUMMARY OF CONCLUSIONS, STRONG INDICATIONS AND SUGGESTED FUTURE RESEARCH

CONCLUSIONS

1 There is an immediate need for a large mileage of low cost improved roads having a traffic capacity of 300 to 1500 vehicles per day exclusive of heavy trucks.

2. Progressive or stage construction in which the road is improved with successively higher type surfaces, as required by increasing traffic, is an economic and safe method of improving highways. It avoids building in excess of traffic requirements. Progressive type surfaces can be built which are adequate for existing traffic and which can be improved from time to time so as satisfactorily to serve increased volumes of traffic without the destruction or waste of the original investment.

3. The utilization of local, short-haul, materials as surfacing or aggregate is the principal factor in keeping the cost of construction and maintenance at a minimum.

4. Materials which are adaptable and suitable for untreated surfaces and which can be improved later by the addition of other types of surfacing include stone, slag, gravel, lime rock, marl, caliche, chert, shale, disintegrated granite, sand clay and volcanic cinders.

5 Non-slaking binders for untreated surfaces, such as disintegrated limestone and stone screenings, are more satisfactory than clay and loam.

6. For bituminous surface treatments by the surface application and mixed-in-place methods, crushed aggregates which are hard and durable are preferred; they include crushed stone, crushed slag and crushed gravel Clean gravel and clean coarse sand are satisfactory and their cost is usually lower than that of the crushed aggregates.

7. Bitumens are the most adaptable and the most widely and satisfactorily used binders for the improvement of existing roadway surfaces which are composed of the materials listed under the fourth conclusion.

8. Calcium chloride in certain instances reduces dust and loss of surfacing materials at a cost commensurate with the results obtained

9. Construction and maintenance methods which include blading, dragging or screeding result in smooth riding surfaces. Blading is the most important operation in securing a uniform mixture of bitumen and aggregate for mixed-in-place types Low crowns, ¼-inch to ⅜-inch per foot, are desirable and feasible.

10 Untreated surfaces capable of carrying mixed traffic of 300 to 500 automobiles and light trucks daily can commonly be built for less than $10,000 per mile, with a width of not less than 18 feet

The annual surface maintenance cost exclusive of lost material is usually less than $500 per mile. Replacement of lost surfacing may greatly increase the annual maintenance cost.

11 Bituminous surface treatments of the dual and mixed-in-place types, capable of carrying daily 600 to 1500 automobiles including light trucks, can commonly be built for less than $5000 per mile for a width of not less than 18 feet The annual surface maintenance cost including scarifying and retreatments usually averages less than $800 per mile.

12. The cost per vehicle mile for construction, maintenance and interest on investment averages less than $0.01 over a period of from 5 to 10 years when progressive construction is used.

13. Progressive construction is not satisfactory unless intelligent maintenance operations begin during the construction period and are perpetuated

14 The passage of a few heavy trucks during a period of unfavorable weather and bad soil conditions may seriously damage an untreated or treated surfacing which is not of the rigid pavement type

STRONG INDICATIONS

1. Low cost improved roads will continue to include more than half of the surfaced mileage in the United States

2 Relatively expensive high type pavements have been constructed where a surfacing costing less than half the amount would have furnished adequate service. Relatively low cost untreated surfaces have been and are being laid where probable future traffic will warrant the pavement type; but they are considered a good investment as a subgrade treatment and they are giving reasonably good service in certain instances during the time required for the stabilization of new embankments

3 Soft aggregates can be used more economically in a base course than in a surface course

4. Surfaces constructed or maintained by blading or by dragging should be composed of aggregates passing the 1 or ¾-inch screen.

5. Tar products of low viscosity are generally preferred for penetration prime coats on previously untreated surfaces, but satisfactory results are claimed in certain localities where asphalt products are used for prime coats.

6. Either asphalt products or tar products give good results as subsequent applications. They are of higher viscosity than the prime coats.

7. Preference for asphalt products is found in certain locations. Preference for tar products is found in other places. Several localities use both asphalt and tar products for surface treatments.

8. Asphaltic cement is preferred for bituminous penetration macadam.

9. Asphalt products and tar products are used for pre-mixed-bituminous surfaces which are laid at atmospheric temperatures.

10. Asphaltic cement is preferred for pre-mixed-bituminous surfaces which are laid hot.

11. Improved construction and maintenance methods are making low cost roads more popular within recent years because of the more durable and smoother riding surfaces which are obtained

12. More accurate and uniform maintenance cost data will become available from state highway departments, and future traffic conditions can be estimated These estimates will greatly assist in the selection of type.

13 Comprehensive surveys of local types under local conditions of climate, soil and traffic are justified and should be encouraged. Present examples are, the investigation of "Light Asphaltic Oil Road Surfaces" on the Pacific Coast, "Surface Treatment of Top-Soil Roads" in South Carolina, "Semi-Gravel, Top-Soil and Sand-Clay Road Materials" in Georgia; "Investigation of Sand-Gravel Surfaced Roads" in Nebraska

SUGGESTED FUTURE RESEARCH

1. The development of standard tests for determining the suitability, proportions and characteristics of aggregates and their gradation for mixed-in-place bituminous surfaces and for pre-mixed-laid-cold bituminous surfaces.

2 The development of bituminous emulsions suitable for cold surface treatments of various types.

3 A determination and classification between limits of the important characteristics of bitumens most suitable for treatments of the surface application, mixed-in-place or other types, together with simplified and reasonably uniform specifications for materials and methods of construction

4 A study of nonbituminous materials which may be now suitable for surface treatments and the development of others

5 A study of finishing methods for pre-mixed bituminous surfaces with a view of developing smoother riding surfaces

CHAPTER 2

PRACTICAL APPLICATION OF FINDINGS

Although complete detailed information may be lacking on such important subjects as drainage, subgrades, climate, maintenance and vehicle operating costs on simplified classifications of bitumens and on weights and volumes of traffic, nevertheless construction and maintenance of low cost improved roads have gone forward.

Practical applications of the furnishing of adequate service over thousands of miles of roads may be seen in the field as demonstrations, but to illustrate their feasibility four tentative charts of stage construction are presented. The materials costs and traffic limitations are assumed for no particular piece of road but are based on known conditions which exist in the field. They are selected typical examples.

Figure 1 illustrates how a graded road is surfaced with sand clay, clay gravel or similar material Under maintenance it can be made to serve daily up to 300 or 500 automobiles and light trucks. Later, by a mixed-in-place or a dual bituminous surface treatment, greater traffic volume may be carried and at the same time dust and loss of material will be eliminated. Such surfaces reduce the hauling costs of materials for subsequent pavement construction because they are more serviceable than ordinary earth subgrades. They have also proved valuable as subgrade treatments.

Figure 2 shows how a graded road is improved by a compacted gravel or macadam surface. Such surfaces are still being built but a large mileage of them now in poor condition were inherited from the early days of macadam construction.

Instead of tearing them up and wasting the materials and labor which they represent as was the practice in certain localities they are now being surfaced with bituminous materials. Modern methods of construction increase their life and traffic capacity and greatly improve their riding qualities.

Figure 3 illustrates the improvement of a gravel or macadam section of modern construction. For this the depth and condition of the untreated surface should be sufficient to warrant the addition of relatively expensive types of bituminous surfaces. The cost of such bituminous surfaces is near the upper limit for low cost improved roads.

Figure 4 illustrates the improvement of a graded road with a traffic bound surface. Such surfaces represent a minimum initial investment. The surfacing is gradually increased in thickness at periodic intervals to meet increased traffic until a well compacted surface of appreciable thickness is obtained. The next step may be a treatment with calcium chloride to reduce dust and loss of surfacing material. This step may or may not be omitted before a dual or mixed-in-place bituminous surface is added.

The method used for estimating the average annual cost of the roadway surface follows the procedure described by Agg and Carter in Bulletin 69 of the Engineering Experiment Station, Iowa State College. This method was examined by the Committee on Economic Theory of Highway Improvement, of the Highway Research Board and the 1924 report of this committee recommends it as being correct

Briefly stated as applied to these cases the average annual cost of the roadway surface is computed as follows:

$C = M + RS$, in which
C = Average annual cost of surface per mile
M = Equated annual maintenance cost
S = Salvage value, or permanent value, of the surface
R = Interest rate.

As the annual maintenance cost usually varies from year to year it is necessary to take account of the time value of money in determining the average annual cost of maintenance during the cycle from rebuilding to rebuilding. This is accomplished as follows: Compute the sum to which the maintenance cost for each year would amount if placed at compound interest until the end of the period in question. Add together all of these sums and then determine the annuity required to produce that quantity during the same period. This theoretical annual deposit is the factor M in the formula. If the annual maintenance costs are equal, the cost equate themselves and the arithmetical average cost may be used for the factor M.

In estimating the costs of the road surfaces for the following examples of stage construction, the cost of the first stage (the graded road) is not included since the comparison is to be between surface types.

STAGE CONSTRUCTION

METHOD I

Feather edge sand clay or clay gravel. Followed by a mixed-in-place, fine aggregate type, bituminous surface or by a dual bituminous surface treatment Shown in Figure 1

Stage 2, It is assumed that the use of the sand-clay surface covers three years before the bituminous surface is applied. The costs during this period are estimated as follows:

Year	Construction	Maintenance	Amount of maintenance in 3 years at 4%
1	$1500	$500	$567
2	500	500	541
3		1000	1040
	$2000		$2148

The annual deposit necessary to accumulate $2148 in three years is $688, which is the average annual maintenance cost. Since the roadway is maintained to keep it in the same condition each year, the salvage or permanent value equals the amount spent for construction or $2000.

$$Average\ Annual\ Cost = M + RS$$

Average annual maintenance	$688
Interest on 2000 @ 4%	80
	$768

If the average traffic during this period is 400 vehicles per day, the road surface in cost per vehicle mile equals

$$\$748 \div 400 \times 365 = \$.0051$$

Stage 3, It is assumed that the mixed-in-place bituminous surface will need renewal every three years. In has therefore no permanent value, but the salvage value of $2000 of the sand-clay base still remains

Year	Expenditures	Amount of expenditures at end of 3 years at 4%
1	$3000	$3375
2	1000	1082
3	500	520
		$4977

The annual deposit necessary to accumulate $4977 in three years at 4 per cent is $1594.

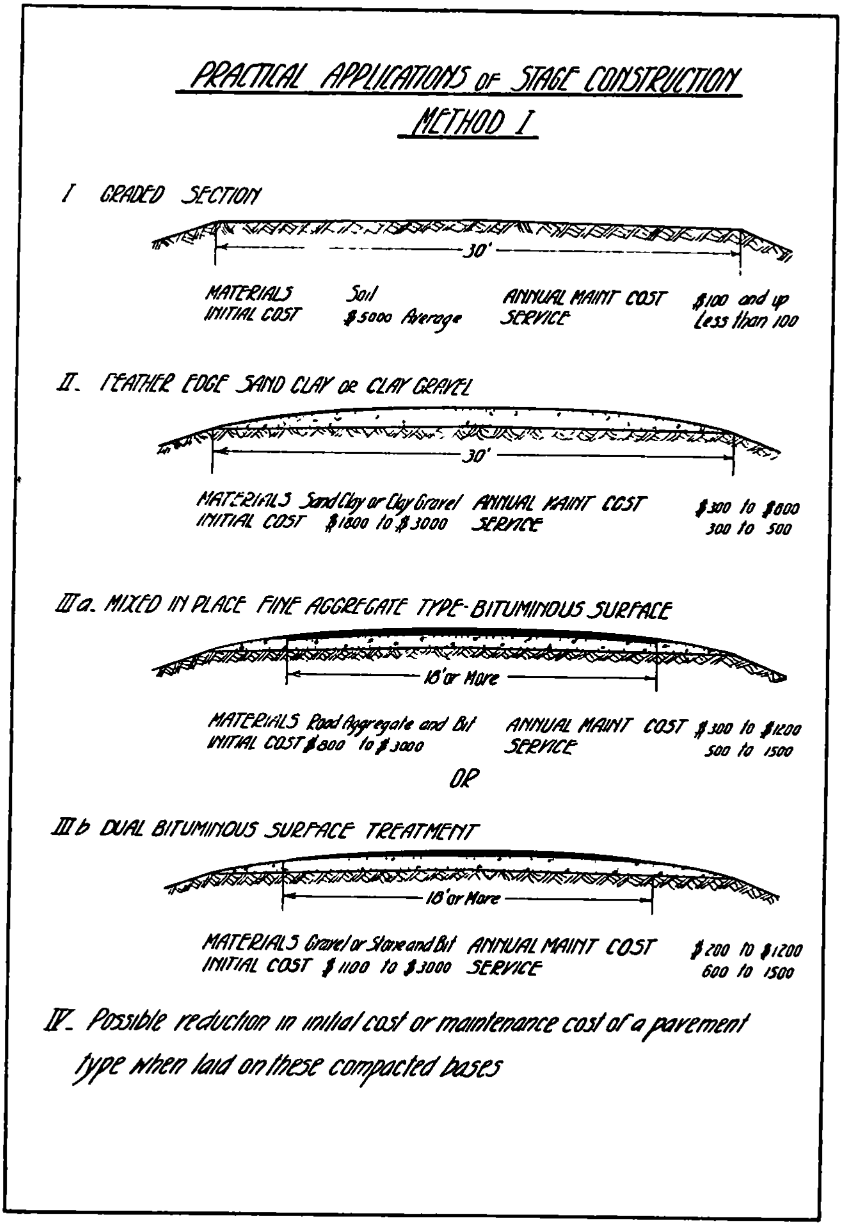

PRACTICAL APPLICATIONS OF STAGE CONSTRUCTION
METHOD I
I GRADED SECTION
30'
MATERIALS Soil
INITIAL COST $5000 Average
ANNUAL MAINT COST $100 and up
SERVICE Less than 100
II. FEATHER EDGE SAND CLAY OR CLAY GRAVEL
30'
MATERIALS Sand Clay or Clay Gravel
INITIAL COST $1800 to $3000
ANNUAL MAINT COST $300 to $800
SERVICE 300 to 500
IIIa. MIXED IN PLACE FINE AGGREGATE TYPE-BITUMINOUS SURFACE
18' or More
MATERIALS Road Aggregate and Bit
INITIAL COST $800 to $3000
ANNUAL MAINT COST $300 to $1200
SERVICE 500 to 1500
OR
IIIb DUAL BITUMINOUS SURFACE TREATMENT
18' or More
MATERIALS Gravel or Stone and Bit
INITIAL COST $1100 to $3000
ANNUAL MAINT COST $200 to $1200
SERVICE 600 to 1500
IV. Possible reduction in initial cost or maintenance cost of a pavement type when laid on these compacted bases

Figure 1

Average Annual Cost

Average annual maintenance	$1594
Interest on $2000 at 4%	80
	$1674

This would be the average annual cost so long as prices and traffic did not change.

For a daily traffic of 1000 vehicles the road surface cost per vehicle mile would be $.0046

METHOD II

Untreated surface of gravel or macadam Followed by mixed-in-place bituminous surface, coarse aggregate, Type I or II. Shown in Figure 2.

Stage 2, The average annual cost of the gravel or macadam surface would consist of the interest on the original cost (= salvage value in this case) plus the average annual maintenance, and if the yearly maintenance costs are equal plus one year's interest on the maintenance cost.

Average Annual Cost

Average annual maintenance	$800
Interest on $800 at 4%	32
Interest on $12,000 at 4%	480
	$1312

For a daily traffic of 700 vehicles the cost per vehicle mile would be $.005.

Stage 3, Assuming that the mixed-in-place bituminous surface would be renewed at five-year intervals the average annual cost would be as follows:

Year	Expenditure	Amount of expenditures in 5 years at 4%
1	$3000	$3651
2	500	585
3	500	563
4	500	541
5	500	520
		$5860

The annual deposit necessary to accumulate $5860 in five years at 4 per cent would be $1082.

Average Annual Cost

Average annual maintenance	$1082
Interest on $12,000 at 4%	480
	$1562

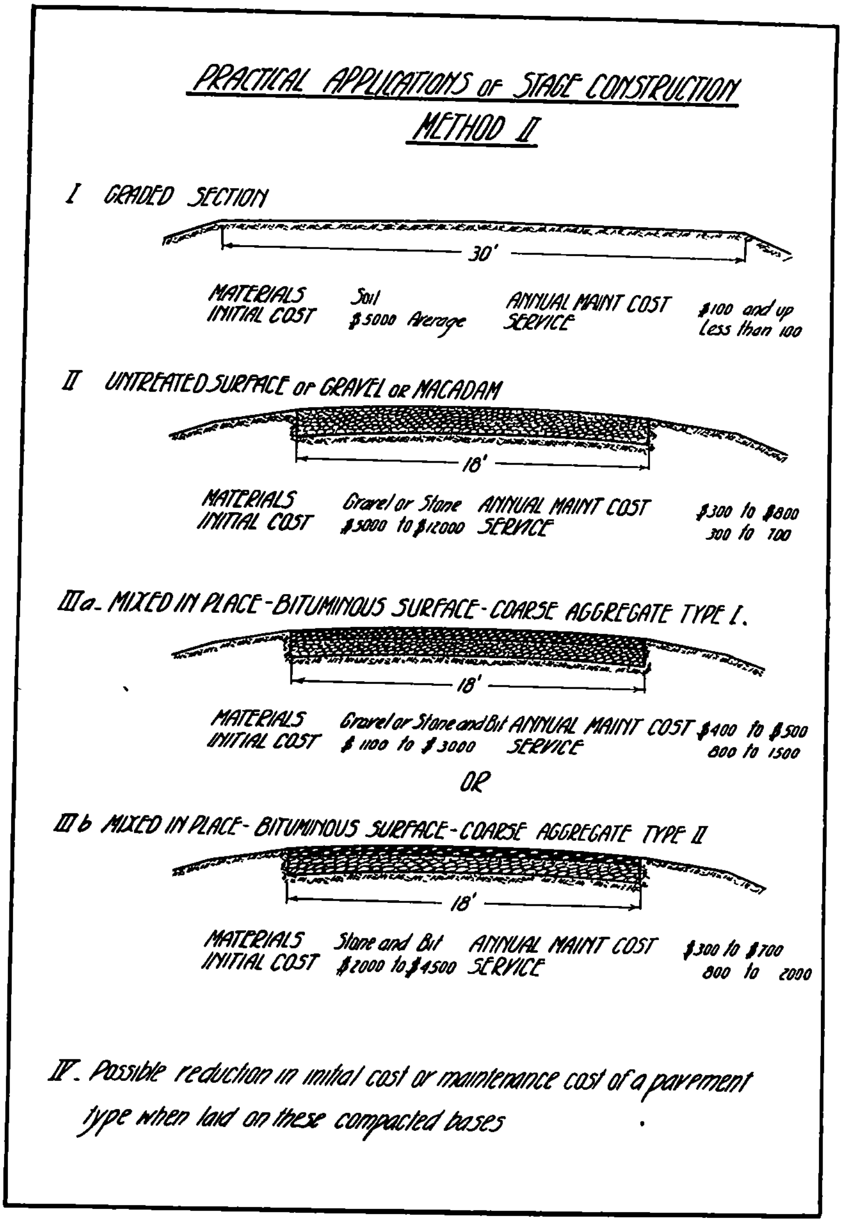

PRACTICAL APPLICATIONS OF STAGE CONSTRUCTION
METHOD II
I GRADED SECTION
30'
MATERIALS Soil
INITIAL COST $5000 Average
ANNUAL MAINT COST $100 and up
SERVICE Less than 100
II UNTREATED SURFACE OF GRAVEL OR MACADAM
18'
MATERIALS Gravel or Stone
INITIAL COST $5000 to $12000
ANNUAL MAINT COST $300 to $800
SERVICE 300 to 700
IIIa - MIXED IN PLACE - BITUMINOUS SURFACE - COARSE AGGREGATE TYPE I.
18'
MATERIALS Gravel or Stone and Bit
INITIAL COST $1100 to $3000
ANNUAL MAINT COST $400 to $500
SERVICE 800 to 1500
OR
IIIb MIXED IN PLACE - BITUMINOUS SURFACE - COARSE AGGREGATE TYPE II
18'
MATERIALS Stone and Bit
INITIAL COST $2000 to $4500
ANNUAL MAINT COST $300 to $700
SERVICE 800 to 2000
IV. Possible reduction in initial cost or maintenance cost of a pavement type when laid on these compacted bases

Figure 2

For a daily traffic of 1500 vehicles the cost per vehicle mile would be $.0031.

METHOD III

Bonded gravel or macadam. Followed by one and one half inch pre-mixed bituminous top, laid cold on prime coated base. Shown in Figure 3.

Stage 2, The annual cost of the gravel or macadam would be as follows before treatment, yearly maintenance being equal:

Average Annual Cost

Annual maintenance	$800
Interest on $800 at 4%	32
Interest on $12,000 at 4%	480
	$1312

For a daily traffic of 800 vehicles the cost per vehicle mile would be $.0045.

Stage 3, Assuming that the surface treatment would need renewal in five-year cycles the average annual cost would be as follows:

Year	Expenditures	Amount of expenditures in 5 years at 4%
1	$12,000	$14,600
2	300	351
3	300	338
4	500	541
5	600	624
		$16,454

The annual deposit necessary to accumulate $16,454 in five years would be $3027.

Average Annual Cost

Average annual maintenance	$3027
Interest on $12,000 (value of base) at 4%	480
	$3507

For a daily traffic of 1500 vehicles the cost per vehicle mile would be $.0064.

METHOD IV

Traffic bound stone, slag or gravel. Followed by calcium chloride treatment; dual bituminous surface treatment; and by mixed-in-place bituminous surface, coarse aggregate Type II. Shown in Figure 4.

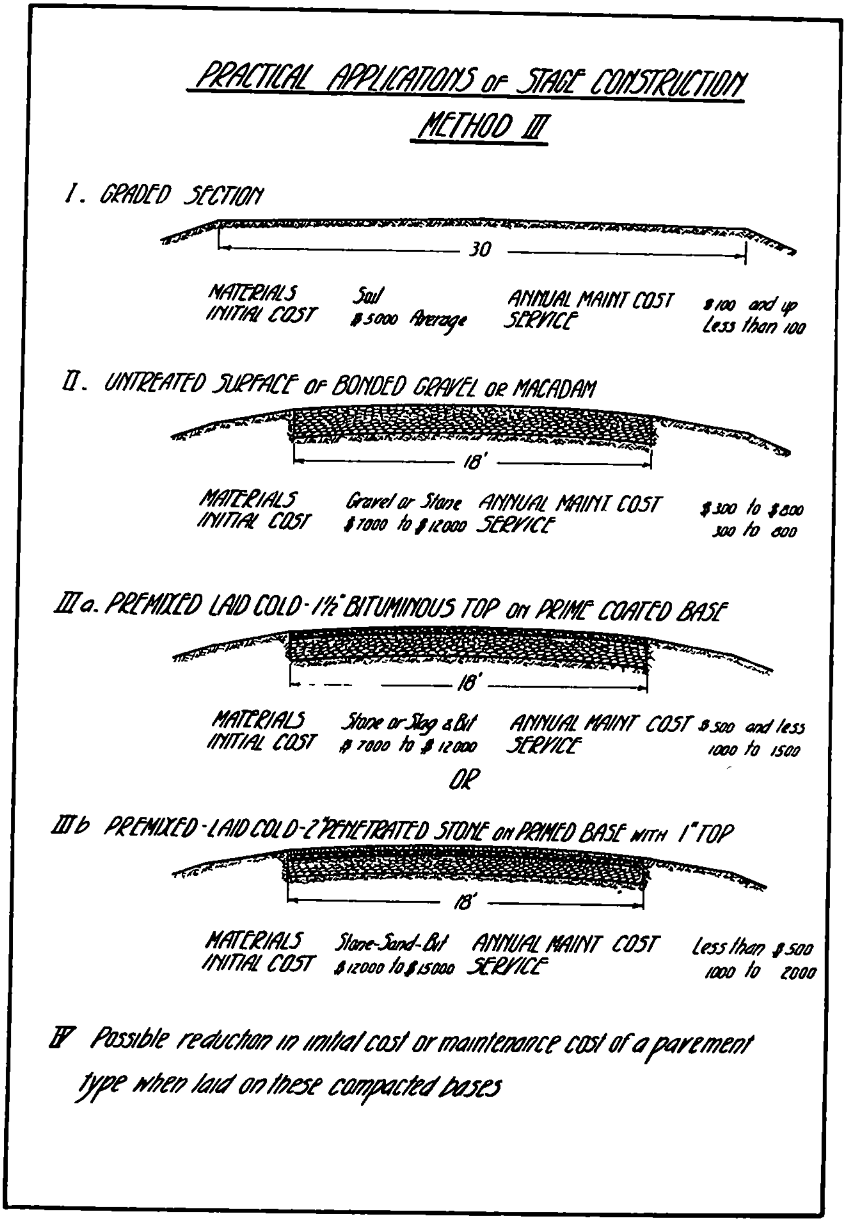

PRACTICAL APPLICATIONS OF STAGE CONSTRUCTION
METHOD III
I. GRADED SECTION
30
MATERIALS Soil ANNUAL MAINT COST $100 and up
INITIAL COST $5000 Average SERVICE Less than 100
II. UNTREATED SURFACE OF BONDED GRAVEL OR MACADAM
18'
MATERIALS Gravel or Stone ANNUAL MAINT COST $300 to $800
INITIAL COST $7000 to $12000 SERVICE 300 to 800
III a. PREMIXED LAID COLD-1½" BITUMINOUS TOP ON PRIME COATED BASE
18'
MATERIALS Stone or Slag & Bit ANNUAL MAINT COST $500 and less
INITIAL COST $7000 to $12000 SERVICE 1000 to 1500
OR
III b PREMIXED-LAID COLD-2" PENETRATED STONE ON PRIMED BASE WITH 1" TOP
18'
MATERIALS Stone-Sand-Bit ANNUAL MAINT COST Less than $500
INITIAL COST $12000 to $15000 SERVICE 1000 to 2000
IV Possible reduction in initial cost or maintenance cost of a pavement type when laid on these compacted bases

Figure 3

Stages 2 and 3, This type of surface needs renewal every three to five years Using four years, the average annual cost would be as follows:

Year	Expenditures	Amount of expenditures in 5 years at 4%
1	$2300	$2691
2	600	675
3	600	649
4	600	624
		$4639

The annual deposit necessary to accumulate $4639 in four years at 4 per cent would be $1092, which is the average annual cost of the surface

For a daily traffic of 600 vehicles the cost per vehicle mile would be $ 005

Stage 4, The use of calcium chloride would tend to lessen the loss of material and should therefore prolong the rebuilding cycle An estimate of cost is as follows:

Year	Expenditures	Amount of expenditures in 5 years at 4%
1	$2700	$3286
2	600	702
3	600	675
4	600	649
5	600	624
		$5936

The annual deposit necessary to accumulate $5936 in five years would be $1096, which would be the average annual cost of the surface including the rebuilding of the original surface.

For a daily traffic of 800 vehicles the cost per vehicle mile would be $ 0038.

Stage 5, Assuming that this surface would need renewal in three years, the average annual maintenance cost would be estimated as follows.

Year	Expenditures	Amount of expenditures in 3 years at 4%
1	$3000	$3375
2	400	430
3	400	416
		$4221

The annual deposit necessary to accumulate $4221 in three years would be $1352.

Average Annual Cost

Average annual maintenance . .	.$1352
Interest on $2000 (salvage value of gravel base) at 4%	80
	$1432

For a daily traffic of 1200 vehicles the cost per vehicle mile would be $.0032.

Stage 6, This surface being heavier should last longer before retreading is necessary. Assuming five years, the average annual maintenance cost is estimated as follows:

Year	Expenditures	Amount of expenditures in 5 years at 4%
1	$5000	$6085
2	400	468
3	400	450
4	400	433
5	400	416
		$7852

The annual deposit necessary to accumulate $7852 in five years would be $1450

Average Annual Cost

Average annual maintenance	$1450
Interest on $2000 (salvage value of gravel base) at 4%	80
	$1530

For a daily traffic of 2000 vehicles the cost per vehicle mile would be $ 0021.

These estimates of cost apply only for uniform traffic conditions With increase in traffic, maintenance costs for any of these types will increase until either the annual cost becomes greater than that of the next higher type, or until it becomes impossible to keep the road in a satisfactory condition In such cases we are not interested in the average annual cost but in the actual cost from year to year.

The value of the surface as a subgrade treatment for a pavement type has been demonstrated in the field

There is a saving in the cost of vehicle operation on surfaced highways as compared with earth roads For example, assume for comparison an average of 400 vehicles per day operating on ordinary earth roads and on best gravel roads. According to Iowa * tests, the

* Bulletin No 69 Engineering Experiment Station, Iowa State College

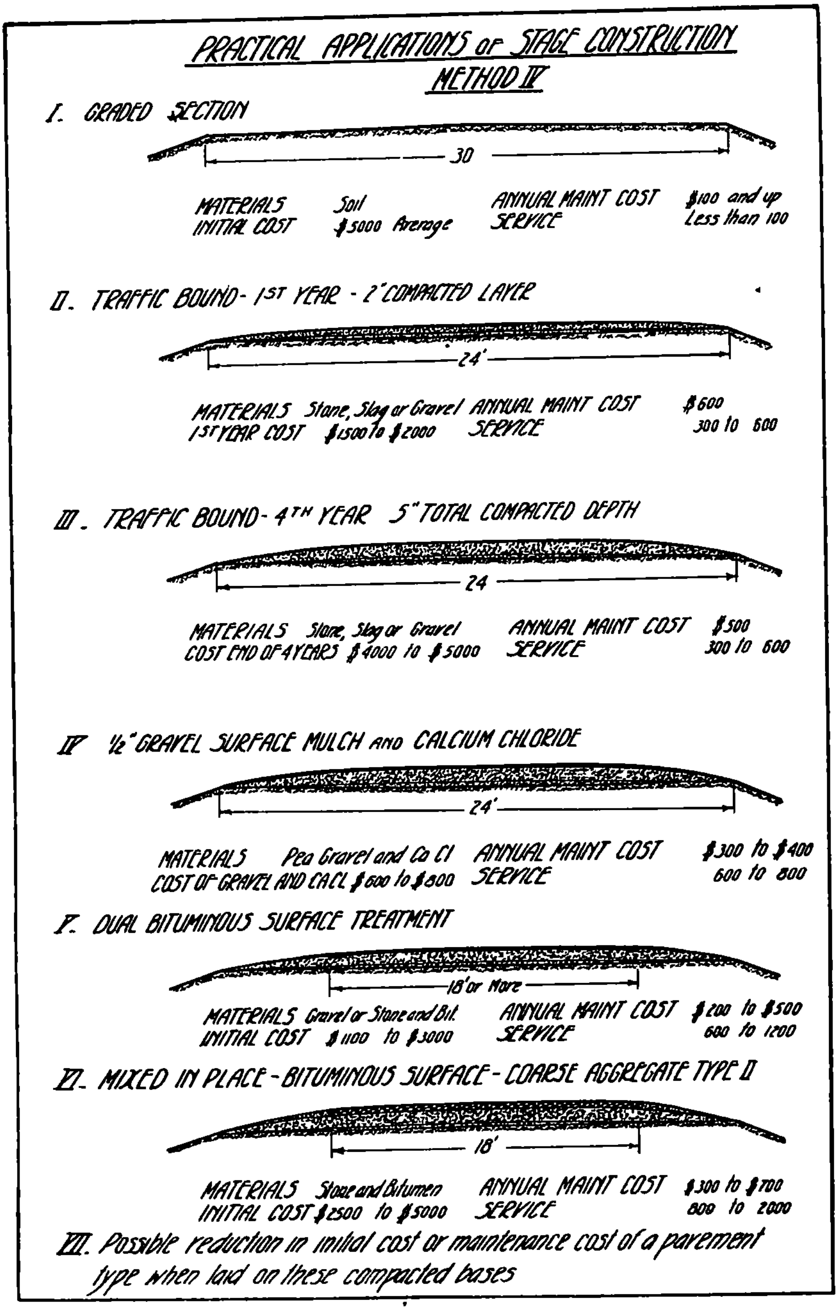

PRACTICAL APPLICATIONS OF STAGE CONSTRUCTION
METHOD IV
I. GRADED SECTION
30
MATERIALS Soil
INITIAL COST $5000 Average
ANNUAL MAINT COST $100 and up
SERVICE Less than 100
II. TRAFFIC BOUND - 1ST YEAR - 2" COMPACTED LAYER
24'
MATERIALS Stone, Slag or Gravel
1ST YEAR COST $1500 to $2000
ANNUAL MAINT COST $600
SERVICE 300 to 600
III. TRAFFIC BOUND - 4TH YEAR 5" TOTAL COMPACTED DEPTH
24
MATERIALS Stone, Slag or Gravel
COST END OF 4 YEARS $4000 to $5000
ANNUAL MAINT COST $500
SERVICE 300 to 600
IV 1/2" GRAVEL SURFACE MULCH AND CALCIUM CHLORIDE
24'
MATERIALS Pea Gravel and Ca Cl
COST OF GRAVEL AND CACL $600 to $800
ANNUAL MAINT COST $300 to $400
SERVICE 600 to 800
V. DUAL BITUMINOUS SURFACE TREATMENT
18' or More
MATERIALS Gravel or Stone and Bit.
INITIAL COST $1100 to $3000
ANNUAL MAINT COST $200 to $500
SERVICE 600 to 1200
VI. MIXED IN PLACE - BITUMINOUS SURFACE - COARSE AGGREGATE TYPE II
18'
MATERIALS Stone and Bitumen
INITIAL COST $2500 to $5000
ANNUAL MAINT COST $300 to $700
SERVICE 800 to 2000
VII. Possible reduction in initial cost or maintenance cost of a pavement type when laid on these compacted bases

Figure 4

cost for operation on earth for automobiles is 12.6 cents per vehicle mile and on best gravel it is 10 9 cents The saving is 1.7 cents per vehicle mile, or $6.80 per day for the 400 vehicles Over a yearly period the saving is $2482 for 400 vehicles traveling one mile each day of the year If the 400 vehicles traveled 30 miles each day the annual saving would be $84,460 If the gravel surface had a bituminous surface treatment the cost of operation would be still further reduced.

There is a value in time saved by travel over a well-maintained surfaced highway compared with ordinary earth in a poor state of maintenance. Assume the average daily trip of an automobile to be 30 miles and that 90 minutes are required to travel the 30 miles on earth roads, and 60 minutes on a surfaced road. The time saved per day per vehicle is 30 minutes. The average daily traffic is assumed to be 400 vehicles. The value of a car minute was determined in studies for the Holland Vehicular Tunnel, between New York and New Jersey and is given by F. Lavis, consulting engineer, New York, as:

For trucks, 2 3 cents per minute.
For passenger cars (busses), 2.1 cents per minute.
For pleasure cars, 1.0 cent per minute.

Assume the average value of a car minute on rural highways to be 1.5 cents The daily saving in time for one car traveling 30 miles per day is 30 minutes; for 400 cars it is 12,000 minutes The value of this time saved each day is 12,000 $\times$ \$ 015 = \$180 00 In one year this represents a saving of $65,700.

Low cost improved roads are profitable investments provided they are intelligently maintained and not overloaded by heavy trucks.

CHAPTER 3

DIGEST OF FINDINGS

MATERIALS OF CONSTRUCTION AND MAINTENANCE

Practically all roadway surfaces contain two essential elements, aggregate and binder. Among the untreated types of surfacing, gravel is most commonly used as aggregate with clay as the binder. For surface treatments and surface courses gravel, coarse sand and crushed stone predominate as aggregates, and bitumens are most widely used with them as binders.

The quality of aggregates usually depends upon that of the available local materials Gradation is governed by several factors, among which are ease of maintenance for untreated surfaces and stability of surface for bituminous mixtures

Various types of surfaces are produced by combining aggregates with binders.

I. SOURCE OF AGGREGATES

Certain materials suitable for untreated surfaces or bases are sometimes found in pits at or near the ground surface, along the roadside or within a short-haul distance of it Such materials are sand clay and top soil in the South and Southwest, shale in West Virginia and Pennsylvania, disintegrated granite in the West and Southwest, gravel in many of the states, chert in Georgia and Alabama, and caliche in several of the Southwestern states. Occasionally the graded road is composed of serviceable material and requires no immediate surfacing. Arizona has stretches of road of this character Gravel, slag, crushed stone and lime rock are furnished by commercial plants; although it is not unusual for the project contractor or state and county forces to produce their own aggregates

II SOURCES OF BINDERS

Such binders as clay and volcanic cinders for untreated surfaces are usually obtained locally.

Tars, asphalts, calcium chloride and lignin binders are commercial products.

Some bituminous mixtures are prepared at central plants and shipped relatively long distances. Among them are the natural rock asphalts and mixtures of stone or slag and bitumen. These mixtures

Figure 5. Sand Pit—North Carolina

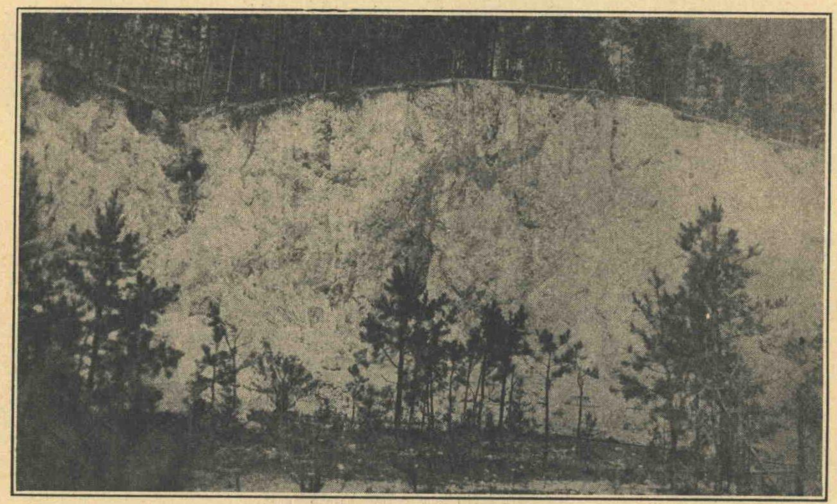


Figure 6. Chert Pit—Georgia

are shipped by rail and laid at atmospheric temperatures usually not lower than 50° or 60° F.

III. QUALITY AND GRADATION OF AGGREGATES

Quality is usually determined by tests for percentage of wear and toughness, although the toughness test is not as frequently specified as the wear test. Some specifications simply call for "hard, durable" material. Nearly all specifications require that aggregates shall be clean and free from "foreign" material.

The gradation requirements of aggregate are principally affected by the purpose for which they are to be used. If the material is intended for base construction, softer aggregates and larger sizes are sometimes permitted than for wearing courses; but surfaces which are maintained by machining and dragging are usually composed of durable aggregates whose maximum size is less than 1 inch

A. Aggregates for Untreated Surfaces

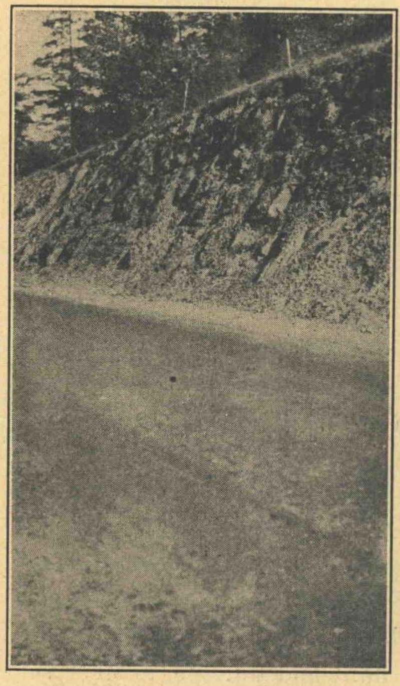
Sand Clay This mixture for best results should contain sand composed of hard durable grains, preferably angular in shape. Silt is usually present by tolerance. The clay should be sticky and non-slaking in character. The total sand content should be 65 to 80 per cent of the total, silt not more than 15 per cent, and clay not more than 20 per cent Sand in sizes above No. 10 sieve is particularly desirable.

Chert. Several kinds of chert may be found in one county according to experience in Alabama; one very hard and durable, another soft and chalky. There are no standard tests for chert, but its suitability and durability are determined by usage. A typical specification in Georgia requires that all material pass the 1½-inch screen and at least 60 per cent be retained on the No. 10 sieve.

Shale. There are various classes of shale but those which have given best results under traffic in West Virginia contain more than 55 per cent silica and more than 4 per cent iron oxide. The maximum size of particle allowed in that state, is 3 inches Under traffic and maintenance the larger pieces are broken down to much smaller sizes.

Disintegrated Granite. The wearing quality of this material is furnished by the silica content which is more than 60 per cent of the total. The bonding properties are furnished by the iron and calcium content, which form over 6 per cent of the total. The material is placed on the road in sizes up to 4 and 6 inches but is broken down to less than half these sizes under maintenance, traffic or rolling.

Gravel. Surfacing gravel is usually specified as a "hard and durable" material. Clay in excess of 20 per cent is not usually tolerated. Ten to 15 per cent total clay and loam is considered better practise, but non-slaking binders such as iron oxide and lime stone are preferred. In California 50 per cent of the gravel must consist



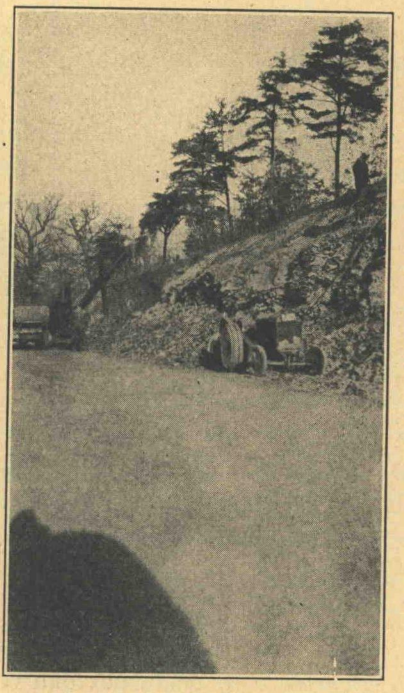


Figure 7. Shale Pits—West Virginia

Figure 8. Soft Sand Stone Quarry—West Virginia

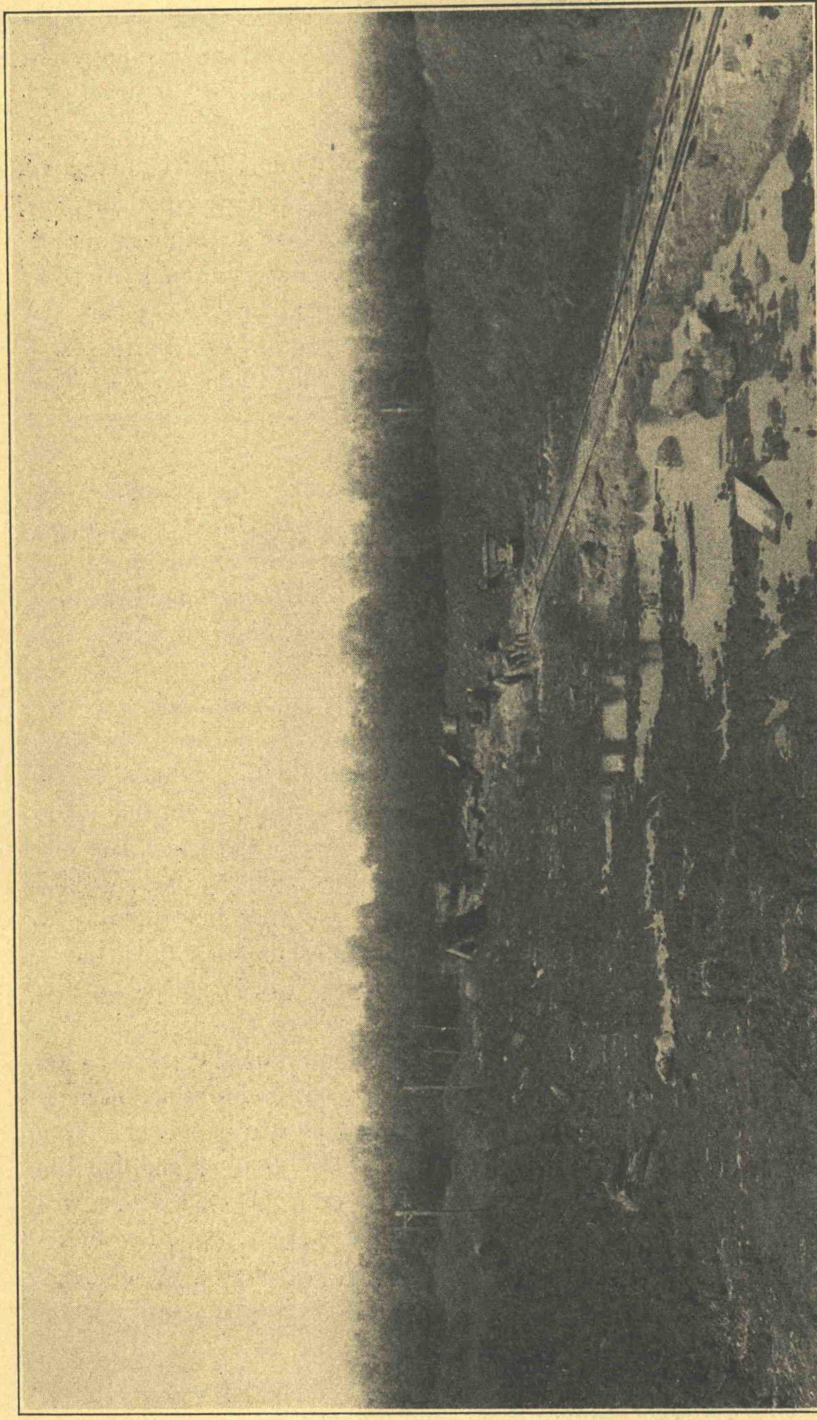


Figure 9. Marl Pit—North Carolina

of crushed particles. Experience has shown that best results are obtained when all of the aggregate passes the 1-inch screen, and where a high percentage, 35 or more, is retained on the No 10 sieve.

Gravel, Slag and Stone for Traffic Bound Surfaces The quality of these materials for such surfaces is usually high; that is, the particles must be hard and durable. As specified they are equal to those used for water-bound and penetration macadam, or highest quality gravel roads. Screenings when used are produced from hard rock In gradation, best results are effected when all material passes the ⅞-inch or ¾-inch screen Practise varies as to the lower limits Ohio practise permits about 10 per cent through the 10-mesh sieve, Tennessee uses all stone through the 1½-inch screen including dust of fracture

Stone for Macadam. For base courses softer aggregates are tolerated than for wearing courses For example, in Ohio the maximum allowable per cent of wear may be as high as 10 or 12 for limestones, 15 or 20 for slag and 25 for sandstone In such cases the gradation calls for larger size particles; all passing the 5½-inch screen and retained on the 2½-inch for the coarse stone.

The top course is usually composed of harder stone but if a bituminous surface treatment or bituminous surface course is to cover the top course, soft stone is sometimes permitted. Usually the top course is stone having a per cent of wear of not more than 5 or 6. The gradation of the coarse stone for this surface is between the 4-inch and 2½-inch screen in Ohio, and between the 2½-inch and 1¼-inch screen in Massachusetts, thus showing considerable variance in practise.

Lime Rock, Marl and Caliche These materials are soft, in fact so soft that wear tests are meaningless. They consist principally of carbonate of lime, of which more than 50 per cent is desirable The best bases of Florida Lime Rock contain more than 70 per cent carbonate of lime Small stones and sand are not undesirable. A small percentage of clay, less than 10 per cent, is tolerated in caliche. When power rolling and watering are used in the shaping and bonding process, Florida permits all material to pass the 3½-inch screen with not less than 30 per cent retained on the ¾-inch In some of the western states using caliche smaller sizes, all passing the 1¼ or 1-inch screen, are specified when the surface is to be traffic bound without watering.

Miscellaneous Materials such as Stone Screenings, Mine Chats, Iron Ore Top Soil, Stamp Sand, and others

As used, nearly all of these aggregates are fragments of hard, durable material. In size they all pass the 1½-inch or 1-inch screen and may or may not contain a high percentage of material passing the ¼-inch screen or No. 10 sieve. The fines should preferably be non-slaking in character.

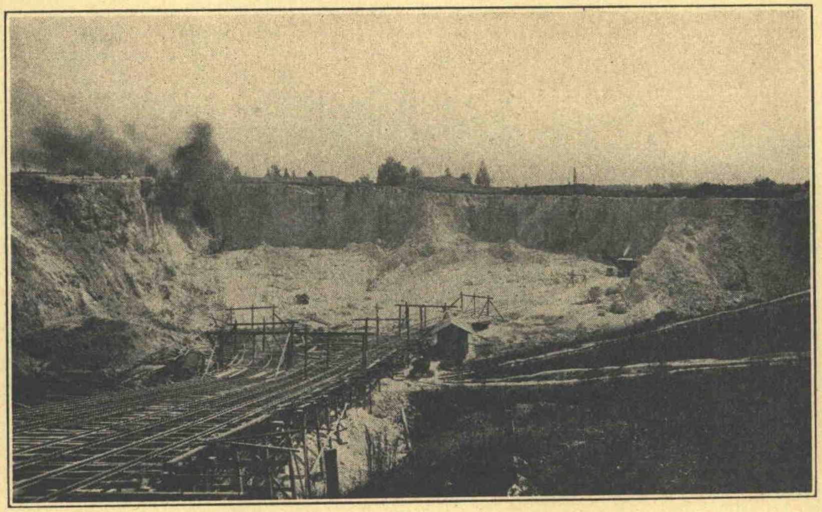


Figure 10. Lime Rock—Florida

B. Aggregates for Surface Treatments and Surface Courses

Calcium Chloride. Various aggregates have been treated with this material, including surfaces of sand clay, shale, gravel, marl and stone. The principal use has been on gravel surfaces, in regions of average or high humidity and rainfall.

Single and Dual Bituminous Surface Treatments. The aggregates for this work are commonly hard durable materials and include stone and slag chips, fine gravel and coarse sand. Clean material is always specified. If the aggregates are hard and durable their size is commonly between ¾-inch and ⅛-inch. If the particles are friable, larger sizes are used up to 1¼-inch.

Single treatments with a light liquid bitumen are used with finer aggregates than the heavier hot or cold applications used in dual treatments.

Mixed-in-Place Bituminous Surfaces, Fine Aggregate Type. There are few specifications published for aggregates used with this type

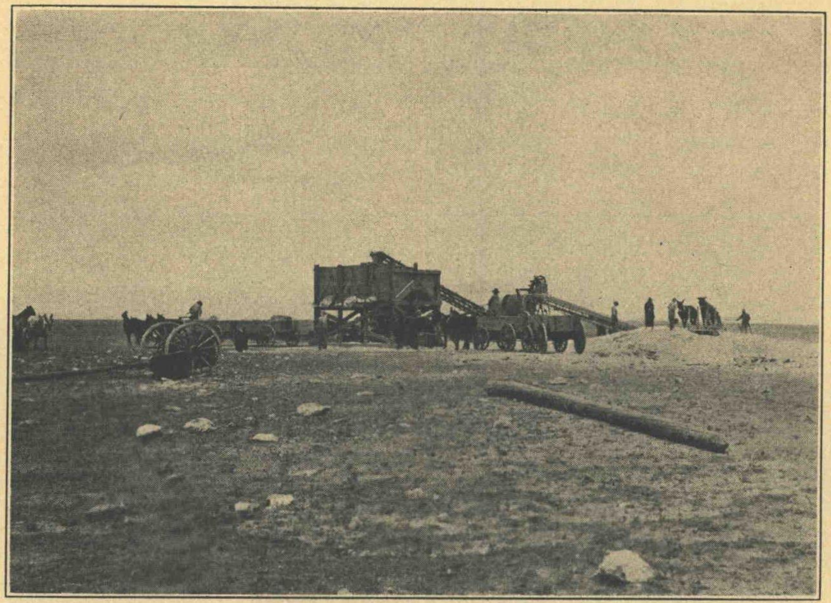


Figure 11. Caliche—New Mexico

of surfacing The aggregates actually used are those found in the existing road surface and include mixtures of fine gravel or sand, loam and clay. When seal coats are used the aggregates for cover are similar to those used in Single and Dual Bituminous Surface Treatments

The presence of an excess of clay, more than 15 or 20 per cent, is not considered desirable. Analyses of road samples show that nearly all material passes the ¼-inch screen and that 5 to 11 per cent pass the 200-mesh sieve The class and gradation of the aggregates have a direct bearing on the quantity of bitumen used. Preliminary analyses or even test sections of road may be necessary to determine the correct percentage of aggregate and bitumen.

Mixed-in-Place Bituminous Surface, Coarse Aggregate Type I The principal aggregates are crushed and uncrushed gravel, stone or slag as found in the existing roadway surface If new material is added it is similar to that already in the untreated roadway surface The hardness and toughness of these materials and their suitability is usually judged by their previous service For example, a surface which had been inadequate for 300 or 400 vehicles per day, except for dust, would appear unsuitable

The largest size particles are commonly less than 1-inch in size and more than 40 per cent is retained on the 10-mesh sieve Clay in excess of 20 per cent is unsatisfactory and smaller percentages are better. Laboratory analyses of field tests are desirable in determining suitable percentages of aggregate and bitumen

Mixed-in-Place Bituminous Surface, Coarse Aggregate Type II Crushed stone or crushed slag are the aggregates In quality they are equal to these materials as specified for bituminous penetration macadam The maximum allowable per cent of wear is usually not more than 5 or 6.

The gradation depends somewhat on the proposed thickness of finished surface Practise in Pennsylvania and Tennessee calls for stone passing the 1½ or 1¼-inch screen and retained on the ⅝ or ⅜-inch, for surfaces up to 2 inches in thickness. In Indiana for surfaces 2 to 3 inches in thickness all stone passes the 3-inch screen, 95 to 100 per cent passes the 2½-inch, 0 to 15 per cent passes the 1½-inch.

Pre-Mixed Bituminous Surface, Laid Cold The customary aggregates are crushed stone or slag Gravel is also used Sand may be added for greater density. In quality they are hard and durable with a maximum percentage of wear of 5 or 6 for stone, and somewhat higher for slag. Sand must be clean and coarse Uniform grading from coarse to fine is recommended for all aggregates. For courses 1½ to 2 inches in thickness the coarse aggregate, for one specification which uses asphalt, passes the 2-inch screen and is retained on the ⅜-inch; for one using tar, coarse aggregate passes the 1¼-inch screen and is retained on the ⅝-inch; for another using tar, coarse aggregate passes the 1-inch screen and is retained on the ¼-inch; larger sizes are also used but details are not available. The correct amount of a given class of bitumen will vary with the gradation and porosity of the aggregates, the more porous and finer aggregates taking more bitumen than the more dense and coarse materials.

Natural Rock Asphalt and Surfaces. There are no wear tests for the aggregates in these natural mixtures. The gradation of the limestone rock asphalts when crushed and ready for use includes that which passes the ¾-inch screen The gradation of the sand in sandstone rock asphalts is similar to that in sheet asphalt, though not as good according to Hubbard

Modified or Puddle Bituminous Macadam Cold Penetration Method. Both hard and soft stone have been used for this work. Hard stone having a percentage of wear of not more than 5 is specified in Virginia and West Virginia But soft sand stone which crushes under ordinary rolling is also used in West Virginia

In Virginia coarse stone passes the 4-inch screen and is retained on the 2½-inch screen. Intermediate stone passes the 2½-inch screen and is retained on the 1-inch Fine stone or chips pass the 1-inch screen and are retained on the ¾-inch In West Virginia the soft sand stone is specified in larger sizes than hard stone.

Bituminous Macadam Hot Penetration Method. Crushed stone or slag are the aggregates. Hard durable materials are desirable. The maximum allowable per cent of wear for stone is seldom more than 6. A higher percentage is tolerated for slag

The gradation and maximum size vary with the proposed depth of surfacing. The maximum size is usually about equal to the proposed depth. For surfaces 2½ inches thick the coarse stone passes the 2½-inch screen and is retained on the 1½ or 1¼-inch, the intermediate stone passes the 1¼ or 1-inch and is retained on the ¾ or ⅝-inch, the fines pass the ¾ or ⅝ and are retained on the ⅜ or ¼-inch.

For 3-inch thick surfaces the sizes are proportionately larger.

Pre-Mixed Laid Hot Bituminous Surfaces. For the more durable and standard surfaces the quality and gradation of aggregates are carefully selected When local materials of somewhat inferior gradation are used the requirements are not as severe

Crushed stone, stone screenings, sand and filler dust are the principal aggregates for Bituminous Concrete and Sheet Asphalt of the standard types Suitable quality and gradation are stated in specifications of the Bureau of Public Roads, various State Highway Departments and the Asphalt Association

The specifications for such local mixes as Sand Asphalt, and Bituminous Concretes using local aggregates are covered by the States of North Carolina, Massachusetts, Michigan and others

Miscellaneous Surfaces Principally Lime Treatments of Clay. As indicated, clay is the principal aggregate although treatment of other soils with Lime and Portland Cement is being investigated

There are a few isolated and non-conclusive experiments of treating stone with silicate of soda or deliquescent salts

IV. CLASSES OF BINDERS

There are three classes of binders, mineral, bituminous and those not included in these two classes

1. *Mineral Binders* These include, clay, loam, volcanic cinders, stone screenings, limestone, lime rock dust and materials containing iron oxide All are used with untreated surfaces. The clays and loams are least desirable, particularly because they are unfavorably affected by wet and dry weather conditions The other materials are less affected by moisture but may become dusty in dry weather

2. *Bituminous Binders* These are widely and satisfactorily used in low cost road work They range all the way from light road oils up to asphaltic cements Extensive details of each are not covered in this report.

There is on the market a class of bitumen more or less suitable for nearly every type of surfacing yet devised, in fact several of the satisfactory types were developed under the direction or at the suggestion of producers of bitumen Within reasonable limits of success the following bitumens have been used with the types indicated.

Bituminous Surface Treatments, Single Application Method.

Cold liquid tars, of low specific viscosity

Cold liquid road oils.

Hot tar, of such consistency that it must be heated for application

Hot asphaltic oil which must be heated before application

Cut-back asphalts and tars which require liquifiers to produce a fluid state for cold application

The cold applications appear more popular at the present time

Dual Bituminous Surface Treatments Present practise indicates a cold liquid tar for a prime coat especially on porous bases Cut-back asphalts are also used

For the second application a hot asphaltic oil or hot tar is more generally specified than are cold applications If a cut-back material is used it is of higher viscosity, that is, of a heavier material, than is used for the prime coat

Mixed-in-Place Bituminous Surface, Fine Aggregate Types The bitumen is usually a slow curing asphaltic road oil, a cut-back asphalt and less frequently a tar product

The seal coat, if used, is a heavier bitumen, usually of asphaltic content, which requires heating or a liquifier before it can be applied from a distributor

Mixed-in-Place Bituminous Surface, Coarse Aggregate Type I Both tars and asphalts have been used for this type The tars as used are of relatively low viscosity and are applied cold, or with slight heating, from a distributor.

The asphaltic road oils are usually of high asphaltic content which may be applied at atmospheric temperatures or with slight heating

The second application may be a heavier bitumen than the first. The first should have high penetrating qualities to assist in stabilizing the existing surface, but both should be of such consistency that the necessary manipulation of the aggregate and bitumen may be accomplished before they set or become sticky and hard.

Mixed-in-Place Bituminous Surface, Coarse Agregate Type II. The bitumens are usually applied at atmospheric temperature or with light heating They must not become sticky or hard before the necessary mixing and shaping have been finished Liquid tars, and to a lesser extent, cut-back asphalts have been the binders used

Pre-Mixed Bituminous Surfaces, Laid Cold. Both tar and asphalts have been used. They must be of such grade and consistency that the mixture may be laid without heating at normal temperatures. Heating may be necessary before the mixture is unloaded from cars

A material which fulfills the requirements for this type of surface is so heavy that liquifiers or heat may be necessary for the plant mixing As the volatile oils evaporate the mixture becomes stiff, and finally on the road it sets into a hard and dense mass.

Natural Rock Asphalt Surfaces. Texas limestone rock asphalts contain bitumens of low penetration and are mixed with a flux before being used for road work. Pure bitumen picked from the rock crevices showed a penetration of 2 (at 77 F., 100 g. 5 sec.). Bitumen recovered by extraction showed a penetration of 7.

In their natural state Kentucky sand stone rock asphalts contain bitumen which is said to vary from "soft to hard." As shipped ready for use the bitumen is said to be of "very high penetration." Exact data are not available.

Modified or Puddle Macadam, Cold Application. Cold liquid tar or asphalt are the bitumens used. In Europe emulsions are said to be satisfactory.

The liquid tars or asphalts are cut-back materials which become stiff after the volatile oils have evaporated Their specific viscosity is below 35 (Engler 50 cc. at 40 C.) as used in West Virginia.

Bituminous Penetration Macadam, Hot Penetration Method. The bitumen is commonly an asphaltic cement or heavy asphaltic oil. Tars are not as widely used. The penetration of the asphalt is usually between 80 and 100, but in a few localities it is used at from 100 to 120.

