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O. M. LELAND, Director

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THE USE OF MARL IN ROAD CONSTRUCTION

BY

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MINNEAPOLIS

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INTRODUCTORY NOTE

The Legislature of Minnesota, at its last session, made an appropriation for the investigation of the use of marl for various purposes. The Engineering Experiment Station of the University of Minnesota, of which Dean O. M. Leland is director, was assigned the task of investigating the use of marl as a road-surfacing material. Mr. F. C. Lang, assistant professor of highway engineering at the University, and engineer of tests and inspection for the Minnesota Highway Department, had general supervision of the investigation. Mr. Charles H. Dow conducted the laboratory experiments, supervised the building of experimental roads, and prepared this report. Mr. R. E. Bergford, assistant engineer of tests of the Minnesota Highway Department, made suggestions and criticisms in connection with the laboratory routine, and Mr. L. C. Brooks, chemist of the Minnesota Highway Department, developed chemical and physical analyses of specimens of marl.

Through the courtesy of Mr. John H. Mullen, chief engineer, the coöperation of the Minnesota Highway Department was obtained.

The experimental road at Rice, Benton County, was built by county forces which were placed at the disposal of the investigation by Mr. Paul Zeese, Benton County highway engineer. The expense of construction was shared by the county and state.

Similarly, the road east of Pequot was built through the courtesy of Mr. Walter M. Murphy, Crow Wing County highway engineer, at the expense of the county.

The road in Anoka County was built by state maintenance forces furnished by Mr. Karl Moulton, maintenance superintendent for that district.

Acknowledgment is due to all those mentioned for their helpful and unfailing courtesy and interest in the work of the investigation.

The conclusions of Mr. John C. Koch, of Georgia, in an article on sand-clay roads published in the *Transactions of the American Society of Civil Engineers,* December, 1914, were studied and valuable information derived from them as to design of surface mixtures. His graph has been reproduced by permission (Plate II, page 11).

The outline of procedure in the investigation is as follows:

Bibliography
Correspondence with state and federal authorities
Laboratory experiments

1. Cementing tests with mixtures of various marls and sands. Comparison of above with clay mixtures
2. Slaking test with the above mixtures
3. Analyses of clay and marls based on a separation into the following component parts: carbonates, clay, sand, and organic matter
4. Drying out tests. Marl mixtures versus clay mixtures
5. Tests with sands of various fineness, marl, and clay
6. Charting results
7. Comparison with the results of Professor Koch on sand-clay roads in Georgia

Field work

1. Interviewing highway officials and people in various localities
2. Sampling and inspection of marl beds. Investigation of availability of deposits for road purposes
3. Experimental road-building
    a. 1,000 feet built at Rice, Benton County, with various mixtures and methods of working the surface
    b. 2,800 feet built seven miles east of Pequot, Crow Wing County, with a hilly profile
    c. 200 feet built on Central Avenue Road, Anoka County
4. Observation of above roads, sampling surfaces, etc.

Preparation of report.

THE USE OF MARL IN ROAD CONSTRUCTION

MARL

Minnesota has many sandy roads. The accepted practice for improving such roads is to spread clay upon them, and by plowing and harrowing, thoroly mix the clay into the sand of the subgrade. The road then becomes surfaced with a sand-clay mixture. The best ratio of materials appears to be two of sand to one of clay. This has been found to be a desirable ratio, both by analyzing the material of existing natural topsoil roads, and, experimentally, by combining material for surfacing.

The similarity, in many respects, between marl and clay has suggested the use of marl as a binder on sandy roads. Fortunately, Minnesota has many marl deposits which are situated in the vicinity of such roads. Certain properties of marl can be observed and studied in the laboratory. The behavior of the substance under laboratory experiments can be used, to a great extent, as a guide in preparing proper mixtures for road-surfacing and, in a measure, to predict its behavior after being placed on the road. The next step is to build experimental road surfaces and to note the results with reference to the material used.

In the *Twenty-fifth Annual Report of the Department of Geology and Natural Resources,* W. S. Blatchley, state geologist of Indiana, gives the following definition: "Marl is a soft, earthy material, composed principally of an amorphous form of carbonate of lime." In other words it is equivalent to limestone in a finely divided form.

Because of its wide occurrence in Minnesota and in order that it may be easily recognized, the following description of marl, from Mr. Blatchley's report, is given here. He says that the color of marl

varies with the percentage of impurities which it contains. In the wet or damp state in which it occurs in lakes or marshes, it ranges from a milky-white through varying shades of brownish-yellow to a dark brown, which may finally grade over or merge into the overlying or adjacent rock. After exposure to the air a short time, a wet marl that at first may seem almost white turns a bluish or drab color on account of some chemical change which takes place. In drying, the color of the marl tends to lighten again, but seldom gets beyond a light dove color, and is generally a decided drab, running from a light drab to a slate color. The purer forms, however, when dry, are white or slightly cream colored. The grains or particles composing the dry mass cohere very loosely and vary in size from coarsely granular to fine powder. They effervesce very freely and in time wholly disappear when a few drops of muriatic acid are applied, and in this way may be readily distinguished from any soft clay or mud, which effervesces or bubbles but slightly or not at all upon the application of acid. On dissolving the marl in acids small particles of vegetable and other organic and insoluble materials usually remain scattered throughout the solution.

The Division of Soils of the College of Agriculture has been investigating marl with reference to its use as a fertilizer of soils. Through the courtesy of Professor F. J. Alway, who is in charge of this work, various samples of marl have been furnished which were used in the laboratory experiments. Professor Alway also furnished information in regard to the location of marl deposits through the state. The map of the state, with notations thereon, indicates the widespread occurrence of these deposits (Plate I).

Numerous samples of marls, clays, and sands were obtained in the field, as well. Their analyses appear in this report in tabular form (page 8).

Professor Alway makes the following general statement:

> The territory in which the marl is likely to be found may be defined as all of the State east of a line from St. Vincent, in Kittson County, to Glencoe. Nearly always, it occurs at the bottom of a bog on which the natural growth consists of grass, sedges, or tamarack.

MARL DEPOSITS REPORTED IN MINNESOTA

(Numbers refer to locations on Plate I.)

(Names are of persons familiar with the deposits.)

1. Howard Lake, J. H. Nixon, Nevis
2. Preston, William E. Newman
3. Underwood, Carl Anker
4. Underwood, J. V. Bopp
5. Hill City, H. J. Lillibridge
6. Popple, C. A. Dahlquist
7. Taconite, D. H. Pierce
8. Warroad, William Rosencrantz
9. Sec. 3-58-24 Itasca County, Frances Bluntache
10. Lundgren, August Lundgren
11. Glenwood, etc., A. D. Anderson
12. Grand Rapids, A. J. McGuire
13. Shevlin, Melvin Hoff
14. Pequot, D. E. Willard
15. Detroit, Charles G. Sturtevant, Soo Line
16. Sec. 2-136-38 Ottertail County, J. B. Flannigan
17. Douglas and Pope counties, F. E. Balmer
18. Thief River Falls, Lars Skoume
19. Sec. 10-66-22 Koochiching County, C. Durheim
20. Little Falls, F. W. Dobbyn
21. Aven, P. E. Schauble
22. Melvin, Ole Larson

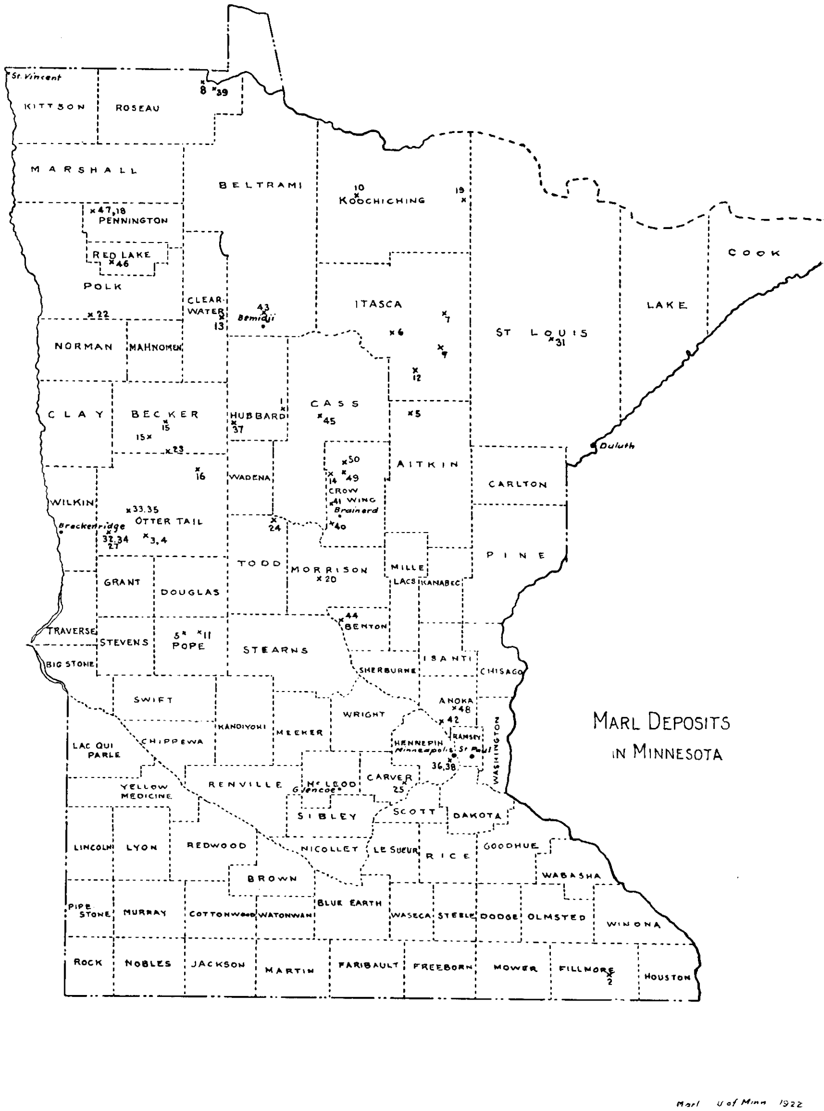
23. Frazee, Theodore C. Zitzow
24. Staples, W. H. Poole
25. Chaska, A. T. Faber
26. St. Cloud, M. Whitney
31. Sparta, W. E. Bender
32. Fergus Falls, W. B. Stewart
33. Weggeland, Herman O. Schol
36. Loring Park, Minneapolis
37. Park Rapids, W. W. Townsend
38. Keegan's Lake, Minneapolis
39. Roosevelt
40. Barrows, Walter M. Murphy, Brainerd
41. Five miles northwest of Brainerd, marl-clay, Walter M. Murphy
42. Coon Creek Experimental Farm, Professor Alway *(Fig. 1)*
43. Bemidji, S. D. Snyder
44. Rice, Paul Zeese, Foley *(Figs. 5, 6, and 7)*
45. Walker, C. J. White
46. Red Lake Falls, H. E. Palmer
47. Thief River Falls, B. F. Nudland
48. Ham Lake, Anoka County, F. C. Lang *(Fig. 10)*
49. Seven miles east of Pequot, J. F. Flannigan *(Figs. 8 and 9)*
50. Star Lake, Crow Wing County, Anton Peterson, Pequot *(Fig. 2)*

Numbers 1 to 39 were furnished by Professor Alway. Included among them are 25 and 26 from Minnesota Geological Survey and 31 to 39 from the Department of Geology, Professor Grout, University of Minnesota. The remaining items were obtained from the correspondence of F. C. Lang, State Highway Department, or secured incidental to the investigation.

An idea as to the origin of marl may be an aid in discovering new deposits. Several theories of its origin prevail. Mr. Blatchley believes that the immediate source of marl is in the clays deposited by glaciers—these clays being "rich in finely divided limestone and other soft rock-forming materials, many of which contain the components of marl." Water containing carbon dioxide when cool and under pressure dissolves the carbonates and holds them in solution until it issues forth as a spring in the side or bottom of a lake. Then the carbon dioxide escapes, the pressure is reduced, the spring water rises in temperature, and the excess of the dissolved material is precipitated in the form of a fine powder. Another theory of the formation of marl deposits is that they are incidental to the life and growth of aquatic plants and animals. Mr. Blatchley also shares this latter view.

Of the deposits used on the experimental roads built in connection with this investigation, the one at Rice occurs in a pocket overlaid with the ordinary soil of a field under cultivation. Springs issue through it.

PLATE I


MARL DEPOSITS
IN MINNESOTA
St. Vincent
KITTSON
ROSEAU
MARSHALL
BELTRAMI
KOOCHICHING
PENNINGTON
RED LAKE
POLK
CLEARWATER
Bemidji
ITASCA
ST LOUIS
LAKE
COOK
NORMAN
MAHNOMEN
CLAY
BECKER
HUBBARD
CASS
AITKIN
Duluth
CARLTON
WADENA
CROW WING
Brainerd
WILKIN
Breckenridge
OTTER TAIL
TODD
MORRISON
MILLE LACS
KANABEC
PINE
GRANT
DOUGLAS
BENTON
TRAVERSE
STEVENS
POPE
STEARNS
ISANTI
CHISAGO
BIG STONE
SHERBURNE
SWIFT
ANOKA
KANDIYOHI
MEEKER
WRIGHT
CHIPPEWA
LAC QUI PARLE
HENNEPIN
Minneapolis
RAMSEY
St Paul
WASHINGTON
YELLOW MEDICINE
RENVILLE
McLEOD
Glencoe
CARVER
SIBLEY
SCOTT
DAKOTA
LINCOLN
LYON
REDWOOD
NICOLLET
LE SUEUR
RICE
GOODHUE
WABASHA
BROWN
PIPE STONE
MURRAY
COTTONWOOD
WATONWAN
BLUE EARTH
WASECA
STEELE
DODGE
OLMSTED
WINONA
ROCK
NOBLES
JACKSON
MARTIN
FARIBAULT
FREEBORN
MOWER
FILLMORE
HOUSTON
Marl U of Minn 1922

The deposit lies in a slight depression adjacent to a small stream, with practically the whole deposit above the stream level. It is underlaid with sand. Except for the portions immediately over the springs, the marl is firm.

The deposit used on the Pequot Road is on the shore of Long Lake and under a thin sod, but extends back from the lake under a peat bed. This seems to be in the line of seepage from Pelican Lake.

The deposit at Ham Lake on the Central Avenue Road is in a sink hole. The bulk of the marl, about twenty feet in depth, is semiliquid. A road built through this sink hole has caused some of the firmer marl in a pocket to erupt through cracks in the peat beside the roadway. From these eruptions, the material was obtained for our road-surfacing.

A very large deposit at Star Lake, Crow Wing County, is illustrated in Figure 2. It is from seven to sixteen feet in thickness. This lake is fed largely by seepage from Cross Lake and the government reservoir. The level of Star Lake has subsided several feet, leaving the marl exposed along the shores. Most of the portion inspected had no covering but a scanty sod. One very deep pocket lies under peat. There has been a very general lowering of lake levels in this and the Pelican Lake vicinity, so that the marl deposits at Long Lake also are partly above present water level.

LABORATORY EXPERIMENTS

Parallel tests were run on clay and marl mixed in various proportions with sand to establish a basis of comparison of marl with clay, the properties of clay being fairly well known. The clay used came from Red Wing; it has good binding properties. The marl came from Hill City and Coon Creek. The former, having a high percentage of carbonates, is nearly pure marl. The latter has a large amount of impurities, especially organic matter. The sand was obtained from a shallow cut north of Minneapolis, along the East River Road to Anoka. It is typical fine Minnesota sand.

The essential constituent of marl is calcium carbonate ($CaCO_3$). The form of analysis adopted separated the marl samples into carbonates and other solubles, clay, sand, and organic matter. These constituents seem to be the governing ones, from a physical standpoint. The method of analysis as developed by Mr. Brooks follows:

Procedure for Approximate Analysis of Marl

Determination of carbonates plus other soluble material.—Treat a 1-gram sample of marl with 25 c.c. of dilute hydrochloric acid (1:1). When effervescence ceases, filter off the solution retaining the insoluble material on a gooch filter which has been previously ignited and weighed. Dry at 110° for half an hour and weigh. The increase in weight of gooch filter represents insoluble material. Subtract this weight from 1 gram and the difference equals the weight of carbonates, plus other soluble material.

