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ENGINEERING EXPERIMENT STATION

Series 24

THE GRADING OF EARTH ROADS

by

HARRY A. LA RUE

Associate Professor of Highway Engineering

ISSUED THREE TIMES MONTHLY; ENTERED AS SECOND-CLASS MATTER AT THE POSTOFFICE AT COLUMBIA, MISSOURI—16,000

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INTRODUCTION

Although the State of Missouri has embarked on a program of constructing a state system of hard roads, earth roads will still remain of great relative importance to the majority of the people in the state; and this condition will continue to exist for a great many years to come.

The total mileage of roads in the state is approximately 124,000 miles. Of this amount only 7,630 miles have been designated as State Roads on which the State Bond Issue and Federal Funds are to be expended. This leaves more than 115,000 miles of earth roads, to be maintained by local, township, and county road officials, with the use of local, township or county funds.

It follows, therefore, that any improvement in methods of constructing and maintaining earth roads is a matter of vital importance to the population of the state. Without passable roads as connecting links from the state highway system to outlying districts, it will be impossible for the vast majority of the residents of the state who do not live on the state roads to derive much benefit from them.

It has been demonstrated that an earth road can be constructed and maintained in such manner as to make it the most desirable road for serviceable travel during a large portion of the year, and even passable for the few winter months of the year.

Acknowledgments.—The investigations were conducted as a research problem by the Engineering Experiment Station of the University of Missouri, E. J. McCaustland, Director, with H. A. La Rue, Associate Professor of Highway Engineering, in direct charge.

The project was made possible by the cooperation of the road officials of the Columbia Special Road District and by the assistance of the commercial organizations interested in road improvement. The Holt Manufacturing Company of Peoria, Illinois furnished a ten-ton caterpillar tractor and operator, to pull the grader; the J. D. Adams and Company of Indianapolis, Indiana, supplied a 12-foot grader and operator to grade the roads. Mr. J. L. Lyons, Chairman of the Road Commission for Columbia Special Road District and Mr. L. D. Shobe, Superintendent of the Columbia Special Road District, designated a section of road in the District, furnished the men and teams for clearing the brush from right-of-way, and also repaired and lengthened the culverts preparatory to doing the grading, which involved a widening of the roadway.

The Grading of Earth Roads

Purpose.—For the purpose of illustrating the methods of properly grading an earth road to obtain adequate drainage, and to secure a roadway of sufficient width and crown for modern traffic, the Engineering Experiment Station of the University of Missouri, in cooperation with the road officials of the Columbia Special Road District, carried on an experimental road grading project during May, 1923.

The object of the experiment was to demonstrate the proper use of modern machinery in constructing an earth road of standard cross-section, crown and grade; to make provision for proper drainage of the roadway by forming adequate ditches and outlets, also to determine the cost of carrying on such operations.

Scope of Project.—The section of road selected for the grading operations was a six mile stretch of road, over rolling country, in which the soil varied from a light sandy loam to a very heavy, tough clay. The conditions found on this road might be considered as fairly typical of Missouri road conditions for a large part of the state. The pictures shown in this bulletin illustrate the conditions found here in the grading operations.

WORK PRELIMINARY TO GRADING

Surveys.—In order to obtain complete data as to amount of earth moved and to determine the cost of doing the work, a complete survey was made of the road. This consisted of running the center line with transit and measuring the distance accurately, setting station stakes every 100 feet, and taking a full set of cross-sections at each station for the purpose of computing the amount of earth moved. Line stakes were also set for the ditch so that an even width of roadway and straight ditches could be constructed.

Clearing Right-of-Way.—All tall grass, weeds and brush were cleared from the road sides since such material has a tendency to roll up in bunches under the grader and become finally discharged into the middle of the roadway. Some stumps were found that would interfere with the widening of the roadway, but these were easily pulled out with the tractor if they did not exceed six or eight inches in diameter. Larger stumps were removed with explosives.

Road Cross-Section.—The typical cross-section for the experimental road is represented in the sketch, Fig. 1.

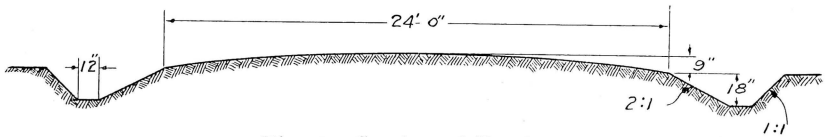

Fig. 1. Section of Roadway

This cross-section has a relatively flat crown, which insures more comfortable travel than if a steep side slope to the roadway is used; this slope will drain well if the surface is maintained in a smooth condition by consistent dragging; the shoulders were well defined in order to separate the side

FIG. 2.—Road immediately before grading.

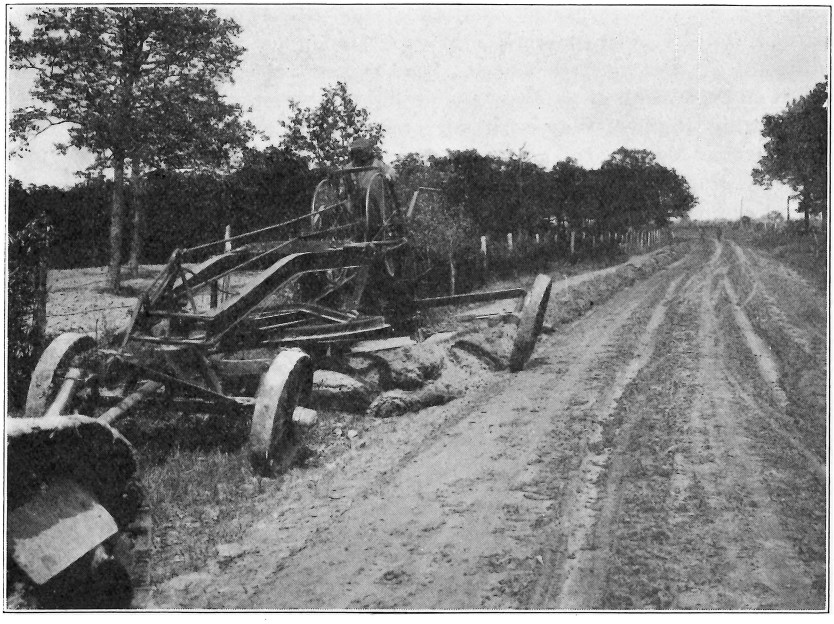

FIG. 3.—*First Cut With Grader.*
A shallow cut produces thin pliable sods that can be cut up by the tractor and covered.

FIG. 4.—*First Cut With Grader.*
Rear view of grader, showing set of grader and depth of ditch cut on first round.

