THESIS

ECONOMICS

OF

ROAD BUILDING

FRANK F ROGERS

1908

Roads

Rogers

E C O N O M I C S O F R O A D B U I L D I N G

ESPECIALLY APPLIED TO MICHIGAN

Evolution of the Wheel.

At the dawn of history our ancestors were moving about in caravans, driving their flocks and transporting their goods on the backs of men and beasts. Those peoples fortunate enough to have located by streams and seas immediately devised rude water-craft.

That the sledge was in use by the early Egyptians is clearly proven by carvings on ancient monuments; and that rollers were used under the massive blocks of stone as they were moved into place to form the great pyramids can scarcely be doubted. It was but another step to put rollers under the sledge and thus form a rude wheeled vehicle with rotating axle. Later solid wheels were cut off the ends of logs and placed on rigid axles. But that the built up wheel is also very old is attested by such words as "nave", "felloe" and "tire" in both the Bible and the writings of Homer.

The earliest chariots were two wheeled vehicles with open backs used for war, state purposes and hunting, but rarely as a conveyance. When the Romans conquered Britian they found a chariot with high wheels and a seat which so pleased Cicero that he requested that one be sent to Rome for a pattern.

With the development of wheeled vehicles, and the advancing needs of society the trail, always the first means of

THESIS

communication in a new country, gave way to tracks and roadways over which such vehicles could be drawn.

The Roman Roads.

While the Romans were the foremost road builders of antiquity every notion that has been noted for progress has been a nation of road builders. Indeed the Roman roads, which extended from the wall of Antonius in Britian to the limits of the empire on the Euphrates, were so substantially constructed that in many places they are the most lasting reminders of Roman conquest.

The prime object of these roads was military, and they were not especially built for wheeled vehicles. They were built by enslaved labor regardless of expense, and in the most direct lines regardless of grades between the places joined. It has been estimated that they cost fifty million dollars a mile. They have survived the ravages of time more because of their massivemess than because of the engineering skill displayed in their construction, though the latter was not wanting in many particulars.. They were,in fact, almost continuous walls of masonry about three feet deep and the full width of the traveled way.

Near the cities more pains were taken and the surface was paved with hexagonal stone blocks, well trimmed and so carefully fitted that even today it is difficult to locate the joints.

The center of the roadway was the highest and on the sides were gutters to carry off the water. Where the road

traversed flat countries the gutters became ditches, thus complying with modern requirements for road drainage.

Modern Roads of Europe.

With the deline of the Roman Empire their roads fell out of repair and gradually out of use. It was not until 1764 that Tresaguet, a French Engineer, began to construct roads, upon more scientific principles, using small fragments of broken stone placed upon a well shaped bed of larger stones set on edge.

Similar roads were introduced into England by Telford in 1824, and to this day roads so constructed are designated by his name.

The macadam roads of Europe began to be built rapidly in the first quarter of last century. It was in 1816 that John L. Macadam, then Surveyor General of the Bristol district, began the construction of a system of broken stone roads which soon covered England and became, for a time, the finest roads of Europe. So fast did the work progress that it is estimated that, at the time of Macadam's death in 1836, there were not more than two hundred fifty miles out of a total of twenty-five thousand six hundred miles or road in the kingdom that had not been thus paved.

The famous roads of England and France were all built in the years just prior to the development of the railroad, the latter being promoted by the First Napoleon entirely as a war measure, yet they contributed in a great degree to the rapid social and commercial development of both countries.

Early American Roads.

During these years the United States was not idle, and not less than fourteen millions of dollars was appropriated by congress previous to 1830 for the building of trunk line highways to penetrate the undeveloped west.

The results were such undertakings as the National Road extending from Cumberland, Maryland westerly, passing through southwestern Pennsylvania, Central Ohio and Indiana, St. Louis, Missouri being the objective point, but which was never reached. Some seven million dollars was expended on this road alone.

The "Wilderness Turnpike", a toll road aided by the government, formed a similar highway across Central Kentucky and facilitated migration from the Virginia settlement westward.

State Aided Roads.

With the development of the railroads national aid for highways ceased, and not until within the last two decades did the recent awakening to the economic value of well constructed highways attract general attention. This time it was taken up by individual states, although the government promptly established a Bureau of Public Roads in the department of Agriculture which aids in the building of object lesson roads and tests road materials free of charge.

