THE CONSTRUCTION, REHABILITATION, AND MAINTENANCE OF GRAVEL ROADS SUITABLE FOR MODERATE TRAFFIC

BY

CARROLL C. WILEY
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The Engineering Experiment Station,
University of Illinois,
Urbana, Illinois
THE CONSTRUCTION, REHABILITATION, AND MAINTENANCE OF GRAVEL ROADS SUITABLE FOR MODERATE TRAFFIC

BY

CARROLL C. WILEY
ASSISTANT PROFESSOR OF HIGHWAY ENGINEERING
## CONTENTS

<table>
<thead>
<tr>
<th>NO.</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td></td>
</tr>
<tr>
<td>I. INTRODUCTION</td>
<td>7</td>
</tr>
<tr>
<td>1. Introduction</td>
<td>7</td>
</tr>
<tr>
<td>2. Acknowledgments</td>
<td>7</td>
</tr>
<tr>
<td>II.</td>
<td>8</td>
</tr>
<tr>
<td>II. TEST ROAD AND EQUIPMENT</td>
<td>8</td>
</tr>
<tr>
<td>3. The Road</td>
<td>8</td>
</tr>
<tr>
<td>4. Materials</td>
<td>8</td>
</tr>
<tr>
<td>5. Machinery</td>
<td>8</td>
</tr>
<tr>
<td>III.</td>
<td>14</td>
</tr>
<tr>
<td>III. PRELIMINARY OPERATIONS</td>
<td>14</td>
</tr>
<tr>
<td>6. Studies</td>
<td>14</td>
</tr>
<tr>
<td>7. Plans</td>
<td>14</td>
</tr>
<tr>
<td>IV.</td>
<td>14</td>
</tr>
<tr>
<td>IV. CONSTRUCTION OF GRAVEL ROAD—MILE A</td>
<td>14</td>
</tr>
<tr>
<td>8. Description</td>
<td>14</td>
</tr>
<tr>
<td>9. Proposed Work</td>
<td>16</td>
</tr>
<tr>
<td>10. Reditching</td>
<td>16</td>
</tr>
<tr>
<td>11. Regrading</td>
<td>16</td>
</tr>
<tr>
<td>12. Final Preparation of Subgrade</td>
<td>17</td>
</tr>
<tr>
<td>13. Curing Mudholes</td>
<td>17</td>
</tr>
<tr>
<td>14. Lime as a Soil Stabilizer</td>
<td>17</td>
</tr>
<tr>
<td>15. Type and Method of Graveling</td>
<td>18</td>
</tr>
<tr>
<td>16. Width and Thickness of Gravel</td>
<td>18</td>
</tr>
<tr>
<td>17. Hauling Gravel</td>
<td>19</td>
</tr>
<tr>
<td>18. Spreading Gravel</td>
<td>19</td>
</tr>
<tr>
<td>V.</td>
<td>20</td>
</tr>
<tr>
<td>V. REHABILITATION OF GRAVEL ROAD—MILE C</td>
<td>20</td>
</tr>
<tr>
<td>19. Description</td>
<td>20</td>
</tr>
<tr>
<td>20. Proposed Work</td>
<td>22</td>
</tr>
<tr>
<td>21. First Grading Work</td>
<td>22</td>
</tr>
<tr>
<td>22. Second Grading Work</td>
<td>23</td>
</tr>
<tr>
<td>23. First Application of New Gravel</td>
<td>23</td>
</tr>
<tr>
<td>24. Fall Work, 1925</td>
<td>24</td>
</tr>
<tr>
<td>25. Winter Work, 1925-26</td>
<td>25</td>
</tr>
<tr>
<td>26. Spring Work During Thaw, 1926</td>
<td>25</td>
</tr>
<tr>
<td>27. Program for 1926</td>
<td>26</td>
</tr>
<tr>
<td>28. Regrading</td>
<td>26</td>
</tr>
<tr>
<td>29. Placing New Material</td>
<td>26</td>
</tr>
<tr>
<td>30. Winter Work, 1926-27</td>
<td>27</td>
</tr>
<tr>
<td>31. End of Work on Road</td>
<td>27</td>
</tr>
<tr>
<td>NO.</td>
<td>CONTENTS (Continued)</td>
</tr>
<tr>
<td>-----</td>
<td>---------------------</td>
</tr>
<tr>
<td>VI.</td>
<td>COMPOSITION OF GRAVEL ROADS</td>
</tr>
<tr>
<td>32.</td>
<td>Analyses of Road Samples</td>
</tr>
<tr>
<td>33.</td>
<td>Gradation and Drainage</td>
</tr>
<tr>
<td>VII.</td>
<td>SUMMARY OF CONDITIONS AND OPERATIONS ON TEST ROAD</td>
</tr>
<tr>
<td>34.</td>
<td>Mile A, April, 1925</td>
</tr>
<tr>
<td>35.</td>
<td>Mile C, April, 1925</td>
</tr>
<tr>
<td>36.</td>
<td>Mile A, October, 1925</td>
</tr>
<tr>
<td>37.</td>
<td>Mile C, October, 1925</td>
</tr>
<tr>
<td>38.</td>
<td>Mile A, April, 1926</td>
</tr>
<tr>
<td>39.</td>
<td>Mile C, April, 1926</td>
</tr>
<tr>
<td>40.</td>
<td>Mile A, October, 1926</td>
</tr>
<tr>
<td>41.</td>
<td>Mile C, October, 1926</td>
</tr>
<tr>
<td>42.</td>
<td>Mile A, April, 1927</td>
</tr>
<tr>
<td>43.</td>
<td>Mile C, April, 1927</td>
</tr>
<tr>
<td>44.</td>
<td>Mile A, October, 1927</td>
</tr>
<tr>
<td>45.</td>
<td>Mile C, October, 1927</td>
</tr>
<tr>
<td>46.</td>
<td>Mile A, April, 1928</td>
</tr>
<tr>
<td>47.</td>
<td>Mile C, April, 1928</td>
</tr>
<tr>
<td>VIII.</td>
<td>CORRUGATIONS ON GRAVEL ROADS</td>
</tr>
<tr>
<td>48.</td>
<td>Causes of Corrugations</td>
</tr>
<tr>
<td>49.</td>
<td>Removal of Corrugations</td>
</tr>
<tr>
<td>IX.</td>
<td>COSTS OF GRAVEL ROADS</td>
</tr>
<tr>
<td>50.</td>
<td>Cost of Construction</td>
</tr>
<tr>
<td>51.</td>
<td>Cost of Maintenance</td>
</tr>
<tr>
<td>X.</td>
<td>SUMMARY AND CONCLUSIONS</td>
</tr>
<tr>
<td>52.</td>
<td>Conclusions</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>NO.</th>
<th>Description</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>General Location of Experimental Road</td>
<td>9</td>
</tr>
<tr>
<td>2.</td>
<td>Analyses of Gravel as Supplied by Newell Township</td>
<td>10</td>
</tr>
<tr>
<td>3.</td>
<td>Analyses of Washed Gravel as Supplied by the Neal Gravel Company</td>
<td>10</td>
</tr>
<tr>
<td>4.</td>
<td>Comparative Analyses Showing the Ultimate Composition of the Surface Made with a Mixture of Gravels</td>
<td>11</td>
</tr>
<tr>
<td>5.</td>
<td>Rear View of Heavy Roller Showing Blade Reshaping the Road</td>
<td>11</td>
</tr>
<tr>
<td>6.</td>
<td>Close-up of Heavy Roller Showing Both Blade and Scarifier in Operation</td>
<td>12</td>
</tr>
<tr>
<td>7.</td>
<td>General View of Light Roller with Scarifier at Rear</td>
<td>12</td>
</tr>
<tr>
<td>9.</td>
<td>Eight-foot Blade Grader</td>
<td>13</td>
</tr>
<tr>
<td>10.</td>
<td>General Plan and Profile of Experimental Road</td>
<td>14</td>
</tr>
<tr>
<td>11.</td>
<td>Graphical Outline of Proposed Investigation of Construction and Maintenance of Gravel Road (Mile A)</td>
<td>15</td>
</tr>
<tr>
<td>12.</td>
<td>Graphical Outline of Proposed Investigation of Rehabilitation and Maintenance of Gravel Road (Mile C)</td>
<td>21</td>
</tr>
<tr>
<td>13.</td>
<td>Revised Schedule of New Surfacing Material on Mile C</td>
<td>22</td>
</tr>
<tr>
<td>14.</td>
<td>Analyses of Material from Section CS Showing Change of Composition due to a Surface Application of Pea Gravel</td>
<td>29</td>
</tr>
<tr>
<td>15.</td>
<td>Comparative Analyses of Typical Samples of Road Gravel and of Surface Material as Taken from the Road</td>
<td>30</td>
</tr>
<tr>
<td>16.</td>
<td>Analyses of Material Taken Directly from Experimental Road</td>
<td>32</td>
</tr>
<tr>
<td>17.</td>
<td>Analyses of Material Taken from Natural Sand-Clay or “Top Soil” Roads in Georgia</td>
<td>34</td>
</tr>
<tr>
<td>18.</td>
<td>Drainage through Porous Gravel</td>
<td>35</td>
</tr>
<tr>
<td>19.</td>
<td>Section A2, September, 1926</td>
<td>36</td>
</tr>
<tr>
<td>20.</td>
<td>Section A1, September, 1926</td>
<td>37</td>
</tr>
<tr>
<td>21.</td>
<td>Section A2, September, 1926</td>
<td>38</td>
</tr>
<tr>
<td>22.</td>
<td>Section A2, October, 1926</td>
<td>38</td>
</tr>
<tr>
<td>23.</td>
<td>Section A7, May, 1928</td>
<td>39</td>
</tr>
<tr>
<td>24.</td>
<td>Section A8, June, 1926</td>
<td>39</td>
</tr>
<tr>
<td>25.</td>
<td>Section A8, June, 1926</td>
<td>40</td>
</tr>
<tr>
<td>26.</td>
<td>Section A8, June, 1926</td>
<td>40</td>
</tr>
<tr>
<td>27.</td>
<td>Section A4, January, 1927</td>
<td>41</td>
</tr>
<tr>
<td>28.</td>
<td>Section A2, April, 1927</td>
<td>41</td>
</tr>
<tr>
<td>29.</td>
<td>South Half of Section A6, April, 1927, Looking South</td>
<td>42</td>
</tr>
<tr>
<td>30.</td>
<td>North Half of Section A6, April, 1927</td>
<td>42</td>
</tr>
<tr>
<td>NO.</td>
<td>Description</td>
<td>PAGE</td>
</tr>
<tr>
<td>------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>31.</td>
<td>Section A6, April, 1927</td>
<td>44</td>
</tr>
<tr>
<td>32.</td>
<td>Section C1, October, 1925</td>
<td>44</td>
</tr>
<tr>
<td>33.</td>
<td>Same Spot as Shown in Fig. 32 After Ten Minutes' Work with Motor Grader</td>
<td>46</td>
</tr>
<tr>
<td>34.</td>
<td>Section C4, June, 1925</td>
<td>46</td>
</tr>
<tr>
<td>35.</td>
<td>Section C6, May, 1925, Before Work Was Started</td>
<td>47</td>
</tr>
<tr>
<td>36.</td>
<td>Section C7, December, 1925</td>
<td>48</td>
</tr>
<tr>
<td>37.</td>
<td>Section C7 at Junction with Section C6</td>
<td>49</td>
</tr>
<tr>
<td>38.</td>
<td>Section C4, April, 1926</td>
<td>50</td>
</tr>
<tr>
<td>39.</td>
<td>Section C4, May, 1926</td>
<td>51</td>
</tr>
<tr>
<td>40.</td>
<td>Sections C4 and C5, April, 1927</td>
<td>52</td>
</tr>
<tr>
<td>41.</td>
<td>Section C4, April, 1927</td>
<td>53</td>
</tr>
<tr>
<td>42.</td>
<td>Section C7, Looking South, April, 1927</td>
<td>54</td>
</tr>
</tbody>
</table>
THE CONSTRUCTION, REHABILITATION, AND MAINTENANCE OF GRAVEL ROADS SUITABLE FOR MODERATE TRAFFIC