Determination of organic matter.—Ignite the weighed gooch filter and contents from the previous determination for fifteen minutes, cool in a desiccator, and weigh. The loss in weight represents organic matter.

Determination of sand.—Treat a 5-gram sample with 100 c.c. of dilute HCL (1:1). When effervescence ceases and all particles have come in contact with the acid, dilute to 400 c.c., stir, then allow to settle thirty seconds and carefully decant off the liquid. Repeat this process three times, finally washing the residue on to a gooch filter which has previously been ignited and weighed. Dry and ignite for fifteen minutes, cool and weigh. The gain in weight represents sand.

Determination of clay.—The per cent of clay is obtained by adding together the percentages of the other constituents obtained and subtracting this from 100.

The sand was also washed to obtain the percentage of clay, according to the routine of the Minnesota Highway Department, as follows:

Material was first thoroly mixed, after which a sample weighing approximately 500 grams was secured by the method of quartering. This sample was weighed in a round aluminum pan of known weight, about 10 inches in diameter and 4 inches deep. Sufficient water was poured in to cover the material and agitated vigorously fifteen seconds with a stirring rod. It was allowed to settle for fifteen seconds, after which the water was poured off through a 200-mesh sieve. This routine was repeated until the water was clear. The material retained on the sieve was then washed back into the pan and the sample dried at 100° C. to constant weight. Percentage of clay was computed by ratio of loss in weight to original weight.

A comparison of results of analyses by Mr. Brooks and by washing methods follows:

TABLE I

COMPARATIVE RESULTS OF ANALYSIS

	Carbonates	Organic Matter	Sand	Clay
Red Wing clay by washing.............			5.00	95.00
Red Wing clay by Brooks' method......	2.83	6.04	13.50	77.63
Anoka Road sand by washing...........			97.50	2.50
Anoka Road sand by Brooks' method...	.69	1.60	97.65	.06

The washing method appears defective in distinguishing the identity of the finely divided portions of materials. Neither method establishes the dividing line between clay and silt.

Some initial experiments were made with sand and clay ground to a paste in the ball mill, in the usual manner for determining cement values. It was soon decided, however, that native sand mixtures would be more representative of road conditions.

The question of the possibility of making successful surface mixtures with fine sand was raised. The graph of Mr. Koch (reproduced in Plate II) indicated the likelihood, later confirmed, that the fine sand mixtures would be satisfactory. Referring to the graph, line S^1 is a washed sand for concrete and S^2 is the Anoka Road sand. By inspection, it will be seen that the addition of 30 per cent of clay to each of these will make S^1 fall on the upper limit of desirability as a surface mixture, and make S^2 fall within the useful zone. Cementing and slaking tests shown on those graphs, respectively, bear out this indication. Mr. Koch's statement, "The greater proportion of coarse to fine sand, the harder and more durable will the road surface be," gives, in words, the type of curve which his graph illustrates.

In order to get the benefit of comparison, screen analyses were made on the Koch basis. (See Table III, page 10.) Incidentally, a natural sand-clay giving satisfactory service near Brainerd is listed and is likewise shown on the graph. The 50 per cent mixture of Coon Creek marl with Anoka Road sand as well as other mixtures are shown.

TABLE II

ANALYSIS OF MARLS, CLAYS, AND SAND

Locations	Carbonates	Organic Matter	Sand	Clay
Marl, Coon Creek Experimental Farm, used in laboratory experiments......	69.78	17.09	2.38	10.73
Marl, Hill City, used in laboratory experiments	93.05	2.30	1.05	3.60
Marl-clay, 5 miles northwest of Brainerd, used by county on road..........	21.34	3.07	7.27	68.32
Marl, Barrows, being sold by the pound as fertilizer	91.63	1.57	5.61	1.19
Marl-clay, dredged material from Coon Creek, east of experimental farm, being used on township road...........	11.88	2.15	72.57	13.40
Marl, Benton County pit, 2.5 miles east of Rice, used in experimental road....	82.26	1.02	8.55	9.17
Marl-silt, Little Rock Lake, east of Rice, used for metal polish................	26.11	2.66	14.71	56.52
Marl road-surfacing, 3 miles east of Rice, after several years' use, applied originally as a thin coating.............	22.94	4.42	7.06	65.58
Marl, Long Lake, 7 miles east of Pequot, used in experimental road...........	93.60	3.17	1.92	1.31
Marl, Central Avenue, Anoka County, semiliquid part of slough near Ham Lake	70.66	21.30	3.72	4.32
Marl, same place as above, plastic material squeezed up through cracks in peat by subsidence of highway embankment, used to build experimental road......	83.74	8.12	1.56	6.58
Marl, Central Avenue, beneath peat in drainage ditch 1 mile north of above location	72.38	9.47	10.35	7.80
Marl-clay, Central Avenue, north bank of Rice Creek, 100 feet west of road....	17.93	3.16	28.94	49.97
Clay, Red Wing, used in laboratory experiments	2.83	6.04	13.50	77.63
Sand, Anoka Road, used in laboratory experiments	.69	1.60	97.55	.06

PLATE II

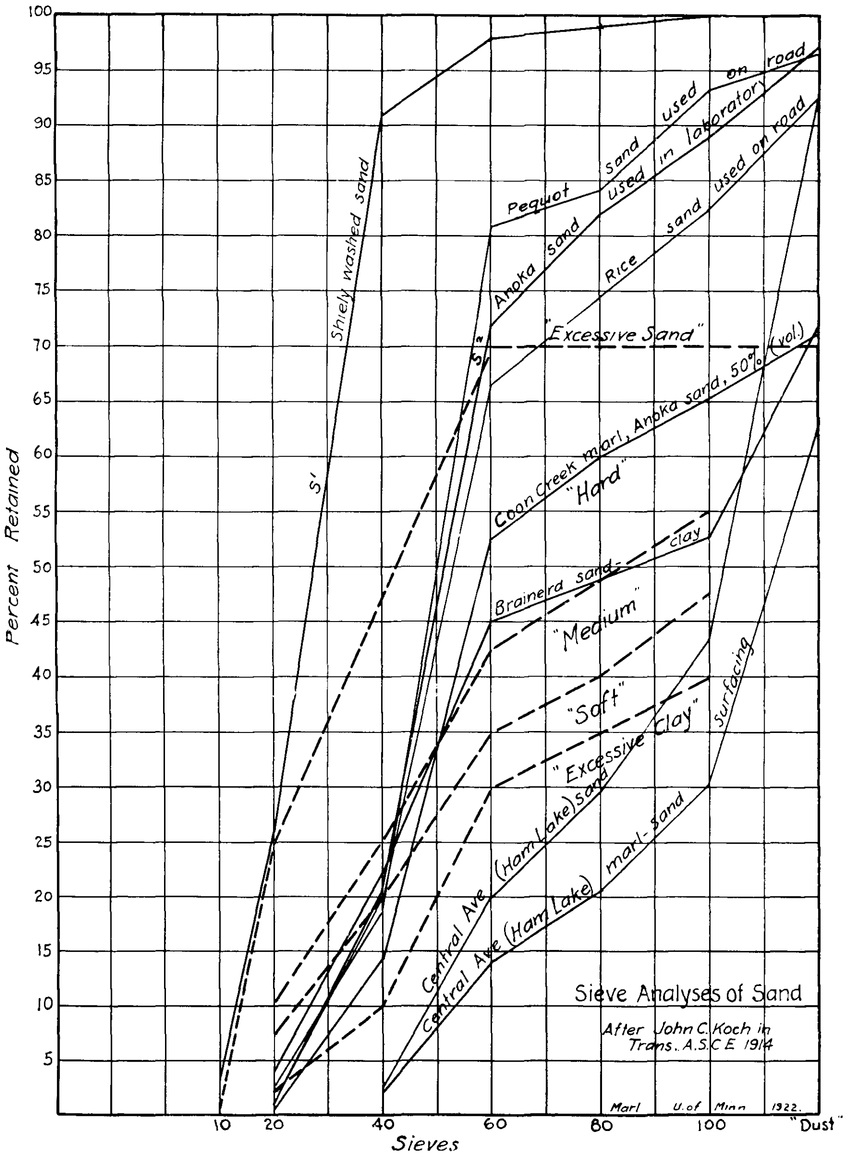

Sieve Analyses of Sand
After John C. Koch in Trans. A.S.C.E. 1914
Percent Retained
Sieves
10
20
40
60
80
100
"Dust"
Shiely washed sand
S'
S"
Pequot sand used on road
Anoka sand used in laboratory
Rice sand used on road
"Excessive Sand"
(vol.)
Coon Creek marl, Anoka sand, 50%
"Hard"
Brainerd sand-clay
"Medium"
"Soft"
"Excessive Clay"
surfacing
Central Ave (Ham Lake) sand
Central Ave (Ham Lake) marl-sand
Marl
U. of Minn
1922.

TABLE III

SIEVE ANALYSIS

Percentages by weight retained on various sieves. Portion retained on No. 10 has been discarded in calculating remaining percentages. A Ro-Tap Sieve Shaker was used.

Screen Number	Shiely Washed Sand, S1	Anoka Road Sand, S2	Anoka Road Sand with 50% Coon Creek Marl by Volume	Central Avenue Sand	Central Avenue Sand with 50% Marl, by Volume (approx.)	Brainerd Natural Sand-Clay	Rice Sand	Pequot Sand
10	3.0	.1	....	....	....	11.2	....	....
20	26.0	.7	.5	....	....	8.0	1.5	2.3
40	91.0	20.3	15.0	2.1	1.5	24.7	20.3	18.2
60	98.0	72.0	53.0	19.8	13.9	45.2	66.7	80.4
80	98.6	81.9	60.0	29.3	20.5	50.5	70.1	83.9
100	100.0	89.1	65.0	43.3	30.3	54.9	82.2	93.2
Dust	....	97.2	72.0	91.8	64.3	73.7	92.3	96.5
Clay	....	100.0	100.0	100.0	100.0	100.0	100.0	100.0

For the purpose of obtaining information on the cementing value of marl, parallel tests were run on cylinders one inch in diameter and one inch long, prepared from various percentages of clay and sand and of marl and sand.

Samples of clay and marl were dried and pulverized in a ball mill for the convenience of handling and for the sake of uniformity. However, several tests using marl pulverized by the trowel only during the mixing with sand gave substantially the same results.

The mixtures were made by volume of dry powdered clay and marl with the dry sand. Because of the very approximate mixtures possible in mixing materials on road surfaces, which, of course, are necessarily by volume, the laboratory mixture by volume was thought to be sufficiently accurate and, perhaps, more thoroly suited to the purpose than the mixture by weight. However, the reduction is made to weight, and a graph of the results is shown.

Because of the existence of clay, sand, and organic matter in the samples of clay, marl, and sand, other graphs have been prepared to show the final percentages of these substances in the various mixtures made and tested.

The cylinders were molded fairly moist under 132 kg. per sq. cm. in the briquetting machine. Cylinders were mixed with the utmost possible amount of water that would leave them still able to be formed and molded to accurate shape. This was done in order that the materials might be thoroly mixed, depending on the water to act as a flux. Some samples, indeed, were mixed to a thin plastic state and then dried out to a workable condition for the purpose of molding.

A variety of conditions were used in making and drying the cylinders, but it may be said that the uniformity of results depended little on precise conditions. For instance, dry mixtures and wet mixtures were tested from the same percentage batch, with no observable differences traceable directly to those causes. In the same way, samples which were dried in air two days behaved in the same manner as samples dried one day in air. After molding, the cylinders were dried in the laboratory at a room temperature for twenty-four hours, and later dried to constant weight in an electric oven at 100° C., taking, in some cases, up to six hours' time. These cylinders were tested to failure in a Page impact machine 1 kg. weight, fall 1 cm. and results tabulated on the basis of the number of blows necessary to break the specimen.

A graph of the results of these tests on clay, Hill City marl, Coon Creek marl, and some others, is shown (Plates III and IV).

For the purpose of determining the resistance of marl mixtures to the action of water, as compared with clay, cylinders two inches in length and one inch in diameter were molded and dried in the same manner as described above for the cementing test. These cylinders were then placed on end in water at 21° C. and in this slaking test, the number of minutes required for the disintegration was made the measure of their resistance to water.

Slaking test cylinders were first made four inches long, in hand molds, but later made two inches long in a briquetting machine. The long specimens fell over before complete disintegration occurred, disturbing relative conclusions. From three to six cylinders for each test were made and the results noted were averaged. Results of slaking tests are shown on Plate V. Using the coarse Shiely washed sand, percentages of marl under 40 per cent did not give binder enough to make good cylinders.

Graphs of analyses of the marl-sand and clay-sand mixtures used are shown on Plates VI, VII, and VIII.

PLATE III

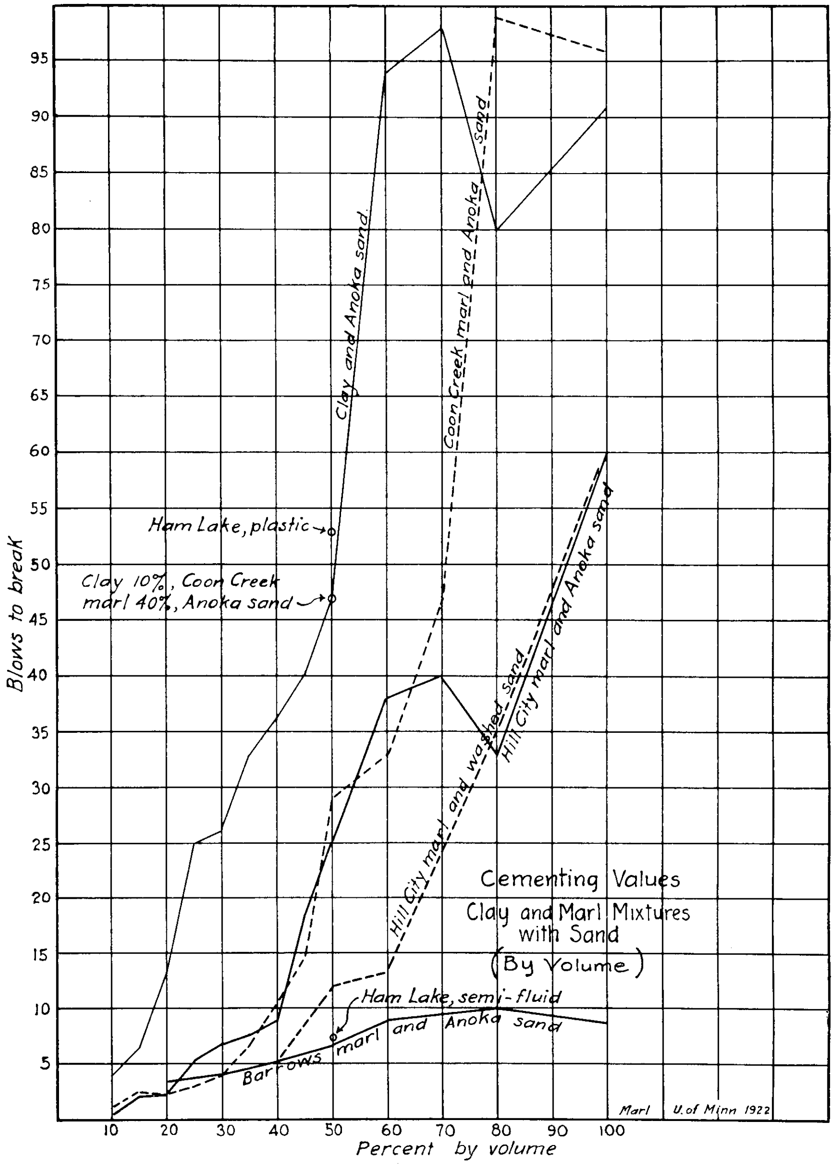

Cementing Values
Clay and Marl Mixtures with Sand
(By Volume)
Blows to break
Percent by volume
Clay and Anoka sand
Coon Creek marl and Anoka sand
Hill City marl and washed sand
Hill City marl and Anoka sand
Barrows marl and Anoka sand
Ham Lake, plastic
Clay 10%, Coon Creek marl 40%, Anoka sand
Ham Lake, semi-fluid
Marl U. of Minn 1922