As the cost of constructing first class gravel and macadam roads is considered too great for individual counties and townships to undertake unaided, twenty-two states in the

Union are now rendering some form of assistance. Thirteen of these are giving cash, two are furnishing convict prepared materials, one furnishes the state prisoners free to work on the roads under certain restrictions, while the others are, at present, serving only in an advisory capacity.

States giving money aid vary considerably in the amounts given. In New Jersey the state pays thirty-three and one-third per cent, the county fifty-six and two-thirds per cent and the township ten per cent of the cost. In Massachusetts the state pays seventy-five per cent and the county twenty-five per cent of the cost.

In Connecticut the state pays from two-thirds to three-fourths of the entire cost, the towns paying the remainder. The smallest sum is paid only where the town is valued at one million dollars or less.

In New York the state pays fifty per cent of the cost, the county thirty-five per cent and the township fifteen per cent.

Michigan's plan is more simple. A reward or bonus is given for roads built in accordance with the state's specifications as follows:

Class	A.	Clay-gravel	$250 a mile.
"	B.	Gravel	$500 " "
"	C.	Stone-gravel	$750 " "
"	D.	Gravel-stone	$750 " "
"	E.	Macadam	$1000" "

The disadvantage of the Michigan plan are : (1) Lack of uniformity and completeness of surveys and plans, which the State Highway Department is trying to correct by means of

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lectures and personal talks with surveyors and engineers engaged in such work.

(2) Even though every officer,who builds a road, is furnished with general specifications by the state and is advised with from time to time, the work is often crude and not handled to the best advantage. If frequently has to be gone over onee or twice after the local parties think the road completed before it can be accepted by the state.

(3) The final finish is not always as neat as it would be if superintended by skilled road-builders.

Its advantages are: (1) Surveys are made by local surveyors and engineers who need the work and gradually become resident skilled road builders. The cost is much less than it could be if enginaers were sent out from the State Highway Department.

(2) Responsibility of supervising construction is thrown on local officers, who take more interest and learn the principles of road building faster than when the entire charge is assumed by outside men.

(3) The state only advises, furnishes general specifications and inspects completed work, thus keeping the cost to the state very much less than is possible in any state giving a fixed percentage on the cost of the completed road. Michigan is much larger than states working under other systems and is separated into two peninsulas, with communication between them slow and expensive; hence plans that might be adopted to small, compact and densely populated states would

be entirely impracticable here.

(4) The educational feature of the Michigan plan, which provides for an annual institute with the road officers in each county, is a valuable one, as has been demonstrated by the result of three years work, viz.over two hundred miles of completed roads on which state reward has been paid. This is much more than was completed by any other state in the same time after commencing work.

Construction and Maintenance.

Two methods are in general use in this country for the construction and maintenance of public highways, viz. by (1) Labor tax, (2) Cash tax.

The former was introduced to this country from England, where it had been handed down from the Feudal Ages. That it was not a great success in England, may be inferred from a statement of the historian Macaulay, who speaking of the condition of English roads some two hundred years ago says:

"One chief cause of the badness of the roads seems to have been the defective state of the law. Every parish was bound to repair the highways which passed through it. The peasantry were forced to give their gratuitous labor six days in the year. If this was not sufficient, hired labor was employed and the expense was met by a parochial rate".

It has not been a great success in the United States but when the country was new and the only commodity at the disposal of the people was labor, no other system could have been tolerated. There were then pratically no crops to market and no loads to draw back to the farm. Indeed every farm and every household was its own factory, consuming nearly all the products of the farm and manufacturing everything used by the farmer and his family. There were then no railways nor market-towns as we now know them.

The states are gradually dropping the statute labor plan and adopting a cash tax. In 1907 thirteen states were collecting all of the road taxes in cash. Twleve others had a poll tax only. The remaining states still held to the labor tax plan.

The Michigan law of 1907 abolished, both, statute labor and poll taxes and provided a money tax for maintaining all of the highways in the state. In the aggregate it is large tax. In 1907 it was over three and one-half million dollars. Ordinarily it is greater than the entire levy for state taxes. If it could all be expended under wise supervision, it would not only maintain the roads in passable condition and build the bridges, but would provide a fund sufficient to properly gravel and macadamize all of the trunk roads in Michigan within the next quarter of a century. That is no more than would be accomplished by any first class railway organization, if confronted with the same problem and given the same resources.