I. INTRODUCTION

1. Introduction.—In many localities gravel offers a possible means of satisfying the insistent demand for reasonably good all-weather and all-season roads on the secondary and outlying highways where traffic is comparatively light and funds are usually meager.

During the past few years considerable study has apparently been devoted to the gravel road. Practically all of this study, however, has been directed at the problem of how to protect existing gravel roads from rapid destruction by excessive traffic, rather than to that of finding effective and economic methods of building and maintaining untreated gravel roads of low cost suitable for light to medium traffic.

The immediate object, therefore, of these investigations was to secure reliable data concerning the methods, materials, and equipment best suited to the construction, rehabilitation, and maintenance of low cost gravel roads subjected only to moderate traffic.

2. Acknowledgments.—These investigations were made possible primarily by the generosity of the Austin Manufacturing Company of Chicago which established two two-year fellowships in highway engineering at the University of Illinois and in addition furnished certain machinery together with funds for its care and operation.

Vermilion County, Illinois, authorities offered every assistance to the work; a county road was used for the experiments, county forces did all of the heavy grading, ditching, and much of the hauling of materials, and county equipment and funds were made available for a considerable part of the incidental work.

The Indiana Sand and Gravel Association donated about 1000 cubic yards of washed gravel and aided in other ways. Newell Township supplied about 1000 cubic yards of local gravel. In addition, the Illinois Division of Highways, the U. S. Bureau of Public Roads, the National Lime Association, and the Solvay Process Company aided the work in minor but important ways.

The investigations were carried on as part of the regular work of the Engineering Experiment Station, of which Dean M. S. Ketchum is director, and the Department of Civil Engineering, of which Prof. C. C. Williams was head when the work was begun and Prof. W. C.
Huntington was head during the completion. The writer had general direction of the work, while Mr. J. E. Keranen, Mr. A. H. Finlay, and Mr. C. F. Smith, Graduate Research Assistants under the Austin Fellowships, were in charge of the detailed operations. Much credit is due these three men for their ability, skill, and faithful work.

II. Test Road and Equipment

3. The Road.—The road selected was a 3-mile stretch extending north and south on the old Bismarck road about 6 miles northeast of Danville, Illinois. It was on a state-aid route and therefore under the direct jurisdiction of the county. Its location and general features are shown in Fig. 1. This road was chosen because it combined in a single stretch a mile of gravel, a mile of macadam, and a mile of earth. It was also readily accessible at all times and the normal traffic was about the average of that to be expected on the class of roads to which the results of the investigation would apply.

4. Materials.—In addition to the material already in place on the road considerable quantities of local gravel and of washed gravel were used.

The local gravel was obtained from an open pit about a mile east of the south end of the test road. The gradation and composition of this gravel are shown in Fig. 2. This material carried an excess of sand and a deficiency of pebbles. It seemed to lack binder, and sometimes behaved as if it contained quicksand, but when combined with clean pebbles it behaved fairly well.

The washed gravel came from the plant of the Neal Gravel Company at Attica, Indiana. This material was excellent in every respect. Most of it was pea gravel ranging in size from about \( \frac{3}{16} \) to \( \frac{1}{2} \) inch, as shown in Fig. 3, but several cars of concrete gravel (Fig. 4, Curve C) and two cars of "road gravel" (Fig. 3) were also used.

5. Machinery.—The following machinery was used on the work:

(1) An Austin 14-ton combination 3-wheel roller, scarifier, and blade grader (Figs. 5 and 6).

(2) An Austin Pup or 4-ton combination roller, scarifier, and blade (Fig. 7).

(3) An Austin motor grader, using a Fordson power plant (Fig. 8). This machine was equipped with rubber tires, 8-ft. blade, and scarifier.

(4) An Adams patrol grader.

(5) An 8-ft. Adams leaning wheel blade grader with back sloper (Fig. 9).
Fig. 1. General Location of Experimental Road
FIG. 2. ANALYSES OF GRAVEL AS SUPPLIED BY NEWELL TOWNSHIP

FIG. 3. ANALYSES OF WASHED GRAVEL AS SUPPLIED BY THE NEAL GRAVEL COMPANY
The road at this point was surfaced in October, 1926 with a 6-inch layer of gravel containing 30 per cent of material A, 40 per cent of material B, and 30 per cent of material C. This mixture was spread directly upon an extremely poor subgrade, which had been previously rolled, and the gravel was compacted by rolling. This surface rendered excellent service.

Note the horizontal plate attached to the blade which helped level the gravel, reduced chattering of the blade, and tended to compact the gravel.
The adjustments were such that the blade and scarifier could be used separately or both together and at different angles with the horizontal.

A blade attachment could be suspended in front of the front roller.
Fig. 8. General View of Light Motor Grader Equipped with Fordson Power Plant, Rubber Tires, Leaning Front Wheels, 8-Foot Blade and Scarifier

This machine is easily operated by one man. It is excellent for spreading gravel and for maintenance work on the surface, but is not suited to ditching.

Fig. 9. Eight-Foot Blade Grader

This type of implement pulled by a tractor is excellent for ditching and regrading work. It is too heavy and too expensive for maintenance operations although it will do good work. The patrol grader is similar but smaller and when pulled by horses can be operated by one man.
(6) A 5-ton Holt caterpillar tractor.
(7) Two light trucks (Fords) with a capacity of about 1 1/4 cu. yd.
(8) A 5-ton truck with dump body.

III. PRELIMINARY OPERATIONS

6. Studies.—Before laying plans for actual work considerable study was made of gravel roads in Illinois, Wisconsin, Iowa, Minnesota, Indiana, Michigan, Vermont, and Maine. Roads of nearby states were visited, articles and reports from the other states studied, and certain items checked by correspondence. From this information the equipment, materials, or methods which gave the greatest promise of success, or which needed further study, were selected.

At the same time a profile of the road was made and cross-sections were taken. Drainage features were carefully examined and all information concerning the soil, rain, floods, etc., secured.

Complete traffic surveys were contemplated but for several reasons never made. Several partial counts were made at different times which indicated the general character and volume of the traffic.

7. Plans.—From the information so obtained tentative plans were made for the work. These plans were followed as closely as possible. In some cases time and weather factors caused a modification and in others changes were made as suggested by the progress of the work.

Two major projects were determined upon as follows:

(1) The construction and maintenance of a mile of gravel road, including the preparation of the subgrade.