Pre-Mixed-Laid Hot Bituminous Surfaces The bitumen for these surfaces is asphaltic cement. The quality and penetration as specified by various Highway Departments conforms rather closely to those recommended by the Asphalt Association. They range in penetration from 30 to 80. The exact 10 point limits are set to suit the various conditions of climate, traffic and materials.

Sand asphalt, for example, in North Carolina contains bitumen of 30-40 penetration. The "Mixed Macadam" as laid in Canada contains bitumen of penetration between 75 and 100.

3. *Calcium Chloride and Hydrated Lime.* These are well-known commercial products. They are not varied in composition to suit any local condition of climate, traffic or material. Standard specifications and requirements are published by the American Society of Testing Materials.

CONSTRUCTION METHODS AND CLASSIFICATION OF LOW TYPE ROAD SURFACES

Current technical literature and text books have devoted much space to research and usage on construction methods for high type pavements Construction methods for low type roads deserve much more attention and study than they have received. In spite of this apparent lack of attention by road builders as a whole, those engineers who through necessity have had large mileages of low cost roads to construct have worked out methods which show marked improvement over methods of even five years ago. The improved successful methods are similar in different parts of the country. They differ somewhat in details but their similarity is sufficient to permit classification into groups They are principally the result of experimenting with materials and equipment in the field, rather than in the laboratory or on test roads They were necessarily cut and dry methods which have since become more or less standard practise, but there is now evidence that laboratory control and definite tests may assist in the construction of even the lowest types.

Several methods of construction are common to both low and high type surfaces For the purpose of identifying and collecting them, the methods are discussed as they apply to three general types of surfacing:

I Untreated surfaces
II Types using nonbituminous admixtures
III. Bituminous surface treatments and surface courses.

I. UNTREATED SURFACES

The principal differences in construction methods for untreated surfaces lie in the processes of bonding, spreading and compacting the surfaces and in the number of courses With these conditions in mind the following classification is made for untreated surfaces.

1. Traffic bound, layer method.
2. Traffic bound, one course method.
3. Roller bound, one or two course method.

There are some variations in practise such as obtaining compaction by rolling in addition to that of traffic, in both 1 and 2.

1. *Traffic Bound, Layer Method.* The principal example of this method on an extensive scale is the recent work in Ohio. It has been practised also in other states, including Tennessee, Indiana, Nebraska,

Iowa and Minnesota. It is useful in obtaining quick service over long mileages at a nominal cost. By it the correct amount of aggregate is concentrated over the weak spots of the subgrade and a minimum amount of necessary material is placed on the more substantial areas of subgrade. The final surface although of unequal thickness is of uniform capacity throughout.

The object of this method is to first stabilize the raw subgrade by the addition of clean hard aggregate. Blading and dragging keep the surface regular Traffic does the compacting. New material is added periodically. This becomes bonded and keyed to that previously placed until a dense and regular surface is obtained. Compaction is thus secured from the bottom or subgrade upward.

The successive applications of aggregate are in reality layers or courses. Due to the thinness of each layer, which is less than 2 inches, a maximum degree of compaction is secured.

The construction operations are very simple. They consist of hauling, dumping, and spreading of the aggregates, all done by mechanical equipment. This equipment is practically the same as that used in maintaining soil and gravel roads

2. *Traffic Bound, One Course Method.* This method is generally followed for the construction of selected soil, sand clay and one course gravel and is one of the most commonly used.

After the materials are spread on the subgrade, the principal operation is mixing in place This is accomplished by plowing, harrowing and blading. If rains are infrequent, sprinkling with water produces an increased density

Traffic and hauling over the surfacing material finally bring it down to a well compacted mass. It may be advisable to use a roller on materials which carry little or no binder, and a heavy roller is successfully used on the lime rock bases of Florida although they bind together readily

Some surfaces built by this method are not smooth because the aggregates were dumped in separate piles on the subgrade and allowed to remain there for a considerable time before being spread and harrowed.

Power rolling of a course as thick as it is usually built is not always effective because of the type of roller used. Even where the surface is built up in relatively thin layers the standard types of three-wheel and tandem rollers may result in compaction of the immediate surface of each layer only. Excessive rolling with rollers of this type may partially destroy the bond between successive layers.

3. *Roller Bound, One or Two Course Method.* Water-bound macadams using various aggregates come under this heading

The method is primarily to spread a layer of coarse aggregate, shape it, roll lightly and then fill the voids with a finer aggregate Water may or may not be sprinkled on the surface to assist in the void filling and binding process Compaction is secured by frequent and protracted rolling.

These surfaces are seldom as smooth as those which use blading or dragging as a part of the construction process.

They are usually built up in one or two layers of from 2½ to 5 inches in thickness Single courses of more than 6 inches compacted thickness are unusual

The cost of initial construction, its relatively slow rate of progress, and the fact that these surfaces are difficult to maintain with blades have reduced the popularity of this method and type

II TYPES OF NONBITUMINOUS ADMIXTURES

The nonbituminous methods may be classed as·

1 The surface application method
2. The mixed-in-place method
3 The pre-mixed method.

They are all done without heating

1. *The Surface Application Method* Calcium chloride is applied to the surface in flake or powder from a lime spreader. The spreader is hauled by a truck Frequent light applications of ½ pound per square yard appear to be favored over less frequent and heavier applications

If a light surface mulch of fine gravel is retained on the roadway surface, the chloride appears to be more effective It is possible to apply chloride in solution as is done with lignin binders.

2. *The Mixed-in-Place Method* The principal work of this method has been experimental Lime or Portland cement is mixed with road soils The soil is first loosened by plowing and harrowing The admixture is then applied, followed by mixing with plow, harrow or road blader The final surface contour is obtained by blading. Traffic does the compacting.

3. *Pre-Mixed Method Cold.* Although limited in actual work done and conclusive results obtained, this method is included because of the possibilities of utilizing local materials which are not customarily used

The binder and aggregate are mixed in a standard concrete paver, dumped and spread in much the same manner as in standard Portland cement concrete paving. The aggregates are quite fine (all passing the ¾-inch screen) which allows unusual freedom in methods of finishing, when Portland cement is the binder

The resulting mixture is so dry and dense that workmen may walk over and work upon this surface in less time than in the case of ordinary concrete paving The finishing methods include screeding, tamping, rolling, and the removal of high spots by scraping with hand tools Low spots are easily filled with the scrapings or with new mixture This bonds readily with the unset material

III BITUMINOUS SURFACE TREATMENTS AND SURFACE COURSES

During the past four year's new construction processes have been undertaken and developed Some of them are radical departures from the old methods

They are creating a wider interest in low cost roads and from present indications they will fill a long felt need in this field

These methods are principally the results of usage, and of some experimentation which may or may not be classed as research They have been tried out in one way or another in many parts of the United States and under widely varying conditions of climate and topography

Tars and asphalts have been used separately and in combination

Early experiments and developments of these methods used tars for binders, but within a few years asphaltic binders have entered the surface treatment field

As in nearly all types of surfacing there are three different methods in use

1 The penetration method
2 The mixed-in-place method
3 The pre-mixed method

1. *The Penetration Method.* This method is in common usage for penetration macadam The penetration method is used also in all types of surface treatment work, that is, surface treatments which include one or more applications of bitumen and one or more spreadings of cover material.

For the dual treatment or two application method, the principal operations are:

1. Cleaning the compacted base by sweeping with powder sweepers
2. The application of one or two prime coats of bitumen, cold.
3. Allowance of time for this to penetrate. A light cover coat of coarse sand or chips may or may not be used This should be omitted if traffic conditions will permit.
4. The second application of bitumen, hot or cold.
5. Immediate cover with coarse clean and hard aggregates.
6. Compaction with a power roller or by traffic Good practice calls for a power roller.
7. After several days or weeks a seal coat of cold or hot bitumen covered with fine chips, gravel, or coarse sand may be used The texture of the surface and apparent bitumen content will indicate whether or not this seal coat is advisable

Thorough sweeping is important as a layer of dust may destroy the bond between base and top, or it may prevent the penetration of the prime coat

Bitumens are usually applied from a power distributor. Better penetration and greater speed are made possible

Cover materials are spread from piles along the roadside, from dump boards, direct from trucks, by spreading devices attached to the trucks or by mechanical spreaders

Satisfactory results are obtained by using any of these methods.

Following the spreading, some brooming with hand push brooms is usually necessary.

Dragging or light blading with a road machine or both will improve the regularity of the surface

Although some specifications and practise do not call for rolling the final application of cover, rolling with a power roller secures quick initial compaction and prevents, to a large extent, the loss of cover material.

When traffic alone does the compaction the loosely bound cover is easily displaced by the fast moving wheels and it may be lost or mixed with earth at shoulders or ditches.

The construction methods as used for bituminous macadam of the penetration type are described on pages 234-239. They are similar in some features to those described for the dual surface treatment. The principal operations are:

1 Place a layer of coarse stone on the prepared base and roll until particles are interlocked.
2. Apply hot or cold bitumen from a distributor
3. Spread immediately, stone of intermediate size, broom and roll thoroughly.
4. Apply second application of bitumen, hot or cold, and cover with stone chips, fine gravel or coarse sand.
5 Roll thoroughly.

Tightly bound surfaces of stone, gravel, sand clay, lime rock and various other surfaces are suitable for this method The smoothness of the resulting surface is almost directly dependent on the smoothness of the surface to be treated.

2. *The Mixed-in-Place Method.* From present indications the main features of the mixed-in-place method are growing in popularity. It is comparatively new and was developed in Wisconsin about 1923 as a means for forming a bituminous surface on gravel roads which had a loosely bound surface. Today its principal features are used for surfacing sand-clay roads, crushed and screened gravel roads and old or new macadams.

It is particularly adapted to treatments of loosely bound and otherwise unstable aggregates. Surfaces of from 1 to 6 inches thick have been built up by this method.

The depth of treatment depends somewhat on the distance from the road surface to a plane of previously compacted or bonded material, or in the case of sand clays to the predetermined thickness which the engineer may consider adequate to meet climatic and traffic conditions. The resulting surface is regular in contour and has smooth riding qualities. Minor irregularities in the old surface are automatically corrected by this constructive process.

There are two principal types of the mixed-in-place method: *A,* in which no *new aggregates are added* to the *existing surface; B,* in which the *base* is *undisturbed* and *new aggregates* are *added* for mixing with the bitumen

A When no new aggregates are added to the existing surface, except mineral cover for the seal coat (if used). The following are the principal operations:

1. Bring surface to be treated to a regular and smooth contour.
2. Scarify, if necessary, to the proposed depth of new surfacing, harrow, blade and shape
3 Apply first coat of bitumen and mix with harrow and road blade
4 Apply second coat and mix thoroughly.
5 Sometimes a third coat is applied followed by more mixing Mixing is continued until a uniform color results
6. Follow with a final shaping by road blade or drag.
7 Secure initial compaction by rolling. Traffic may serve the purpose.
8 A seal coat of bitumen and chips, gravel or sand may be necessary

Practise in some states calls for a blading of material to the road side The exposed surface is then treated with a prime coat This is followed by a second application The material at the roadside is then bladed over the treated surface and mixed by blading back and forth across the road

B. When new aggregates are added to the existing surface:

1 The old compact surface is smoothed and patched
2. A prime coat of bitumen is applied and allowed to penetrate. It may be left under traffic for several days. A light cover of aggregate may be applied to prevent picking up by traffic
3. If cover is applied it is lightly bladed or turned over with a road machine set nearly cross-wise of the road
4. The second coat of bitumen is applied and covered with aggregate
5 Blading is continued until the cold mix begins to set up
6 Compaction is preferably secured by a roller instead of traffic alone.

C. An alternate method is the following:

1. Patch and smooth the existing surface
2. Spread layer of aggregate
3. Roll until properly shaped
4. Apply first coat of bitumen.
5. Blade lightly to retain crown and cross section until bitumen begins to set.
6. Roll.
7. Apply bitumen for seal coat and spread mineral cover.

If the existing surface is gravel poorly bonded and of inadequate depth, a mixed prime coat of bitumen with the existing gravel may be used instead of the penetration prime coat After mixing, shaping and rolling this course is covered by a bituminous mixed-in-place surface using new aggregates This is in effect two courses, the first or lower course a mixed-in-place prime coat and the second or top layer a mixed-in-place wearing course.

3. *The Pre-Mixed Method* This may be either a hot or cold process. The hot mixed method includes standard mixes of sheet asphalt, bituminous concrete, black base and mixed macadam The cold mixes include cold-patch mixtures, Amiesite, natural rock asphalts and "unnatural" or synthetic rock asphalts They are newer in design and methods of construction that the hot mixes.

The principal steps in construction according to present practise are quite similar.

1. Application of prime coat (if used) of bitumen to the prepared base.
2. Placing and rolling binder course (if used).
3. Mixing and hauling the top or wearing course mixture.
4. Dumping, spreading and raking
5. Compaction by rolling
6 Application of seal coat (if used)

Prime coats of bitumen on bases for hot or cold top have not been standard practise They are called for now in some specifications There is indication that they assist in binding together and waterproofing the immediate surface of the base, and that the top course is more securely bonded to the base The bitumen is applied from a power distributor Cover material is not commonly used.

Binder courses may consist of pre-mixed black base or a course of stone penetrated with bitumen. Binder courses are intended to key the top to the base and to increase the stability of the entire surface.

Dumping, spreading and raking methods are similar for both hot and cold mixes Recently successful attempts have been made to obtain smoother surfaces at less expense for these operations by using mechanical equipment to spread, rake and smooth the loose mixtures, prior to rolling

The cold mixes allow a longer period for patching, luting and screeding A new method used on Kentucky rock is to blade the surface with a heavy road drag after rolling. This insures a much smoother surface than rolling alone. The placing and finishing of cold mixes is less interrupted by traffic and weather conditions than the hot mixes.

Initial compaction of the hot mixes is generally done with a heavy roller and the rolling completed on a given stretch within a few hours Compaction by rolling on the cold mixes may continue with good results over a period of several days.

New construction methods which are meeting with success, and which give promise of increased usage are:

The traffic bound stone, gravel or slag surfacing method.
The mixed-in-place surfacing method
The pre-mixed cold method, and the cold penetration method

New methods in low cost road construction are resulting in smoother riding surfaces, better compaction, faster progress and less interruption to traffic.

MAINTENANCE METHODS

Maintenance work is commonly done by the owner, that is the State, County or Municipality, but contracts are not unusual, especially when the work is extensive and can be definitely specified. The field work is usually performed under the patrol system, or less frequently by the gang system, or by both.

Patrol maintenance is effective for surfaces which require constant attention, such as the frequent blading or dragging of untreated surfaces Gang maintenance is commonly employed where heavier work of considerable extent is necessary, such as scarifying and reshaping, the addition of new materials or the retreatment of bituminous surfaces

Just what the correct definition of highway maintenance may be is still a moot question. In some instances it includes all work not done by the construction contractors, in others it does not include betterments and reconstruction For the purpose of clarity in describing the methods of maintenance it will here include the principal work done to the original surface course for the purpose of keeping it in serviceable condition These items are:

1 Scarifying and reshaping.
2 Blading and dragging.
3 Patching.
4. Addition of new materials, which are similar to those in the existing surface.

One or several of these operations are commonly necessary on any type of low cost road surface. In fact low cost surfaces can give adequate service only by perpetual and persistent maintenance. Because this fact has become generally realized, noteworthy progress in maintenance methods and quality of service has been made

I. SCARIFYING AND RESHAPING

When a roadway surface is so irregular that traffic cannot use it in safety and comfort these two operations may become necessary. The immediate conditions which require these operations on untreated surfaces are high crowns, large areas of pot holes, large protruding stone and corrugations

Bituminous surface treatments and surface courses are scarified and reshaped because of excessive pot holes, corrugations, shoving and raveling. This does not apply to the hot mix and pavement type of surfacing Generally the depth of scarifying is only sufficient to correct or get to the bottom of the irregularities Deep scarifying to the subgrade is usually avoided, care being taken to loosen no more of the existing compacted surface than is necessary.

The surface is scarified or loosened by spikes, securely fastened in a suitable frame. This frame in turn is attached to or pulled by a power roller, tractor or road machine.

Following the scarifying the loosened material is harrowed until the lumps are broken to about the average size of the aggregate in the road. The large lumps and over-size stone are removed

The surface is then bladed until the materials are uniformly mixed and the surface has the desired crown and regularity of contour.

Final compaction is by a power roller or by traffic The operation of scarifying and reshaping usually precedes the addition of new material.

The work is done, if possible, during the season of the year when traffic is light Heavy rains on newly scarified sand-clay roads may make them impassable to traffic or the lack of rain may delay their bonding. Less difficulty to traffic is experienced with stone and gravel surfaces. The season of the year usually selected is soon after the frost has left the ground and before heavy summer traffic begins, or before freezing begins in the fall of the year and after the peak of the summer traffic.

Figure 12. Scarifying a Well-Compacted Surface, Using a Light Roller with Scarifying Attachment

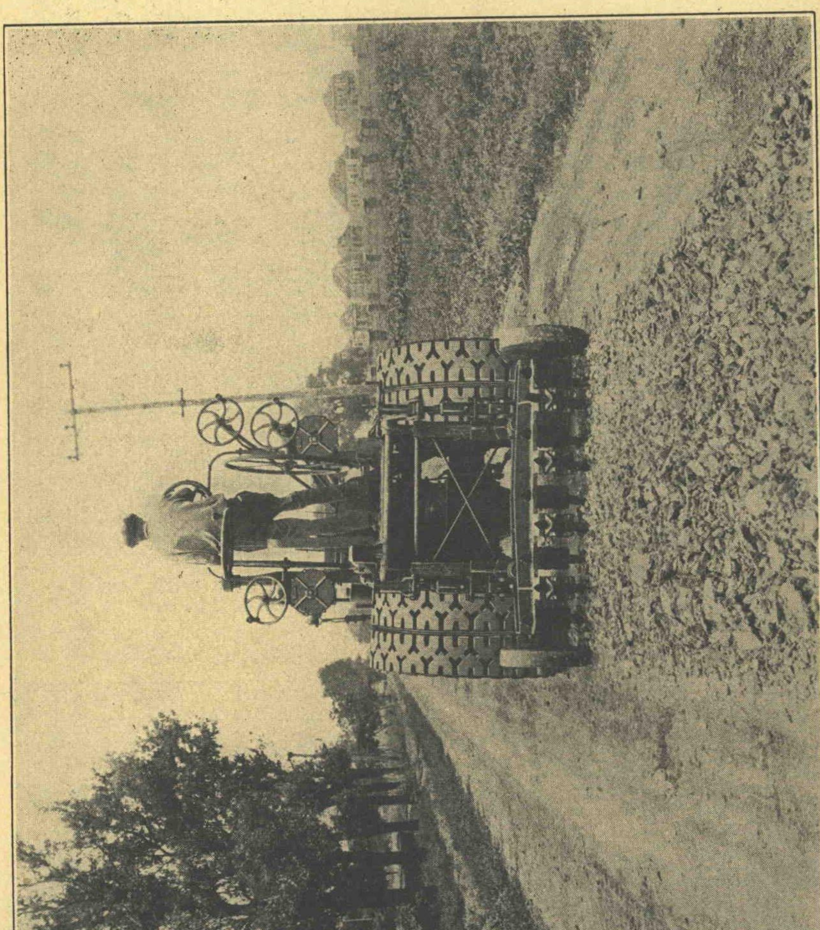


Figure 13. Scarifying with a One-Man Patrol Grader

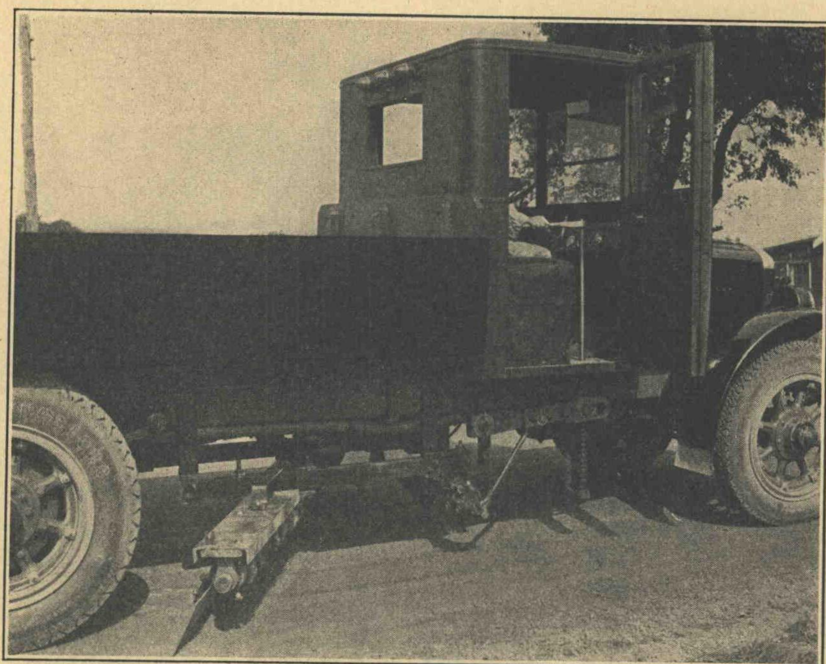


Figure 14. Blading the Thin Surface Gravel Mulch with Spring Blade Swung Beneath a Truck. An Effective Method

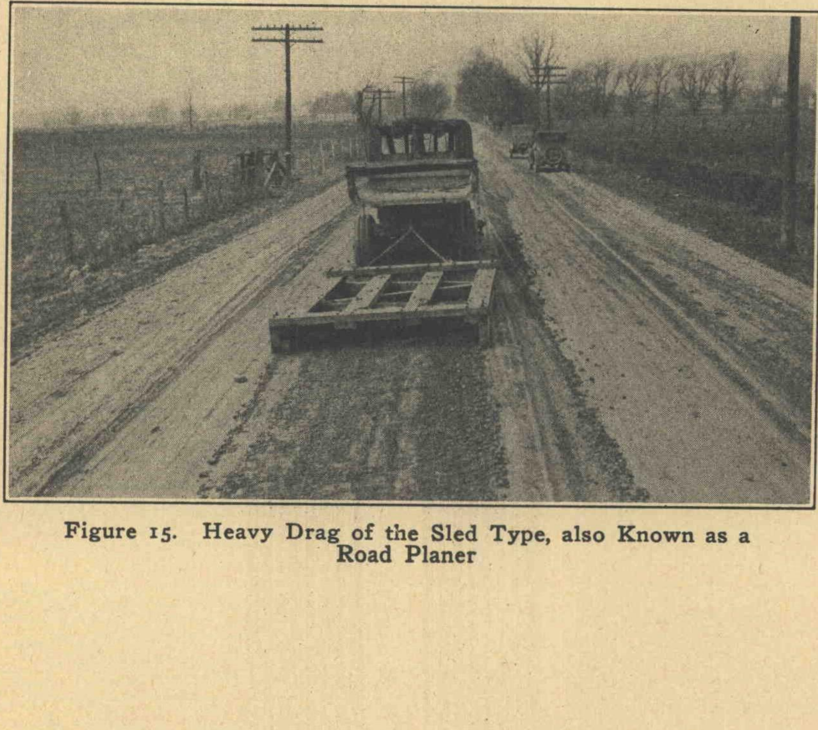


Figure 15. Heavy Drag of the Sled Type, also Known as a Road Planer

2. BLADING AND DRAGGING

For *Untreated Surfaces* containing aggregates which pass the 1½-inch screen one or the other of these operations are required daily or at least three times each week in order to retain a smooth riding surface. The purpose is to cut down the high spots and fill up the low ones.

Maintenance of this character is most satisfactory when the untreated roads or surfaces are treated with calcium chloride and have a thin (about ½-inch) layer of loose stone or gravel on their surface. By blading or dragging this loose material back and forth or along the surface the formation of pot holes and corrugations is retarded.

Figure 16. Blading with Road Machine and Caterpillar Tractor

Light road machines, one-man patrol graders, spring blades attached to trucks and drags are used for the daily and routine maintenance. Heavy road machines and planers are used at less frequent intervals when required to remove irregularities upon which the lighter equipment is not effective.

The light routine work begins as soon as the surface is shaped up in the spring, continues through the summer months and is stopped during the winter if the road is frozen.

During seasons of little or no rainfall an excess of loosened material may be bladed to the outer edges of shoulders to be bladed back again when weather conditions permit.

The blading and dragging operations are continued regardless of weather conditions, except as stated during the time the road surface is frozen These untreated surfaces are put in the best possible condition before going into the winter months, rainy seasons or dry season.

Water-bound macadams or other surfaces which are composed of aggregates larger than two inches are usually well compacted They may be maintained by light blading and dragging if a thin layer of pea gravel or fine stone is kept on the surface at all times

The use of heavy road machines and planers on water-bound macadam is rare A few isolated cases have been reported. *Bituminous Surfaces* seldom require blading and dragging for surface maintenance.

In Long Island on the mixed-in-place fine aggregate type, high spots are cut down and low ones are filled by cutting with a heavy road machine which is followed by a drag or planer. This method is suitable for bituminous surfaces which are more or less plastic and become soft during high atmospheric temperatures.

On bituminous macadam in Connecticut, a treatment with a cut-back or other cold bitumen is used to soften the surface This is followed the next day by repeated draggings with a very heavy road plane. The material thus cut fills the low spots or is spread evenly by drags along the shoulders The results are said to be very satisfactory.

For Bituminous Concrete and Sheet Asphalt the surface heater is used to soften the surface, so that irregularities may be removed.

3. PATCHING

Patching is a necessary but often a temporary expedient

For Untreated Surfaces or those with nonbituminous materials it becomes necessary to fill pot holes which are not properly filled by ordinary blading and dragging. In macadam the loose material is removed and the edges cut square. The hole is then cleaned and fillled with new aggregates containing sufficient binder. Water may be sprinkled on the patch or mixed with the aggregates. Calcium chloride is used as a powder sprinkled on the patch or mixed in solution

Patching of untreated surfaces is done during the seasons of heavy traffic, which are frequently the dry summer months, or when scarifying, reshaping and heavy blading are not advisable.

For Bituminous Surfaces patching is common practise and the results somewhat more permanent than for untreated surfaces. It is for the purpose of filling holes or correcting surface raveling and disintegration

Large holes are cleaned out, their edges cut vertical, the sides and bottom painted with bitumen and the hole filled with a pre-mixed bitumen and aggregate Bituminous concrete and sheet asphalt are patched with either hot or cold patch mixtures For all other bituminous surfaces cold patch mixtures are customarily used. Shallow holes and raveling may be patched by separate applications of aggregate and a hot or cold bitumen

Patching is done throughout the year, except that the major work is not commonly done during the winter months

4 ADDITION OF NEW MATERIALS

This method of maintenance must be resorted to frequently for untreated surfaces Treated surfaces or surface courses require much less new material

For Untreated Surfaces the replacement of lost aggregates is the most costly item in surface maintenance This cost and the depletion of supplies of local aggregates has forced the majority of highway builders to use surface treatments.

The report of the Committee on Maintenance, Sixth Annual Meeting, Highway Research Board, on observations in Indiana showed that the amount of gravel lost was directly proportional to the amount of traffic. Over a three year period on 236 miles of gravel road under observation, the average loss was 257 cubic yards per mile, for an average daily traffic of 892 vehicles Some enlightening information is found in "Public Roads," Vol 8, No 7, where the following statements are made relative to untreated gravel and fine crushed stone roads; "Wyoming and Colorado report an inch of material lost per year under traffic of 200 or 300 vehicles per day and even higher losses in districts where wind is unusually severe Wisconsin reports a loss of 1 to 1½ inches per year for traffic of 500 vehicles per day, and California and Oregon confirm Wisconsin figures"

A report of the Sub-Committee on Maintenance, American Association State Highway Officials, 1926, estimated the annual loss of surfacing gravel to be not less than 300 cubic yards per mile for 400 or more vehicles per day.

A report by Dr. C. M Strahan on Semi-Gravel, Top-soil, and Sand-Clay Road Materials (Highway Research Board, Seventh Annual Proceedings, 1927) states under the subtitle "Loss of Slab Material

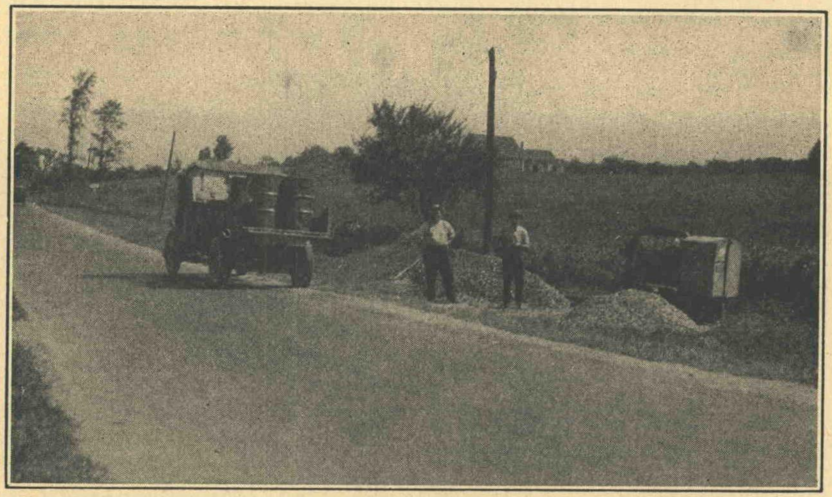


Figure 17. Equipment for Patching Bituminous Treated Gravel

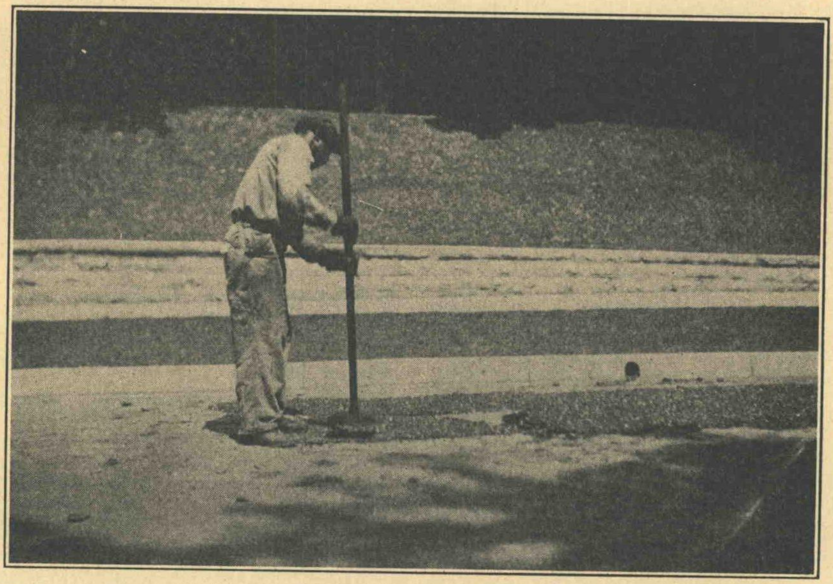


Figure 18. Tamping Cold Patch Material into Holes

under Service," "An approximate general figure from the observed data may be indicated, lying between ½-inch and 1-inch per year under traffic count of 400 to 600 vehicles per day."

In spite of the necessity of replacing lost material many roads must still be maintained in this manner until funds and time are available for surface treatments.

New materials are those similar to that in the existing surface, as a general rule. They are hauled to and there spread and shaped over

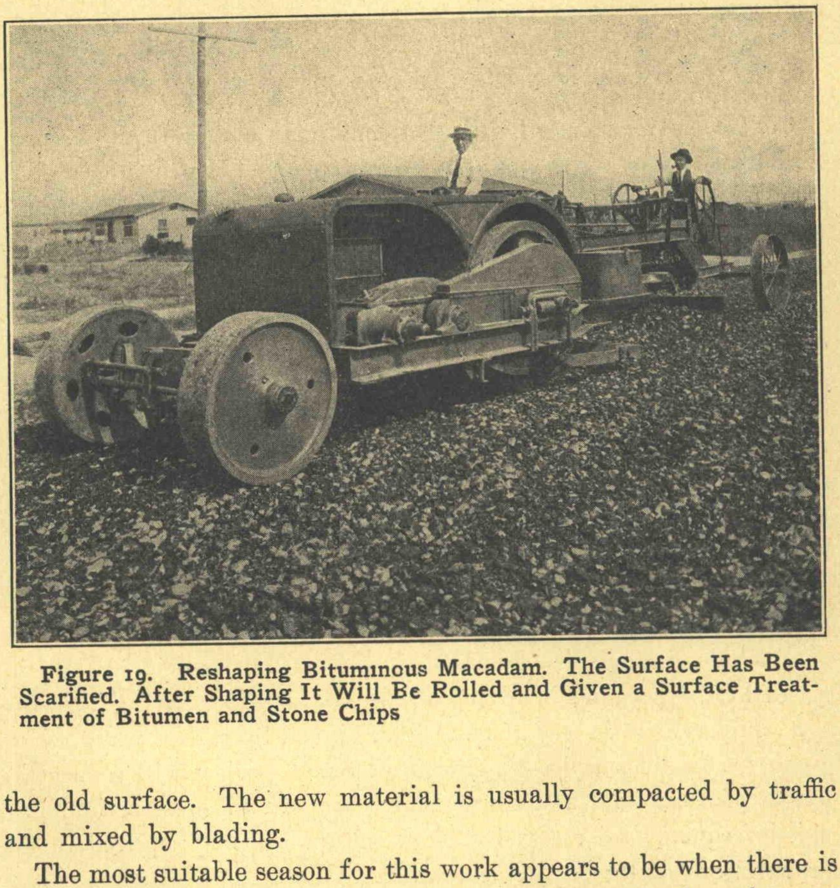


Figure 19. Reshaping Bituminous Macadam. The Surface Has Been Scarified. After Shaping It Will Be Rolled and Given a Surface Treatment of Bitumen and Stone Chips

the old surface. The new material is usually compacted by traffic and mixed by blading.

The most suitable season for this work appears to be when there is sufficient moisture for blading and compaction, and when the new material can become bonded to that in the old surface.

Under traffic, gravel and other surfaces may become loosened, clay is then added as a binder. It must be thinly and evenly applied and thoroughly mixed with the gravel. Iron oxide and non-slaking binders are preferred.

For Bituminous Surfaces scarifying and reshaping are followed by retreatments of bitumen and aggregate for cover. Sometimes additional aggregates are placed and rolled prior to retreatments

Bituminous surfaces which show wear, appear dry and cracked, open or "lean," are given a light retreatment of bitumen and a light cover Surfaces which appear too "rich" and become displaced by traffic are sometimes improved by rolling stone chips or crushed gravel into the surface.

There has been a general marked improvement in maintenance methods during the past eight years.

COSTS OF CONSTRUCTION AND MAINTENANCE

Contract prices for unit items of construction vary from one project letting to another and at a single letting unit bid prices on a given item for a given type of surfacing frequently show wide variations Unit costs for maintenance and construction done by force account are more difficult to obtain than for contract work, this is due in part to the wider variations in maintenance methods, designation of items, standards of workmanship and methods of recording costs Until maintenance records and standards become reasonably uniform, cost data must remain approximate. Nevertheless, from the information available at the present time we may clarify the situation by stating, between necessarily wide limits, the various costs of construction and maintenance They will show, relatively, what work has been done with stated amounts of money

The principal items of cost in construction operations are; for materials, their preparation, hauling and placing This survey does not include an analysis of each of these items. It is evident that the use of local aggregates involving no rail haul effects a saving in initial cost compared to the use of materials shipped by rail or water. Frequent sources of supply of aggregate along a project will reduce the length of local haul and consequently the cost of construction, provided frequent and expensive plant set-ups are not required in the preparations of the surfacing mixtures.

Surfaces which are prepared on the road by mixing in place or by the penetration method show a lower initial cost than those which are prepared at a mixing plant.

The larger the quantity of aggregate and binder which must be shipped in and hauled to the road surface, the greater the cost will be.

For example, sand-clay surfaces are low in first cost because all of the materials are found along the roadside and within short haul distance of final placement, on the other hand pre-mixed types such as natural rock asphalts and certain commercial types of bituminous concretes are shipped relatively long distances by rail, unloaded, and hauled relatively long distances to the point of placement

The principal item of cost in maintenance operations is for new material which must be added to the road surface, including cost of haul Daily blading or dragging of untreated surfaces is a fixed item which is seldom execessive Scarifying and reshaping is done at infrequent intervals of from one to three or four years and does not represent a high yearly cost Patching of untreated surfaces is a small item, but for overloaded bituminous surfaces or pavement types it may reach serious proportions Light retreatments of bituminous surfaces is a relatively small item when figured over a number of years as compared with the necessary addition of large quantities of new aggregates to untreated gravel surfaces

Preliminary surveys for locating suitable local aggregates have in many instances effected a saving in the cost of construction and maintenance.

TABLE 1, APPROXIMATE INITIAL COST OF SURFACING LENGTH ONE MILE, NOT LESS THAN 18 FEET WIDE

Type of surface	Initial cost	Examples in
Untreated Surfaces		
Sand Clay	$1300 to $2600	Southern and Western States
Chert, Shale, Disintegrated Granite	$3000 to $7000	Geo, Ala, W Va, Penn, Ariz, Mex
Gravel	$1500 to $9000	Nearly every state and Canada
Traffic-Bound, Gravel, Slag, Stone	$2000 or less	Ohio, Ind, Tenn, Nebr
Macadam	$8000 to $15,000	Ind, Ky, Ohio, Tenn, N. England
Lime Rock, Marl, Caliche	$4000 to $15,000	Fla, N C, Minn, Ohio, Ariz, Tex, New Mexico
Misc Untreated Surfaces	Less than $10,000	Conn, Mo, Tex, Ohio, Mich, La, Mexico
Surface Treatments and Surface Courses		
Nonbituminous Dust Preventives	$ 400 to $ 700	Mich, Me, Vt, Minn, Wis, N J
Single Bitum Surface Treatments	$ 300 to $1000	N England, Del, Md, N Y, Penn, Va, Ind, Ohio, Tenn
Dual Bitum Surface Treatments	$1100 to $3000	Me, Va, N H, N C, Ohio, Fla, S C, Calif, Tex, Oregon
Mixed-in-Place Bitum Surface Fine Aggregate Types I and II	$ 800 to $5000	N. C, S C, Nev, Cal, L Is, N Y
Mixed-in-Place Bitum Surface Coarse Aggregate Type I	$1100 to $3000	Wis, Minn, La, Calif, Wyo, Ohio
Mixed-in-Place Bitum Surface Coarse Aggregate Type II	$2000 to $4500	Penn, Tenn, Ind
Pre-mixed Bit Surface Laid Cold	$7000 to $12,000 or more	Md, Penn, Del, Tex
Natural Rock Asphalt	$3500 to $6500 or more	Tex, Tenn, Ky, Fla, Ind, Ohio, Ga
Modified or "Puddle" Bit Macadam Cold Application	$7500 and up	W Va, Va, Md
Bituminous Macadam Hot Penetration	$9000 to $17,000	New England, N Y, Pa, Ind, Tenn, Va, Ohio
Pre-mixed-laid Hot Bituminous Surfaces	$10,000 to $25,000	N C, Fla, Del, Mass, R I, Mich, N J., Ga, Canada
Miscellaneous Surfaces Principally Lime Treatments of Clay	$2600 to $3300	Mo, Iowa S D

TABLE 2 UNTREATED SURFACES, SURFACE TREATMENTS AND COURSES—THE INITIAL COSTS OF WHICH FALL WITHIN THE VARIOUS LIMITS NOTED

Costs for 1 Mile, Surfacing Not Less Than 18 Feet Wide

Untreated surfaces	Surface treatments and courses
$500 to $3,000	
Sand Clay Traffic Bound Gravel, Slag, Stone Misc Surf of Vol Cinders, Mine-tailings, Industrial Wastes using Traffic Bound Construction	Nonbituminous Dust Preventives Single Bitum Surface Treatments Dual Bituminous Surface Treatments Mixed-in-Place-Bitum Surface Fine Aggregate Type I Mixed-in-Place-Bituminous Surface Coarse Aggregate Type I Mixed-in-Place-Bituminous Surface Coarse Aggregate Type II
$3,000 to $6,000	
Disintegrated Granite Gravel in General Caliche and Marl	Mixed-in-Place-Bitum Surface Fine Aggregate Type II Mixed-in-Place-Bituminous Surface Coarse Aggregate Type II Natural Rock Asphalts-½" to 1" thick
$6 000 to $9,000	
Macadam Lime Rock, Caliche, Marl Chert, Shale Gravel in General	Pre-mixed-laid cold-Bit Surf Course Type I-2" thick Type II-2" thick Modified or Puddle Bituminous Macadam, Cold Application Pre-mixed, Hot Bituminous Surface Courses, 2" thick Top only
$9,000 to $12,000	
Macadam Lime Rock	Pre-mixed-laid Cold Bituminous Surfaces Bituminous Macadam, Hot application Modified or "Puddle" Bituminous Macadam
$12,000 to $15,000 or more	
Macadam Lime Rock	Pre-mixed-laid Cold Bituminous Surfaces Bituminous Macadam, Hot Application Pre-mixed-laid Hot Bituminous Surfaces

TABLE 3. SHOWING APPROXIMATE COSTS FOR SOME KNOWN COMBINATIONS OF BASE AND SURFACE

Base		Top or surface		Base + top
Type	Cost	Type	Cost	Cost
Sand Clay 1" x 10" x 1" x 24'	$ 2,000	Dual Bituminous Surface Treatment ¾" x 18'	$ 2,500	$ 4,500
Traffic Bound Stone, etc., 6" x 18'	5,000	Calcium Chloride 18' wide	600	5,600
Gravel 6" x 18'	5,000	Calcium Chloride 18' wide	600	5,600
Sand Clay 1" x 10" x 1" x 24'	2,000	Mixed-in-Place Bit. Surface 3" x 18' Fine Aggregate Types	4,000	6,000
Gravel 6" x 18'	5,000	M. I. P. B. S. Type I 1½" x 18'	2,000	7,000
Gravel or Caliche 6" x 18'	5,000	Dual Bituminous Surface Treatment ¾" x 18'	2,500	7,500
Traffic-Bound Stone, Slag, Gravel 5" x 18'	4,000	M. I. P. B. S. Type II 2" x 18'	3,500	7,500
Traffic-Bound Stone, etc., 6" x 18'	5,000	Dual Bituminous Surface Treatment ¾" x 18'	2,500	7,500
Broken Sandstone Base 5" x 18'	7,500	Surface Mulch of Loose Gravel 1" x 18'	1,000	8,500
Macadam 6" x 18'	10,000	Single Bituminous Surface Treatment ¼" x 18'	600	10,600
Macadam 6" x 18'	10,000	Mixed-in-Place Bit. Surface C. A. Type II 2" x 18'	3,500	13,500
Lime Rock or Macadam 6" x 18'	10,000	Dual Bituminous Surface Treatment ¾" x 18'	2,500	12,500
Pre-mixed-laid Hot Bituminous Base 3" x 18', Sand Agg.		Pre-mixed-laid Hot Bituminous Surface 2" x 18'	....	14,000
Broken Sandstone Base 5" x 18'	7,500	"Puddle" Bituminous Macadam 3½" x 18'	7,500	15,000
Macadam 6" x 18'	10,000	Pre-mixed Hot Bituminous Surface 2" x 18'	11,000	21,000
Macadam 6" x 18'	10,000	Bituminous Macadam, Hot Penetration 2½" x 18'	11,000	21,000
Pre-mixed-laid Hot Bituminous Base 3" x 18', Stone Agg.		Pre-mixed-laid Hot Bituminous Surface 3" x 18'		24,000

TABLE 4. SHOWING ANNUAL MAINTENANCE COST OF UNTREATED SURFACE, SURFACE TREATMENT AND COURSES FOR TRAFFIC WITHIN LIMITS NOTED

Untreated surface	An. maint. cost	Surface treatment and courses	An. maint. cost
200 to 500 Vehicles per Day			
Sand Clay	$300 to $600	Single Bitm. Surface Treatments	$300 to $500
Disintegrated Granite	500	Nonbitum. Surface Treatments	300 to 500
Tr. Bd. Gravel, Slag, Stone	250 to 500		
Lime Rock, Caliche and Marl	200 to 600 and up		
Misc. Surf. of Vol. Cinders, Mine Tailings and Industrial Wastes	About equal to Sand Clay		
500 to 1000 Vehicles per day			
Sand Clay	$600 and up	Nonbitum. Dust Preventives	$300 to $600 and up
Chert, Shale	500 and up	Single Bitm. Surface Treatments	200 to 800
Gravel in General	500 to 1000 and up	Dual Bitm. Surface Treatments	200 to 1200
Tr. Bd. Gravel, Slag, Stone	500 to 800 and up	Mixed-in-Place Bitm. Surface—Fine Aggregate Types	300 to 1200
Macadam	500 to 800 and up	Mixed-in-Place Bitm. Surface—Coarse Aggregate Types	300 to 900
1000 to 1500 Vehicles per Day			
		Dual Bitm. Surface Treatments	$200 to $1200
		Mixed-in-Place Bitm. Surface—Coarse Aggregate Types	300 to 900
		Pre-mixed Bitm. Surf. Laid Cold	No data
		Natural Rock Asphalt Surface	200 to 400
		Modified or "Puddle" Macadam	250 to 500
		Bitm. Macadam, Hot Application	150 to 600
		Pre-mixed-laid Hot Bitm. Surf	50 to 300
1500 to 2000 Vehicles per Day			
		Bituminous Macadam, Hot Application	$150 to $600
		Pre-mixed-laid Hot Bituminous Surface	50 to 300

The following information is taken from "Roads and Streets," January, 1928, and is based on reports from state officials, for contract work done during 1927.

AVERAGE CONSTRUCTION PRICES FOR SURFACING

Maine.

	Contract prices
Gravel subbase	$2.156 per cubic yard.
Gravel base course	1.865 per cubic yard.
Stone base course	2.822 per cubic yard.
Crushed stone base course	4.375 per cubic yard.
Gravel surface course	1.959 per cubic yard.
Bituminous Macadam surface course, Stone	5.125 per cubic yard.
Bituminous material applied and delivered in barrels but does not include freight and cost of bitumen	0.055 per gallon.

Pennsylvania.

3-inch Penetration on Reconstructed Base Course	$1.10 per square yard.

Ohio.

	Miles	Contract prices
Surface treating	247.5	$192,523
Traffic Bound Macadam	175.8	352,203
Bituminous Macadam	157.3	4,015,683
Water-bound Macadam	102.5	2,115,994

Indiana.

Bituminous Macadam 7-9 inches thick, 18 feet wide	$18,000 per mile.
Macadam	7,000 per mile.
Gravel	5,000 per mile.
Bituminous Re-tread top 2 inches x 20 feet	5,000 per mile.

Wisconsin.

Crushed Stone Surfacing	$2.19 to $2.43 cubic yard.
Gravel Surfacing	1.00 to 1.40 cubic yard.
Shale Surfacing	1.22 to 1.44 cubic yard.
Top-Soil Surfacing	0.82 per cubic yard.
Mine Tailings Surfacing	0.77 per cubic yard.

North Dakota.

Preparing subgrade for gravel surface	$75.00 per mile.
Load, unload, compact and maintain gravel	0.23 per cu. yd.
Gravel hauling	0.17 per cu. yd. mile.
Screening gravel	0.03 per cubic yard.

South Dakota.

Gravel 24 feet wide, 7 inches thick	$5,000.00 per mile.

Nebraska.

Estimated for 1928	
500 miles of gravel road	$ 2,000,000.

Delaware.

Total 14-ft. widening with concrete 8 inches thick	$ 8,000 per mile.
Macadam 12 feet wide, 6 inches thick	8,000 per mile.

Maryland.

Macadam 15 feet wide, 8 inches thick.................$16,000 per mile.
Gravel 15 feet wide, 8 inches thick.................. 9,000 per mile.
Concrete Shoulder 3 feet each side
Total 6 feet wide, 8 inches thick................... 10,500 per mile.

Virginia.

Widening and oiling 322 miles.......................$965,774.

West Virginia.

Stone base ....$5.00 per cu. yd.
Top for Bituminous Macadam roads............... .75 per sq. yd.
Oil asphalt applied.............................. .18 per gallon.
Tar applied .... .20 per gallon.

North Carolina.

Plain Concrete 16 and 18 feet wide—8"-6"-8" and 6" thick ....$25,000 per mile.
Gravel, Top Soil and Sand Clay—30 to 35 feet wide, feather edge section (9 inches center thickness) .... 9,000 per mile.
Sand Asphalt 18 feet wide, 5 inches thick............ 17,000 per mile.
Road Oil Treatment (various widths)............. 5,200 per mile.

Florida.

Lime Rock Base surface treated 236.6 mi..........$3,580,584.

Idaho.

Oil Treated Macadam 18 feet wide 2 inches thick..$2,017 per mile.
Crushed gravel or rock surfacing.................. 1.748 per cubic yard.
Surfacing Binders .... 0.53 per cubic yard.

Montana.

Gravel road 16 feet wide and 6½ in. thick..........$10,000 per mile.

Wyoming.

Gravel surfacing ....$1.59 per cubic yard.
Crushed rock surfacing........................... 2.76 per cubic yard.
Overhaul .... 0.03 per station yard.

Nevada.

Gravel and Crushed Rock (Surfacing)—15 feet wide, 6½ inches thick..........................$7,364 per mile.
Gravel Surface only—18 feet wide, 6½ inches thick .... 3,991 per mile.
Oiled Gravel, Turnover Method, 18 feet wide, 3 inch Penetration .... 2,105 per mile.
Crushed Gravel surface........................... 1.36 per cubic yard.

Oregon.

Gravel or broken stone surface, 18 feet wide, 8 inches thick....................................$7,000 per mile.
Oiling surfacing .... 900 per mile.

California.

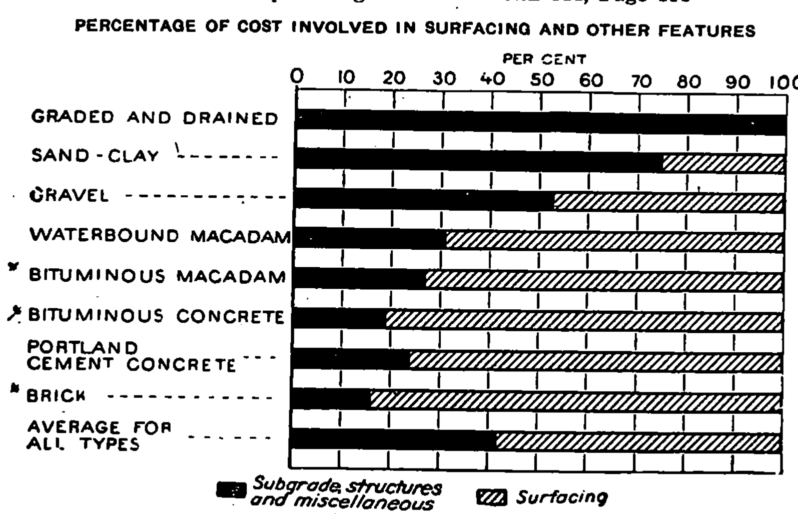
Graded and Rock Surfacing.
Surfacing 4 to 8 inches thick and 20 to 24 feet wide. ....$25,154 per mile.

AVERAGE 1927 CONSTRUCTION PRICES FOR GRADING AND DRAINING

		Miles	Contract prices
Ohio	Grading and Drainage Structures.	128	$1,914,282
Wisconsin	Graded and Drained		6,050 per mile.
Minnesota	Graded and Drained 30 to 40 ft. wide		11,378 per mile.
Missouri	Graded and Drained		14,000 per mile.
North Dakota	Graded and Drained 24 ft. wide..		3,800 per mile.
South Dakota	Graded and Drained	200	640,000
Nebraska	200 miles of grading and 500 miles of gravel road		2,000,000
Virginia	Graded and Drained	110	2,146,338
West Virginia	Graded and Drained		15,000 per mile.
North Carolina			8,500 per mile.
Georgia	Grading	354	2,866,231
Mississippi	Graded and Drained		5,000
Oklahoma	Graded and Drained		5,500 per mile.
Texas	Grading and Drainage Structures.	389	2,648,752
Idaho	Graded and Drained		3,243 per mile.
Montana	Graded and Drained		9,500 per mile.
Wyoming	Graded and Drained		7,000 per mile.
New Mexico	Graded and Drained		7,193 per mile.
Oregon	Graded and Drained		15,000 per mile.
California	Graded and Drained		19,038 per mile.

AVERAGE COST OF FEDERAL ROADS 1917 TO 1924

From U. S. Dept. of Agriculture Bulletin 914, Page 114



x—Includes base course.

Figure 20. In the Construction of a Road the Grading and Structures May Be Considered as the Relatively Permanent Parts of the Road, and the Expenditure Therefor as a More or Less Permanent Investment. The Surfacing Requires Renewal at Intervals, the Length of Which Depends Upon the Type and the Traffic

TABLE 5 AVERAGE COST OF FEDERAL-AID ROADS PER MILE 1917 TO 1924

From U S Dept of Agriculture Bulletin 914, Page 114

Type	Average cost per mile	Per centage of average cost per mile for— Grading	Surfacing	Shoulders	Struc-tures	Miscel laneous
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Graded and drained earth	$7,800	68			28	4
Sand-clay	7,400	41	25		29	5
Gravel	9,900	31	47		18	4
Water-bound macadam	17,500	17	69		11	3
Bituminous macadam includes base	29,100	13	73	2	10	2
Bituminous concrete includes base	33,500	9	81	1	6	3
Portland cement concrete	38,300	13	76	1	8	2
Brick includes base	44,700	9	84	1	5	1
Average for all types	16,900	23	58	1	15	3

NOTE —Structures include culverts under 20 feet in span, drains, retaining walls, revetments, etc

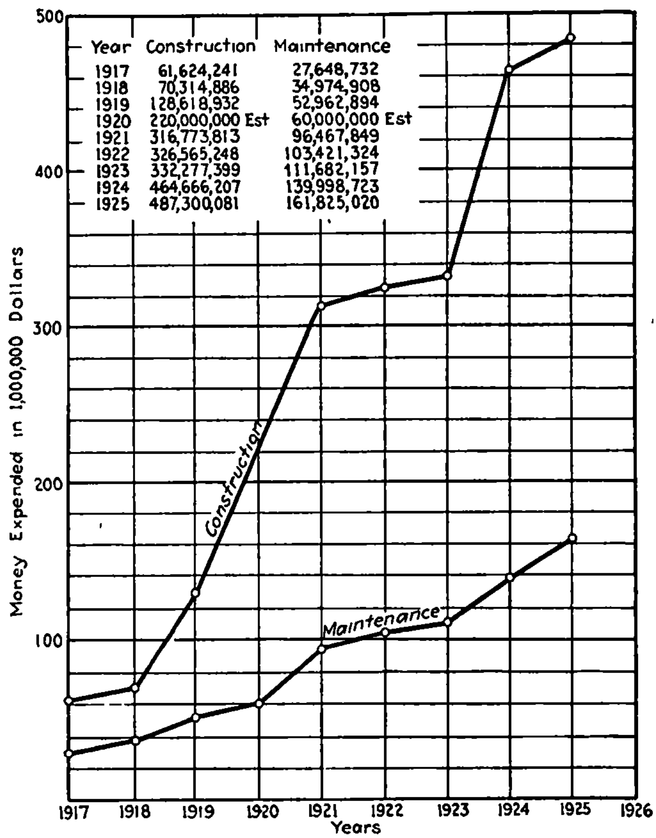


Figure 21 Annual Expenditures by State Highway Departments

(From Engineering News Record, Vol 99, No 5 "Road Maintenance by Contract." By C F Schlesinger)

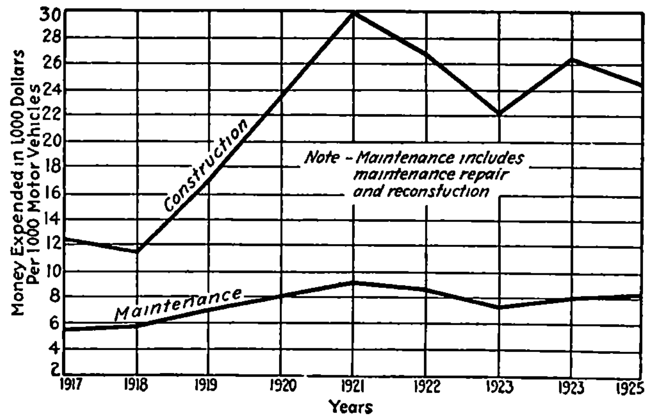


Figure 22. Annual Expenditures on State Roads Per 1000 Motor Vehicles, (Maintenance Includes Repairs and Reconstruction)

(From Engineering News Record, Vol 99, No 5 " Road Maintenance by Contract " By G F Schlesinger)

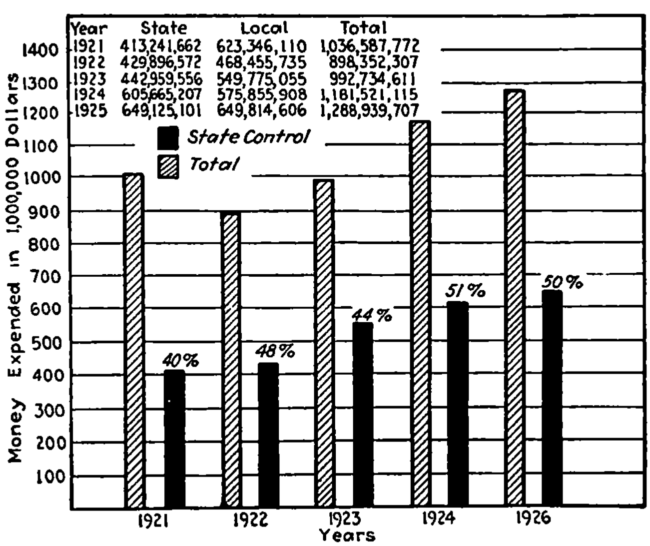


Figure 23 State vs. State and Local Highway Expenditures

(From Engineering News Record, Vol 99, No 5 " Road Maintenance by Contract " By G F Schlesinger)

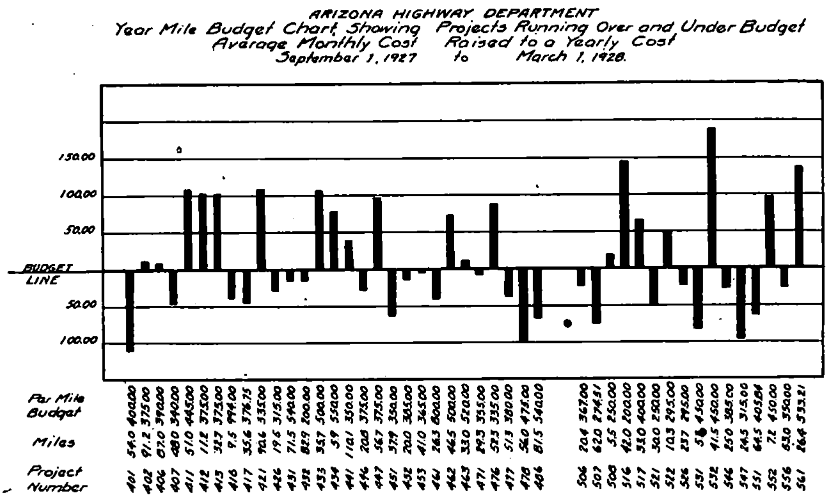


Figure 24. Budgeting Maintenance Costs in Arizona

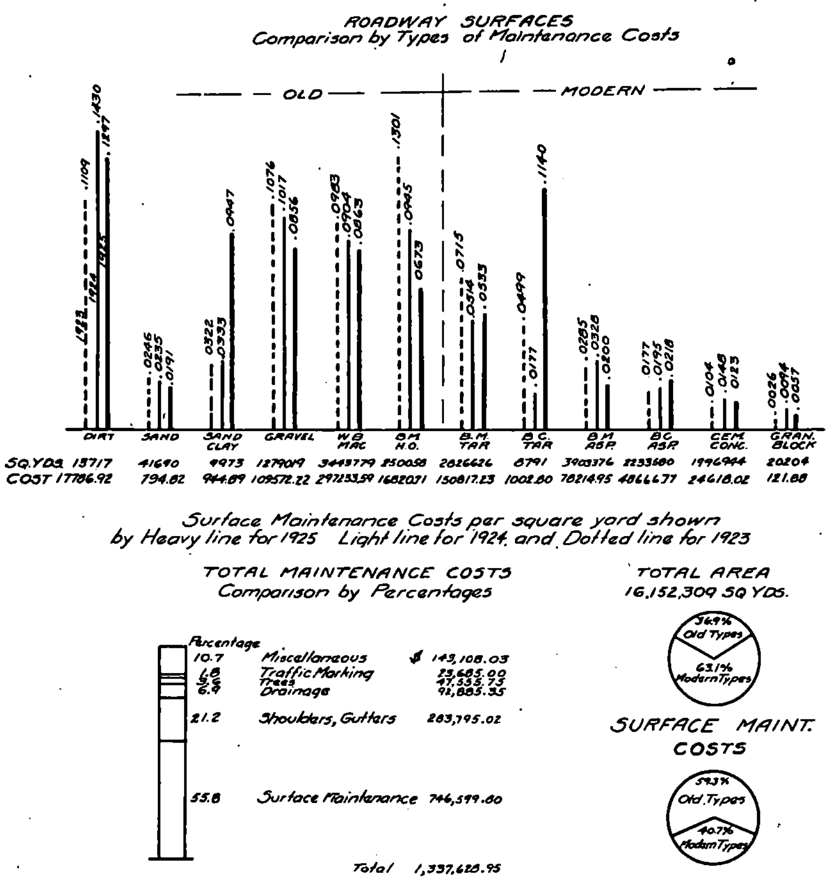


Figure 25. Surface Maintenance Costs in Massachusetts

The cost of grading and drainage may or may not be a relatively expensive item as compared with the total cost of the completed road The foregoing information from the various states and Figure 20 show that the average cost of grading and drainage is no more than the cost of the more expensive types of untreated surfaces In mountainous country it may be much more, but in flat and gently rolling country it may be much less than the cost of the more expensive untreated surfaces

Where anticipated traffic is light, Ohio has utilized the locations of existing roads in fairly heavy country. Only the necessary widening and drainage has been done This, with a traffic-bound surface of stone, slag or gravel has kept the initial cost of grading and surfacing to about $3000 per mile

Untreated surfaces in general cost less than $10,000 or $12,000 per mile and more than $2000 Sand clays and the traffic-bound types are the lowest in cost, lime rock and macadams are the most expensive, the cost of gravel is about an average of these two The annual maintenance cost of untreated surfaces is seldom permitted to exceed $600 or $800 per mile for traffic up to about 600 vehicles per day before surface treating or a change in type Some untreated surfaces are carrying more than this number at a lower maintenance cost, while others are carrying a smaller number at an equal or greater cost.