Surveys and Plans.

The first step toward the construction of a well built highway is a properly prepared plan which can only be made from the notes of a complete survey. In most instances, after the plans are completed and turned over to the commissioner, the road must be completed without further assistance from the engineer, consequently the work should be staked out and the plans prepared with this end in view, except where it is known that an engineer will superintend the work of construction.

Where the road lines follow section lines or the regular subdivision lines of a section, they should be accurately located, as in cases of land surveying. If the roads are angling, it is important that starting points and termini be accurately located with reference to section lines and corners, or from regular sectional subdivision lines and corners, and the courses and distances given. It is also important to note where the road intersects with section lines and the distance to nearest corners.

Property lines and buildings may be determined from occupation, the notes being kept by stations and pluses measured on the center line as the survey progresses. Notes should be made as to the injury that might result from cutting or filling in ffont of residences and private drives and any other information that might be useful in preparing the plans, establishing grades and designing a system of thorough drainage.

In Michigan most of the highway improvement consists of re-grading and metaling old roads; but when opportunity offers to make a new survey, as it frequently does in the newer counties, it should be done with the same regard for suitable location with easy grades, low cost of construction and

permanancy of road bed that would characterize a survey for a railroad.

Due prominence should be given to directness, but it is well to remember that slight curves increase the length of road but little. Byrne estimates that a road may be curved so that one could never see more than a quarter of a mile at once and not increase the distance between two places ten miles apart more than four hundred fifty feet. Frequently the cost of right of way around a bad hill is much less than then the cost of grading the hill down. A case recently came to notice of the writer where an old road which had gone over the hill for many years was re-located on a new right of way around the hill and the loading capacity of the road doubled at a cost of only seventy dollars.

Levels must be run on all new work and profiles prepared in practically the same manner as for railroad work. The work of cross-sectioning cannot be neglected, as grading on work of this kind will usually be let by contract at a fixed price per cubic yard on the excavation required. Special attention should be given to the staking out of road ditches and culverts, for it is important that all highway ditches have continuous grades with free outlets.

When old roads are to be rebuilt the staking out is somewhat different, and the survey does not necessarily include cross-sections, for the grading is rarely let by the cubic yard and approximate estimates of the earth work required may be made from center cuttings.

Two lines of stakes, twenty to twenty-five feet distant from and paralled to the axis of the road, one on either side, should be set as nearly opposite each station point as they can be set without using an instrument for turning angles. The main requirement is that they shall all be placed uniform distances from the center and far enough out to be across the ditches but a convenient working distance from their edges. Suitable stakes may be made from inch boards two or three inches wide and about twenty inches long planed on one side for marking. These should be supplemented with good strong peg stakes, ffom six to ten inches in length driven flush with the ground on the face side of and close to each stake. All stakes should be set facing the center of the highway and plainly numbered with some lumber crayon or red keel. Some engineers prefer to use stakes that are two inches square and driven so firmly that levels may be taken on their tops, in which case plug stakes are not required.

When old roads are staked in the manner above described at least five readings of the level rod will be required at each station, viz., center of old road and the stakes and ditches on either side. Plus readings must be taken at all culverts, cross roads, private driveways and at all abrupt changes in the surface. It is also important to take levels in the beds of all cross ditches and creeks, on the down stream side, as far as the range of the level will reach, for they may require cleaning out to form suitable outlets for the road ditches.

All Culverts should be located and kind and size noted, also suggestions regarding new ones where needed.

The rod readings may all be kept in a single column, a page of the level book being ruled and headed as follows:

Sta.	Rod Read'g.	Height Inst.	Elev.	Elev. Grade	Cut	Fill	Remarks
B.M.	3.00	103.00	100.00				
0	4.0		99.0				
R.	3.5		99.5				
d	5.0		98.0				
L							
d							

The profile and plan are more convenient when placed on one sheet, the plan being projected directly above the profile, the angles being indicated without attempt at orientation.

A convenient scale is one hundred feet to an inch horizontal and eight feet to an inch vertical, unless profile paper is used, when it is convenient to make the vertical scale four feet to an inch on plate "A" and six feet to an inch on plate "B", except when the surface is so uneven as to make so large a scale impracticable. It is best not to use a scale too much distorted, for it permits of better work in laying grades.