PLATE IV

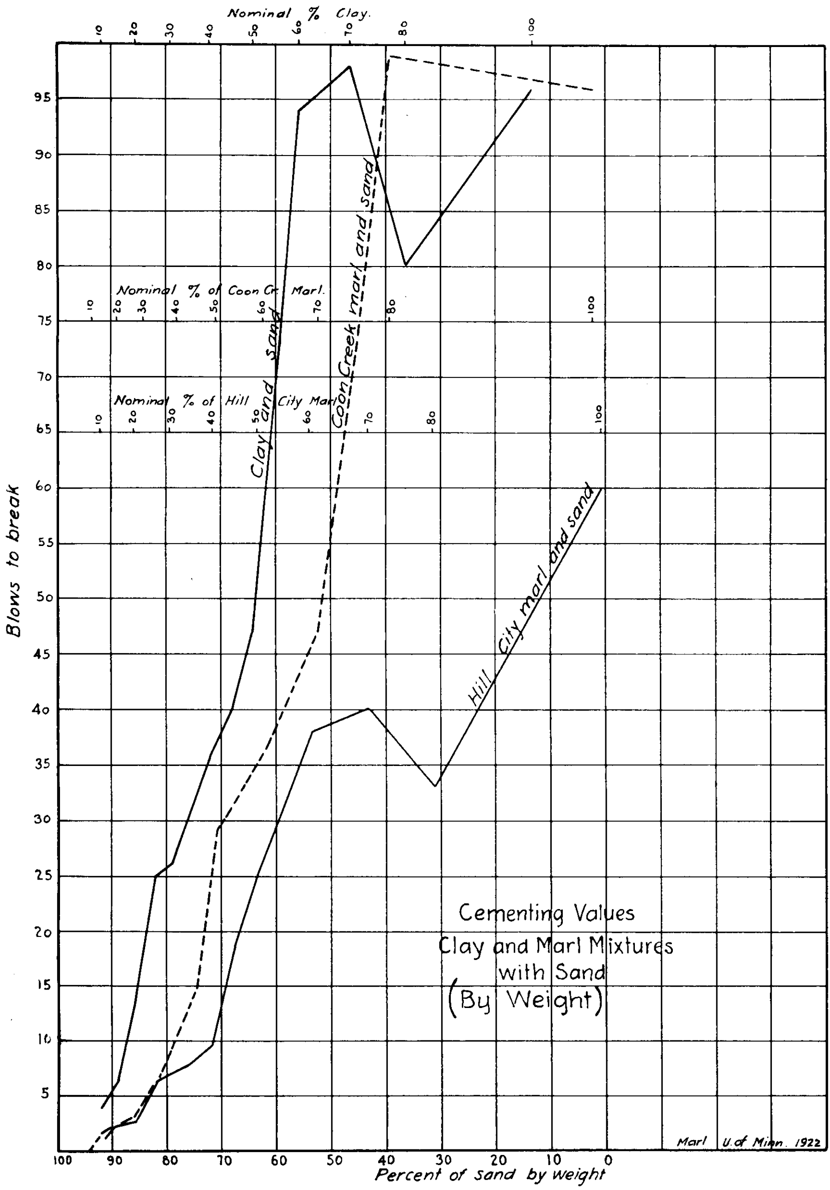
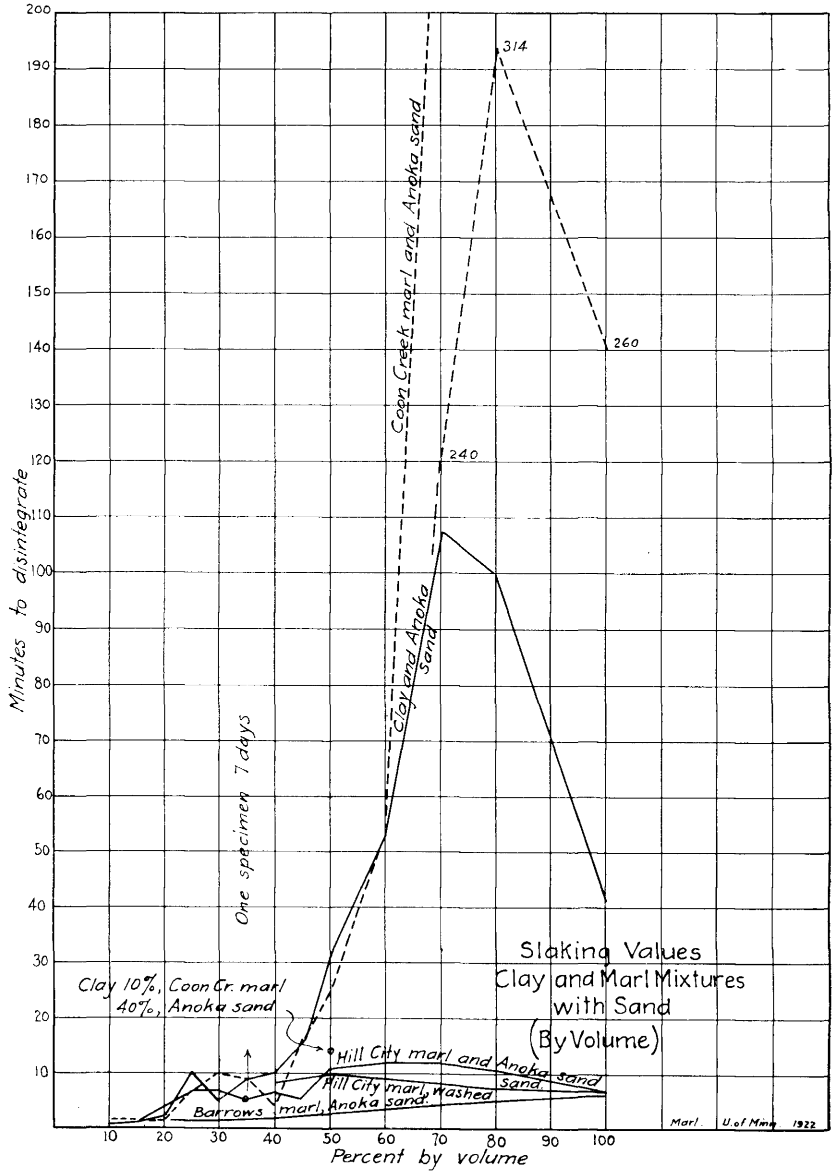

Nominal % Clay.
Nominal % of Coon Cr. Marl.
Nominal % of Hill City Marl
Blows to break
Percent of sand by weight
Clay and Sand
Coon Creek marl and sand
Hill City marl and sand
Cementing Values
Clay and Marl Mixtures
with Sand
(By Weight)
Marl U. of Minn. 1922

PLATE V



Minutes to disintegrate
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
10 20 30 40 50 60 70 80 90 100
Percent by volume
Coon Creek marl and Anoka sand
314
260
240
Clay and Anoka Sand
One specimen 7 days
Clay 10%, Coon Cr. marl 40%, Anoka sand
Hill City marl and Anoka sand
Hill City marl, washed sand.
Barrows marl, Anoka sand.
Slaking Values
Clay and Marl Mixtures with Sand
(By Volume)
Marl. U. of Minn. 1922

PLATE VI

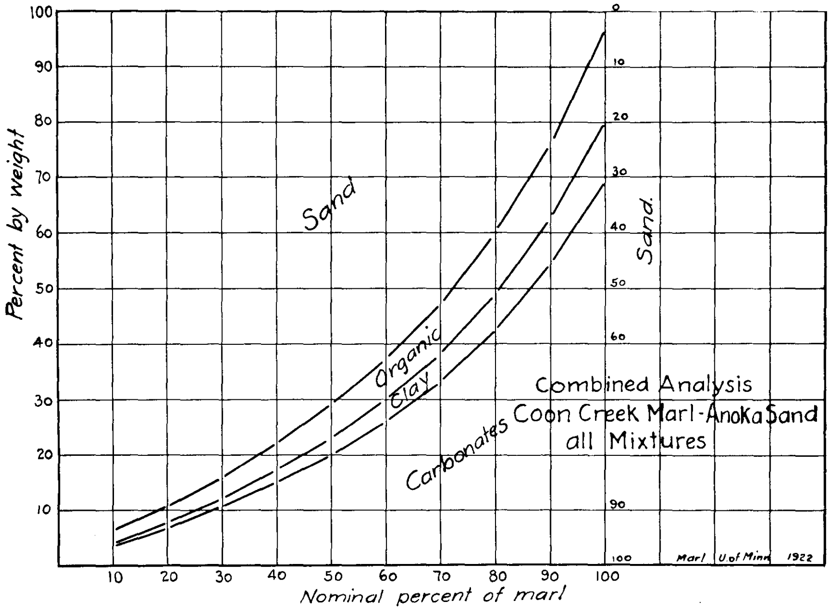


PLATE VII

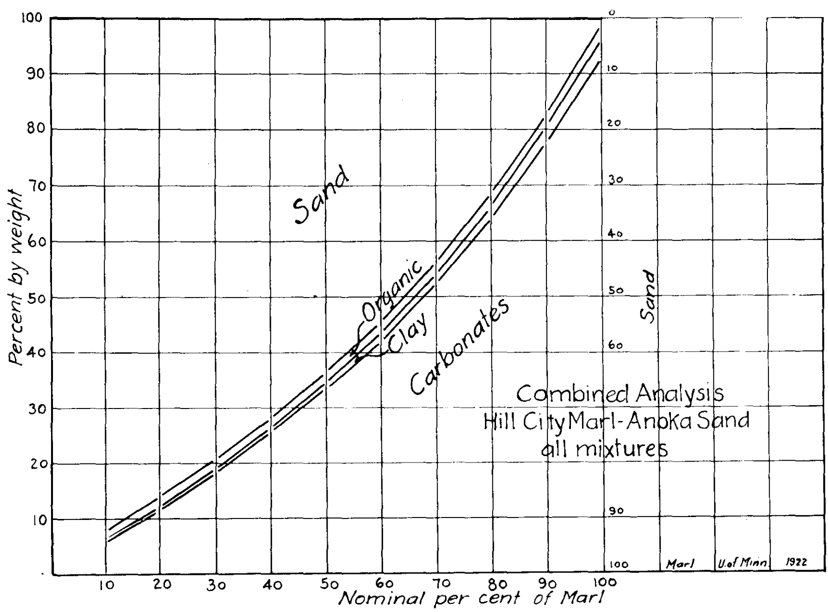
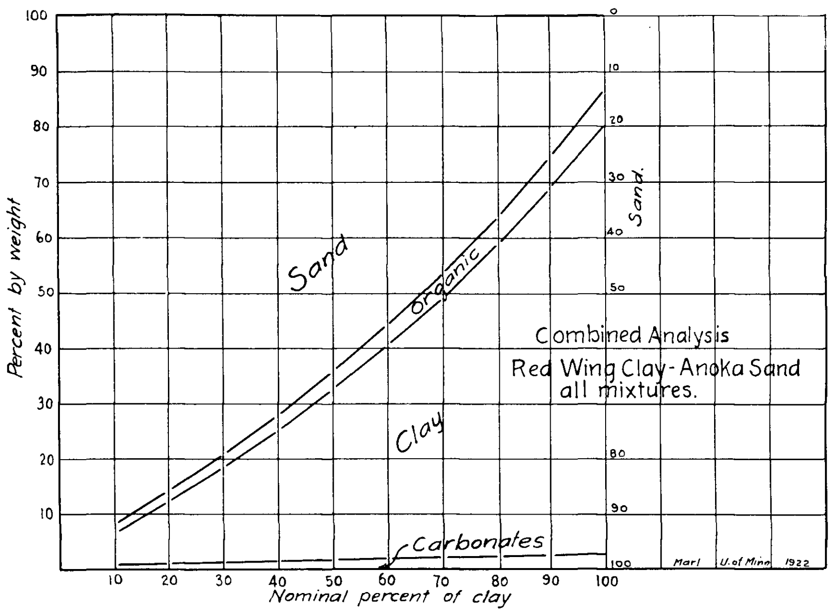


PLATE VIII



OBSERVATIONS ON BEHAVIOR OF MARL UNDER LABORATORY EXPERIMENT

At low percentages, the sand in the marl itself has a large effect relatively.

Slaking of clay and Barrows marl was very violent, as tho chemical action were taking place.

Slaking clay made the water muddy, but the marl noticeably did not, indicating lack of solubility, or ability to remain in suspension.

It was with difficulty that water was mixed with the marl powder, but, on the contrary, clay and water seemed to have an affinity for each other. Marl-dusty roads would shed water for a time.

The ability of the 35 per cent mixture of Hill City marl, noted on the slaking graph, to withstand water for seven days is unexplained.

Shrinking of marl mixtures, under pressure, and the giving up of excess moisture were noticeable. A test of 6 inches of marl and 6 inches of sand gave, under standard pressure, only 8 inches combined.

Marl mixtures do not become sticky until the very high percentages are reached. Marl, unlike clay, yields moisture under pressure.

Clay disintegrates progressively in finely divided particles. Marl separates in flakes.

Indications are that marl mixtures abrade easily.

Slaking of some marl cylinders was somewhat indeterminate as the cylinder retained its shape long after its firmness had gone. The test was therefore arbitrarily concluded in such cases by its response to the touch.

Referring to cementing value graphs, we note that clay mixtures beyond 30 per cent by weight gain strength rapidly. This point of rapid increase is about the same for marl, but at a lower lever of strength. The ultimate strength of clay and Coon Creek marl are about the same, but with different percentages of the marl. Hill City mixtures fall behind Coon Creek in high percentages. This probably is due to less final clay content, as shown by the graph of composite mixtures. The effect of the substitution of 10 per cent of clay for a like amount of Coon Creek marl gave the same cementive value as the clay and sand. In the case of Coon Creek marl, the organic matter does not seem to be detrimental, but in the 50 per cent Ham Lake, the situation is quite the reverse. Barrows marl appears to be the poorest of all. It will be noted that it has the lowest clay content of all.

If any useful purpose would be served, there is a field of experiment in determining, to a nicety, the effect of the various constituents of marl as we find it. We may say, in general, however, that the binding power of the carbonates is increased materially by clay; that sand, of course, is only an adulterant; and that organic matter weakens the mixture, unless offset by extra clay. Organic matter may, however, serve the useful purpose of reducing stickiness and of holding moisture—the latter being very desirable, as will be noted later in the account of surfacing experiments.