(2) The rehabilitation and maintenance of a mile of existing gravel roadway built of local material and in a fair to poor state of repair.

It was also originally planned to do certain work on the rehabilitation and maintenance of ordinary macadam (Mile B), but conditions did not permit.

IV. CONSTRUCTION OF GRAVEL ROAD—MILE A

8. Description.—Mile A, the southernmost mile of the project, was an earth road in very poor condition. It contained several low places, was frequently overflowed, especially near the south end, and consequently was often impassable, thus compelling traffic to seek less direct routes over poor gravel.

Figure 10 shows the plan, profile, and general condition of the road before work on it was started.
GRAVEL ROADS FOR MODERATE TRAFFIC

Gravelled by "Iowa" Method

Gravelled by Various Methods, Mostly Modifications of the "Iowa" Method

<table>
<thead>
<tr>
<th>Problem No. 1</th>
<th>Problem No. 2</th>
<th>Problem No. 3</th>
<th>Problem No. 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crown on Subgrade</td>
<td>Crown on Subgrade</td>
<td>Traffic Compacted</td>
<td>Traffic Compacted</td>
</tr>
<tr>
<td>Roller-Compacted</td>
<td>Roller-Compacted</td>
<td>&quot;Iowa&quot; Method Modified Use Roller to Compactor Each Layer of Gravel</td>
<td>Apply Gravel in 2 Layers Allowing Traffic To Conver Each Layer</td>
</tr>
<tr>
<td>Bent Run Gravel ½ mi.</td>
<td>50% 2R + 50% Coarse ½ mi.</td>
<td>50% 2R + 50% Fine ½ mi.</td>
<td>50% 2R + 50% Fine ½ mi.</td>
</tr>
</tbody>
</table>

- A1
- A2
- A3
- A4
- A5
- A6
- A7
- A8

Crowned Subgrade
Flat Subgrade
Slightly Crowned Subgrade

Surface Kept Constant
Subgrade Kept Constant

New Earth Road
To be Gravelled by Various Methods
Mile "A"

Fig. 11. Graphical Outline of Proposed Investigation of Construction and Maintenance of Gravel Road (Mile A)
9. Proposed Work.—It was obvious that the drainage had to be improved and the road regraded before any attempt could be made to gravel the surface. This offered opportunities to study the preparation of the subgrade as well as the operations of graveling.

Figure 11 gives in diagrammatic form the original program of the proposed work. This program was carried out almost as shown. Due to climatic and other conditions several minor changes and some shifting of sections or modification of operations were necessary as the work progressed.

10. Reditching.—The first step was to clean the culverts at A and B (Fig. 10) and open their channels above and below. The culvert at C was rebuilt with enlarged waterway and the channels were cleaned.

The ditch on the west side from Sta. 0 to Sta. 10 (Fig. 10) was then cleaned out and deepened. The soil was so tough and mucky that work with horses was impossible and hand work too expensive. The most effective method with available equipment was to use a slip scraper pulled by the caterpillar tractor by means of a snatch line. This excavated the muck and carried it to the roadway where teams hauled it to the point needed. The spoil was used to build up the grade, but there was not sufficient material to raise the bank enough to prevent overflow across the road.

The county authorities also decided to open the east ditch through the hump between Sta. 17 and Sta. 34 in an attempt to relieve the overflow condition centering at Sta. 36. This called for a very deep ditch (about 6 feet at the deepest) which was dangerous to traffic and which did not prove very effective. The spoil was used to build up the grade against overflow but there was not enough earth to make the grade high enough by at least a foot. The opening and rebuilding of the inlets at Sta. 36 + 30 was much more effective in curing the conditions there.

The rest of the side ditches were straightened and brought to shape in the regrading.

11. Regrading.—The entire mile was regraded to a standard width of 26 ft. between shoulder lines. This work was done principally with the 8-ft. grader pulled by the caterpillar. The light roller was used to scarify some very hard places and to compact thin layers, while the heavy roller was used to compact the heavier filling. The motor grader was used in the finishing work. The hump between Sta. 54 and Sta. 57 was cut down a foot or more to fill in the eroded area on the
west side. It was here that the scarifier for loosening the soil and the heavy roller for compacting were used.

The road was finished to the desired crown, and then maintained in this condition almost wholly by means of the motor grader. An ordinary drag furnished by Newell township was used when the surface was too soft for the grader.

12. Final Preparation of Subgrade.—The preparation immediately preceding graveling consisted of making the surface as true and firm as possible. Ruts were often cut when hauling the gravel over the road, and at times the gravel was not placed on as smooth a surface as desired. In some cases only dragging or blading was used and in others the light roller was employed.

13. Curing Mudholes.—Several mudholes developed, due principally to the interference of the gravel piles with surface drainage. These places dried slowly and when dry were rough and full of ruts. They were cured in the following manner:

One afternoon, following a rain, the free water was drained from the areas by means of small transverse ditches cut with pick and shovel. The next morning the grader was ineffective, but it was found that the light roller could be run over the spot, squeezing down the soft soil and ironing out the ruts. Two or three passes of the roller caused the soil to become too plastic to support the roller, but after waiting an hour or two several more passes could be made. By night the mudholes were firm enough to support ordinary automobiles, with scarcely an indentation, and by the next morning it was possible to trim the surface with the motor grader, and to spread the first course of gravel.

14. Lime as a Soil Stabilizer.—Hydrated lime has often been suggested as a stabilizer for mucky or gummy soils. It is thought that the lime tends to flocculate the extremely fine or “colloidal” clay in the soil, thus making it more granular and less plastic. A number of experiments have been made on earth roads at various places to demonstrate this theory and all have apparently been successful. The process has therefore been suggested as a method of preparing subgrades in such soils to receive pavements or other types of surfaces.

In order to test the effectiveness of lime treatments, two stretches each about 100 feet long in Section A2 near Stations 9 and 12 were accordingly treated as recommended by the National Lime Association. The soil was scarified to a depth of about 6 inches and pulver-
ized with a farm disk. About $3\frac{1}{2}$ pounds per square yard of commercial hydrated lime were then spread on the surface and disked into the soil. The surface was then shaped with the motor grader and rolled with the light roller.

These two sections were undoubtedly superior to the adjacent untreated sections in resistance to water and to traffic. The soil did not become as muddy during wet weather and dried up more quickly when the rain stopped. Ruts were not cut as deeply by the traffic when the soil was wet, nor did dust form as readily when it was dry. The surface was easily worked with the drag or blade and consequently was easily prepared to receive the gravel.

Unfortunately, after the gravel had been applied it was impossible to determine whether or not there had been any permanent or appreciable benefit from the liming, because the entire Section A2 stood up so well after graveling, at least for the year or more it was under observation, that there were no means of distinguishing the treated from the untreated sections. The experiments with lime were, therefore, inconclusive both from the standpoint of effectiveness and of the economic value of the treatment.

15. Type and Method of Graveling.—After carefully considering work elsewhere it was decided to use only the feather-edge type of construction, in which the gravel is placed on top of a flat crowned subgrade without the use of a trench or supporting shoulders, and permitted to feather out to a thin edge. It was also decided to place most of the gravel by dumping it in piles at the edge of the traveled way and then working it into place with the blade grader or motor grader. This is sometimes called the Iowa method. This permitted the gravel to be spread in any number of successive increments or layers as desired.

16. Width and Thickness of Gravel.—A study of traffic conditions indicated that for the most part only a single track roadway would be necessary. On the other hand, passing of vehicles at times became too frequent for convenience although not frequent enough to demand a double lane. Also, due to the softness of the shoulder in wet weather, reasonable convenience in passing was imperative for safety. It was therefore decided to make the graveled way with an overall width of about 16 ft. Such width would provide full support for normal traffic in the center and also provide fair support at the edges for passing. Any damage done to the thin edge could be repaired by the maintenance operations at less cost than that required to give full depth of gravel for a two-lane width.
A study of adjacent roads and the character of the traffic led to the conclusion that, at least at first, a maximum compacted thickness of 6 in. would be ample. The cross-section would thus be essentially a parabolic segment 16 ft. wide and 6 in. thick. This gives a compacted volume of about 1040 cu. yd. per mile requiring approximately 1250 cu. yd. of loose material. Approximately this quantity was placed, although the depth was not kept constant at 6 in.

17. **Hauling Gravel.**—The hauling of the gravel proved to be the item of construction which required the most time and involved the greatest expense. Neither the preparation of the roadway to receive the gravel nor the spreading and compacting of the gravel were at all comparable with the hauling with respect to cost or time required. This is a fact which must never be overlooked if delay and extra cost in building a gravel road are to be avoided.

In this case, the county undertook to haul the gravel with two $1\frac{1}{4}$-yd. trucks. Since about 1250 cu. yd. of gravel were to be hauled to Mile A about 1000 trips would be required. At the maximum possible rate of operation this meant about 60 days of continuous hauling. Weather conditions naturally caused some delay, several hundred yards of gravel had to be placed on Mile C, and the trucks could not be assigned permanently to the work on account of roadwork elsewhere in the county; hence the haulage rate to Mile A was greatly reduced. The Illinois Division of Highways came to the rescue with a 5-ton dump truck which was used for hauling a large amount of the local gravel. Even at this, the greater part of a year elapsed before all of the gravel was delivered. This fact accounted for the delay in finishing Mile A, occasioned some of the changes in the program, and prevented the complete consummation of some of the studies in the available time.