Tracing cloth, either plain or in profile patterns is convenient for original drawings as it is so easily duplicated by blue printing. Sheets eighteen by thirty inches are suitable when drawn on the scales above named, using two sheets to the mile. They can be easily handled and permit the use of a flat filing system.

A horse working on a level can exert one tenth of his weight as a tractive force and travel at the rate of two and one half miles and hour for a period of ten hours per day, keep the work up continuously and remain in good condition. If, however, the horse be compelled to work on an incline, the power will be diminished by ten per cent for each degree of the incline. Professor Baker gives the following formula for the effective work of a horse on any grade :

$$L = \frac{(t-g)}{(r+g)}W$$

in which L equals load; t equals per cent of weight of the horse available as a tractive force; g equals per cent of grade; r equals road resistance; and W equals weight of horse. Thus it will be seen that a three thousand pound team working on a level grade, where the coefficient of road resistance is one-twentieth, can draw a load equal to double the weight of the team. But substitute a five per cent grade and the team will be able to draw only a load equal to one half its weight, or fifteen hundred pounds.

The following table shows loads that can be drawn on different road surfaces with varying grades when the tractive force is constantly three hundred pounds.

Kind of Road	Road Res.	Level	3%	4%	5%	6%	10%
Earth- A	1 - 10	3000	2308	2143	2000	1875	1500
Earth- B	1 - 20	6000	3750	3333	3000	2727	2000
Gravel	1 - 30	9000	4737	4091	3600	3214	2250
Macadam	1-- 40	12000	5454	4615	4000	3530	2400

The above calculations are based on the formula :

$$L = \frac{f}{r + s}$$

in which L equals load; f equals tractive force; r equals road resistance; s equals sine of angle of incline.

In Michigan the maximum grades for roads on which state reward is paid is limited to six per cent. No other state has placed a limit, the officers in charge having it at their discretion.

Gillette says, "The tractive power of a horse is greater than authorities state and that a team can readily exert four times as much tractive energy going up short hills as the avergge pull on a level". As Gillette's observations are based on the actual use of teams on contract work they should be quite trustworthy. If so no state rewarded road in Michigan will have grades steep enough to reduce the average loading capacity. Although steeper grades are permissable where actually required, the best practice would keep the maximum down to two or three per cent, the slope of repose for a wagon on first class macadam and gravel road surfaces. A minimum as well as a maximum grade should be kept constantly in mind, the former being at least one half per cent, unless the cost of introducing such grades is practically prohibitive. Road surfaces are always maintained at less cost on slight grades than on long level stretches. A level road, crowned sufficiently to shed water to the sides at all seasons, is too steep for convenient and safe travel. Indeed this very steepness soon defeats its own end by concentrating the traffic along the apex of the grade, where wheel tracks are soon formed which hold water if longitudinal drainage is wanting.

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Cross Sections.

The width of grade, transverse slop and form of ditches should all appear on the plans. In Michigan the law fixes the minimum width of turnpike or grade at eighteen feet. Twenty-four feet is a reasonable maximum. The specifications of the Michigan State Highway Department demand a cross-section, oval (parabolic) in form, having an average rise of one inch to the foot from the sides to the center. The writer advises a slight extra rise at the center to remedy the flatness of the parabolic curve.

Plate No. I shows the forms of cross-section recommended by eleven of the leading states now giving state aid.

Drainage.

Open drains should not be larger than are required to handle the water that naturally flows along the highway. They will necessarily vary in size from the shallow gutter, formed by a continuation of the transverse slope to the gutter bottoms, to the open drain of considerable size. Frequently the latter is a previously constructed county drain, so deep that the roadway must be protected by a suitably constructed guard rail.

Tile drains should be used wherever the soil comprising the road bed is springy, or a heavy water bearing clay. The Massachusetts Highway Commissioner reports that, "A subgrade of sandy loam is the most difficult to know how to treat. Generally speaking, if thirty per cent or more of the material will pass a No. 100 screen, the introduction of a tile drain does no particular good, the capillarity of the soil being so great that it will not give out the ground water".

Under drains may be placed under the gutter, in the shoulders, or under the road metal according to the judgment of the engineer, but always on the side from which the water flows, so as to cut it off before reaching the road bed. For ordinary purposes four inches unglazed land tile are most suitable. In a few cases larger tiles may be required. It is always well to fill over the tile for several inches, if not the full depth of trench, with some porous material like gravel, or cinders, or broken stone, so as to enable the water to reach the tiles more quickly.