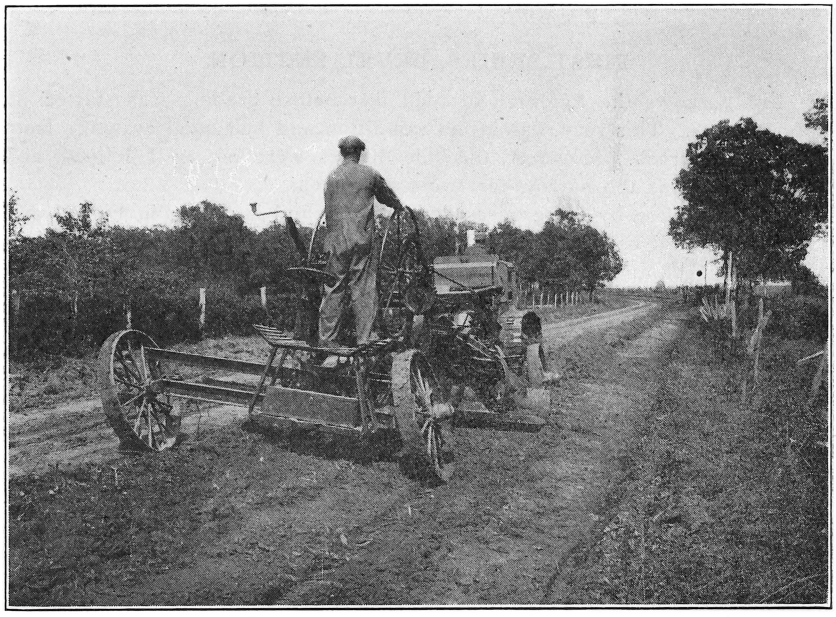

FIG. 6.—*Second Round With Grader.*
The loose earth and sods from first ditch cut are moved in and spread so they can be covered with earth obtained from the ditch in succeeding rounds.

ditches from the wearing surface. The ditches are made of sufficient depth and width to enable the water to drain away from the roadway readily. The back face of the ditch is inclined so that the bank will not crumble down and fill up the ditch as rapidly as would occur if the bank were vertical.

During the summer following the grading of this road, and under the normal traffic the roadway developed a smooth track that was easy to travel upon; at the same time the water from the rainfall drained readily into the side ditches. The crown of this road is much flatter than the crown found on most earth roads which are, as a rule, exeessive and are not satisfactory for travel under any condition.

OPERATIONS OF GRADING ROAD

Successive Rounds of Grader.—The cuts used to illustrate the method of grading an earth road are reproduced from photographs taken of the machinery in operation on the experimental road.

Two series of pictures are shown herewith to illustrate two conditions of roadway which may be termed typical for many old roads in the State; the first type of road is a level stretch of roadway with light ditches and balanced section, in which the roadway is approximately level with the adjacent land; the second series illustrates an old roadway worn down until it has a high bank on each side, and a very narrow track is left for travel. This particular section is regarded locally as a bad stretch of road on account of being so narrow that vehicles in meeting are often crowded into the soft ditches and mire down.

FIRST SERIES, LEVEL SECTION

Fig. 2 shows the condition of road just before grading was started on May 18, 1923. This road was in fair condition and had good drainage from the traveled track. However, the side ditches were not well defined, and the roadway was too narrow for two-way travel.

The cut taken by the grader on the first round is shown in Figs. 3 and 4. For this first cut on a road, the blade is set to cut an even depth along its entire length and at a sharp cutting angle nearly parallel to the direction of travel.

When the grading has been completed, the surface of the road should be free from sods. This requires that the sods be reduced to a minimum and that the quantity of fine earth be a maximum. As most of the sods come from the first cut of the grader, this cut should be as shallow as possible without permitting the blade to come out of the ground; under ordinary conditions this will mean a cut two or three inches deep. The resulting sods will be thin and pliable; in addition, the total volume of sods will be small, and they can be easily cut up and covered.

In making the first cut, the point of the blade should be kept a few inches inside the outer edge of the finished ditch. Then, by having each of the successive ditch-cuts a little deeper and a little nearer the center of the road, the rough ditch will have a stepped back face as shown in cross-section by the dotted lines of Fig. 5. With the point of the blade located as

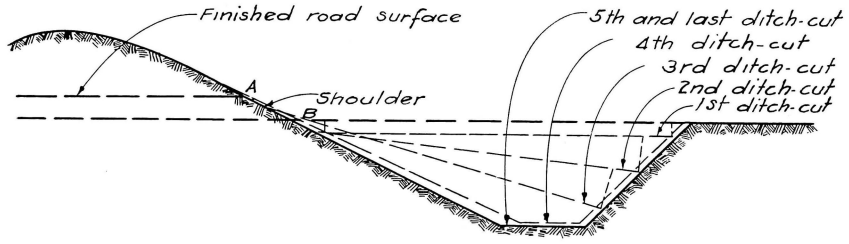

Fig. 5. Cross-Section Showing Cuts Taken by Successive Passages of Grader.

As the point of the blade is lowered for the successive rounds, the heel is raised so as not to disturb the shoulder AB. For successive cuts the point of the blade is kept away from the finished back slope.

described, and with the stake-line at the middle of the ditch, the operator will be in a position to sight along the stake-line when he makes the first cut.

It is very important that the first cut be straight, as the succeeding cuts are governed by the first, and any curve which appears in the first cut is likely to persist in the finished ditch.

The second round of the grader is illustrated in Fig. 6. The ridge of sods formed by the first round, was broken up and spread so that it could be covered with fine earth obtained in later cuts from the ditch.

The second ditch-cut which is the third round of the grader is illustrated in Fig. 7. For this cut, the point of the blade was set a little deeper than the heel in order that the ditch might be deepened without disturbing the earth which forms the shoulder. The dotted lines in Fig. 5 represent a section of the second ditch-cut. It is to be noted that the second cut does not extend as far to the right as the first, and that the stepped face of the rough back slope becomes apparent.

Figs. 4 and 7 show the spoil from the ditch-cuts being delivered on the line of the finished shoulder. The grader should be hitched to the tractor with just enough offset to insure that, with the grader making a ditch-cut, the outside wheel (or track, in the case of a caterpillar tractor) of the tractor will run on this spoil. The relative positions of the grader and tractor are shown in Figs. 18 and 31.