Lath stakes were driven at intervals to indicate the line and keep the roadway straight. The loads were spotted to give the necessary amount of gravel when distributed. Where only one kind of gravel was used all of it was placed on one side of the road. Where two materials were to be mixed they were placed in alternate piles on the same side. Where two materials were to be placed in separate layers on top of each other they were placed on opposite sides of the roadway. The center of the piles was placed about two feet inside of the outer edge of the finished graveled way.

18. **Spreading Gravel.**—For the most part, the gravel was spread with the motor grader. A small part was spread with the large blade, but the small one-man outfit was so superior from the standpoint of
efficiency and cost that it was used almost exclusively. Also, a small amount was dumped directly in the middle of the roadway and spread with the blade.

In spreading the gravel a cut was made from the piles with the point of the blade taking as much as the blade would carry. This was bladed across the road to the far edge of the graveled way and followed by successive cuts until a layer of desired thickness and width was built up. Traffic, aided by occasional blading, soon compacted the first layer of gravel, whereupon another layer was added in the same way.

Through this process the gravel was thoroughly mixed and spread in a thin uniform layer. The shallow depth of loose gravel at each application offered little obstruction to traffic, and enabled the entire gravel bed to compact thoroughly and uniformly from the bottom. By using the motor grader only one man was required, and he could give a blading or apply a layer of gravel when needed, with little delay and at low cost.

Normally 3 or 4 round trips were required to spread a 1½-in. to 2-in. layer of gravel, and the machine would average approximately 2 miles per hour in low gear, including turns and delays. One man on this outfit could, therefore, usually spread a layer of gravel over the entire mile in a half day or less.

During each of the operations careful observations were made of the behavior of the subgrade, the gravel, and the equipment. Rates of progress were recorded as were any items which seemed to affect the rapidity or cost of the work.

Construction merged imperceptibly into maintenance. No sharp division between construction and maintenance can be made with this type of construction. Moreover, parts of the road received all of the gravel allotted to them before other parts did, and therefore, different stages of progress existed at the same time on different parts of the road. Consequently, the end of construction and the beginning of maintenance, considering the road as a whole, could not be separated. The same round of the grader might do maintenance work on one section, spread gravel on another, and smooth the subgrade on another.

V. REHABILITATION OF GRAVEL ROAD—MILE C

19. Description.—Mile C is the northernmost mile. Its general plan, profile, and conditions are shown in Fig. 10. The gravel surface was about 16 feet wide and made of local bank-run gravels from sev-
### Reinhabilitated and Maintained

<table>
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<tr>
<th>Problem No. 8</th>
<th>Problem No. 9</th>
<th>Problem No. 10</th>
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<tr>
<td>Old Gravel Road</td>
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<td>To be Rehabilitated and Maintained</td>
<td>Mile &quot;C&quot;</td>
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**Legend:**
- C1: Maintenance Using New Material
- C2: Maintenance Without New Material
- C3: Maintenance Using New Material
- C4: Use 3" Crown for ½ mi.
- C5: Use 1" Crown for ½ mi.
- C6: Use ½ Crown for ½ mi.
- C7: Use ½ Crown for ½ mi.
- C8: Use ¼ Crown for ½ mi.

**Fig. 12. Graphical Outline of Proposed Investigation of Rehabilitation and Maintenance of Gravel Road (Mile C)**
eral different pits. It had been constructed by the old-time method of dumping gravel from wagons, raking the piles together, and letting traffic compact it. Much of it possessed fair depth of gravel and through long service was fairly smooth. Some stretches had been recently patched in the same fashion and were very rough. General lack of care during the last few years had permitted the ditches to fill up, the culverts to become obstructed, and the surface to get into bad condition due to ruts, soft spots, and overflows during heavy rains. The gravel was not all alike so that there was considerable difference in the character of the surface at various points.

20. Proposed Work.—A tentative scheme of treatment was outlined as part of the original plan as shown in Fig. 12. This general scheme was followed quite closely, but a revised schedule of treatment, as shown in Fig. 13, was later adopted and carried out during the summer of 1926.

Although it seemed quite evident that regrading the ditches and otherwise improving the drainage condition should be the first work it was decided not do this at once but to start work on the surface. This was due partly to expediency and partly to see what could be done on a gravel surface under adverse drainage conditions.

21. First Grading Work.—The first work was done from May 26 to 28, 1925, when the south half of Mile C was scarified and reshaped, using the big Austin roller (see Figs. 5 and 6).

Two general methods were tried. First, the roller was driven down the center of the road, scarifying deeply. Then a more shallow cut was made at each side, the blade at the rear being used to spread the gravel, reduce the crown, and thicken the surface towards the sides. Three cuts thus reshaped the surface fairly well. Part of the loosened gravel was then rolled and part left for traffic to compact.

In the second method four cuts, or two round trips, were made, working each way from the center line. Again part was rolled. There
seemed to be little difference in the results by the two methods, leaving a slight advantage for the first method because it required less work.

These operations were quite effective in reshaping the crown and in eliminating bumps. Section C1 had been patched during the previous year and every wagon load of gravel was still evident. This first grading work rid the road of practically all such bumps. The rolling did not seem to recompact the road thoroughly. It merely served to partially consolidate the surface so that the first wheels did not cut into the loose gravel, and hence the surface became solid sooner than when unrolled. It also required less work immediately to prevent ruts from developing. The advantages derived from rolling do not seem enough to justify the importing of a roller for this purpose only, but, on the other hand, if a roller is available it is worth the time and other expense to give the surface a rolling. One passage entirely over the surface with the big roller seemed sufficient, as additional rolling helped but little.

22. Second Grading Work.—During June, 1925, practically all of the surface of the remainder of Mile C was regraded. The Pup was used on part of it and the motor grader on part. All of this work was very effective and several valuable things were learned concerning the different pieces of equipment and their use.

23. First Application of New Gravel.—The services of the graduate research assistants were not available during July and August, 1925. At this time the county forces were busy grading Mile A and on other county work; therefore, only a little work could be done on Mile C. It was, however, decided to try some light surfacing.

For this purpose two cars of gravel were obtained. One contained about 40 cu. yd. of pea gravel. About 10 cu. yd. of this was stored for use on Mile B but was later transferred to Mile A. About 5 cu. yd. was stored for use on Mile C opposite Section C7. The remainder was used for surfacing. The other car contained about 33 cu. yd. of well-graded $\frac{3}{4}$-in. to 1$\frac{1}{2}$-in. concrete gravel. About 8 cu. yd. of this was used on Mile A and the remainder spread on Mile C.

The space chosen for the surfacing was in the north half of Section C6 and the south half of Section C7. At this location the old gravel was very fine and powdery. In dry weather dust would form two or three inches deep, while in rainy weather a sloppy mud about as deep would result.

The surface was first trued up with the motor grader. About 300 feet was covered with pea gravel to a depth of 1 inch giving one cu. yd.
to each 36 sq. yd. or one yard about every 20 lin. ft. An additional 300 feet received about \( \frac{2}{3} \) as much, or one yard every 30 feet. This material was spread with shovels as uniformly as possible. Similar sections were covered with concrete gravel. They were shorter, since the coarser gravel could not be spread as thin as the pea gravel.

At the time the gravel was placed (about July 20, 1925) the road was very dry. A few days previously State Route No. 1 (see Fig. 1) was closed for repairs and the traffic detoured through Bismarck which brought it over the experimental section. One Thursday the traffic between 9 and 11 o'clock in the morning averaged 65 vehicles per hour and between 2 and 4 o'clock 80 vehicles per hour. The total for 24 hours probably averaged about 40 vehicles per hour or about 1000 per day. On Saturdays and Sundays this increased at least 50 per cent, although no exact count was made. This excessive traffic lasted for about a month, when the number dropped to about 200 or less per day in the summer.

These sections were carefully watched during the following year and a record was kept of all maintenance work done on them. It was soon evident that the pea gravel was standing up better and making a better surface than the coarse gravel. With the dry road, the pea gravel seemed to unite with the dust and form a layer that was not easily displaced. A light blading once a week kept it in good condition. A good rain combined with a blading put this stretch into fine condition, and for almost a year the part with a 1-in. layer of pea gravel stood out conspicuously as the best section on the whole road. The lighter application did not last quite so well.

The section treated with coarse gravel did not knit together when the road was dry but remained loose and shifting. With the coming of rain it solidified but was difficult to keep smooth, the large pebbles raveling out. At no time did it compare with the pea gravel. It should be remembered, however, that this was the behavior of coarse gravel used on the surface. Its behavior as a base course is considered in connection with Mile A. This section was ultimately covered with pea gravel with excellent results.

24. Fall Work, 1925.—Beginning in September, 1925, intensive work was started in preparation for winter. No new material was added to Mile C, but the surface was carefully maintained. Wherever the surface was rough or bumpy it was scarified and reshaped. Part was rerolled and part left for traffic to compact. Culverts were examined and cleaned in so far as possible and ditch outlets opened.
GRAVEL ROADS FOR MODERATE TRAFFIC

Most of the surfacing work was done with the motor grader, some with the Pup, some with the heavy roller, and a little with a horse-drawn one-man grader. Careful observations were made of the behavior of the road and the equipment in each operation.