Surface treatments and surface courses on previously untreated surfaces which are used as bases, seldom exceed $5000 to $6000 per mile, according to present practise They are expected to accommodate from 600 to 1500 vehicles per day

The initial calcium chloride treatments and their first year's surface maintenance is less than $1000 per mile. The dual bituminous surface treatments and some mixed-in-place types cost less than $3000 per mile for the initial construction and first year's maintenance

The thicker mixed-in-place types which use relatively high cost aggregates may cost $4000 to $5000 per mile.

Natural rock asphalts and pre-mixed bituminous concretes, when shipped by rail, and bituminous macadams usually cost $8000 to $12,000 or $15,000 per mile.

If the combined cost of base, surface treatment and surface course exceeds one half the cost of a pavement such as Portland cement concrete, engineers commonly consider the pavement preferable, for new construction.

Highway officials appear willing to spend for maintenance up to $600 per mile for untreated surfaces, up to $1000 per mile for surface treatments and up to about $300 to $500 per mile for the more expensive types of surface courses. This is, provided these surfaces are carrying up to 500 or 600 vehicles daily on the untreated surfaces, up to 1000 or 1500 for the surface treatments and more than 1500 for the pavement types.

Budgeting maintenance costs is now common practise in state highway organizations. The Arizona chart (Figure 24) is an example The chart (Figure 25) for Massachusetts shows that maintenance costs of various types in that state are under yearly comparison. The curves shown in Figure 21 indicate that maintenance on state highways is about 30 per cent of the construction costs.

Figure 22 shows that maintenance costs on state highways for each 1000 vehicles have not increased in the past seven years and that construction costs have decreased.

Figure 23 indicates that the state highway units have gradually increased their expenditures until 1926 when they were ½ the total amount spent by the local units and state highway departments combined.

Surfaces low in first cost are still being built where funds are not available for high types and the cost of maintenance on these types for traffic of less than 1000 vehicles per day apparently is not a deterring factor in their selections.

SELECTION OF TYPE

The selection of type for low cost road surfaces is based on two principal factors, necessity and adequacy. Necessity is evidenced by the immediate need for long mileage of roads of this class in communities which have insufficient funds for long connected mileages of high type surfaces.

The adequacy of certain local materials for surfacing has been demonstrated by states which have used them extensively either treated or untreated.

Such materials will quickly become inadequate without careful construction and intelligent maintenance.

Selection of untreated surfaces is based primarily on the availability and cost of suitable local aggregates. They should be of such quality and gradation that the surface built from them can be bladed or dragged at frequent intervals by motor-driven equipment. Untreated surfaces which meet these requirements are sand clay, gravel, shale, chert, disintegrated granite, traffic bound surfaces of fine stone, slag or gravel and caliche.

Macadam and lime rock need a layer of gravel or fine crushed stone before they can be maintained by blading.

Surface treatments with nonbituminous dust preventives are adequate when maintained by frequent blading or dragging.

Bituminous surface treatments or surface courses are considered adequate provided they are susceptible to scarifying, reshaping and retreating at periods of from 1 to 3 years and the cost does not exceed about $1200 per mile for the work and materials. Such types are the dual bituminous surface treatments and the mixed-in-place bituminous surfaces.

Surfaces which approach or include the pavement types, such as bituminous macadams, natural rock asphalts and the pre-mixed bituminous types which are laid hot or cold are not as readily maintained by scarifying, reshaping and retreating, and they are not as frequently selected for low cost surfaces.

The riding qualities of a surface are of prime importance Those types which include blading, dragging or screeding in their construction or maintenance have better riding qualities than those which do not.

Types are desirable which under maintenance or reconstruction can be renewed by the addition of small quantities of new materials as required and without serious interruption to traffic

The reconstruction and resurfacing of old existing surfaces which have been compacted through years of traffic are frequently possible and advisable This new surface is usually one of the low cost bituminous types.

Progressive or stage construction is now recognized as a sound economic policy.

It means the gradual improvement of a highway, first by proper grading and draining; and second, by the addition of untreated surfacing aggregates either in thin layers placed at periodic intervals as required, or placed to a greater depth in one operation.

As traffic demands increase, this untreated surface is given one of several types of surface treatment. When traffic requirements become still more severe, a pavement type of surfacing may be indicated By this method of stage construction, the original investment has not been lost because the materials already in the road have given adequate service for the changing conditions of traffic and the weak spots in the subgrade have been corrected under maintenance.

In the last stage, the existing untreated or treated surface is of value as a sub-base for a pavement.

Although it is true that tests have shown a greater cost of vehicle operation and tire wear on gravel and stone surfaces than on pavement types, yet it has not been shown by research or test what it costs the owners of vehicles to be without these gravel and stone surfaces.

It is also probable that tests on surface treated gravel and stone would show a considerable reduction in vehicle operation costs below those for the untreated surfaces

There is small doubt that expensive pavement types have been constructed where a surface of less than half the cost would have been adequate The desire to cut maintenance costs, to avoid the inconvenience of perpetual surface maintenance, and the lack of knowledge or of equipment to perform this maintenance have been the principal reasons for such selections.

Climatic and soil conditions apparently have not been of major importance in selecting low or high type surfaces, for treated and untreated gravel is found in nearly every state regardless of the local conditions.

There is no doubt that unit vehicle weight is a factor which cannot be ignored in the selection of type. If the present or probable traffic is to include even a small number of heavy trucks, equipped with solid tires, low type surfaces will become inadequate. This was proved for average conditions of soil and climate during the war period of 1916-1918 when many miles of macadam and lower cost roads were destroyed.

More recently busses, milk trucks, and gasoline trucks have become a factor which must be considered or regulated when making a selection of surface.

Selection of type is a prescription proposition

An engineer who is already familiar with the local conditions of his own surfaces, available materials and funds, will do well to make an examination of the work done by others under similar conditions His final choice will be more easily and intelligently made.

In spite of the deterring factors and perplexing problems involved in selection, low-cost road construction has been found necessary and must continue as evidenced by the following tabulations and this recent statement from the Chief of the Bureau of Public Roads:

"As a matter of fact, to a large extent all highway construction must be stage construction, and there can be no just criticism of whatever is undertaken if it be undertaken intelligently with a well-defined conception of the future development and if the execution of the idea is efficient."

TABLE 6

ILLUSTRATING THE PREPONDERANCE OF LOW COST TYPES AND THE UTILIZATION OF LOCAL MATERIALS FOR UNTREATED TYPES

UNITED STATES DEPARTMENT OF AGRICULTURE, BUREAU OF PUBLIC ROADS

STATE HIGHWAY SYSTEMS [a]

EXISTING MILEAGE AT END OF YEAR 1925 M-4 (1925) Revised R S A.

States	1925 year ends	Grand total mileage, state highway system	Earth roads, non-surfaced: Total non-surfaced mileage	Earth roads, non-surfaced: Unimproved, and partly graded	Earth roads, non-surfaced: Improved to estab grade and drained	Surfaced roads by types: Total surfaced mileage	Sand-clay and top-soil	Gravel, chert, shale, etc (treated and untreated)	Water-bound macadam (treated and untreated)	Bituminous macadam by penetration	Sheet asphalt	Bituminous concrete	Portland cement concrete	Block pavements: Vitrified brick	Block pavements: Asphalt	Block pavements: Wood	Block pavements: Stone	States
Alabama	9/30	3,953 5	2,120 5	2,076 2	44 3	1,833 0	591 5	1,016 7	52 4	36 8	5 7	93 6	36 1			0 2		Alabama
Arizona	12/31	2,014 4	561 9	248 1	313 8	1,452 5		1,265 2			15 0	31 7	140 6					Arizona
Arkansas	12/31	8,295 0	4,500 0	3,860 0	640 0	3,795 0		2,913 0	217 0	156 0	32 0	271 0	206 0					Arkansas
California	12/31	6,591 4	3,208 1	2,534 3	[b]673 8	3,383 3		[b]862 0	[b]61 0	325 4		390 2	1,744 7					California
Colorado	12/31	8,932 8	5,476 0	4,844 2	631 8	3,456 8		3,231 7				5 9	219 2					Colorado
Connecticut	6/30	1,871 9	146 9		146 9	1,725 0		412 1	686 0	205 1		125 2	294 9	1 7				Connecticut
Delaware	12/31	505 7				505 7		1 0	1 3	18 1		2 3	476 6	6 4				Delaware
Florida	12/31	5,615 8	3,070 9	3,029 2	41 7	2,544 9	789 8	8 3	802 6	177 6	206 3	33 7	131 6	337 0	58 0			Florida
Georgia	12/31	6,231 7	3,759 2	3,629 4	129 8	2,472 5	1,542 2	498 3	48 8	118 6	34 9	9 2	219 9	0 6				Georgia
Idaho	12/31	4,627 8	2,430 9	2 081 4	349 5	2,196 4	83 3	1,582 8	404 0		5 4	77 5	43 4					Idaho
Illinois	12/31	4,793 6	656 7	385 0	271 7	4,136 9			0 6	5 7	4 6	8 7	4,047 4	69 9				Illinois
Indiana	12/31	3,936 0	75 6	14 7	60 9	3,860 4		1,629 8	1,028 3	172 9		26 0	933 8	68 6		1 0		Indiana
Iowa	12/31	6,674 1	3,644 7	1,848 7	1,796 0	3,029 4		2,460 8					535 3	33 3				Iowa
Kansas	12/31	7,386 0	6,423 2	5,931 4	491 8	962 8	81 0	201 1		94 9		3 0	450 5	132 3				Kansas
Kentucky	12/31	8,000 0	5,727 7	5,186 2	541 5	2,272 3		603 9	1,267 1	223 3		13 8	159 0	5 2				Kentucky
Louisiana	12/31	7,000 0	3,178 3	3,178 3		3,821 7		3,752 1	8 5	20 2		12 4	13 5	15 0				Louisiana
Maine	12/31	1,459 4	240 7	240 7		1,218 7	7 3	950 9	7 5	197 1			55 9					Maine
Maryland	9/30	2,275 8				2,275 8		332 0	1,058 8		37 9	24 3	821 5	1 3				Maryland
Massachusetts	11/30	1,541 8	12 7		12 7	1,529 1		133 3	344 8	655 5		192 7	200 1	0 8		0 1	1 8	Massachusetts
Michigan	12/31	6,706 4	680 8	680 8		6,025 6		3,610 4	645 8	76 6		183 7	1,502 6	6 5				Michigan
Minnesota	12/31	6,954 5	975 8	98 6	877 2	5,978 7	151 3	5,151 5	14 8	8 0		67 8	560 2	12 6		12 5		Minnesota
Mississippi	12/31	5,500 9	2,811 2	2,534 2	277 0	2,689 7	5 4	2,440 9	10 7	4 9	6 7	18 9	188 0	19 2				Mississippi
Missouri	12/31	7,640 0	5,086 9	3,149 0	1,937 9	2,553 1		1,481 4		94 4			960 4	16 9				Missouri
Montana	12/31	7,957 2	7,097 8	6,815 2	282 6	859 4		818 9	0 6	5 5		2 3	32 1					Montana

[a] Roads under control of state highway departments Does not include roads under county and local control
[b] Estimated, as state does not segregate mileage of earth improved, gravel and waterbound macadam

TABLE 6—Continued

ILLUSTRATING THE PREPONDERANCE OF LOW COST TYPES AND THE UTILIZATION OF LOCAL MATERIALS FOR UNTREATED TYPES

UNITED STATES DEPARTMENT OF AGRICULTURE, BUREAU OF PUBLIC ROADS

State Highway Systems [a]

Existing Mileage at End of Year 1925 M-4 (1925) Revised R S A.

States	1925 year ends	Grand total mileage, state highway system	Earth roads, non-surfaced			Surfaced roads by types												States
			Total non-surfaced mileage	Unimproved, and partly graded	Improved to estab grade and drained	Total surfaced mileage	Sand-clay and top-soil	Gravel, chert, shale, etc (treated and untreated)	Water-bound macadam (treated and untreated)	Bituminous macadam by penetration	Sheet asphalt	Bituminous concrete	Portland cement concrete	Block pavements				
														Vitrified brick	Asphalt	Wood	Stone	
Nebraska	12/31	6,255 9	4,325 7	3,453 9	871 8	1,930 2	315 1	1,523 4			2 6	8 7	60 9	19 5				Nebraska
Nevada	12/31	2,996 7	2,123 1	1,928 6	194 5	873 6	10 1	791 4		22 1		3 2	46 8					Nevada
New Hampshire	12/31	2,196 7	375 3	290 7	84 6	1,821 4		1,508 0	106 9	127 5		66 3	12 7					New Hampshire
New Jersey	12/31	1,290 0	108 1		108 1	1,181 9		279 1	88 4	13 7	52 2	229 0	497 8	4 1	2 7	6 3	8 6	New Jersey
New Mexico	12/31	9,159 7	7,543 5	7,343 5	200 0	1,616 2		1,544 2				0 7	71 3					New Mexico
New York	12/31	14,068 0	4,500 6	4,495 8	4 8	9,567 4		106 6	2,313 7	4,078 3		247 1	2,536 4	262 6	23 4	0 6	3 7	New York
North Carolina	12/31	6,134 0	742 4		742 4	5,391 6	2,286 3	778 6	156 6	361 9	63 9	674 5	1,023 0	46 8				North Carolina
North Dakota	12/31	6,174 0	5,370 5	3,051 3	2,319 2	803 5		796 3			0 5		6 7					North Dakota
Ohio	12/31	10,784 0	3,558 8	3,452 4	106 4	7,225 2		1,694 5	1,237 5	1,303 8	34 9	235 5	1,364 6	1,354 4				Ohio
Oklahoma	12/31	5,589 0	4,240 6	4,215 0	25 6	1,348 4		788 6				73 0	454 5	32 3				Oklahoma
Oregon	12/31	4,446 6	1,438 2	1,102 9	335 3	3,008 4		2,113 7				695 2	199 5					Oregon
Pennsylvania	12/31	10,842 7	3,300 1		3,300 1	7,542 6		335 9	2,842 5	381 0	201 8	274 9	3,134 7	358 5	7 1	3 4	2 8	Pennsylvania
Rhode Island	12/31	768 5	362 7	362 7		405 8		19 0	105 5	95 9	5 5	134 4	45 5					Rhode Island
South Carolina	12/31	4,951 0	1,730 2	1,688 4	41 8	3,220 8	2,643 6	279 6	27 3	11 2	65 9	49 0	144 2					South Carolina
South Dakota	12/31	5,918 0	3,895 0	1,720 9	2,174 1	2,023 0	20 4	2,001 3					1 3					South Dakota
Tennessee	12/31	5,046 4	1,715 9	1,481 3	234 6	3,330 5		1,532 2	1,080 4	479 0	35 0	66 7	137 2					Tennessee
Texas	12/31	18,728 0	9,946 6	8,882 8	1,063 8	8,781 4	424 2	5,354 3	739 6	1,601 2	19 6	25 0	535 3	82 2				Texas
Utah	12/31	3,227 9	2,169 2	775 8	1,393 4	1,058 7		803 2			11 1	43 4	201 0					Utah
Vermont	12/31	4,453 0	1,453 0	503 0	950 0	3,000 0	1,000 0	1,875 0	50 0	41 0			34 0					Vermont
Virginia	12/31	5,077 3	1,517 3	1,259 2	258 1	3,560 0	921 8	710 2	1,028 6	456 9	8 8	3 2	430 5					Virginia
Washington	12/31	3,266 3	724 0	558 0	166 0	2,542 3		1,910 0		40 0	2 0	40 0	536 0	14 3				Washington
West Virginia	12/31	3,664 0	2,401 3	1,719 3	682 0	1,262 7		164 9	117 6	388 6	0 7	74 9	365 1	150 9				West Virginia
Wisconsin	12/31	10,264 5	2,286 5	822 1	1,464 4	7,978 0	152 0	5,747 2	145 7	111 6			1,821 5					Wisconsin
Wyoming	12/31	3,143 3	2,341 5	1,797 5	544 0	801 8		755 5	8 1			27 1	11 1					Wyoming
Totals		274,910 7	130,056 6	103,270 7	26,785 9	144,854 1	11,025 3	68,770 8	16,709 0	12,105 3	853 0	4,560 7	27,644 9	3,052 9	91 2	24 1	16 9	Totals

TABLE 7

THE LOW COST ROAD SURFACES OF LOCAL MATERIALS ARE IN GREATER EVIDENCE IN THE SECONDARY ROADS THAN IN THE STATE HIGHWAY SYSTEMS

UNITED STATES DEPARTMENT OF AGRICULTURE, BUREAU OF PUBLIC ROADS

TOTAL MILES OF EXISTING ROADS IN COUNTY AND LOCAL RURAL ROADS AT END OF YEAR 1925

(NOT ON STATE HIGHWAY SYSTEMS)

M-5 (1925) R S A

States	Grand total mileage rural roads, other than state hwy system	Unimproved and earth partially graded	Earth to established grade and drained	Total miles of road, surfaced	Sand-clay	Gravel, etc., untreated	Water-bound macadam, untreated	Surface-treated macadam and gravel	Bituminous macadam, by penetration	Sheet asphalt	Bituminous concrete	Portland cement concrete	Block pavements					States
													Brick	Stone	Wood	Asphalt	Misc	
Alabama	57,587 8	38,819 0	7,540 8	11,727 5	6,199 9	4,742 1	426 9	185 3	118 0	28 1	14 4	12 8						Alabama
Arizona	20,537 7	16,990 2	1,809 0	1,738 5	648 8	761 9						261 2						Arizona
Arkansas [a]	66,570 0	62,604 5	1,261 0	2,704 5	150 2	2,224 9	162 2	28 4	83 7	9 4	35 9	9 8						Arkansas
California	72,606 0	28,034 0	29,953 0	14,619 0	[b]2,380 0	7,110 4	941 8	175 6	1,206 1		807 1	1,998 0						California
Colorado	58,905 7	24,878 4	28,884 3	5,143 0		5,108 5					34 5							Colorado
Connecticut	11,474 1	8,010 5	2,579 1	884 5		8 4	135 4	564 3	100 8	4 0	19 7	51 9						Connecticut
Delaware	3,290 3	1,777 1	1,237 0	276 2		50 0	28 4	151 8	21 1		20 8	4 1			0 5			Delaware
Florida	25,773 4	15,000 2	3,124 1	7,649 1	3,429 0	1,381 4	627 2	501 8	389 6	611 7	47 3	146 6	389 5			125 0		Florida
Georgia	91,660 5	51,408 4	24,014 4	16,237 7	11,866 7	3,203 1	182 5	114 3	274 2	36 7	70 0	490 2						Georgia
Idaho	30,775 0	8,155 0	12,700 0	9,920 0		9,315 0	475 0		60 0		—						70 0	Idaho
Illinois	91,506 5	79,746 5	669 0	11,091 0		7,075 7	2,628 5	138 0	64 1	28 4	34 0	962 3	152 0		8 0			Illinois
Indiana [e]	69,195 3	24,930 5		44,264 8		30,908 9	11,744 8	235 8	267 0		162 1	796 8	149 4					Indiana
Iowa	96,247 0	92,466 0	824 5	2,956 5		2,954 5						2 0						Iowa
Kansas	120,577 8	112,783 1	5,562 6	[d]2,232 1	478 6	668 7	245 8	68 2	127 8	1 5	6 8	552 9	86 8					Kansas
Kentucky	60,704 0	45,526 0	219 2	14,958 8	70 0	3,173 0	10,648 9	845 3	28 5	56 0		36 1	4 0		5 0		97 0	Kentucky
Louisiana	32,803 0	31,441 2		1,361 8		1,350 0			3 2		5 6		3 0					Louisiana
Maine	19,806 1	16,287 4	8 9	3,059 8	73 7	2,910 7	9 9	47 9	11 7	1 5	2 5	1 8		0 1				Maine
Maryland	12,489 0	8,600 0	1,579 0	2,260 0	414 0	830 0	[c]442 0	444 0	70 0			60 0						Maryland
Massachusetts	17,540 6	558 8	10,623 1	6,359 2		2,168 6	141 1	2,785 7	922 2	0 7	275 1	48 6	4 8	10 5	1 9			Massachusetts
Michigan	70,576 7	54,253 6	835 1	15,488 0	67 5	12,858 9	1,240 6	365 7	119 0	2 0	93 4	505 4	3 6				231 9	Michigan
Minnesota	101,125 7	80,736 3	1,983 4	18,406 0	3,815 1	14,349 0	75 4	67 4		7 8	21 9	66 0	2 5					Minnesota
Mississippi	50,607 1	42,400 4	986 8	7,219 9	407 4	6,464 4	39 5	71 6	182 6		6 0	45 3	3 1					Mississippi
Missouri	102,860 0	84,789 0	10,014 0	8,057 0	1,872 0	3,426 0	154 0	2,297 0	147 0		49 0	112 0						Missouri
Montana	59,219 9	58,889 9		330 0		330 0												Montana

[a] During year 1,577 miles of county roads were transferred to State highway system, about 370 miles were surfaced roads
[b] Includes about 2,000 miles of sand-clay roads not previously reported
[c] The decrease of about 7,000 miles from previously reported mileage due to a new survey by State Maintenance Department
[d] Large increase in surfaced mileage, over 1924, due to corrections of survey
[e] Includes 224 0 miles of traffic-bound loose rock road

TABLE 7—Continued

THE LOW COST ROAD SURFACES OF LOCAL MATERIALS ARE IN GREATER EVIDENCE IN THE SECONDARY ROADS THAN IN THE STATE HIGHWAY SYSTEMS

UNITED STATES DEPARTMENT OF AGRICULTURE, BUREAU OF PUBLIC ROADS

Total Miles of Existing Roads in County and Rural Roads at End of Year 1925

(Not on State Highway Systems)

M-5 (1925) R S A

States	Grand total mileage rural roads, other than state hwy system	Unimproved and earth partially graded	Earth to established grade and drained	Total miles of road surfaced	Sand-clay	Gravel, etc, untreated	Water-bound macadam, untreated	Surface-treated macadam and gravel	Bituminous macadam, by penetration	Sheet asphalt	Bituminous concrete	Portland cement concrete	Block pavements: Brick	Block pavements: Stone	Block pavements: Wood	Block pavements: Asphalt	Block pavements: Misc	States
Nebraska	81,549 5	77,137 6	3,791 7	620 2	342 8	260 1	0 7		4 4		2 0	6 8	3 4					Nebraska
Nevada	20,174 0	18,173 0	1,623 0	378 0		377 0		1 0										Nevada
New Hampshire	11,720 6	11,595 0		125 6		123 0			2 6									New Hampshire
New Jersey [f]	16,431 8	17 7	9,987 6	6,426 5		2,647 6	1,312 6	512 8	783 7	270 6	488 9	290 3	35 9	81 3	0 4	2 4		New Jersey
New Mexico	39,135 6	37,752 8	558 0	824 8	583 0	241 8												New Mexico
New York [g]	67,973 0	50,794 9	440 7	16,737 4		5,513 4	3,827 9	3,637 4	3,023 1	16 5	17 3	636 8	65 0					New York
North Carolina	61,716 0	33,111 0	13,900 0	14,705 0	11,140 0	2,751 0	255 0	193 0		169 0	67 0	90 0	40 0					North Carolina
North Dakota	100,324 4	99,137 8	206 0	980 6		980 6												North Dakota
Ohio	74,099 0	43,352 0	.	30,747 0		22,684 0	5,448 0		1,517 0	233 0		550 0	315 0					Ohio
Oklahoma	128,673 0	124,755 7	3,579 8	337 5		26 9	29 7	269 8			1 6	9 5						Oklahoma
Oregon	45,306 0	30,107 5	7,452 0	7,746 5		7,329 0					286 5	131 0						Oregon
Pennsylvania	81,931 0	62,755 0	7,874 0	11,302 0	1 0	5,223 0	4,275 0	65 0	434 0	1 0	412 0	382 0	509 0					Pennsylvania
Rhode Island	1,606 0	438 5	796 3	371 2		113 0	48 2	121 0	75 5	7 0	0 5	3 0		3 0				Rhode Island
South Carolina	59,682 8	46,302 6	6,540 2	6,840 0	6,338 1	401 8	19 1	5 0		1 0	26 1	48 9						South Carolina
South Dakota	110,988 1	105,861 8	4,642 1	984 2		984 2												South Dakota
Tennessee	60,677 2	40,835 5	9,615 8	10,725 9		5,153 6	4,383 8	682 8	95 6	331 4	49 2	28 5			1 0			Tennessee
Texas	151,017 0	136,925 4	1,931 0	12,160 6	1,500 0	9,810 8	307 8	148 0	243 2	[illegible]	45 4	24 0						Texas
Utah	20,248 8	16,752 9	1,422 0	2,073 9	697 6	1,280 1	12 0	3 6	7 2		21 7	51 7						Utah
Vermont [h]	10,408 0	8,241 0	554 0	1,613 0		1,613 0												Vermont
Virginia	54,160 0	43,762 0	4,176 0	6,222 0	3,410 0	1,102 0	804 0	798 0				108 0						Virginia
Washington	45,750 0	21,332 0	9,689 0	14,729 0		12,905 0		112 0		20 0	229 0	1,250 0	53 0				160 0	Washington
West Virginia	31,579 0	30,736 9	476 8	[i]365 8		80 6	123 5	47 6	111 7	1 9								West Virginia
Wisconsin	68,699 7	48,360 0		20,339 7	2,825 6	17,431 6	251 0					331 5						Wisconsin
Wyoming	43,432 5	35,551 7	7,775 6	105 2		104 7						0 5						Wyoming
Totals	2,731,171 7	2,111,825 8	243,439 9	376,406 0	58,210 5	222,511 9	51,448 2	15,679 6	10,489 6	1,921 5	3,420 4	10,106 3	1,820 0	94 9	16 8	127 4	558 9	Totals

[f] During year 259 7 miles of county roads transferred to State highway system

[g] Legislature transferred 2,640 0 miles of county roads to State highway system

[h] Used data of 1921 as only available mileage

[i] Surfaced mileage overstated in 1924, should have been 248 0 miles instead of 716 1 as reported

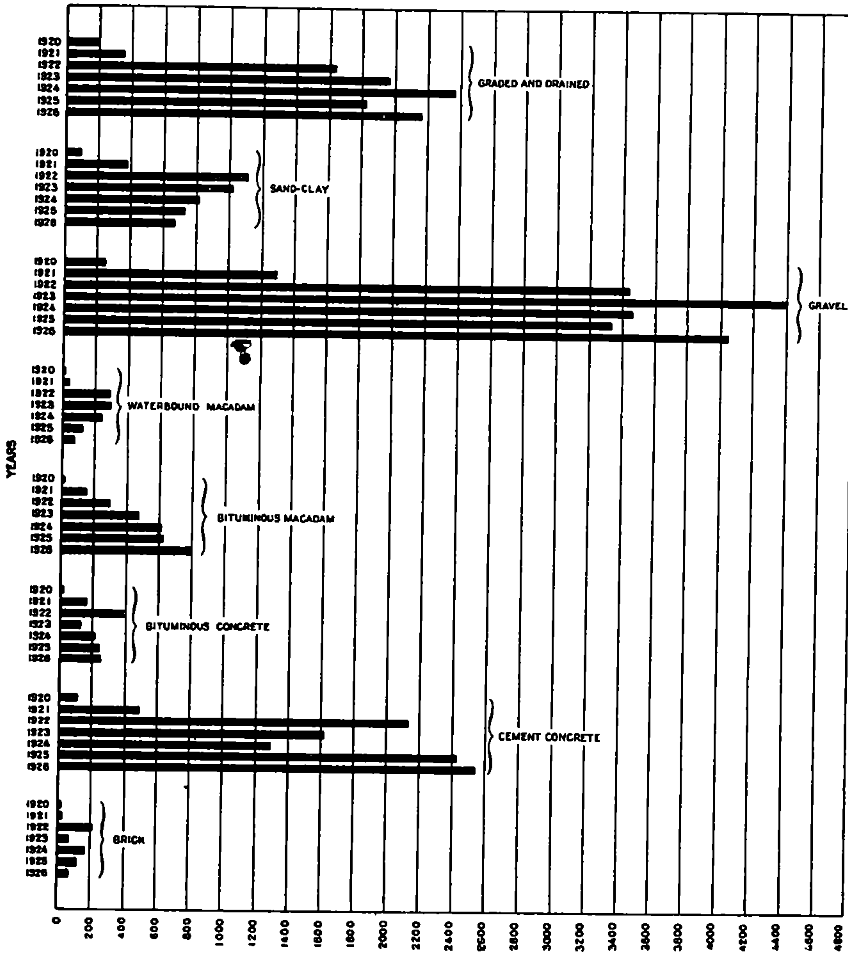


Figure 26 Mileage of Each Type of Road Constructed with Federal Aid Each Fiscal Year Since 1920

(From "Public Roads," Vol 8, No 1)

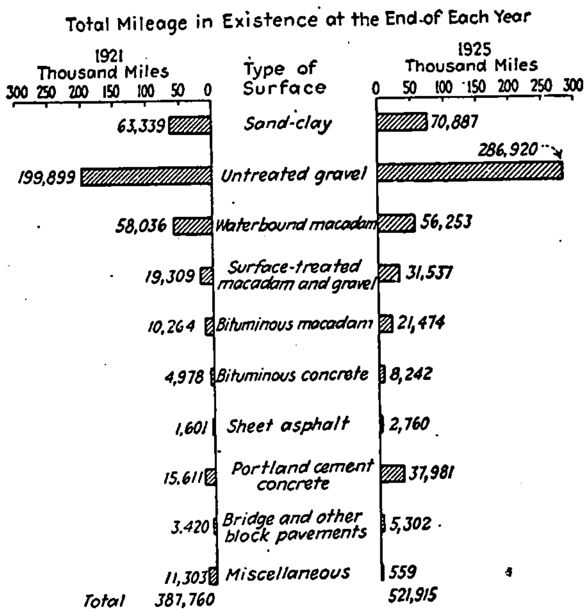


Figure 27. Showing Trend in Types of Surfacing on Federal Aid Highways, from 1921 to 1925

(From article by Thomas H. McDonald, Chief, U. S. Bureau Public Roads, Washington, D. C., Engineering News Record, Vol. 99, No. 9)

TABLE 8

ILLUSTRATING THE TREND IN TYPES FOR FEDERAL AID PROJECTS TO 1927. LOW COST ROADS AND STAGE CONSTRUCTION PREDOMINATE

(From U. S. Bureau of Public Roads)

The total of Federal-aid projects completed, under construction, or approved for construction as of July 1, 1927, was 76,708 miles, divided as follows:

	Miles
1. Stage construction, graded, and drained	15,500
2. Sand, clay, and gravel	34,474
3. Waterbound macadam	1,431
4. Bituminous macadam	4,307
5. Cement concrete	18,009
6. Brick	832
7. Bituminous concrete and asphalt	1,923
8. Bridges	232

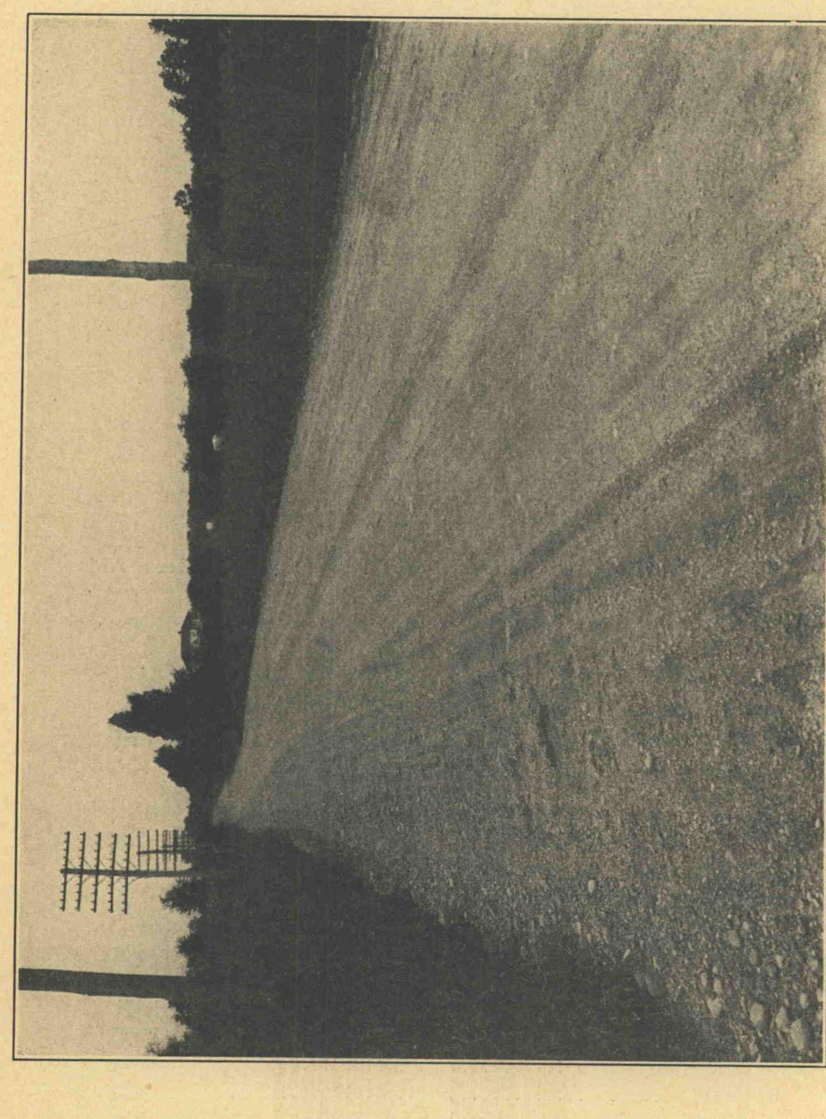


Figure 28. A Typical Untreated Gravel Surface Which Has Been Selected for Improvement by a Bituminous Surface Treatment

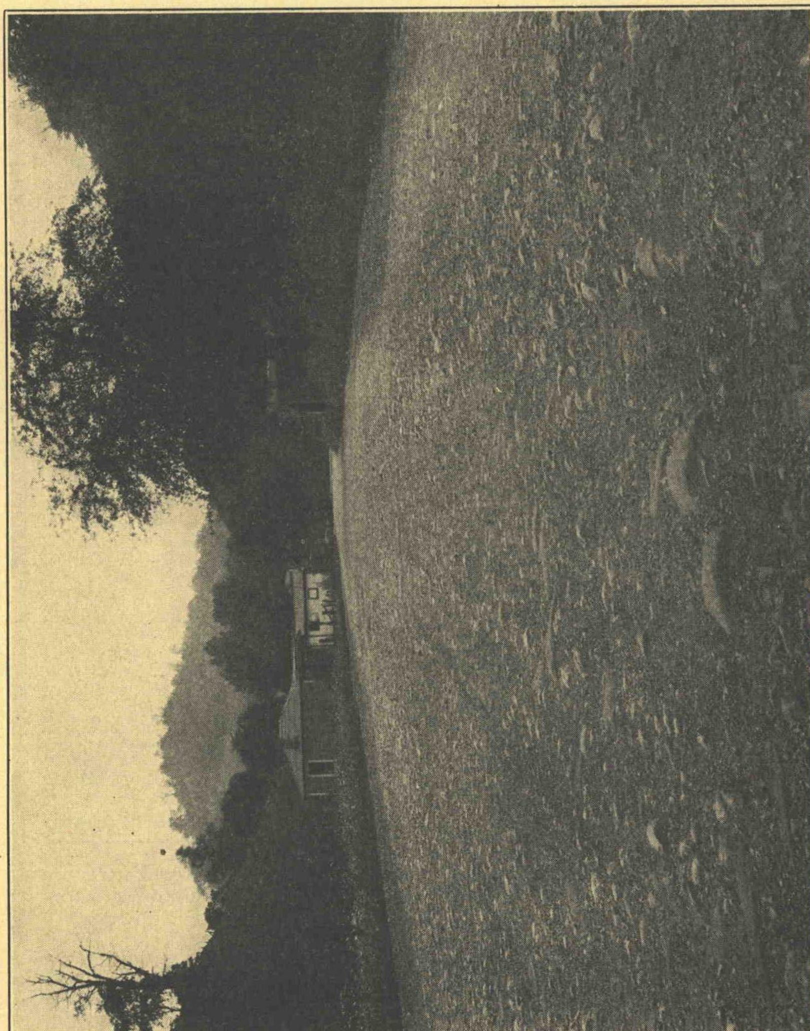


Figure 29. A Well-Compacted Untreated Macadam. It Is Inadequate in This Condition, but the Original Investment May Be Preserved by Bituminous Patching and Surfacing

SELECTION OF TYPICAL CROSS SECTION

The principal features of a typical cross section for roadway surfacing are width, thickness at various points, and crown

These must be suitable for the materials used, and for the methods of construction and maintenance. Alignment, traffic, and weather conditions must also be considered

UNTREATED SURFACES

Such surfaces as sand clay, gravel, fine crushed stone, and other materials which are maintained by constant blading are commonly

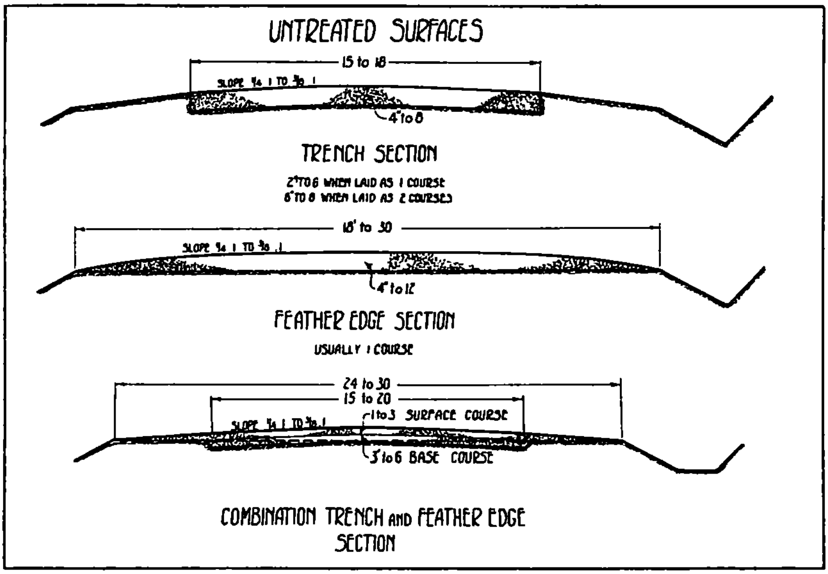


Figure 30 The Three Principal Cross Sections Used for Untreated Surfaces. Except for the Trench Section They Are Commonly Maintained by Blading and Dragging

built from out to out of shoulder or within 3 feet of each shoulder edge. The total surfaced width is seldom less than 24 feet on state highways where the feather edge section is used.

The feather edge section has its greatest depth at the road center and tapers to 1-inch or less at the outer edges. The center depth is usually from 4 to 9 inches The crown is from ¼ to ½-inch per foot with a tendency toward the lower limits in dry weather and the higher in wet weather. On super-elevated and widened curves a uniform depth section with no crown is used.

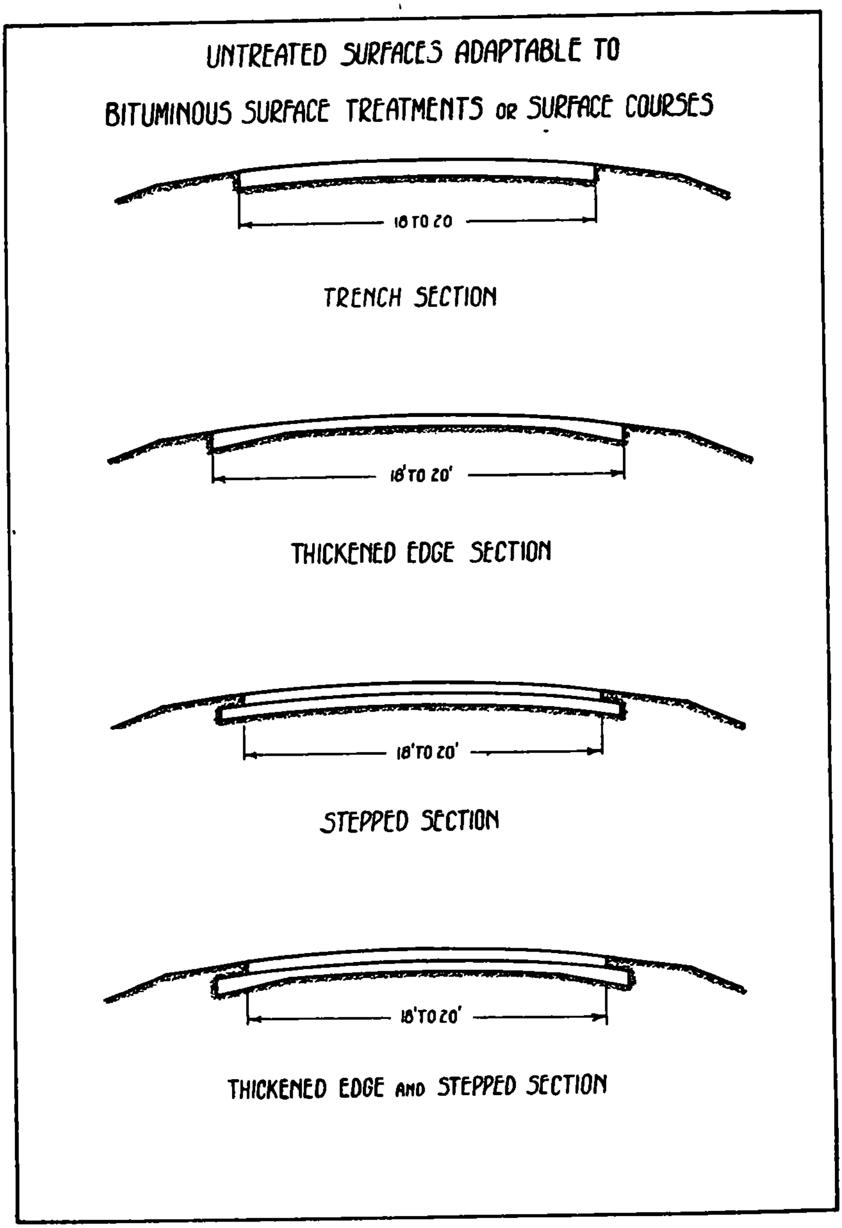


Figure 31. Sections Which Are Consolidated by Rolling and Are Commonly Used as Bases for Bituminous Surface Treatments and Surface Courses

Such surfaces as macadam, lime rock, gravel, chert and other materials which are compacted by rolling during construction and which are not easily maintained by blading or dragging are commonly built in widths of from 15 to 20 feet. The trench section is commonly used with a uniform thickness of from 4 to 8 inches.

A few cross sections show an increased edge thickness, the center being 6 inches and the outer edges 8 inches The stepped section is also used, that is, one in which the lower courses are wider than those above. The offsets at each edge vary from 3 to 12 inches for the cases studied.

Florida shows 12 inches and Ohio 3 inches One section showed a thickened edge and offsets. The crown is seldom less than ¼-inch to the foot and seldom more than ½-inch From ¼ to ⅜-inch is general practise for the cross sections studied.

SURFACE TREATMENTS

Surface treatments with such materials as calcium chloride, single or dual bituminous applications, and the bituminous mixed-in-place types which utilize the aggregates in the roadway surface may extend from out to out of shoulder, if the existing surfacing aggregates have that width. Commonly, however, they are not less than 17 or 18 feet wide nor more than 24 or 26 feet. The intention is to secure a uniform depth of treated surface of from ½ to 3 inches

The crown is that of the surface being treated usually from ¼ to ½-inch per foot, with preference shown for ¼ to ⅜-inch.

SURFACE COURSES

Such surfaces as bituminous macadam and all pre-mixed bituminous types have a width equal to or less than the base on which they are laid. Their thickness is uniform for the entire width of surface and is seldom less than 1-inch nor more than 3 inches for one course construction Thickened edge designs are unusual

WIDTH

Untreated surfaces with the feather edge cross section are commonly built to a greater width than trench or stepped sections. Wide sections from shoulder to shoulder are desirable because of easier maintenance with blade and drag, a wider distribution of traffic, less tendency to form or travel in ruts and less undesirable shoulder material such as sand or clay becomes mixed with the selected surfacing aggregates.

Surface treatments and surface courses of the bituminous types when built with a uniform depth of section and less than 18 feet in width, show a tendency to break down or become displaced vertically

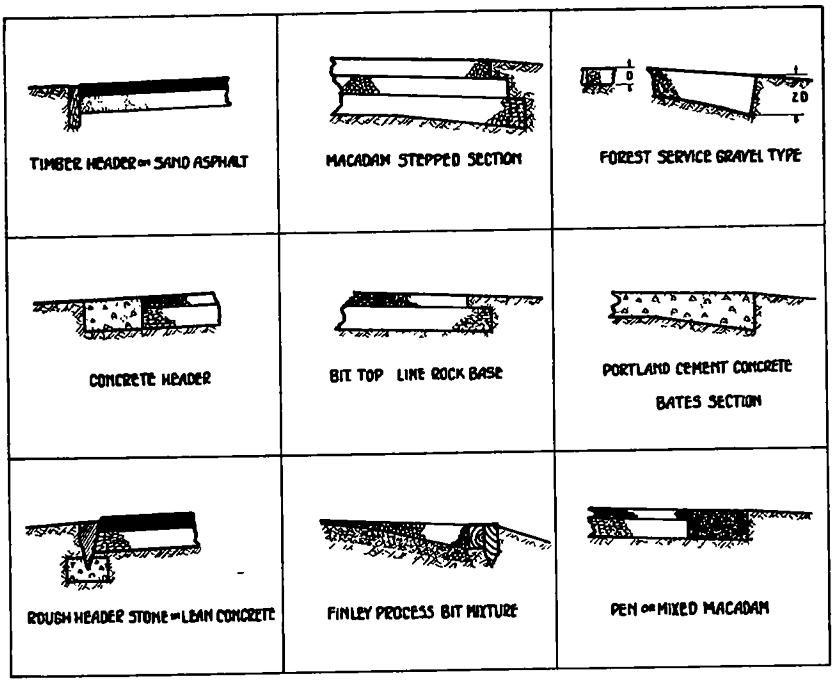


Figure 32. Various Methods Used to Prevent Edge Breakage Under Traffic

and laterally near their edges This is due to wheel concentrations Width greater than 18 feet tends to reduce such breakage and displacement.

CROWN

Crowns of more than ½-inch to the foot are rare in modern surfacing of any type Steep crowns are dangerous to traffic; they create a tendency to formation of ruts. Distribution of traffic over the entire surface is unusual on roadways having steep crowns.

Greater erosion occurs with steep crowns on untreated surfaces and skidding on treated surfaces is more frequent

Crowns of ¼ to ⅜-inch to the foot have proved sufficient for surface drainage; they are less easily eroded and more easily maintained. The riding qualities and distribution of traffic are better with the lower crowns.

THICKNESS

The factor of safety for recent designs in concrete pavements is about 2; that is the strength of the pavement under maximum probable loading conditions is designed to be two times the internal stress created by that loading.

The factor of safety for all other types, except for a few pavements, has not been determined by controlled tests or by sustained theory. It has been accepted within wide limits of thickness by usage only. In general, the thickness of untreated surfaces, surface treatments and bituminous surface courses is such that it will not show excessive failure under the expected loads, or, if it does fail, repairs may be made without serious traffic interruption or expense.

The compacted thickness of untreated surfaces of the traffic bound stone or gravel type is sometimes as low as 2 inches If the traffic is light this may be sufficient.

On the other hand, common practise in the New England States calls for a sub-base of gravel or stone which may be from 2 to 12 inches in depth, before even a gravel surface of 4 to 6-inch thickness is laid.

There appear to be two tentative theories, one in which a fairly narrow trench section of uniform depth or a thickened edge section of 15 to 18 feet is used with a depth of from 6 to 12 inches, and the other in which a feather edge or uniform depth section of 20 to 30 feet width is used with an average depth of from 2 to 7 inches. The volume of material may be about the same for each case. Apparently the thought is to prevent wheel concentrations by using the wide sections which are of shallow depth in the one case or by using a thick but narrower section (or one with a thickened edge) to absorb the stress of wheel concentrations in the other. In other words, it is a case of lateral or vertical distribution of the effects of traffic.

EDGE STRENGTHENING

Edge strengthening by various methods is illustrated in Figure 32

An excellent article by A. T. Goldbeck, Director Bureau of Engineering, National Crushed Stone Association, on "Studies in the

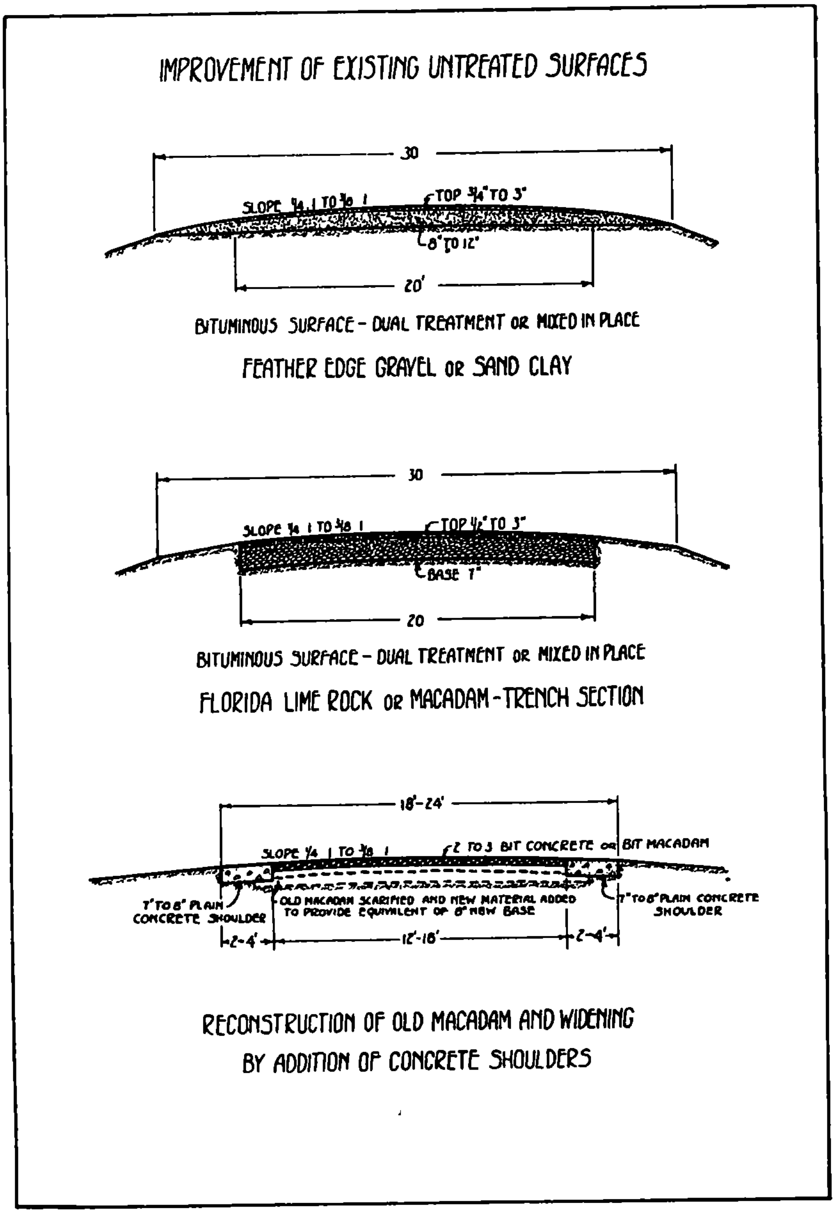

IMPROVEMENT OF EXISTING UNTREATED SURFACES
30
SLOPE 1/4 1 TO 3/8 1
TOP 3/4" TO 3"
8" TO 12"
20'
BITUMINOUS SURFACE - DUAL TREATMENT OR MIXED IN PLACE
FEATHER EDGE GRAVEL OR SAND CLAY
30
SLOPE 1/4 1 TO 3/8 1
TOP 1/2" TO 3"
BASE 7"
20
BITUMINOUS SURFACE - DUAL TREATMENT OR MIXED IN PLACE
FLORIDA LIME ROCK OR MACADAM - TRENCH SECTION
18'-24'
SLOPE 1/4 1 TO 3/8 1
2 TO 3 BIT CONCRETE OR BIT MACADAM
7" TO 8" PLAIN CONCRETE SHOULDER
OLD MACADAM SCARIFIED AND NEW MATERIAL ADDED TO PROVIDE EQUIVALENT OF 8" NEW BASE
7" TO 8" PLAIN CONCRETE SHOULDER
2-4'
12'-16'
2-4'
RECONSTRUCTION OF OLD MACADAM AND WIDENING
BY ADDITION OF CONCRETE SHOULDERS

Figure 32

Structural Design of Bituminous Macadam Roads," treats this subject at some length.

The possible value of the strengthened edge designs for other than concrete roads is attracting deserved attention.

An ideal section is one whose width, thickness and crown are of such dimensions that all portions of the section transmit external loads to the subgrade without the internal resistance of these portions being exceeded. These conditions are fairly well met by sections wider than 20 feet which are of uniform thickness or of the feather edge type, and, for narrower sections, by those which have suitable edge strengthening Flat crowns of ¼ to ⅜-inch per foot should not be exceeded in either case.

EFFECT OF CLIMATE AND SOIL ON ROAD TYPE

The effects of climate and soil on construction and maintenance show wide variations. Soil and subgrade studies are still in progress, principally by the U S Bureau of Public Roads. The effects of weather conditions on pavement construction has been made a subject of investigation by the Engineering-News Record and by the U S Bureau of Public Roads.

Untreated surfaces of gravel and other types which are located in regions of low rainfall suffer serious losses of surfacing material, particularly during high winds, even under traffic of less than 300 or 400 vehicles per day.

Arizona reports such conditions. Western Oregon, where the rainfall is moderately heavy, has less difficulty in maintaining gravel and stone roads than the eastern portion of that state which has low rainfall.

Alaska, where there is plenty of rain, cold weather and a continuously wet soil, reports no trouble from dust on gravel surfaces.