There are three distinct advantages in having the tractor run on the shoulder when the grader is in the ditch. First, the tractor is clear of mud, and water, and it can, therefore, deliver a maximum drawbar pull. Second, the sods during the first ditch-cut are cut to pieces and rolled down during the second cut so that the grader, in transferring earth from the shoulder to the center of the road, does not move the sods. Thus, the sods are not only kept off the center of the road, but by the time the road is finished, they have been for the most part entirely cut to pieces. Third, since successive passages of the tractor pack the shoulder, by the time the road is finished, the shoulder is solid and more stable than a shoulder of loose earth would be.

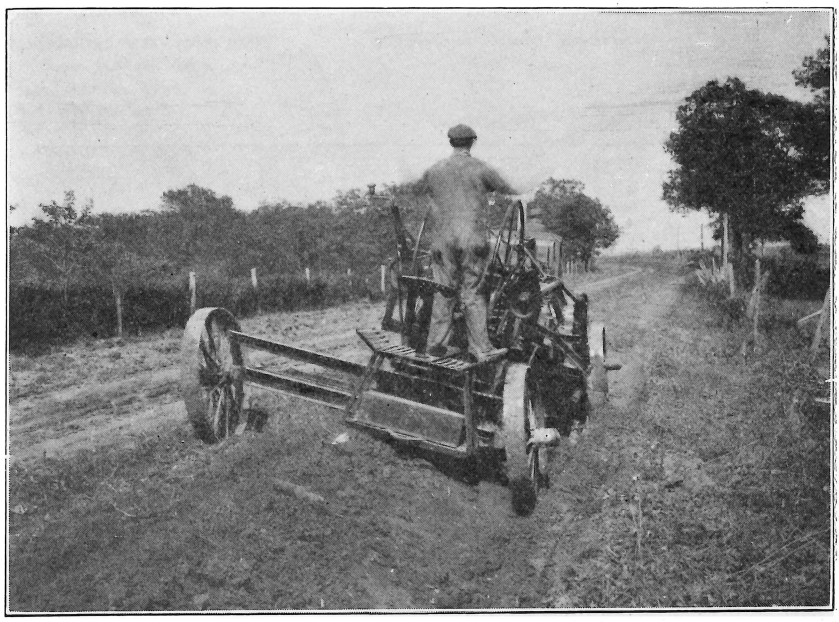

FIG. 7.—*Third Round of Grader, Second Ditch Cut.*
The ditch is deepened and the spoil delivered at the heel of the blade.

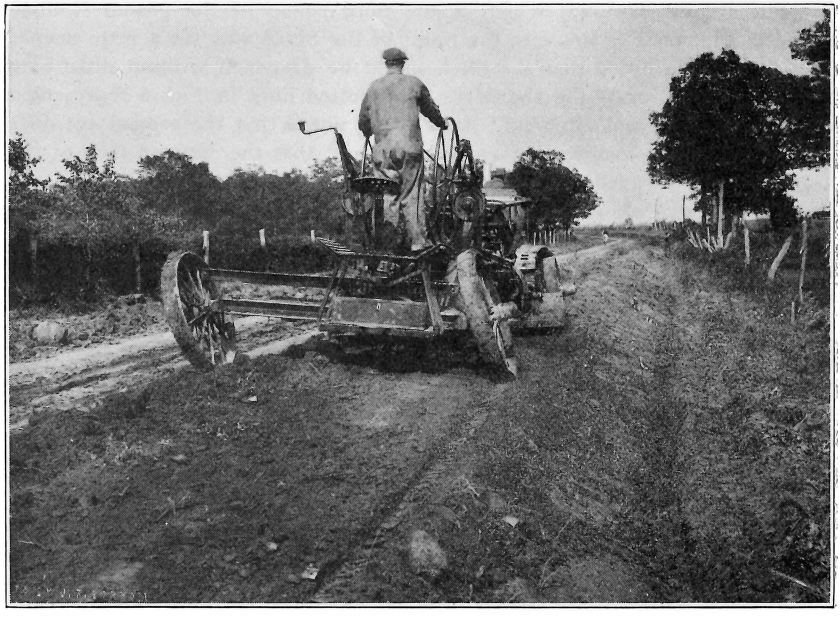

FIG. 8.—*Fourth Round of Grader.*
The loose earth is transferred from the shoulder toward the center of the road.

The fourth round of the grader is illustrated in Fig. 8. The purpose of this round is to move the excess earth from the shoulder toward the center of the road. For this work the blade should be set a little straighter across the road than for the ditch-cuts. This is done in order that the earth may be transferred a maximum distance with a single passage of the grader.

The blade should also be placed low enough to transfer the loose earth resulting from the second ditch-cut, but high enough to slip over and not disturb the sods of the first ditch-cut. If this is done, and it can be done with a high degree of success by a competent operator, the loose earth will be in the center of the road, and the sods will remain at the shoulder where they are further ground up and packed down by successive passages of the tractor.

Transferring the earth from the shoulder toward the center of the road necessitates a much smaller draw-bar pull than the ditch-cut does, so that, if a tractor having three speeds is used, it can be run in "intermediate" or even possibly in "high" for this round, thus expediting the work.

Fig. 9 shows the fifth round of the grader, which was the third ditch-cut, the earth removed from the ditch being represented in cross-section by the dotted lines of Fig. 5. For this cut, the blade was again set nearly parallel to the edge of the road; the point of the blade was set down while the heel was kept up so as to clear the solid ground at the shoulder and to deliver the spoil just inside the shoulder line; the point was kept back from the back face in order to cut another step in the rough back slope. This passage of the grader left a ridge of mellow earth on top of the sods just inside the shoulder line.

Fig. 10 presents the sixth round of the grader. In this operation the loose earth was transferred from the shoulder toward the center of the road. As in the third round, the blade can be set a little more across the road than for the ditch-cut; and the tractor, if it has three speeds, can be run in "intermediate" or "high."

This operation is essentially the same as that of the fourth round, with a difference, however, in the case of an unbalanced road section. It is at this point that the correction of an unbalanced section is begun. Description of the operations required for this process is given on page

On the seventh round the back-sloper was attached and the fourth ditch-cut was made. The back face of the ditch was cut on a slope and the ditch was deepened. This cut delivered a ridge of fine, loose earth on the line of the shoulder which is later used to finish the surface of the roadway. This operation is illustrated in Figs. 11 and 12.

The eighth and ninth rounds are illustrated in Figs. 13 and 14. These operations carried the loose earth from the shoulder toward the center and distributed it in such a way that at the end of the ninth round the road approximated the finished section.

The tenth round of the grader is shown in Fig. 15. This is the fifth and last ditch-cut. In this round the back slope of the ditch is smoothed

FIG. 9.—*Fifth Round of Grader, Third Ditch Cut.*
The ditch is deepened, and the spoil delivered onto the shoulder.