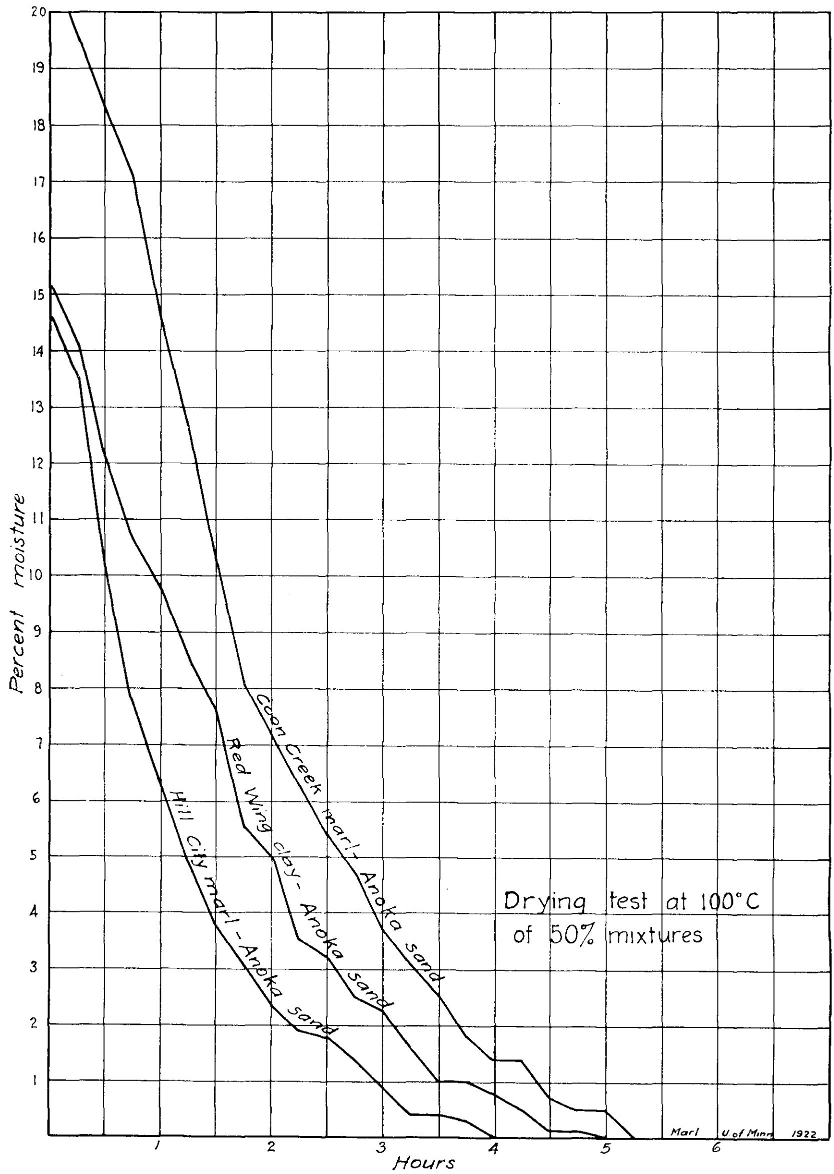
The comparative weights of equal volumes of sand and pulverized marl and clay, giving an idea of their density, follow. There are also shown specific gravities, as determined by Le Chatelier apparatus.

TABLE IV

RELATIVE DENSITY AND SPECIFIC GRAVITIES

	Density	Specific Gravity
Anoka sand	100	2.65
Red Wing clay	65	2.51
Hill City marl	55	2.54
Barrows marl	48	....
Coon Creek marl	39	2.18

PLATE IX


Percent moisture
Hours
Coon Creek marl - Anoka sand
Red Wing clay - Anoka sand
Hill City marl - Anoka sand
Drying test at 100°C
of 50% mixtures
Marl
U of Minn
1922

The voids in Anoka sand were found to be 39.7 per cent.

Samples, moist as molded, dried out at 100° C., indicated no great difference in drying out qualities between clay and marl. It was not believed that tests with more precise regulation of moisture at atmospheric temperatures would serve any practical end in this connection. A graph of the drying out tests is shown (Plate IX).

Indications from the laboratory were summarized just before the road work was undertaken. These observations follow, as prepared at that time, and it is interesting to note that they were substantially confirmed on the road work.

CONCLUSIONS REACHED FROM LABORATORY EXPERIMENTS ON MIXTURES OF CLAY AND SAND, AND MARL AND SAND

Marl-sand is a weaker combination than clay-sand. It will therefore break up more readily under traffic and become dusty. This condition of dustiness may be overcome by sprinkling with calcium chloride.

Marl-sand may, however, be strong enough to stand light traffic and not reach a critical point where it breaks down. It may withstand the action of auto tires where it may not withstand the action of steel wagon tires.

The Coon Creek marl-sand is light and fluffy, not at all sticky, very compressible, and molds readily in the hand. This absence of stickiness would indicate that, while in wet weather the surface of the road will cut into ruts, these ruts will not deepen, since no material will be lifted out while new material will be dragged in, partially filling the ruts. Hill City marl-sand is slightly sticky, but entirely unlike clay-sand. Both marl-sands are lighter and more compressible than the clay-sands.

There is no indication that the Coon Creek marl-sand will be slippery. The Hill City marl-sand, however, will be somewhat slippery. The presence of organic matter in the Coon Creek marl seems to make it much less sticky and slippery. However, an excess of organic matter will increase the tendency to dustiness.

On slaking, the marl-sand does not muddy or discolor the water. It is practically insoluble. For this reason, less marl-sand surfacing will wash away in rainy weather than clay-sand.

Marl-sand does not long remain suspended in water. When marl-sand is dry, it resists for a long time the penetration of water. On the contrary, clay-sand has an immediate affinity for water. This quality of marl may prevent the dry, dusty road from getting the full benefit of light rainfalls.

As the subgrade of the roads to be treated with marl will be invariably of sand, the waterproof quality of marl will be of no advantage, as it is desirable to have the sand subgrade moist.

Marl-sand dries out nearly as slowly as clay-sand. If the subgrade is moist, the marl surface should keep in good condition, because it will exhale moisture slowly at the surface.

Mixtures of marl-sand are very compressible. Finger-packed mixtures compacted under the machine one-fourth. Clay-sand is much less compressible. Marl-sand yields its surplus water very readily under pressure, while clay-sand retains its water content.

Marl-sand retains its molded shape under pressure. Clay-sand flows under pressure. On the road, this would indicate, in the case of clay-sand, that the ruts would become indefinitely deep from repeated pressure of traffic. The marl-sand would probably yield to a certain degree of compressibility, but would reach a limit where the rut probably would not deepen by direct pressure.

Being about the same as limestones, marl dust would probably be very objectionable.

EXPERIMENTAL ROAD AT RICE

Through the coöperation of Mr. Paul Zeese, highway engineer for Benton County, arrangements were made in May, 1922, to surface 1,000 feet of the road being graded east from Rice toward Gilman and Foley. The remainder of the road was surfaced with gravel by the county, as planned *(Fig. 56)*, the county devoting to our experiment the 1,000 feet on the extreme east and adjoining the concrete pavement on State Road No. 27. This was partly in cut and partly in fill, with a small proportion of fine sandy loam entering into the composition of the fill. The subgrade in the cut was pure sand. The roadbed was 24 feet and marl was spread 20 feet.

The deposit from which the marl was secured lies 2.5 miles east on the north side of the road and is an old pit from which large quantities of marl have been hauled previously to other portions of this road *(Fig. 5)*. This marl was spread with no mixing of any kind. The road had not been entirely satisfactory, because the marl in its unadulterated form, became slippery in wet weather, and because the crown was excessive. Still, upon careful consideration, the marl seems to be the saving constituent of this road to-day, even after its recent gravel-surfacing. The crown is now very moderate *(Fig. 55)*.

This marl deposit has several springs in it, at present, making its recovery at this time of the year somewhat expensive. A stratum of sand underlies the marl, and ordinary sandy loam averaging 2½ feet in thickness covers it *(Fig. 7)*. The costs were high because of the difficulty of getting out the small amount of marl which was required. If a larger quantity of marl were needed, more elaborate and suitable methods could be devised to reduce the expense materially. The organization of the county forces, because of the pressure of other work, was not economical. Some difficulty may generally be expected in obtaining marl. After hauling it 2½ miles from the pit, the moist marl consolidated into a single cake. This did not unload easily from long, narrow truck bodies, but slid out readily from the broad, shallow truck bodies. This detail of hauling should receive consideration.

The marl was hauled partly by wagon, by trucks with trailers, and by trucks alone. Hauling began May 18.

For the purpose of comparing various proportions and methods of applying marl to the surface, the 1,000 feet of experimental road was divided into four sections. The subgrade was carefully smoothed before spreading the marl.

Upon Section 1 was spread six inches of marl without any mixing with the sand below. It was not anticipated that this section would be desirable, but it seemed necessary to demonstrate the wrong way of applying marl as a surfacing material.

Upon Section 2 was spread three inches of marl, and six inches of sand of the subgrade was plowed up and mixed with it. The mixture was completed by four plowings in all.

Section 3 had a two-course treatment, each course containing three inches of sand and three inches of marl.

After the first three inches of marl and three inches of sand had been mixed, an additional three inches of sand was hauled over this surface by slips, the material having been left for this purpose in the partially finished ditches *(Fig. 21)*. After spreading the remaining three inches of marl, the final mixture was obtained by plowing again four times.

Section 4 was the same as Section 2, except that five inches of marl was mixed by plowing with six inches of sand.

Cores from the surface were taken after completion of the various sections by means of a collapsible galvanized iron tube *(Fig. 24)*. Of course, nothing approaching a laboratory mixture is possible. Much better mixtures were obtained at Pequot, where the method of mixing was better developed. Each of the materials, sand and marl, have qualities of stability when wet and dry, respectively, that offset each other, when the surface mixture is either wet or dry. Of course, the mixture improves under traffic, for in wet weather, the marl flows and mixes under pressure until equilibrium is reached.

On account of the organization of the county forces doing the hauling, it seemed necessary to spread the entire amount of marl before any mixing was done. Consequently, the marl became quite dry. It was found that a thoro discing with a spade disc *(Fig. 11)* was necessary to pulverize the marl so that it would mix well in the plowing *(Fig. 13)*. The disc cleaned well, even when the marl was wet. The surface was plowed four times, the mixture progressing to a satisfactory fineness *(Figs. 15–20)*. Careful regulation of the depth of plowing was necessary to assure the desired proportions of sand and marl *(Fig. 14.)* It is desirable that the marl be mixed promptly after being hauled, in order to retain its initial moisture. After plowing, the mixture is light and fluffy and subsequent shrinkage is very great, as it packs under traffic.

The final development in the method of mixing is described later in detail under Pequot Road.

Various attempts were made to mix marl and sand with the subgrade by discing and by the use of a tooth harrow, but the plowing seemed to be the most thoro and most precise method. Working the marl spreads it at the sides, and allowance should be made for this in the width of distribution.

The outstanding feature of the marl-sand mixture is its ability to pack under traffic, and at the final shaping of the surface, with blade, it was found that horses which sank deeply into the mixture at first, soon were travelling nearly on top, as the material compacted so quickly. Initial traffic produced only shallow ruts and, after these had been filled with the blade once or twice, they disappeared and broad wheel tracks took their place. In fact, on account of the very flat contour of the surface, tracks soon spread throughout the surface *(Fig. 25)*.

Sections 2 and 3, five hundred feet, were rolled after shaping with a nine-inch pneumatic tired truck weighing 8,400 pounds when empty. This truck was rented at $2.50 per hour from the paving job adjacent. Eight round trips covered the surface in fifty minutes' time. Rolling, where the surface mixture is very wet, would be difficult, but no difficulty was experienced at Rice, where the materials, tho loose, were comparatively dry. It can not be said that the rolling is necessary, but it compacts the road at once throughout its width, preventing ruts from forming under traffic, and greatly reducing the initial blade maintenance.

Because of the sand subgrade, only an inch or two of crown was used on the surface, with the expectation that drainage conditions would be satisfactory. The surface was complete June 1 *(Fig. 23)*.

It may be noted here that in the other roads which were built, mixing of the marl proceeded promptly as it was being spread, and that the moisture retained in the marl made a more plastic surface. For a time, the ruts were fairly deep, but yielded very rapidly to maintenance and finally attained a condition very similar to that at Rice.

After a very heavy rain on June 15, the surface of the road was unimpaired and very firm *(Fig. 26)*. Some wash occurred on the sand shoulders. It seems that very little maintenance will be necessary, as compared with that on gravel roads in their initial stages.

Up to the time when the surface gets dusty, it improves with travel. Because of its homogeneity, it does not pit or develop waves, to any great extent.

After a protracted dry spell, it was found that fast traffic raised a great deal of dust *(Fig. 27)*. Two treatments were tried to overcome this objectionable feature. On one section, a scant inch of fine gravel was spread *(Fig. 28)*. This acted as an effective dust blanket, and seemed, also, to preserve the surface under the abrasion of traffic. Another section was spread with calcium chloride in a dry form, 1.4 pounds per square yard *(Figs. 31 and 32)*. The surface has not deteriorated or raveled on this section, but has the texture and feel of a well-beaten foot path.

The cost of the road is summarized as follows:

331¼ cubic yards of marl in pit at $0.15	$ 49.69
Pit expense, { Stripping average 2½ feet; Stock piling }	227.30
Hauling by wagons and trucks 2½ miles	331.25
Spreading on subgrade	45.25
Rolling 500 feet	2.50
Mixing marl with sand of subgrade, etc	30.90
Calcium chloride treatment, 350 feet	24.00
Gravel dust blanket, 150 feet	10.00
Cost 1,000 feet	$720.89

The value of a marl-sand mixture for road-surfacing develops only with a thick coat, say a minimum of 4 inches of marl with 6 inches of sand, which will consolidate to about 7 inches. The sand needs only a little help. Because a laboratory mixture, filling the sand voids, is impossible, it must be inferred that the stability of the sand is developed through pocketing the sand in the mixture against displacement.

The marl dust is very objectionable, rising in a blinding cloud and adhering tenaciously to vehicles and to the adjacent landscape. Beneath the dust, the surface remains hard.

The pure marl on Section 1, as has already been remarked, is not desirable. It is too expensive because of the excessive thickness necessary. It is difficult to maintain a surface free from waves, and it becomes slippery in wet weather. The dust nuisance is an accompanying defect, as well.

Where the fine gravel dust blanket has been spread, dusting and disintegration have stopped *(Fig. 29)*. This appeared to be so satisfactory that the remainder of the experimental road was covered in the same manner, with the exception of the section noted just below.

The portion of the surface treated with calcium chloride has remained satisfactory. It is smooth and free from dust, and there seems to be no disintegration in progress.

The indications are that this surface will stand an indefinite amount of pressure without breaking through, but that to save it from attrition, the surface must be protected by a gravel blanket or calcium chloride treatment.

The road was again visited August 10. Recent rains had largely restored the surface smoothness and it appeared in very good shape throughout, the gravel- and chloride-treated portions being especially good.

The Rice Road was visited again on October 25 and again examined as to its condition. Preceding this examination, there had been no rain except for a very light shower, for five or six weeks, so it was feared that a considerable disintegration of the surface would have taken place. On the contrary, close examination indicated that the calcium chloride treatment and gravel blanket had, in each case, been effective in stopping the dust disintegration and had preserved the surface nearly intact. Vehicles passing raised practically no dust on the graveled portion and none at all on the calcium chloride section. This latter section has retained its moisture and, to all appearances, the surface has not suffered any loss of material nor become disfigured by traffic. It appears likely to remain indefinitely in its present condition, if this is possible *(Fig. 33)*.

The surface is very hard and smooth throughout, except where pure marl was applied. On this section, the surface was not bladed smoothly before the application of a gravel blanket and is now bumpy and in poor condition for driving. As has been said before, this pure marl-surfacing was not believed to be either desirable or economical. If bladed carefully, it may develop satisfactorily now that it is in place.

Joining the experimental road on the east is the section of road graveled by the county upon a loam blanket spread over the sandy subgrade. It has packed little and the travel is confined to single tracks. The contrast with the marl road is very noticeable *(Fig. 56)*.

Portions of the road farther east, where marl had been applied unmethodically, from time to time, by the county, are in good shape. Due to the final blending of sand, marl, loam, and gravel by constant working, a fine surface has been obtained. Marl appears to be the saving constituent *(Fig. 55)*. However, the experimental road built this summer is as good, if not better, and was obtained almost immediately in what was practically a single operation and with great economy of the materials which had to be hauled, namely, the marl and gravel.

Local road men seemed to be much pleased with the experiment, the maintenance man being especially so. The ease with which marl can be worked up in the road, as compared with the difficulty experienced in working clay in surfacing operations, was the subject of favorable comment.

It appears from the texture and soundness of the crust as shown by cutting out a sample, that it might withstand any ordinary weight of traffic and perform well its primary function of covering the subgrade with a puncture-proof coating *(Fig. 30)*. In this case, due to the extreme dryness, the surface required protection from attrition. Where the calcium chloride preserved the moisture content, the material became self-surfacing.

Under Section 3, where there was a two-course application of marl, there is a ten-inch crust.