Table 9 is made up from a study of U. S Weather Bureau reports and shows weather conditions over the United States

TABLE 9

WEATHER DATA, UNITED STATES OF AMERICA, COMPILED BY F D NASH, FROM U S WEATHER REPORTS, SEPT AND OCT 1927

Ref No	State	Portion	Mean annual precipitation inches	Highest mean temp	Lowest mean temp	Mean freezing date in spring	Mean freezing date in fall
81	Alabama	Nor & Western	49 00±	105	— 9±	Apr 25±	Oct 15±
82	"	E Cent. & Sou	55 32±	105	zero	Apr 20±	Oct 15±
Sec 1	Alaska	S & S Eastern	75 40±	85	—16±	May 20±	Oct 1
" 2	"	Inter Valleys	24 90+	89	—59±	June 20±	Sept 1
" 3	"	W & Northern	27 27±	78	—49±	June 10±	Sept. 20
3	Arizona	Southern	10 95±	113	+ 9±	Apr 15±	Oct 25±
4	"	Northern	16 12±	107	—10±	June 1±	Sept 20±
47	Arkansas	. Southern	46 22±	108	— 9±	Mch 20±	Nov 10±
48	"	Northern	47 25±	109	—17±	Apr 15±	Oct 15±
13	California	. Southern	14 10±	110	+15±	Apr 10±	Nov 1±
14	"	Central	18 85±	111	+17±	Apr 20±	Oct 15±
15	"	Northeastern	34 81±	108	+ 4±	June 1±	Oct 5±
16	"	Northwestern	40 22±	107	+14±	May 25±	Oct 15±
95	Chesapeake Bay Region		42 82±	104	—11±	May 5	Oct 25±
7	Colorado	Southeastern	17 80±	99	—30±	June 15±	Sept 15±
8	"	Northeastern	16.88±	99	—32±	June 25±	Sept 15±
9	"	Western	17 03±	94	—33±	July 1±	Sept 5±
105	Connecticut		42 01±	99	—24±	June 5	Sept 10
95	Delaware	(See Chesapeake Bay Region)					
83	Florida	Northern	53 60±	103	+10	Apr 15±	Nov 1±
84	"	Southern	41 43±	99	+22	Mar 10	Dec 1
85	Georgia	Western	52.48±	104	— 4±	Apr 25	Oct. 20
86	"	Cent & Eastern	49 44±	107	— 2±	Apr 20	Oct 15
	Hawaii	...All	75 80±	90	+49±	No frost	
21	Idaho	Northern	23 22±	103	—24±	June 25±	Sept 1±
22	"	..Southern	14 56±	105	—29±	July 1±	Sept. 1±
64	Illinois	Northern	33 12±	107	—27±	June 1	Sept 15±
65	"	. Central	36 04±	106	—25±	May 15±	Sept 20±
66	"	. ....Southern	41 41±	109	—20±	May 10±	Sept 25±
67	Indiana	Northern	36 07±	105	—23±	May 25±	Sept 15±
68	"	Southern	42 52±	107	—22±	May 15±	Sept 20±
52	Iowa	Western	32 39±	108	—36±	May 20±	Sept 15±
53	"	Central	32 39±	108	—33±	May 20±	Sept 15±
54	"	Eastern	32 39±	107	—31±	May 25±	Oct. 5±
38-39	Kansas	. All	28 50±	111	—27	Apr 25±	Oct 20±
75	Kentucky	Eastern	46 87±	104	—20±	May 10±	Sept 25±
76	"	..Western	45 50±	106	—21±	May 10±	Sept 25±
45	Louisiana	. Southern	56 37±	106	+ 7	Mar 10	Nov 15±
46	"	Northern	49 32±	107	— 2±	Apr 20	Oct 20±
106	Maine	All	40 66±	98	—29±	June 15	Sept 10
94	Maryland	W and Central (See Potomac River Basin)					
95	"	...Eastern (See Chesapeake Bay Region)					
105	Massachusetts		42 01±	99	—24±	June 5	Sept 10
61	Michigan	...Upper Penin	30 00±	99	—37±	June 15±	Sept. 1
62	"	. Western Lower	31 00±	102	—29±	June 5±	Sept 10±
63	"	Eastern Lower	32 00±	103	—29±	June 15±	Sept 10±
55	Minnesota	...Southwestern	25 31±	104	—38±	May 15±	Sept 25±
56	"	. ...Southeastern	28 65±	105	—40±	May 15±	Oct 1±
57	"	Northern	24 98±	102	—48±	June 15±	Sept 1±
79	Mississippi	Northern	49 30±	104	— 6±	Apr 25±	Oct 10±
80	"	. Southern	55 82±	104	+ 2±	Apr 20±	Oct. 20±
49	Missouri	Southwestern	40 00±	109	—27±	May 15±	Sept. 20±
50	"	Southeastern	44 98±	109	—24±	May 15±	Sept. 25±
51	"	Northern	36 67±	109	—26±	May 15±	Sept 25±
26	Montana	Southeastern	14 35±	106	—45±	June 10±	Sept. 1±
27	"	Southwestern	15 06±	101	—43±	June 20±	Aug 20±
28	"	Western	17 82±	102	—33±	June 20±	Aug 25±
29	"	North Central	16 00±	102	—46±	June 20±	Aug 25±
30	"	Northeastern	14.27±	108	—52±	June 15±	Aug 25±
35	Nebraska	Northwestern	19 75±	106	—35	June 5	Sept 10±
36	"	Northeastern	27 75±	109	—36	May 25	Sept. 15±
37	"	. Southern	25 00±	111	—33	May 25	Sept. 15±
12	Nevada	..All	7 21±	106	—21±	June 25±	Sept 1±
105	New Hampshire		42 01±	99	—24±	June 5±	Sept 10±
99	New Jersey	S Int. & Seacoast	47 68±	103	—10±	May 20±	Sept. 25±
100	" "	Northern	47 44±	104	—18±	May 20±	Sept. 20±
2	New Mexico	Western & Sou	13 43±	113	—18±	May 7±	Oct. 20±
5	" "	..Northwestern	14 09±	100	—22±	June 15±	Sept. 25±
6	" "	. Northeastern	17 87±	102	—20±	May 25±	Oct 1
101	New York	Western	35 20±	99	—23±	June 10	Sept. 10
102	" "	Central	39 09±	98	—30±	June 10	Sept. 10
103	" "	South Central	38 76±	99	—30±	June 15	Sept. 10
104	" "	..Eastern	41 68±	100	—24±	May 25	Sept. 15
78	North Carolina	East & West	51 66±	98	—16±	May 20±	Sept 25±
89	" "	W Central	51 46±	102	— 7±	May 5	Oct 5
90	" "	Cent. & S East	48 06±	104	— 4±	May 5	Oct 10
91	" "	.N Eastern	48 23±	102	— 2±	Apr 25	Oct 15

TABLE 9—CONTINUED

Ref No	State	Portion	Mean annual precipitation inches	Highest mean temp	Lowest mean temp	Mean freezing date in spring	Mean freezing date in fall
31	North Dakota	Western	15 69	105	—47	Abt June 15	Abt. Aug 25
32	" "	Eastern	19 26	105	—46	June 15	Aug 20
69	Ohio	Northern	36.74±	104	—23±	June 1±	Sept 15±
70	"	Southwestern	39 36±	105	—24±	May 20±	Sept 25±
71	"	South Central	38.68±	105	—26±	May 25±	Sept 20±
72	"	Southeastern	39 38±	104	—26±	May 25±	Sept 20±
40	Oklahoma	Eastern	38 75±	110	—14	Apr 25±	Oct. 10±
41	"	Western	30 00±	112	—14	May 1±	Oct 1±
17	Oregon	Western	51 44±	101	— 5±	June 1±	Sept. 25±
18	"	Eastern	14.00±	104	—24±	June 20±	Sept 10±
96	Pennsylvania	Western	41 41±	103	—14±	June 5	Sept. 15
97	"	Central	40 08	103	—24	June 5	Sept. 15
98	"	Eastern	46 09±	103	—18±	May 20	Sept 20
94	Potomac River Basin		39 37±	104	—19±	May 15	Oct 5
105	Rhode Island		42 01±	99	—24±	June 5	Sept. 10
87	South Carolina	Western	48 75±	105	— 1±	Apr 20	Oct 15
88	" "	Eastern	47 16±	105	+ 2±	Apr 15	Oct 20
33	South Dakota	Western	18 50	108	—40	June 1	Abt Sept 5
34	" "	Eastern	22 30	107	—42	June 25±	Sept 1
77	Tennessee	Middle West	50 83±	104	—18±	May 15±	Oct. 1±
78	"	Eastern	51 66±	98	—16±	May 20±	Sept 25±
42	Texas	Northwestern	24 50±	109	—10	May 10	Oct 15±
43	"	Central	26 50±	110	— 4	Apr 25	Oct 20±
44	"	Eastern	40 00±	111	— 5	Apr 25	Oct 20±
1	"	Southern	31 88±	107	+ 8±	Apr 5±	Oct 25±
2	"	Western & Sou	13 43±	113	—18±	May 7±	Oct 20±
10	Utah	Eastern	11 18±	104	—25±	June 20±	Sept 10±
11	"	Western	13 93±	103	—23±	June 25±	Sept 10±
74	Virginia	S & Southwest	43.60±	100	—19±	May 20±	Sept 25±
92	"	S & Eastern	42 87±	102	— 4±	Apr 25	Oct 10
93	"	...Central	41 60±	104	—13±	May 15	Oct. 5
105	Vermont		42 01±	99	—24±	June 5	Sept 10
19	Washington	Western	49 14±	97	zero	May 25±	Sept 25±
20	"	Eastern	15 48±	107	—24±	June 25±	Sept 15±
73	West Virginia	Northern	45 84+	103	—26±	May 30±	Sept. 25±
74	" "	S & Southwest	43 60±	100	—19±	May 20±	Sept. 25±
58	Wisconsin	Northwestern	30 00±	101	—43±	June 10±	Sept 5±
59	"	Central	32 00±	102	—41±	June 10±	Sept 5+
60	"	Eastern	31 40±	106	—32±	June 1+	Sept 20+
23	Wyoming	Western	16 04±	94	—46±	July 15±	Aug 10±
24	"	Southeastern	14 28±	98	—38±	June 20±	Aug 25±
25	"	Northeastern	13 03±	101	—38±	June 20±	Aug 20±

The following remarks, from the 1927 report of the Committee on Structural Designs of Roads of the Highway Research Board are pertinent to subgrade studies:

"One cannot walk over certain road grades without realizing that the requirements for supporting traffic in some locations must be different from those in others The influence of this subgrade variation is very marked in our low type pavements, in certain flexible types and in rigid types of less than 6 inches thickness As the pavements become thicker and especially when reinforcement is added and joint or groove spacing is reduced, the subgrade influence gradually vanishes This means that the pavement, throughout its length has been designed to meet the requirements which in some instances exist in prhaps but 2 or 3 per cent of its length

"Thus it can be seen that the object of subgrade studies is not primarily to learn how to build a rigid pavement, but rather to determine when rigid pavements are required and when and where other types will be satisfactory, and in this way receive from our road expenditures a considerably increased mileage of serviceable roads"

The extracts of discussions and conclusions which follow represent present thought on the features of soil, subgrade and weather conditions as they affect roadway surfaces.

By A. C Rose, Associate Highway Engineer, U S Bureau Public Roads, "Public Roads," September, 1925

Relating to Subgrade Studies Completed or in Progress I Generally speaking, all the data obtained in the United States indicate, the character of the clay remaining constant, that good subgrade soils have a low clay content by mechanical analysis and bad subgrade soils are characterized by a high percentage of clay. Illustrative of an exception is the "rotten limestone" formation in the Black Waxy Belt of Texas, which, though high in clay, is not a bad subgrade material

The construction methods which may be adopted in bad subgrades, assuming the quality of the materials and the workmanship on the pavement to be uniform, are in general as follows:

(a) Use upland coarse grained soils for building fills over lowland clay soils
(b) Use side ditches of special design
(c) Use tile drains In heavy clays these are generally useless except in uncommon cases such as open seams or pores in the soil, water-bearing strata, or hydrostatic pressure
(d) Use a granular sub-base such as sand, sand clay, topsoil, stone, or gravel.
(e) Thicken the pavement.
(f) Add steel reinforcement

The study of the California highway system by the Bureau of Public Roads showed that 70 per cent of the pavement failures occurred on adobe soils The cracking of the pavements on adobe soils indicated a distortion of the subgrade due to varying moisture content and shrinkage.

Clay soils, as compared with sands, show a relatively large heave when frozen, according to field tests by Stephen Taber, State Geologist of South Carolina.

Bureau of Public Roads laboratory tests show a greater percentage of water freezable in sands than in clays This does not mean that the amount of the heave in sands due to freezing will be greater than in clays. On the contrary it would seem that the greater heaving would occur in clay with capillary water present because of the greater total amount of water frozen

Cracks are infrequent in pavement laid on well-drained sand or porous subgrades.

The more compact the subgrade soil, the more frequently cracks occur.

The permeability or the porosity of soils seems to increase with the size of the soil grains, the character of the grains remaining constant.

The best subgrades are found in fills and the worst in cuts.

The selection and redistribution of subgrade soils to secure a stable roadbed is a possible method of construction. The use of a granular sub-base over the undisturbed subgrade soil is the more general practise.

A sand sub-base prevents clay subgrade material from working up into the voids of a macadam road

Granular sub-bases seem to be more beneficial on bad subgrades than admixtures of Portland cement or hydrated lime

Sand is as effective as Portland cement or hydrated lime when used as an adulterant to reduce the shrinkage of a clay soil.

Semigravel, topsoil, and sand-clay roads provide effective surfacing material in the Southeastern States. They could be and have been used elsewhere but under other names

It is not possible to remove capillary water from subgrades by drainage. Free water only may be removed by practicable methods.

By A. T. Goldbeck, Director, Bureau of Engineering, National Crushed Stone Association, "Crushed Stone Journal," 1926.

In general, it might be said that the extreme characteristics of subgrade soils are as follows:

Bad Soils

a. Extremely fine state of subdivision (as in clays).
b. High moisture capacity
c. Extreme plasticity.
d. Difficulty of drainage
e. Low bearing value.
f. High volume change.

Good Soils

a. Coarse, granular texture
b. Low moisture capacity.
c. Non-plastic when wet.
d. Easily drained.
e High bearing value.
f. Low volume change.

IMPROVING BAD SUBGRADES

It goes without saying, that if granular soils furnish good support and plastic soils poor support, it will be quite possible to improve a bad soil by the admixture of enough good material. The use of an admixture of sand with a clay soil to form a sand-clay road surfacing is a typical example of this procedure and such a surfacing forms an excellent foundation for a broken stone road. The much discussed "stage" construction of the South consists in the building of a sand-clay or top-soil road for the small amount of traffic then to be accommodated, to be followed later with a higher type of surfacing, often a bituminous macadam. The use of a layer of granular material such as fine stone screenings, cinders, fine sand or similar material would also be beneficial for several reasons.

A. Because such a layer would serve as so much more effective thickness for distributing the load to the subgrade

B. Because such a layer would aid greatly in preventing the upward intrusion of clay into the broken stone layer, thereby preventing its full effective depth from being decreased through lubrication of the stone by the clay.

C. Drainage of the upper layers of the subgrade would be facilitated and the accumulation of capillary moisture in the upper layer would be lessened.

Admixtures of certain materials which might improve the physical characteristics of plastic soils are also not without possibility and are under experiment at the present time by several agencies. A few states have been using a granular sub-base under their pavement surfaces with very good results. A sub-base of granular material having the characteristics listed above for good soils would be beneficial under macadam roads laid on bad subgrades

By F. H Eno, Ohio State University. Proceedings Sixth Annual Meeting Highway Research Board.

PAVEMENT DISPLACEMENT DUE TO WATER AND FROST

1. No definite relationship appears to exist between the displacement of the pavement and the mechanical analysis of the soil, or with the various characteristics of the sub-soils. The nearest possible chance of a relationship appears to be with capillary water. Displacement seems to increase with increased capillarity.

2 There appears to be greater irregularity of displacement of the pavement on bituminous and macadam roads than upon brick and concrete roads, also upon new roads than upon long used roads.

3 The displacement is due both to moisture and freezing There are not sufficient data at present to evaluate the amount due to each cause In three cases at least the moisture caused the maximum movements, for they occurred in May and August. Six times the minimum height occurred during February or March.

4 In Ohio under normal seasonal conditions, the displacement of the pavements is upward during the late fall and early winter and downward during the late winter, spring, summer and early fall Exceptions are noted in paragraph No 3 above

5 The amount of displacement ranges from 0 025 to 0.265 of a foot, averaging about 0 063 foot in Ohio for the two seasons 1925 and 1926

6 The wet, humid weather of August, 1926, made some rather marked differences in the movement of pavements in August of the two years 1925 and 1926.

7. The maximum height of pavements occurred later in 1926 than in 1925, due evidently to different weather conditions. The maximum height was reached later in the northern portion of the state than in 1926 than in the southern part

8. It is quite certain that there are more severe climates in other parts of the United States than in Ohio and that in more severe winters and wetter seasons greater movements of pavements will take place

By C. A. Hogentogler, I. B. Mullis and A C Benkelman, U. S. Bureau of Public Roads Proceedings Sixth Annual Meeting Highway Research Board

PRESENT SUBGRADE PRACTISE

A scrutiny of current practise in regard to subgrades seems pertinent at this point. Many states give it little or no consideration, using the same pavement designs for all conditions of support. Other states consider subgrade influence and compensate for it in varying degrees and manner From information furnished by the District Engineers of the Bureau of Public Roads, specific practises in subgrade compensation are given as follows:

Arizona. Design of pavements dependent on subgrade, rainfall and temperatures Type and thickness of pavement varied Silty sand subgrade stabilized by adding mixture of gravel, caliche and clay Very fine dust subgrade (high cementing value) surfaced with clean coarse gravel Adobe soils surfaced with volcanic cinders, gravel or similar available material In some cases, this treatment is used as "stage" construction for surfacing

California Subgrade soil tests are part of routine on new construction jobs Soils of low shrinkage and low moisture equivalent values are given preference for embankments When moisture equivalent exceeds 30 per cent and the lineal shrinkage exceeds 5 per cent, subgrades are stabilized by the addition of sand, decomposed granite or similar material

Oregon. Inspections by division engineers generally determine subgrade conditions but in some cases laboratory tests are employed In some cases of questionable subgrades, sand sub-bases (thickness dependent on soil shrinkage values) are used, while others (soft places or "dobe") slab design is changed by adding reinforcement and reducing joint spacing

Washington Subgrades are inspected by Construction Engineer, and the District Engineer Questionable subgrade compensation consists of increasing the thickness of paving, increasing or adding reinforcement, reducing the slab lengths or by adding gravel sub-bases Soft spots are dug out and back filled with gravel Tile drains are used in wet and spongy places

Colorado Subgrades sampled and tested before pavement construction Subgrades having lineal shrinkage in excess of 5 per cent receive sand treatments 2 to 10 inches) varying in depth in accordance with the extent the moisture equivalent exceeds 20 per cent

Minnesota Clay subgrades are stabilized by additions of sand and gravel and sand subgrades by the admixture of clay In swampy sections, fills are made with coarse-grained upland materials while deep wide ditches and a generous amount of tile are used to accommodate free water Frost boil failures are treated with admixtures of gravel Special reinforcement is added to concrete pavements when soil seems especially unstable In some cases subgrades are oiled

Kansas In isolated cases, a sand sub-base is used on gumbo soil

Massachusetts Subgrade conditions determined by visual inspection during spring breakup, test pits along the proposed project and by inspection during construction Concrete pavements are not varied, but foundations (stone and gravel) and drainage are. Side drains are effectively used.

Rhode Island Subgrade conditions are determined by inspections made in the spring when frost is leaving the ground and the subsoil is well saturated with water When road follows new location samples of subgrade are secured for test Sub-bases of gravel are used under penetration macadam or concrete roads as questionable subgrade compensation.

Connecticut. Double reinforcement in the slab and either sand, gravel or stone sub-bases connected to underground drains, are used in locations where heaving is expected

Maine, New Hampshire, New Jersey and *New York* also compensate for questionable subgrade This compensation includes gravel and stone sub-bases, bituminous treatments on the subgrade and steel reinforcement in the slab

Where extreme conditions of lack of support are found, rather elaborate precautions have been taken. In North Carolina one road consisting of heavily reinforced slabs has been laid on four rows of piling. In the flat land of southwest Missouri, drainage by tiling into wells which are carried down to a sand or gravel stratum has been used. And in Louisiana, conditions were improved by dredging out the original muck and back filling with lake bottom soil.

Weather and Climate, Engineering News-Record, September 8, 1927.

With the end of the "third wettest August (1927)" since 1871 commiseration with road builders is in order. Occasion, too, is offered for comment on the fact that of all hindrances to steady profitable road-construction output, those due to rain are accepted with the least show of determination to find preventives In a study made by the Bureau of Public Roads of losses in concrete road construction, one-half of all time losses is charged to weather—rain, cold and frost As a rule delays due to actual frost are small, and cold weather milder than freezing acts only to prolong the period for which the effects of rainfall hinder construction Substantially, then, rain is the whole weather cause of time loss in fine grading and paving for concrete roads, and be it remembered weather losses are a half of all time losses. That of the Bureau of Public Roads, for example, shows that it is not inches of rainfall but continuity of light rains, ½ to ¾-inch falls, which most delays construction It shows that rain in the hot months is less a hindrance than in cold months It shows that failure to provide means by which the subgrade will quickly drain off rainfall prolongs rain delays In general it indicates "that a goodly proportion of the time lost now as the direct or indirect result of rainfall is not inherent in the nature of the physical conditions, but rather, at least in part, is due to difficulties inherent in or connected with the present methods of operation and management." These are conclusions which challenge the road builder to take stock of his practises before accepting weather delays as irremediable dispensations of Providence.

By A C. Rose. A paper presented at the April 22, 1927, meeting of the American Society of Civil Engineers.

FOUNDATIONS AND DRAINAGE OF HIGHWAYS

The adverse character of the subgrade soil depends primarily on the volume change caused by variations in moisture content or frost action The main adverse action of the volume change occurs in one direction—the vertical

The volume changes of the soil distort the subgrade, which displaces the pavement unevenly and subjects it to excessive localized stresses.

The adverse character of the subgrade soil is shown to increase with the clay content.

Committee on the Structural Design of Roads, Highway Research Board Report of Subcommittee on Subgrade Studies, December, 1927.

Climatic and topographical conditions being equal, the resistance of a subgrade against deformation depends on the purely mechanical properties of the soil, viz, compressibility, elasticity, and permeability.

Surfaces of the exposed soils change moisture content quickly from 2 to 124 per cent of the dry weight of the soil due to rain, thawing and drying weather

Only free or gravitational water can be removed by ditches and drain tile.

Water, capillary and absorbed, cannot be reduced by drain tile or trenches directly. Thus drain tile laid in dense soil free from stratification cracks and other openings is not generally useful.

Observations made at the University of North Carolina showed that drains were not sufficient for removing capillary moisture from the subgrade.

On one section of the Bates Road 200 feet long tile drains were laid under the side edges of the pavement 24 inches below the subgrades, the trenches were back filled with cinders and free outlets were provided for the tile. Observations covering a period of three years showed no measurable difference in moisture contents of the subgrade where the tile was used and in adjacent sections where no drainage was provided

Observations on experimental sections at Arlington, Va, did not show that side ditches with drain tile were effective for reducing the moisture content of the subgrade nor for reducing the heaving of the pavement slabs during frost.

In railroad work tile drainage has been effective for removing or intercepting free water under all conditions where the resistance to flow through the tile is less than that of the material to be drained. In stratified soils tile drainage is ineffective unless it is placed in a favorable position for receiving and delivering the flowing water.

The behavior of sand and clay subgrades during freezing is different.

Noticeable heave from frost is confined to clays and other soils with very small voids.

The difference in behavior of soils upon freezing is dependent upon the proportions of free and unfree water and the number of successions of frost and thaw.

Pavements can heave under continuous frost action or with repeated freezings and thawings.

One investigator finds detrimental heaving occurs with freezing following a thaw.

In locations subjected to extreme moisture conditions well drained sub-bases of stone, gravel, slag, etc., may be efficient for reducing the heaving, cracking and breaking up of pavements

Sub-bases in all cases have not been beneficial.

The strong indication is that additional depth over 2 inches in porous sub-bases is detrimental as well as more expensive

The benefits of subgrade treatments have yet to be determined

Cement-clay and lime-clay admixtures for sub-bases beneath high type roads are impracticable due to the impossibility of securing a reasonably good admixture with a sticky, tough, clay soil during any continued rainy weather conditions.

For equal superimposed loads the pressure on the subgrade when exerted through a concrete slab is distributed over a larger area and is of considerably less maximum magnitude than when exerted through a broken stone surface.

Rigid slabs laid on soft and yielding subgrades of very low but uniform supporting value might develop less cracks than those laid on firm unyielding subgrades especially if rough.

Slabs laid on firm subgrades such as old road bed and rolled stone base course, might develop cracks before slabs laid on softer bases. Firm bases, however, seemed effective against breakage and surface unevenness in the slabs.

In a survey of the California roads the pavements with no breakage were laid on sands, those with a slight amount of breakage were laid on loams, and those containing the greatest amount of breakage were laid on clays.

With respect to the type of topography, roads whose lateral drains do not extend below the lower surfaces of the pavement, major pavement failures due to subgrade weakness are frequently found

a. On transverse slopes.
b. At or near the foot of hills.
c. On low level plains contiguous to higher ground.

Likewise the fewest pavement failures occur on the tops of ridges

From investigations primarily of railways it was found that the best conditions were usually on fills (settlement and slide not considered). Likewise the poorest conditions were found in cuts and on transverse slopes unless the inflow of gravitational water had been intercepted. A cut increases the probability of encountering springs or seepage while a fill decreases such probability.

In railways " soft spots " result from seepage, impervious under lying layers or uneven soil structure, and are most frequently found on transverse slopes, at or near the change of the road grade, at points where water-bearing strata reach the subgrade sometimes on fills near the mouth of a cut on a higher elevation and in fills containing water pockets.

" Frost boils " occur under conditions similar to those favorable to " soft spots " but are of course confined to sections where considerable freezing occurs.

By H. G. Nicholson, Minnesota Highway Dept., " Oiled Subgrade Stops Frost Boils in Gravel Roads," Engineering News-Record, January 19, 1928.

1. For the class of road developed (gumbo soils) it is cheaper and more expedient to treat subgrades with oil before application of gravel.

2. Conservation of gravel is made possible.
3. Maintenance costs are reduced.
4. A more serviceable road in all seasons is developed.
5. The dust hazard is practically eliminated, making traveling safer and more pleasant for the riding public.

Information by letter from Calcium Chloride producer.

LOWEST HUMIDITY AT ANY GIVEN TEMPERATURE AT WHICH CALCIUM CHLORIDE IS EFFECTIVE FOR DUST PREVENTION

Below is a series of temperatures and corresponding humidities. At the temperature given, any relative humidity above that indicated should furnish sufficient moisture to the Calcium Chloride to dissolve it. It should be remembered, however, that when the relative humidity is only slightly higher than that indicated for any given temperature the absorbtion of moisture and dissolving of the Calcium will be very slow. The higher the humidity, the faster is the absorption

Temperature °F	Minimum % relative humidity
plus 14 0	45.2
32 0	42.5
50 0	38 0
68 0	32.3
77 0	28.5
83 3	24 3
85 1	22 6
86 4	21 0

SERVICE TRAFFIC AND COSTS

Of the three factors, service, traffic and costs, the one of service is probably the most important to the public, whereas all three deeply concern the road builder.

The cost of service is commonly reckoned in cost per vehicle—or ton—mile and may be made to include two main classifications. One, the cost of construction, maintenance and financing; two, the cost of vehicle operations and the cost (or value) of time gained by having adequate service, or lost by having inadequate service.

Road builders are giving increased thought to the quality of service as evidenced by smoother riding surfaces, snow removal and generally improved maintenance conditions.

The importance of traffic surveys for determining the volume and weight of traffic is recognized by nearly all highway officials.

For a given locality it is possible to calculate within reasonable limits the cost of furnishing adequate service for a given number of vehicles whose weights are known and to estimate the probable life of a road surface for such vehicles Changes in volume and weights of vehicles must be based on forecasts

Forecasts are made from a knowledge of present and past traffic, vehicle registration, industry and population.

Adequate service is possible only with continuous maintenance. In general terms it means that vehicles may pass between objectives in safety and comfort and at reasonable rates of speeds

Untreated surfaces of sand clay, gravel and stone are usually limited to adequate service for a traffic of less than 500 or 600 vehicles per day. These vehicles are commonly limited to automobiles and light trucks with pneumatic tires Heavy trucks and an increased number of vehicles may use such surfaces but increased dust and loss of surfacing material are the results The passage of a few heavy trucks during periods of freezing and thawing may seriously break the surfacing

Bituminous surface treatments of the various types improve the quality of service by preventing dust and the loss of surfacing material. The number of automobiles and light trucks can be safely increased when bituminous surface treatments are placed on sand clay, gravel and stone bases

Treatments of these surfaces with nonbituminous dust layers are effective in reducing dust and the loss of surfacing material.

The passage of heavy trucks may seriously damage bituminous and nonbituminous surface treatments except under favorable conditions of climate, season or subgrade The number of automobiles and light trucks with pneumatic tires which may economically use these surfaces appears to vary between limits as wide as 600 and 3000 per day. An average capacity of 800 to 1200 per day appears to be all that road builders are expecting of them

With few exceptions a pavement type of surfacing is selected when moderate or heavy trucking is to use the road even though the number of automobiles and light trucks may not exceed 400 or 500 per day.

Conclusions reached by prominent economists and road builders are valuable in considering service traffic and costs. The following extracts are given to show the trend of current opinion based on research and to add correlated information on this subject

TRAFFIC ANALYSIS

Report of Committee on Highway Traffic Analysis, Proceedings Sixth Annual Meeting Highway Research Board

The unit weight of truck traffic on certain highways may be such as to definitely require a high type surface. These cases, however, are exceptional and selection is generally influenced by economy rather than carrying capacity.

It is frequently stated that the type of improvement should be selected so as to give the lowest annual average cost per mile when the fixed charges (interest on investment and depreciation), and maintenance costs are added to operating costs (average costs of motor-vehicle operation per car mile on the particular type of surface multiplied by the annual traffic, total number of vehicles).

A difficulty appears here. Traffic conditions are so changing from year to year and our acquaintance with present day high-type pavements is so short that it is difficult to forecast economic life and annual maintenance costs

Passing this difficulty there are four objections to using a hard and fast rule for any theory of selection of type by traffic:

1. From the standpoint of first cost, funds are not always available in amount sufficient to make all improvements that actually appear economic, Until our state highway systems are 100 per cent improved, there will have to be considered in some localities the expediency of stage construction and the laying of more miles of "semi-durable" type than would be possible with a higher type.
2. From the standpoint of annual cost there are many cases where the carrying charges and maintenance costs (not considering operation costs) for the "semi-durable" type would be less than for the higher type.
3. From the standpoint of traffic service, the traveling public, which actually assumes the cost, in many cases shows a preference for the "semi-durable" types
4. From the standpoint of practicability, availability of materials and construction features would provide many exceptions

The traffic volume, along with economic factors, has a determining influence in the selection of the general class of pavement, and the economic factors determine largely the choice of type within the groups Where the traffic is composed of a considerable number of heavy trucks the type selection must be confined to those pavements which can economically carry the loads applied.

It is suggested that each selection of type be principally influenced by economy in annual charges (average annual maintenance plus equal annual charges for depreciation and interest) and that value or economical first costs be the basis of final determination.

The danger in a low traffic community lies largely in over-improvement by selecting the high-class pavements to the sacrifice of needed serviceable highways.

The relative value of two or more types can be determined, assuming that information as to economic life and maintenance costs is sufficient, by use of a table of annuities.

In many cases where the economy of a particular type and practicability of financing is evident, the economical type should be selected. In cases where there is reasonable doubt as to the economy of one type as compared with another, especially if funds are limited, and there is a greater demand for improvements than can be immediately satisfied, it may be desirable to give preference to the lower first cost type, provided it furnishes satisfactory traffic service.

It is true that construction costs have increased greatly in the last twenty years, and that within the next twenty years there will probably be further increase, so that from this standpoint long life improvements are advantageous, but, on the other hand, we have been continually improving our design for high-type pavement and the lower first cost improvements may be safer investments

SUPPLEMENT TO ROAD LAWS OF OHIO, 1925

Sec 7250 (Reduction of weight and speed during times of thaws and moisture.) When thaws or excessive moisture render the improved highways of this state or any sections of the same insufficient to bear the traffic thereon, or when such improved highways or any sections of them would be damaged or destroyed by heavy traffic during the period of thawing or excessive moisture, the maximum weight of vehicle and load, or the maximum speed, or both, for motor vehicles as prescribed by law shall be reduced in the following manner.

On main market roads and inter-county highways of the state, which have been taken over by the state, the director of highways and public works shall prescribe such reduction which shall not be more than twenty-five per cent; on improved highways other than main market roads and inter-county highways taken over by the state, the county commissioners shall prescribe such reduction which shall not more than twenty-five per cent

PLANNING THE IMPROVEMENT OF HIGHWAY SYSTEMS

By J G McKay

Chief, Division of Highway Economics and Transport, U S Bureau of Public Roads

In Proceedings Association Highway Officials North Atlantic States 1927

The principal traffic factors involved in the classification of highways are:

(a) Average daily and maximum total traffic and truck traffic

(b) Forecast of average daily total traffic and truck traffic for periods of 5 and 10 years

(c) Average daily and expected future number of loaded light, medium and heavy trucks for each route or section of route.

(d) The ratio of the total number of loaded trucks to the total traffic in order to separate for special consideration routes or sections of routes on which motor trucks are an abnormally large or small proportion of total traffic

(e) The number and frequency of critical heavy loads.

(f) Average maximum traffic as one measure of the width of the improvement, the necessity for improvement of additional parallel routes and the "by-passing" of congested centers of local traffic

(g) Analysis of highway maintenance and capital costs and vehicle operating costs as an important factor in determining the traffic limits for the various types of improvement.

The influence of large centers of population is marked. Traffic in the terminal areas of Philadelphia and Pittsburgh is greater in volume and in the numbers of loaded large capacity trucks using the highways in these areas than any other sections of the state (Pennsylvania).

Areas of low, decreasing population have a comparatively small expectancy of traffic on adjacent highways, while areas of dense and rapidly increasing population will have large increases of traffic on the highways. A highway department having no traffic data available can obtain a fair knowledge of the future traffic importance of highways in the various parts of the state by an analysis of population density and its trend.

The Ohio Transport Survey is one of the most recent and clearly indicates its value. Extensive surveys of this character cannot always be made but the conclusions reached are of immense value to road builders for studying their own traffic conditions.

THE OHIO TRANSPORTATION SURVEY *

By J G McKay

Chief of the Division of Highway Economics and Transport, U S Bureau of Public Roads

Conclusions from Survey Summarized

The results of the survey show that during the next five years the state should reconstruct 1220 miles of the state system, widen 1594 miles, and build 1707 miles, the latter comprising 1007 miles of construction superior to gravel and 700 miles of traffic-bound improvements. The cost is estimated at $100,000,000

On the basis of the traffic observed during the survey, it is estimated that the state highway system, which comprises 13 per cent of the total rural mileage, provided highway service for a traffic of 2,160,-435,000 vehicle-miles, equal to 57 7 per cent of the total motor-vehicle traffic on the rural highways of the state in 1925; that the county highways, which include 27 1 per cent of the rural mileage, provided service for 1,108,870,000 vehicle-miles, 29.6 per cent of the total traffic; and that the township highways, which constitute 59.9 per cent of rural mileage, provided service for 477,055,000 vehicle-miles, or only 12 7 per cent of total rural traffic The daily traffic on the state system averages over nine times that upon the county and township roads.

The largest volume of motor-vehicle traffic is found in the areas adjacent to large centers of urban population and on the main through-traffic routes.

Of the 11,000 miles of state highway system, 1.2 per cent carried 2500 or more motor vehicles per day, 7.8 per cent carried 1500 or more, 29.4 per cent carried 600 or more, and 70 6 per cent carried less than 600 vehicles per day in 1925.

Motor-truck traffic is an important part of total traffic on the principal routes. On the state system in 1925, 2.7 per cent of the mileage carried 200 or more trucks per day, 5 7 per cent carried 150 or more, 13.1 per cent 100 or more, and 27 5 per cent carried 60 or more

* Digest of report of Cooperative Studies of U S Bureau of Public Roads and Ohio State Highway Department given in June Public Roads

trucks per day. Based on the traffic forecast, it is expected that by 1935 over 1300 miles of state highways will carry 200 or more trucks per day, while a comparatively small mileage is expected to carry from 500 to 1000 trucks a day.

Four-fifths of the trucks operating on the state system are small units, 2½ tons capacity or less. The comparatively small number of large capacity trucks and heavy loads observed may perhaps be attributed in a measure to the gross-load limitation of 20,000 pounds fixed by law in the state

The average daily density of traffic in 1925 was 538 vehicles on the state system, 132 on county highways, and only 26 on township roads, each mile of road of the state system providing traffic service more than equal to that of 4 miles of county and 20 miles of town roads.

The federal-aid system, slightly more than half the state system, carried 70 6 per cent of the daily traffic of the state system; the main market roads, approximately one-third of the state system mileage and included for the most part in the federal-aid system, carried over half of the traffic, and the principal routes of the system, 8 8 per cent of the mileage, carried over one-fourth of the traffic.

The survey clearly shows that the traffic using the state system is predominantly city passenger-car and motor-truck traffic, farm-owned passenger cars and motor trucks making up only 12 4 per cent and 15 5 per cent respectively, of the total passenger-car and motor-truck traffic. The improvement and maintenance of state highways (in Ohio) is, therefore, primarily the result of the demand for highway service by city motor-vehicle owners.

The volume of traffic in a given area is principally produced by the population residing within a radius of 30 miles since less than 30 per cent of the truck traffic and less than 40 per cent of the passenger-car traffic travels more than 30 miles.

As a basis for the plan of highway improvement, the state highways are classified in three groups designated as major, medium, and minor traffic highways, according to their average daily traffic Routes or sections of routes carrying 1500 or more motor vehicles per day are classed as major routes, those carrying 600 to 1500 vehicles per day as medium routes, and those carrying less than 600 vehicles daily are classed as minor routes.

Experience in many states indicates that ordinary untreated gravel and similar surfaces can not be economically maintained when the traffic exceeds 500 to 600 vehicles per day and similar experience in Ohio points to approximately 600 vehicles per day as the limit. Above that traffic density the type and design of surface required are largely functions of the frequency of heavy loads, the choice of types including bituminous macadam for the lower densities and the several rigid types for roads of greater density.

If, on the basis of this experience, those sections of the Ohio state systems which carry a traffic of 600 or more vehicles per day be considered as requiring a type of surface superior to untreated gravel, it is found that in 1925 over one-third of the 11,000 miles of the state system, or 3852 miles, required such surfaces, and 10 years later, in 1935, based on the estimated traffic, approximately half the system, or 5221 miles, should be so improved.

Truck Traffic an Important Factor

Although motor-truck traffic on the state highway system is only 9 5 per cent of total motor-vehicle traffic measured in vehicle-miles, motor-truck traffic is an important factor in highway-traffic planning

The average gross weight of motor-trucks using the state system is over twice that of passenger-cars, while maximum motor-truck weights are four times the maximum weights of passenger cars The importance of the motor truck is further emphasized by the fact that many trucks are equipped with cushion and solid tires, which are much less effective in cushioning the impact of the wheels than the pneumatic tires with which the passenger cars are equipped A study of the rear-wheel tire equipment of motor trucks using the state highway system shows that 15 per cent of all the trucks are equipped with solid tires and a like percentage with cushion tires, and that 95 per cent of the 3 to 7½-ton trucks are equipped with cushion or solid tires on the rear wheels

Since motor trucks carry heavier gross loads than passenger cars, and the larger capacities are equipped with solid or cushion tires, and because the trucks do not have the refinements in shock-absorbing devices and spring equipment possessed by passenger cars, the motor truck, where it forms an appreciable part of motor-vehicle traffic, presents a special problem for the highway builder.

On routes carrying a small average daily truck traffic, especially those on which there are less than 30 trucks, and many sections on which the daily density ranges from 30 to 59 the number of trucks is practically negligible in planning highway improvements An improvement sufficient for passenger-car traffic will, with but few exceptions, prove satisfactory for the small-capacity trucks using these routes. On those routes carrying 60 or more, and particularly the routes carrying 100 or more, the motor truck becomes an important factor in planning the improvement of the highways

Proposed new construction, reconstruction and widening in Ohio should be planned to provide service for future traffic as well as for present traffic The building of a highway which will not meet traffic demands during the expected life of the improvement will result in traffic congestion and early reconstruction and is an uneconomic investment of public funds. Building in excess of the traffic needs of any route is undesirable, since it requires an outlay of public funds which could be used more advantageously for other highway improvements The principle of stage construction in highway development is a conservative method of adjusting highway improvement to traffic needs when the trend of traffic increase is unknown A knowledge of future traffic, in so far as it can be predicted with reasonable accuracy, is, however, essential in the establishment of a sound plan of highway improvement.

In the absence of any comprehensive historical series of traffic records in Ohio it has therefore been assumed that highway traffic in Ohio is increasing directly with the increase in motor-vehicle registration

The increase of motor-vehicle registration is a function of two variables. (1) The increase in population; and (2) the increase in ownership and use of motor vehicles in proportion to population, measured by the number of persons per motor vehicle The past trend of both of these factors may be determined from available records.

THE HIGHWAY TRAFFIC PROBLEM

By W A VanDuzer

Deputy Engineering Executive, Pennsylvania Department of Highways, 13th Annual Road School, Purdue University, 1927

The Traffic Problem in Itself

The development of motor traffic is largely measured by motor-vehicle registration.

There is a tendency for lighter cars. They have been developed to a high point of efficiency in continental Europe. We may expect similar development in this country.

As a matter of fact, the combined influence of increased efficiency of automobile equipment, decreased operation costs and increased road facilities (notably uninterrupted use of the roads throughout the winter) must be expected to continuously increase the ratio of traffic to registration from year to year

Classifying the Roads

Classification of highways according to the expected loads these highways will carry is, therefore, the logical result of traffic studies. The probable classification would be industrial, semi-industrial, and non-industrial, or light traffic roads. The industrial highways would be those carrying a large percentage of maximum weight trucks, the semi-industrial carrying a very small percentage of heavy trucks but a large number of medium weight trucks, and the non-industrial carrying principally passenger-car traffic

Selecting the Type of Improvement

The nature of traffic, that is, the amount and frequency of heavy wheel loads, practically determines the type of surface improvement The surface to be laid should be such as will justify itself by carrying traffic at reduced operating cost and with a reasonable road cost including interest, depreciation and maintenance.

A light type surface will carry up to a certain amount of wheel load without injury, and will carry an occasional injurious load with such slight damage that the annual cost of the light type, including repairs, will be less than the costs of a higher type surface In some instances there are practical conditions, scarcity of funds or difficulties of construction, that retard the transition to heavy type surfaces.

Increasing frequency of injurious wheel loads, however, will, at a certain point, justify increased expenditure for surface construction, especially if consideration is given to the fact that traffic is subjected to annoyance by frequency of repairs and by the deteriorated road surface awaiting repair.

In order to permit constant passing, the total number of cars on a 2-track road should not exceed the theoretical capacity of a single lane, that is to say, a 2-lane road should not carry traffic exceeding about 2000 vehicles an hour.

Car Mile Costs

The effect of traffic on maintenance costs is important. In general, maintenance and repair of road surfaces are necessitated by traffic and weather With most types of surface, a certain amount of traffic is a preservative rather than a destructive agent. On an earth, gravel, or stone road, light traffic will keep the road from heaving.

Bituminous binders will retain their life, that is, their elasticity, longer if they are under compression at moderate intervals than if they are permitted to lie dormant.

Records in Pennsylvania show maintenance costs increasing with volume of traffic for all types except hard surfaces. Our hard surfaced roads are comparatively new and so far do not show sufficient wear to determine relative effects of varying volume of traffic

The final measure of costs is the vehicle mile or ton mile. Including allowance for depreciation and interest on the costs of construction as well as maintenance and repair costs, a number of sections of road in Pennsylvania on which we have investigated show with fair consistency vehicle-mile costs ranging between a fourth and a half of a cent.

Whatever form of expression is used, whether vehicle-mile cost, or ton-mile cost, the figure is of great interest in connection with problems of selection of type for improvements

TREND IN MOTOR VEHICLE LEGISLATION

By Russell Huffman
Secretary Motor Vehicle Conference Committee

From an Article in Highway Engineer and Contractor, October, 1926

Size, Weight and Speed

At the present time three-fourths of the states have enacted laws regulating the width and height of motor vehicles. These regulations, of course, only affect busses and trucks. In 1921, only one-half of the states had such regulations. The greatest width permitted in any state at the present time is 108 inches and the narrowest width is 84 inches. The majority of the states have fixed the width limit at 96 inches and the height at 12 feet 6 inches. It must be noted, however, that the tendency is toward the reduction in the permissible width

All the states but three have enacted regulations fixing the weight of vehicles operating over the highways In 1921, 40 states had such requirements These requirements, generally not only fix the gross weight and capacity weight permitted on four wheels, but also the axle and per inch width of tire weight. The gross weight limitation ranges from 30,000 to 18,000 lbs, the average being about 24,000 lbs. Practically every state has a provision in its law which permits state and local highway officials to decrease this weight allowance when weather conditions have softened the roads so that it would be unadvisable to permit heavy vehicles to operate.

One of the noticeable movements during the past two years with reference to weight limitations is the tendency on the part of the highway officials to base the weight allowance upon the character of the highway over which the vehicle is to operate This is known as the classification of highways Under this method all highways are divided into four classes—terminal highways, highways connecting industrial centers, intermediate highways and local highways Under this plan the heavy loads are confined to those highways constructed to carry such weight. While no state has yet enacted such a law several of the state highway officials are using this plan to fix the weight permitted over certain of the state highways There is no doubt but that this plan has great merit, and it may go a long way toward solving the difficulties as regards highway weight regulations which exist now in a great many of the states

It is interesting to note at this time that one of the very recent developments with reference to speed regulations is the tendency toward a minimum speed limit rather than a maximum limit. There is considerable agitation at the present time for minimum speed laws among some of the state highway officials, and at least one state has enacted a law which prohibits the operation of a motor vehicle on the highways which cannot maintain a certain minimum of speed.

TRENDS IN MOTOR TRUCKS

In an article by Edward F. Loomis, Secretary, National Motor Truck Committee of the National Automobile Chamber of Commerce, published in Manufacturers Record, January 5, 1928, Mr. Loomis, writing on "Trend in Motor Trucks," says, "From the manufacturing end, two particular trends in 1927 are noted. First, the demand for high-speed, pneumatic tired vehicles. Second, increased conservatism in selling methods"

COST OF VEHICLE OPERATION

That this item of cost is receiving more attention is evidenced by current engineering literature The following is taken from the Engineering News-Record of January 26, 1928, and refers to a paper presented at the Highway Division meeting, in January, 1928, of the American Society of Civil Engineers

"Economic Comparison of Various Types of Road Surfacing" was the subject of a symposium before the Highway Division meeting on Thursday afternoon Paul D Sargent, former chief engineer of the Maine State Highway Commission, Frederick E Everett, commissioner and chief engineer of the New Hampshire State Highway Department, and H. J Kuelling, Wisconsin state highway engineer, presented papers giving, for their respective states, the economic factors considered in road surfacing, construction and maintenance costs for different types of surfacing and the tire and fuel costs for operating vehicles over these roads The experiences of these three indicate that operating costs were almost invariably much higher than those for construction and maintenance The comparison was arrived at through traffic counts to give an average per-mile yearly travel In the discussion of these papers it was brought out that the highway problem is being viewed from a broader viewpoint by most engineers, the economic factors having become a major consideration Traffic counts were shown to be of little value in considering suitable road surfacing, unless distinction is made between truck and light car traffic A suggestion was made that road surface selection be considered from the standpoint of returns on capital investment. The type of surface selected should be that which produces the maximum return, represented by the saving in maintenance and vehicular operation, in proportion to the capital invested in the road

The Highway Engineer and Contractor contained this statement in October, 1926:

"Salesmen who are paid for the use of their cars on a mileage basis and who travel all classes of roads find that the saving on paved roads over that on ordinary earth averages 2½ cts per mile Few people keep an accurate account of the cost of their automobile transportation Traveling salesmen who use cars constantly and particularly those who are paid upon the mileage basis usually keep a somewhat accurate account. A tabulation or summarization of hundreds of these accounts bear out the expressed opinion that the saving on paved roads is at the approximate rate of 2½ cts. per mile."

What it Costs to Own and Operate Automobiles

(Estimated by Bureau of Industrial Technology of National Automobile Chamber of Commerce, 1926)

ANNUAL COSTS

		Per cent
Cost of cars and accessories	$3,750,000,000 =	26 2
Depreciation	2 500,000,000 =	17 5
Upkeep and Repairs	2,000,000,000 =	14 0
Drivers' Wages	1,600,000,000 =	11 2
Gasoline	1,200,000,000 =	8 4
Garages	900,000,000 =	6 3
Taxes	625,000,000 =	4 4
Interest on Investment	500,000,000 =	3 5
Tires	618,000,000 =	4 3
Oil	300,000,000 =	2 1
Insurance	300,000,000 =	2 1
Total	$14,293,000,000 =	100 0
Average Cost per Car per Year	=	$700 0

The report of the Committee on the Economic Theory of Highway Improvement of the Highway Research Board, 1924, contained information on the cost of vehicle operation T R Agg reported on the "Investigation of Rolling Plus Air Resistance" at Iowa State College, in part as follows

The work that has been completed indicates that the magnitude of rolling plus air resistance for self-propelled types of vehicles is affected by the following factors.

1 The smoothness of the road surface
2 The degree of rigidity of the road surface
3. The type of tire.
4. The temperature of the tire, and of the road surface if of bituminous type
5 The exact texture of the road surface
6 The gross weight carried by the tires.
7. That size of tire seems to affect rolling resistance very little so long as the tires conform to good practise as to size relative to load.
8. That low pressure cord tires have somewhat higher rolling resistance than the high pressure cords but the difference decreases for the rougher surfaces.

9. That average values for rolling plus air resistance for the several classes of vehicles under all-the-year-round operating conditions appear to be as follows:

Busses and automobiles at 35 miles per hour, high pressure cord tires:

Best paved surfaces	37 lbs per ton
Paved surfaces in average condition	42 lbs per ton
Best water-bound gravel	55 lbs per ton
Ordinary gravel	65 lbs per ton
Fair to good earth roads	75 lbs per ton
Best earth roads . . .	65 lbs per ton

For low pressure cord tires, add 10 pounds per ton

Trucks with pneumatic tires at 15 miles per hour.

Best paved surfaces	22 lbs per ton
Paved surfaces in average condition	30 lbs per ton
Best water-bound gravel	40 lbs per ton
Ordinary gravel	50 lbs per ton
Fair to good earth roads	60 lbs per ton
Best earth roads .	50 lbs per ton

The investigations of the relation between rolling resistance and fuel consumption show that the higher the resistance the greater the fuel consumption, but the relation is by no means a simple one Type of vehicle, speeds, and the personal equation of the driver all enter into the problem.

Table 10 shows the average cost of vehicle operation over each type of road in cents per mile as determined by experiments and a study of actual cost records as reported by T R. Agg Since trucks vary a great deal in weight the figures for trucks are in terms of the ton-mile To get the total cost per mile for any truck, multiply the figure in the table by the weight of the truck plus the average load

TABLE 10

Type of surface	Type and speed of vehicle			
	Solid tire trucks 10 M.P H, cents per ton mile	Pneu tire trucks 15 M P H, cents per ton mile	Automobiles 25 to 35 M P H, cents per vehicle ml	Motor busses 25 M P H cents per bus mile
Ordinary earth with light traffic Yearly average .	9 5	9 95	12 6	29 6
Best earth, well packed by traffic Yearly average . . .	9.2	9 50	12 00	27.8
Ordinary gravel Yearly average	9 0	9 40	11.8	27.8
Best gravel Yearly average .	8 5	8.8	10 9	25 7
Best P C concrete and asphalt filled brick	7 75	7 70	9 3	22 50

Another portion of the report of this committee was made by W C. McNown, University of Kansas, and contained the following conclusions.

It is believed that certain general conclusions can be made from this preliminary work.

1 The difference in the effects of certain high type pavements such as concrete and brick and probably asphalt, upon tire wear is not great if these pavements are in high-class surface condition
2 Roughness of longitudinal contour causing bounding, acceleration, impact, and deceleration, with its accompanying slippage, has a marked effect upon the wear of tires running with standard inflation.
3. Under-inflation is probably the cause of much greater wear then is ordinarily assigned to it, although it cannot be said how much this effect is offset by decreased wear due to the lessened amount of bounding and impact.
4. A vast amount of tire wear results from various causes not assignable to pavement type And if a great amount of value in tires is dissipated in other ways than in running, properly controlled, over well made surfaces, then care should be taken not to over-estimate these values in the solution of problems in highway economics until more data are available
5. Tire wear investigation, using laboratory methods and small-scale devices instead of standard equipment, may give results wholly misleading Relative values may be obtained, but should be used with caution until more is known about the relation between the amount of value actually existing in tires and that used in other ways than by running properly over first-class pavements, such as by stopping and starting, by physical deterioration while standing, running over rough pavements, and abuses such as under-inflation and high speeds

It should be noted that no data are given for operating costs on bituminous surfaces or surface treatments On such surfaces it should be less than on untreated gravel and similar untreated types and it should not exceed that on concrete surfaces by any appreciable amount.

The Proceedings of the Second Annual Convention of the Association of Highway Officials of the North Atlantic States, February, 1926, contain an enlightening paper by William H. Connell, en-

gineering executive, Department of Highways of Pennsylvania Mr Connell in part stated:

"This saving in motor vehicle costs, both for Pennsylvania and the entire United States, exceeds the annual cost of the improved highways The average cost of durable type construction in Pennsylvania is about $50,000 a mile The annual cost for each mile of road constructed, including interest and sinking fund on the capital outlay, plus the annual maintenance charge, is about $4,800 per mile or $21,600,000 for 4,500 miles The construction of these roads also saved the annual maintenance charge of $2,250,000 for the 4,500 miles of dirt roads which have been replaced Therefore, the additional annual charge due to the construction is only $19,350,000 Deducting this from the saving in operating costs of $51,750,000, leaves a net annual saving of $32,400,000

"The average cost of the several types of hard-surface road construction in the United States is about $33,200 a mile and of gravel roads about $10,000 a mile, based on costs on the Federal-aid system from 1917 to 1925 The annual cost for each mile of hard-surfaced road constructed, including interest and sinking fund on the capital outlay, plus the annual maintenance charge, is about $3,350 or about $446,000,000 for 133,196 miles, for the gravel roads it is about $2,000 per mile, or $305,000,000 for 153,000 miles, making a total of $751,000,000 annual charge for the hard-surfaced and gravel roads The maintenance costs that have been used for the different classes of roads in the United States are based on the maintenance costs for similar roads in Pennsylvania for the traffic of 700 vehicles a day that has been assumed for the United States The construction of these roads also saved the annual maintenance charges of $143,000,000 for the 286,000 miles of dirt roads which have been replaced Therefore, the additional annual charge due to the construction is only $608,000,000 Deducting this from the saving in operating costs of $1,630,000,000, leaves a net annual saving of $1,022,000,000

"While the owners of motor vehicles in Pennsylvania are saving $51,750,000 annually as a result of the building of 4,500 miles of hard-surfaced roads to replace dirt roads on the State Highway System, they only paid to the State in 1925 $29,500,000 (to support the construction and upkeep of the entire 10,800 miles maintained by the Department) in motor vehicle registration fees and gasoline tax, which leaves them a net saving of $22,250,000

"The figures for the entire United States show that while the owners of motor vehicles save annually $1,630,000,000 in operating costs due to the construction of 286,000 miles of gravel and hard-surfaced roads, they only paid $420,000,000 in 1925 in motor vehicle registration fees and gasoline taxes, leaving them a net saving of $1,210,000,000"

COST OF ROAD SERVICE

The cost of vehicle operation has not been kept in highway organization records, except in a few instances, but the cost of maintenance per vehicle-mile is a matter of record with several of them

In some the cost of surface maintenance is not separated from other items, nor are the record forms or items of work always similar as between various states or counties That some organizations are making records and studies of these items is evidenced by the following data which are from typical examples

Taken from 1927 Annual Repoɪt, Board of County Road and Park Commıssioners, Kent County, Mıchıgan

TOTAL MAINTENANCE COSTS FOR ALL ITEMS ON 339.29 MILES OF ROAD

(The gravel surfaces are all treated wıth calcıum chlorıde Detaıls may be found ın the report ıtself)

AVERAGE COST OF MAINTAINING THE TRUNK LINE MILEAGE WAS $539.88 PER MILE

Average cost per vehıcle mıle of State Trunk Lıne	$0 001134
Average cost per vehıcle mıle of gravel	002293
Average cost per vehıcle mıle of concrete	000832
Average cost per vehıcle mıle of asphalt	000527
*Average cost for mıle of gravel	690.31
*Average cost for mıle of concrete	479.37
Average cost for mıle of asphalt	335 38

AVERAGE COST OF MAINTAINING THE COUNTY ROAD MILEAGE WAS $629 18 PER MILE

Average cost per vehıcle mıle of County Road	$0 006372
Average cost per vehıcle mıle of gravel	007418
Average cost per vehıcle mıle of concrete	001797
Average cost for mıle of gravel	674 73
Average cost for mıle of concrete	301 65

AVERAGE COST OF MAINTAINING THE STATE TRUNK LINE AND COUNTY ROAD MILEAGE WAS $605 82 PER MILE

Average cost per vehıcle mıle of State Trunk Lıne and County Roads	$0 003761
Average cost per vehıcle mıle of gravel	006609
Average cost per vehıcle mıle of concrete	001102
Average cost per vehıcle mıle of asphalt	000527
*Average cost for mıle of gravel	676 58
*Average cost for mıle of concrete	402 13
Average cost for mıle of asphalt	335 38

* Does not include T L. 37

From the Eleventh Bıennial Report of the State Hıghway Commıssıoner, Michigan, 1925-1926.

1925 TRUNK LINE AND FEDERAL AID MAINTENANCE COSTS

Type	Miles	Total cost 1925 maıntenance	Average maintenance cost per mile	Average maintenance cost per vehıcle mıle
Earth	495 120	$78,648 11	$158 85	$ 003370
Stamp Sand	66 900	19,517 56	291 74	003078
Gravel	2,729 605	1,160,909 43	425.30	004016
Water-bound Macadam	416 450	238,619 63	572 99	003453
Bıtumınous Macadam	31 300	18,123 11	579 01	002292
Bıtumınous Concrete	143 537	53,999 67	376 62	000654
Cement Concrete	1,106 161	400,726 79	362.27	000688
Brıck	6 965	1,297.32	186.26	000385
Unclassıfied	1,854 937	680,631 93	366 93	002498
Totals	6,850 975	$2,652,473 55	$387 17	$ 001978

Above costs for State of Michigan include the following features of maintenance work:

1. Work on Grade
2. Bridges and Culverts
3. Dragging and Patching.
4 Dust layers or Surface Treatments on practically all Water-bound Macadam Roads and on approximately 600 miles of Gravel Road.
5. Resurfacing of Gravel and Stamp Sand Roads
6 Snow Removal on the more heavily traveled roads.
7. Taking Traffic Census and Enforcing Truck-loading Law
8 Markers and Signs.
9 Overhead and Supervision.

INVESTIGATION OF NEBRASKA SAND-GRAVEL ROADS

Summary of Test Analyses and Field Data For Samples Obtained from 76 Nebraska Road Projects

An extensive investigation of Sand-Gravel Surfaced Roads has just been completed by the Department of Public Works, Nebraska. Under the date of March 1, 1928, this report states in part the following.

During the past four years Nebraska has constructed 3246 miles of sand-gravel roads, varying in thickness from ½-inch to 4 inches Prior to 1924 the total mileage of sand-gravel roads in Nebraska was only 153, but this small amount was sufficient to show the adequacy of this type of Low Cost Improved Road The following summary will show the rapid growth of sand-gravel roads in Nebraska and the thickness of the application used.

Year	Miles
1919	42
1920	15
1921	32
1922	53
1923	11
1924	462
1925	908
1926	693
1927	1451

Includes 268 miles which have been given a second application

Thickness	Miles
½ inch	7
¾ inch	53
1 inch	224
1½ inches	98
2 inches	1121
3 inches	1897
4 inches	263
6 inches	4

It can be clearly seen from the above tabulation that sand-gravel roads in Nebraska are no longer an experiment. This type of Low Cost Improved Road is being referred to in this investigation as a sand-gravel road because it is distinctly different from the class of roads usually referred to as gravel roads or from the class referred to as sand-clay roads From the standpoint of materials of construction it lies between these two classes and is superior to both It partakes of the smoothness of a sand-clay road and has the wearing and carrying capacity of the best gravel roads

The general specified analysis of the material to be used for surfacing is as follows 100 per cent passing one inch sieve, from 0 to 50 per cent retained on a No 4 sieve, and from 70 to 90 per cent retained on a No 10 sieve This material is fine enough so that the surface does not ravel and with proper maintenance can be kept in excellent condition.

This type of road is entirely free from slipperiness and can be safely traveled at higher speeds than most pavements and with more comfort. The only objectionable feature of this type of road is the dust nuisance which it is hoped may later be partially overcome by the use of the proper road oil The low cost of construction and maintenance of sand-gravel roads in Nebraska is largely responsible for their rapid growth A road consisting of a 3-inch application of sand gravel and of a width 3 feet less than the clear roadway can be constructed, maintained and replaced every 2 or 3 years, for a price equal only to the interest, figured at 5 per cent on the amount that would be required to construct a pavement.

Nebraska by adopting the present sand-gravel road program has been able to expand its mileage of improved roads from 10 to 20 times the amount that would have been possible under a paving program It is generally considered that gravel roads are not economical in other states where the traffic exceeds 500 vehicles per day, but this type of Low Cost Improved Road constructed with a 4-inch application of sand gravel has proven successful where traffic has been as high as 2500 vehicles daily in Nebraska

The greater part of the sand-gravel roads of Nebraska have been constructed on the natural surface soil, which after being shaped to the proper cross-section and grade is considered the subsoil of the road surface However, some of the roads located largely in the north central section, have been constructed over very sandy soil and before surfacing these with sand gravel it was first necessary to clay surface the natural soil.

It is not now and may never be possible to state the exact traffic capacity of any type of road surface or its exact initial and maintenance costs It is practicable to now indicate between conservative limits the volume and weight of traffic which each type is serving in a given locality, and the initial cost and the maintenance cost

The relative cost of vehicle operation may be estimated but the loss to a community which has no surfaced highways can be shown as greater than the cost of operation on well maintained untreated surfaces such as gravel or sand clay Data on all of the fundamental traffic and cost items can be determined From them it is possible to decide whether or not a defined type is a feasible investment under known local conditions As the number of variables is small and their quantitative value can be closely estimated, the problem can be solved

EQUIPMENT FOR CONSTRUCTION AND MAINTENANCE

The maintenance and construction of low cost roads received real encouragement with the distribution of surplus war material by the federal government to the various states Although much of it is now worn out or obsolete, it nevertheless was the means of improving thousands of miles of roadways and showed the possibilities of maintenance and construction with motorized equipment.

Present practise and future tendencies call for equipment which will do road work quickly and efficiently, with little delay or obstruction to traffic It is important to have equipment which will be in the right place at the right time and which can "get in and out" quickly

There is a tendency toward equipment which is suitable for construction and for maintenance including snow removal and for equipment which may be used for maintaining untreated as well as treated surfaces. One-man units such as the patrol grader are replacing the drag hauled by a truck with its driver and one or two assistants

Heavy bladers have proved their usefulness for mixing-in-place on the road both bituminous and untreated surfaces and smooth riding surfaces have resulted The use of a drag or screeding device has been found valuable in producing smoother riding bituminous surfaces of all types

Following are listed surfacing types of this report with which various types of equipment are commonly used.

BLADERS

For Construction and Maintenance

Grading
Sand clay
Disintegrated granite
Shale
Chert.
Gravel.
Traffic bound surfaces
Lime rock, marl, caliche
Volcanic cinders
Mine tailings.
Nonbituminous dust preventives
All mixed-in-place bituminous surfaces.
Soil treatments with nonbituminous materials.

SCARIFIERS OR PLOWS

Grading
Sand clay
Disintegrated granite.
Shale.
Chert.
Gravel.
Traffic bound surfaces
Macadam.
Lime rock, caliche and marl
All mixed-in-place bituminous surfaces.
Bituminous penetrated surfaces.

DRAGS OR ROAD PLANES

For Construction, Reconstruction and Maintenance

Grading.
Sand clay.
Disintegrated granite
Shale
Chert.
Gravel.
Traffic bound surfaces
Caliche.
Volcanic cinders.
Mine tailings
Macadams with gravel or stone surface mulch
Mixed-in-place bituminous surfaces
Soil treatments with nonbituminous materials

POWER ROLLERS

For Construction and Reconstruction

Grading, chert.
Some gravel surfaces
Macadam.
Lime rock
Some single bituminous surface treatments
Some dual bituminous surface treatments
Some mixed-in-place bituminous surfaces
Pre-mixed-laid-cold bituminous surfaces.
Natural rock asphalt.
Modified or puddle macadam.
Bituminous macadam, hot application
Pre-mixed-laid-hot bituminous surfaces

HARROWS

For Construction and Reconstruction

Grading
Sand clay.
Some gravels.
Some mixed-in-place bituminous surfaces.

DISTRIBUTORS

For Construction, Reconstruction and Maintenance

Single and dual bituminous surface treatments
All mixed-in-place bituminous surfaces
Prime coats of bitumen for pre-mixed bituminous surfaces and natural rock asphalts.
Modified or puddle macadam.
Bituminous macadam

PAVERS

For mixing cold-mix bituminous patching and surfacing mixtures

PLANT FOR BITUMINOUS SURFACES

Including tanks, screens, driers, elevators, bins, mixers

Pre-mixed laid cold, and pre-mixed laid hot types.