FIG. 10.—*Sixth Round of Grader.*
The loose earth is transferred from the shoulder toward the center of the road.

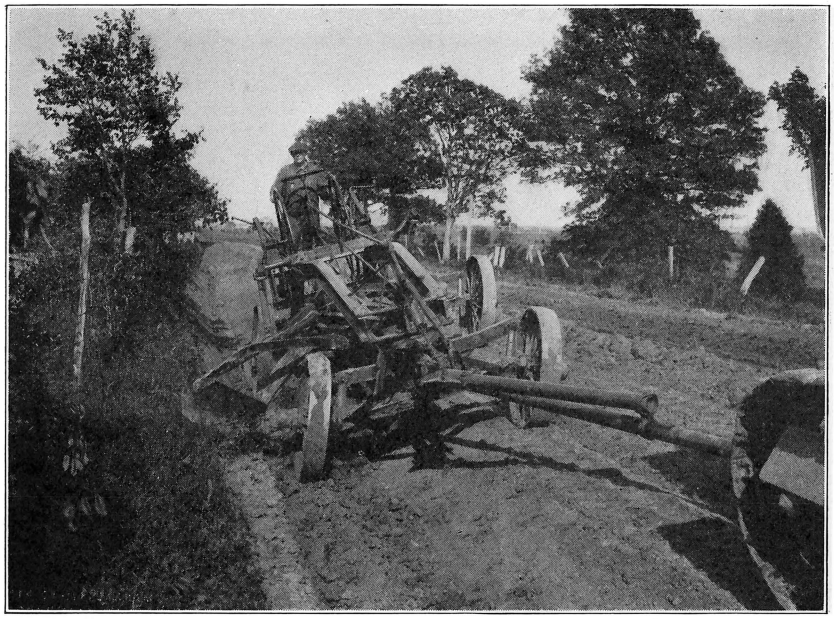

FIG. 11.—*Seventh Round of Grader, Fourth Ditch Cut.*
The ditch is deepened and the back-slope is trimmed by the attachment to the grader.

FIG. 12.—*Seventh Round of Grader With Back-Sloper Attached.* Rear View.

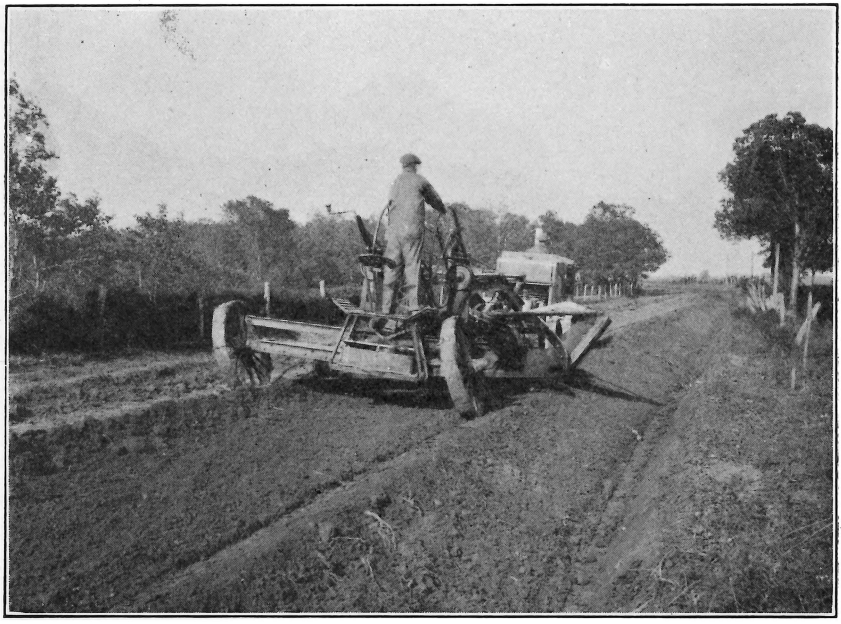

FIG. 13.—*Eighth Round of Grader.*

The loose earth is moved toward center of road and a ridge is formed at the heel of the blade.

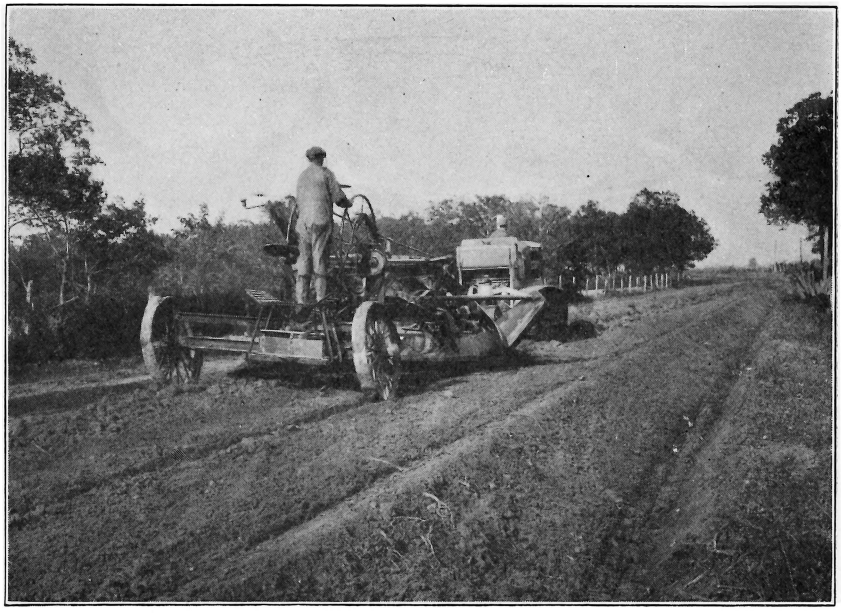

FIG. 14.—*Ninth Round of Grader.*

The ridge of earth formed by the previous round is spread toward the center of the road, approximating the finished section.