EXPERIMENTAL ROAD AT PEQUOT

The road improved with marl surfacing in Crow Wing County was located about seven miles east of Pequot, and consisted of about 2,800 feet of very sandy road, a great part of which was on pretty stiff grades. In fact, the day the work was started, it was necessary to haul a roadster up through the deep sand at one of the steep places before we had hardly disturbed the surface by any shaping *(Figs. 34 and 35)*.

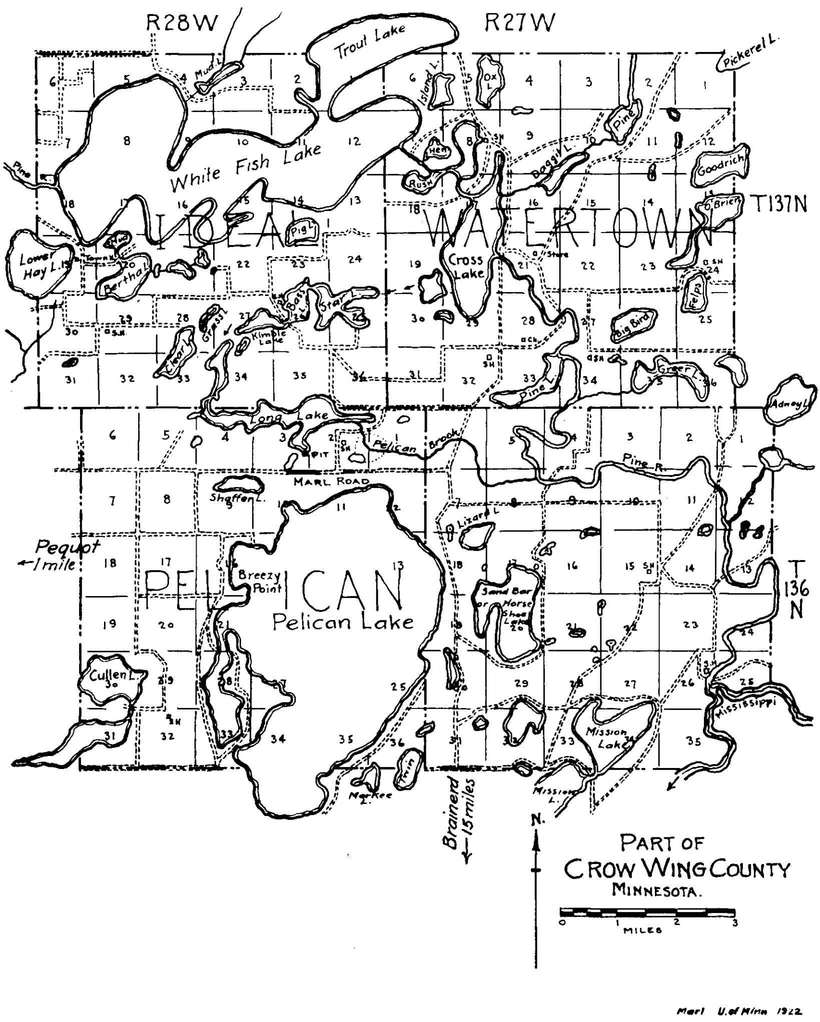
This road, when improvement was undertaken, while a laid out road, was little more than a trail, and before surfacing, it was necessary to do a considerable amount of work in straightening short stretches between summits, and to do some widening also *(Figs. 36 and 37)*. Marl was spread to a width of only twelve feet and the subgrade prepared sixteen to eighteen feet, without crown or ditches, as it was believed that the drainage in this loose, sandy subsoil would take care of itself. The topography is such, also, that little water comes to the road from the sides. It was also desirable to get as long a stretch of road completed as possible, fixing up the impassable portions first.

This improvement takes care of the worst places in this ten-mile east and west road.

This work was made possible through the coöperation of Mr. Walter M. Murphy, highway engineer of Crow Wing County, the expense of the operation being borne by the county. The patrolman of this road, Mr. Halvor Halvorsen, acted as foreman, and after the routine had been established, was able to build a very satisfactory surface without further supervision. This circumstance was considered a good demonstration of the simplicity of the method. He also surfaced the county relocation built soon afterwards, a little west of the experimental road *(Figs. 59 and 60)*.

The marl deposit is on the south shore of Long Lake, where it approaches closest to Pelican Lake *(Figs. 8 and 9)*. The situation of Long Lake in relation to surrounding lakes is shown on the accompanying map (Plate X). This deposit may be from the Pelican Lake seepage, as the water remains open in winter in front of the deposit, about where such seepage would be expected. This deposit is above water level and about two feet thick where taken, but to oblige the farmer, by refraining from cutting up his field, the marl was taken

PLATE X


R28W
R27W
T137N
T 136 N
Trout Lake
White Fish Lake
Lower Hay L.
Bertha L.
Pig L.
Cross Lake
Star L.
Kimble Lake
Long Lake
Pine L.
Big Bird
Greer L.
Goodrich
Pickerel L.
Adney L.
Pelican Brook
Pine R.
MARL ROAD
PIT
Shaffer L.
Lizard L.
Breezy Point
Pelican Lake
Sand Bar or Horse Shoe Lake
Cullen L.
Mission Lake
Mission L.
Mississippi
Markee L.
Pequot ←1 mile
Brainerd ←15 miles
IDEAL
WATERTOWN
PELICAN
N.
PART OF
CROW WING COUNTY
MINNESOTA.
0 1 2 3
MILES
Marl U. of Minn 1922

very near the water's edge. This proved to be but a slight disadvantage. The lake levels in this vicinity have all been lowered considerably, and abundant and dry deposits occur along all the shores of these lakes.

The road was divided into sections about 200 feet long for working. Four inches of marl, with six inches of sand, were used for the greater part. Five inches of marl and seven inches of sand were combined on the steepest grade. A skin coat of two inches was disced into a level stretch already comparatively firm. There proved to be little benefit derived from this last. The application of marl needs considerable depth of mixing to secure a thick, homogeneous crust over the sand.

Hauling and spreading began at the distant end of the section nearest to the pit, as wet marl is a difficult surface upon which to haul. Spreading followed on the next section beyond, making it necessary to haul through the loose material of the first section during the time it was being mixed. This did not develop any great difficulty, because a plow team was available to help, as it was occasionally needed. So the benefit of hauling over the smooth road as it was completed, section by section, was realized.

Hauling was done by team entirely, with pole-bottomed wagons. The haul varied from 2,000 to 6,000 feet. About one cubic yard to a load was carried. There were several rains during the progress of the work. The marl was mixed with considerable difficulty, requiring repeated use of the spade disc harrow. Traffic cut in rather deeply, at first, but after a small amount of maintenance, the surface became smooth and rutless *(Figs. 39 to 45, 47, and 48)*.

The method tried out at Rice, improved upon here, and followed later on the Central Avenue Road, is as follows:

1. Subgrade is smoothed by any convenient method and brought to a very low crown, say not over three inches for twenty feet of width.

2. One half of the total amount of marl to be used is spread over a width of about 2 feet less than the proposed finished surface.

3. The third operation is to thoroly pulverize the marl as finely as possible with a disc harrow before plowing. If dry, tooth harrows may be used. Some marls are friable, as in the case of the Central Avenue material, and there a tooth harrow was very satisfactory.

4. Plow this marl coating under, setting the plow to elevate the required amount of sand to be mixed with the marl. This will vary with the kind of marl used, but will be approximately equal in amount. The first furrow should be started at the left of the center, throwing towards the center, and so on around, leaving at its completion, deep furrows at each side of the road.

5. Spread the remaining half of the marl *(Fig. 38)*.
6. Thoroly pulverize the second coating of marl.
7. Plow three times more, the second plowing beginning at the outside and finally leaving a deep furrow in the center. The third plowing leaves furrows at the sides and the fourth plowing leaves a furrow in the center again. If the marl is very wet, it will be advisable to do some pulverizing between the plowings. Be sure the first plowing is not deeper than the ones following, so as not to lose any of the marl.
8. The last operation is to blade the surface to the proper crown and contour.

The road is now ready for traffic. Maintenance should fill the ruts two or three times in the next few days. Light blading appears to be best for this purpose. The crown should be kept low. In fact, it was kept flat on the twelve-foot width at Pequot. No wash has resulted on the hills from several rains during a month and a half up to the time it was last observed.

Cost figures follow. This cost very closely approximates a reasonable charge for doing the work and may be considered typical on this class of road. The length in this case is 2,800 feet.

Shaping subgrade	$ 23.40
352 cubic yards of marl in pit at $0.10	35.20
Digging and hauling marl	238.20
Spreading	50.85
Mixing marl with sand of subgrade	40.50
Rental of tools	3.00
	$391.15

Road work was in progress at Pequot from June 9 to June 23, 1922, inclusive. When visited August 2, it was still in excellent shape, only a little dust appearing in one place. The two-inch disced coating had pitted and loosened a little. It is believed that the prompt mixing of the marl, thus retaining its moisture, was an important factor in developing a hard, firm crust. Some rain during the construction benefited the road as well, tho somewhat hampering the building operations.

The Pequot Road was again visited October 26 and 27 and was found to be in as good a condition as when last inspected, August 2, 1922. Since then, there had been little rain. The patrolman had record of passing the Minnesota Planer over the surface, September 16, 23, and October 19, each time after a light rainfall. Only a few small stretches showed dust *(Fig. 46)*. The remainder was smooth and hard *(Figs. 47 and 48)*. The absence of waves and chuck holes was in great contrast to the average gravel road at this season. Though only twelve feet wide, there was an almost complete absence of ruts.

This surface, where examined, was too hard for the shovel, so a hole was carved through with the knife. It so happened that at the spot selected, only six inches of crust were found, but as noted above, it was very dense. The intention was to apply five inches of marl, but due to its wetness when applied, there seems to have been considerable consolidation.

The local comment was uniformly favorable and the road is considered very successful. The county highway engineer, Mr. Murphy, was particularly enthusiastic over the results and has caused a search to be made for marl deposits adjacent to county highways now under construction with a view to its use in surfacing operations.

Some marl-surfacing has been done by the county, where the sand road already has been surfaced with clay. This is not believed to be desirable as sand should be worked up into the mixture to provide for wet weather conditions. It is now as hard and smooth as baked clay *(Figs. 57 and 58)*.

This Merrifield Road is a fine road, pushing north and taking the place of the woodland trails typical of this country *(Fig. 61)*.

A little west of the experimental road, there was a steep, crooked, sand road which would have been improved when building the experimental road, but the expense was prohibitive. Since that time the township has relocated and graded this stretch and the county has surfaced it with marl. The foreman was instructed to use the method employed on the experimental road. He applied about five and one-half inches of marl eighteen feet wide. The result is a smooth, hard road *(Figs. 59 and 60)*. This is a further demonstration of the simplicity of the method as developed. The cost was $132.90 for 600 feet of surfacing eighteen feet wide, at the rate of $1,170 per mile.

Mr. Murphy has surfaced several portions of the Merrifield Road. For the time being, the marl has been spread only in a thin layer upon the clay-surfacing previously applied over the sand subgrade. For some reason, though the weather has been dry for a long time, there is no dust. The surface is smooth and hard like baked clay. The whole surface may break up under continued rain or after frost, as does an ordinary clay road. It is not believed that this is an ideal application of marl. It may ameliorate the stickiness of the clay. If the present marl-clay surfacing is worked up with the sand of the subgrade, the marl and clay ought to be most useful as surface ingredients.

Stimulated by the general interest in the road experimentation and the simultaneous investigation of the use of marl for the manufacture of cement, many deposits of marl have been recently discovered. So no lack of material is anticipated where marl is desirable for surfacing.

CENTRAL AVENUE EXPERIMENTAL ROAD

The Central Avenue Road is a continuation of Central Avenue, Minneapolis, passing two miles east of Bethel, and extending to Isanti and to points beyond.

There is a distance of about eighteen miles, where the grading has been completed and bridges built, but which has not been surfaced in any way, and a more unsatisfactory road on which to travel is difficult to picture *(Fig. 49)*. There is considerable milk and garbage truck traffic on this road each day, and the deep tracks have become very crooked, and undulating to an almost impassable extent.

A search was made for both clay and marl which might be used as material for providing either a satisfactory surface in themselves, or a basis for later application for gravel. Incidentally, clay was found at the south end only, in one large deposit, and at the north end in several deposits, but not between them.

One large deposit of marl was found near Ham Lake, other deposits being negligible. The one at Ham Lake is in the form of a sink hole, some portions of which have pushed up through the peat on the sides, due to the subsidence of the deep fill which was found to be necessary in order to pass over it. The experimental road was built from this material, pushed up through the old ditch beside the road. It had spread into rather large masses, close enough to the road to be handled by wheelbarrows on planks *(Fig. 10)*.

No new features were encountered at Ham Lake, excepting the extreme fineness of the sand and the peculiar friability of the marl, making the use of a tooth harrow desirable in pulverizing the marl when spread *(Fig. 50)*. The road is surfaced twenty-four feet in width, with practically no crown *(Fig. 51)*. Costs on this road were very high, because it was necessary to import men and tools from Anoka, as the farmers along the road were unable to assist at the time the road was built, namely, the last week in July. As the costs are not in any way typical of large scale operations, they are not introduced. Neither is it likely that the close proximity of the marl could be duplicated; it was situated on the right of way and therefore cost nothing.

For lack of a blade to trim the surface after mixing, an additional plowing was introduced, resulting in a very level surface, but with deep furrows at the sides. Due to the width surfaced and the light traffic, these were not considered objectionable and will gradually disappear.

The inaccessibility of this road makes its frequent examination impossible, but on a visit one week after completion, it appeared to be forming slowly as had the other experimental roads *(Fig. 52)*. It has had very little travel and negligible maintenance. The first section built received a little maintenance while Section 2 was under construction, and is in good shape. The marl was very wet and there had been some rain, so the single tracks through Section 2 were still deep through lack of maintenance. There was some difficulty in passing traffic during the process of spreading and mixing.

The Central Avenue Road was visited again on October 25. It was reported that the ruts had been filled once by hand with a shovel. The road had been dragged twice, perhaps. The ruts were found to be completely filled and replaced by broad, flat wheel tracks *(Figs. 53 and 54)*. Because of the shortness of the section built (only 200 feet) and adjacent single ruts in the sand road at both ends, the traffic has not spread out over the whole width. The surface of the road in the wheel tracks is hard, firm, and free from dust. The remainder of the surface is spongy, but will bear traffic without much penetration.

This development of a firm surface practically without maintenance brings out one of the essential characteristics of the marl-sand mixture, namely, that it will pack under traffic, yielding up its excess moisture as had been anticipated from results of laboratory experiments.

A farmer living near this road said that the two deep ruts continued for some time, leading to the opinion that the road was no improvement. However, the ruts of themselves then began to fill up and his opinion had changed to a decidedly favorable one.

The surface is free from longitudinal waves and vertical chuck holes, which are such an objectionable feature of the typical sand road under truck traffic and which contribute more to impassibility than the crookedness of the ruts.

An examination of the material of the surface showed a very thoro mixture of marl and sand, perhaps better than any of the other roads built. This was probably due to the peculiar friability of the marl from this deposit and to the additional plowing during construction.

It is anticipated that Central Avenue will be paved soon. Consequently, the local people do not exhibit any great enthusiasm for this experiment. Very little of the marl in this deposit is above water. If it can be excavated cheaply, perhaps during the winter, the township authorities are planning to treat with marl some of the side roads which intersect Central Avenue. To this extent, local people have been converted to the idea of using marl in their problem of sandy roads.

CONCLUSIONS

The experimental roads were built during June and July and have been held under observation until the last of October. This has carried them through long dry periods, the most trying time for marl roads. Altho this period of observation is not long enough to justify ultimate conclusions, certain deductions seem warranted and appear definite enough to record.

As a slab to bear up the weight of traffic against breaking through into the subgrade, the marl-sand surface has proved entirely satisfactory.

The surface has withstood heavy rains without noticeable injury. Beyond a certain amount of absorption, it seems to be impervious to water. In fact, the road seems to thrive on moisture and is at its best under fairly frequent rains.