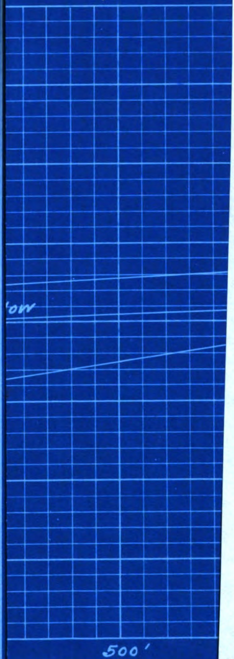
Earth Roads.

Whenever the route of a proposed road is graded and drained in accordance with plans above outlined a well built earth road is formed, which will be more or less satisfactory, according to the nature of the soil composing the bed,

The cost of grading is in direct proportion to the amount of earth that must be handled and commonly varies from two or three hundred to two or three thousand dollars per mile.

For ditching and turnpiking, ~~the~~ road plows, the flat scraper or Doan scraper, and the four wheeled road machine (scraping grader) are the principal tools employed. In the prairie states elevating graders have been used with much success. To make cuts and fills drag scrapers, wheeled scrapers and wagons are used according to length of haul.

Plate No.2, platted from Gillette's rules, shows the in-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itial cost, extra cost for each hundred feet of distance that earth is moved and ~~also~~ the economical lengths of haul for the above named tools.

Sand-Clay Roads.

In places where gravel and stone are wanting, or the expense of getting them prohibitive, the sand-clay mixture is frequently used for road surfaces to good advantage. It has met with greatest favor in the Atlantic and Gulf states, which, no doubt, is partly due to the mild winters of the south and the absence of freezing and thawing, which disintegrates and softens our northern soils.

It should be noted that the hauling of sand on clay and vice versa, without attempting to obtain the proper mixture, is not building the sand-clay road, and that results obtained by the former method cannot be compared with the results obtained by the latter.

There is much difference in the quality of clays. Clays known as "slaking clays" are more easily mixed and usually preferable, but the plastic clays, no doubt, have rather better binding qualities when the proper mixture is obtained.

The amount of clay required in the mixture is approximately the volume of the voids in the sand used. The mixture will rarely ever consist of more than one part of clay to three parts sand, and frequently one part of clay to four parts of sand should be used.

No doubt the best results would be produced, if the mixture could be made in a pug mill, with just the right

proportions of sand and clay and the required amount of water. But in practice no such methods can be employed on account of the cost.

Clay on Sand.

To place the mixture on sand, it is first necessary to grade the road so as to conform to the plans, making very shallow gutters. It is important, however, that the finished road shall have the regular crown and the gutters a true grade. The bed for receiving the clay can usually be formed by pushing a part of the sand from the proposed bed to either side with the scraping grader. Upon this bed a layer of clay, not less than four nor more than six inches thick, should be uniformly spread, rolled sufficiently to crush the lumps, if there are any, then harrowed until thoroughly pulverized. Immediately after the harrowing three or four inches of sand, which may now be scraped from the sides with the road grader, should be spread uniformly over the clay. The road must then be sprinkled to saturation or allowed to remain in this condition until thoroughly soaked by a heavy rain. When it is wet it must be thoroughly mixed with such tools as the disc harrow or cut-away, smoothed down and rolled and if still sticky, covered with another thin layer of sand. If the finished road lacks binding power it is an indication that too much sand has been worked into the clay and more clay will have to be added. If the road covering thus prepared proves too thin, another layer of clay-mixture may be added. Roads built in this manner are giving good satisfaction in several places in Michigan, where the travel is not heavy.

Sand On Clay

Sand can usually be mixed with a clay sub-grade, with less expense, but with somewhat poorer results, owing to the less perfect drainage offered by the clay foundation.

The clay road must be well shaped and drained, having a rather flat cross-section. In this climate quite satisfactory results may be obtained by applying five or six inches of rather course sand to the clay subgrade, thus allowing it to become mixed with the clay under travel during the wet weather of fall, winter and spring. As the ground becomes settled in the spring the road must be floated down with road machines, or other floating tools, and allowed to go into the summer smooth.

Usually two or more applications of sand will be required before desired results are produced.