Sand stone rock asphalts are mixed at a plant near the source of supply by combining rock asphalts containing various percentages of bitumen

Lime stone rock asphalts require plant mixing at the supply source or near the place of laying the material

POWER SHOVELS, SCOOPS, TRACTORS, FRESNOS, TRUCKS, SCRAPERS

For Construction and Reconstruction

Grading
Sand clay.
Disintegrated granite
Chert.
Shale.
Gravel.
Lime rock, marl, caliche

TRACTORS

For Construction, Reconstruction and Maintenance

Grading.
Sand clay.
Disintegrated granite.
Chert.

Shale.
Gravel.
Lime rock, marl, caliche.
All mixed-in-place bituminous surfaces.
Soil treatment with nonbituminous materials.

TRUCKS

For Construction, Reconstruction and Maintenance of all Types of Surfacing

Cuts of equipment are designated by numbers and name. A brief description of each is given. The numbers progress approximately as the order of the work to which the equipment is adapted.

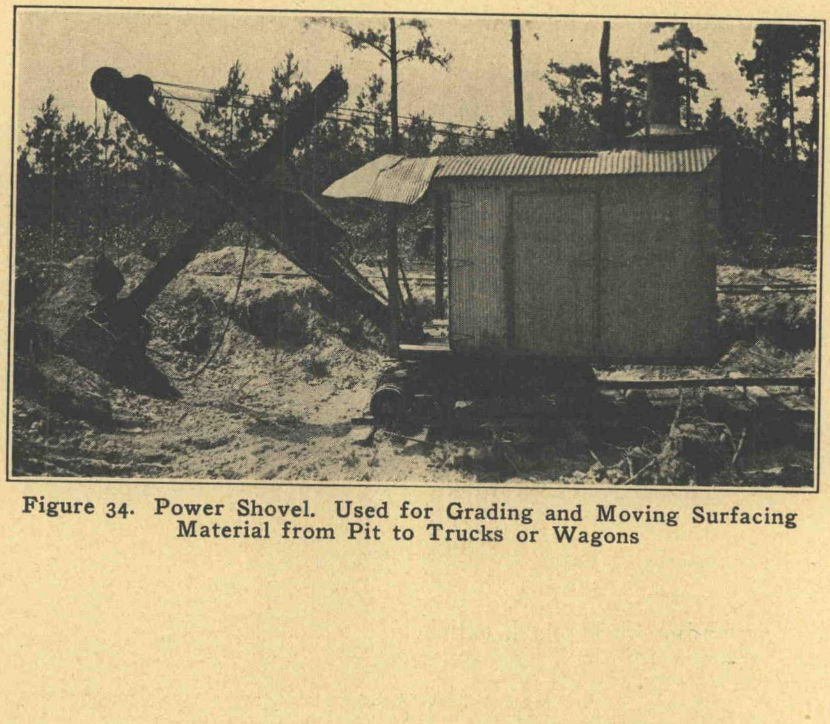
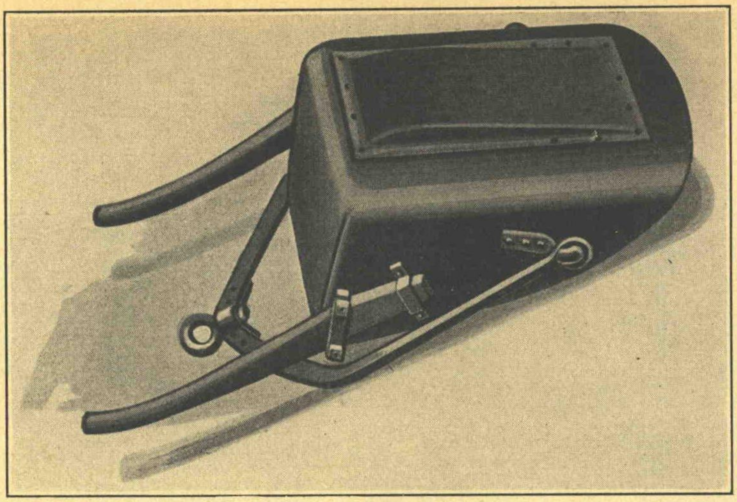
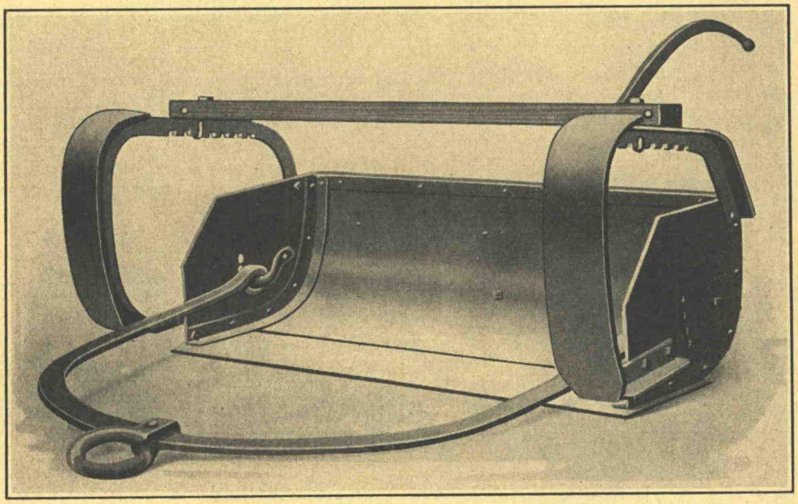


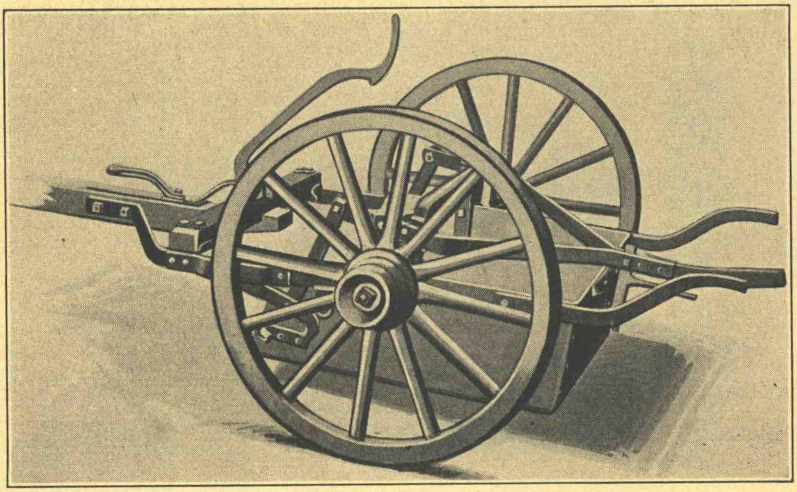
Figure 34. Power Shovel. Used for Grading and Moving Surfacing Material from Pit to Trucks or Wagons



Drag Scraper



Fresno



Wheel Scraper

Figure 35. (Three Photos Grouped.) Drag Scraper, Fresno, Wheel Scraper Are Used for Grading and Moving Surfacing Materials from Local Pits to Roadway or Through a Hopper into Trucks or Wagons

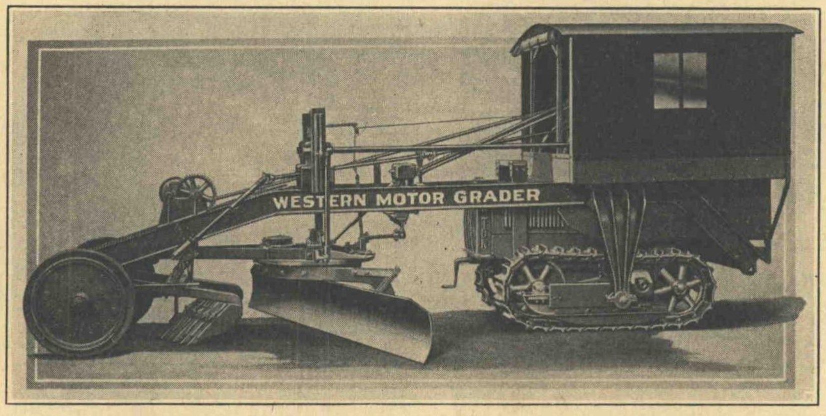


Figure 36. Blade Graders Are Used for Rough and Fine Grading, Ditching, Surface Maintenance, Mixing Aggregates with Bitumen in Place on the Road, Scarifying, Shaping and Reshaping. They Are Self-Propelled or Hauled by Truck or Tractor. There Are Various Types and Lengths of Blades. A Recent Model Has Two Blades. Several Models Have "Leaning" Wheels. The Wheels on Drive Axle May Have Solid or Pneumatic Tires or Caterpillar Tread

Figure 37. Drags Are Commonly Used for Smoothing Untreated Roadway Surfaces. They Have Been Found Useful in Shaping Up the Cover Coat of Bituminous Surface Treatments. Drags Are of Metal or Wood, or Both. They Are of Heavy and Light Construction. Heavy Drags Are Also Known as "Road Planes."

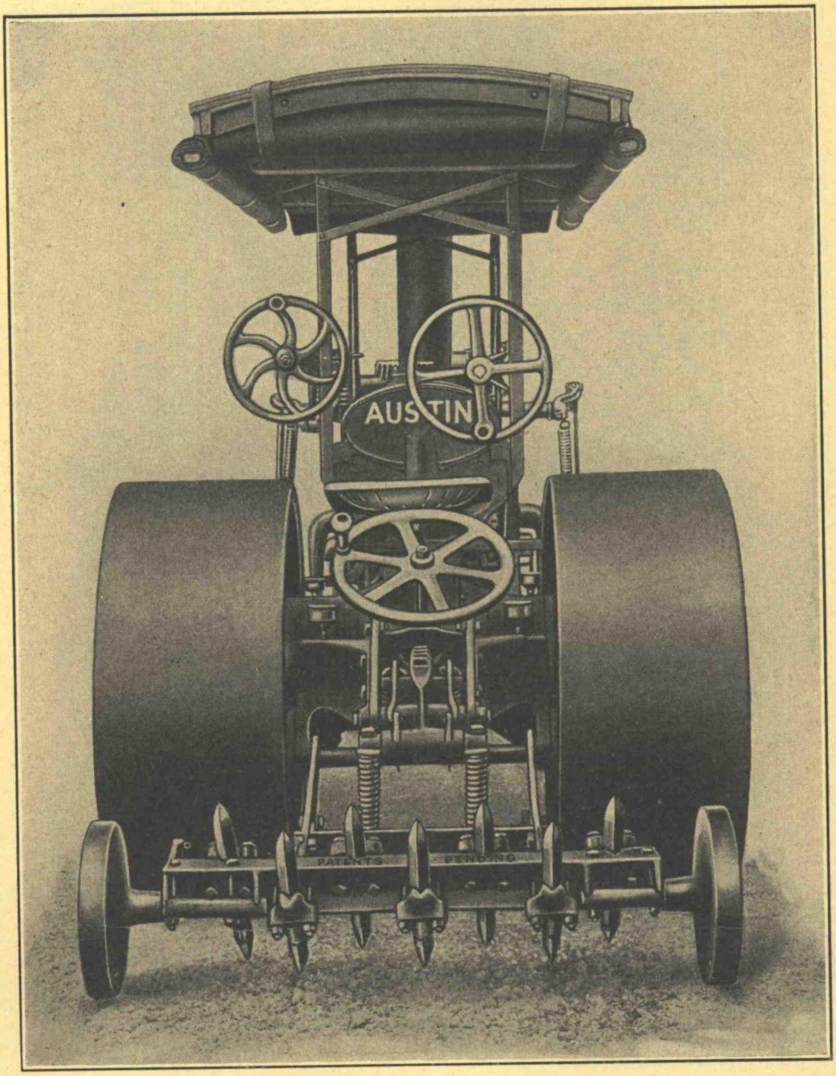


Figure 38. Scarifiers, Consist of Removable Sharp Metal Teeth Securely Fastened in a Metal Frame. The Unit May Be Attached to a Blade Grader, Roller, Tractor or May Be a Separate Piece of Equipment on Wheels. They Are Designed for Light and Heavy Duty and Are Used to Loosen and Break Up Road Surfaces. Surfaces Which Cannot Be Loosened by Scarifiers Require a "Rooter" Plow.

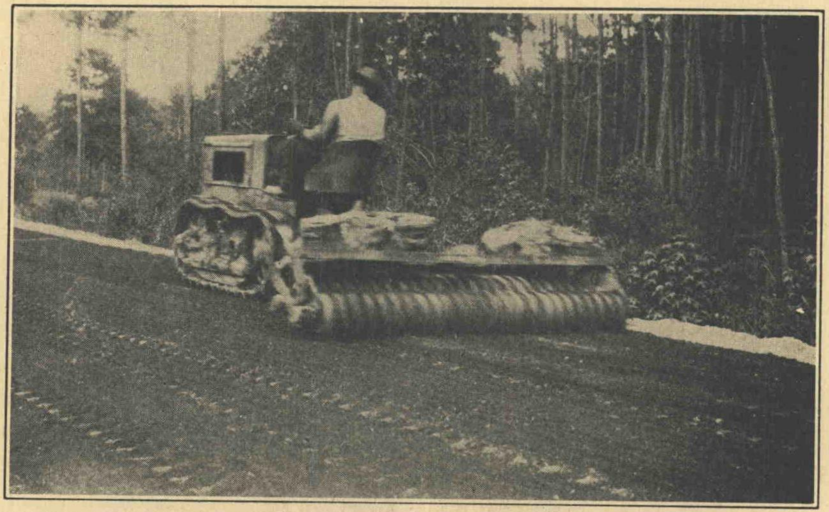
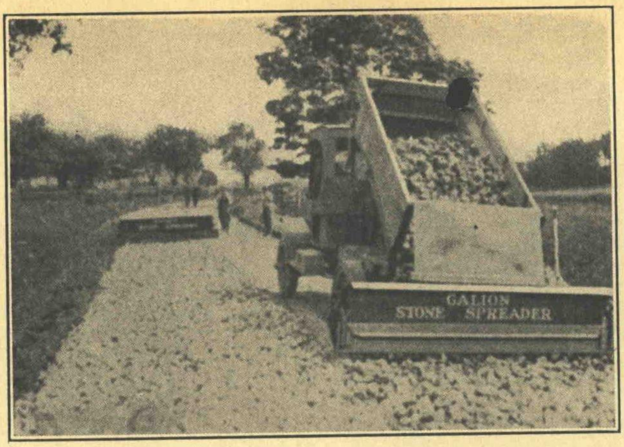


Figure 39. Disk Harrow. Harrows Are Commonly of Three Types. Disk, Spring-Tooth and Spike-Tooth. They Are Used to Break Up Lumps of Earth or Surfacing Materials and to Assist in the Mixing Process of Mixed-in-Place Bituminous Surfaces. They Are Hauled by Truck or Tractor

Figure 40. The Hand Broom Is Being Replaced by Rotary Power Brooms for Removing Dust and Foreign Particles from a Roadway Surface Prior to the Application of Bitumen in Surface Treatment Work. Hand Brooms Are Commonly Used for Spreading Cover Aggregate



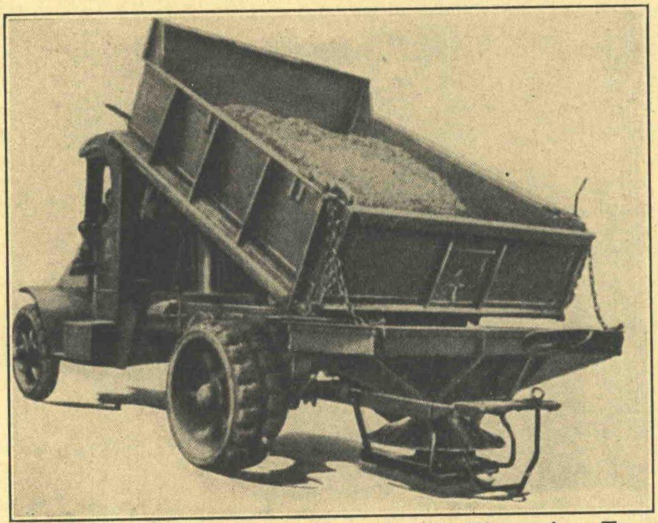


Figure 41. "Aggregate Spreaders." There Are Two Principal Types. One Is Used to Spread Coarse Material for Macadam Surfaces, the Other for Spreading Finer Material for Cover of Bituminous Surface Treatments. They Are Commonly Attached to or Hauled by a Truck

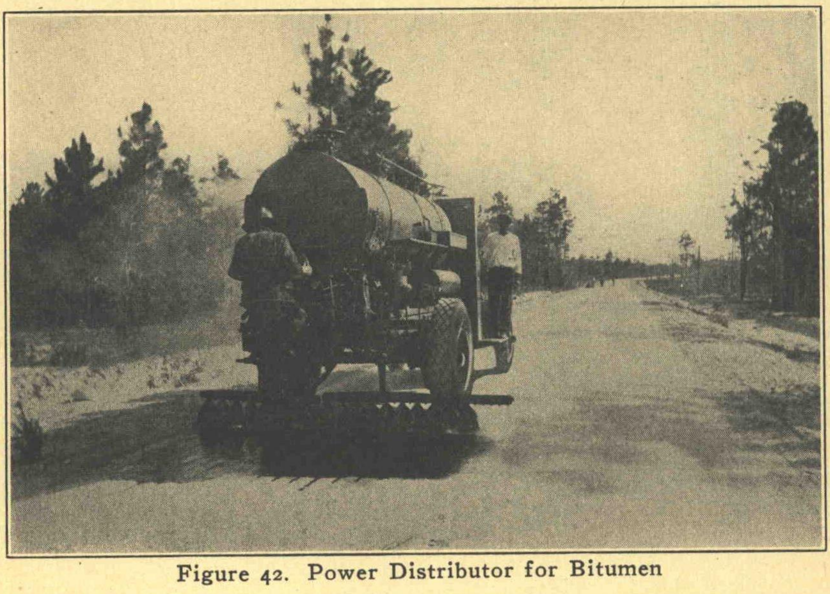


Figure 42. Power Distributor for Bitumen

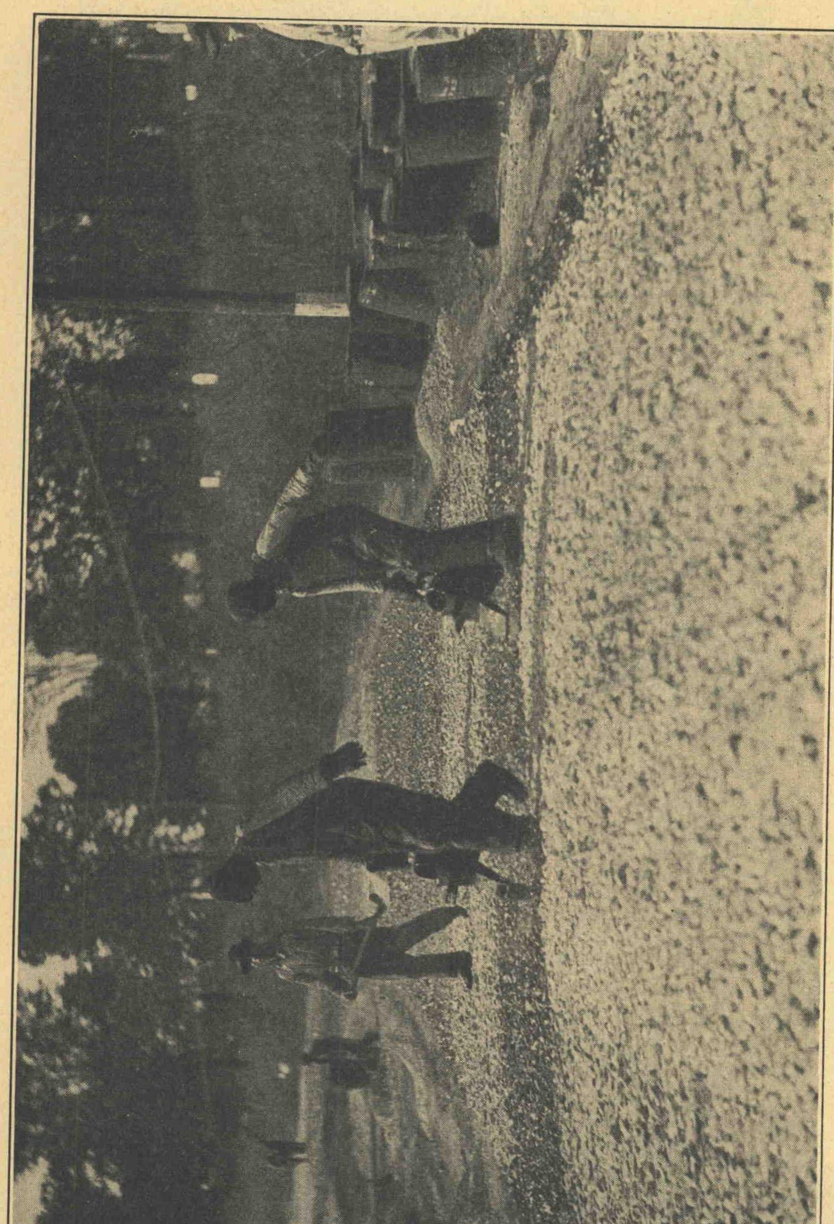


Figure 43. Hand Distribution of Bitumen

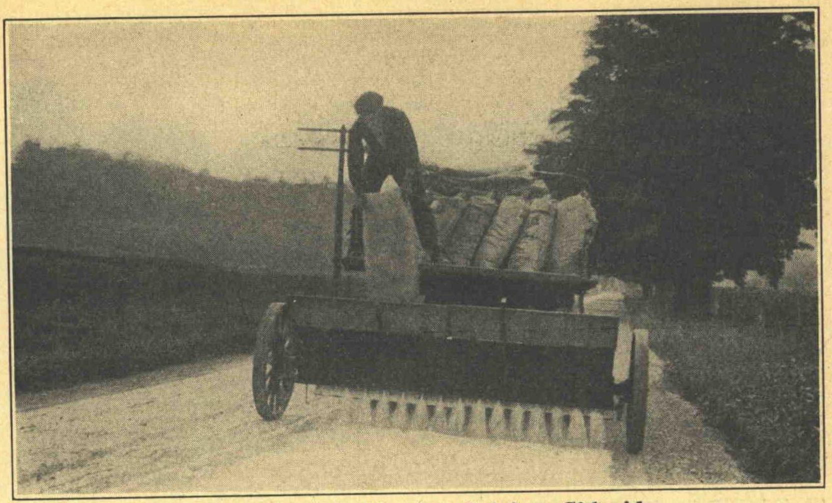


Figure 44. Distributing Calcium Chloride

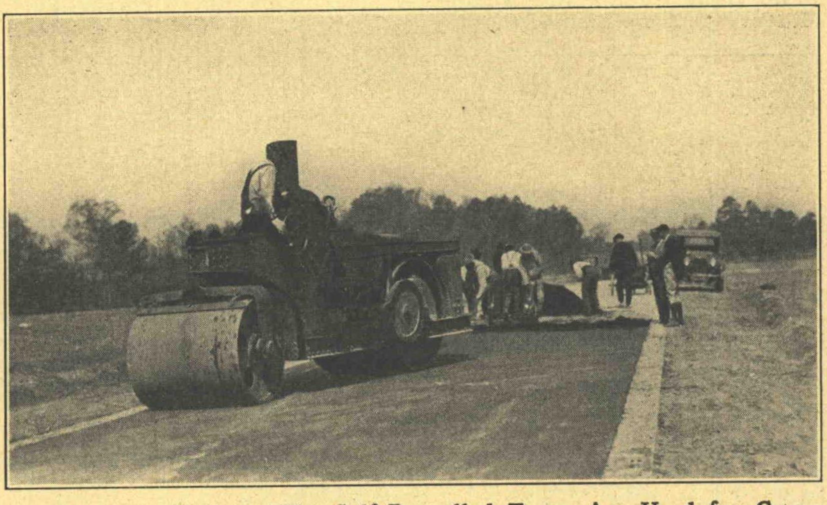
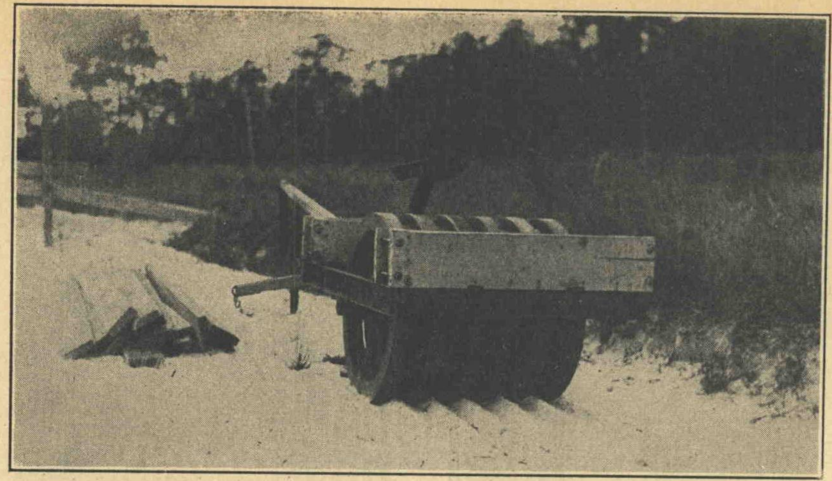


Figure 45. Rollers. The Self-Propelled Types Are Used for Compacting All Classes of Bituminous Surfaces, Macadams, Some Gravels and Other Untreated Materials. They Range in Weight from 3 to 16 Tons. They Are of the "Three-Wheel" and "Tandem" Types



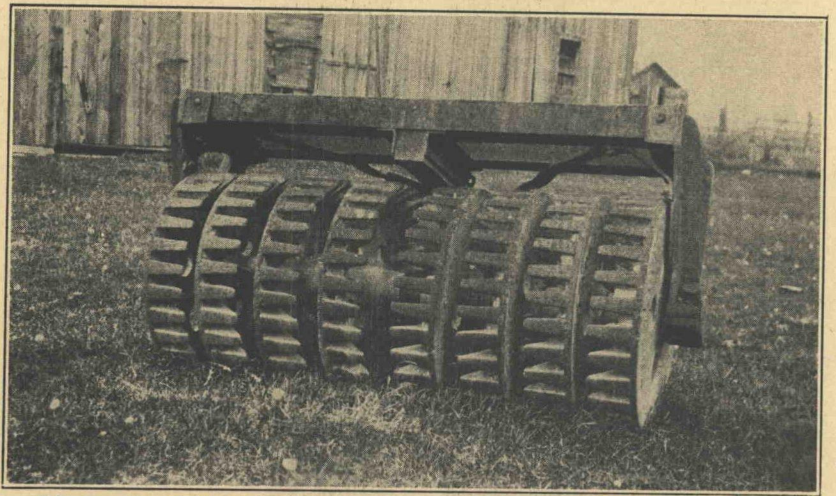


Figure 46. Rollers for Gravel or Sand-Clay Are Sometimes Designed to Give High Unit Pressures Below the Immediate Roadway Surface; Two Such Rollers Are Shown; Another Type, the "Sheeps'-Foot Roller" Is for a Similar Purpose

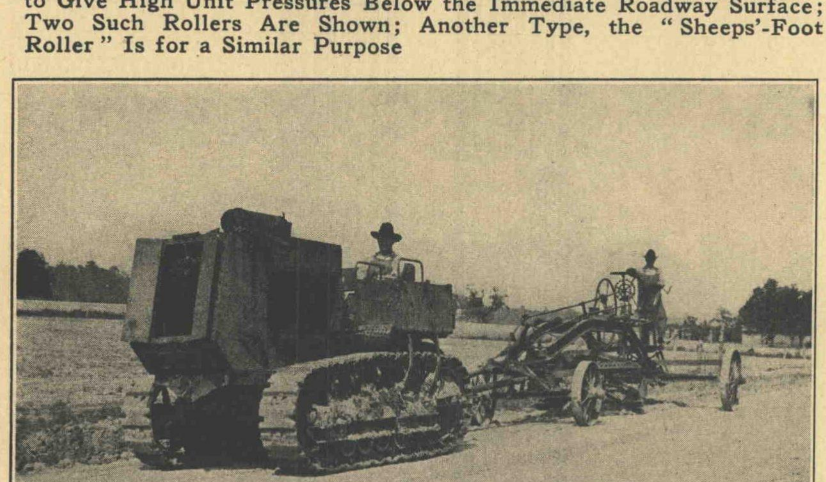


Figure 47. Tractors Are of the Caterpillar and Wheel Type; Are for Heavy and Light Duty and Are Used to Pull Graders, Plows, Drags and for Pulling Stumps and Small Trees

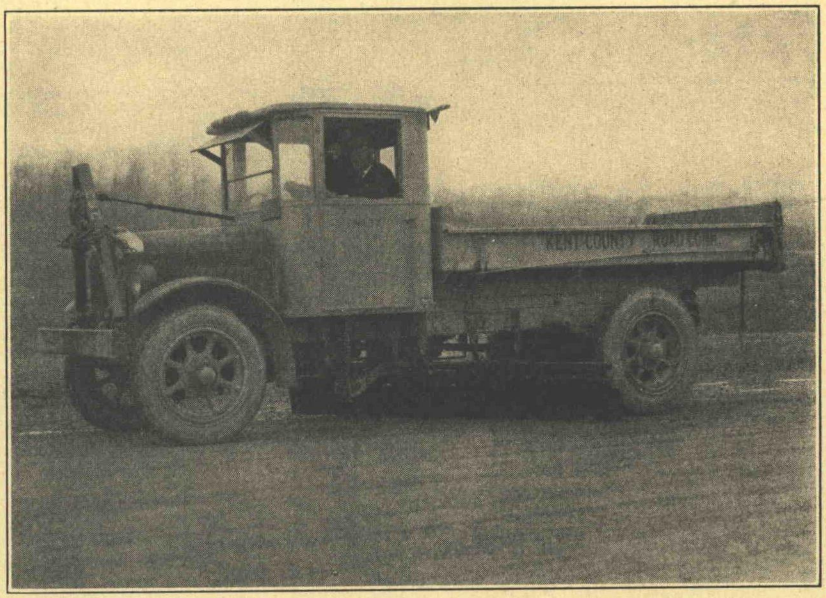


Figure 48. Trucks Are a Most Important Piece of Equipment in Construction and Maintenance. The One Shown Is Effective for Hauling Surfacing Materials, Blading the Roadway Surface, and for Snow Removal by Attaching a Plow to the Bracket in Front

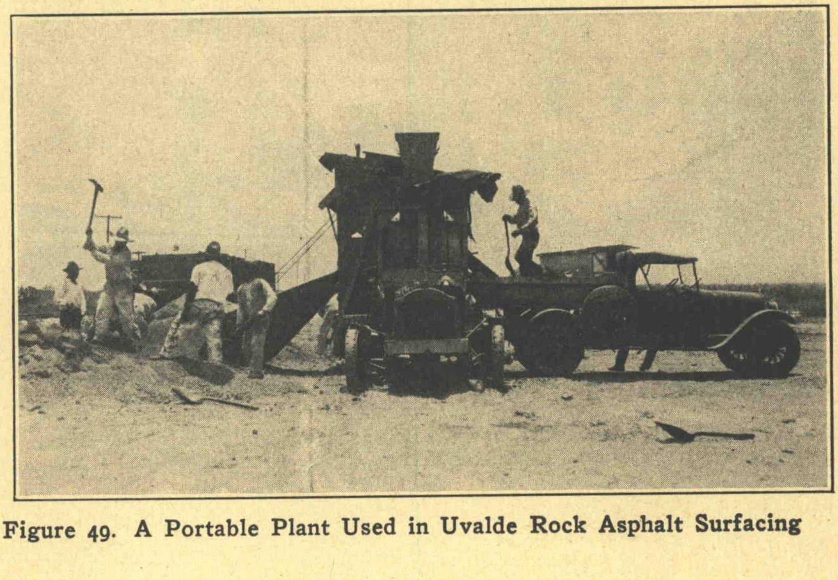


Figure 49. A Portable Plant Used in Uvalde Rock Asphalt Surfacing

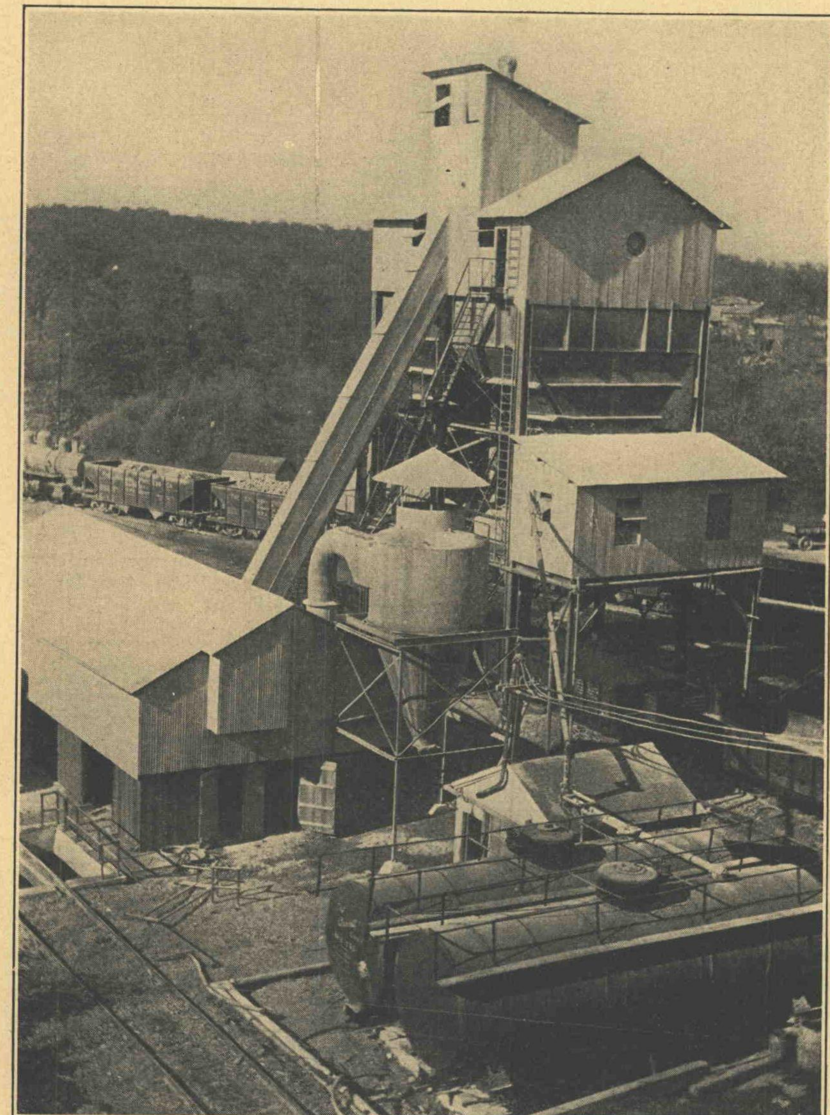


Figure 50. A Plant Used for the Preparation and Mixing of Pre-Mixed Bituminous Surfacing Which Is Laid Cold

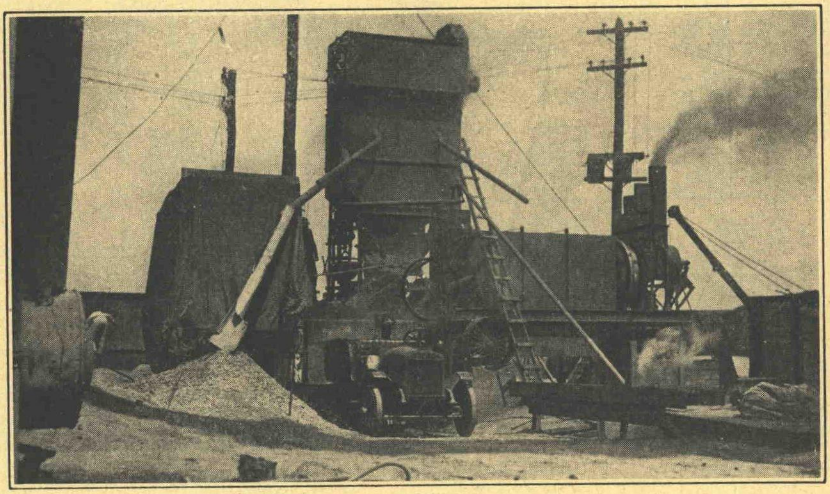


Figure 51. A Plant Used for the Preparation and Mixing of Pre-Mixed Surfaces Which Are Laid Hot

CHAPTER 4

PRESENTATION OF FINDINGS

SAND CLAY SURFACES

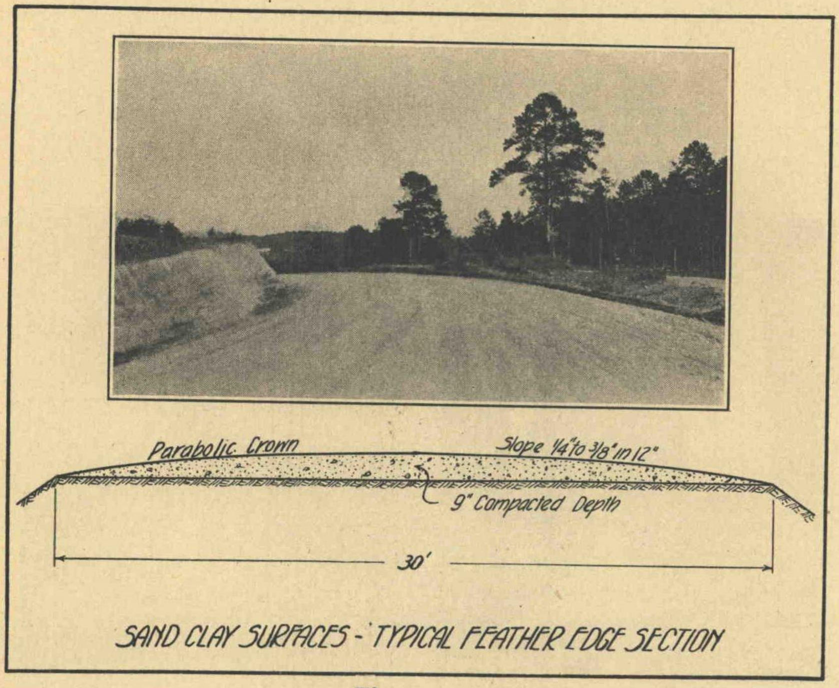


Figure 52

Materials	Costs per mile	Service daily	Examples in
Natural or artificial mixture of sand and clay.	For construction $1300 to $2600. For maintenance $300 to $600 per year.	Average 300-600 vehicles including light trucks.	North Carolina South Carolina, Florida. Georgia, Alabama, Texas.

1. *General Description.* The finished surface consists of an intimate and compacted mixture of sand and clay.

2. *Materials.* " Top soil " is a natural mixture of sand and clay found as a surface deposit. Subsurface material is found in two or three foot layers and in pits having a depth of five feet or more.

For best results in Georgia, Dr. Strahan has indicated the following specifications as effective:

	Per cent
Clay	12 to 18
Silt	5 to 15
Sand	65 to 80

Of this sand content 45 to 60 per cent should be above the No. 60 sieve.

Sand clay and top soil roads are built and giving good service which have wider limits than shown in the foregoing table

Coarse material above the No 10 sieve in amounts greater than 10 per cent distinctly increases the stability and durability of the road slab Sizes up to ¾-inch are satisfactory

The clay should be sticky and non-slaking in character

An excess of silt, very fine sand, and clay, during rains, tends to reduce percolation, retain water and rapidly weaken the stability of the slab

The entire mass is stabilized because of interlocking of coarse particles, bond, and a rather complete filling of voids with the finer particles

Artificial mixes of volcanic cinders and disintegrated limestone have been used successfully in Mexico

3 *Construction Methods* There are four ways of placing sand-clay surfacing materials

1 The natural mixture of sand clay is placed on the road, given additional mixing and consolidated
2. Sand and clay are placed separately on the road, mixed, and consolidated
3 Clay is hauled and placed on a subgrade of suitable sand, mixed with it and consolidated.
4. Sand is hauled and placed on a subgrade of suitable clay, mixed with it and consolidated.

In each instance the subgrade should be prepared to a true and regular cross section before the surfacing material is applied. Number 1, which contains sand and clay mixed by nature, is most generally used and gives the most uniform service

The selected materials are hauled from the pit or fields and deposited on the subgrade in a loose layer of uniform width and depth. The customary length of each layer so placed is from 500 to 1000 feet. The depth and width are such that when spread and consolidated the desired typical cross section will be fulfilled

For example, a width of 18 to 24 feet having a depth of 12 to 14 inches, will spread and compact to a section 30 feet wide, 9 inches deep at the center and tapering to 1 or 2 inches at the edge

After the materials have been deposited on the subgrade, they are thoroughly mixed with plow, harrow and road machine blade

During the mixing and shaping process, traffic and hauling compact the surfacing from the subgrade upward.

Rains, or sprinkling with water, assist in securing increased compaction and density.

Rollers are seldom used Those having flat surfaces tend to consolidate only the immediate surface Ring rollers, sheep's foot rollers and similar types which produce a high unit intensity of pressure, even though lighter in gross weight, are more effective.

Following a final shaping with blader the surface is practically complete However, constant maintenance of the surface must begin at once and continue throughout the life of the road.

For this type of surfacing the feather edge section, extending from out to out of shoulder, is good practise Better surface drainage is obtained and inferior material from the shoulder does not become mixed with the surfacing

Flat crowns, from 1/4 to 3/8-inch per foot are easier to maintain and are less seriously eroded. They are smoother and safer to ride upon and tend to increase the traffic capacity of the road.

4 *Maintenance Methods* Whether sand-clay roads are opened to traffic during or after construction, maintenance must begin during construction This requirement is included in some contracts

As in all types of untreated surfaces, traffic, erosion and winds cause loss of surface material. This loss has been estimated by some as about 2 inches each year This figure is higher than a careful investigation disclosed in Georgia Observed data there indicated an annual loss of between 1/2 and 1-inch

The principal operations are scarifying, adding new materials, blading, dragging and patching. The first two operations are at periodic intervals of from one to several years The last three must be at frequent intervals The most satisfactory results follow daily patrol maintenance, in wet and dry weather Lighter equipment is suitable when the surface is soft after rains

5. *Construction Costs* The surfacing is usually done by contract at a unit price per cubic yard of sand clay complete in place

The typical cross sections are usually wide, that is from 24 to 30 feet. They require from 2000 to 3000 cubic yards per mile of surfacing

Length of haul is the principal item affecting the cost.

The costs are about the same all over the South for similar requirements of specifications and workmanship

The range of cost per mile is from $1300 to $2600. A fair average is about $2000.

6. *Maintenance Costs.* When serving within their traffic capacity these surfaces are well maintained for from $300 to $600 per mile per year. Surface maintenance by machining and dragging should be from $200 to $300, scarifying and reshaping may range from $50 to $150, replacement of lost material with new material from $250 to $500 per mile. Scarifying and reshaping may or may not be done yearly.

New materials may be necessary only at two or three year intervals.

7. *Service.* In the South observation and investigation have shown

Figure 53. Patching a Sand-Clay Surface

the traffic capacity of this type to be from 300 to 600 vehicles per day. For average conditions this is about 400. Regions having extremes of wet or dry weather affect this figure unfavorably.

Poor quality of materials or maintenance seriously affect serviceability. Records in Georgia show a satisfactory quality of service for an average life of more than 6 years.

This type of surfacing has been successfully surface treated with bitumen and aggregates in North Carolina and South Carolina.

As a sub-base for pavement it presents a subgrade uniform in quality and bearing power, well compacted and semiporous.

In Georgia there are noticeably fewer cracks in concrete pavements laid on old top soil roads than in those of equal age laid in unselected natural subgrades.

South Carolina has shown confidence in this subgrade support by reducing the thickness of concrete slabs when they are laid on old sand-clay roads

REFERENCES

1. Personal inspections in North Carolina, South Carolina, Georgia and Florida.
2 State Highway Specifications, North Carolina, South Carolina, Georgia and Alabama
3. Bulletins of Bureau of Public Roads
4 Highway Research Board 7th Proceedings 1928, by Dr Strahan.
5. Highway Research Board 7th Proceedings 1928, by W R Neel
6 Bulletin University of Georgia 1921, Vol. XXII.
7 Transactions A. S C E. Vol 77, Dec 1914 J. C. Koch
8 College of Texas Bulletin 19 B K Coughlan

CHERT, SHALE AND DISINTEGRATED GRANITE SURFACES

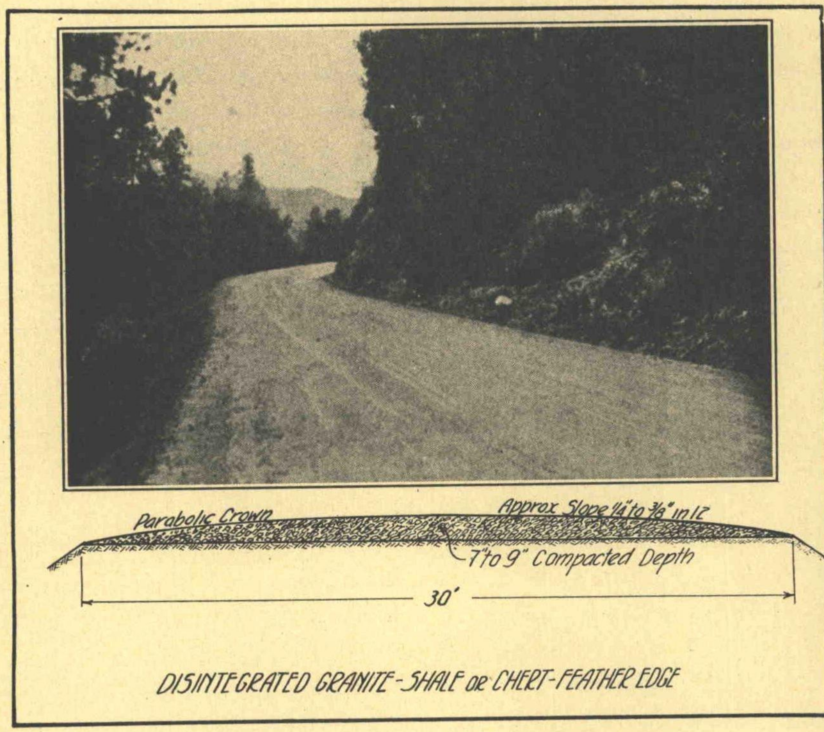


Figure 54. Disintegrated Granite, Mexico

Materials	Cost per mile		Daily service	Examples
	Const.	Maint.		
Chert	$7,000	$550	800 vehicles	Georgia, Alabama.
Shale	7,000	500	600 vehicles	West Virginia, Penn.
Dis. Granite	3,000	500	400 vehicles	Arizona, Mexico.

1. *General Description.* The materials as obtained in pits are broken or crushed to suitable size. After they have been placed on the subgrade the surface is prepared in much the same manner as a sand clay or one course gravel road. The principal operations are harrowing and blading. Rolling is required by some engineers but not by others. Both the feather edge and trench sections are used.

2. *Materials.* Disintegrated granite and shale in suitable sizes for road work can be obtained from pits by blasting. They usually break up into fragments and seldom require crushing by machine. The larger pieces may be broken by hand. For this reason production cost is lower than for cherts which may require machine crushing and screening as well as blasting.

Not all disintegrated granites, cherts and shales are suitable for surfacing. Those containing an excess of clay may become soft or slippery during wet weather In case of doubt a short section of surface may be laid as an inexpensive experiment. Such experiments with untried local materials of this nature frequently result in a considerable saving over shipped-in and long-haul aggregates.

Chert. This material as shown by chemical analysis is largely amorphous silica.

Georgia specifications for chert call for all the material to pass the 1½-inch screen and at least 60 per cent to be retained on a number 10 sieve The material passing the 10 sieve is known as binder with the following composition:

	Per cent
"Clay" (Amorphous silica)	20 to 40
Silt	10 to 30
Total sand	30 to 60

Sand above No 60 sieve should be 20 to 40 per cent.

Shale According to B. E Gray, the highest grade shale as used in West Virginia has the following analysis:

	Per cent
Moisture	0 51
Silica	66 78
Al_2O_3	16 40
Fe_2O_3	6 42
CaO	0.56
MgO	1 34
Volatile matter and water of hydration	3 94

From analysis and service results, Mr Gray concludes "that a percentage of silica in excess of 55 is required, that the presence of iron oxide in excess of 4 per cent is necessary and that the cementing quality of the material largely depends on this factor. When Al_2O_3 is present in excess of 20 per cent by volume the surface tends to becomes very slippery when wet.

Disintegrated Granite Arizona reports that this material gives better service than the gravel and caliche found in that state. Wisconsin uses it as a temporary surfacing. The writer has used it in Mexico with results equal to those with the best sand clays in North Carolina.

The following table from the Encyclopedia Britannica is of interest in denoting the slight differences between fresh hard granite and the sandy mass of disintegrated granite.

I. Analysis of fresh grey granite
II Brown moderate firm granite
III. Residual sand, produced by the weathering of the same mass.

	H_2O	SiO_2	Al_2O_3	FeO	Fe_2O_3	CaO
I	1 22	69 33	14 33	3 60		3 21
II	3.27	66 82	15 62	1 69	1.88	3 13
III	4 70	65 69	15.23		4 39	2 63

NOTE—The balance of these analyses show small quantities of MgO, Na_2O, K_2O, and P_2O_5

The differences are surprisingly small and are principally an increase in the water and a diminution in the amount of alkalies and lime, together with the oxidation of the ferrous oxide.

It is necessary to screen chert to the required size which should not be over 1¼ inches for a one course surfacing Finer sizes are even more satisfactory Disintegrated granite and shale should be broken down to 4 inches or 6 inches in the pit before hauling to the road. During the construction process they are broken down to 1 inch size and smaller.

3. *Construction Methods* The materials are hauled and spread on the subgrade in a loose layer of uniform thickness in much the same manner as in sand clay construction Harrowing and machining bring about a well mixed and uniform surface. When the trench section is used rolling is required in Wisconsin for disintegrated granite The feather edge section has been used satisfactorily and the surface bound by traffic Sufficient machining with a heavy road planer is necessary to secure a smooth riding surface Temporary side forms and a trench section are used in Georgia for chert.

4. *Maintenance Methods* Maintenance methods are much the same as for sand-clay roads. They consist of road machining, patching and the addition of layers of new material when the original surface becomes reduced in thickness.

5. *Construction Cost.* These surfaces are used when suitable local deposits of stone and gravel are not available Their cost will be less than for imported crushed stone and about the same as for local gravel. If the cost of crushing and screening are absent, hauling will be the most expensive item

The initial cost of chert surfaces in Georgia, 19 feet wide, compacted depth 8 inches, averages about $7000 Shale surfaces, in West Virginia, 18 to 20 feet wide and 8 to 9 inches compacted thickness, cost around $7000 per mile In Arizona, disintegrated granite gravel and caliche-gravel, equivalent to 21 feet wide and 6 inches compacted thickness cost about $3000 per mile.

6 *Maintenance Costs* Direct maintenance costs include the necessary machining, dragging, patching and resurfacing

Chert surfaces are being maintained in Georgia for approximately $150 per mile per year for machining, scarifying and patching. Lost surfacing is less than for sand clays in that state It averages less than ½-inch per year

Good shale surfaces in West Virginia are maintained for less than $500 per mile per year

Disintegrated granite in Arizona, where the annual rainfall is between 10 and 16 inches, is said to give better service than local gravels Local gravels show an annual maintenance cost per mile in Arizona of less than $500

7. *Service* Shale as used in West Virginia, Wisconsin and North Carolina is equal to or better than the best sand clays If it becomes slippery in wet weather a thin layer of fine gravel, coarse sand or crushed stone has corrected the condition

Disintegrated granite does not become slippery except when an excess of clay is present Some deposits in Mexico contained practically no clay.

Good chert surfaces in the South are carrying an average of 800 vehicles per day without undue maintenance cost but with more dust than local gravels

Shale in West Virginia is carrying from 300 to 600 vehicles per day during the summer months and about ⅔ that amount in the winter.

Disintegrated granite in Arizona is carrying traffic equal to local gravel roads Traffic counts in Arizona show an average of 330 vehicles per day on gravel surfaces

Chert, shale and disintegrated granite surfaces have salvage value as subgrade treatment. Chert and shale have been successfully treated with bituminous surface or wearing courses No records are available for surface treatments on disintegrated granite

REFERENCES

1 Personal inspections of shale in North Carolina and West Virginia Disintegrated granite in Mexico
2. State Highway Specifications—chert, Alabama and Georgia, shale, West Virginia and North Carolina, disintegrated granite, Arizona.
3 Roads and Road Materials, Geological Survey of Alabama, Bulletin No 11
4. Highway Research Board 7th Proceedings 1928—by B E Gray
5. Highway Research Board 7th Proceedings 1928—by W. R. Neel

GRAVEL SURFACING

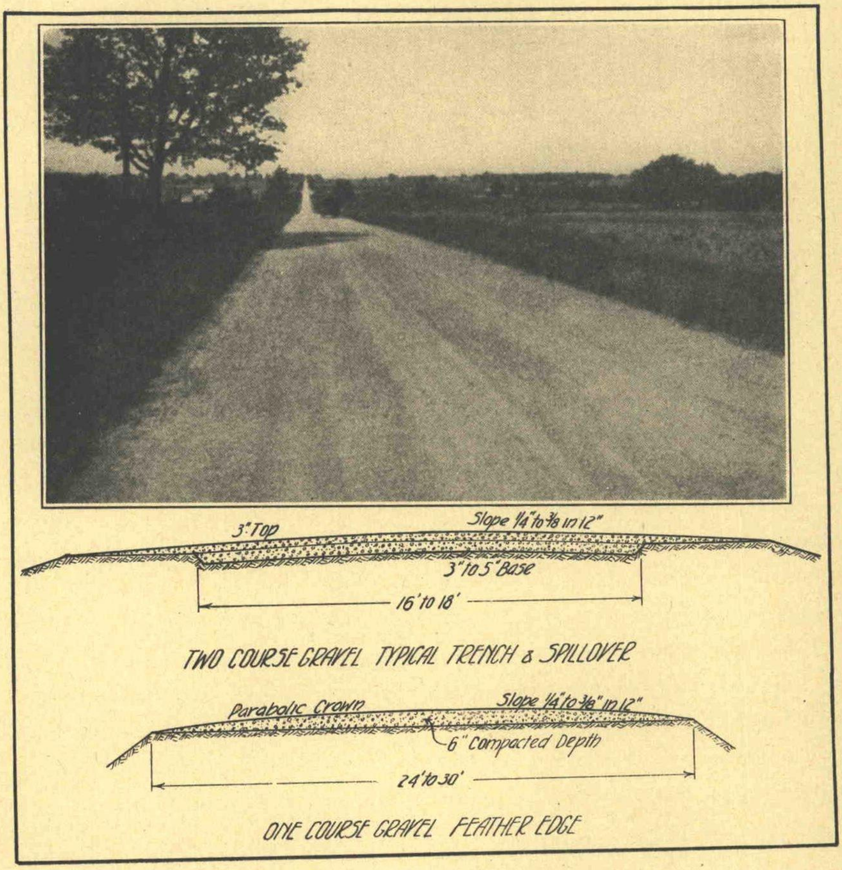


Figure 55. Michigan

Materials	First cost	Maint. cost annual	Service daily
Pit or river gravel and binder.	$1500 to $9000 Average $5000	$250 to $800 Average $500	300 to 800 vehicles

Examples in nearly every state and Canada.

1. *General Description.* Gravel surfaces consist of one or more layers of aggregate evenly spread on the subgrade and compacted by rolling or by traffic.

A surface mulch of loose material, ½-inch in thickness, on compacted surfaces is advantageous.

2. *Materials* are generally the best available local gravel. Shipped-in gravel may increase the cost as much as 40 per cent. The top layer which carries the traffic should be hard and durable pebbles.

Gravel up to 2½ and 3 inches in size for base course is permitted in some specifications The states which have large mileages of smooth riding untreated gravel surfaces do not permit material larger than 1 inch in the entire slab Crushed gravel is preferred to rounded particles by some, because they key together more readily and more securely with less binder.

Good binder materials are iron oxide and limestone. Clay and loam are used when no better materials are available In untreated surfaces, clay and loam binders become dusty in dry weather and lose their binding power in wet weather

The success of an untreated gravel surfacing appears to depend upon the size of coarse aggregate, and the amount and character of the binder. When clay or loam is used as binder small amounts are advisable. More than 20 per cent is questionable practise 10 to 15 per cent give more satisfactory results

Binder materials which are little affected by the presence or absence of moisture are excellent. Such materials are volcanic ash, limestone dust, and fines from quarries or gravel pits.

The bonding of loose gravel is frequently difficult, but an excess of silt or clay should be avoided An excess of clay, particularly when a loose surface mulch of clean aggregate is absent, tends toward pot holes under traffic An excess of sand below the No. 10 sieve may be the cause of early and persistent corrugations

Michigan has good gravel roads The specifications require.

	Per cent
Passing 1-inch circular opening	100
Retained on 8-inch sieve	75 to 85
Clay and silt content not more than	10

South Dakota specifies as follows:

	Per cent
Passing 1¼-inch screen	95 to 100
Retained on ¼-screen	10 to 40
Retained on 10-mesh sieve	35 to 70

California requires:

	Per cent
Passing 1-inch circular opening	100
Retained on No 3 sieve....	50 to 70

The remainder shall consist of rock screenings, disintegrated granite or other cementaceous material of which not less than 8 nor more than 20 per cent shall pass the 200-mesh sieve At least 50 per cent of the total volume shall be crushed aggregate

3 *Construction Methods* Three general methods are used:

1. The trench method, in which a trench narrower than the graded width is filled with gravel
2. The trench and feather edge, in which a trench about 16 or 18 feet wide is filled with gravel This is covered with a top course of gravel which extends to the full width of the shoulders
3. The feather edge method, which consists of a surface for the full width of roadway, that is, out to out of shoulders It varies in depth from a maximum at the center of the road to one or two inches at the edges. A uniform depth of material for the full shoulder width is also used

Best results are obtained when the gravel is spread from vehicles having spreading devices, from dump boards or from piles along the road The dumping of gravel in piles on the subgrade before spreading may result in a wavy surface, particularly if the entire pile is not immediately spread after dumping Gravel is generally spread by road machines or it may be done by hand shovels

The practise of using large gravel containing particles up to 3 inches and larger in size, and then working the large material ahead on the subgrade is not good practise, because some of the large particles may be left near the surface or they will work to the surface within a year or two They are always a source of annoyance when the road is reshaped or scarified Their dislodgment at that time will destroy the compacted surface below the desired depth of scarifying. If left in the surface they are a contributing cause of corrugations

Harrowing with a spike tooth harrow is frequently done, particularly when clay is spread over the layers as a binder. Binder material must be thoroughly mixed with the gravel by nature, at the pit or on the road Watering to secure bond and compaction is of considerable assistance when the gravel contains a small amount of binder.

Rolling is not universal practise However, if quick compaction is desired rolling undoubtedly gives it more quickly than traffic. Ring rollers, sheep's foot rollers and the Michigan type shown on page 134 give good results Surfaces which had early compaction obtained by the addition of excessive amounts of clay and rolling may not resist traffic and the elements as well as surfaces containing a smaller amount of good binder which were compacted from the subgrade upward by traffic. Rolling cannot, however, be depended upon to give smoothness of surface Smooth riding qualities are secured by harrowing and a large amount of blading

4 *Maintenance Methods* Flat crowns ¼ to ⅜-inch to the foot in dry weather will greatly assist in maintenance. A slightly higher crown may be used in wet weather

A ½-inch loose layer of clean gravel passing the ¾ or ½-inch screen and retained on the ¼ should be retained on the surface at all times This retards the formation of pot holes, corrugations, erosion, and partially reduces dust The surface should be dragged or machined daily for traffic of over 200 per day For lighter traffic alternate days will be sufficient

Untreated gravel surfaces lose ¾ of an inch or more of their surface each year This lost material must be replaced if sufficient depth of surface is to be retained Material for resurfacing is frequently stock piled along the road sides If the graded width between shoulders is 30 feet or more, it may be placed in windrows along the sides, with suitable openings for drainage

Pot holes, corrugations and dust are the principal objections to the best gravel surfaces. They may be minimized as already stated, but surface treatment or the addition of a bituminous wearing course is indicated even when fast moving, light traffic is in excess

Scarifying and reshaping twice a year or annually are not unusual These operations together with blading and dragging can well be done during or immediately after rains. None of these operations are done after the surface has been prepared for the winter in heavy frost sections of the country Maintenance should begin during the construction period

5. *Construction Costs* As in all types of surfacing length of haul by truck or rail greatly affect the initial cost. Such items as washing, screening and crushing also affect the cost For these reasons the cost of gravel surfacing varies between wide limits Manipulation and compaction of the material on the road are comparatively small items in the total.