By the time freezing weather came Mile C was in as good condition as could be secured without the addition of new material and without regrading the ditches and providing some additional drainage features.

25. Winter Work, 1925-26.—It was the belief that, contrary to usual practice, effective maintenance work could be done during the winter. Consequently, the road was carefully observed at least twice a week throughout the winter months. With the road thoroughly frozen, traffic did little damage to it and maintenance work was neither needed nor possible. A slight thaw, however, would be the occasion for ruts to start. These were promptly stopped by means of the blade. For this purpose there was nothing superior to the motor grader. In this manner ruts were not permitted to develop and the road remained in good condition at all times. This work abundantly demonstrated the merit of winter surface work whenever partial thawing occurs.

26. Spring Work During Thaw, 1926.—The time of the general thaw in the spring is a critical one for gravel roads. The subgrade is soft and saturated and the gravel surface is likewise loosened and full of water; consequently, traffic is very likely to damage the road seriously. It was thought that much might be done to relieve this condition by careful attention to the road at this time.

The road was carefully watched and as soon as ruts began to appear they were bladed full. The shoulders were dragged so that the water got away quickly. The motor grader was used almost daily at the critical time. The results justified the effort and verified the expectations. With the exception of a few places where the gravel was too thin and several places where the drainage was very bad, the road came through in excellent condition and even these places were bad only by comparison.

In contrast, the mile to the north of Mile C which was under observation but on which no work was done was in very bad condition. Deep ruts were cut. In some places they went entirely through the gravel, and where the drainage was poor the road was all but impassable. The experimental mile stood out conspicuously among the roads for miles around for its good condition.
27. Program for 1926.—As previously stated, it was apparent that the drainage of the road needed improvement but the surface work was undertaken to demonstrate just how effective such work could be under adverse conditions. Although the results obtained were even better than expected it was clearly evident that three things were needed to put the road into satisfactory condition: first, the ditches needed regrading and the drainage otherwise required improvement; second, the surface needed reinforcing in several places by increasing the depth of gravel; and third, practically the entire mile would be improved by light surfacing to stabilize the surface. The working program, therefore, called for these operations. Arrangements were also made to have one of the research assistants on duty all summer so that there would be no interruption in the work.

28. Regrading.—The first step was to regrade the ditches. This was no small task. In some places the old ditches were so silted up and so full of weeds and sod that it was almost like grading a new road. At the same time the right of way and the graded way were both so narrow that it was a problem how to dispose of the sod and dirt without contaminating the gravel. By dint of perseverance and ingenuity the problem was solved in most cases by throwing the sod towards the fence. The net result was a well-graded roadway about 24 ft. wide with fairly good ditches on each side.

In the spring of 1926 the water had crossed the road just north of culvert K and washed out the gravel, making a bad hole. This culvert was found to be badly clogged and in poor condition. It was cleared but not rebuilt. The old wooden culvert at J was so badly caved in that only rebuilding would suffice, but since no funds were available the ditch on the east side was graded deep enough to permit an outfall through culvert K. Culvert K was too small for this combined duty, and water overflowed the road again in the spring of 1927, but did little damage. On the whole, by the fall of 1926 the road was in such a condition that trouble with drainage during the winter was anticipated at only two or three points. Mile B was regraded at the same time.

29. Placing New Material.—While the grading was being done a schedule was made out for the placing of new material. As soon as the grading was completed the hauling of materials was started. The gravel was dumped in piles along the edge of the graveled way, the same as on Mile A, and distributed with the motor grader. Figure 13 shows the amount of material to be placed on each section. For the most part only about 1 to 1½ inches of fresh material were spread
GRAVEL ROADS FOR MODERATE TRAFFIC

at a time, leaving sufficient intervals for each layer to compact before placing the next. A few sections were heavily covered immediately, as shown in Fig. 13, in order to make a comparison of the effectiveness of the two methods.

Owing to the fact that the hauling equipment was limited and work was in progress on Mile A, the delivery of materials was rather slow. Nevertheless, the schedule was completed except that all of the material was not distributed on Sections C7 and C8 before cold weather. This material remained in piles throughout the winter but did not interfere with traffic, drainage, or maintenance work.

30. Winter Work, 1926-27.—General winter work, 1926-27, was the same as during the preceding winter. The surface was carefully watched and bladed whenever a partial thaw made it possible. Likewise at the final thaw special care was taken to keep ruts and holes filled.

Twice in early spring water crossed the road near culverts I and K and washed out considerable gravel. These holes were speedily fixed. At no time was the road out of service, and the general results were as expected. Again Mile C was by far the best graveled road in the vicinity. By improving the drainage many of the troubles of the preceding year were overcome and by the addition of gravel most of the rest were corrected. Larger culvert capacity at I and K would have made the road come through the winter in almost perfect condition. The unworked mile to the north was impassable a number of times for intervals of several days. Considerable traffic, however, reached the experimental road at the north end from the east over a township road in fair condition; consequently, it was not idle during these critical periods, but received enough traffic to give it a test. At the low point the number of vehicles passing per day was between 50 and 60, principally farm wagons and ordinary automobiles, with an occasional truck such as a gasoline tank truck.

31. End of Work on Road.—Tentative plans were made for some intensive work during the spring and early summer of 1927. Owing to political situations which arose in the county at the spring elections only a small amount of work was possible, and active operations therefore ceased July 1, 1927, with the expiration of the Austin Fellowships. Since that time occasional observations have been made on the road, but little work of any kind has been done, due to the new policy of the County Board of Supervisors.
VI. COMPOSITION OF GRAVEL ROADS

32. Analyses of Road Samples.—Although gravels of all kinds have been used for many years there appears to be little or no definite information as to the best composition or gradation of material for road use. Specifications for road gravel seem to be based altogether on information obtained for purposes other than road building, instead of on analyses of those gravels, taken directly from the road, which have proved their quality and characteristics. No reports of such analyses were available although correspondence was conducted with a number of states having large mileages of gravel road. In one or two instances it was reported that such tests were proposed or contemplated but no actual results could be obtained. To supply some information of this kind a number of samples were taken from the road. They were cut out by means of pick and shovel, about 25 pounds being taken from each hole. Record was kept of the location of each sample and of the behavior of that section of road.

These samples were first submitted to the silt test and then to sieve analysis. The material smaller than 1/4 inch was termed sand and its mean effective diameter was determined. Figures 14 to 16 show the results of these tests, together with the observations made on the character of the roadway. A study of these data gives some interesting information. First, every sample taken from the road had a large amount of silt or binder, much more than is usually recommended or permitted by specifications. Comparison with tests of the fresh gravels indicates that the amount of silt in the road increases with age, probably due to wear on the particles or to silt being carried onto the road by water, traffic, or maintenance operations. The maximum amount allowed by specifications should therefore be well under the maximum amount likely to develop. Second, every sample shows a large excess of fine sand. Probably the original amount has been augmented by wear of the particles. Third, the amount of coarse material or pebbles is normally quite low. This is a normal defect of bank-run materials. Since observation showed that the sections containing the larger amounts of pebbles, other things being equal, formed the best surface, the possibility of improving bank-run gravels by the addition of screened gravel is indicated. This fact is established by other operations on the experimental road. Fourth, in many respects the roads under observation might more properly have been termed sand-clay roads in which a limited amount of gravel was embedded. However, observation showed that the presence of as little as 10 per cent of pebbles greatly improved the stability
of the surface. Taken altogether these tests show that the gradation and silt content of road gravels may vary over quite a wide range and yet reasonably satisfactory results under moderate traffic may be obtained.

Figure 17 shows the composition of some natural sand-clay or "top soil" roads in Georgia. Note the similarity between the sample from one of the best sections on Mile C (Fig. 16) and that from Glenwood, Georgia (Fig. 17), which also formed a good road.

33. Gradation and Drainage.—It has been frequently noticed that certain sections of gravel roads drain off and dry out much quicker than others. It has usually been assumed that this was due to sub-grade or soil conditions. Certain indications on the test road led to the conclusion that the gradation of the gravel and the percentage of silt had a considerable influence on this phenomenon.

It seems quite evident that a gravel road is not a water-proof or impervious surface, but that a greater or less amount of the water falling on the surface penetrates the gravel and drains away by percolation. It is believed that the conditions on a feather-edge road are
COMPARATIVE ANALYSES OF TYPICAL SAMPLES OF ROAD GRAVEL AND OF SURFACE MATERIAL AS TAKEN FROM THE ROAD

Note the difference in amount of fine material contained in the two samples, and also the relative silt contents.

as illustrated in Fig. 18. Water falling on the surface penetrates the gravel to the subgrade. If the rate of rainfall is greater than the rate that the water can pass through the gravel, the gravel becomes saturated and the excess water is shed to the sides due to the crown of the road. If the subgrade is pervious, the water penetrating the gravel passes on down. If impervious, the water is deflected laterally and percolates out at the edge of the gravel. When the rain stops, the water in the gravel continues to flow out. With a pervious subgrade the entire gravel course dries practically simultaneously, while with the impervious subgrade the center dries quickly while the edges remain wet for some time due to the water percolating to the sides.