Where this method is considered too slow, the subgrade should be loosened before the sand is applied and the sand immediately mixed with the clay by plowing and harrowing, much as described for working the clay into the sand. In either case plenty of water during the mixing is indispensable.

Gravel Roads.

Authorities have differed somewhat on the requirements of suitable road building gravels, most of them, in the writer's opinion, laying too much stress on the immediate packing qualities. Indeed, the average township commissioner, and farmers, generally, have become so imbued with the necessity of secur-

ing a gravel that will pack quickly that they have almost lost sight of the fact that the only thing that makes a gravel road better than an earth road is the pebbles-real stones-that it obtains and is solely dependent upon to bear the traffic and resist wear.

Some authorities specify much larger pebbles than have been required by many modern road builders. An attempt to follow such specifications with the general run of Michigan gravels would make gravel road building so expensive as to be practically prohibitive, and would necessarily discard many whole pits from which excellent roads have been made.

Gillmore in his "Roads and Pavements", says: "A capital distinction must be made between gravels that will pack under travel and clean rounded gravel which will not, due to some small proportion of clayey or earthey matter contained in the former, which unites and binds the material together".

Regarding size, he says:"Reject gravel for the top that passes a one-half inch mesh screen, as being too fine and that which will not pass a one and three-fourths inch screen as being too coarse." But he advises the use of the unscreened gravel for the bottom layer.

Byrne in his work on Highway Construction, says : "In selecting gravel the chief quality to be sought for is the property of binding." The binding properties he gives as two: "The presence of ferruginous clay, which causes gravel to set or become hard as soon as it is exposed to the atmosphere, and the angular shapes and sizes of the stones".

He advises rejecting all pebbles that are so large that they will not pass a one and one-half inch screen, also all that are small enough to pass through a threefourths inch screen. He also says that gravel in bottom should be no larger than gravel on the top.

A. O. Baker, speaking of gravel in his "Roads and Pavements," says: (1) "The fragments should be so hard and tough as not easily to be ground into dust by the impact of wheels and hoofs. (2) The pebbles should be of different sizes, each of the proper proportion. (3) There should be intermixed with the coarser particles some material which will cement and bond the whole into a solid mass".

Pebbles over two inches in size are held to be too large, but this author does not place a limit for the smaller pebbles.

He says further: "That to secure contact at every point all the interstices between the fragments should be filled. The larger pebbles with smaller pebbles, the smaller pebbles with sand grains, and the sand grains with finer material called binder. The binder may be clay, loam, silica, stone dust, iron oxide, etc., or some ingredient which will crush under traffic and supply this dust."

In the writer's work as Deputy State Highway Commissioner, directing construction of and inspecting State Reward roads that have been built in Michigan for the past three seasons, the least trouble has been to secure gravels that will consolidate under traffic, and the most difficult task of all has been to secure gravels, without resort to screening, having a large enough content of pebbles to insure a reasonable degree of service. He has yet to find a bank gravel in this state in which the pebbles are all so smooth and clean, and which contains so few lime pebbles that it will not become reasonably firm under travel in a few months, if properly treated.

The most common material sought for binder is clay, yet, considering all kinds of weather, it is probably the poorest cementing material we have. If present in quantities much in excess of twenty per cent of the mass it makes muddy roads and at best is the most treacherous substance we are sometimes forced to use for that purpose. The New Jersey gravels, used in their state aid roads, contain one-fifth their weight of clay. But they are very fine. Of three samples examined by Prof. Baker over fifty per cent passed through a one sixteenth inch mesh screen. Again these roads for the most part are built over sandy soils, and the very fine pebbles which are practically sand, pretty thoroughly negative the bad effects of the clay. In fact, roads built of such gravels are but a few degrees removed from the typical "sand clay" roads so much used in the south and referred to above.

It is the clay gravels that always break up in the spring when the frost is coming out, while the gravels that depend on oxide of iron and stone dust for their cementing qualities are always good, whether the road is wet or dry, frozen or baked in the hot summer sun.

Gravels that come from the pit with the pebbles cemented together, even though they contain no clay, will re-consolodiate in the road and become harder than they were in the pit. Tests of a specimen of that kind will always show a lime reaction, and this lime is usually accompanied with iron, due to the fact that water flowing over the lime has a tendency to deposit its iron content.

Michigan Gravels.