For surfaces containing 1500 to 2500 cubic yards of compacted aggregates the cost will be from $1200 to $10,000 per mile The average cost for 2000 yards of material is about $5000

6 *Maintenance Cost* The items of blading and dragging are easily determined for fixed amounts of traffic Scarifying and reshaping may be reasonably estimated The replacement of lost surfacing material is the principal item of maintenance expenditure and the one which seriously increases the maintenance costs of gravel surfaces. For average traffic of 300 to 500 vehicles per day the data show the highest losses in regions of low humidity and precipitation

such as Arizona. On the other hand, Alaska reports no difficulties from dust and little lost material Yearly losses range from ½-inch to 2 or 3 inches In Indiana 22 sections on 236 miles of gravel road showed an average annual loss of 257 cubic yards for an average daily traffic of 892 vehicles The average annual rainfall in Indiana is about 37 inches The cost of daily blading should be about $200 or $300 per year, scarifying and reshaping annually about $100 The cost of new materials will naturally vary with local conditions With gravel at $2.00 per cubic yard loose measurement in place, a replacement of 1 inch, loose, per mile per year would, for an 18 foot width of surfacing, amount to $580 The cost of scarifying, reshaping and continuous blading seldom amounts to more than $400 per mile per year The cost of replacing lost surface materials therefore is a serious item. When the cost of maintenance exceeds $600 or $800 per mile, regardless of traffic intensity, common practise indicates the advisability of some type of surface treatment or a pavement

7 *Service.* Gravel roads are furnishing service to more square miles of territory than all other types of surfacing combined More than 52 per cent of the total surfaced mileage of the United States is gravel Whenever materials are locally available, gravel surfaces are found from Maine to California and from Louisiana to Alaska Climatic and geographic conditions, although affecting the quality of service, do not prohibit its usefulness.

When constructed with suitable aggregate and maintained perpetually, safe speeds of 40 to 60 miles per hour can be maintained for hours at a time. Untreated gravel surfaces are seldom satisfactory for more than 600 vehicles per day The average appears to be about 400, arid regions report 200 or 300 to be the maximum; and Alaska with its damp soils, reports no trouble from the dust nuisance When the traffic capacity of a gravel surface is passed, loss of surfacing material, dust, corrugations and pot holes indicate the necessity of surface protection.

Gravel surfaces are being successfully surface treated and their traffic capacity doubled They have proved to be of value as a subbase for pavements and they are still the predominating type of surfacing

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TRAFFIC BOUND SURFACES OF GRAVEL, STONE AND SLAG

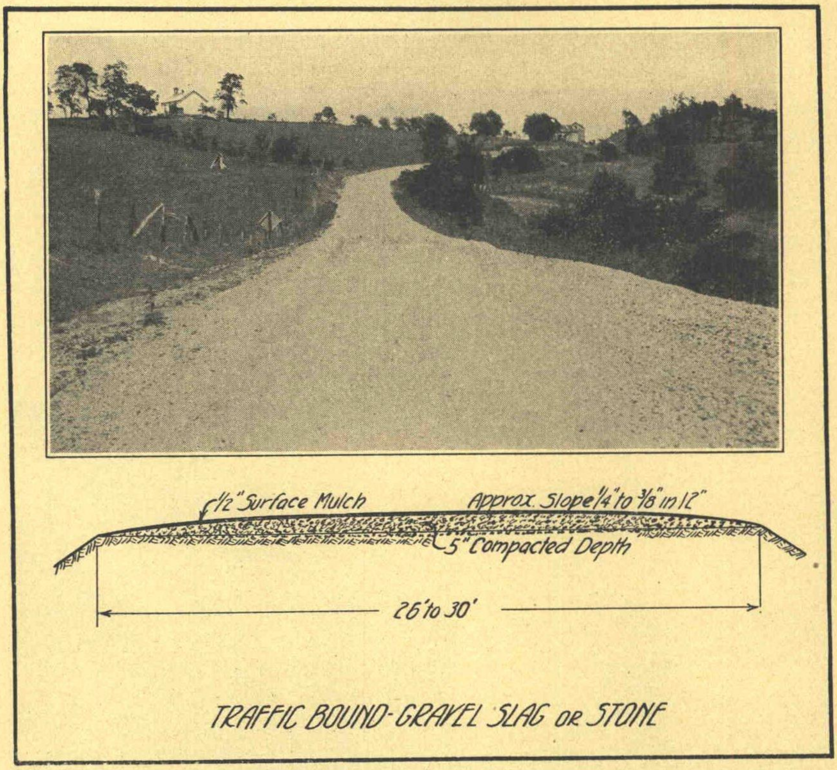

Figure 56. Ohio

Materials	Construction and maintenance costs	Service	Example in
Crushed stone. Crushed slag. Screened or crushed gravel.	First year $2000. Second year $1000. Third and successive years $500.	300 to 600 vehicles including light trucks.	Ohio. Indiana. Tennessee. Nebraska. Iowa.

1. *General Description.* This type of construction has been used with success on previously graded and unsurfaced subgrades and as a method of resurfacing and widening an existing untreated surface. This untreated surface may be an old sand-clay, gravel or stone macadam. The construction methods are similar in each instance but more new material will ordinarily be required on raw subgrades. Some scarifying and reshaping of old surfaces may be necessary prior to the addition of new surfacing.

The surfacing is a layer of clean crushed stone, slag, crushed or screened gravel evenly spread on the prepared subgrade. This layer is kept smooth by constant blading. Traffic gradually compacts it from the subgrade upward.

New material is added, under traffic, periodically until a surface of suitable thickness is built up. This surface is seldom more than 5 or 6 inches in depth after a period of several years. It is kept covered at all times with a loose layer usually of the same materials as are in the body of the surface. The surfacing should preferably extend from shoulder to shoulder. This distance should not be less than 20 feet; 30 is better.

The crown should be low, about 1/4 to 3/8-inch per foot has been found sufficient. It is easy to maintain, to ride upon, there is less

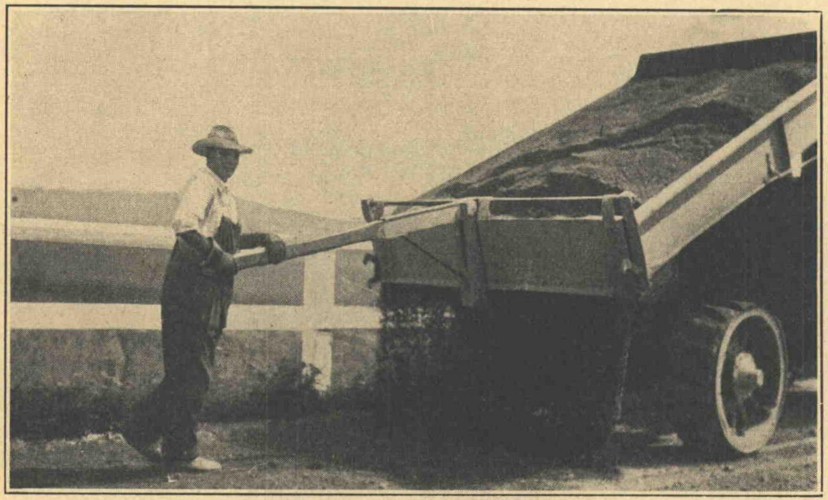

Figure 57. Spreading Gravel, Stone or Slag

erosion than with high crowns, and it seldom needs building up or cutting down when used as a base for future surface courses or surface treatments.

2. *Materials.* Suitable materials are hard crushed stone, slag and crushed or screened gravel. Other materials have been used, such as stone screenings, pea gravel and cinders. They may also be successfully applied as a subgrade treatment for the first year. Good results have been obtained when the materials all pass the 1-inch or 7/8-inch screen, with little passing the 1/4 and less than 10 per cent passing the number 10 sieve. The material should be uniformly graded from coarse to fine. Crusher run below the 1-inch has also been used. Riding qualities are improved, and tire wear probably reduced, when the maximum size is 1/2 or 3/4-inch. Materials over 1-inch and up to

$1\frac{1}{2}$ have been used, but the surface is rougher and tire wear probably greater.

An excess of fines may cause corrugations with gravel aggregate. They will become more dusty in all types under traffic. Clay causes dust and pot-holes. It is a disadvantage in case of future surface treatments. Clay is sometimes necessary as a binder when screened uncrushed gravel is used. It should be applied dry, evenly and sparingly.

Several thousand miles of roads of excellent riding qualities have been built in Iowa by the methods described herein for traffic bound

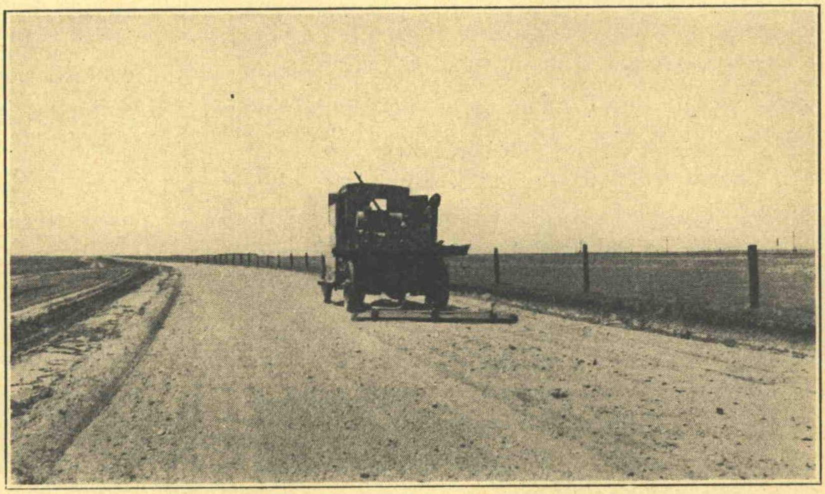

Figure 58. Dragging. Note the Windrows of Loose Surfacing Material Which Have Been Bladed to the Side During Dry Weather. The Material Will Be Pulled in As Required

surface except that pit run gravels and crusher run limestones conforming to the following specifications have been used:

	Class A gravel	Class B gravel	Crushed limestone
Maximum size	1 inch	1 inch	1 inch
Max. clay, mud-balls, etc.........	8 per cent	12 per cent	5 per cent
Passing No. 8 sieve not more than	50 per cent	65 per cent	15 per cent
Maximum per cent of wear......	....	....	5 per cent

3. *Construction Methods.* The construction operations are simple and consist of hauling, dumping and spreading the aggregates. All of them are done by mechanical equipment. The same equipment is also used for maintenance.

The subgrade is first prepared to a firm uniform cross section and a loose layer of aggregate is spread and machined to a uniform depth. This layer should not be of greater thickness than traffic can safely use.

There are several methods · one of the most satisfactory is to dump the surfacing in a continuous pile along the center of the roadway or in two piles, one on each side It is then bladed over the roadway in a smooth layer of uniform depth of from 1 to 3 inches, depending on the character of subgrade the amount of moisture it contains As the first layer becomes compacted, more material is bladed in from the side windrows so that a loose mulch about ½-inch deep is present at all times Traffic and hauling of surfacing material compact each thin layer from the subgrade upward. Blading and dragging each day keep the surface regular and free from pot holes and ruts

The first year's work, which may be considered the construction period, will result in a densely compacted surface 2 to 3 inches in depth.

4 *Maintenance Methods.* Maintenance methods are similar to the construction methods They consist of the addition of new material which is either stock piled along the road or placed in windrows at the sides. This is usually applied when the road surfaces are wet, a condition permitting better bond with the old surface One-man patrol graders with straight or spring blades, followed by an occasional planing with heavier equipment serve to keep the surface in excellent condition.

In sections of the country subject to conditions of freezing and thawing such as Ohio, Michigan, and Indiana, these surfaces may break through in places especially during the first winter and spring Repairs are simple and are made before the existing surfacing becomes lost in the subgrade Reducing the amount and weight of traffic during these periods has reduced the maintenance costs

5. *Construction Costs* On a large program of construction, sufficient amounts of material delivered at the proper time and place can best be handled by contract It should be delivered in stock piles at several mile intervals or placed in piles at the roadside or in stock piles along the road On small programs for this type of construction, portable outfits and small set-ups have been used and the entire work done by force account The surfacing will cost for the first year, which may be considered the construction period, about $2000 when local aggregates are used

6. *Maintenance Cost* This includes furnishing and placing material and machining it on the road It will gradually decrease after

the first year For the second year it is about $1000, and for the third about $500

7. *Service* This type is easily and quickly constructed, traffic, after the grading operations, may use the road at once There is no time out for the surfacing operation On account of the flat crown, surface mulch and small amount of aggregate below the ¼-inch screen, erosion is not serious In Ohio the slag and stone surfaces are less dusty than the gravel, and show fewer corrugations

Due to the constant dragging or machining the riding qualities are excellent. Speeds of 40 to 50 miles per hour are limited only by traffic, alignment and grade These roads will accommodate from 300 to 600 vehicles per day consisting of automobiles, a fair percentage of 2½ ton trucks and infrequent 5 and 7 ton trucks The surface mulch retards the formation of pot-holes and corrugations. Crushed stone and slag have been used to prevent them on gravel bases Clean gravel has been used on macadam base

The principal objection to this type of surfacing is the wear on tires and rather high tractive resistance After the road has been in service and under observation for 3 or 4 years it may be successfully treated with one of the several satisfactory types of bituminous or nonbituminous surface treatments Its traffic capacity may then be doubled and dust eliminated.

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MACADAM

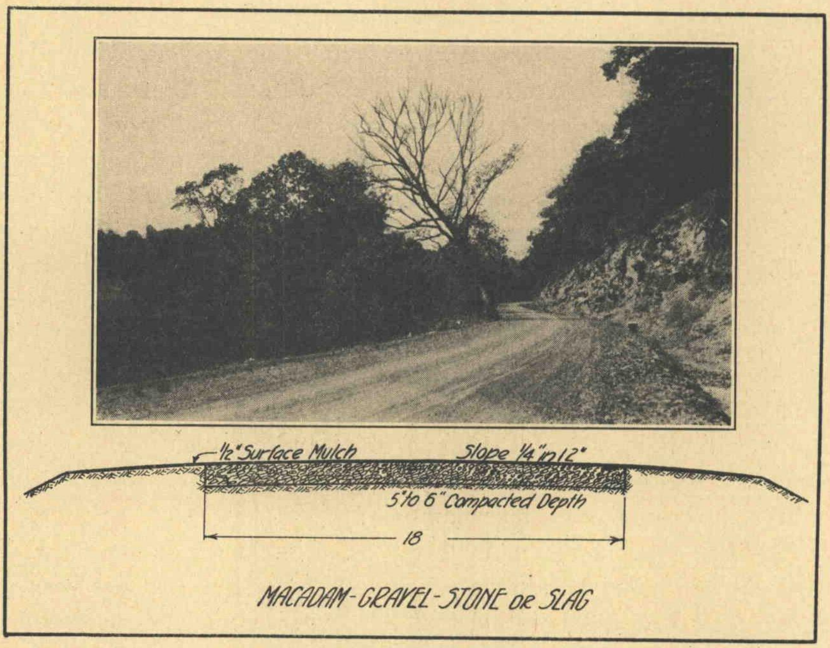

Figure 59

Materials	First cost	Maintenance cost	Service	Examples
Crushed stone. Crushed slag. Crushed gravel.	$8,000 to $15,000.	$300 to $600.	500 to 800 vehicles per day.	Indiana. Kentucky. Ohio. Tennessee. New England.

1. *General Description.* Macadam roads have been built which show wide ranges in quality and size of aggregate, thickness of section and method of construction. It is one of the oldest types. This perhaps accounts for the variations, although present practise is by no means uniform.

In general these surfaces consist of one or more courses of coarse broken aggregate, whose voids are partially filled with finer aggregate. The whole mass is keyed and interlocked together by protracted rolling. Water may or may not be used to assist in the void filling process.

2. *Materials.* These roads are usually built of crushed stone. Crushed slag and gravel are less widely used as macadam aggregate. A study of specification requirements shows they have been written to secure good quality and a practical gradation of the available local material and that a softer stone is usually permitted in the base course than in the wearing course. The maximum allowable per cent

of wear for the surface course is about 5, for the average specification, trap rock is specified as low as 4 while limestone is permitted as high as 6

Base course requirements are not as severe A per cent of wear of 10 and 12 is tolerated for limestone, 15 and 20 for slag and 25 for sandstone The grading requirements indicate that larger maximum sizes are customary when softer stone is used

When stone of the same quality is used in both base and surface courses the gradation may be the same for each In this case the courses may be of equal thickness For example some typical state highway specifications for quality and gradation of stone are given

OHIO SANDSTONE BASE COURSE

" When sandstone having an abrasion loss of over 12 per cent is used, it shall be broken to sizes ranging between 3 and 5½ inches, with the larger sizes predominating When sandstone having an abrasion loss of 12 per cent or less is used No 0 or No 1 size may be used The sandstone shall be broken to proper size before being placed in final position No knapping will be permitted after the sandstone has been placed "

Per cent of wear not over 25, toughness not less than 3 No 0 size, gradation requirement for passing screens having circular openings is; through the 5½-inch 95 to 100 per cent, through the 2½-inch 0 to 10 per cent No 1 size gradation is, through 4-inch 95 to 100 per cent, and through 2½-inch 0 to 10 per cent

OHIO WATER-BOUND MACADAM SURFACE COURSE

This course consists of crushed limestone or slag and screenings The maximum allowable per cent of wear for limestone is 8 and the toughness factor is not less than 5 " The stone shall show no signs of checking, cracking or disintegration in the sodium sulphate test for soundness In no case shall the maximum size permitted exceed the compacted thickness of the course by more than ½-inch "

The specified sizes of stone passing screens with circular openings are given in percentage·

	Passing	Passing	
No 1,	4 inch, 95-100,	2½ inch, 0-10	
No 5,	¾ inch, 95-100,	¼ inch, 30-60,	100 Sieve, 5-20
No 7,	½ inch, 95-100,	¼ inch, 60-100,	100 Sieve, 10-30

Virgina state specifications designate a " broken stone base course or a hand broken base course " in which no screenings are used unless especially required. For the broken stone base course the coarse stone must pass a 4-inch circular perforation and be retained on a 2½-inch. The per cent of wear is not more than 8 and the toughness factor not less than 5.

For the water-bound macadam surface course, Virginia specifies all stone to pass the 2½-inch circular perforation and be retained on the 1-inch The per cent of wear is not more than 5 and the toughness factor not less than 7. The stone screenings consist of material passing the 1-inch screen with the dust in. The quality of screenings is the same as for surface stone.

In Massachusetts broken stone is designated as No. 1, No. 2 and screenings No. 1 passes the 2½-inch ring and is retained on the 1¼-inch No 2 passes the 1¼-inch ring and is retained on the ¾-inch. The screenings all pass the ¾-inch. The allowable per cent of wear is not more than 4 and toughness is not less than 8.

California specifies two types of water-bound macadam base, but does not specify a water-bound macadam surface course. The broken stone for Type A base course must all pass a 3½-inch circular opening and be retained on a 1¼-inch The screenings all pass the ½-inch opening and include the dust of fracture Maximum allowable per cent of wear is 5. For Type B all stone must pass the 2½-inch circular opening and be retained on the ¼-inch. Maximum per cent of wear is 8 The filler or binder may be rock screenings, sandy loam or disintegrated granite, 90 to 100 per cent of which shall pass the ¼-inch screen.

3 *Construction Methods.* Current practise varies in details but the principal features are similar The trench section is in general use Wood blocks or temporary timber side forms are used to gauge the loose depth of stone in the trench Earth from the shoulders is generally used to prevent lateral displacement during the rolling The compacted depth of any course is seldom more than ½-inch greater than the maximum size of coarse stone. This type may consist of a base and surface course or a base course only. Six inches compacted appears to be maximum depth for a single course macadam, but 4-inch is nearer the average for the cases studied The principal construction features are:

1. Hauling and spreading the layer of coarse stone. The stone is never dumped directly on the subgrade or base course.
2. Shaping this layer of stone by hand tools. Harrowing and machining are required in some specifications

3. Rolling with one or two, ten ton power rollers, usually the three wheel type.
4. Spreading fine stone, screenings or other suitable fillers. These are spread thinly and gradually and broomed over the surface
5. Rolling is then continued, usually on the dry surface.
6. Watering, the addition of more screenings or filler and protracted rolling are continued until a thin " mud " or " grout " appears on the surface and applied water runs to the edges of the surface

Some states, Ohio, Indiana and others, require the surface to be carefully tested with a straight edge and all inequalities corrected

Base courses are sometimes built without watering Surface courses are sometimes of the traffic bound type, not rolled, in this case the maximum size aggregate is 1½-inch or better still ¾-inch Rolling begins at the edges overlapping the shoulder It progresses toward the center of the roadway On super-elevated curves rolling is sometimes begun on the inside of the curve and progresses outward across the entire width.

4. *Maintenance Methods* Experience has shown that untreated macadam surfaces become dusty, ravel and pot hole under traffic Pot holes are isolated holes in the surface They are the result of lost binder and coarse stone removed by traffic. If not patched at once with new stone they quickly cause a very rough riding surface Pot holes, raveling and a reduction in dust may be partially retarded by covering the macadam base or surface with a ½-inch loose layer of ¾ gravel screenings or other hard aggregate. This layer must be lightly bladed or dragged from two to six times each week. Sprinkling the surface with water, if available, is of assistance in reducing raveling and dust. Surface treatments with bitumen or calcium chloride are the most common practise Scarifying, reshaping and the addition of coarse stone and filler are also common

Heavy road planes and bladers are said to be useful in removing high spots The material planed off is deposited in the low spots and compacted by traffic

5 *Construction Cost.* Skilled labor and competent supervision are important factors for good macadam construction. These are not always available. For this reason macadam prices may be relatively high or local contractors may not care to bid on this type of surfacing. Except when local stone or a short haul are available macadam is not growing in popularity

6

The cost of watering may become a serious item if the surface is water-bound An unusually dry period during a working season, or construction in naturally dry, arid regions may make a long haul unavoidable If not previously anticipated serious financial loss may result to the contractor

To obtain maximum density under the heavy rolling required, a firm subgrade is essential This is dependent on variable soil and climatic conditions It is sometimes difficult to obtain a smooth riding surface without frequent patching This is undesirable and an excess of patching is expensive

For the foregoing reasons macadam is high in first cost compared with traffic bound types These are built up in thin layers on average subgrades, shaped with a road blader, without watering, and traffic gives adequate compaction

In macadam types it is desirable to avoid waste by using the entire output of the crusher, if the stone is crushed on the job An excess of fines or coarse may be used with success to improve the bearing capacity of the subgrade

From the available information local stone macadam 5 to 6 inches in thickness and 18 feet wide can be laid for $7000 to $10,000 per mile The cost of greater depths to suit local soil or other conditions may reach $20,000 For average conditions depths of 7 to 9 inches cost about $15,000 per mile for an 18 foot width

6 *Maintenance Costs* Untreated macadams show about the same traffic capacity and maintenance cost as the traffic bound and gravel types This is from $300 to $600 per mile per year for a surface which is maintained free of pot holes and raveling

Frost boils, occasioned by the freezing of moisture in the subgrade, may require scarifying, reshaping, new materials and rolling This item may amount to $50 or several hundred dollars per mile yearly depending on the quantity of new aggregate required

Sub-base of gravel, stone or sand will reduce frost boils A loose surface mulch of fine hard aggregate will reduce pot holes and raveling.

7 *Service* Although still included as a standard type by nearly all states the Bureau of Public Roads records show a proportionate decrease in macadam mileage as compared with other types

Macadams and rolled broken stone surfaces and bases are now usually laid with the intention of future improvement by bituminous surface treatments.

Traffic of more than 600 or 800 vehicles per day quickly disintegrates the surfaces as evidenced by dust, raveling and pot holes Even though the body of the macadam remains intact these surface failures indicate the advisability of surface treatments.

Because of high first cost, low traffic capacity, rough riding surface and non-adaptability to machine maintenance other types are replacing macadams for light traffic in all but a few states

Old macadams are excellent bases for surface treatment and bituminous wearing courses and many miles are thus salvaged and improved annually

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LIME ROCK, MARL AND CALICHE, BASE AND SURFACE

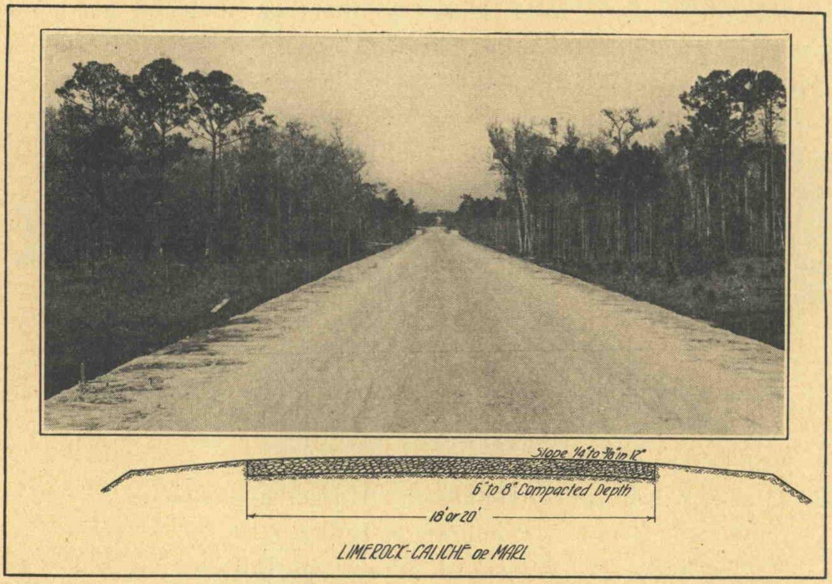

Figure 60. Lime Rock Base. Florida

Materials	Costs per mile	Service	Examples in
Lime rock. Ojus rock. Coquina rock. Disintegrated limestone. Marl. Shell rock. Caliche.	Construction $4,000 to $15,000. Maintenance, said to be high without surface treatment.	200 to 300 without treatment. 1500 to 2000 with bituminous surface treatment.	Florida. North Carolina. Ohio. Minnesota. Arizona. New Mexico. Texas.

1. *General Description.* When deposits of stone or gravel are not available locally or when their cost is excessive, excellent base courses have been constructed from these materials. They are usually laid in a one course trench section to a compacted thickness of from 6 to 8 inches. Four inches have been used but are not recommended. The material is spread on the subgrade, harrowed, wet, machined, rolled and machined again. The result is a finely bonded smooth riding surface with but little resistance to the wear of traffic during dry weather. The immediate surface may be improved by scarifying to a depth of one or two inches and covering with fine hard stone or gravel. Gravel or sand have been mixed with marl or caliche to increase their resistance to abrasion. Apparently the best method is to place a bituminous surface treatment. This method will be described under the title of Surface Treatments. There is evidence also that calcium

chloride is effective for reducing dust on marl By far the greatest and best mileage of lime rock base is in Florida. Similar materials are found elsewhere in the country and they may be used for this type of construction successfully by following the Florida methods

2. *Materials.* All of the materials listed are a limestone formation and consist essentially of carbonate of lime.

Florida State Specifications require the following minimum percentage of carbonate of calcium and magnesium. Florida Lime Rock 97; Ojus Rock 70 with cementing value not less than 45; Coquina Rock 80, cementing value 45.

Marl is a calcareous clay or mixture of lime with soft friable clay. It may also contain shells, fossils, teeth, potash and phosphoric acid The lime content of marl suitable for road construction varies from 25 to 75 per cent and higher Marine marl is found in the Atlantic Coastal Plain. Fresh water marl is found in Michigan, Indiana, Ohio and Minnesota. Sand, though not abundant, is usually present

Caliche is described as a soft earthy limestone It is a calcareous deposit formed beneath the surface sand or soil in Arizona and adjacent territory Texas specifies suitable caliche as a natural mixture of calcareous dust and quartz sand with or without the presence of gravel or small stones and not more than 10 per cent clay.

Other materials such as disintegrated limestone are similar in character. They are considered acceptable for road building provided they show no tendency to air slake or undergo chemical change when exposed to the weather They are found in wet or dry pits, with or without overburden. Blasting, crushing and sizing may or may not be necessary It is usually required for lime rock in Florida and the Atlantic Coastal Plain In Minnesota blasting was not necessary for marl.

Gradation requirements are similar for all these materials. Florida's requirements where water is used to assist in compaction are:

Passing a screen with 3½-inch circular opening 95 per cent. Retained on screen ¾-inch circular opening not less than 30 per cent. All fine material shall consist of the dust fracture.

When water is not available the materials should be crushed all to pass the 1¼ or 1-inch screen The surface is then bonded by traffic, blading and an occasional rainfall

3. *Construction Methods* Of the various specifications studied and work inspected in the field, the Florida methods are complete and the resulting work is excellent Other specifications such as Texas'

are similar. The following are the principal methods for constructing lime rock base in Florida

Temporary timber side forms are first set and staked to line and grade The crushed stone, containing dust of fracture, is spread on the subgrade by any standard method Dumping directly upon the subgrade is not permitted Care is taken to prevent segregation in fine or coarse areas, by replacement with stone of acceptable grading. The spread material is shoveled or raked to produce the required loose thickness. This is about 1/3 more than the desired compacted thickness Rolling is commenced and water sprinkled over the material until it receives maximum compression under a 10 ton roller Sprinkling is commenced while the material is being dumped and spread After being watered and rolled the entire surface is thoroughly scarified to a depth of 4 inches or more, then shaped with a 2½ ton road machine, watered and rerolled. The rolling and machining are continued until the entire depth is thoroughly bonded and compacted

If the materials are taken from a wet pit less watering or none at all will be necessary A marl base in North Carolina was built of wet material and no watering was required. Watering may be done at the pit instead of on the road

Blading with the road machine insures a smooth riding surface Some specifications make rolling optional with the engineer in charge The surface may be constructed in one or more courses It is satisfactorily built in one course in Florida.

On a 40 mile project in New Mexico insufficient water was available for sprinkling the caliche surfacing material during construction It was therefore crushed to pass a screen having 1¼-inch circular opening, and "dry" compaction was obtained after several months of traffic. Grader and drag were used continuously during this period

4 *Maintenance Methods* It is customary to leave these surfaces open to traffic for a month or more before surface treatment. Under light traffic in dry weather the surface becomes dusty and pot holes appear in a short time These weak spots are patched with material similar to that in the base They are mixed or sprinkled with water to insure bond Bitumens with stone chips or calicum chloride are suitable surface treatments A thin layer of gravel has been found to reduce dust and surface wear

5. *Construction Costs* Contract prices for the 8-inch compacted base in Florida have varied from $1.10 to $2.12 per square yard, with

an average of $1 45 to $1.60 Florida lime rock is frequently hauled long distances by rail With local materials nearby and using a thinner base, surfaces of marl and caliche have been laid for $3000 per mile for an 18 foot width In New Mexico caliche surface costs less than gravel New Mexico claims that a fair average cost of a caliche road would be $7000 per mile This would provide for a roadbed 24 feet wide and a surfacing 16 feet wide by 8 inches deep

6 *Maintenance Costs* For the untreated surfaces the maintenance costs will be for patching, replacement of lost material, scarifying and reshaping These become serious items for even light traffic in such states as Arizona and Texas In Arizona the annual surface maintenance cost is given as about $150 per mile for comparatively light traffic.

7 *Service* As a surface course these materials are limited to light traffic of not more than 200 or 300 vehicles per day because of abrasion As base courses for surface treatments and bituminous surface courses they are giving excellent service in Florida and North Carolina Bases 6 and 4 inches thick on fine loose sand, have failed under heavy traffic in Florida A marl surface in Ohio shows an excellent surface during freezing weather in mid-winter. Untreated caliche and caliche-gravel surfaces in Arizona show expensive maintenance due to loss of surfacing under traffic in dry weather Some instructive experiments on the use of local marl in road construction were made by the University of Minnesota It is evident that all of these materials make excellent bases at a reasonable cost. They show practically no cracks due to expansion or contraction under extreme changes of temperature and moisture and on varying subgrades

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MISCELLANEOUS UNTREATED SURFACES

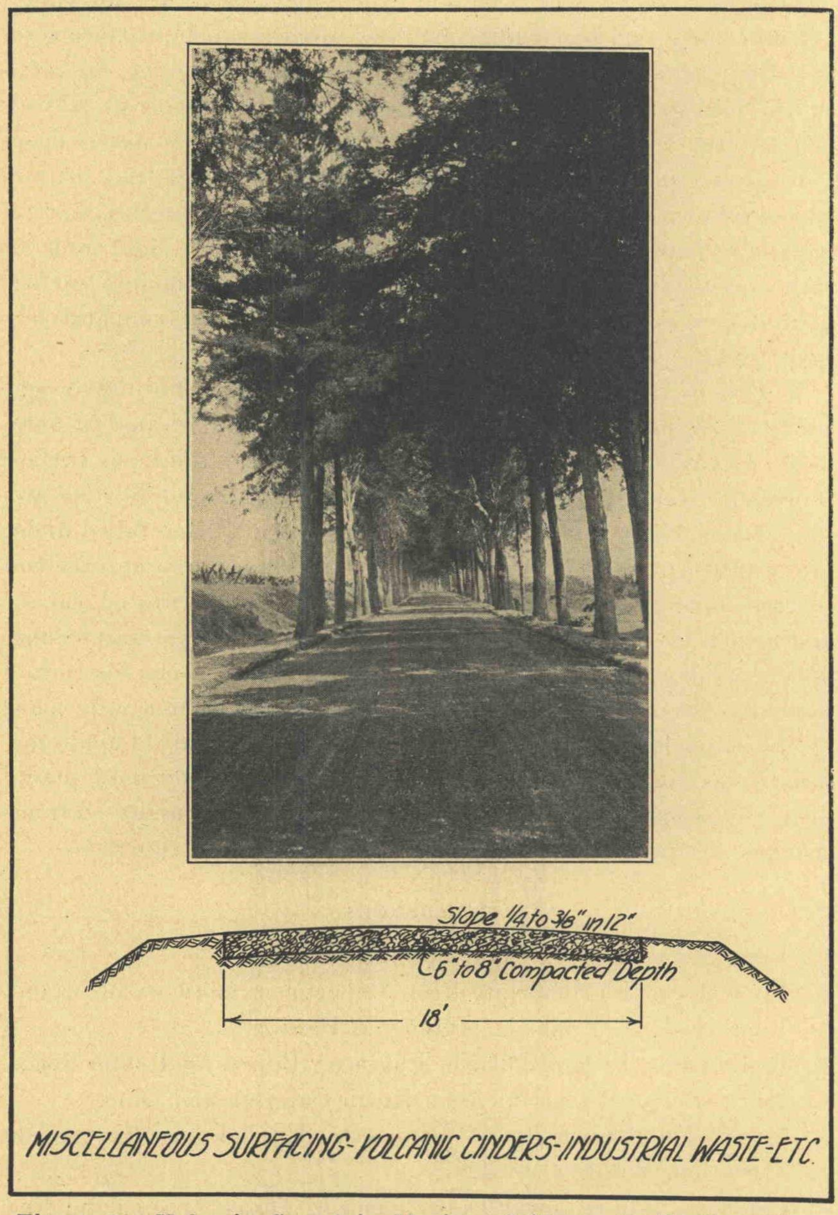

Figure 61. Volcanic Gravel in Mexico. Spillover or Feather Edge Sections Are Suitable for Material Which Passes the 1-Inch Screen

Materials	Cost	Service	Examples in
Stone screenings Mine "chats" Iron ore top soil Granulated slag Pea gravel Stamp sand Shell Volcanic cinders	Construction, less than $10,000 per mile Maintenance, less than $600 per mile per year	For automobiles and light trucks 200 to 500 per day	Connecticut Missouri Texas Ohio South Dakota Michigan Louisiana Mexico

1 *General Description* Materials which are practically unknown to the majority of road builders have given satisfactory service in widely separated sections of the country. This can be seen from the foregoing list of examples of materials and locations. In general, the materials should contain little clay, be of good bonding quality, all passing the 1½ or 1-inch screen and be capable of maintenance with blade machine and drag. Long haul for these materials or expensive construction methods, which involve protracted rolling and watering may exclude them from low cost classification.

2 *Materials* The specification requirements for some miscellaneous materials are given

Stone screenings as used in the Connecticut towns of Wallingford, Cheshire and Winchester are fine particles of crushed trap rock in size from ⅜-inch down to and including stone dust. This dust is about 75 per cent of the total.

Mine "chats" are residue accumulated in the production of lead and zinc. They have been successfully used in bituminous surface treatment work in the Southern States and as aggregate for untreated surfaces in Joplin Co, Missouri. They are produced from a hard flint rock formation. This material will all pass a ¾-inch screen.

Iron-ore top soil as included in the Texas specifications consists of hematite, hydrated hematite, or limonite ore as found at the surface. It must be free from vegetable matter and contain not over 15 per cent clay. In size it must pass the 1½-inch screen.

Granulated slag as used for base course in Ohio is specified as water or steam cooled. It is of such fineness that 90 per cent shall pass the ¾-inch screen.

Pea gravel is specified in South Dakota and consists of hard durable fragments of stone mixed with sand or clay or binding material

Passing the 1¼-inch screen	95 to 100 per cent.
Retained on ¼-inch screen	10 to 40 per cent.
Retained on 10 sieve	35 to 70 per cent.

Stamp sand as used in the Upper Michigan Penisula is a product of crushing copper-bearing rock, composed of hard durable particles of rock, uniformly graded Approximately all of the material will pass a No. 8 mesh sieve and be retained on a No. 100 mesh sieve

Shell as a surface or base course has been and is still used in Maryland, Florida, Texas and Louisiana Louisiana specifications state that shell shall consist of reef shell, clam shell, bank shell or other commercial shell, free from worm holes, or marks of deterioration or disintegration. Steamed shell shall not be used Grading requirements are:

Clean, dry, sound shell, retained on a ¼-inch sieve, shaken to refusal and measured by volume, not less than 70 per cent. Of the material passing a ¼-inch sieve, not more than 15 per cent shall be removed by elutriation, and the remainder shall consist of shell particles, chert and sand

Volcanic cinders are found in parts of the Southwest, Mexico and other volcanic regions Some of these materials bind together readily under traffic or rolling, but others require the addition of local disintegrated limestone or clay. They make excellent surfaces for light traffic roads.

3. *Construction Methods* The traffic bound method of construction as previously described on page 153 for crushed stone, slag and gravel or the sand-clay type are economical and satisfactory, provided the materials all pass the 1½ or 1-inch screen The section used may be the feather edge, or trench section of uniform depth A surfaced width from shoulder to shoulder is desirable.

Surfaces of these materials are also built to a trench section using temporary side forms or wood blocks to gauge the depth of placed materials. The spread material is then rolled and watered to secure compaction and density

The construction methods described on page 138 for sand clay have been successfully employed in Mexico for volcanic cinders combined with a local clay known as "tepetate" Rolling and watering were required as there was not sufficient traffic to secure adequate compaction.

The methods used for water-bound macadam construction are expensive and may generally be avoided if fine crushed material is applied gradually and compacted by traffic.

4 *Maintenance Methods.* Surfaces of fine material may be and are maintained by light and heavy blading or dragging New material

is added as required Water-bound and rolled surfaces of coarse and fine material which cannot be bladed must be maintained by patching and occasional scarifying

5 *Construction Costs* Nearly all of the materials indicated under Miscellaneous Surfaces may be obtained suitable for surfacing without blasting, heavy crushing or screening The principal cost item usually is for haul which can be estimated for known local conditions The depth and width of surfacing naturally affect the quantities to be handled In general the cost of these surfaces compare favorably with sand clay, gravel and the traffic bound types as given on pages 138, 147, 153.

6 *Maintenance Costs* The greater part of surface maintenance consists of blading, replacement of lost surfacing, with occasional scarifying These costs for light traffic seldom exceed $600 per mile per year If large quantities of material must be replaced annually, that is 400 or 500 cubic yards, the maintenance costs will become serious and a new type of surface or a surface treatment will be indicated

7 *Service.* Few traffic counts or reliable records are available on these miscellaneous types From the information available and from some personal experience and observation, these surfaces are an economical investment, particuarly where no other suitable local materials are available and where their cost, if shipped in, would increase the service cost per vehicle mile beyond the limits of available funds

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1 Personal inspections in Michigan, Louisiana and Mexico
2. State Highway Departments and specifications, Texas, Ohio, South Dakota, Michigan, Louisiana and Comision Nacional de Caminos, Mexico.
3 Mine Chats "How Missouri County Builds Good Roads" Article By W T. Withrow in The Highway Magazine, February, 1925
4 "Waste Products Used in Road Building," Article by Cecil H Holmes in The Highway Engineer and Contractor, October, 1925.
5 "Trap Rock Screenings for Low Type Roads." Information received from the Connecticut Quarries Company relative to road work in Wallingford, Winchester, Cheshire and other towns in Connecticut

NON-BITUMINOUS DUST PREVENTIVES

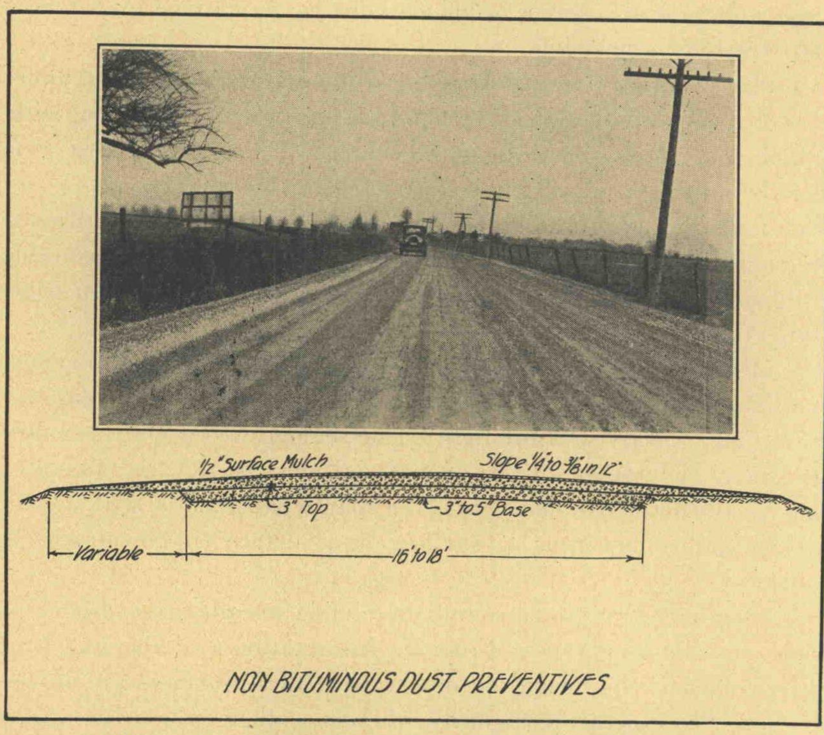

Figure 62. Surface Treatment of Calcium Chloride

Materials	Cost per mile	Service	Examples in
Calcium chloride or lignin binder.	First year $400 to $700. Succeeding years $300 to $600.	500 to 1200 vehicles.	Michigan. Maine. Vermont. Minnesota. Wisconsin. New Jersey. (lignin binder).

1. *General Description.* Calcium chloride is applied to gravel, stone macadam, sand clay, earth and other surfaces primarily as a dust layer but it also greatly reduces loss of binder and surfacing aggregates. Lignin binders are applied to gravel and similar surfaces for the same purpose. They are not as widely used as calcium chloride. Calcium chloride is usually applied to the road surface in flake or powder form. Lignin binder is applied in liquid form. Several applications of these materials are required each season.

2. *Materials.* Commercial calcium chloride is manufactured from a by product resulting from soda ash manufacture. For road work it is shipped in sacks or air-tight drums. Sacks are more convenient for handling in the field.

Lignin binder is a liquid obtained in the manufacture of wood pulp. It is received as a concentrated liquor and diluted with an equal amount of water before application. Calcium chloride attracts or absorbs moisture from the atmosphere in amounts varying with the degree of atmospheric humidity.

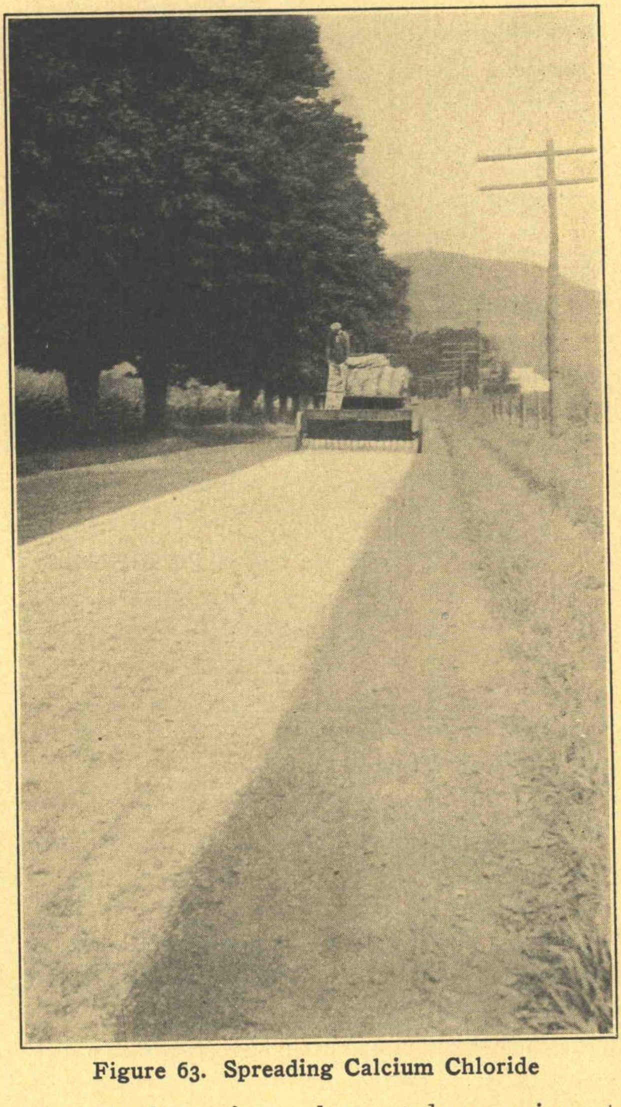

Figure 63. Spreading Calcium Chloride

The materials in the surface to be treated are an important factor in the efficacy of both calcium chloride and lignin binder. For example it has been found that a loose or poorly bonded surfacing allows the applications to pass on downward into the road. A surface containing an excess of clay binder may become slippery or easily rutted in wet weather

3. *Construction Methods* The first season of application will be considered as the construction period. Practise varies somewhat in different states but results under like conditions of materials and climate are similar.

For calcium chloride, the construction methods of Michigan, and for lignin binders, the methods of New Jersey are selected for description

CALCIUM CHLORIDE IN MICHIGAN

1 In the spring the road bed to be treated is cut with a heavy blade machine and brought to an even and smooth cross section

2. If the gravel surface is too loose, a small amount of clay or loam is added to bind the aggregates.

3. Before the first application of chloride, the surface of the road should have a thin cover of loose gravel lying evenly on the surface It should all pass the 1-inch or ¾-inch screen and be retained on the ⅛-inch screen.

4 For the first treatment 1 to 1½ pounds of chloride are applied to the square yard The application is made from a lime drill or distributor preferably on cushion or pneumatic tires. The distributor is hauled by a 3 to 5 ton truck.

5. The chloride is allowed to penetrate for about 24 hours

The surface is next bladed lightly with the regular patrol blading machine

The loose material on the surface is bladed toward the center one day and back the next.

6 The surface for best results should be bladed once each day thereafter throughout the season, although in case of light traffic, less than 300 vehicles per day, blading every third or fourth day may be sufficient.

7 Frequent light treatments with chloride at the rate of ½ pound per square yard per treatment have been successful in Michigan.

The following schedule for a season is recommended and used by Kent County, Michigan The season begins about June 15 and ends about August 15.

For traffic of less than 100 vehicles, no treatment.

For traffic of from 140 to 200 vehicles, two ½ pound treatments.

For traffic of from 200 to 500 vehicles, three ½ pound treatments

For traffic of from 500 to 1000 vehicles, four ½ pound treatments

For roads having over 1000 vehicles, five ½ pound treatments or a total of 2½ pounds per season.

Other states and counties prefer to apply the same total quantity per season but in two applications

LIGNIN BINDER IN NEW JERSEY

The roads treated were compacted surfaces of local gravel which contained various percentages of clay binder. The best results were obtained when the percentage of clay was about 12

1. The material is received as a concentrated liquor and is diluted by about an equal amount of water

2 It is applied cold to the roadway surface with a distributor or sprinkling truck The rate of application per year is about 0 6 gallon concentrated liquor per square yard or about 1.2 gallons of the diluted mixture The total quantity may consist of two or more applications. The successive applications follow each other at intervals sufficient to allow each previous one to penetrate the surface, thus leaving it in condition to absorb the following application.

3. The application for an 18-foot width of surfacing is made over the 12 feet at the center.

4. *Maintenance Methods* These are similar for both materials and include blading, patching and the addition of small amounts of new aggregates. A slight residual value from the previous seasons' treatment allows a slight reduction in the initial treatment of the second season For calcium chloride this may be ½ to ¾ of a pound less per square yard

The maintenance operations may include scarifying, harrowing and reshaping of the surface if the surface is irregular from corrugations or pot holes. Pot holes at infrequent intervals are patched with gravel, similar to that in the road surface

Too much clay in the compacted surface may cause pot holes, too little may result in corrugations. A light surface mulch of clean gravel passing the ¾-inch screen if bladed daily tends to reduce their formation.

The moist condition of a chloride treated surface will permit effective blading at more frequent intervals than one not treated Under traffic of 2000 or more per day it may be necessary to blade the surface to a depth of 2 or 3 inches during the summer season

5 and 6. *Construction and Maintenance Costs* These are about equal for each year except for the slight residual value from season to season.

Calcium chloride sells for about $24 00 per ton, f. o b. cars factory. Due to freight charges and length of haul the cost for chloride delivered and applied on the road may vary from $100 to $600 per mile per year In Michigan, which is near a source of supply, the costs will average from $200 to $300 for applied chloride on a mile of gravel treated to a width of 18 feet. To this cost should be added the cost of blading, patching and the addition of new aggregates. These items in sections of normal humidity and rainfall will not average more than $300 to $400 per mile annually, but for heavy traffic this item may reach $600 or $800

Lignin binder, as used in New Jersey, furnished and applied will cost about $500 to $600 per mile per year. The cost of scraping, dragging and patching in New Jersey is estimated at $300 per mile. In many cases, particularly under heavy traffic, this cost has run from $700 to $900 per mile per year.

7. *Service* The service rendered by nonbituminous surface treatments is apparent to the public by the absence of dust and the presence of a good riding surface. But to the highway official the principal service is a reduction in the loss of surfacing aggregates This may amount to from 50 to 300 cubic yards of material per year. The cost of replacing this has been found to be about equal to the cost of the treatments.

Experience in Michigan with calcium chloride and New Jersey with lignin binder indicates that maintenance costs of surfacing will be excessive on gravel roads carrying over 1500 vehicles per day

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3. Kent County Highway Commission, Michigan.
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5. Highway Research Board Proceedings of November, 1922, meeting, Committee on Maintenance, W. H. Root, Chairman
6. The Solvay Process Co , Syracuse, N. Y , and New York City
7. The Dow Chemical Company, Midland, Mich.

SINGLE BITUMINOUS SURFACE TREATMENTS

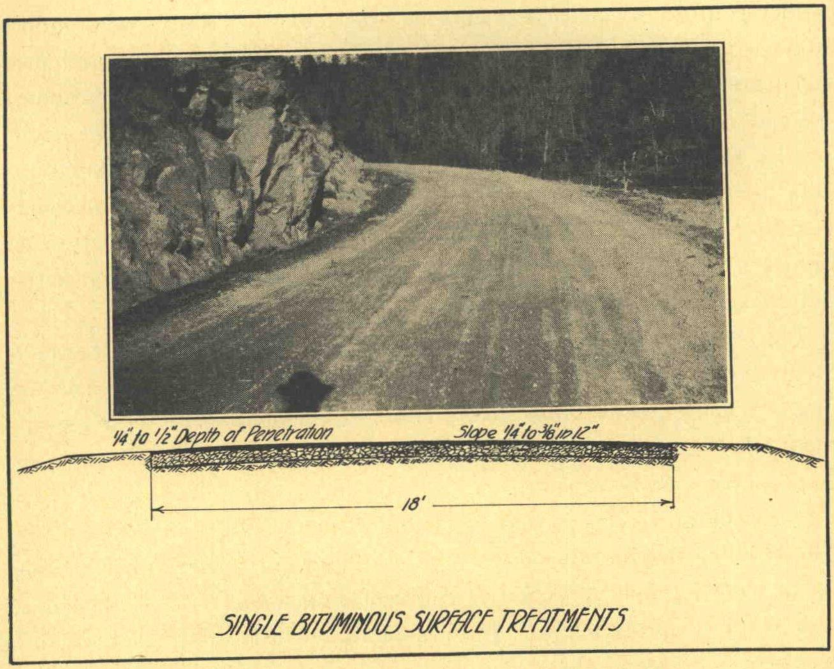

Figure 64. Treated Macadam, North Carolina

Materials	Cost per mile	Service	Examples in
Asphalt, cold or hot; tar, cold or hot; sand, gravel, crushed stone, or crushed slag.	For first year $300 to $1000. For each succeeding year $200 to $800.	600 to 1500 vehicles per day.	New England States. Delaware. Maryland. New York. Pennsylvania. Virginia. Indiana. Ohio. Tennessee.

1. *General Description.* (a) *Bituminous Dust Preventives.* The use of bitumens primarily as a dust preventive on earth and soil roads has not met with marked success and is generally considered a temporary expedient.

The materials used are light asphaltic oils applied cold, with or without cover. Tars have not been as extensively used for this purpose. Some of the oils have proved unsatisfactory because they contained lubricants instead of binder. Cover of earth, sand or loam is better than no cover at all.

Except in a few notable instances the materials and construction methods have been unsuitable. This has resulted in unsatisfactory service because of peeling and pot holes The actual cost of treatment with bituminous dust layers may be less than for a single or a double surface treatment with suitable bitumens, cover, and accepted construction methods, our present practise favors surface treatments instead of bituminous dust layers because a higher residual value results from year to year, and a more satisfactory riding surface is obtained Experimenting with bitumens as dust layers in the early years of surface treatment work probably led to the selection of higher grade materials, improved methods and present day practise with bituminous surface treatments

(b) *Bituminous Surface Treatments.* This and similar methods of surface treating macadams and broken stone roads have been in use in the United States since about 1910 As a method of treating surfaces which are less substantial, less firmly compacted and which are more porous, it is of comparatively recent origin In this class are the gravels and better grades of sand clays, shale, and similar materials The distinction between this and several other similar types is not well defined The Single Surface Treatment as described here is a single application of tar or asphalt covered with coarse sand, pea gravel or stone chips, but a prime coat of bitumen is desirable especially on the more porous and less firmly compacted bases Periodic retreatments at yearly intervals or more are usually necessary Some specifications call for two applications the first year of treatment, in amounts of ¼ gallon each instead of one at ½ gallon The dual method of treatment is described on page 186. The use of the single surface treatment is generally confined to such bases as well compacted macadam, and to concrete

2 *Materials* The bitumens used for single surface treatments have varied all the way from thin oils applied cold up to heated materials applied at 250° or 300° F Cover materials range all the way from a clean sharp sand up to clean gravel and crushed stone chips ¾-inch or larger in size The more fluid cold applications use sand for cover but heavier and hot applications use the coarser materials Frequently bids are asked on tar or asphalt, either hot or cold, to secure competitive prices Some state specifications are written to include these several classes of bitumen and various classes of cover material In some instances a definite class of bitumen and cover are specified and a single class of bitumen or cover may be used from year to year even though several alternatives may appear in a specification The reverse is also true, some states using either tar

or asphalt, or tar and asphalt on various projects Some typical requirements on bitumen follows:

The U S Bureau of Public Roads specifies bituminous material as follows:

Refined Tar for Hot Application

General The refined tar shall be homogeneous and free from water.

Physical and Chemical Properties It shall meet the following requirements:

(1) Specific gravity 25°/25° C (77°/77° F.) not less than 1.130.
(2) Float test at 32° C. (90° F.) 60 sec. to 150 sec
(3) Total distillate by weight:
 To 170° C. (338° F) not more than 1 per cent
 To 270° C. (518° F.) not more than 15 per cent.
 To 300° C. (572° F) not more than 25 per cent.
(4) Total bitumen (soluble in carbon disulphide) not less than 85 per cent.

Refined Tar for Single Surface Treatment
(Cold Applications)

General. The tar shall be homogeneous.

Physical and Chemical Properties It shall meet the following requirements:

(1) Specific gravity 25°/25° C (77°/77° F.) not less than 1.100
(2) Specific viscosity at 40° C (104° F.) 8 to 13
(3) Total distillate by weight:
 To 170° C (338° F.) not more than 5 per cent.
 To 270° C. (518° F.) not more than 30 per cent.
 To 300° C. (572° F.) not more than 40 per cent.
(4) Total bitumen (soluble in carbon disulphide) not less than 90 per cent.

Medium Oil for Hot Application

General The road oil shall be homogeneous, free from water and shall not foam when heated to 120° C (248° F.).

Physical and Chemical Properties. It shall meet the following requirements:

(1) Specific gravity 25°/25° C. (77°/77° F.) 0 950 to 0.980.
(2) Flash Point not less than 100° C (212° F.).
(3) Loss at 163° C (325° F) 5 hours not over 20 per cent.
(4) Total bitumen (soluble in carbon disulphide) not less than 99.5 per cent.
(5) Per cent of residue 100 penetration, 60-70

The Ohio Division of Highways has specifications for 5 different classes of bitumen:

H O Road Oil—Hot Application
C O Cold Oil
H T Tar—Hot Application
M T Tar—Hot Application
C T. Tar—Cold application

The specified bitumens in Ohio, Indiana, Michigan and some other states are similar In Massachusetts the bituminous material is tar or asphaltic oil applied cold in two applications.

Florida specifies for cold treatments an asphaltic road oil or a tar, and for hot applications tar or road oil.

In Ontario, Canada, both asphaltic road oils and tars are specified

On the Pacific Coast asphaltic road oils and fuel oil of high asphaltic content are in use

The cover material may be coarse sand, fine gravel, stone or slag chips. The particles must be hard and durable for best results. Sand and other covers which pass the 3/8 or 1/4 sieve are generally used with the cold liquid bitumens. Chips which pass the 3/4-inch sieve are used with the hot and heavier bitumens.

3. *Construction Methods* Experience has shown that no road should receive this surface treatment unless it is strong enough to bear traffic up to 600 or 800 vehicles per day. Weak spots in the existing surfacing or subgrade must be repaired not less than one month previous to treatment. The surface should have a light crown, 1/4 to 3/8-inch to the foot. It should be smooth and regular in contour, because the riding qualities of the finished surface treatment will be no better than those of the untreated surface

Customary practise is to treat one-half of the roadway at a time, unless it can be closed to traffic. This may save the cost of a detour or the displacement of surfacing material by traffic during construction. Although this discussion is on the single application method it should be stated that a prime coat of bitumen even on dense surfaces such as macadams is common practise. The two methods are therefore presented:

Method I. With prime coats.
Method II. Without prime coats.

Method I. The base course of gravel, stone or macadam is first thoroughly cleaned by sweeping with a power broom. In the case of gravel or other surfacing which is not tightly bonded on the surface care must be exercised not to loosen the larger aggregate.

Figure 65. Distributing Slag over Bitumen. Bangert Distributor, Michigan

When the heavier asphaltic oils and tars are to be used for the second application a greater depth of sweeping may be done. This applies especially to stone macadams.

The first application or prime coat is a light cold tar or cold asphaltic oil applied at the rate of 1/6 to 1/4-gallon per square yard. If the bitumen tends to flow too freely toward the edges of the roadway it should be lightly covered with coarse sand, otherwise no cover is applied. From 2 to 24 hours or longer may be allowed for the prime coat to penetrate. In the case of more porous surfaces a second prime coat of about 1/6 to 1/4-gallon per square yard is advisable.

The final application or seal coat may be the same as the first application or it may be a heavier bitumen If a light material, applied cold (or with very moderate heating up to 150° F.), the rate of application varies for different specifications from 2 to .4 gallon per square yard. The amount of cover will vary from 20 to 40 or 50 pounds per square yard.

Asphaltic oil generally takes up more aggregate than the tars The aggregates are spread over the final application of bitumen from piles along the road or from trucks designed for the purpose

For city streets larger quantities of cover are used than on rural highways, to reduce displacement of the treatment by traffic and the possible spattering of vehicles with bitumen.

Method II The surface to be treated is prepared as in Method I

Tar or asphaltic oil is applied in one application It may be either hot or cold. The heavier the bitumen the thicker the mat which will be formed More bitumen and consequently more cover material are customary for the heavier materials

The rate of application varies in different specifications The more fluid materials must be applied at a lesser rate to prevent them flowing from the road surface Rate of application varies from .2 to 6 gallon per square yard The amount of cover will range from 10 to 40 pounds per square yard In general the amount of cover should be of just sufficient quantity to prevent traffic from taking up the material.