This theory explains why many gravels behave differently when used in trench construction in heavy soils, where lateral flow is prevented by the side of the trench, than when used in feather-edge construction where lateral flow can take place. It also indicates a factor contributing to the change of behavior of some gravels when the top is rendered water-proof by a treatment with bituminous material. It also explains why differences in gradation affect the rate of drying.
The rapidity with which water passes through sand is a function of the gradation of size of particles. Experiments with sand filters indicate that this rate of flow varies with the square of the "mean effective diameter," this diameter being defined as a size such that 10 per cent of the material by weight is smaller and 90 per cent larger.

In order to test this latter hypothesis the mean effective diameter of the sand smaller than ¼ in. screened from the samples of gravel taken from the road was determined. Each section of road where a sample was taken was carefully watched after several rains to note its behavior and rapidity of drying out. Of course it was quite impossible to set up even an approximate mathematical relation between mean effective diameter and time of drying because of the indefiniteness in determining when the road was dry and also because variations in the amount and kind of binder (silt) must be expected to have some effect. It seemed quite evident, however, that there is a relationship between size and gradation of particles and the rate of drying, which is indicated by the general behavior shown in Fig. 18. It seemed too that a gravel containing a sand whose mean effective diameter was less than about 0.005 inch was likely to be objectionably slow in reaching a reasonable state of dryness. No upper limit could be estimated from the data at hand.

VII. Summary of Conditions and Operations on Test Road

34. Mile A, April, 1925.—This was an earth road in very bad condition. Culverts were partially silted, ditches were filled up, and the drainage ditch was shallow. Sections A1, A2, and A6 were flooded regularly during heavy rains. Section A6 was badly eroded near the north end and there were several mudholes, especially in Sections A1 and A6. The road was impassable most of the winter and spring.

35. Mile C, April, 1925.—This was a gravel road of bank-run gravel. The ditches were filled up and the culverts clogged. The road was overflowed at culverts I, J, and K and also at times near the middle of Section C1. Part of the surface was in fair condition, especially at Sections C4 and C5. Sections C1 and C2 were badly rutted, with the gravel cut through, and with some indications of corrugations. The gravel on Sections C6 and C7 was very fine, cutting to dust or mud. Most of the mile had an excessive crown, except parts of Sections C1 and C2 which had been patched where the crown was irregular and flat.
![Graphs and Table]

**FIG. 16. ANALYSES OF MATERIAL TAKEN DIRECTLY FROM EXPERIMENTAL ROAD**

(Compare with Fig. 17)

See notes on opposite page
A—Sample from top 2 inches of surface at Sta. 120 + 00, Sec. C3. The road at this point withstood very well sudden breakup due to rise of temperature from -10 deg. F. to +40 deg. F. Side ditches were good, being at least 2 ft. 6 in. below crown. Crown was approximately 1:16. There was no serious rutting despite the fact that the earth subgrade was within 4 inches of surface (Jan. 4, 1926).

B—Sample from top 2 inches of road at junction of Secs. C4 and C5. This top dressing is resting upon an exceptionally firm base, a sample of which is analyzed also (Curve C). The road at this point was in fair condition (March 17, 1926).

C—Sample taken from bottom 2 inches of road at junction of Secs. C4 and C5. Road was in fair condition with very solid base, from which this sample was taken (March 17, 1926).

D—Sample from surface of road 100 feet north of junction of Secs. C5 and C6. Road at this point showed considerable rutting (March 17, 1926).

E—Sample from top 3 inches of road surface at junction of Secs. C6 and C7. Road was in fair condition after sudden breakup (Jan. 4, 1926).

F—Sample from lower 3 inches of a 6-in. layer of road surface at junction of Secs. C6 and C7. Road was in fair condition after sudden breakup (Jan. 4, 1926).

G—Sample from middle of Sec. C8, Feb. 7, 1927. Road was in fair condition after breakup. This section had been surfaced with pea gravel in 1926.

H—Sample from center of Sec. C8. Road was badly rutted after sudden breakup (Jan. 4, 1926). Compare with Curve G.
36. **Mile A, October, 1925.**—This road was entirely regraded. Culverts were cleared and a new culvert was placed at D and at the farm entrance at Station 43 + 20. The drainage ditch was deepened and catch basins at Station 36 + 30 were filled. In general, it was a well-graded road in fair condition for a newly graded road.

37. **Mile C, October, 1925.**—Most of the mile was scarified and regraded with revised crown. A thin application of pea gravel was placed on parts of Sections C6 and C7, and some coarse gravel was applied to part of Section C6. In general the surface was in fair condition.

38. **Mile A, April, 1926.**—The winter had been rather hard on the road. Sections A1 and A2 had been overflowed and cut into mudholes while flooded. Section A6 had been partly flooded and the ditches had been badly silted. The water had crossed the road near Stations 2 and 8 and started erosion. The road had been passable all winter, but was pretty bad at times. It showed need of larger culverts at A.
and B and higher grade at Sections A1, A2, and A6. Maintenance had been done whenever a partial thaw occurred.

39. Mile C, April, 1926.—The surface was in fair condition. Water had crossed the road at the old points and washed out considerable gravel. Sections C1 and C2 had rutted considerably and a mudhole had started. The road had been usable all winter, and in far better condition than adjacent roads. Maintenance work was done whenever a partial thaw occurred. The motor grader was the most effective implement.

40. Mile A, October, 1926.—The road had been regraded as needed, and a large ditch was cut through the hump on the east side between Stations 17 and 34 to help relieve the drainage. Most of the gravel for the surfacing had been hauled and much of it spread. The entire mile had received at least part of the gravel that was to be placed, and several sections were well compacted. The work was progressing slowly but with promise of practical completion before winter.

41. Mile C, October, 1926.—The ditches and shoulders had been entirely regraded. The culverts had been opened and a relief ditch cut on the east side between culverts J and K. A larger culvert was
badly needed at $I$. It had been intended to cut a relief ditch on the
east side for this culvert but the grader was needed elsewhere so this
work was not done. Gravel for surfacing as scheduled had been
hauled. Most of it was spread and much of it compacted. Main-
tenance work was being done regularly and gravel added as fast as
it would consolidate. The surface was in good condition, and the
drainage in as good condition as possible without the needed culverts.
Sample of gravel from the road had been taken and analyzed.
Some tendency to corrugate had been noted in Section C1 in wet
weather under summer traffic.

42. **Mile A, April, 1927.**—All except about 100 cu. yd. of the gravel
had been placed early in the winter. Where this material was lacking
the road was cut up somewhat. In Section 6, where the soil was poor,
and bank-run material had been used, both alone and in combination
with some coarse gravel, ruts had also formed. Sections A1 and A2
had been flooded and some of the gravel had washed out. Through-
out the winter maintenance work had been done whenever the weather
Rolling mudhole similar to that in Fig. 19. Two or three passes of the roller could be made before the soil became too plastic to support the roller. After a wait of an hour or two the spot could be rolled again.

permitted. Ruts and holes were kept filled. The road was usable every day of the winter, the heaviest loads being oil trucks and a 3-ton truck which made several trips a day hauling railroad ties.

43. *Mile C, April, 1927.*—All of the gravel had not been placed and a little trouble had been experienced near culverts I and K where water had crossed the road and washed out some gravel. Maintenance work had been done all winter as on Mile A with the result that the road was used every day by the same traffic as on Mile A. It was in better condition as a whole than Mile A, as might be expected. Some corrugations showed in Section C1 during the thaw time in the spring, but were removed by scarifying. This mile was by far the best mile of gravel in the vicinity.

44. *Mile A, October, 1927.*—Little work was done after April 1, and all work under the direction of the University of Illinois stopped on July 1. Observation in October indicated that practically no work had been done by anyone else. The remainder of the gravel had not
The same mudhole shown in Fig. 19 partially rolled. After rolling several times at intervals of one to two hours the soil became firm enough to support ordinary automobiles without much depression, and by the next morning gravel could be distributed with the motor grader.

The same location as shown in Fig. 19 about three weeks later, after the gravel had been spread. The breakup shown in Fig. 28 is just north of the mudhole shown in Figs. 19 and 21.
FAU. 23. SECTION A7, MAY, 1928

Erosion in the west shoulder caused by the lack of a farm entrance culvert opposite, which deflected the water from the east ditch across the road. A culvert was built but it was placed too high and did not entirely relieve the overflow, but no further erosion occurred.

FIG. 24. SECTION A8, JUNE, 1926

Subgrade with stakes to guide the first application of gravel. The gravel piles on the right were placed too far away from the center line, with the result shown in Fig. 26.
FIG. 25. SECTION A8, JUNE, 1926

Spreading the first course of bank-run gravel. Note the large stones. These should be thrown out or else covered with not less than two inches of good gravel of not more than 1-inch size.

FIG. 26. SECTION A8, JUNE, 1926

Note the crooked windrows of gravel due to placing the piles too far from the center line. It is troublesome and expensive to correct this kind of a mistake.
Filling ruts by hand in winter. This could have been done with the motor grader since there was enough loose gravel on top of the frozen material. Work of this kind, either by hand or machine, will do much to help the new road during the first year and to preserve it afterward. Winter neglect is one of the most common faults on both earth and gravel roads.