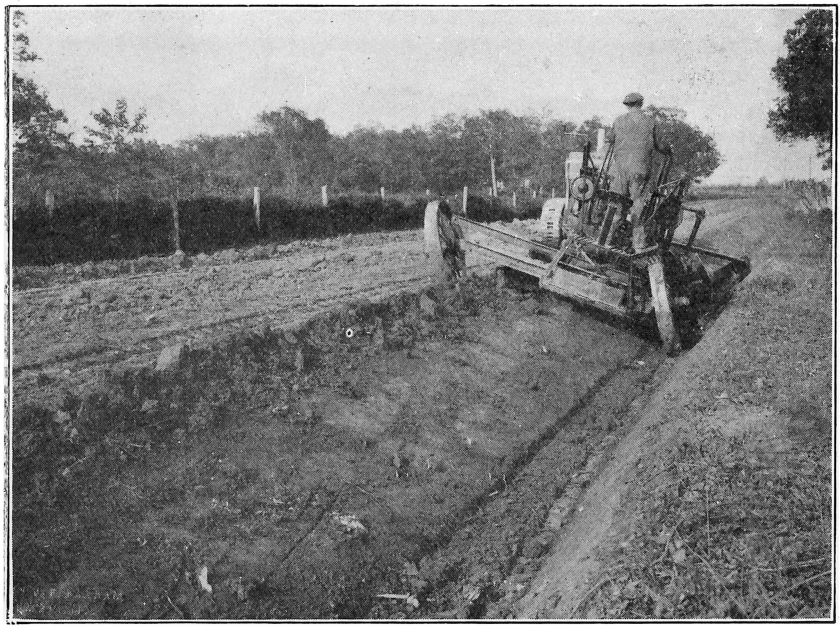

FIG. 15.—*Tenth Round of Grader, and last Ditch Cut.*

The ditch is smoothed up and deepened. This cut provides additional fine material for finishing the road surface.

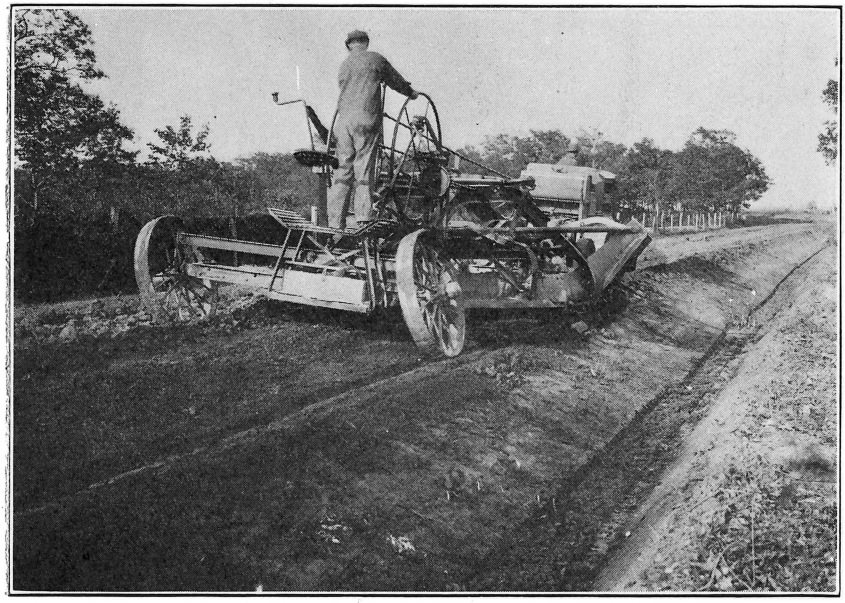

FIG. 16.—*Eleventh Round of Grader.*

The earth is transferred from the shoulder toward the center of the road and a ridge is formed at the heel of the grader. The back sloper is used for this round to prevent loose earth from rolling into the ditch.

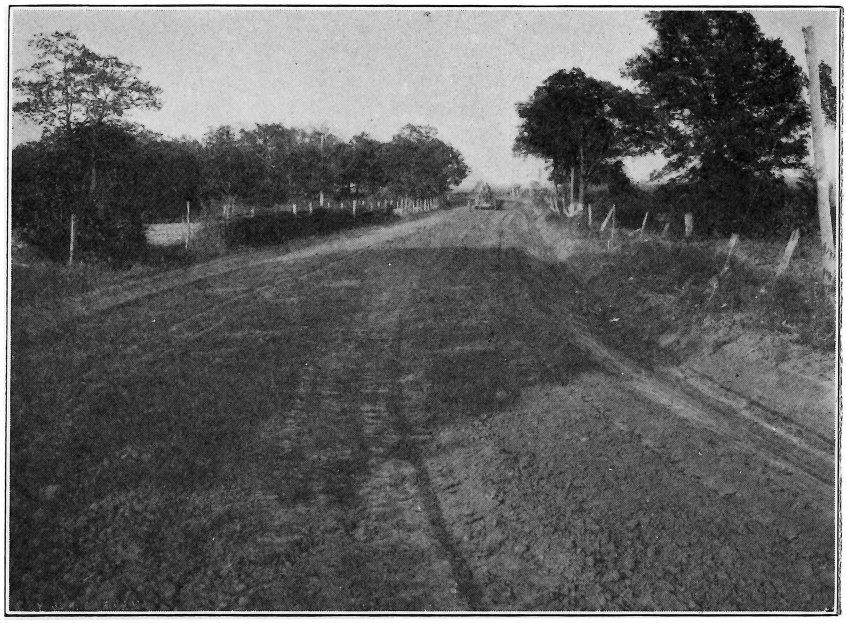

FIG. 17.—*Finished Road.*

Last round of grader is being made in the distance. Near view in the photograph shows finished road, taken on the same day as Fig. 2.

FIG. 18.—*View of Tractor and Grader.*

The tractor is direct-connected to the grader, but it is offset so that the tractor will travel on the shoulder and the grader is in the ditch.

up, and any loose material in the ditch is cleaned out and discharged on to the shoulder. In order to deliver this earth to the shoulder, the blade should be tipped forward at the top. This cut deposited on the shoulder a quantity of fine, loose earth, which was in excellent condition for distributing over the road to complete the finishing of the surface.

By cutting the back slope smooth and at an easy grade, the grader makes a ditch much less likely to fill than if the back slope is left rough or vertical. Besides, the smoothly cut back slope gives the road a finished appearance.

As a result of the eleventh and twelfth rounds, Figs. 16 and 17, the loose earth was again transferred from the shoulder toward the center of the road, and the road was brought to a finished surface. Figure 17 made from a photograph taken at 5 p. m. on May 18, 1923, shows a portion of the road after the twelfth and last round had been completed.

SECOND SERIES—OLD ROAD IN DEEP CUT

The second section shown in the second series of photographs following, was an old narrow road between high banks. This section was widened by pulling down the banks, raising the level of the roadway with the earth so moved and forming side ditches for the drainage of the roadway.

The effectiveness of the machinery used on this project for such a purpose is well shown in the accompanying cuts.

The first two or three rounds with the grader resulted in cutting down the banks and moving the earth out to form a level portion along the banks on which to operate the machinery in a level position. It is impossible to successfully cut down a high bank by beginning at the bottom of the slope. The adjustments of the grader make it possible to start on the side of a very steep bank and begin the cutting at the top.