In both Methods I and II rolling with a power roller assists in compacting the surface and in reducing the quantity of cover kicked to the roadside by traffic and in keying the cover into the base

4 *Maintenance Methods* The completed surface treatments whether with or without prime coats are maintained in the same manner. Without a prime coat there is more tendency for the mat to peel off due to the lack of bond and the fact that the old surface is not stabilized and waterproofed to as great a depth

The maintenance consists in patching pot holes and deeply raveled places with cold patch mixture of stone or gravel and bitumen Places which are not deeply raveled are given a light (.1 to 2 gal sq. yd.) application of bitumen and lightly sanded

Retreatments of the entire surface are customary and necessary at intervals of one, two or three years In the course of a number of years the retreatments build up a mat of ½-inch or more in thickness This may then become unstable during the warm summer months and

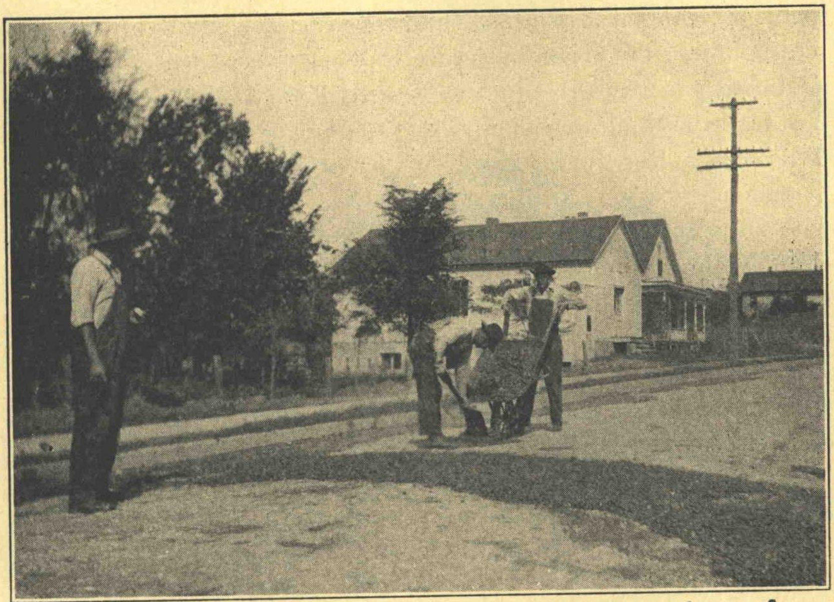

Figure 66. It Is Sometimes Necessary to Patch Large Areas of Bituminous Surfaces

Figure 67. Light Patching Is Done with Thin Layers of Bitumen and Aggregates Applied Separately

be displaced into ridges by traffic A satisfactory remedy for this condition, as used in Philadelphia, consisted of spiking up the road, redistributing the bituminous covered stone to a proper cross section, adding as much clean ¾-inch stone as is necessary to absorb the surface tar or asphalt, and then rolling thoroughly with a 10-ton roller. After this rolling a seal coat of hot tar or asphalt at a rate of ⅓ to ½-gallon per square yard is applied The seal coat is then covered with 20 pounds per square yard of ½ to ¾-inch trap rock chips and rolled with a 10-ton roller This method is reported to be effective and satisfactory on the Lincoln Highway, Philadelphia-New York route.

5. *Construction Costs* The first year's work or original treatment will be considered as the construction period. It includes the prime coats if used and the seal coat.

Single surface treatments on macadams with sand cover will be as low as $300 or $500 per mile for an 18 foot width. On less stable bases, with one or two prime coats and a seal coat, the cost may be doubled.

6. *Maintenance Costs* Averaged over a period of 5 or 6 years the maintenance cost of these treatments on stone macadams ranges from $200 to $500 per mile for an 18 foot width On the less stable bases where more frequent scarifying may be necessary or heavier retreatment required, the maintenance costs may be doubled for an equal amount of traffic.

7. *Service.* On account of the comparatively thin skin of surface treatment, the greatest service in cost per vehicle mile will be on the well compacted macadams The treated macadams and gravels which are not scarified at periodic intervals are not in general as smooth riding as the surfaces which are scarified, bladed and retreated Blading makes a smooth-riding road. Successive applications which build up a thick unstable mat or the effect of frost or an unstable base may cause a rough-riding surface The omission of a prime coat, or insufficient cleaning of the base, may be the cause of the treatment peeling from the base under the action of traffic.

Some statements claim traffic up to several thousand vehicles per day, the average, however, is much less and does not exceed 800 to 1000.

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8. "Quality of Oil for Surface Oiling of Earth Roads and Streets," by F. L Sperry, a paper presented at the Annual Meeting, A. S T. M., 1925.

9 For Experiments and Practise using Oil for Dust Preventive, reference is made to Division of Highways, Springfield, Illinois, and The Pennsylvania Highway Department, Harrisburg, Pennsylvania.

10 "Surface Treatments of Various Types of Roads," by John N. Mackall, chief engineer, State Roads Commission, Maryland American Road Builders' Association, Convention Proceedings, 1926.

DUAL BITUMINOUS SURFACE TREATMENTS PENETRATION METHODS

Figure 68. Florida

Materials	Cost per mile	Service	Examples in
Tar or asphalt. Tar and asphalt. Stone chips. Slag chips. Fine gravel. Coarse sand.	Construction, $1100 to $3000. Maintenance, $200 to $1200.	600 to 1500 vehicles per day.	Maine. Virginia. New Hampshire. North Carolina. Ohio. Florida. South Carolina. California. Texas. Oregon.

1. *General Description.* This type of surfacing is suitable on well compacted bases whose surface is regular and free from loose material. Roadway surfaces of broken stone, gravel, lime rock, marl, caliche, shale and sand clay have been successfully treated by this method. Various classes of bitumens and cover materials are used. Construction methods also vary, but in general they are similar. They consist of the application of a prime coat of bitumen with or without a light cover of mineral aggregate. This is followed later by the second application of bitumen which is immediately covered with

mineral aggregate and rolled The prime coat serves the purpose of bonding and waterproofing the particles in the immediate surface of the existing roadway, and bonds the final application and its cover to that surface

2. *Materials* The prime coat, or first application, is usually a cold liquid tar, a cut-back asphalt or a low viscosity road oil If a second prime coat is advisable the bitumen used is the same as for the first. The final application is a heavier bitumen such as a hot asphalt, a hot tar, a cold cut-back asphalt or a heavy road oil.

The prime coats are not usually covered with aggregates The omission of cover permits better penetration of the base If used, coarse clean sand may be applied very sparingly The aggregates for final cover material range all the way from a coarse clean sand to stone or slag chips which pass the 1¼ screen and are retained on the ¼ sieve. The cover material should be hard and durable If soft or friable material must be used then the larger sizes with angular faces are preferred As is the case in single bituminous surface treatments a variety of bitumens and cover are often included as alternatives in a given specification This is somewhat confusing as the materials actually used do not always represent such wide variations.

In Maine, New Hampshire and Wisconsin, on gravel roads where similar materials and methods are used, a cold tar is the binder The cover is coarse sand or fine gravel.

In California, on crushed stone and gravel roads "fuel oils" are specified for prime and second application. They have an asphaltic content 60 to 70 per cent Light "road oils" having a higher asphaltic content are also used for second application They are applied cold or slightly heated The cover material is hard crushed aggregate

In Oregon, on crushed rock and crushed gravel roads asphaltic oils and tars have been used The prime coat, when asphaltic oils are used, is a 60 per cent asphalt fuel oil with a cover of screenings The second coat is 95 per cent asphaltic oil applied hot and covered with ¾ to ⅛-inch screenings Light and heavy tars are applied in a similar manner.

In Mexico, asphaltic oils are used for a prime coat and a specially prepared heavier asphaltic cut-back is used for the second application Coarse sand is used for the cover.

In South Carolina, on selected sand clay and clay-gravel, after some experimentation with various bitumens and cover, present practise calls for a cold tar prime coat without cover and a hot asphalt second application. The cover for this is a coarse chip passing the 1¼-inch and retained on the ¼-inch screen, when using local granite.

In Virginia and North Carolina, for surface treatments of selected sand-clay and clay-gravel roads, a variety of materials are specified and have been used. These included prime coats of cold tar or asphalt; second applications of cold tar or cold asphalt, hot tar or hot asphalt, and cut-back asphalts. The cover used has ranged all the way from coarse sand to stone chips and gravel. Present practise within these

Figure 69. Dual Bituminous Surface Treatment. Sweeping Surface Before Bitumen Is Applied. Wisconsin

states has not apparently been centered on any combination of bitumen and cover. A light bitumen for a prime coat with little or no cover and a hot heavier bitumen for the second application with coarse chips are growing in favor.

In Ohio, on traffic bound stone, slag and gravel surfaces, best results are claimed for a cold tar prime and a hot second coat of heavy asphalt. The preferred cover is a hard crushed stone chip up to 1-inch in size.

In Florida, on lime rock base, excellent results have been obtained with a cold tar prime and a hot second coat of heavy asphalt and coarse slag chips. The use of sand as cover has been abandoned.

3 *Construction Methods* They are similar in the several states although the materials are not. The untreated surface is first thoroughly prepared for treatment by sweeping with power brooms. The surface may be closed to traffic or treated one-half at a time The method of treatment is simple and consists of.

(a) The application of the prime coat of bitumen from a power distributor The rate of application is from 2 to .3 of a gallon per square yard If the surface readily absorbs the bitumen two prime coats of about 2 gallon each may be used A cover of mineral aggregate for the prime coat is usually omitted to permit maximum penetration If used the quantity should be small and preferably removed before the final application of bitumen The prime coat is allowed to penetrate from several hours to several weeks During this time weak spots in the surface are corrected.

(b) The second application of bitumen (sometimes called the seal coat) is applied from a power distributor The rate of application is from 3 to 4 of a gallon per square yard A few states, for example California and New Hampshire, apply about 2 gallon for the second application and 3 for the prime coat.

(c) Cover is immediately spread on this application from piles along the road or suitable spreading devices attached to a truck The amount of cover varies with its character and the class of bitumen used If the bitumen is a heavy material applied hot and stone chips or dense slag is the cover, the amount varies from 35 to 50 pounds to the square yard If the bitumen is a light cold oil or a cut-back, and sand is the cover, it may be applied in 1 or 2 separate spreadings until the surface will "take up" no more and "bleeding" ceases The amount varies from 15 to 30 pounds per square yard.

(d) If this application is a hot bitumen, the cover of coarse chips or gravel is evenly spread by brooms and at once rolled with a power roller. If the bitumen is a light oil or a cut-back, the surface is usually dragged to an even contour. Coarse cover is usually rolled, but fine cover may or may not be rolled

(e) A seal coat may or may not be applied at once or during a succeeding season If the surface is open or inclined to ravel, a seal coat is indicated It may be a cold or a hot application of 1/6 to 1/5-gallon per square yard Coarse sand is usually the cover

4 *Maintenance Methods* They consist of blading for plastic surfaces All surfaces will need patching The deeper holes are patched with pre-mixed aggregates and bitumen Small breaks and raveling are corrected by an application of bitumen and cover

In the case of surface breakage or irregular surface over a considerable area it may be as economical and more satisfactory to lightly scarify the entire surface treatment The broken up surface is then disk harrowed, spread with a road blade and rolled. Bitumen is then applied followed by suitable cover

Light retreatments may be necessary at intervals of one, two or several years

5 *Construction Cost* The initial construction of prime coat, second coat and cover varies from $1100 to $3000 per mile for an 18 foot width depending on local conditions and the class of materials used.

6 *Maintenance Costs* Such items as scarifying and retreatments will greatly affect the annual maintenance costs Without these two items it amounts to from $200 to $500 per mile With retreatments, with or without scarifying, maintenance of surface ranges from $800 to $1200 per mile, with an average over a period of years of $1000 and less

7 *Service* Traffic on this type for various bases ranges from 700 vehicles per day to 2000 or more. The maintenance costs increase with the volume of traffic, but 1000 vehicles per day does not exceed the capacity of dual surface treatments on substantial bases

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MIXED IN PLACE BITUMINOUS SURFACE FINE AGGREGATE TYPE

Figure 70. North Carolina

Materials	Cost per mile	Service	Examples in
Sand clay or sand loam or fine clay gravel and bitumen.	Type I—Construction \$800 to \$3000. Maintenance \$300 to \$1200. Type II—Construction \$4000 to \$6000. Maintenance \$300 to \$1200.	Type I, 500 to 1500. Type II, 300 to 1000 vehicles per day.	Long Island, N. Y. North Carolina. South Carolina. California. Nevada.

1. *General Description.* This type of construction consists of mixing-in-place local aggregates as found on the road with either a slow or a quick curing cold asphaltic oil or tar. Final compaction is secured either by traffic or by rolling. The seal coat if used may be either coarse sand, fine gravel or crushed stone, and bitumen. The construction may be one of two types:

Type I. In which a slow curing oil is applied cold. This is covered with a mixture of coarse sand or fine gravel containing some clay or silt or loam The surface is mixed by dragging and compacted by traffic No seal coat is used

Type II. In which sand clay surfaces or sand loam as found mixed in the existing roadway are mixed in place with a cut-back asphalt, tar or road oil The surface is mixed by harrowing and blading. Final compaction is usually obtained by a power roller. A seal coat is frequently necessary

In Type I a surface of appreciable thickness 1 to 4 inches is built up over a period of as many or more years. In Type II the full depth of section is built during the current working season.

2 *Materials* For both types similar aggregates have been tried They include sand clays of good and poor quality, sand or fine gravel-loams, fine clay-gravels, desert sand and beach sand containing silt or mixed with loam The bitumens combined with these aggregates in the road include slow curing asphaltic oils, cut-back asphalts, tars and fuel oils of high asphaltic content.

An analysis of two samples taken from a Type I surface in Long Island, New York, showed bitumen contents of 8 3 per cent and 7.2 per cent, all of the aggregates passed the 1/4-inch screen and were of uniform gradation from coarse to fine, with from 5 to 10 per cent passing the 200 mesh sieve.

Analysis of samples taken from Type II show that the relatively clean, very fine sandy soils may require as high as 10 or 11 per cent of bitumen. Soils of coarser gradation may only require 4 to 7 per cent bitumen On the test road in South Carolina it was found that clay in the clay-bearing aggregate assisted in bonding the mixture and that it was then possible to use these lower percentages of bitumen

The analyses of 6 different samples taken from Nevada Federal Aid Project No. 46 showed this average: passing 10 mesh 91.3 per cent, passing 40 mesh 78 2 per cent, passing 80 mesh 44 9 per cent, passing 100 mesh 28 2 per cent, passing 200 mesh 9.8 per cent, total bitumen 7.4 per cent.

A sample cut from an oiled sand road in Stanislaus County, California, showed that the material passing the 10-mesh sieve was considerably finer than an ordinary sheet asphalt mixture and the amount of silt (passing 200 mesh) slightly more than the dust filler for such a sheet asphalt mix The bitumen content was 7.9 per cent.

A sample taken from an oiled sand road in San Bernadino County, California, showed 100 per cent material passing the 10-mesh sieve, 11 per cent passing the 200-mesh sieve and bitumen content 8 1 per cent.

The recent experimental work in South Carolina showed that variations in the class and gradation of aggregate as well as the classes of bitumen required wide variations in bitumen content for best results

3 *Construction Methods Type I.*

(a) The road surface is first graded to a low crown with a road machine.
(b) The oil is applied cold with a pressure distributor at the rate of .33 to .4 gallon per square yard. One half of road is treated at a time.
(c) The spread oil is covered with coarse sand or fine gravel from piles along the road side
(d) When each half of road has been treated traffic is allowed on the surface.
(e) Dragging is done at sufficient intervals to obtain and retain a smooth surface.
(f) A second application of oil and coarse sand or fine gravel is made the first year
(g) The second year another treatment is given of oil and sand.

The number of succeeding periodic treatments will vary with local conditions of traffic

During the first year the surface is built up to about ¾-inch in thickness, which is increased by successive treatments Each layer is compacted by traffic The total quantity of oil applied the first year in 2 applications is from 6 to 8 gallon, and the total cover for this amount of oil is from 50 to 60 pounds of coarse sand per square yard Periodic applications during following years amount to about ⅓ gallon of oil and 25 pounds of sand per square yard for each application.

Type II

(a) The compacted road surface is first scarified to a depth usually of from 2 to 4 inches It is then thoroughly mixed with disk harrows, tooth harrows and road machines until the sand and clay or sand and loam are well mixed, with all lumps out and a powdered condition exists
(b) The bitumen is next applied cold at a rate of from 5 to .75 gallon per square yard per application from a pressure

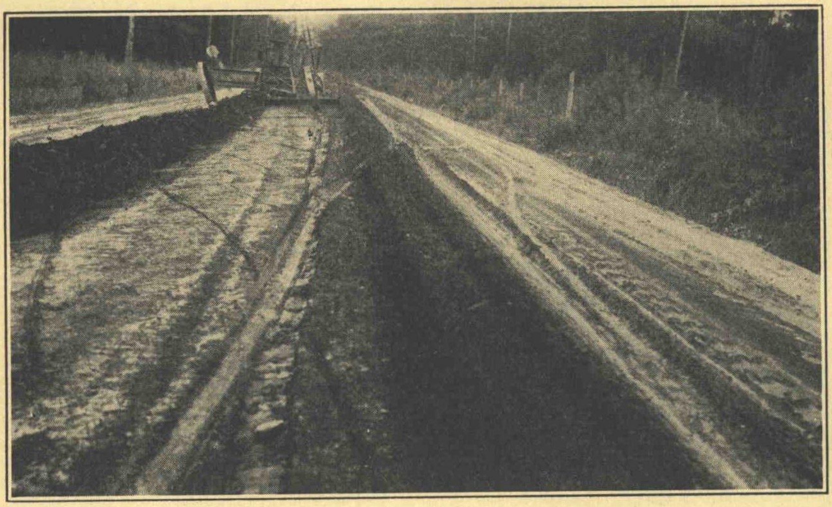

Figure 71. Mixed-in-Place Bituminous Surface, Fine Aggregate Type. Showing the Mixing of Sand Clay As Found in the Road with Bitumen. South Carolina

Figure 72. Mixed-in-Place Bituminous Surface, Fine Aggregate Type. Final Dragging of the Mixture Before Compaction with a Power Roller. North Carolina

distributor The entire width of the road is treated in two trips of the distributor

(c) The oil and sand clay are then bladed back and forth across the road to mix the bitumen with the aggregates Harrows and drags are also used to help in this mixing process

(d) The mixing is stopped when the mixture has a uniform dark brown color. The uncompacted surfacing material is now machined and dragged to a smooth and even contour

(e) Compaction is next secured with a power roller of from 5 to 8 tons capacity The rolling process is similar to that done on hot asphaltic surfaces

(f) The base thus constructed is exposed to traffic for several days or longer. During this time weak spots are patched with a pre-mixed combination of bitumen and coarse sand

(g) A seal coat is applied Two principal types are used, the one in which cut-back bitumen is applied to the surface and covered with coarse sand, the other in which hot bitumen is applied and covered with coarse stone chips

Experience in South Carolina showed that a total of about 1 5 gallons (applied in two applications) per square yard of non-volatile binder was the correct amount required to produce a stable mixture of 2-inch thickness. In California and Nevada the total amount of oil per square yard was from 4 to 6 gallons for compacted depths of about 6 inches.

Seal coats were used on work of this type in South Carolina and North Carolina. Some of the California and Nevada work had no seal coat. They carried a higher percentage of bitumen in the mixture.

4. *Maintenance Methods Type I.* The surface is machined with a heavy road machine to cut down the high places The material thus cut is dragged to the low spots and compacted by traffic The surface tends to wave and shove at times, especially during hot weather. This condition exists on the Long Island work, but the heavy road machine keeps the surface reasonably regular in contour

At times it is necessary to scarify and reshape entire sections. This is done with satisfactory results in Long Island Holes in the surface are patched with pre-mixed aggregate and bitumen Shallow holes or raveled spots may be patched with a light application of bitumen and aggregate.

Type II. The maintenance methods for the work in South Carolina include patching, scarifying, remixing, reshaping, rerolling, followed by a new seal coat. When heavy seal coats are not used in the initial construction and a slow curing oil is the bitumen then the surface may be maintained with a blade and drag The Nevada work is an example of this method for Type II.

5 and 6. *Construction and Maintenance Costs Type I* Where a depth of from 2 to 6 inches is obtained over a period of several years the cost of Type I in Long Island is from $800 to $1500 per mile per year for varying width of surfacing The treated width will average from 24 to 30 feet. Some surfaces are as narrow as 16 feet. The initial cost of similar types in other states has been from $1800 to $3000 the first year and $500 to $1200 for an average of each succeeding year for widths of 18 feet.

Type II The initial cost of this type in the Southern States is from $4000 to $6000 per mile for a treated width of 18 feet and a treated compacted depth of 3 or 4 inches.

In California and Nevada the reported initial costs are from $3000 to $8700 per mile for an 18 footh width and a depth of 6 inches, the average being about $5000

Maintenance costs are not available for Type II in the Eastern and Southern states. These surfaces in the Western states are being maintained for light traffic for $500 and less per mile per year

7. *Service. Type I* The best example of this type over a period of several years is the work in Long Island, New York Traffic there during the summer months is said to reach 5000 to 6000 vehicles per day on some of the surfaces The average, however, is probably less than 1/3 of these figures Soil conditions there are favorable for this type There is a tendency for this type to form into ridges under traffic, but the condition is fairly well corrected during warm summer days by blading.

Type II. The work in South Carolina is carrying from 800 to 1200 vehicles per day with some signs of fatigue which are corrected by maintenance methods.

In North Carolina the work near Southport is also new The traffic is less than 800 vehicles per day and requires continuous maintenance Conclusion on the work in South Carolina, as stated in "Public Roads," are, "Results on mixed treatment experiments are inconclusive, but indicate the probable success of lean mixture supplemented by surface enrichment." "A light supplementary application of bituminous material which will enrich the surface and at the same time seal any small break or areas not sufficiently covered has been found to be necessary shortly after the original treatment."

The service of both types I and II for conditions in California and Nevada is summarized in "Public Roads" as follows

The success or failure of these oiled earth roads depends largely upon the character of the material Sandy, gravelly, or even silty soils have produced serviceable roads in most instances when properly treated and maintained

Heavy clays or alkali soils have been similarly treated but the results have been almost universally unsatisfactory These clays are inherently unstable, have high moisture carrying capacity, and are constantly changing in volume Uniformity of soil from point to point on the project is highly desirable, but experienced workmen will overcome considerable irregularity of soil by varying the quantity of oil and the details of treatment

This type of treatment is adapted to roads carrying less than 500 vehicles per day where soil conditions are suitable and particularly in arid and semi-arid climates

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MIXED IN PLACE BITUMINOUS SURFACE COARSE AGGREGATE TYPE I

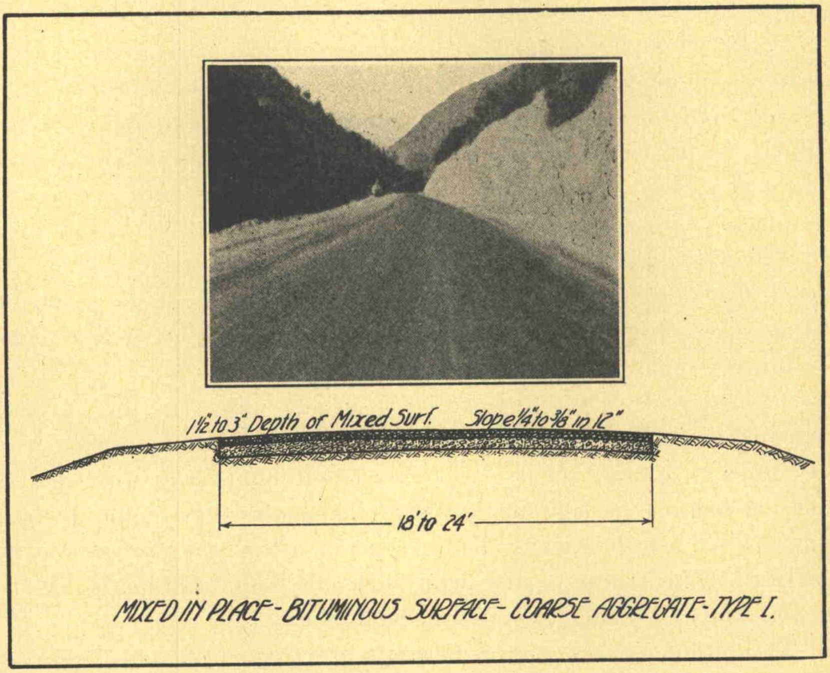


Figure 73. California

Materials	Cost per mile	Service	Examples in
Gravel. Stone. Slag. Bitumen.	Construction $1100 to $3000. Maintenance $400 to $900.	800 to 1500 vehicles per day.	Wisconsin. Minnesota. Ohio. Louisiana. California. Wyoming.

1. *General Description.* This type of surface is designed to form a well bonded mixture of bitumen and the more or less loose material of the existing road surface, and further to key and bond this mixture with the compacted and untreated materials beneath. It is usually applied to gravel roads, although traffic bound surfaces of crushed stone and slag are treated in a similar manner. There are three principal construction methods of placing the prime or initial application, each of which aims at the same result.

A. In which the loose material of the existing surface is first treated with an application of bitumen before mixing and further applications are commenced.

B. In which the loose material is bladed from the surface and the compacted surface thus exposed receives the first application of bitumen before mixing and further applications are commenced.

C. In which the surface of the existing road is strengthened by a prime coat of bitumen applied to the exposed base followed by a mixing with bitumen of the loose material in the existing surface, this is in effect a mixed prime coat The surface thus primed is then covered with a mixed-in-place surface of new aggregate and more bitumen.

The most suitable method must be determined after a study of local conditions which include thickness of existing surface, degree of compaction, gradation of aggregates, and the characteristics of the bitumen in combination with these aggregates

2. *Materials* The aggregates are usually those in the existing road surface These methods of treatment have been used principally on crushed or uncrushed gravel roads but equal or greater success may be had on crushed stone or slag The aggregates should all pass the 1½ or 1-inch screen. The gradation below this size should be uniform from coarse to fine, with sufficient fines to properly fill the voids Small amounts of clay may be tolerated.

The bitumens used for prime coats are frequently light asphaltic oils, tars or cut-backs which are low in viscosity and high in penetrating qualities For the final application (not the seal coat) higher viscosity bitumens are favored. The same bitumen has been used for the prime application and the actual mixture but this practise is not as general as the use of light material for the prime and a heavier bitumen for succeeding applications.

Experience with aggregates used and analyses of samples taken from road surfaces are illustrative, but complete specifications for materials and methods of construction are not generally available

In California, the conclusions are drawn that

The principles involved are similar to those governing asphaltic concrete, excepting that the low viscosity asphaltic binder used in this process covers the particles with a thinner film than does the harder asphalt Tests indicate that three-fourths as much light oil should be used as asphalt for like mixtures A stain test modified from sheet asphalt practise promises to be useful The amount of oil depends primarily upon the amount of sand and dust passing a 10-mesh screen

Experience has demonstrated that the amount of oil to be used should be kept at a minimum In California the percentage ranges from 2 per cent to 7 per cent with an average of 3 per cent to 4 per cent In order to obtain best results a screen analysis should be made prior to oiling

Aggregate containing from 40 per cent to 60 per cent of 10-mesh material (material retained on 10-mesh sieve) usually gives more satisfactory and stable results than aggregate containing more than 40 per cent passing a 10-mesh A hard nonporous gravel will usually require less oil than a porous volcanic rock In the final analysis the amount of oil used must be governed by appearance, and the mixing is continued until the material (mixture of oil and aggregate) assumes a dark brown or chestnut color

The experience of one industrial organization in the use of tars on gravels is valuable Better success has resulted in treating gravel with a large percentage of stone than a gravel with a large sand content The more crushed or irregular aggregate in gravel, the better. The largest size particles of gravel should be about 1-inch, with at least 60 per cent above the ¼- inch size. More than 20 per cent of clay usually causes trouble and in general better results are obtained with the clean gravels The fact is also recognized that gravel in the pit and gravel in the road may be entirely different, and that the material in the road should be examined before the methods of treatment and amounts of bitumen are decided upon. Cut-backs, that is, asphalt or tar cut with naptha or other material to increase their fluidity and the movability of the mixture, are now being tried instead of the slower curing bitumens. No definite information on the use of emulsions for this type of construction is available.

3. *Construction Methods.* There are several principal methods of construction each of which includes a proper preparation of surface to be treated—from 2 to 4 applications of bitumen, blading, shaping and compaction The object of all of these operations is to obtain a thoroughly mixed and compacted bituminous concrete which is bonded to the surfacing material beneath Variations in the methods are not unusual but they must secure the foregoing results for success

The construction steps of some typical examples are given.

IN CALIFORNIA, USING ASPHALTIC OILS AND GRAVEL OR STONE

1. Preliminary scarifying
2. Balance grading.
3. Final scarifying.
4. First application of oil
5. Disk harrowing.
6. Second application of oil
7. Disk harrowing
8. Third application of oil.
9. Disk harrowing.
10. Preliminary or rough blade mixing.

11 Final or finish blade mixing.
12 Spreading mix
13. Surface compacting and smoothing
14 Seal coat (if needed)
15 Correction of construction defects and maintenance

Where the grading of the aggregates shows in excess of 50 per cent passing the 10-mesh sieve a total of 1½ gallons per square yard of oil are used for a 3-inch mixed and compacted surface The surface may be treated for its entire width or one half at a time

IN WISCONSIN, USING TAR AND GRAVEL

1 Preliminary scarifying and shaping of untreated surface.
2 First application of tar to half the road
3. Loose treated material bladed to a few feet beyond center of road
4 Second application of tar to the base thus exposed by operation 3.
5. Treated material near road center bladed back over second application of tar
6 Blading back and forth, continued until all particles of gravel are coated and the mixture is uniform in color.
7. The second half of road is treated in the same manner.
8 If a seal coat is used it consists of a light seal coat of tar covered with stone chips, pea gravel or coarse sand.

Compaction may be obtained by traffic or by a power roller. The total amount of applied tar exclusive of the seal coat is about ⅔ gallon per square yard. The seal coat requires about ⅛ gallon per square yard The treated depth is from 1½ to 2 inches.

IN MINNESOTA, USING TAR AND GRAVEL

1. Preliminary scarifying and shaping of untreated surface
2. The loose untreated gravel on half of the road is bladed into a windrow just beyond the road center
3 First application of ⅓ gallon per square yard of tar to the compacted surface thus exposed by operation 2.
4. The entire road is left open to traffic for 24 hours or longer During this time the first application penetrates the hard surface and any breaks or surface raveling are patched with a mixture of tar and gravel.
5 Second application of ⅓ gallon per square yard of tar to the previously treated half.

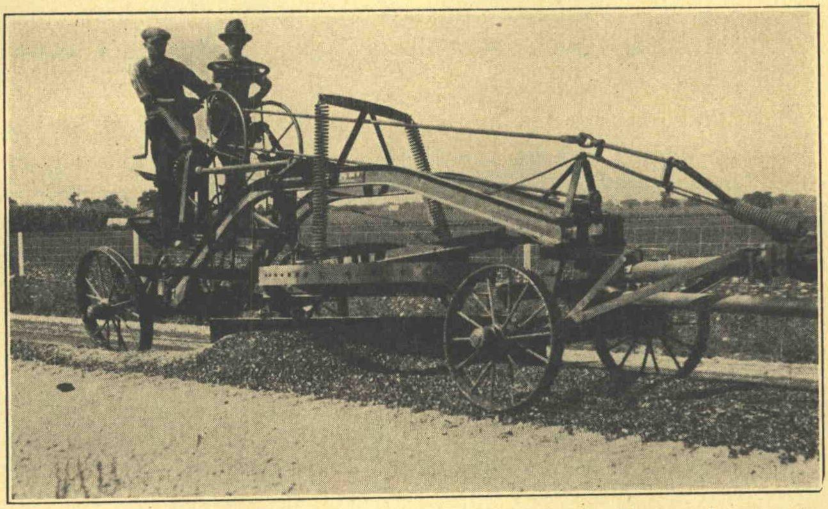
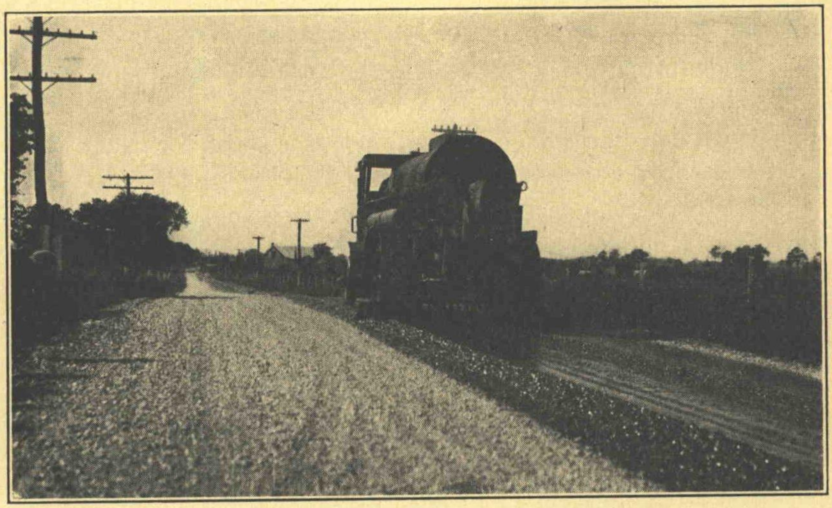


Figure 74. Mixed-in-Place Bituminous Surface. Coarse Aggregate Type I. Mixing Loose Gravel or Stone with Bitumen with a Road Blade



Fgure 75. Mixed-in-Place Bituminous Surface Coarse Aggregate Type I. Distributor Applying Bitumen to Exposed Base. Traffic Bound Stone Road. Ohio

6. The loose untreated gravel from the windrow near road center is immediately bladed over the wet second application of tar
7. The same processes are repeated on the other half of the roadway. There is now ⅔ gallon of tar per square yard beneath a loose layer of gravel.
8. As the tar works up into the loose gravel, the surface is remixed by blading and kept smooth by blader and drag Blading and dragging are continued until the surface mixture sets up and blading cannot be continued
9 Final compaction is obtained by traffic.
10 A seal coat of tar and coarse sand may or may not be required

The total amount of applied tar exclusive of seal coat is ⅔ gallon per square yard Each application is ⅓ gallon The depth of finished compacted surface is from 1 to 2 inches.

IN LOUISIANA, USING A CUT-BACK ASPHALT AND GRAVEL

1. Preliminary scarifying and shaping of existing surface
2. First application to the loose surface of ¼ to ½ gallon of light cut-back asphalt.
3 The treated gravel is bladed to one side of the roadway
4 Second application of ¼ to ½ gallon of light cut-back asphalt is applied to the base thus exposed.
5. The treated gravel (moved in operation 3) is bladed back and forth over the roadway surface until thoroughly mixed
6 The surface is struck off with a blade grader to a smooth and uniform surface and allowed to set up (The volatile oils are allowed time to evaporate)
7. The surface is compacted by a power roller
8 Third application of bitumen This is applied directly to the mixed prime coat just completed and is a heavy cut-back asphalt applied at the rate of ¼ to ½ gallon per square yard.
9. Clean fresh gravel is evenly spread over this application
10. Fourth application of bitumen consisting of the heavy cut-back asphalt applied at the rate of ¼ to ½ gallon per square yard.
11. The new gravel and heavy cut-back are mixed by blading until the mass begins to set up. Then it is given a final blading to insure a regular contour
12 Final compaction by a heavy power roller.

The foregoing method uses from 1 to 2 gallons per square yard of bitumen for a total depth of from 2 to 4 inches That is about ½ gallon per inch of compacted thickness of surface.

The methods as used in California, Wisconsin and Minnesota are fairly well standardized for those states, but slight variations are made from time to time. The method described for Louisiana is new and less information is available on it.

4 *Maintenance Methods.* The principal operations are patching, the addition of seal coats, scarifying and reshaping.

Small holes and raveled spots are patched with a skin coat of bitumen and aggregate Larger holes are patched with pre-mixed bitumen and aggregate.

If too rich a mixture is indicated by shoving or surface displacement, scarifying and the addition of fresh aggregate has corrected the condition.

Too lean a mix may be corrected by a seal coat of bitumen and chips or by scarifying and remixing with more bitumen

5 *Construction Costs* For the California work the average cost for this type is given as from $1200 to $1500 per mile for a 20 foot width. An average of 1.32 gallons of oil were used per square yard. Surfacing in Wyoming of a similar character and with similar materials cost $0 1131 per square yard which is about $1200 per mile for an 18 foot width.

In Wisconsin, the cost of mixed-in-place surfacing is given as $900 to $1400 per mile for an 18 foot width

In Ontario, Canada, the Wisconsin method costs approximately $1750 per mile for a 20 foot width.

In Minnesota, the costs are given as $1500 to $1800 per mile for a width of 18 to 24 feet.

Costs are not available for the Louisiana work but they are doubtless higher than for the California work because cut-back asphalts are more expensive than the road oils as obtained in California

6. *Maintenance Costs* This type of surfacing in California is new and maintenance costs are not available The correction of construction defects by scarifying and remixing has cost from $90 to $180 per mile The addition of a seal coat of ⅛ gallon of oil per square yard with cover would not make the total cost including patching more than $500 per mile per year.

In Wisconsin, the average yearly maintenance cost over a four year period has been $600 per mile.

In Minnesota, the annual maintenance costs are given as $300 to $600 per mile.

In Ontario, Canada, the expected maintenance cost was given as $800 per mile, using the Wisconsin method

In Indiana, the average maintenance cost on a 12.6 miles untreated gravel was $700 per mile for a 6 months period just prior to treatment. For the first 6 months after treatment it was $210 dollars per mile.

7. *Service* The riding qualities of mixed-in-place types are universally claimed to be better than for penetration types This is because the surface is bladed by a road machine As proof of the relative smoothness in California a device called the "Roughometer" showed the average roughness of 153 miles of the surface penetration type to be 53 2 inches and for 119 miles of the mixed-in-place type to be 31 6 inches. Nearly all the states using this type consider it suitable for a daily traffic of from 800 to 1500 vehicles. During periods of the year traffic may greatly exceed these amounts Wisconsin reports 6000 vehicles daily during summer months with average throughout the year of 1375.

With this type of surfacing it is possible to economically improve thousands of miles of gravel and crushed stone surfaces

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MIXED IN PLACE BITUMINOUS SURFACE COARSE AGGREGATE TYPE II

Figure 76. Tennessee

Materials	Cost per mile	Service	Examples in
Crushed stone. Crushed slag. Bitumen.	Construction, $2000 to $4500. Maintenance, $300 to $700.	800 to 2000 vehicles per day.	Pennsylvania. Tennessee. Indiana.

1. *General Description.* This type of construction was developed on a large scale in Pennsylvania as a surface intended to be more durable than the single or dual surface treatments.

It was not expected to give results comparable with bituminous penetration macadam.

It has been used with gratifying results on old, well compacted bases of stone, slag, gravel and shale.

The principal features are the priming of the base course with a cold bitumen, followed by the application and mixing of more bitumen with a hard, clean, crushed coarse aggregate. Compaction is usually obtained by rolling. The exact details and procedure of construction may vary but similar results are obtained with similar materials. This Type II is probably more substantial than Type I owing to the higher class of selected and specified coarse aggregate.

It is also more expensive than Type I. The type is known by various names, such as "Oil Bound Broken Stone Surface," in Pennsylvania; "Carpet Treatment," in Tennessee, and quite generally by the trade name of "Retread."

2. *Materials.* The aggregate generally used is hard crushed stone Crushed slag has also been used to a limited extent Slag unless non-porous requires more bitumen than crushed stone.

As specified in Pennsylvania, the stone shall be uniformly graded, free from dust, dirt, foreign materials and coatings of any character, and from an excess of flat and elongated pieces. The stone shall be uniformly graded and conform to the following mechanical analyses

	Min percentage	Max. percentage
Passing 1½-inch screen	100	
Passing 1¼-inch screen	95	100
Passing ⅝-inch screen	0	30
Passing ⅜-inch screen	0	8

The crushed stone shall be obtained from clean, tough, durable rock free from slaty texture or cleavage planes and having a percentage of wear of not more than 5 and a toughness of not less than 6. All stone shall meet the requirements of the "Soundness Test."

The crushed stone as used in Tennessee all passes the 1¼-inch screen and is retained on the ⅝-inch screen A hard and durable product is required.

The size and gradation of stone as used in both Pennsylvania and Tennessee are about the same for each state but the finished depth of surfacing in Tennessee is from 1 to 1½ inches, while in Pennsylvania it is 2 inches.

In Indiana, the following gradations are used for the indicated loose depth of surfacing:

	Percentage Passing Circular Opening						
Loose depth of stone	½-inch	¾ inch	1 inch	1¼ inch	1½ inch	2½ inch	3 inch
1 inch		0-15	25-75	100			
2, 2½, 3 inch		0-2		. .	0-15	95-100	100

The quality of stone for all recommended cases is similar to that used for bituminous macadam for which a per cent of wear of 6 is permissible. If softer stone must be used it should be specified in larger sizes.

The bitumens used are a cold application of either tar or a cut-back asphalt.

Pennsylvania and Tennessee use tar generally. Indiana started with tar but is now using tar or a cut-back asphalt.

In Pennsylvania, the tar mixture of flux and base has a specific viscosity (Engler, 50 cc. @ 40° C) of 20 to 28.

In Tennessee, the prime or first application of tar consists of material having a specific viscosity between 13 and 18 and for the second application between 18 and 27.

In Indiana, where either tar or asphalt are specified, the following classes of bitumen are included, but the so-called "cold" applications are generally used

1. Cut-back Asphalt, Liquid Asphalt A C, which has a specific viscosity of 20 to 100 at 122° F. It must be applied at such a temperature that it will flow readily on the road surface or be incorporated with the aggregate

2 Asphalt O H 2 (for use in final application). The residue from distillate is required to have a penetration of 175 to 250 at 25° C (50 g 5 sec).

3 Liquid Asphalt C B (for use in final application: also in all applications if stone is comparatively large)

The residue from distillate is required to have a penetration at 77° F. (100 g 5 sec) of 50 to 110 When applied this asphalt shall be at such a temperature that it will flow readily on the road surface or be incorporated in the mix

4. Refined Tar T H (for use in final application)

The float test at 32° C shall be from 120 to 180 seconds The tar T H shall be at a temperature between 150° F and 200° F. when applied to the road surface.

5. Tar T M (for use in first and second application)

The specific viscosity at 40°C must be between 25 and 40. It shall be at a temperature of 125° to 250° F when applied to the road surface

3 *Construction Methods* In general they are similar but vary in details In all methods a suitable existing base of stone, slag, shale, gravel or other well compacted material is selected. It should be free from holes but may be slightly irregular in contour Variations in regularity of ½ to ¾-inch in the base may be tolerated. The base must be thoroughly cleaned of all foreign substances by brooms, blowers or other effective equipment.

PENNSYLVANIA METHOD

1 Scarify and shape old base adding additional stone if necessary or merely sweep base clean of dust and dirt if it is already of proper cross section and grade, and well solidified.

2. Spread layer of loose stone to such depth that when compacted it will be 2 inches in thickness.

3. First application of bitumen at the rate of 0.5 to 0 75 gallon per square yard.

4 Blade surface to proper cross section

5. Continue blading to maintain desired cross section until surface begins to set.

6. At the end of 4 or 5 days after the surface has set apply about 0.25 gallon of bitumen followed by a light cover of stone chips Traffic is permitted to operate during the entire construction

Raking may be substituted for blading but it is not as satisfactory.

Rolling with a 5 to 10 ton roller is desirable The rolling may follow immediately after the first application and blading

Rolling gives good results even after the mixture of bitumen and stone can no longer be bladed

Rolling of the seal coat is also effective in securing quick compaction and reducing loss of chips

As in all surfacing of similar character, operations are simplified if traffic is kept off the road during construction.

TENNESSEE METHOD

Although patterned after the Pennsylvania method, the actual procedure varies somewhat from it and also from place to place within that state.

1. The base is thoroughly cleaned and must be well compacted over a period of several months previous to bituminous surfacing.

2. First application of bitumen is made at the rate of 3 to 4 gallon per square yard.

3 Stone chips are spread at the rate of 10 to 20 pounds per square yard and immediately bladed with a light one-man blader

4 Blading is continued until the bitumen sets up

5. The surface is kept open to traffic from 4 to 15 days. During this period the bitumen partially penetrates the base, and weak spots and pot holes developed by traffic are patched Patching is done by a mixture of bitumen and stone placed in the holes and tamped.

6. The second application of bitumen is made at the rate of .3 to .5 gallon per square yard.

7. This is immediately covered with stone at the rate of 50 to 80 pounds per square yard.

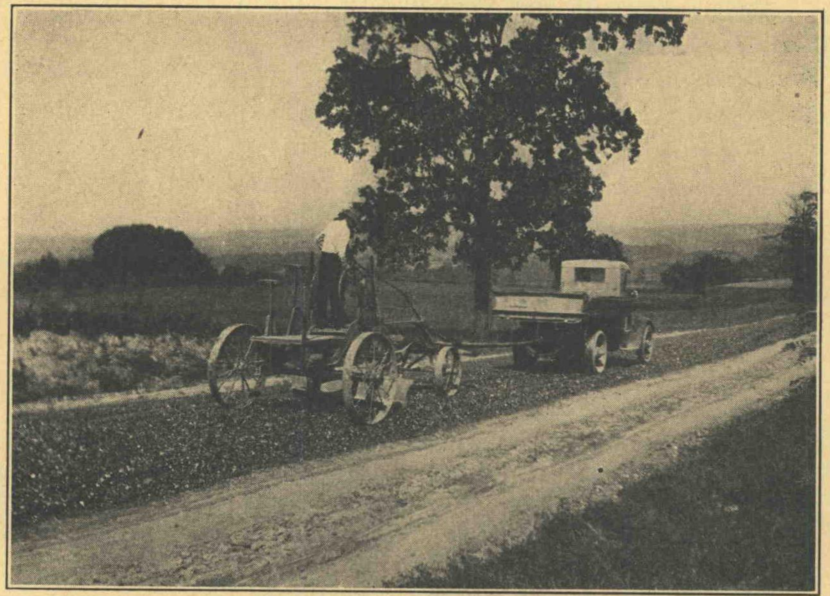

Figure 77. Mixed-in-Place Bituminous Surface. Coarse Aggregate Type II. Blading to Obtain a Regular Contour. The Blade Is Set At a Greater Angle with the Road Than in Mixing (Figure 37), and the Mixture Is Not Turned Over.

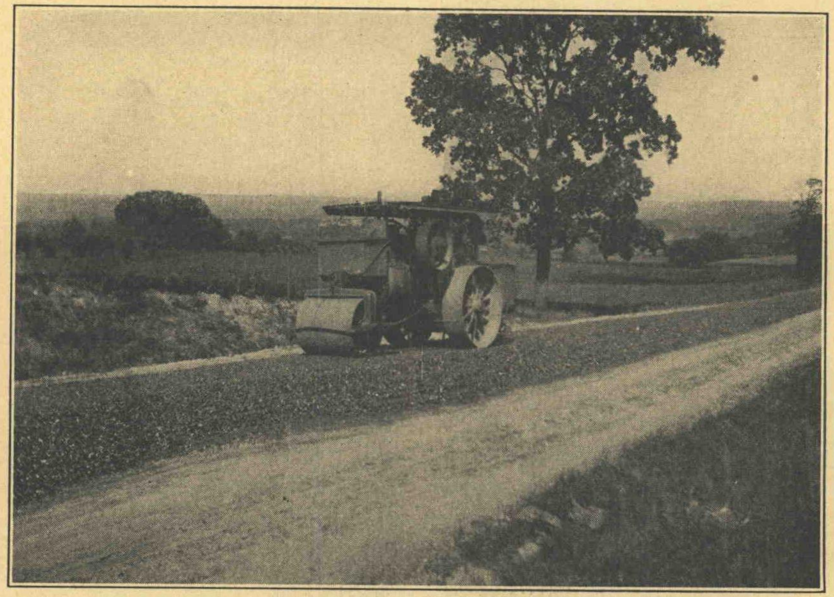

Figure 78. Mixed-in-Place. Bituminous Surface, Coarse Aggregate, Type II. Final Compaction with Power Roller

8 The second application of bitumen and stone are bladed and dragged for 2 or 3 days until the volatile matter has evaporated and the mixture becomes too stiff for blading

9 The surface is rolled with a 3 to 5 ton roller. The rolling is continued each succeeding day until the surface is thoroughly hard and consolidated Seal coats are not customary practise.

INDIANA METHOD

1 Scarify and shape old base, if necessary or merely sweep it clean of stone and dirt.

2. Spread layer of stone to the desired thickness (2, 2½ or 3-inch loose, use 1¼ to 2-inch commercial size stone, 1-inch loose use ¾ to 1¼-inch stone)

3 Roll stone lightly

4 First application of bitumen is applied at the following rates per square yard for different depths of materials: .5 gallon for 3-inch loose stone, .4 gallon for 2, and 3 gallon for 1-inch.

4 Blade immediately only moving the top layer (about 1-inch).

6 Roll immediately after blading and again after 2 days.

7. Fill surface voids with stone chips applied sparingly.

8. Second application of bitumen, after first application has set, is applied at the rate of about 2 gallon per square yard

9. Drag surface, preferably with light drag.

10. Roll chips into surface after dragging

11. The third application of bitumen after about 2 weeks is applied at the rate of about .15 gallon per square yard

12 Cover sparingly with chips and roll thoroughly

It has been found that a prime coat of bitumen, applied the year before the mixed-in-place surface is put down, may be advisable on some gravels and shales

3 *Maintenance Methods.* Maintenance should begin immediately after the completion of the surface

Pot holes are patched with pre-mixed material consisting of bitumen and stone Raveled and lean spots are patched with an application of bitumen and chips. A seal coat over the entire surface may be advisable the second year, for the more open and lean surfaces. For this 25 to 50 gallons of bitumen is used and 30 to 40 pounds of ¾-inch chips

A second mixed-in-place surface may be placed on the initial surface after one or several years as conditions may indicate.

4. *Construction Costs* In Pennsylvania this type of surfacing costs on the average $2500 per mile for a 16 foot width and depth of 2 inches.

In Tennessee the average cost is given as $2000 per mile for an 18 foot width and depth of 1-inch

In Indiana the cost is stated to be $3500 to $5000 per mile for a width of 20 feet and thickness from 1 to 2½ inches

5 *Maintenance Costs* The average maintenance cost for surface repairs in Pennsylvania is given as $405 per mile In Tennessee, surface maintenance exclusive of retreatments, is stated to be $300 per mile Maintenance costs in Indiana are not available

6 *Service* The highway officials of Pennsylvania claim that this surface is not economical for more than 500 vehicles per day for a section having a 4-inch stone base and a 2-inch mixed-in-place top Several roads of this type in that state are carrying more than 500 vehicles per day

In Tennessee the traffic ranges from 400 to 1000 vehicles per day including several bus lines Figures are not available on the Indiana transport conditions

Considering the traffic which surface treatments of the dual application and mixed-in-place gravels are carrying, there is good reason to believe that these thicker surfaces of crushed stone and bitumen, which approach bituminous macadam in quality should give even better service

Due to the blading process in construction mixed-in-place surfaces have excellent riding qualities On account of the coarse chips or stone at the surface they do not become slippery in wet weather For the same reason they are not easily displaced into ridges under traffic.

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PREMIXED BITUMINOUS SURFACE LAID COLD

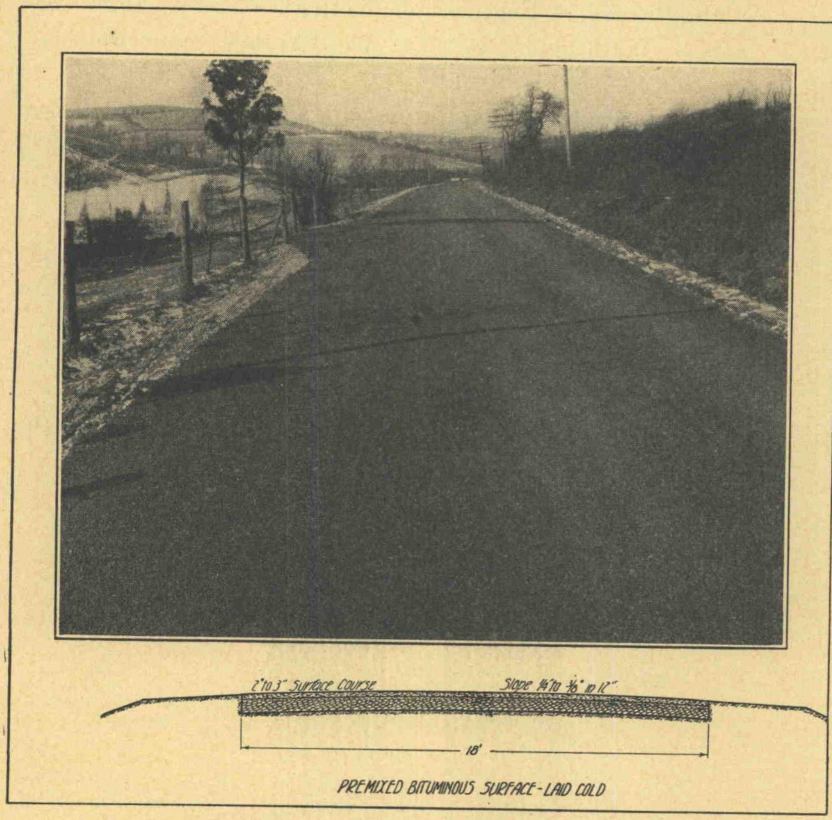

Figure 79. Tarmac in Pennsylvania

Materials

Coarse aggregate, Type I.
Stone, slag or gravel and bitumen.
Fine aggregate, Type II.
Sand, dust and bitumen.

Service

Type I 1000 to 2000 or more vehicles.

Type II no data.

Cost per mile

Type I $8,000 to $12,000 (estimated).

Type II $7,000 to $10,000 (estimated).

Examples in Type I

Maryland, Penn., Delaware, Texas.

Examples in Type II

Florida.

1. *General Description.* With the exception of some patented products pre-mixed surfaces, which are laid cold, are new. During 1926 and 1927 interest in the possibilities of this type became evident. The surfacing is primarily an intimate mixture of aggregates and bitumen. Although the actual mixing may be done with hot or cold materials the resulting mixture must be such that it can be laid at normal atmospheric temperatures.

Type I uses coarse aggregate and may or may not require a seal coat It is similar to asphaltic concrete, coarse aggregate type.

Type II uses a fine aggregate and is similar to sheet asphalt in composition

On porous bases a prime coat of bitumen may be advisable A thin course of penetrated stone or mixed binder course may increase the stability of Type II.

2. *Materials* For Coarse Aggregate Type I, the aggregates are a durable crushed stone, slag or gravel. The bitumens are a cut-back tar or asphalt. Sand may also be added to obtain a dense mixture Hydrated lime is added in the patented product known as " Amiesite " The amount of sand, if used, will depend upon the hardness of the coarse aggregate. A soft stone which fractures readily will require less sand than a hard material There should be enough material below the 1/4-inch screen to sufficiently fill the voids One part sand to 3 parts stone is recommended by one producer of tar.

Cold cut-back tar and asphalt have been used Hot asphaltic cement and a liquifier are used in Amiesite mixtures.

Materials for Amiesite

This patented pavement is usually laid in two courses to a total compacted thickness of 2 inches, the bottom course 1½ inches and the top course ½-inch

The following limitations should not be exceeded for Amiesite:

Materials	Bottom layer Maximum percentage	Top layer Maximum percentage
Broken rock	86 to 92	83 to 90
Liquifier	0 4 to 1 0	0 4 to 1 0
Asphalt cement	4 to 6	5 to 7
Hydrated lime	0 5 to 1 0	0 5 to 1 0
Mineral filler	0 to 6	0 to 8

Broken rock for the bottom layer must be dry, clean and durable It is required to pass a 2-inch circular opening and be retained on 3/8-inch screen with not more than 15 per cent retained on the 1½-inch opening For the top layer all stone must pass the 5/8-inch circular opening and be retained on an 8-mesh screen

The liquifier is a mineral oil, both kerosene and naphtha have been used.

The asphaltic cement has a penetration of 65 to 110 at 77° F.

Hydrated lime is required to meet the A. S T M standard specifications

The mineral filler is clean, crushed rock screenings, 90 per cent of which will pass an 8-mesh sieve

The aggregate for the squegee coat, if used, has 90 per cent passing the 16-mesh sieve, and 75 per cent retained on the 50-mesh sieve, the bitumen is a cut-back asphalt applied cold having a penetration of 55 to 100 at 70° F.

The mixtures using tars, are aggregate and a tar similar to that used in cold-patch work This is specified in the U. S Government Master Specification "Tar for Use in Repair Work" as TR-1-25 and TR-2-25. TR-1-25 has a specific viscosity (Engler at 40° C) of 35 to 60, TR-2-25 has a specific viscosity of 60 to 80

The aggregates are specified as "¾-inch broken stone and sand, about one part sand to three parts broken stone" The proportions recommended are 12 gallons of cold-patch tar to 27 cubic feet of total aggregate Three-quarter-inch stone in some states is a uniformly graded product all of which passes the 1¼-inch screen and is retained on the ⅝-inch screen If slag is used as coarse aggregate a larger proportion of bitumen is usually required This is due to the porosity of the average commercial clay

The bitumen for the seal coat is the same as for the mix Coarse, clean sand is used for cover

On some small projects in Ottawa, Canada, asphalt in the form of a liquid cold patch material was used with crushed stone The quantity of asphalt used varied from 8 to 11 imperial gallons per ton of stone.

Materials for Type II Fine Aggregate Type

The object is to use material which will produce, when complete in place, a surface having the characteristics of hot mix sheet asphalt. The gradation of the fine aggregates is said to be similar to the dust used for filler The bitumens used are asphaltic cements and flux Few definite data are available on the exact proportions

3 *Construction Methods* In both Type I and Type II the aggregates and bitumen are thoroughly mixed in a standard concrete mixer, a pug mill or by hand Machine methods are preferable The aggregates should be clean and dry Whether or not heating of the bitumen is necessary will be governed by its consistency If the bitumens contain volatile oils a sufficient time, after mixing, may be required for them to evaporate Three or four days are usually sufficient Many of these mixtures may be stored for several months before being laid as surfacing

A prime coat of 1/5 to 1/4 gallon of liquid tar or asphalt may be advisable on previously untreated surfaces which are porous or unstable at their surface

The coarse aggregate types are laid in two courses to a compacted depth of 2 inches The second course is the seal and may be from 1/8-inch to 1/2-inch in thickness depending on the type of seal coat used

The construction operations for Type I are:

1 Clean the base thoroughly
2 Spread the pre-mixed material on the base from dump boards or other suitable devices
3 Rake to a smooth regular surface.
4. (A device for obtaining a regular surface after raking is desirable)
5. Roll with 10 ton roller for hard stone on a firm thick base Use a lighter roller for soft stone and a less stable base
6. Apply after 7 days a squegee coat of bitumen and sand or stone chips for cover, and roll again
7. Or spread mixed seal coat, rake and roll

The construction methods for Type II consist of suitable dumping, spreading, raking and rolling

The surfaces may be laid for one half the roadway width, allowing traffic on the other half. Although not prohibitive it is advisable to keep traffic off the newly laid surface for 24 hours until some of the lighter oils have evaporated and the surface is less easily displaced

4 *Maintenance Methods* The usual procedure is to patch surface breaks with pre-mixed surfacing mixture Seal coats may be required at varying periods if the surface is too open or tends to ravel under traffic

5 *Construction Costs* Little reliable cost data is available. The bid prices are usually in competition with pre-mixed hot bituminous surfaces or bituminous macadam

The actual construction costs should be less than for hot mixes, because less expensive plant equipment is required, and more frequent plant set-ups along the construction work may be made at a smaller cost per move

If the surfacing is mixed at a central plant and hauled long distances by rail, this will represent a considerable item in the total cost

6 *Maintenance Costs* Except for Amiesite the surfaces are so new that costs over a period of years are not available. On Amiesite

Figure 80. Premixed Bituminous Surface. Laid Cold. Dumping on Dump Board, Placing and Spreading. Pennsylvania

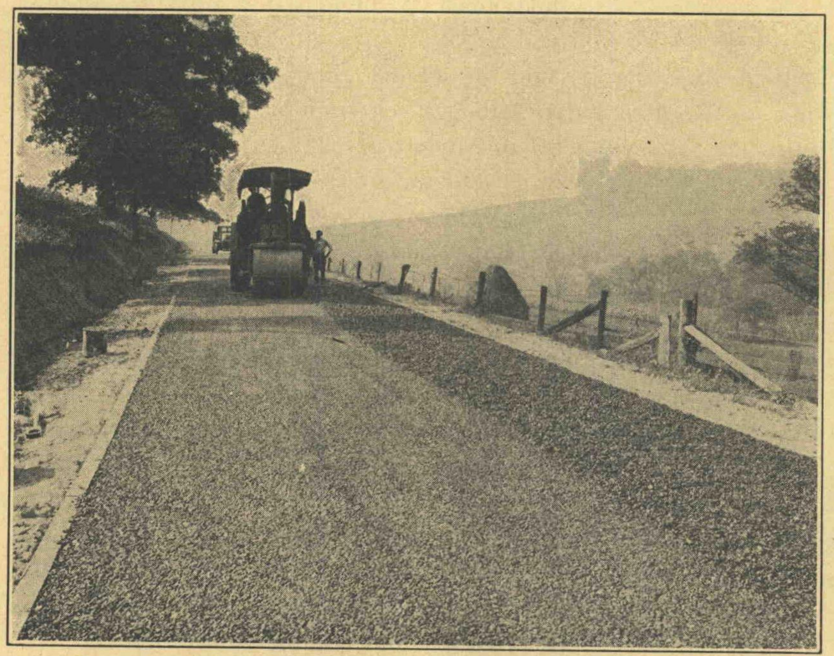

Figure 81. Initial Compaction with Heavy Roller on Premixed Bituminous Surface Laid Cold. Pennsylvania

the maintenance costs are said to be low, and comparable with standard hot mixes on similar bases

7 *Service.* Because of better control of aggregate gradation and bitumen content, a more uniform surface mixture is obtained than with the mixed-in-place bituminous surfaces This should result in better service except that with present construction methods the riding qualities of pre-mixed types are not so good The traffic capacity, however, should be equal to or greater than mixed-in-place types of equal thickness and on similar bases

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NATURAL ROCK ASPHALT SURFACES

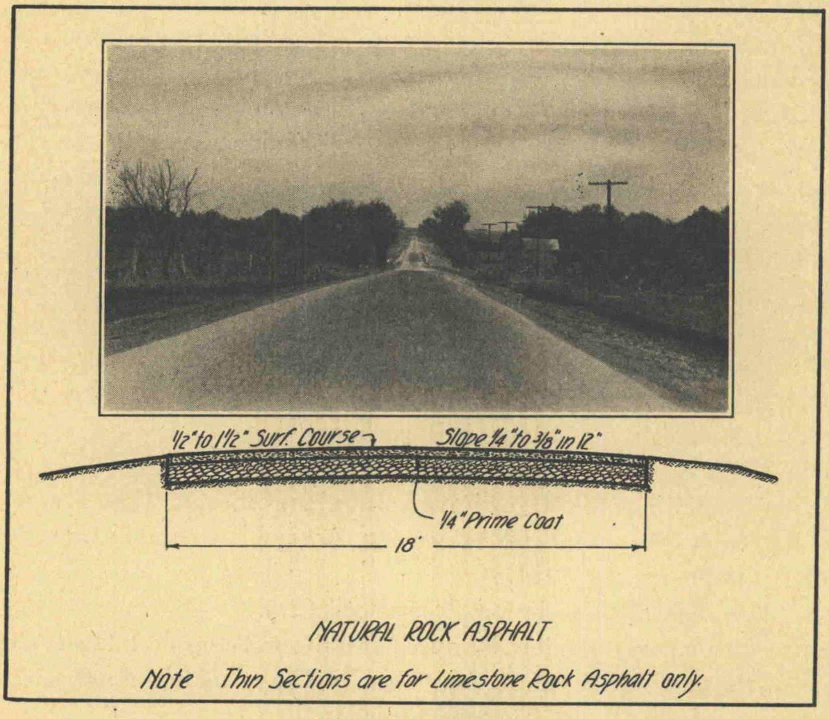

Figure 82. Texas

Materials	Cost per mile 18 feet wide
Prime coat of asphaltic oil or tar. Surface course natural rock asphalt with or without flux.	Construction, ½ inch to 1 inch thick. $3500 to $6500. Maintenance, $200 to $400.