A breakup in the spring due to poor gravel on a mucky soil. This spot is just north of the mudhole shown in Figs. 19 and 21, which was covered with a good gravel and suffered but little, as shown in the foreground of this view.
The road at this point had been flooded frequently and made impassable for weeks at a time for many years previous to the work done on it as part of these investigations. It was regraded in the summer of 1925, and surfaced with about 4 inches of mixed local and screened gravel in July and August, 1926. This view late in April shows it at its worst. It had been passable every day throughout the winter. It is evident, however, that more gravel is needed. A location such as this should have at least 8 inches of gravel.

Looking in the opposite direction from the same point as in Fig. 29. The soil was practically the same but it was surfaced at the same time as the south half with 4 inches of local gravel covered with two inches of pea gravel. This was its normal condition all winter. Two rounds of the motor grader put it into excellent shape, but it would be more secure with another inch or so of gravel.
been spread and apparently no maintenance work had been done. The road was approaching the winter with the surface in fair condition except in Sections A1, A2, and A6, where additional gravel was needed. It had been expected to supply gravel to these sections but the cessation of work prevented this. The ditches needed a little attention.

45. Mile C, October, 1927.—The same general conditions existed on Mile C. The lack of maintenance work was evident.

46. Mile A, April, 1928.—This mile showed decided evidence of having been practically neglected for the year. Owing to a rather dry winter and spring, free from continued heavy rains, there had been little overflow in Sections A1 and A2, but in several places in these sections the traffic had cut through the gravel where the local gravel only, or local gravel with a light topping of screened gravel, had been used. The nature of these holes indicated that they would have been largely prevented by moderate maintenance work during the fall, winter, and early spring.

Sections A3, A4, A5, A7, and A8 were in fair condition, but would have been in good condition had they received proper maintenance. Section A6 on the whole was rather poor. It was anticipated that trouble would develop here sooner or later unless more gravel were added, because the original surfacing was thin, some of it made only of local gravel, the soil was mucky, and the drainage conditions were favorable for complete saturation and slow drying. Deep ruts had formed which could have been largely prevented by proper maintenance, but it was evident that both more gravel and better drainage were needed.

The ditches had silted up in many places, especially along the west side of Section A6. The drainage ditch was showing some silting and all the culverts needed a little attention. The water had overflowed the farm entrance at Station 43 20, and eroded the east shoulder, but apparently had not crossed the road and damaged the gravel.

47. Mile C, April, 1928.—The effect of lack of maintenance was evident, although some work was under way when the road was examined (April 20). It was also evident that the repairs to culverts, etc., and relief ditches, previously mentioned were badly needed. None of the gravel left in piles had been added and several of the sections needed it.

Ruts had been cut in Section C1 which would have been largely prevented by winter maintenance work. Additional gravel was needed.
West ditch near Sta. 37 showing silting of channel after heavy rains which clogged the inlets of the tile and ultimately caused flooding of the surface. Such ditches need frequent cleaning.

A soft and rutted spot due to poor gravel and poor condition of road.
Fig. 33. Same spot as shown in Fig. 32 after ten minutes' work with motor grader

This spot was built up from gravel adjacent to it and was kept in fair condition throughout the winter by timely blading. The motor grader is especially adapted to such work because it can be backed up and run over the same spot several times without making a complete round trip over the road. This cannot be done with the big grader and tractor, and it is difficult to do with the patrol grader.

Fig. 34. Section C4, June, 1925

Just after being scarified and reshaped with three trips of the heavy roller, scarifier and blade, and then rolled by three additional trips.
on this section on account of the mucky soil. The surface of the rest of the road was in fair to good condition.

The parts of Sections C6 and C7 which had received the first application of gravel (July, 1925) and only a small additional amount in 1926 showed signs of ruts, and the need of more screened gravel due to an excess of fine material in the existing surface was evident. Sections C3 and C4 were in the best condition as expected.

At culvert I the water had again crossed the road, washing out a channel in the gravel. This would have been prevented by a larger culvert at this point or by the relief ditch previously mentioned. Water had crossed the road at culvert K where a new culvert was also needed.

The general indications were that if it had been possible to complete the work proposed during the early summer of 1927, and then to give the road a little maintenance at the proper time during the winter, the road would have been in good condition in the spring of 1928.

VIII. CORRUGATIONS ON GRAVEL ROADS

48. Causes of Corrugations.—Although only a few corrugations developed in the experimental sections, the study of this phenomenon, combined with observations elsewhere, give the following indications: Corrugations are not likely to occur on secondary roads carrying less than 200 vehicles per day, except under very unusual conditions. They apparently develop at places in the road where the gravel lacks stability, due to excess moisture, poor composition, deficiency of binder, or where unusual tractive or braking effort is required, and they appear to grow under the harmonic action of tires and springs. Sags in the grade line are especially susceptible to the formation of corrugations.

Improper use of maintenance machines may start or aggravate corrugations. The two most common faults are (1) failure to keep bolts well tightened, and (2) trying to make too heavy a cut for the weight and speed of the machine. Both result in chattering, and this causes the formation of slight corrugations, which may then be enlarged by traffic. This action seemed quite certain on one occasion on Section C1.

49. Removal of Corrugations.—Corrugations can be removed by scarifying and blading, but they may reappear while the gravel is reconsolidating or later. Probably the only cure for corrugations is to improve the stability of the gravel. Improved surface and sub-
drainage should be the first step followed by the application of pea gravel or similar material which will take up the excess of fine material and binder, and thus increase the actual stability of the material. The corrugations noted on the experimental road were easily removed by scarifying, and they did not reappear after pea gravel was applied, thus verifying the preceding conclusions.

IX. Costs of Gravel Roads

50. Cost of Construction.—Costs derived from experiments may be misleading when applied to work done under ordinary conditions. On the experimental roads the runs were short and the work was intermittent, both of which factors tend to increase the cost. In addition, operations were often modified or repeated to secure information concerning the effect of such a change or the benefit of repeating the operation, and naturally this increased the cost. The exact cost of the work done on the experimental road is therefore not a safe criterion of costs in general. Certain derived costs, however, may be accepted as indicative and to point out where savings can be made.

Circular No. 10 of the Engineering Experiment Station of the University of Illinois gives the cost of grading an earth road and pre-
The gravel was similar in character to that shown in Fig. 35.

Paring it for oiling as about $150 per mile exclusive of repairs to culverts, tile, etc. Work on Mile C substantiates this cost, based on common labor at 40 cents per hour. The grading work on Mile A cost much more than this, due to the clearing and deepening of the drainage ditch, the reduction of the grade and the filling of eroded places. The grading work on this mile cost approximately $500.

Loading and hauling the gravel to the road was the most expensive item of labor, and showed the widest range in cost. By using the county 1½-yard trucks, with labor at 40 cents per hour, the cost of unloading screened gravel from cars by hand, hauling it two miles, and dumping it was approximately 62 cents per load, or about 50 cents per cu. yd. Bank-run gravel hauled the same distance and loaded by power cost only about 30 cents per cu. yd. A change in length of haulage did not change the cost appreciably, except where the change was enough to increase or decrease the number of loads hauled in a day.

The cost of distributing the gravel with the motor grader was approximately $50 per mile on this road which required 1250 cu. yd. of loose gravel. This was exclusive of interest and depreciation on the machine. The cost would probably vary approximately with a change in the amount of gravel.
The pit cost and freight charges on the gravel are important items in the cost of gravel roads. For example, the bank-run gravel could be obtained for about 25 cents per cu. yd. pit charge, while screened and washed gravel cost about 70 cents per ton or $1.05 per cu. yd. at the plant. The freight rate on screened material was 61 cents per ton or $1.02 per cu. yd. Thus the total cost of screened gravel on the siding was about $2.07 per cu. yd. or about 8 times that of the local material. Pea gravel was somewhat cheaper.

From the foregoing it might be inferred that the local gravel would be the most economical. This is not necessarily true as shown by the results on the road. The local gravel, due to an excess of sand, lack of binder, and other causes, might form a road which would be difficult and expensive to maintain, or which would not support the traffic at all, whereas the more expensive and better graded material would form an excellent roadway easy to maintain and capable of carrying the loads, and hence in the long run would be the cheaper. However, it is frequently possible to combine the two, thus securing a satisfactory road and reducing the cost, as shown on the experimental road.

As an example, assume that a mile of road is to be made with a cross-section about like that on Mile A, using about 4 in. of local
Gravel was recrowned with blade grader. Note the check template. Ditches not completed. Compare with Fig. 34.

Gravel and 2 in. of screened gravel. This would require about 900 cu. yd. of local gravel and 400 cu. yd. of screened gravel. Assuming further that both materials must be loaded by hand, and that the distance of haulage is about 2 miles, the cost would be about as follows:

- Regrading and preparing subgrade: $150
- 900 cu. yd. of local gravel at 25 cents: $225
- Hauling 900 cu. yd. at 50 cents: $450
- 400 cu. yd. screened gravel at $1.05: $420
- Freight on 400 cu. yd. at $1.02: $408
- Unloading and hauling 400 cu. yd. at 50 cents: $200
- Spreading gravel and finishing surface: $50

Total: $1903

If screened gravel only had been used the cost would have been $3540, while with local gravel throughout the cost would have been only $975; but the latter road would not have been nearly so good as that made of the two gravels combined.

51. Cost of Maintenance.—The cost of maintenance cannot be accurately estimated, since it depends on the kind of gravel, the amount and kind of traffic, the organization for the work, and the amount of work per season.