The several stages involved in cutting down the banks, and moving the earth to the middle of the roadway are well shown in the accompanying illustrations, Fig. 19 to Fig. 31 inclusive. This road was widened from a 16-foot track to 30-foot finished section between ditches.

Some very tough and gummy clay, extremely difficult to handle, was encountered in this cut. Evidence of this is shown in the photographs. This part of the material, taken from the bottom of the bank was moved out into the roadway and in later rounds covered with the better soil cut from the top of the banks in back sloping. This better working soil is spread evenly over the surface of the grade and provides a good material for smoothing off the roadway.

Balancing Cross-section.—Another condition often encountered in old roads is to have one side higher than the other. This is often the case on ground sloping transversely to the roadway with a high bank on one side, the other side being lower than the roadway itself. In grading such a road, it becomes necessary to transfer earth completely from one side to the other.

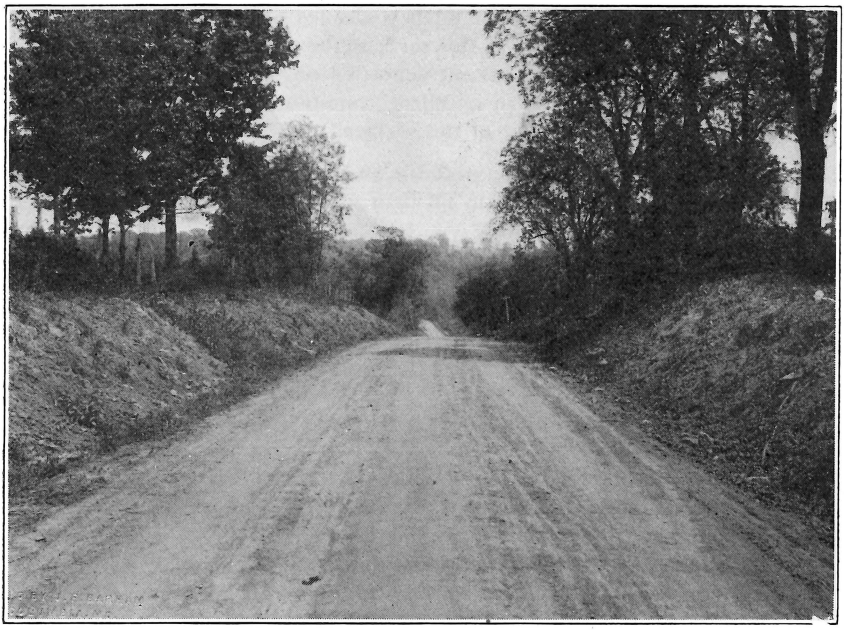

FIG. 19.—Road in cut before grading.

FIG. 20.—*First Round With the Grader.*
The cutting of the banks is started at the top of the slope.

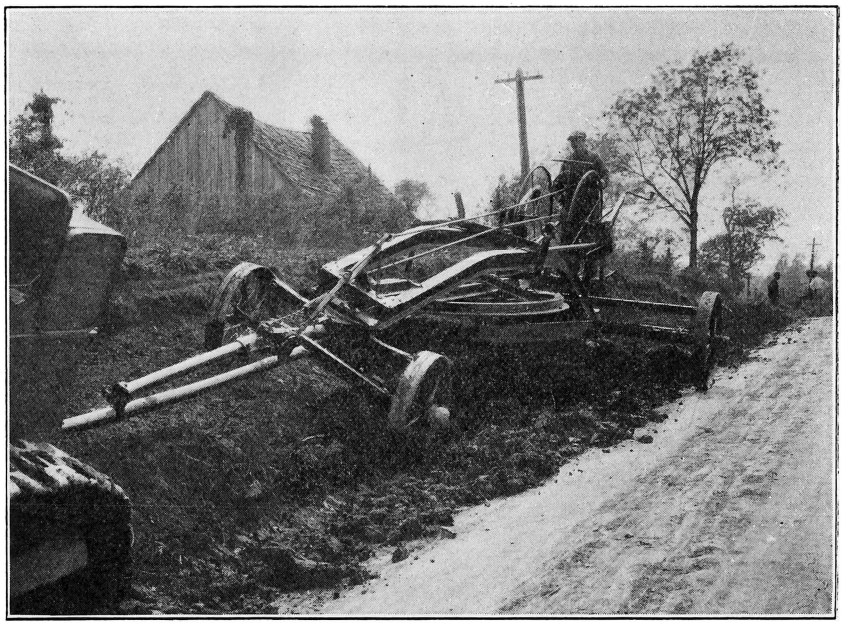

FIG. 21.—*Second Round With Grader.*

A second cut is made near the top of the banks, and the earth moved out to form level bench on which the machinery can travel.

FIG. 22.—*Third Round With Grader.*

The bank is cut in steps as illustrated in Fig. 5 so that a back-slope can be made with the back sloper attachment later.

FIG. 23.—*Fourth Round With Grader.*

In this round the banks have been cut down enough to enable the machinery to travel on practically level ground.

FIG. 24.—*Fifth Round With Grader.*

The loose earth is moved in toward center of road and is used to raise the level of the roadway.

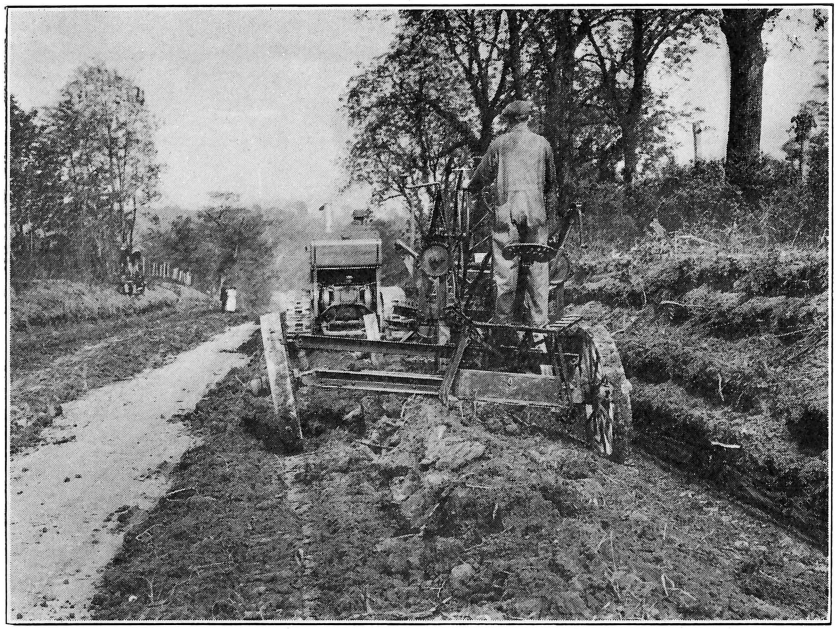

FIG. 25.—*Sixth Round of Grader.*
Another ditch cut is made on this round preparatory to back-sloping the banks.