The application of a uniform coating over the width of the road, with a very low crown, seems to be confirmed in principle, the idea being to induce traffic to use the full width of the roadway, preventing ruts and concentrated wear. Therefore, a feather-edge application would be insufficient.

Due to the large percentage of sand in the mixture, and because of its satisfactory performance in wet weather, we may safely assume that there will be little difficulty from frost action.

The mixture is homogeneous and yields a smooth surface, without waves or chuck holes. Travel is peculiarly pleasing, due to a resilience very much like the feeling under foot of a well-worn foot path through a field.

The application and routine of construction, as developed and described under the Pequot Road, is very simple and of moderate cost. It must be said, however, that such a method must be faithfully followed, or the results will be disappointing. The inherent qualities of marl and sand can be made useful only by intelligent manipulation.

After protracted dry weather and under heavy traffic, the surface becomes very dusty, this dust being somewhat more offensive than the ordinary kinds. Light traffic produces little or no dust, even during protracted dry weather.

We may say that, for light traffic, the surfacing of a sand subgrade with marl-sand surface is satisfactory from every standpoint, compares favorably with other forms of treatment, and is a great improvement over the loose sand through which it is built. The surfacing promises to be durable and permanent to a satisfactory degree under such traffic.

Moderate traffic will require surface treatment on account of the dust nuisance. The blanket of fine gravel, of not over an inch in thickness spread over about two-thirds the width of the roadway, has been entirely satisfactory for this purpose. Calcium chloride serves the same purpose durings its life, perhaps even better. Because marl holds moisture well, the applications seem to be effective for a long time.

Under heavy traffic, disintegration by dusting in dry weather will be rapid without surface protection. Our gravel blanket must be thicker and we shall then have in effect a gravel road upon a base course of marl-sand. There are indications that this combination is almost ideal because of the freedom of the marl-sand from waves and surface pockets. Only a moderate thickness and width of gravel are necessary, as it does not need to contribute structural strength, in addition to the marl slab beneath, and occasional travel at the extreme sides will be well taken care of by the marl.

Comparison was made in the laboratory of marl with clay. Where clay is available and it can be combined in accurate proportions with sand as a surface mixture, it is probably superior to marl-sand. Pit clay varies greatly in its sand content and is difficult of manipulation in surfacing. Clay is at its worst in wet weather and at its best in dry weather. Contrasting the qualities of clay with those of marl that have been set down, we may say that marl compares very favorably with clay and is superior in some respects as a surfacing material for roads.

The experimental road built east of Pequot in Crow Wing County is considered very satisfactory by the county authorities and by local people generally. The county has independently surfaced a piece of road in the vicinity *(Figs. 59 and 60)*, using the precise method developed on the experimental road. It is also giving satisfactory service. A search for marl deposits is being made near newly graded county roads with a view to making quite general use of marl in surfacing operations.

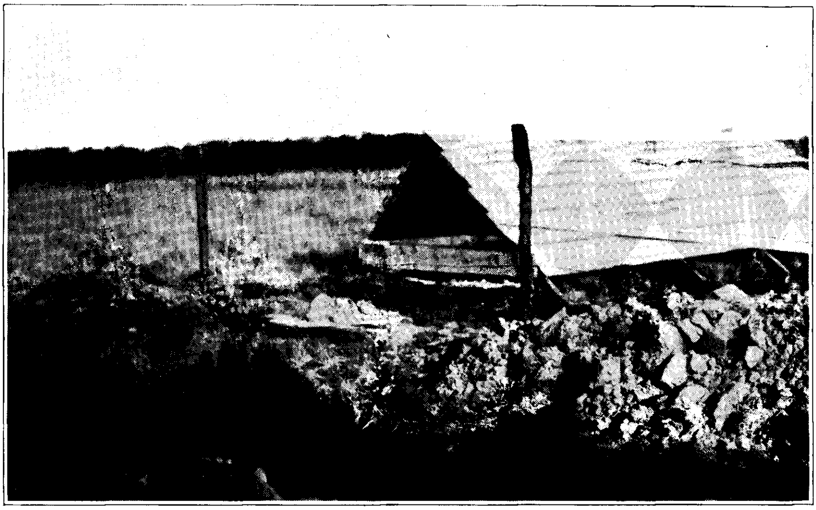


FIGURE 1. MARL PIT, ON COON CREEK

Marl obtained from this pit was used as fertilizer on the Coon Creek Experimental Farm. The pit is in the old bed of Coon Creek which has been deepened by ditching and thus made narrower.

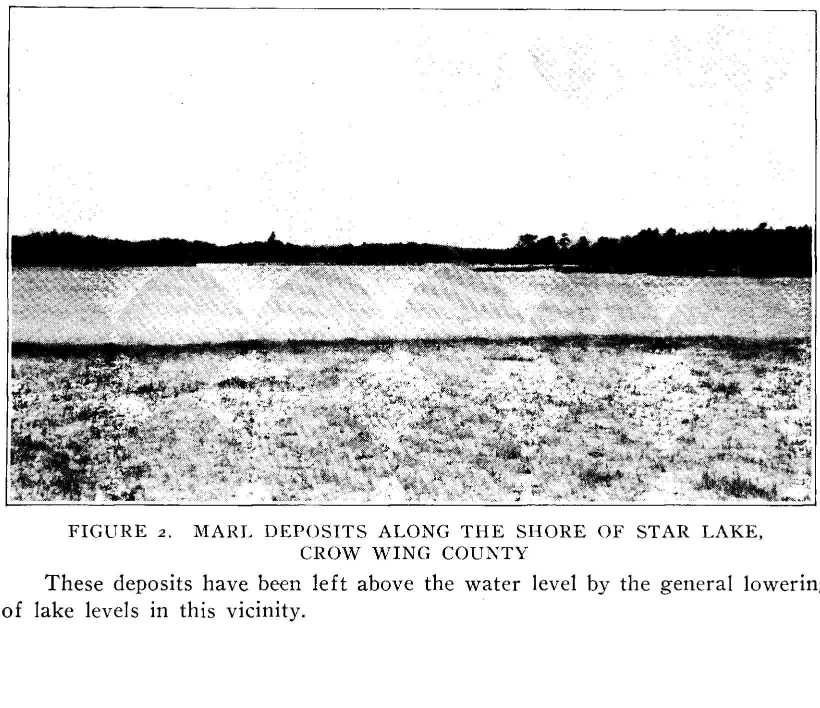


FIGURE 2. MARL DEPOSITS ALONG THE SHORE OF STAR LAKE, CROW WING COUNTY

These deposits have been left above the water level by the general lowering of lake levels in this vicinity.

FIGURE 3. MARL DEPOSIT NORTH OF BRAINERD

Merrifield Road was surfaced from this deposit, which lies in a depression not far from the present shore of a lake. Stripping was dumped into portions of the pit as the marl was exhausted.

FIGURE 4. ROAD CONSTRUCTED THROUGH DEPOSIT OF PURE MARL

Five miles north of Crosby, immediately west of the bridge over the Mississippi River. Note the cut in foreground, then fill, and another cut in the distance.

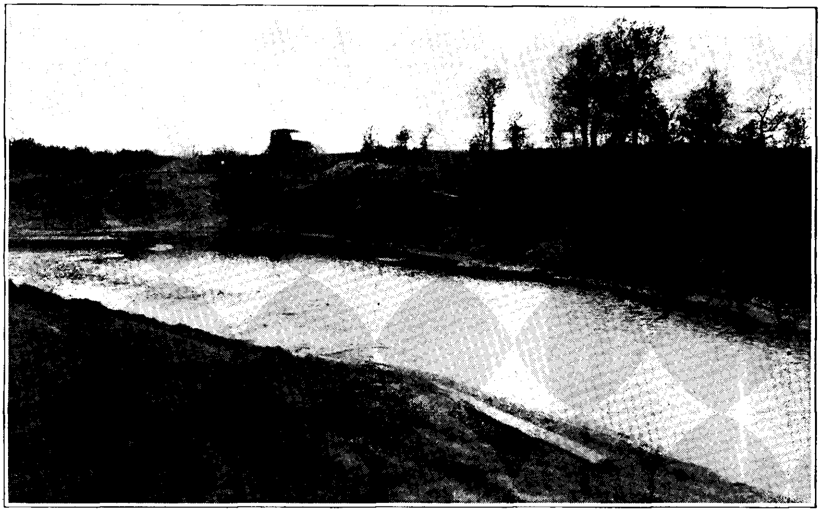


FIGURE 5. BENTON COUNTY MARL PIT

From time to time, large quantities of marl have been taken from this pit to surface the road east of Rice. At the present time, springs issue from this deposit.

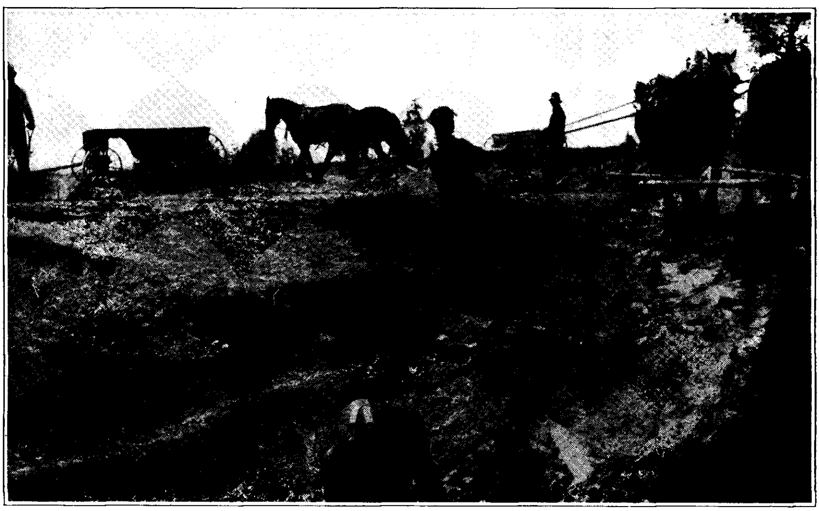


FIGURE 6. RICE ROAD. EXCAVATING MARL BY HAULING IN SCRAPER

As the pit had become wet and too soft to support the horses, they were driven around the edge. The scraper was dropped, and then hauled out as shown.

FIGURE 7. RICE ROAD. TAKING OUT MARL WITH SLIPS

The depth of stripping shows on the left. A stratum of marl, seven feet in depth, rests upon the sand outcrop in the foreground. The upper portion of the marl stratum was firm, but a wet, slippery condition was encountered two feet below. The marl was hauled out and stock-piled just beyond the edge of the pit.

FIGURE 8. PEQUOT ROAD. MARL DEPOSIT ON LONG LAKE

This deposit was found on the shore of Long Lake, where it is nearest to Pelican Lake just south. Local residents say that levels show that Pelican Lake is higher than Long Lake. At any rate, the water in front of this marl deposit does not freeze in winter, indicating seepage into Long Lake from the direction of Pelican Lake. This deposit is covered by a thin sod.

FIGURE 9. PEQUOT ROAD. LOADING MARL FROM PIT

The deposit is two feet thick. Stripping is cast into the pit after the marl has been removed.

FIGURE 10. CENTRAL AVENUE ROAD. MARL PIT BESIDE THE ROAD

The subsidence of the fill has pushed the marl up through cracks in the peat.

FIGURE 11. RICE ROAD. TYPE OF SPADE-DISC HARROW USED IN PULVERIZING MARL AFTER DISTRIBUTION

FIGURE 12. RICE ROAD. BLADE MACHINE FOR SMOOTHING SURFACE AFTER USING THE DISC HARROW

A uniform layer of marl is thus secured before beginning the plowing. Subsequently, this process proved to be unnecessary at Pequot.

FIGURE 13. RICE ROAD, SECTION 3. EFFECT OF THE DISC HARROW

Three inches of marl had been spread on the road. On the left, the marl had lain several days and a certain amount of it had become powdered. On the right, the marl had recently been distributed and was still wet and plastic. In this portion the disc harrow brought up a considerable amount of sand. It was thought, at first, that sufficient sand could be brought up in this manner to make a satisfactory mixture, but this method was abandoned and plowing substituted.

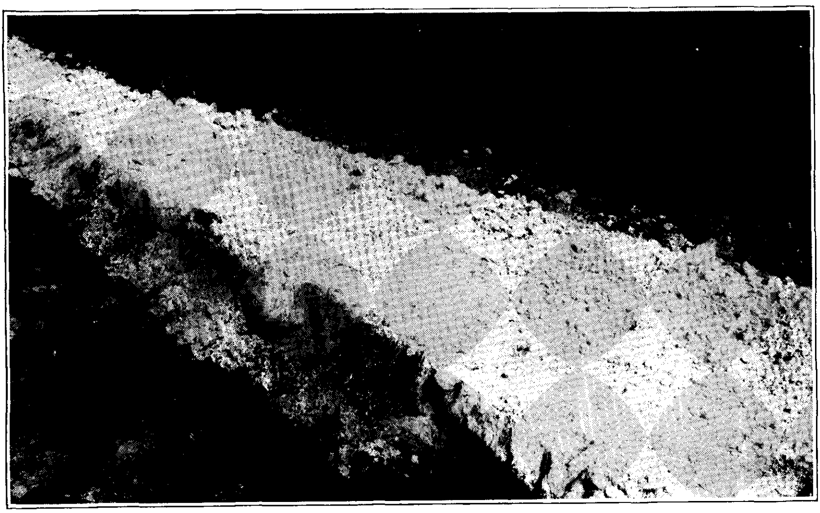


FIGURE 14. RICE ROAD, DEPTH OF PLOWING

The furrow has been thrown toward the left. The depth of the plowing in the sand below the marl can be seen in the foreground.

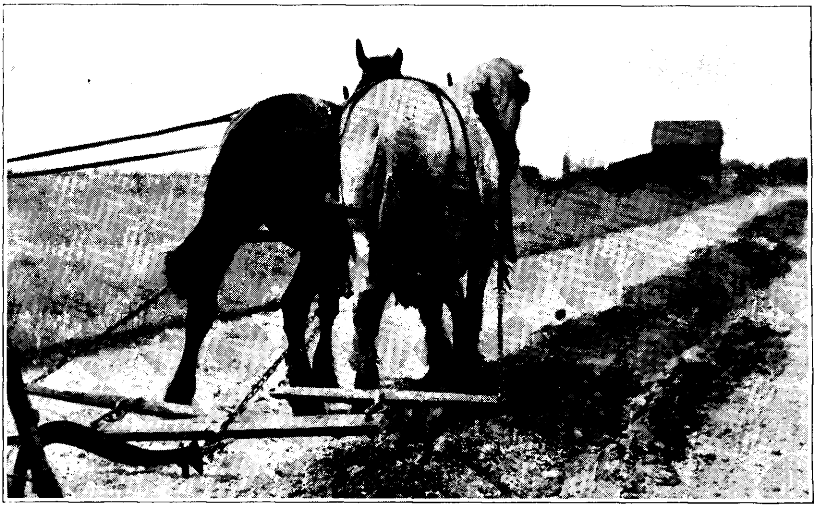


FIGURE 15. RICE ROAD, FIRST FURROW OF THE FIRST PLOWING

This furrow was made toward the observer and the point of the plow set about one foot to the right of the center. The return trip will leave a narrow strip, untouched by plowing, exactly in the middle. This strip will be reached on the second plowing.