Assuming the general characteristics of the experimental road, the motor grader can be operated for about 50 cents per mile. Two round
Rebuilding the shoulders with material provided by reshaping the ditches, using the blade grader. No sod or dirt was taken onto the gravel, and the tractor was used to crush clods. Note the new ditch as shown on the left side. Compare this ditch with that shown in Fig. 35.

Trips are needed at each blading and a probable maximum of 25 bladings per year would be needed on the gravel. This would make the cost of blading $50 per mile. Roughly one-fourth to one-third as much work would be required on shoulders and ditches, thus making the cost of caring for the roadway about $65 per year.

At indefinite intervals there should be a partial regrading at a cost of perhaps $75 to $80 per mile. If this were required every four years the annual cost would be about $20. Also, at indefinite intervals, a surface dressing of about 1 inch of pea gravel should be made. Assuming the conditions existing on the experimental road, probably once every fourth year would be the maximum limit. With the prices given, about 250 cu. yd. costing about $640 would be required. This would mean an average of $160 per year.

The total cost to maintain the road indefinitely would thus be 65 + 75 + 160 or $300 per year. If a satisfactory gravel could be screened at a local pit at a cost of about $1.00 per cu. yd. the cost could be reduced to about $235 per year, which shows that, after all, the cost of the gravel itself is only a fractional part of the total cost of the road. On outlying roads where traffic is less, and where less maintenance is required, these costs might be more than cut in two.

Adequate maintenance is essential for providing a satisfactory gravel road. No scheme of improvement should neglect to provide
Funds and organization for maintenance. The failure to provide maintenance is the reason that rehabilitation is necessary. While it may be possible to rehabilitate at approximately the same total cost as continuous maintenance, the results are never the same. Continuous maintenance will assure a smooth, convenient, safe, and usable road at all times, a condition which cannot be attained by alternate neglect and care. The change in condition of both Mile A and Mile C between April, 1927 and April, 1928 is ample verification of the fact that adequate and continuous maintenance is essential to all-year service of a gravel road.

X. SUMMARY AND CONCLUSIONS

52. Conclusions.—The following conclusions may be drawn:

(1) Efficient drainage is absolutely essential to the stability of a gravel road. Prompt surface drainage is necessary at all points while subdrainage is required only at those places where ground water may cause trouble. Culverts must be of ample size, side ditches of sufficient capacity, and the crown enough to shed the water quickly from the roadway without erosion of the surface or discomfort to traffic. Maintenance operations should keep the crown intact, prevent the formation of ruts and holes, keep the shoulders and ditches free from
obstructions to the flow of water, and assure that culverts are unobstructed, so that the surface water will drain off quickly and completely.

(2) For gravels of the type used on the experimental road the best crown appears to be that with an average cross slope of about $\frac{3}{8}$ to $\frac{1}{2}$ inch per foot, with a maximum of about $\frac{3}{4}$ inch per foot. More than this latter amount tends to develop erosion of the gravel. Shoulder slopes between the edge of the gravel and the ditch appear to work best about $\frac{3}{4}$ to 1 inch per foot.

(3) The rapid drying of the gravel is expedited by a smooth hard subgrade and a favorable gradation of the gravel. An excess of both fine material and binder in the gravel should be avoided, while the mean effective diameter of the contained sand should be not less than 0.005 inch.

(4) The best gravel for the surface of a road where clay is the binder should have a composition similar to that shown in Fig. 4, curve D. The same gradation may be suitable for other kinds of binder, but the amount of binder required may be different.

(5) The composition of existing gravel roads varies over a very wide range. The analyses of the materials from the experimental roads show that in general such gravels contain a large amount of fine material and that the gradation and other characteristics of the
A bad mudhole existed up to 1925 at culvert K located just beyond the second telephone pole. The maintenance during the fall and winter of 1925-26 kept the road passable, but the spot was pretty bad at times due to flooding of the road. The ditches were regraded in 1926, the culvert was cleared out and the surface covered with about 5 inches of pea gravel. No evidence of breakup appeared during the winter and spring of 1926-27 although the road was flooded once or twice and some of the gravel had been washed off.

Gravel after several years of service may be decidedly different from what they were when the gravel was placed. In general, the amount of fine material and binder tends to increase considerably.

(6) The most effective amount of clay binder appears to be from 12 to 15 per cent by weight. Gravel with less than 8 per cent does not compact well, while 20 per cent or more causes the surface to become soft and muddy when wet or unduly dusty when dry. Since the effect of traffic is to increase the amount of binder in the gravel the amount present in new material should be somewhat less than that considered desirable. It is suggested that specifications should provide that the gravel shall contain not less than 6 nor more than 12 per cent by weight of clay or other suitable binder.

(7) Many bank-run gravels form very good moderate traffic roads. A great many bank-run gravels carry an excess of fine material but, as demonstrated on the experimental road, can be greatly improved by selection in the pit, by screening out part of the sand, or by adding clean screened gravel to make up the deficiency in coarse material. In many cases the lower 4 to 6 inches could be made of local bank-run materials and the road then topped with 2 inches of selected or screened materials with greatly improved results, and at a considerable
GRAVEL ROADS FOR MODERATE TRAFFIC

saving over the cost when screened gravel is used for the entire depth. Pebbles larger than about 2 inches in size should not be permitted within about 3 inches of the surface, as they are likely to work through to the top.

(8) Pea gravel appears to be the most suitable material for surface dressings, especially during rehabilitation and maintenance. It unites well with existing materials or bank-run gravels, compensates for an excess of fine material and binder, is easily placed and worked with the blade or drag, and makes a smooth surface pleasing to traffic.

(9) The feather-edge type of construction is well adapted to the gravel road for moderate traffic. Somewhat more material is required than with the trench type, but this is more than compensated for by greater ease in preparing the subgrade, in placing and compacting the gravel and in maintaining the surface. With feather-edge construction the overall width should be a minimum of 15 to 16 feet which permits fairly convenient passing in wet weather. Such a road requires about 200 cu. yd. of loose gravel per mile per inch of compacted center thickness. If the traffic consists of ordinary farm haulage with only occasional heavy trucks a compacted thickness of 6 inches is sufficient on most soils if the maintenance is reasonably good.

(10) The best method of placing the gravel in feather-edge construction is by means of the blade grader or the motor grader from piles along the edge of the graveled way. The first layer should not exceed 4 inches of loose material, while subsequent applications should not exceed \(1\frac{1}{2}\) to 2 inches. Ample time should be allowed between applications for the material to compact. This action can be hastened by keeping the ruts filled and the surface smooth by means of the blade or drag. Rolling is not very effective.

(11) The motor grader proved to be vastly superior to either the ordinary blade grader or the drag, and is preeminently the implement for maintenance work on the gravel surface, for spreading gravel during construction and rehabilitation, and for shaping shoulders. It was, however, not suited to ditch grading. The light type as used on this work is very effective and its moderate cost makes it available for the smaller road units where only a moderate amount of work is done each season. For the larger units or more intensive work the larger model of greater weight and power is doubtless preferable. The scarifier attached to the motor grader is sufficiently strong and adequate for gravel roads.

(12) The motor grader should cut in low gear. Although it will cut at higher speeds the operator does not have time to control the
machine properly and the result is almost invariably rough and irregular work. Earth shoulders should be cut when the soil is moist but not soft; but the best work on the gravel is done when the road is quite wet.

(13) A heavy roller equipped with scarifier and blade, of the type used on this work, is an excellent machine for the rehabilitation and regrading of gravel and probably also of macadam. Since the blade could be adjusted to the road surface independently of the scarifier it was possible to move the loosened material so as to form a new cross slope and at the same time scarify the old surface to a uniform depth. This greatly expedited the work. The horizontal plate attached to the blade reduced the chattering of the blade and gave a smoother surface. Owing to its high initial cost and expense of operation such a machine would prove economical only for the larger road units where the volume of work to be done would keep the machine busy many days of the year.

(14) A light roller equipped with blade and scarifier of the type used on this work has many uses. It can be used to compact both earth and gravel in thin layers, and the scarifier is sufficient for gravel work and often useful in hard earth. The blade, however, did not prove satisfactory for this work. It was mounted in front of the rollers and consequently amplified the variations or irregularities in the profile. At the same time it was so far in front of the center of gravity of the machine that the side thrust of cutting tended to turn the machine laterally. This made it hard to guide the machine and consequently limited the cut the blade could make. If the blade had been suspended between the rollers the results would have been better.

These investigations demonstrate that it is entirely feasible to build and maintain a plain gravel road at moderate cost that will render satisfactory service to moderate traffic throughout the year if materials are available near at hand. If materials must be shipped in the freight charges will add greatly to the cost. No unusual or expensive machinery is necessary. The loading and hauling of the gravel is the most costly operation.

It is also demonstrated that a neglected gravel road can be readily rehabilitated and put into excellent condition at a very moderate cost. The grading work can normally be done at from 50 to 150 dollars per mile. To this must be added the cost of such new materials as may be found necessary.

The results obtained from maintenance operations during the winter and while the general spring thaw was taking place were highly
significant. If advantage is taken of partial thaws throughout the winter to fill ruts and holes and smooth the surface, and if extra care in this direction is taken at the time of final thaw, the road will be serviceable at all times, will not get into very bad condition at any time, and much of the usual midsummer regrading work will not be necessary.
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