Service	Examples in
1000 to 2000 or more vehicles per day.	Texas, Georgia, Tennessee, Kentucky, Florida, Indiana, Ohio.

1. *General Description.* The base to be treated should be sufficiently substantial to warrant the expenditure necessary for this type of surfacing.

The surfacing work consists of first treating or priming the base course, if previously untreated, with asphaltic oil or tar. This is allowed to penetrate and is then covered with a loose layer of natural rock asphalt laid at atmospheric temperature.

After being spread it is rolled with a power roller. The surface is then complete except for a light seal coat which is a meal or fine mixture of natural rock asphalt in the case of the Uvalde rock asphalt.

2. *Materials.* There are two principal classes of this material.

Class I. Limestone which has been impregnated by nature with asphalt.

Class II. Sandstone which has been coated or impregnated by nature with asphalt.

These materials have been used in Europe for the past 30 years The best known deposits in the United States are those in Texas and Kentucky The material is also found in Alabama, Oklahoma, California and Utah.

Class I. Uvalde rock asphalt is quarried and prepared for road use near San Antonio, Texas As quarried, the impregnated limestone contains from 9 to 12 per cent of pure bitumen, and from 88 to 91 per cent of limestone. The material as received from the mines is first run through a hammer mill pulverizer with the grates spaced about ½-inch clear. This gives a grading from ½-inch and down For a thickness of 1-inch and more compressed surface, ¾-inch size and down may be used The state of Texas requires in its specifications ¼-inch material for light surface treatments. Sufficient fine material (passing ⅛-inch screen) is screened out for use as a seal coat. The pulverized material is placed in either a drum or pug mill mixer and hot asphaltic oil (asphaltic content of 100 penetration, not less than 50 per cent by weight) is sprayed on the rock asphalt as it cascades About 4 gallons of fluxing oil is used per 2000 pounds of Uvalde rock asphalt. The flux is necessary because of the hardness of the natural asphalt with which the limestone is impregnated The rock as received from the mines may be crushed and fluxed on the construction work by the road contractor instead of by the producer.

Class II Kentucky rock asphalt, os obtained near Bowling Green, Kentucky, is a bituminous sandstone Hubbard says, "In bituminous sandstones, while the bitumen permeates the natural rock it appears to coat the mineral particles rather than to impregnate them."

The rock is hard and harsh and will scratch glass. As quarried it runs from 3 to 10 per cent bitumen and the remainder is sharp grained silica sand fairly well graded, although not as well graded as sheet asphalt paving mixture. The rock containing varying percentages of bitumen is first crushed at the plant. It is sorted, mixed and analyzed until the final product contains the per cent of bitumen required by specifications This is usually from 7 to 7½ per cent State highway specifications vary in their requirements from a minimum of 5 9 to a maximum of 9 per cent of bitumen

The state of Kentucky requires that 95 per cent shall pass the ¾-inch screen and 20 per cent shall be retained on the ¼-inch screen, and that a uniform percentage of bitumen shall be maintained in the rock asphalt used on each contract. This is from 5 9 to 7.65 per cent.

Analysis of typical rock asphalts of asphaltic limestone and asphaltic sandstone follow:

ANALYSES OF NATURAL LIMESTONE ROCK ASPHALTS

Percentage

	Utah	Oklahoma	Alabama	Texas
Bitumen .	12 to 40	3 47 to 14 53	3.55 to 9 90	3 64 to 14 47
Limestone .	88 to 60	90 10 to 75.53	95.24 to 89.23	90 44 to 84 16
Magnesite, Quartz, Clay, etc)	included in the 88 to 60	6 43 to 9 94	1.21 to 0 87	5 92 to 1 37

NOTE—The percentage and quality of the bitumen vary a little in each quarry

ANALYSES OF NATURAL SANDSTONE ROCK ASPHALTS

Percentage

	Alabama	California	Kentucky	Missouri
Bitumen	3 7 to 11 6	4 0 to 18 6	3 0 to 8 4	3 7 to 8 1
Sandstone	87 4 to 87 1	91 7 to 80 1	95 9 to 91 4	89 5 to 89 8
Limestone, Magnesite, Clay, etc	18 70 to 16.25	4 3 to 1 3	1 1 to 0.2	6.8 to 2 1

	Oklahoma	Texas	Utah
Bitumen	6 6 to 10 4	4 0 to 11 6	4 1 to 7.9
Sandstone	88 4 to 88.5	88.8 to 88 3	87 0 to 87 9
Magnesite, etc	5 0 to 1 1	7.2 to 0 1	8 9 to 4.2

NOTE—The percentage and quality of the bitumen and of the sandstone differ in the above locations, and vary a little in each location

The foregoing tables are from J W Howard, consulting engineer on roads and pavements.

3. *Construction Methods.* The methods as specified by Texas for limestone rock asphalts and by Kentucky for sandstone rock asphalts are given.

LIMESTONE ROCK ASPHALT SURFACE

A cold mix is used and the compacted depth of surfacing, as specified, is laid from ¼ to 1½ inches in thickness.

1 The base course is thoroughly cleaned and all depressions filled with pulverized rock asphalt.

2. A prime coat of hot asphaltic oil is applied to the base in two applications. The first at the rate of 0 10 to 0 15 gallon per square yard is allowed to penetrate for 24 hours
3 The second priming application is applied at the rate of 0.10 gallon per square yard immediately before the crushed rock asphalt is spread.
4 The rock asphalt is spread on the road surface from dumping boards or it may be dumped on the surface provided each pile is entirely rehandled by shovels
5. The spread material is raked to a regular and smooth surface.
6. The surface is rolled with a power roller having a weight of 200 pounds per inch width of tread.
7 The rolled surface is patched as required with rock asphalt and rerolled.
8 A thin "meal" of rock asphalt, free from flux and passing the $\frac{1}{8}$-inch sieve is spread evenly on the surface and rolled This is the seal coat

In recent practise, finished surfaces 1-inch or more in thickness have been laid in two courses The first is a leveling up course about $\frac{1}{4}$-inch in compacted thickness A very light application of oil is applied between courses and the first contains less bitumen than the second

KENTUCKY ROCK ASPHALT SURFACE

A compacted thickness of $1\frac{1}{2}$ inches is customary for this material when laid on previously untreated bases of gravel or water-bound macadam. In Florida 1-inch has been used on lime rock base

When laid on a bituminous macadam, which has no seal coat, the customary depth of rock asphalt is 1-inch A prime coat of 1/10 to $\frac{1}{6}$ gallon of liquid asphalt or tar per square yard is recommended on old gravel bases After the prime coat has been applied or the bituminous macadam laid or if neither are used, the construction operations are:

1 Clean the base surface thoroughly
2 Spread the rock asphalt from suitable dumping boards or piles if entirely rehandled.
3. Rake to a smooth, regular surface which is free of all segregated areas of lumps All lumps over 1-inch in size are removed.
4. After being raked the loose surface is left exposed to the sun and air until it presents an oily appearance

5 The surface is rolled once with a 5 to 7 ton power roller.
6 Depressions and irregularities are corrected by raking and the addition of fresh material.
7. Rolling in a longitudinal direction is continued for 5 consecutive days with a 10 ton power roller
8 Cross rolling with a 5 to 7 ton tandem roller may or may not be required and continued until no roller marks appear.
9. Immediately before final rolling, the surface may be covered with limestone dust or Portland cement. Too much rolling at one time may result in waves, hair cracks or checking of the surface.

After the surface has been laid, raked and gone over once with the roller it may be made more regular by pulling a heavy drag or road plane over the surface This method has been used with success in Indiana.

4. *Maintenance Methods* are similar for both classes of material. They include for failures involving the base, a replacement of base with tamped gravel, macadam, sand clay or other materials similar to those in the original base This is brought up to the bottom of surface treatment. The patch is painted with tar or asphalt, and covered with tamped rock asphalt. If the area which has failed is of any appreciable size, say 10 square yards or more, a new surfacing or base may be necessary These materials are also suitable for patching laid-hot bituminous surfaces.

5 *Construction Costs* The price of Uvalde rock asphalt at the mines in Uvalde is given as about $3 50 per ton. The price of Kentucky rock asphalt at the plant in Bowling Green is given as about $9 00 per ton The cost of completed surfaces with either material is considerably affected by the freight charges from supply point to destination

Approximate prices for Uvalde rock asphalt surfacing in Texas are estimated as follows:

20c per square yard for ¼-inch thickness
35c " " " " ½-inch "
51c " " " " 1-inch "
65c " " " " 1½-inch "

Or about $2100, $3700, $5400 and $7860 per mile for an 18-foot width

Kentucky rock asphalt surfaces thinner than 1-inch are still in the experimental stage, according to the producers They estimate a ¾-inch surface should cost less than $6000 per mile for a width of 18 feet

The actual cost of laying these "cold" materials is less than for hot mixes

6. *Maintenance Costs.* In Texas, Uvalde rock asphalt surfacing 1-inch in thickness is carrying over 1500 vehicles daily for less than $300 per mile for maintenance. Surfaces ½-inch in depth are giving service about equal to that of dual surface treatments in that state.

The annual maintenance cost for Kentucky rock asphalt surfaces does not exceed $300 per mile per year for traffic of 1500 vehicles or more

7 *Service* These surfaces are simply and quickly laid and are easily repaired They are sufficiently plastic to adjust themselves, without serious cracking, to irregularities of the base course From information they are giving good service for traffic of from 1000 to 2000 vehicles per day To justify the initial cost of these surfaces, it is customary to use them only on substantial bases whose traffic capacity may be estimated with reasonable accuracy.

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MODIFIED OR PUDDLE BITUMINOUS MACADAM COLD APPLICATION

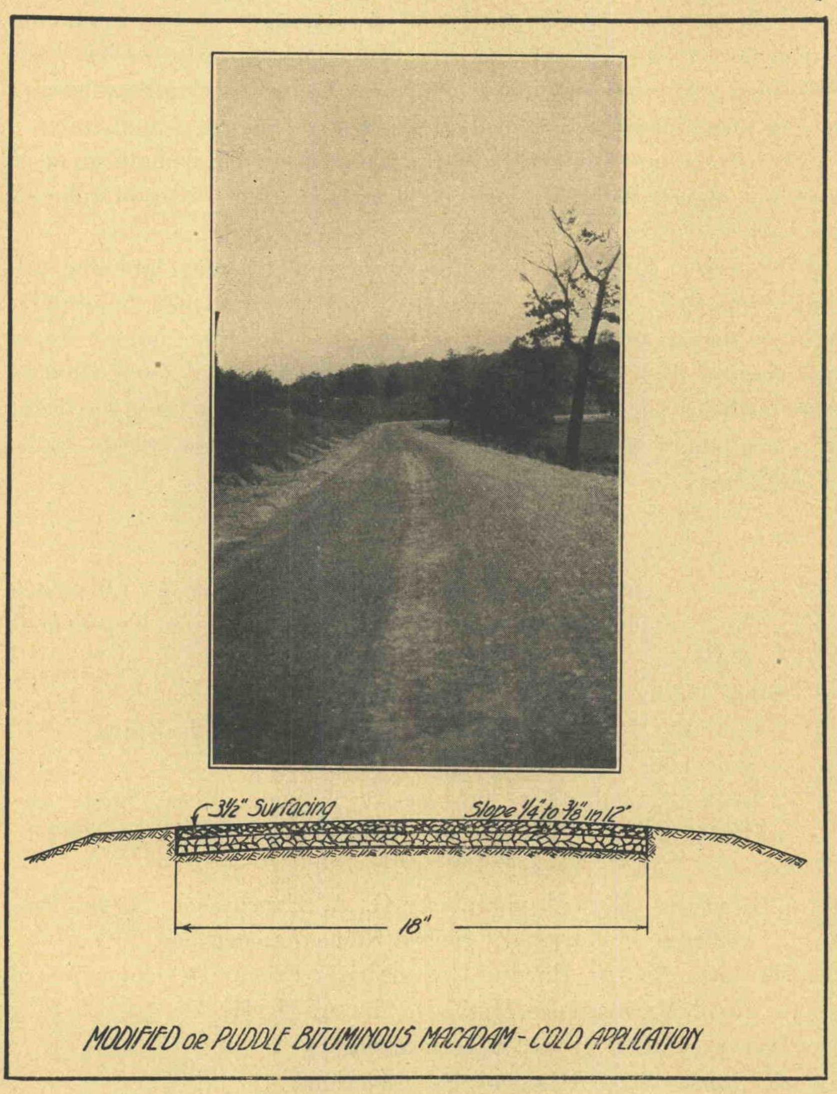

Figure 83. West Virginia

Materials	Cost per mile	Service	Examples in
Crushed stone. Bitumen (cold).	Construction $7500. Maintenance $250 to $500.	100 to 2000 vehicles per day.	West Virginia. Virginia.

1. *General Description.* As constructed in West Virginia the base course may be hand knapped stone, crushed stone, shale or gravel, which have been well compacted by traffic for a number of years. Originally a hard stone was used for the base and surface course

but recently serviceable base and surface have been built with local soft sandstone.

In general, the surface course is constructed in the same manner as a water-bound macadam except that cold bitumen is used for "puddling" instead of water. A seal coat is usually advisable. The total depth of surface course is from 3 to 4 inches This surface is specified by West Virginia as "Modified Bituminous Macadam" and a similar type in Virginia is named "Cold Bituminous Bound Macadam" An excellent discussion of this type by B E. Gray, Division Engineer of West Virginia appears with this report.

2. *Materials* The mineral aggregate for the bituminous surface is graded to utilize the output of the crusher.

WEST VIRGINIA SPECIFICATIONS FOR AGGREGATE

Coarse Stone, 95 per cent passes the 3-inch screen and 85 per cent is retained on the 1¼-inch.

Chips, 95 per cent passes the 1½-inch screen and not more than 15 per cent passes the ¾-inch screen

Screenings, 95 per cent passes the ¾-inch screen and the total passing the ¼-inch screen is 40 to 80 per cent.

The stone is specified to have a percentage of wear of not more than 5, but sandstone as used by Mr Gray may be much softer The size of chips for soft stone is ½ to 1¼-inch

VIRGINIA SPECIFICATIONS FOR AGGREGATE

Coarse stone all passes screens having 4-inch perforations and is retained on screens having 2½-inch perforations.

Chips are from ½ to 1-inch in size for void filling and keying the coarse stone.

For cover, chips 1-inch to ¾-inch are specified.

For seal coat, chips from ½ to ¾-inch

Percentages of wear, not more than 5.

BITUMENS

The bitumen commonly used for first and second applications is a cold tar or a cut-back asphalt. Cold or hot bitumens are specified for the seal coat.

The State Road Commission of West Virginia specified an asphalt having penetration of 150 to 200 (25° C, 100 g 5 sec) and two grades of tar having a specific viscosity (Engler 50 cc at 40° C) of 8 to 35. These are the same as used by Mr. Gray who specifies in addition a cold asphalt having a specific viscosity (50 cc at 50° C) of 18 to 30.

The State Highway Department of Virginia specifies a road oil for cold application having a specific viscosity at 50° C. of 30 to 60, a cold tar with specific viscosity at 50° C. of 10 to 20 and another tar with specific viscosity at 50° C. of 5 to 15.

3. *Construction Methods* The object of the methods is to build a macadam surface which is bonded by bitumen applied cold, rather than by water, and further, to use a smaller amount of bitumen for a given depth of surface than is used for bituminous macadam The methods are a combination of water-bound and bituminous macadam construction All bases must be thoroughly cleaned by sweeping before work on the bituminous surface course is commenced

WEST VIRGINIA METHODS

1. Spread a layer of loose, coarse stone from dump boards or piles along the roadside The total depth of loose stone is one and one-third times the required thickness of proposed finished surface.

2. Roll with 10 ton, three wheel power roller until stone is compacted to a firm and even surface

3 Spread screenings, from dump boards or piles along the roadside, in thin even layers.

4 Roll each layer of screenings, until voids in coarse stone are filled and thorough compaction is obtained

5. Sweep the surface clean of loose screenings

6. Test surface with 10 foot straight edge, correcting all irregularities and segregated pockets of fine or coarse stone.

7. Reroll and resweep.

8. Apply first application of bitumen at the rate of 0.7 to 0 8 gallon per square yard.

9 Spread immediately a uniform even layer of stone chips passing the 1½-inch screen and with 85 per cent retained on the ¾-inch screen.

10 Roll and broom The addition of small amounts of chips, brooming and rolling are continued until the surface is regular and well compacted

11 After 24 hours sweep the surface clean.

12 Apply second application of bitumen at the rate of 0 5 to 0 6 gallon per square yard.

13 Spread, broom and roll additional chips in small quantities at a time until regular and uniform surface results

The total amount of bitumen does not exceed 1.35 gallons per square yard

When softer stone is used the methods described by Mr Gray have been successful in north eastern West Virginia It should be noted that a thick layer of screenings is spread on the surface during the initial rolling This is to prevent undue crushing of the soft sandstone.

VIRGINIA METHODS

1 Spread coarse stone from dump boards or piles.

2. Roll coarse stone with 10 ton roller to a firm, even surface

3 Spread stone screenings over surface.

4 Roll, screenings (without water) until voids between stone are filled and remove excess screenings with brooms

5 Apply first application of bitumen at rate of ¼ gallon per square yard.

6 Spread stone chips (½ to 1-inch in size) at rate of about 25 pounds per square yard, or enough to cover bitumen

7 Roll the surface thoroughly.

8 Apply second application of bitumen at rate of ½ gallon per square yard.

9 Spread stone chips (¾ to 1-inch in size) at rate of 30 pounds per square yard.

10 Roll thoroughly for several days until surface is compact and hard.

11. Apply third application of bitumen at rate of ¼ gallon per square yard.

12 Spread stone chips (½ to ¾-inch size) at rate of 25 to 30 pounds per square yard.

13 Roll thoroughly and open to traffic Rolling is continued for several days thereafter.

4 *Maintenance Methods* They are similar in all respects to those for bituminous macadam, hot application and include patching and retreatments at periodic intervals. These consist of about 0 25 gallon of bitumen per square yard covered with stone chips

5. *Construction Costs.* In West Virginia, using soft sandstone as aggregate, the average cost for a $3\frac{1}{2}$-inch depth of surface is \$7500 per mile 18 feet wide. Since these surfaces use less bitumen than

Figure 84. Puddle Macadam. Spreading Sandstone Top Course

bituminous macadams of equal depth, a saving of at least 20 per cent is claimed under the cost of that type, for bitumen alone.

6. *Maintenance Costs.* The average annual maintenance costs, as given by Mr. Gray, have not exceeded \$50.00 per mile for patching;

and less than $200 per mile for surface treatments as averaged over a three-year period.

7. *Service.* The traffic on these surfaces in the mountains of West Virginia has ranged from 500 to 3000 vehicles per day with a daily average of 500 to 800. The foregoing is for soft sandstone aggregate. The harder stone should show a greater capacity.

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BITUMINOUS MACADAM HOT PENETRATION METHOD

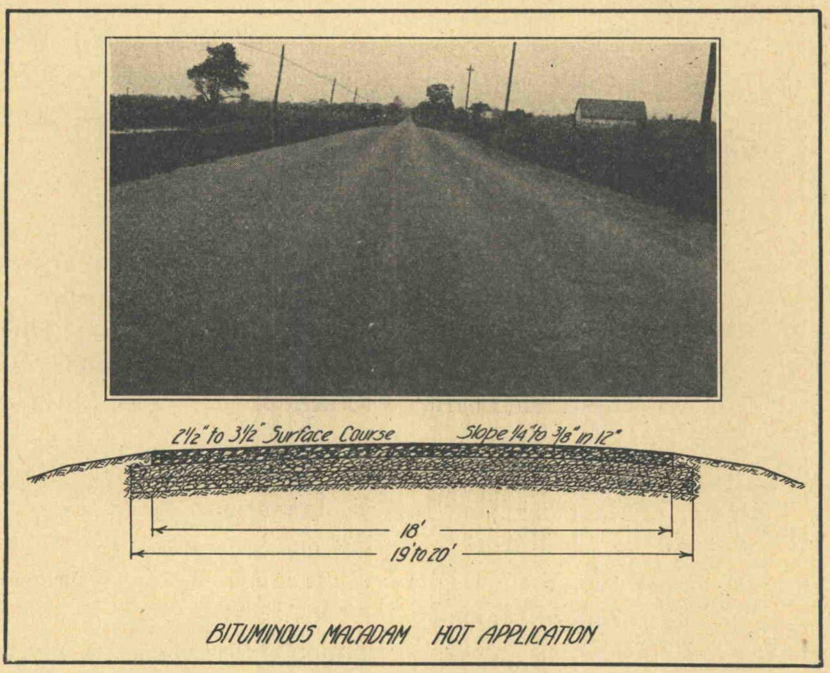

Figure 85. Ohio

Materials	Cost per mile	Service	Examples in
Crushed stone, or crushed slag. Bitumen.	Construction, $9,000 to $17,000. Maintenance, $150 to $600.	1000 to 2000 vehicles per day.	New England States. New York. Pennsylvania. Ohio. Indiana. Tennessee. Virginia.

1. *General Description.* Bituminous penetration macadam has been used in the northeastern part of the United States for more than 13 years. The agregate is usually crushed stone and the bitumen a hot asphalt. Hot tar is not as extensively used. Broken stone or slag is commonly used for the base course although this type has been built on lime rock and gravel bases.

The surface is a stone macadam bonded together by bitumen and by the interlocking of the stone particles.

There are three principal operations in its construction.

First. The spreading and rolling of a layer of coarse stone, the voids of which are partially filled with hot bitumen.

Second The spreading and rolling of a layer of keystone, smaller in size, than the coarse stone. The keystone by the process of rolling still further fills the spaces between the coarse stone.

Third A light application of bitumen followed by a cover of stone chips This forms the seal coat. The seal coat is rolled

2 *Materials* The maximum size stone required varies with the proposed depth of the course and with the hardness of the stone.

This size is about equal to, or ¼-inch larger than the proposed compacted thickness of the finished course.

Specifications for hard trap rock in New England require the following:

For first or penetration course, all to pass the 2½-inch ring and retained on the 1½-inch ring, for intermediate or keystone passing the 1-inch and retained on the ⅝-inch, for the cover or seal coat passing the ¾ or ⅝-inch and retained on the ⅜ or ¼-inch.

In Indiana, the stone or slag for the first or penetration course must all pass the 4-inch screen and be retained on the 1-inch

The variation in size requirements by different states is due partly to variations in hardness of stone, and to an attempt to use the entire output of the crushing and screening operations

The bitumen for the penetration method is generally an asphaltic cement with penetration of from 80 to 100. Some specifications admit higher penetrations, 100 to 120

Practise as to bitumen used in the seal coat varies In place of using the same penetration as in the first application, a more fluid asphalt is sometimes used with penetration as high as 130

The total amount of applied bitumen will vary with finished compacted thickness It will be about one gallon (or slightly less) per inch depth of finished thickness The first application for thicknesses of from 2½ to 3 inches will range from 1 50 to 1 75 gallons per square yard

Most specifications require but one seal coat applied at the rate of from 0 50 to 0 75 gallon per square yard. When two seal coats are specified the first is applied at about two times the rate of the second, the total for the two ranging from 1 00 to 1 50 gallons.

Some typical specifications for aggregate and bitumen are given

BUREAU PUBLIC ROADS

	Percentage
Coarse Stone	
Passing 3-inch screen	95-100
Retained on 1½-inch screen, not less than	95

	Percentage
Intermediate Stone	
Passing 1½-inch screen	95-100
Passing 1-inch screen	25- 75
Passing ¾-inch screen, not more than	15
Chips	
Passing ¾-inch screen	95-100
Passing ½-inch screen	60- 75
Passing ¼-inch screen, not more than	15
Maximum per cent of wear for limestone, 5	
Maximum per cent of wear for sandstone, 4	
Maximum per cent of wear for slag, 15	
Penetration of asphaltic cement (25° C 100 g 5 sec)	85-100
Softening Point of tar (Ring and Ball), 35-40° C	

American Society for Municipal Improvements Proposed October 1925

	Percentage
Coarse Aggregate	
Passing 2½-inch screen	95-100
Passing 1½-inch screen	0- 15
Intermediate Aggregate	
Passing 1½-inch screen	95-100
Passing 1-inch screen	25- 75
Passing ¾-inch screen	0- 15
Fine Aggregate	
Passing ¾-inch screen	95-100
Passing ½-inch screen	25- 75
Passing ¼-inch screen	0- 15

Maximum per cent of wear for stone, 6
Maximum per cent of wear for slag, 10
Penetration of asphaltic cement, 85 to 150
(The engineer to specify the exact penetration desired between these limits)

Rhode Island

The coarse stone all passes the 2½-inch ring and is retained on the 1½-inch
The intermediate stone all passes the 1-inch ring and is retained on the ⅜-inch
The chips (fine stone) is clean stone screening ⅛ to ⅜-inch in size
A hard trap rock is used
The bitumen is an oil asphalt of 85 to 100 penetration

Ohio

		Percentage
Coarse Aggregate		
"No 2"	passing 3-inch circular opening	95-100
	passing 2-inch circular opening	0- 10
Intermediate Aggregate		
"No 4"	passing 1-inch circular opening	95-100
	passing ¾-inch circular opening	75- 90
	passing ½-inch circular opening	25- 50
	passing ¼-inch circular opening	0- 10
	passing No 10 sieve	0- 5
Fine Aggregate		
	passing ½-inch circular opening	95-100
	passing ¼-inch circular opening	0- 50
	passing No 10 sieve	0- 10

Maximum per cent of wear, limestone Grade A-1, is 6
Maximum per cent of wear, limestone Grade A-2, is 7
Maximum per cent of wear, slag, is 15
Penetration of asphaltic cement, 85 to 100 or 100 to 120
For tar, float test at 50° C, 120 to 180 sec

3 *Construction Methods* They are simple and uniform as to procedure for the cases studied. Careful workmanship and intelligent inspection are so necessary for good results that surface failures can frequently be traced to their neglect.

The number of contractors and inspectors who are competent and willing to build penetration macadam appears to be decreasing.

Temporary side forms or permanent headers are not in general use, probably because of the extra expense. Indiana specifies temporary side forms All specifications require that the shoulder material shall not become mixed with the penetration stone. The several construction operations are:

First. Spread the coarse stone in a uniform layer from trucks, dump boards or rehandle from piles.

Second. Roll with a 10 ton roller until the stone is keyed together Rolling is stopped just before the voids are closed enough to prevent free and uniform penetration of bitumen The surface is next tested carefully with a straight edge Irregularities of surface and segregated areas of stone are corrected

Third Hot bitumen is applied at the rate of from 1.50 to 1.75 gallons per square yard; asphalt at from 300° to 250° F, tar at from 200° to 275° F. Even distribution is necessary. This is immediately covered with the intermediate or keystone, and while the surface is still hot.

In cold weather the higher temperature should be approached The road should then be thoroughly rolled before the bitumen hardens enough to prevent the intermediate stone from being readily pressed into it.

Low air temperature will necessitate an early completion of the rolling; high temperature a delayed completion.

Fourth. The surface should again be tested with a straight edge and irregularities corrected A seal coat of hot or cold bitumen is next applied and covered with the stone screenings Rolling is now continued. Good practise frequently requires this last rolling to continue for several days; five days in Indiana

A smooth riding surface can only be obtained by close attention to all details, careful checking of the surface with a straight edge and the correction of all surface irregularities. The blading or dragging of the coarse stone before the first application of bitumen may assist in securing a more regular surface, but segregation of coarse or fine material occasioned by this process must be avoided.

The modern bituminous macadam is more carefully constructed than those of 12 and 15 years ago. The class of bitumen and the gradation of aggregates are more suitable for increased service at lower maintenance costs.

4. *Maintenance Methods.* They include surface treatments, patching, scarifying, reshaping and the addition of new surfacing materials.

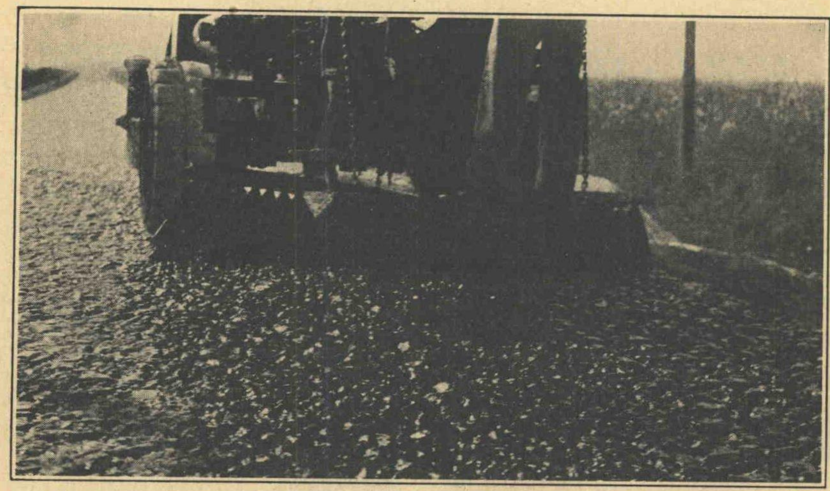

Figure 86. Bituminous Macadam. A Heavy Application of Bitumen to Coarse Stone

Surface treatments are applied at infrequent intervals. Some bituminous macadams have needed no retreatment in 12 years, in other places they are treated at varying intervals of from two to several years. Too frequent retreatments may result in a softening of the surface which will become displaced under traffic in hot weather. Coarse chips, spread and rolled into the surface may correct this condition.

A light application of cold bitumen may be applied to soften the surface. This is followed the next day with a heavy road plane. By dragging the planer over the softened surface, high spots are cut down, and low spots are filled. The excess materials loosened by the planer are deposited in an even layer on the shoulders. The macadam surface is thus smoothed and a bituminous surface is gradually built up on the shoulders The foregoing method is claimed to be successful on Connecticut highways.

Holes and depressions are remedied by cutting their edges into vertical sides and cleaning out all soft and loose material. The edges are then painted with bitumen and the holes are filled with stone and penetrated with bitumen or they are filled with a cold patch mixture of stone and bitumen This new material is then hand tamped or rolled with a power roller.

If the surface has, through neglect or otherwise, become badly broken up, it must be scarified, reshaped and rolled. This is followed by a new bituminous surface or other type of surfacing.

Present practise favors the salvaging of old macadams as a base rather than digging them out and wasting the materials, when a higher type of surfacing is scheduled for construction

5. *Construction Costs.* The surfaces are commonly built from 2 to 3 inches in thickness. The cost will naturally vary in a given locality with the depth The costs for 2½ to 3-inch depth varies from $9000 to $17,000 per mile for an 18 foot width

The cost of materials is an important factor but careful construction operations are imperative for good results Enforcement of rigid specifications appears to be reflected in higher bid prices.

6 *Maintenance Costs* The use of excellent materials and careful workmanship are rewarded by low maintenance costs Investigation has shown this cost, in Rhode Island, to be as low as $150 per mile per year Modern types of asphaltic bituminous macadam are maintained in Massachusetts for an average of less than $300 per mile per year The average for the old types and methods is more than $800.

The average for the cases studied is about $350 per mile per year These include retreatments.

7 *Service* The modern bituminous macadam is a smooth riding surface Some macadams have coarse chips at the surface which prevent skidding, others which have been surface treated with sand and bitumen have the appearance of asphaltic concrete and still others display the coarse aggregate stone used in the first layer, which takes the wear and prevents skidding. Some of these surfaces are not taking their capacity limit. Others are overloaded.

For average conditions, a good bituminous macadam will economically carry from 1000 to 2000 vehicles per day Capacity for trucks will vary with the strength of the foundations and base courses.

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PREMIXED BITUMINOUS SURFACES LAID HOT

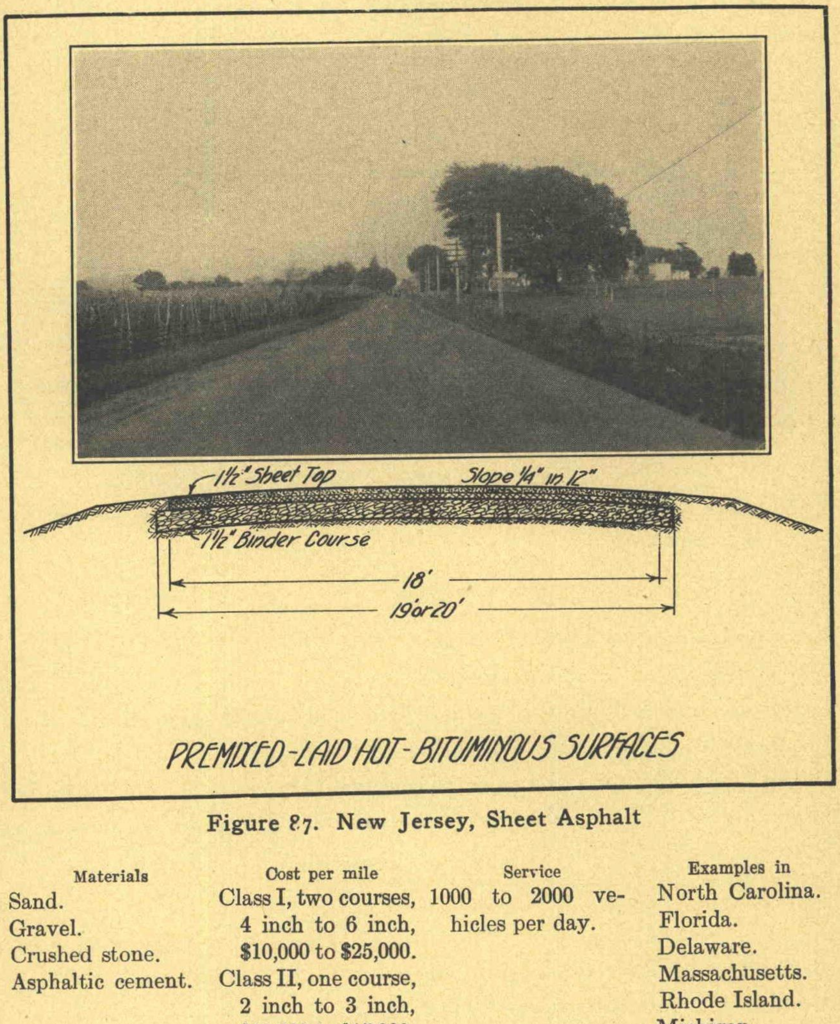

Figure 87. New Jersey, Sheet Asphalt

Materials	Cost per mile	Service	Examples in
Sand. Gravel. Crushed stone. Asphaltic cement.	Class I, two courses, 4 inch to 6 inch, $10,000 to $25,000. Class II, one course, 2 inch to 3 inch, $10,000 to $15,000. Maintenance, $50 to $300.	1000 to 2000 vehicles per day.	North Carolina. Florida. Delaware. Massachusetts. Rhode Island. Michigan. New Jersey. Ontario, Canada. Georgia.

1. *General Description.* Two classes of surfaces are here considered. Class I, in which the base and surface course are bituminous mixtures; Class II, in which the surface course is a bituminous mixture laid on a well compacted base of macadam, lime rock, or gravel. There is a wide variety of surfaces which vary principally in the kinds of aggregate and the percentages of bitumen. The construction and maintenance methods are similar for each type. The materials

used and the construction methods followed are also similar to standard specified practise as recommended for bituminous concretes and sheet asphalt by the Asphalt Association

The types considered are.

CLASS I

a Bituminous Mixtures, Both Courses Using Fine Aggregate
b Bituminous Mixtures, Both Courses Using Coarse Aggregate

CLASS II

c Bituminous Concrete, Fine Aggregate Type
d Bituminous Concrete Coarse Aggregate Type
e Sheet Asphalt or Bituminous Concrete, on Mixed Binder Course
f Sheet Asphalt or Bituminous Concrete, on Penetrated Binder Course

There are also variations in several of the foregoing types such as use and omission of prime coats, seal coats and squegee coats In fact these types could well be made the subject of a separate investigation.

2. *Materials.*

CLASS I

a Bituminous Concrete, Both Courses Using Fine Aggregate.

Materials for "Sand Asphalt" surfacing in North Carolina are local sand and asphalt for the base, and local sand, asphalt and filler for the top Timber side forms are left in place

For the base course all sand passes the ¼-inch sieve and is graded from coarse to fine. This is combined with bitumen by weight as follows:

Sand	91-94 per cent
Bitumen	6- 9 per cent

For the surface course sand, mineral filler and bitumen are combined to meet by weight the following:

	Percentage
Passing 10 mesh, retained on 40 mesh	10 to 40
Passing 40 mesh, retained on 80 mesh	22 to 45
Passing 80 mesh, retained on 200 mesh	12 to 30
Passing 200 mesh sieve	10 to 15
Total Bitumen	9.5 to 12

The proportions are varied within the limits designated by the engineer to suit the local aggregates In North Carolina the bitumen is asphaltic cement having a penetration (at 25° C, 100 g., 5 sec) of 30-40 In Florida the sand gradations and general specifications are similar to North Carolina, but the asphaltic cement specified has a penetration of 40 to 50 Actually in both states, the aim is to have the penetration as near 40 as practicable The base course is 3 inches thick and the surface course is 2 inches.

b Bituminous Mixtures, Both Courses Using Coarse Aggregate The materials are crushed stone, crushed or screened gravel, sand and bitumen, usually asphaltic cement A typical example is the recent work in Ontario, Canada There is little difference between it and " Black Base " in the materials used, although it has been called " Mixed Macadam "

The coarse aggregate consists of crushed stone, screened or washed, and screened gravel The materials must be free from dust and clay and be sound and durable

	Percentage
Passing 2-inch screen	95
Passing 1-inch screen	25-75
Passing ¼-inch screen	0

The fine aggregate is clean sand or stone screenings, hard, durable and free from clay, loam and other foreign matter

Requirements for gradation of sand when tested with laboratory screens and sieves:

Passing	Retained on	Percentage
¼-inch screen		100
¼-inch screen	10-mesh sieve	0-20
10 sieve	40 sieve	15-20
40 sieve	80 sieve	25-65
80 sieve	200 sieve	7-40
200 sieve		0- 6

The final mix of coarse and fine aggregate is required to show the following proportions

	Percentage
Passing 2-inch, retained on 1-inch screen	20-45
Passing 1-inch, retained on ¼-inch screen	25-45
Passing ¼-inch	25-35
Asphaltic cement	4- 6

The asphaltic cement has a penetration of 75 to 100 (77° F, 100 g, 5 sec). The exact 10 point penetration limits are set by the " Engineer "

After final compaction a seal coat is added The seal coat consists of from 1/6 to 1/2 gallon (imperial) of asphaltic oil or light tar or medium tar per square yard. The cover is stone chips, screenings, fine gravel or coarse sand applied at the rate of 1 cubic yard per one hundred square yards This type of surfacing in Canada is laid in two courses each having a depth of 3 inches, exclusive of seal coat

In Massachusetts, on Cape Cod, a bituminous concrete has been laid which utilized local crushed and screened gravel, stone, sand and stone screenings. It was originally laid in one course to a compacted depth of 4 inches Recent practise is two courses of 2 inches each The finished pavements exclusive of bituminous sealing mixture, must not vary in composition more than the limits given below for each course:

	Percentage
Passing 1-inch, retained on ½-inch circular opening	0-15
Passing ½-inch, retained on ¼-inch circular opening	20-45
Passing ¼-inch circular, retained on 10 mesh square opening	10-25
Passing 10 mesh, retained on 30 mesh square opening	4-12
Passing 30 mesh, retained on 50 mesh square opening	6-12
Passing 50 mesh, retained on 80 mesh square opening	6-12
Passing 80 mesh, retained on 200 mesh square opening	5-11
Passing 200 mesh	5- 8
Total stone content retained on 10 mesh sieve	50-70
Bitumen content . . .	6 5- 8

The seal coat is a light squeegee coat of bitumen applied hot to the top course and it is covered with "pea" stone The bitumen for the mixture and for the seal coat is an asphaltic cement having a penetration of 50 to 60 (25° C, 100 g, 5 sec.).

There are, of course, many other examples of the foregoing types of surfacing The examples given are considered typical

CLASS II

The following material requirements include typical examples of the standard types of hot-mix-bituminous surfaces with some variations. They are laid on existing compacted bases other than Portland cement concrete Many of these types are also laid on Portland cement concrete base

c. Bituminous Concrete Fine Aggregate Type

This consists of a mixture of broken stone, sand, mineral filler and asphaltic cement. These are combined to produce a mixture in the finished surface conforming to the following proportions:

	Percentage
Passing ⅝-inch screen, retained on ¼ inch . . .	12-25
Passing ¼-inch screen, retained on 10 mesh sieve .	10-20
Passing 10 mesh screen, retained on 40 mesh sieve	7-25
Passing 40 mesh screen, retained on 80 mesh sieve	11-36
Passing 80 mesh screen, retained on 200 mesh sieve	10-25
Passing 200 mesh sieve	7-11
Total bitumen	7 5- 9 5

The penetration of the asphaltic cement is given by Hubbard as 60 to 70 for the northern climate and 50 to 60 for the southern. The compacted thickness is usually 2 inches.

d Bituminous Concrete, Coarse Aggregate Type

This type of surfacing includes a bituminous concrete covered with a flushed squeegee seal coat or a pre-mixed seal coat. One type of asphaltic concrete, Warrenite Bitulithic, is a patented pavement which uses a mixed seal coat rolled into the surface of the bituminous concrete, immediately after it is laid.

The bituminous concrete usually consists of broken stone, sand, mineral filler and asphaltic cement When combined in the road the following are typical requirements:

	Percentage
Passing 1¼-inch, retained on ½-inch screen	30-60
Passing ½-inch, retained on ¼-inch screen	15-25
Passing ¼-inch, retained on 10 mesh sieve	5-15
Passing 10 mesh sieve, retained on 200 mesh sieve	20-35
Passing 200 mesh sieve	4- 6
Total bitumen	5- 8

The penetration of the asphaltic cement varies for climatic conditions and according to the opinion of the local engineer, the 20 point limits are 60 to 80. In some of the southern states a penetration of 40 to 50 is customary.

The flush seal coat used is asphaltic cement applied hot and covered with stone chips, 95 per cent of which passes the ½-inch screen and 100 to 95 per cent is retained on the 10-mesh sieve.

The mixed seal coat consists of aggregate passing the ¼-inch screen and is similar to sheet asphalt in gradation and percentage of bitumen The compacted thickness usually is 2 inches, including seal coat.

e. Sheet Asphalt or Bituminous Concrete on Mixed Binder Course.

This type of surfacing consists of two layers, The bottom is a binder course of the coarse aggregate type but is not usually as dense as bituminous concrete, coarse aggregate type. The top or surface course is commonly a sheet asphalt but bituminous concrete fine aggregate type is also used.

The binder course is commonly 1½ inches in compacted depth but 1-inch is also used.

The surface course is commonly 1½ inches thick but 1-inch is sometimes used on binder courses which are at least 1½ inches thick.

The materials for the binder course are clean durable crushed rock, occasionally gravel, sand and asphaltic cement They are combined in such proportions as to produce a mixture within the following limits:

	Percentage
Passing 1-inch circular mesh and retained on ½-inch circular mesh	35-65
Passing ½-inch circular mesh and retained on 10-mesh sieve	10-35
Passing 10-mesh sieve	25-35
Asphaltic cement	4- 6

The materials for the sheet asphalt surface course are sand, mineral filler and asphaltic cement They are commonly combined within the following limits·

	Percentage
Passing 10 mesh, retained on 40-mesh sieve	10-40
Passing 40 mesh, retained on 80-mesh sieve	22-45
Passing 80 mesh, retained on 200-mesh sieve	12-30
Passing 200-mesh sieve	10-20
Asphaltic cement	9 5-12

The asphaltic cement has a penetration of from 40 to 50, or 50 to 60, depending upon climatic conditions In the southern states 40 to 50 is commonly specified

Bituminous concrete for this surface course when used is commonly of the fine aggregate type as previously described The total depth of finished surface is 2½ or 3 inches

f Sheet Asphalt or Bituminous Concrete on Penetrated Binder Course

For purposes of economy a penetrated binder course is laid instead of a mixed binder This is from 2 to 3 inches in thickness The top course of sheet asphalt or bituminous concrete fine aggregate type is from ¾ to 2 inches in thickness.

The materials for the penetrated binder course are crushed stone, stone chips and bitumen In quality and gradation they are the same as for bituminous penetration macadam for the coarse and intermediate stone; but the fine stone and second application of bitumen are omitted The bitumen for the penetration course is usually asphaltic cement lower than 100 penetration Work of this character near Atlanta, Georgia, was laid with asphaltic cement having a 60-80 penetration. The rate of application is from 1½ to 1¾ gallons per square yard and in general is equal to the quantity, used for the first application in penetration macadam work

The second or surface course uses aggregates and bitumen as described for sheet asphalt or bituminous concrete surface course instead of the customary seal coat used for penetration macadam.

In all of the foregoing types stone is commonly the coarse aggregate but crushed or screened gravel and coarse sand have been substituted to reduce the intial construction costs rather than to improve the quality of the surfacing.

3. *Construction Methods.*

CLASS I

BASE AND SURFACE COURSES OF BITUMINOUS MIXTURES

The principal operations are:

1. Prepare the subgrade.
2. Set temporary or permanent side forms and roll the subgrade.

Figure 88. Mechanical Spreader and Finisher. Pre-Mixed Bituminous Surface Laid Hot. From Public Works, Vol. 59, No. 3

3. Coincident with 1 and 2 the surfacing materials are prepared and mixed at a central mixing plant and are hauled by trucks to the roadway.
4. Dump the hot base course mixture on dump boards.
5. Spread on subgrade and rake to a smooth uniform surface with hand tools. Machines for these purposes have been put on the market within the past few months (late in 1927).
6. Roll the surface with a self-propelled power roller.
7. Test surface for regularity and correct high and low spots.
8. Dump surface course mixture on dump boards.
9. Spread on base course and rake.
10. Roll with power roller.
11. Test surface with straight edge and correct irregularities.
12. Sprinkle surface with Portland cement.

In the fine aggregate type in North Carolina a hot squegee coat of hot asphaltic cement is applied to the base just before the surface course material is spread on its surface In the coarse aggregate type a seal coat of bitumen and chips is applied to the top of the surface course.

Sand asphalt as laid in North Carolina has a compacted base thickness of 3 inches, a squeegee coat of asphalt between base and surface, and a compacted surface thickness of 2 inches

Mixed macadam as laid in Canada has a compacted base course of 3 inches and a top course of the same materials with a 3-inch thickness. It has in addition a seal coat of bitumen and chips.

CLASS II

Surface Courses of Bituminous Mixtures Laid on a Well Compacted Base of Macadam, Lime Rock or Gravel

Bituminous concrete of the fine or coarse aggregate type is laid in one course to a compacted depth of 2 inches The principal construction operations are

1 Clean the existing compacted surface by sweeping thoroughly
2. Apply or omit a priming coat of cold tar or asphalt and allow sufficient time for it to penetrate.
3 Level up with or omit a mixed binder course, similar to that used with sheet asphalt.
4 Clean the surface again if operations 2 or 3 are included
5. Dump hot bituminous mixture, which has been hauled from plant, on dump boards
6. Spread, rake and roll.
7 Apply seal coat on the coarse aggregate type and roll Seal coat is not used on the fine aggregate type.
8 Sprinkle surface with Portland cement when using fine aggregate type or coarse aggregate type which has a mixed seal coat. Portland cement is not used on the squeegee seal coat which is covered with chips or pea gravel.

Sheet Asphalt or Bituminous Concrete on Mixed Binder Course.

1 Clean the compacted surface by sweeping thoroughly.
2 Dump mixed binder course on dump boards from trucks.
3. Spread, rake and roll.
4. Test surface with straight edge and correct irregularities.
5. Dump surface course on dump boards.

6. Spread, rake and roll surface course
7 Test surface with straight edge and correct irregularities
8. Sprinkle surface with Portland cement

Sheet Asphalt or Bituminous Concrete on Penetrated Binder Course The principal operations are

1 Clean the existing base course.
2 Dump layer of coarse stone on dump boards.
3 Spread, rake, and roll layer of coarse stone.
4 Test surface with straight edge and correct irregularities of surface and pockets of segregated material Reroll
5. Apply bitumen from a power distributor at rate of 1 50 to 1 75 gallons per square yard.
6 Spread from dump boards the intermediate stone.
7 Broom the intermediate stone and roll the surface until the voids are filled and thorough compaction is secured
8 The surface may now be left open to traffic and weak spots corrected
9 Sweep loose stone from surface and spread hot mixture of sheet asphalt or bituminous concrete, fine aggregate type
10 Rake and roll the hot mixture
11 Test surface with straight edge and correct irregularities.
12. Sprinkle surface with Portland cement.

The foregoing construction methods are outlines of the principal operations on the road Plant operation, proportioning the aggregates, temperature control and other important features must also receive careful attention for satisfactory results.

4 *Maintenance Methods* Incipient or marked failures are sometimes occasioned by subgrade and moisture conditions affecting the base and the bituminous surface They may be the result of improper design or preparation of the bituminous mixture.

Subgrade conditions are most easily corrected before or during construction. In North Carolina a double base course of sand asphalt, each course 3 inches thick has corrected some bad subgrade conditions The squeegee coat between base and top has greatly reduced the cracking of the surface course by bonding it securely to the base.

One of the principal causes of failure in these types of surfacing is the entrance of water between the base course and the surface course Cracks in these surfaces are more or less efficiently repaired by cleaning them and filling with asphaltic cement.

Holes and wide cracks are repaired by first cutting the edges to vertical planes, the holes are then cleaned and the edges painted with liquid asphalt They are then filled with a hot mixture of the same material as that in the existing surface or with natural rock asphalt The coarse aggregate types are sometimes patched with a mixture of cold patch bitumen and aggregate After the hole is filled the new material is tamped or rolled to produce a surface even with the surrounding area

On the more open types of surfacing or surfaces which show surface wear, seal coats of bitumen covered with chips or sand have been successful They liven up the old surfaces, seal many of the cracks and improve the appearance of the old pavement.

Areas of hot mix surfaces which become wavy under traffic or which were burnt during the heating, or which cannot be satisfactorily repaired by patching, must usually be removed and resurfaced.

5 *Construction Costs*

a. Bituminous Mixtures, both courses using fine local aggregate have cost from $13,000 to $19,000 per mile for an 18 foot width and a 4½ to 5-inch total thickness The same type of surfacing in Delaware and Florida has been higher than the average prices in North Carolina.

b Bituminous Mixtures, both courses using coarse aggregate have cost in Ontario, Canada, from $20,000 to $25,000 per mile for a 20 foot width and a total thickness of 6 inches

In Massachusetts the 4-inch surface of this type has cost about $10,000 to $12,000 per mile calculated for an 18 foot width

c Bituminous Concrete Fine Aggregate Type, as laid in Michigan, using a prime coat of tar on the gravel base, a thin binder course (less than 1-inch) and a 2-inch bituminous concrete is costing $11,000 to $14,000 per mile for an 18 foot width

d. Bituminous Concrete Coarse Aggregate Type, when laid according to standard specifications with crushed stone, is usually more costly for initial construction than the fine aggregate type.

e Sheet Asphalt or Bituminous Concrete on Mixed Binder Course This type of surfacing seldom costs less than $14,000 per mile for a total thickness of 3 inches and a width of 18 feet

f Sheet Asphalt or Bituminous Concrete on Penetrated Binder Course Surfacing of this kind in Georgia cost about $ 80 per square yard for the penetrated macadam base without seal coat on which was placed a sheet asphalt top at the rate of 75 pounds per square yard and costing $8 50 per ton, the average total depth of macadam and sheet asphalt was slightly less than 3½ inches This would make the cost per mile for an 18 foot width about $12,000

6 *Maintenance Costs* The cost of maintaining these surfaces for various types considered and for various classes of traffic of between 1000 and 2000 vehicles per day ranges from $50 per mile per year to about $300.

7. *Service* These surfaces are seldom as smooth riding as the mixed-in-place bituminous surfaces When laid on a concrete base of even contour smoother surfaces usually result than on stone or gravel bases. Improved methods of spreading, raking and screeding will doubtless result in smoother riding surfaces.

Under heavy truck traffic these surfaces may become displaced near their edges, both vertically and laterally. Edge strengthening is needed for heavy traffic To prevent the entrance of water between base and top some engineers are attempting to bind the top to the base by using a prime coat of bitumen All of these surfaces are said to be carrying 1000 to 2000 vehicles per day without serious fatigue Some of them are carrying more

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MISCELLANEOUS SURFACES PRINCIPALLY LIME TREATMENTS OF CLAY

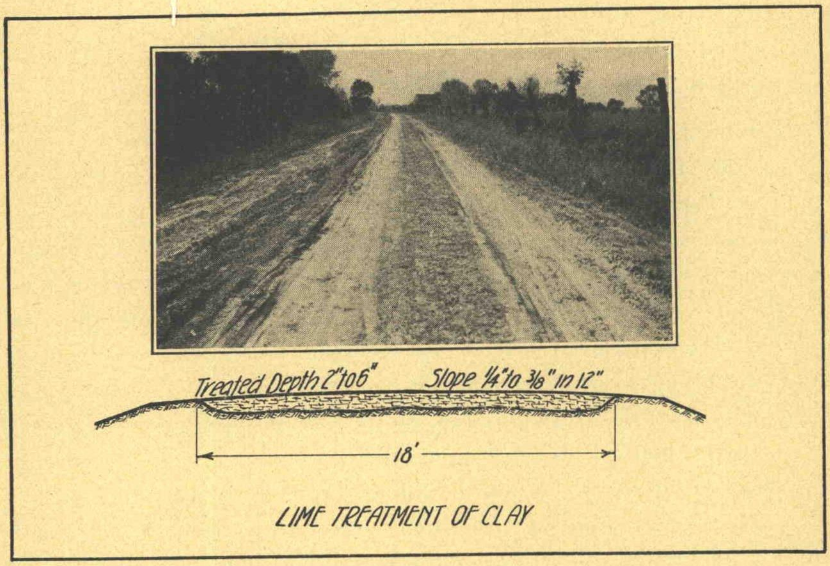

Figure 89

Materials	Cost per mile	Service	Examples in
Lime. Clay.	Construction, 6-inch treated depth, $2600 to $3300. Maintenance, not known.	Not known.	Missouri. Iowa. South Dakota.

1. *General Description.* A wide variety of nonbituminous admixture have been tried, experimentally, to improve the traffic capacity and serviceability of soil roads.

In this list (which does not include mineral aggregates) are hydrated lime, Portland cement, silicate of soda, calcium chloride, sodium chloride and deliquescent salts. Prominent in this list are the recent experiments with hydrated lime and Portland cement. Of these two materials the experiments with hydrated lime have attracted the greater attention. It has therefore been selected as a type.

Lime is mixed in place with the road soil, shaped up and the road opened to traffic.

2. *Materials.* The soils are clay or clay loam which may also contain silt, sand or gravel. Clay and gumbo soils were usually selected for treatment. Commercial hydrated lime was the admixture. The field tests have used various percentages of hydrated lime ranging

from 2 to 5 per cent by weight and from 3 to 9 per cent by volume. The depths of soil treatment have ranged from 2 to 6 inches with the majority of them at 6 inches

3 *Construction Methods* A summary of the experimental methods has resulted in the following procedure.

1. The method employed will vary with the soil, the moisture conditions and the tools available If the soil is a heavy clay, the road should be dry when the work is started It is best to plow the roadway to a depth of 6 inches, breaking about 2 inches at a time to avoid turning out large clods, using a brush plow, a rooter or a scarifier Where a scarifier on a light maintenance machine has been used it has been found advantageous to move the loose material to one side with the blade after each trip.
2. The loose soil is then broken up as fine as possible with a disk harrow before the lime is spread
3. Sacks of lime are distributed along the road so spaced as to give the proper amount of lime per square yard. For a 6 inch depth of treatment about 16 pounds per square yard is recommended for clays and 12 5 pounds for silt loams.
4. The lime is spread in a uniform layer and thoroughly disked into the loose, dry soil If the treatment is more than 3 inches deep it has been found necessary to turn over the loose soil with a plow to secure thorough mixing to the full depth of treatment.
5. When the mixing process has been completed, the surface is shaped up with a road machine blade and opened to traffic.

4. *Maintenance Methods* The surfaces are bladed and dragged to obtain a regular contour

5 *Construction Costs* The cost of some experimental sections for materials and labor on a 6-inch treated depth of clay for two short sections in Missouri amounted to from $2600 to $3300 per mile for an 18 foot width, the quantity of lime used was 5 per cent of the weight of soil. This cost could probably be reduced on a large project. The price of hydrated lime at the plant varies from $12 00 to $15 00 per ton.

6. *Maintenance Costs* None available.

7 *Service.* The result of this treatment in Iowa is summarized by R. W. Crum, then Engineer of Materials and Tests, "the result of this treatment is not entirely a success on either type of soil (a tough, heavy clay and a light loose soil).

Some benefits were observed especially on the clay Further observations will be required before a definite statement can be made as to the value of the treatment. It can be said that the results are such as to preclude any possibility of the use of such treatment on any earth road carrying an appreciable amount of traffic"

Regarding the Missouri experiments Prof E J McCaustland writes in part, "such treatments will not in any degree lessen the production of dust and in some cases the dust may be increased"

Conclusions in "Public Roads," Vol 6, No 7, state that further tests and observations are necessary as to the ultimate value of the lime admixture, and that "granular sub-bases seem to be more beneficial on bad subgrades than admixtures of Portland cement and hydrated lime," and that "sand is as effective as Portland cement or hydrated lime when used as an adulterant to reduce the shrinkage of a clay soil"

A suggested possibility of improving lime treated roads is the addition to the surface of a thin layer of gravel which may later be treated with a suitable bitumen No data, however, are available on this.

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