FIG. 26.—*Seventh Round of Grader.*
The back-sloper is attached and smoothing up the slopes of the banks is begun on the seventh round.

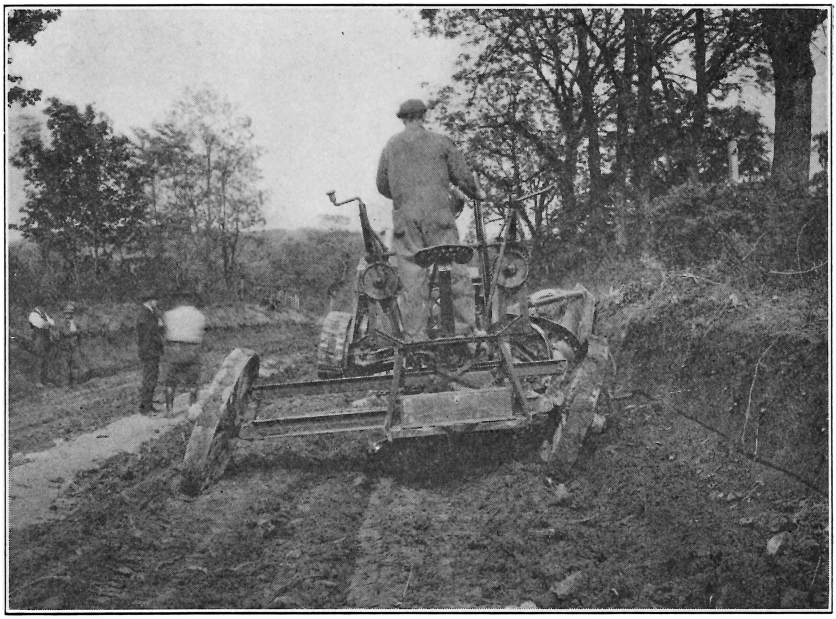

FIG. 27.—*Eighth Round of Grader.*
The trimming of the back slope is continued in this round.

FIG. 28.—*Ninth Round of Grader.*
This round completes the trimming of the back-slope and cuts the ditch.

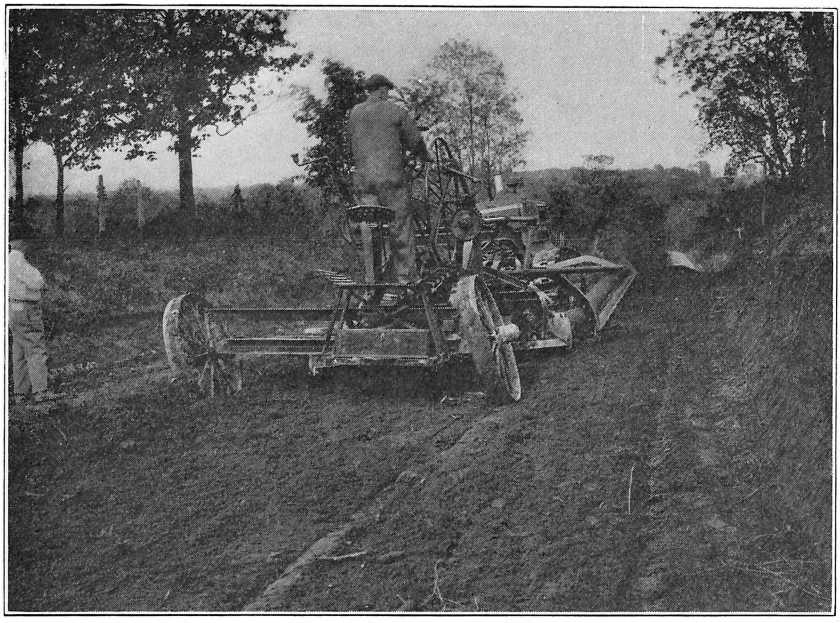

FIG. 29.—*Tenth Round of Grader.*

The loose earth obtained from trimming the banks is moved towards the center of the road and spread so as to produce a smooth surface.

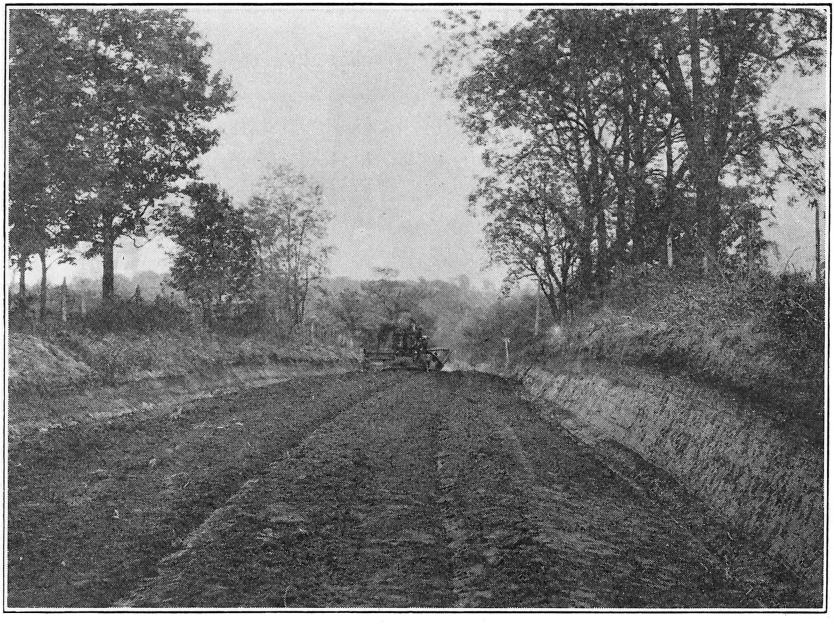

FIG. 30.—*Final Round of Grader.*

The last two or three rounds with the grader can be used to advantage in smoothing the back-slope, cleaning out loose earth in the ditches and spreading this earth over the road for a final smoothing of the surface.