FIGURE 16. RICE ROAD. FIRST PLOWING ABOUT HALF FINISHED, WITH THE MARL TURNED UNDER

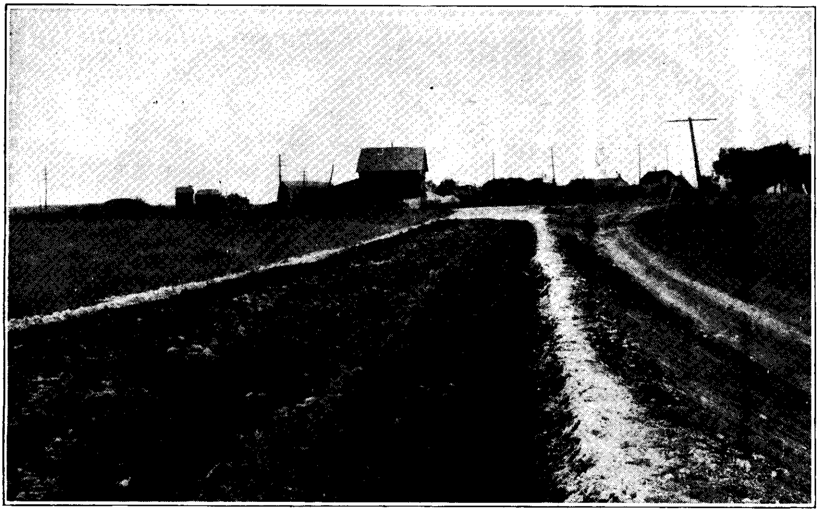


FIGURE 17. RICE ROAD, SECTION 2, AFTER THE FIRST PLOWING

Three inches of marl and six inches of sand were used. A furrow in the edge of the shoulder will be noted.

FIGURE 18. RICE ROAD, SECTION 2, SECOND PLOWING

Two furrows have been cut on the second plowing. In this case, a furrow was drawn toward the shoulder, filling the furrow shown in Figure 17.

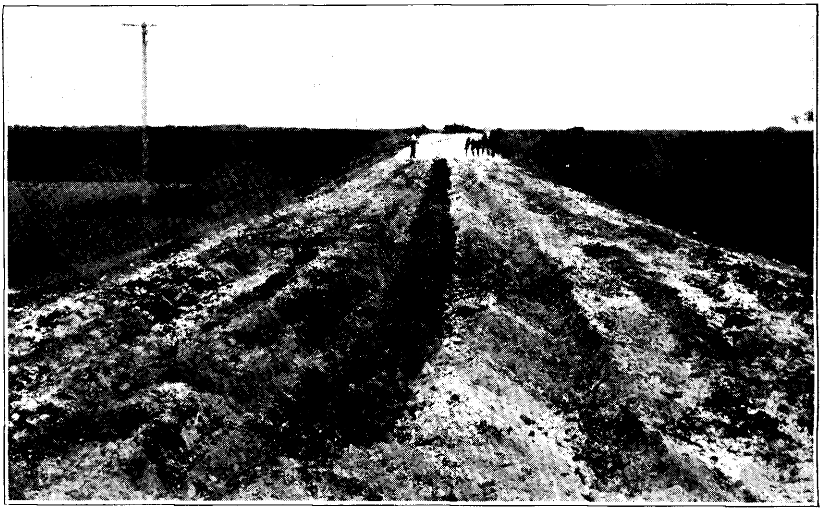


FIGURE 19. RICE ROAD, END OF THIRD PLOWING
The materials are becoming well mixed.

FIGURE 20. RICE ROAD, AFTER ALL PLOWING HAD BEEN DONE

The next operation was merely to smooth the surface with the blade machine. At the beginning of this process, the horses sank six inches or more into the loose material, but after several trips the material became so compact that they could walk practically on top of it. This figure shows the material after being filled to the shoulders, the dead furrow being in the middle. This is typical of an even number of plowings, where the first starts in the middle.

FIGURE 21. RICE ROAD, SECTION 3, TWO-COURSE TREATMENT

Three inches of sand which had been left in the unfinished ditches of the adjacent cut are being added. This will be covered with three inches of marl, the two forming a second course after mixing. This second course was mixed by plowing, as in the other portions of the road. The plow slipped along on the surface of the first course which had been rolled, without penetrating.

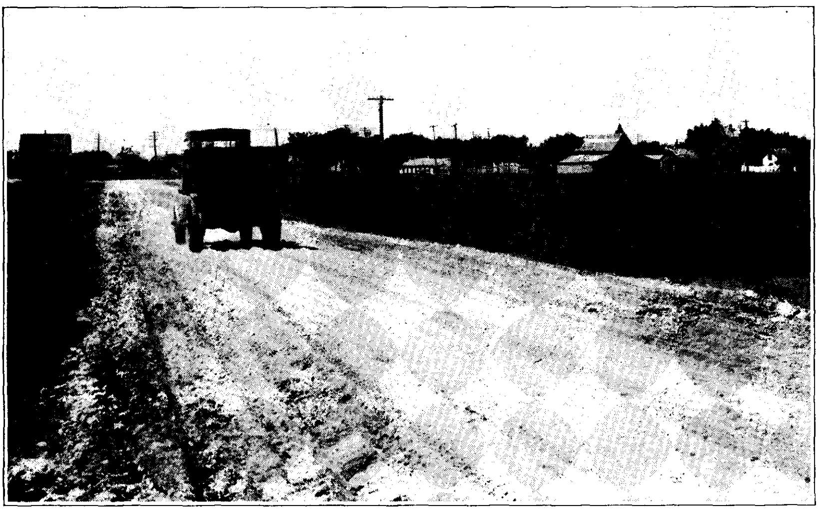


FIGURE 22. RICE ROAD, ROLLING SECTION 2 AND THE FIRST COURSE OF SECTION 3

This was an experiment. The trucks were available because of concrete paving operations at Rice. This is a Sterling 2½-ton truck, weighing 8,400 pounds. The rear tires are the new Goodyear type, with flat treads. The driver made eight round trips over the surface and covered every part of it. The portion rolled was 500 feet in length and the time consumed was 50 minutes. The surface was so compact that the truck itself did not sink below the depth of the first track when zigzagging over the surface after the rolling was done.

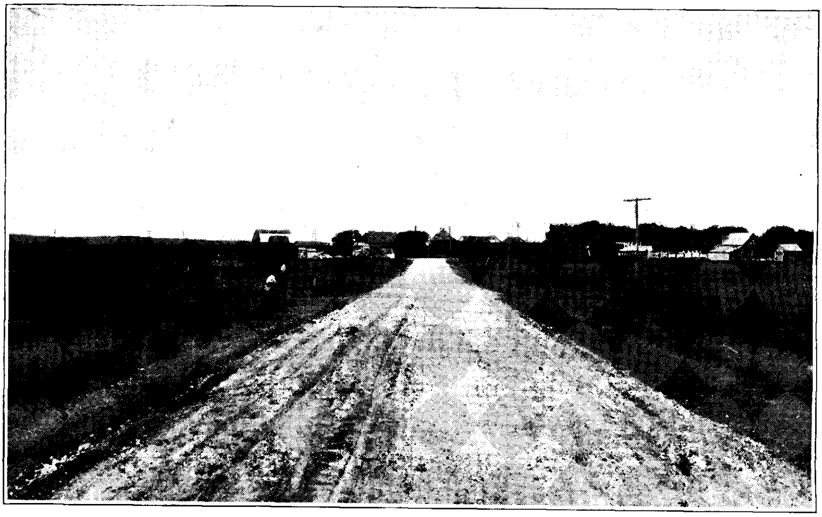


FIGURE 23. RICE ROAD, COMPLETED

Section 4 is in the foreground and Section 1 in the distance.

FIGURE 25. RICE ROAD. WAGON LOAD OF FIFTY SACKS OF CEMENT

The load produced very little impression upon the surface. The absence of ruts or pronounced wheel tracks is notable. The road is only a few days old.

1 2 3 4

FIGURE 24. RICE ROAD. SAMPLE CORES TAKEN FROM ROAD

These cores were taken from Sections 1 to 4 inclusive. From left to right they are Section 1, pure marl; Section 2, three inches of marl and six inches of sand, mixed; Section 3, two courses of three inches of marl and three inches of sand, mixed; Section 4, five inches of marl and six inches of sand, mixed. The distinct line of cleavage is noticeable at the bottom of Sections 2, 3, and 4, and between the courses in Section 3. The cores are three inches in diameter and about eight inches long and were obtained by driving a collapsible tin tube through the surface and withdrawing it.

FIGURE 26. RICE ROAD, AFTER SIX HOURS OF VERY HEAVY RAIN

Notice the small depression made by vehicle on saturated surface.

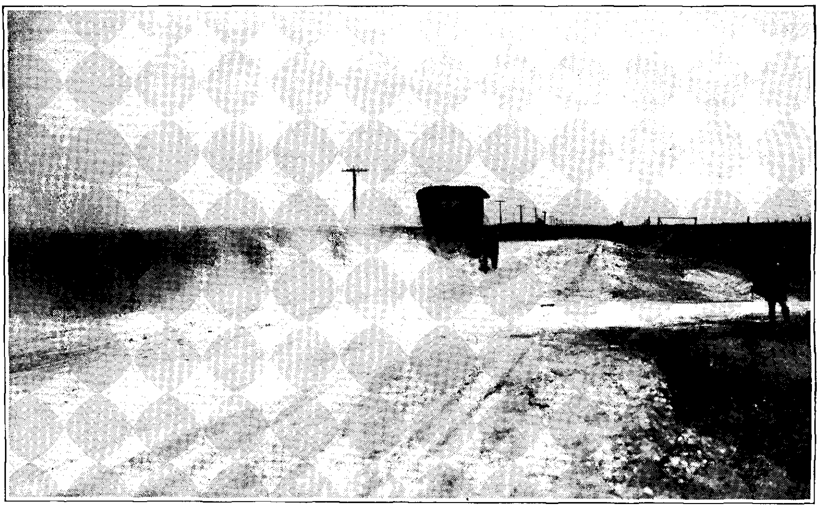


FIGURE 27. RICE ROAD, AGGRAVATED DUST CONDITION UNDER FAST TRAFFIC

Vehicle is moving at the rate of twenty-five miles an hour, and a high wind blowing.

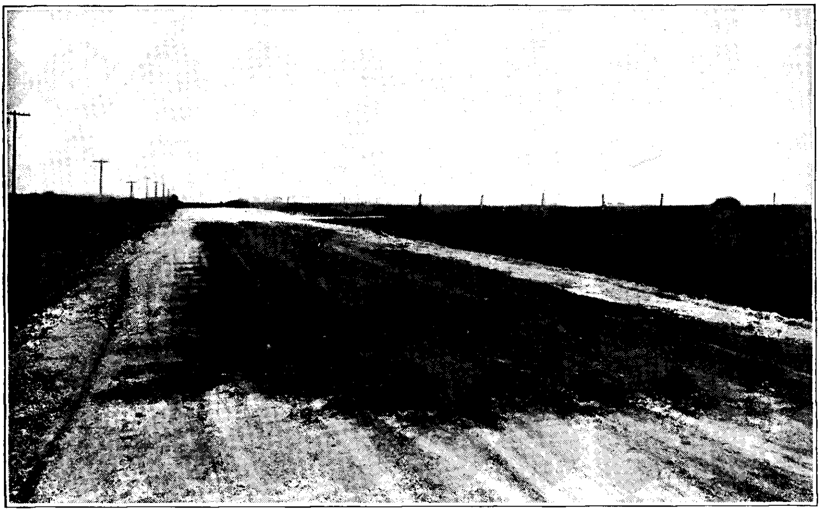


FIGURE 28. RICE ROAD, GRAVEL COATING

A one-inch coat of fine gravel forms a wearing surface and dust preventive on the marl road.

FIGURE 29. RICE ROAD. DUST PREVENTION BY GRAVEL SURFACE

An attempt is made here to show the contrast between the dusty surface and the absence of dust where the gravel blanket has been spread. The vehicle is traveling rapidly.

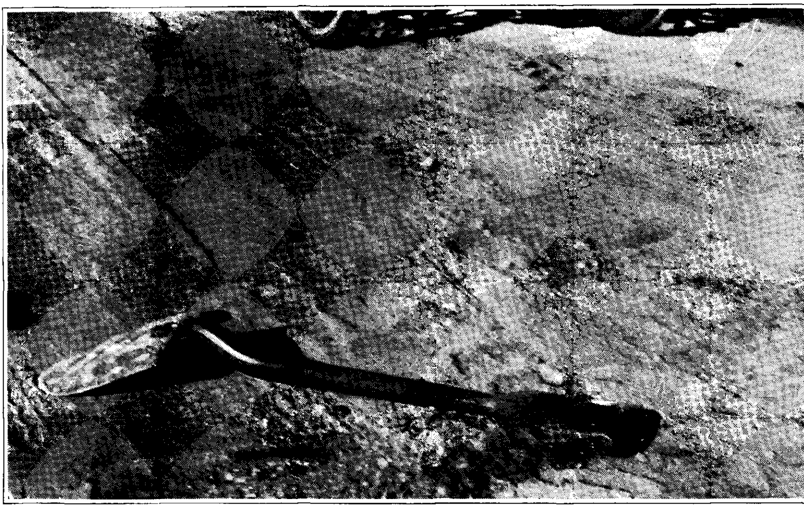


FIGURE 30. RICE ROAD, CLOSE VIEW OF GRAVEL BLANKET

The dark streak in the shallow excavation of the wheel track indicates the thickness of the gravel, which is less than an inch. The firmness of the remainder of the surface is evident beneath the vehicle in the background. The surface is three months old.

FIGURE 31. RICE ROAD, SECTION SPRINKLED WITH CALCIUM CHLORIDE

View of surface just after sprinkling with powdered calcium chloride, 1.4 pounds per square yard. Gravel coating shows in the distance.

FIGURE 32. RICE ROAD, SURFACE TREATED WITH CALCIUM CHLORIDE, AFTER TWO WEEKS

It is to be noted that this coating prevents rutting or raveling of the surface.

FIGURE 33. RICE ROAD, CALCIUM CHLORIDE TREATMENT AFTER THREE MONTHS

One application was made. Practically no maintenance has been necessary.

FIGURE 34. PEQUOT ROAD, BEFORE IMPROVEMENT

This road passes over a ridge which extends into Long Lake. The grades vary from 3 to 10 per cent in short stretches and, before improvement, were at times nearly impassable. In fact, before the grading, one automobile was hauled up the hill, shown in the picture, by team.

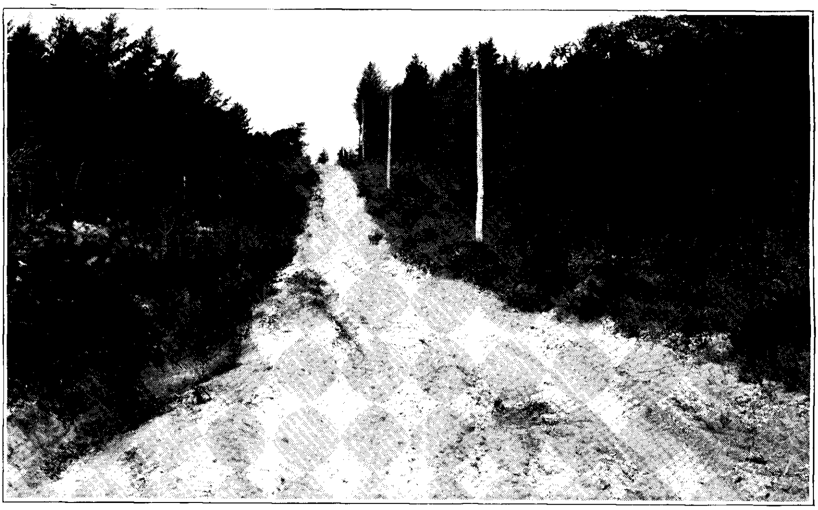


FIGURE 35. PEQUOT ROAD, SANDY SECTION BEFORE IMPROVEMENT

Figure 43 shows the same section after improvement, but viewed in the opposite direction.

FIGURE 36. PEQUOT ROAD, PREPARATION

It was necessary to trim the edges of the existing road to secure a satisfactory alignment and a fairly uniform surface. This was done with the blade machine and by plowing furrows at the edges. The road was shaped eighteen feet wide, without ditches, the subsoil being pure sand.

FIGURE 37. PEQUOT ROAD, TREE DRAG

The previous operations left a large amount of sod on the subgrade which it was desirable to eliminate. The sod was pulverized by dragging a full-sized tree over it and the remaining portions were then forked out.

FIGURE 38. PEQUOT ROAD, APPLICATION OF MARL

A two-inch layer of marl was spread as a second application after the first equal layer had been plowed under.