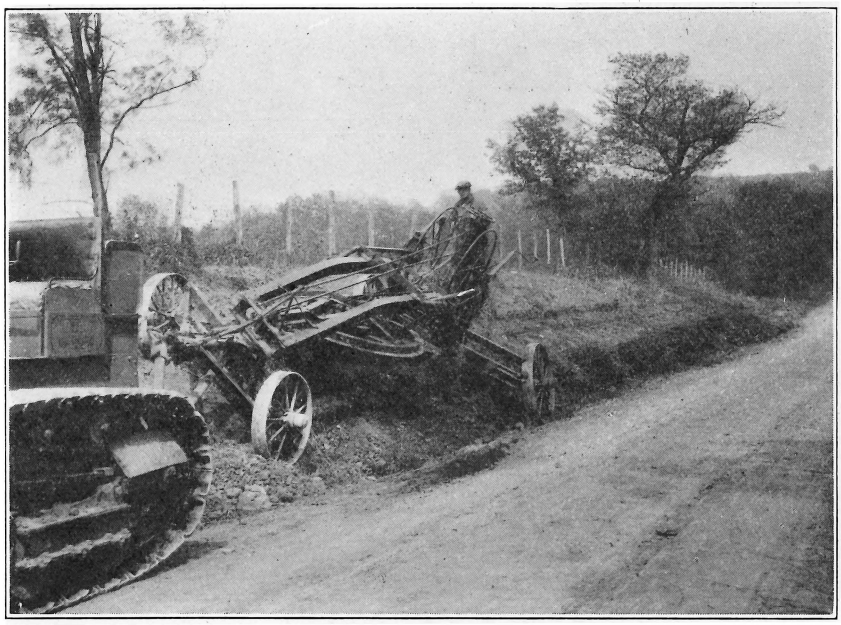

FIG. 31.—*Cutting Down High Bank.*

This photograph illustrates the method of adjusting the grader and connection to the tractor for cutting down banks.

The diagram shown in Fig. 32, represents the cross-section of an unbalanced roadway. The heavy full lines show the condition of the natural road; the dotted lines show the position of earth after the fifth round of the grader. The spoil from the ditch-cuts on the low side is discharged on the line of the shoulder and allowed to remain in that position. The spoil from the ditch on the high side is moved across to the center of the road by an extra round of the grader. On the return trip of this extra round, the blade of the grader is reversed so that all the loose earth on the high shoulder is moved towards the center of the road. In some cases two extra rounds on the high side of the road may be necessary to obtain the desired result. This can best be done after two or three ditch-cuts have been made, to provide sufficient loose earth for filling the low side of the road. The extra amount of earth obtained from the high side in backsloping the bank as indicated in the drawing, can best be disposed of in such manner as described herewith. Extra heavy cuts are necessary on the high side, in order that the bottom of the ditch may be cut to a level with the ditch on the lower side.

Two sections of road on this project were similar to the conditions shown in Fig. 32. These were greatly improved by handling in the manner described above.

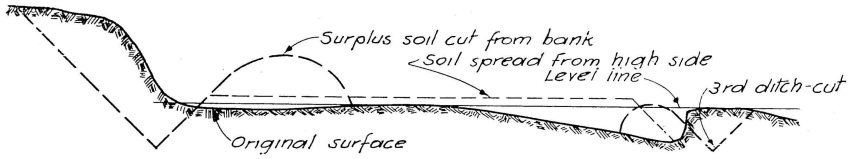

Fig. 32. Method of Balancing Road Section.

The extra earth obtained from cutting down high bank is moved across road by an extra round of the grader in order to raise low side of road. Earth cut from ditch on low side of road is left at line of shoulder.

COST OF GRADING

Items Included in Cost of Road. Records were kept on all the operations from which the cost of grading the experimental road has been computed. This cost includes a consideration of the original investment in the machinery; interest, depreciation and repairs; the cost of material and supplies and the pay of men required to do the work. The tractor used on this work retails at $6,250.00 and the grader including backsloper at $1,790.00. The life of the machinery cannot be exactly determined, but a reasonable estimate for the equipment used would be to assume that it would last five years, working one hundred twenty days per year, at the kind of work and under conditions prevailing on the experimental road.

The fixed charges have consequently been estimated as follows:

Initial Cost of Machinery		Annual Cost of Machinery	
Tractor	$6,250.00	Depreciation at 20%	$1,608.00
Grader	1,790.00	Interest at 6%	482.40
		Repairs at 4% (Est.)	321.60
Total	$8,040.00	Total	$2,412.00
Daily Cost of machinery, based on 120 days per year			$20.10
Hourly cost of machinery, based on 9 hours per day			$ 2.23

The grading crew consisted of two machinery operators and the pay was based on the rate of regular mechanics wages for such work; the tractor operator's wages were taken at $8.00 per day and the grader operator's wages at $6.00 based on a nine hour day. The actual time of operation of the machines was noted and all the items of cost were computed on this basis. Due allowance should be made for lost time for repairs, and for rainy days, which of course is variable and cannot be estimated here. Following is tabulation of data pertaining to all the items involved in the cost of grading the experimental road.

Length of road graded	2.12 miles
Amount of earth moved	4,468 cu. yds.
Total time—actual operation	36 hours

OPERATING COSTS

	Rate	Amt.	Total Cost	Per Mi.	Per Day	Per Hr.
Tractor Oper.	$8.00	36 hr.	$32.00	$15.09	$ 8.00	$ 0.89
Grader Oper.	6.00	36 hr.	24.00	11.32	6.00	0.67
Gas	0.236	210 gal.	49.56	23.38	12.39	1.38
Eng. Oil	1.00	16 gal.	16.00	7.55	4.00	0.44
Tractor Oil	0.30	22 gal.	6.60	3.11	1.65	0.18
Grease	0.20	36 lbs.	7.20	3.40	1.80	0.20
Mach. Invest. Cost	2.20	36 hr.	80.40	39.72	20.10	2.23
Overhead			32.36	15.27	8.09	0.90
Total			$248.12	$117.04	$62.03	$ 6.89

Cost per Cu. Yd. = 5.55c.

The weather conditions during the week of grading were very unsuitable for such work. It rained almost every day and this delayed the handling of the road machinery and prevented the completion of the original project of a six mile section; only 2.12 miles were completely graded in the 36 hours it was possible to work.

The cost figures given above are the average for the entire project, on which some heavy grading was encountered. The conditions here are about what would be encountered in rolling country prevailing over the greater part of the central and northern sections of the state.

However in level country, where light grading would be sufficient to put the road in good shape, the cost of grading may be somewhat lower. In order to determine the cost of grading under such conditions, a short section of level road was graded as a separate unit and the cost determined.

The following data shows the results obtained:

Length of Section ..... 900 ft.
Amount of Earth Moved ..... 432 cu. yds.
Time required to complete section ..... 2¼ hrs.
Cost per hour ..... $ 6.89
Total Cost of grading section $15.50
Cost per Mile of Road $90.92
Cost per Cubic Yard of Earth Moved 3.6c

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MU Engineering Experiment Station Series

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