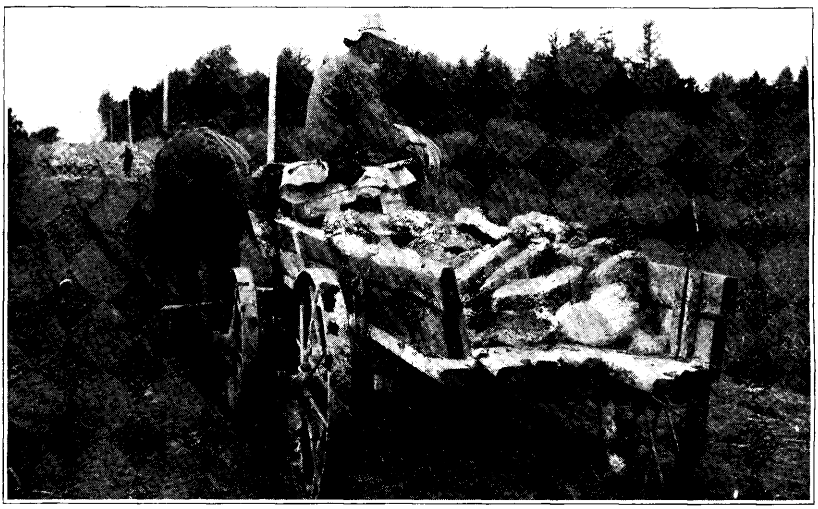


FIGURE 39. PEQUOT ROAD, EFFECT OF HAULING OVER A RECENTLY FINISHED SURFACE

The "load" contained 1¼ yards of wet marl. After plowing, no further preparation was given the surface than to shape it to a flat contour with the blade machine.

FIGURE 40. PEQUOT ROAD, EFFECT OF HEAVY TRAFFIC AFTER HEAVY RAIN

The same road as shown in Figure 39, but after a heavy rain, followed by a day (Sunday) of heavy traffic.

FIGURE 41. PEQUOT ROAD. THE MINNESOTA PLANER

The planer was passed over the rutted surface once in each direction. The ruts disappeared. Figure 42 shows the same section a few days later.

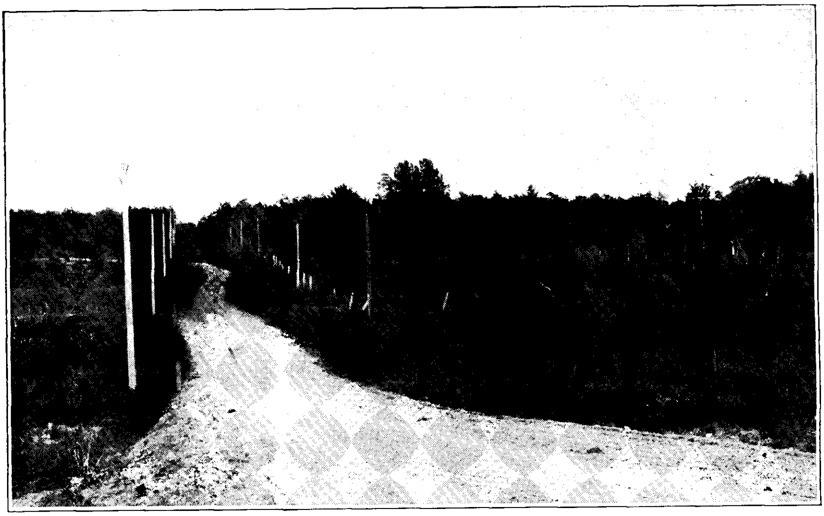


FIGURE 42. PEQUOT ROAD, AFTER COMPLETION

The method of spreading and working the surface was as follows: A section of about two hundred feet was covered with two inches of marl to a width of twelve feet. Spreading was begun at the farthest point and worked back so that loaded teams did not have to travel over the freshly spread marl. This coating of marl was plowed under and two inches more immediately spread. It was found that teams could haul through the freshly plowed surface, with occasional help, to the first load passing. The following loads passed easily in the ruts made by the first. As the work progressed, marl was hauled over completed portions of the road which improved rapidly under this traffic. Four plowings were sufficient to make a thoro mixture.

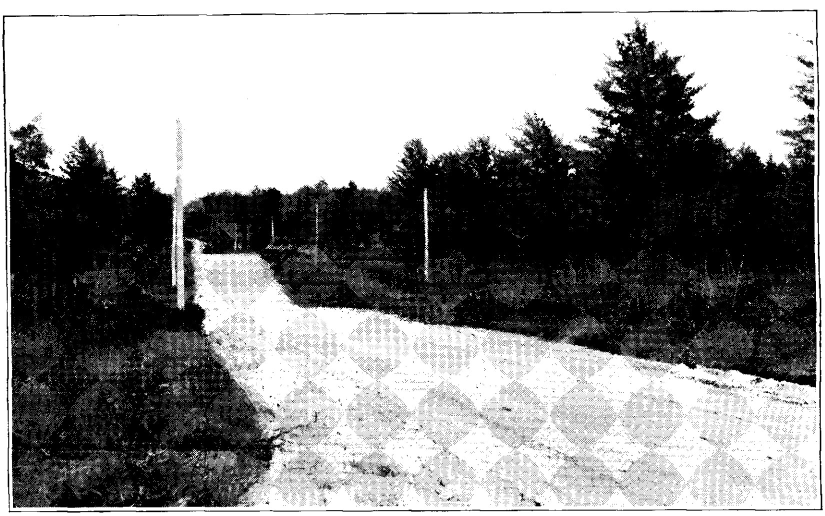


FIGURE 43. PEQUOT ROAD, AFTER COMPLETION

An improvement of the section shown in Figure 35.

FIGURE 44. PEQUOT ROAD, AFTER COMPLETION

FIGURE 45. PEQUOT ROAD, ON DATE OF COMPLETION

Last completed portion of the road with marks of initial travel upon it. The ruts later became broad without further treatment and eventually disappeared under traffic. This section is again shown in Figure 46.

FIGURE 46. PEQUOT ROAD, CROSS SECTION UNDER WHEEL TRACK

This portion, about one hundred feet in length, is the only dusty part of the road. Note the texture and thickness of the surface crust. It is very dense and hard.

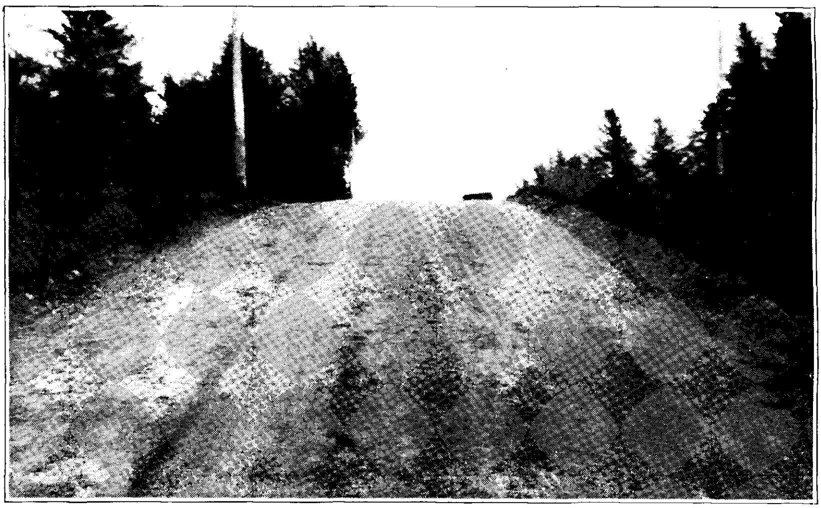


FIGURE 47. PEQUOT ROAD, THREE MONTHS AFTER COMPLETION

A close view of the crest shown in Figures 44 and 48.

FIGURE 48. PEQUOT ROAD, TYPICAL STRETCH IN GOOD CONDITION

Three months after construction. It is practically dustless. The completed road is also shown in Figure 44.

FIGURE 49. CENTRAL AVENUE ROAD, AS BEFORE IMPROVEMENT

Condition of sandy road immediately north of experimental surfacing. This represents the prior condition of the road.

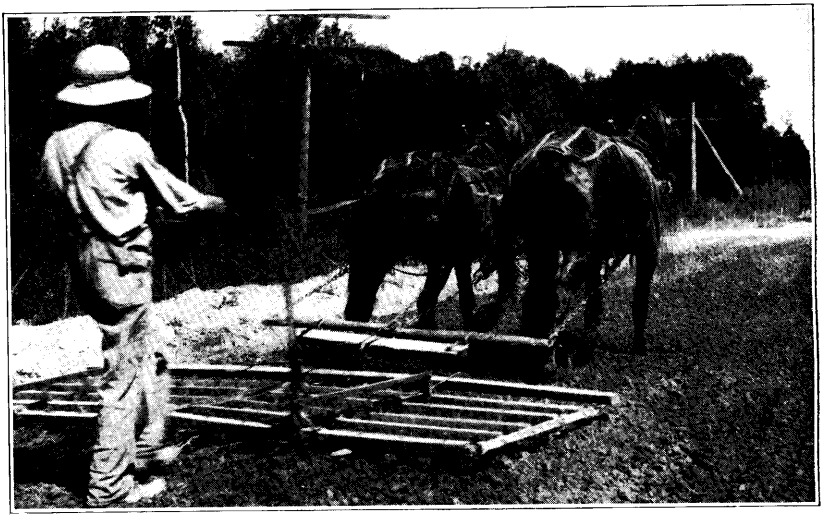


FIGURE 50. CENTRAL AVENUE ROAD. PULVERIZING THE MARL WITH A TOOTH HARROW

FIGURE 51. CENTRAL AVENUE ROAD. USING HARROW AS A DRAG
This was the finishing which followed the fifth plowing

FIGURE 52. CENTRAL AVENUE ROAD, SECTION 2, TEN DAYS AFTER COMPLETION

Without maintenance since its completion ten days before. The tracks of car are freshly made.

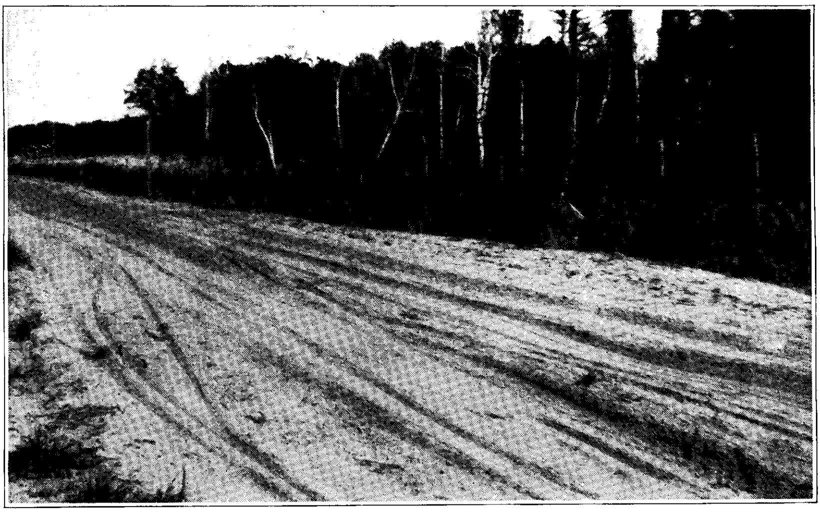


FIGURE 53. CENTRAL AVENUE ROAD, AFTER THREE MONTHS

Surfacing is three months old, after having had practically no maintenance. This illustration is the sequel to Figures 49 and 52. Deep ruts in Figure 52 have disappeared.

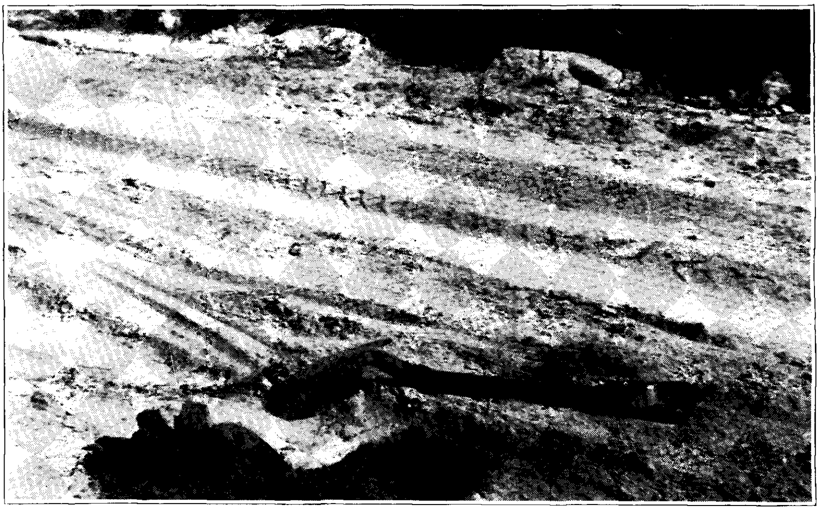


FIGURE 54. CENTRAL AVENUE ROAD, SURFACE TEXTURE

The material excavated from the surface shows that a very intimate marl-sand mixture was obtained.

FIGURE 55. RICE-FOLEY ROAD, TWO MILES WEST OF RICE

Surfacing by the county, of marl, loam, gravel, and sand of the subgrade, after several seasons of travel and maintenance. Marl appears to be the saving constituent.

FIGURE 56. RICE ROAD, JUST EAST OF THE EXPERIMENTAL ROAD

This road, which is now three months old, was surfaced by the county at the same time that the experimental road was being built. Gravel was spread on a loam blanket. The road has had liberal maintenance. Contrast this with the marl road in the distance. See also Figure 33.

FIGURE 57. MERRIFIELD ROAD

Situated about twelve miles north of Brainerd. This road was improved by the county. The sand road was surfaced with clay, followed by one inch of marl, spread without mixing. A very hard, dustless surface was obtained. There are several miles of this road. It is not likely to be satisfactory in wet weather. The sand should be worked up into the surface mixture.

FIGURE 58. TYPICAL CROW WING COUNTY HIGHWAY

Marl is abundant in the vicinity. Beyond the detour sign, the sand subgrade is virtually impassable until surfaced. The road in the foreground is surfaced with clay and marl like that shown in Figure 57.

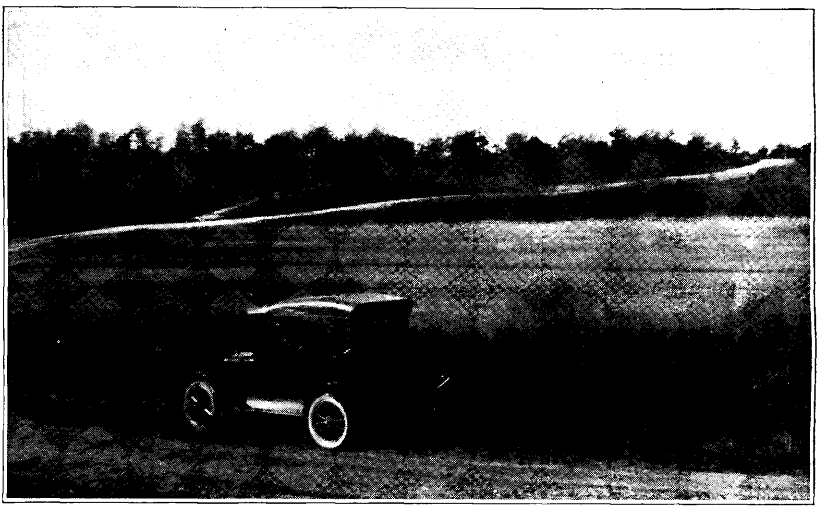


FIGURE 59. PEQUOT, NEAR EXPERIMENTAL ROAD

This road in the distance was relocated by the township, and surfaced with marl by the county. It was built through deep sand, by the method developed on the experimental road.

FIGURE 60. PEQUOT ROAD, SURFACE

The surface of the road shown in Figure 59, at the top of the hill.

FIGURE 61. MERRIFIELD ROAD DETOUR

A typical northern trail on sandy soil. Traveling is good until the natural surface is broken through. After grading, such a road must be surfaced with clay or marl, even if gravel is necessary later.