The bank gravels of Michigan are all of glacial origin and vary quite widely in their character, both as to the kinds of road of which the pebbles are rounded fragments, and the kinds of earth with which they are mixed. This variation is most marked when the gravels of different sections of the state are compared.

The rims of limestone rocks that surround the northern ends of Lakes Huron and Michigan and straits of Mackinac and outcrop at intervals in Menominee, Delta, Schoolcraft, Mackinac and Chippewa counties of the upper peninsula, and in Alpena, Presque Isle, Cheboygan, Charlevoix and Emmet counties of lower Michigan seem to have materially influenced the gravels in those counties and for some distance southward by contributing a large proportion of limestone pebbles. Farther south and in the interior of the state the pebbles represent a larger percentage of ignous rocks, such as granite and trap, also much quartz. It is probable that these came from the harder rocks to the north of Lake Huron, and that considerable percentage of the softer rocks were ground to powder in transit.

The same variation is to a greater extent apparent in the cobble stones or boulder covering these areas.

The wearing qualities of the road, after it has been properly consolodated, are almost entirely due to the ability of the pebbles to resist crushing and abrasion,

There are few gravels in Michigan that do not contain plenty of limestone pebbles to crush and wear into dust and thus supply all of the fine particles required for binder, leaving the tougher and harder pebbles to take the actual wear.

The best of pebbles are the traps and tougher granites. Quartz pebbles are rather easily crushed into sand, after which they are of little use to the road, for in this condition they have practically no cementing value.

However, at the present state of road building in Michigan when gravels can be found with or without sereening, containing a sufficient proportion of pebbles which are fragments of good sound rocks, one must not be too critical as to the kinds of minerals of which they are composed.

Finally, if the writer were to sum up the desirable qualities of gravels for road building in Michigan, he would place them in this order :

(1) In direct proportion to the percentage of pebbles (up to about 80 per cent) constituting the mass.

(2) In direct proportion to the value as road metal of the stones constituting the pebbles.

(3) In direct proportion to the value as a cementing material, under all conditions of weather, of the finer

particles constituting the filler and binder.

The Michigan State Highway Department specifications require that sixy per cent by weight of the gravel shall be coarse enough to be retained on a No. 8 screen; that no pebbles shall be used in the bottom layer that will not pass through a two and one-half inch mesh screen, and that no pebbles shall be used in the top layer that will not pass through a one and one-half inch mesh screen. That would seem like a very easy requirement, but it actually rejects more than three-quarters of the gravels commonly used for road purposes. There are, however, many gravels of a sandy nature from which first class road material could be obtained by screening, and this is being done in some localities.

It is almost invariably cheaper to screen local gravels that are within a wagon haul of the road than it is to pay freight on gravels from a distance and then haul them from point of delivery to the road.

Hand screening is rather expensive. At Mancelona it has cost about forty cents per cubic yard for the screened product. Gravel has been successfully screened and loaded by horse power. A drag scraper loaded with gravel is drawn up an inclined trackway by means of rope and pulleys, when the gravel is allowed to dump onto a chute screen. The screen should be about six feet long, inclined to an angle of forty five ~~per cent~~ degrees and high enough above the ground, five and one-half to six feet, to per mit the gravel to slide into an ordinary wagon.

A suitable screen can be made by using flat bars of steel one-eighth inch by one inch, which are punched, set on edge and rodded together, each bar being separated from the adjacent bars by bolt washers. The bars are then fastened to a frame work made from planks or scantlings. Sometimes round rods, woven together with wires, are used instead of bars.

At Millington, Michigan a chute screen, like the one above described but eleven feet long, is placed over storage bins, the gravel being raised to it by means of an ordinary bucket elevator driven by a 4-H. P. gasoline engine. The bottom of the elevator terminates in a receiving hopper which is depressed so that its top is level with the ground in the bottom of the pit. The top of the hopper is protected with a grating made of roads spaced so as to exclude stones larger than three inches and the gravel is delivered to it with drag scrapers hauled by single horses. This plant puts out from thirty-five to seventy cubic yards of screened gravel daily, varying according to the amount of waste material (sand) the gravel contains. The cost of screening is said to average about twenty-five cents per cubic yard of screened product , which practically includes the cost of loading, as the storage bins are high enough so that the wagons are driven under chutes and loaded by gravity. The cost of loading by hand would not be less than ten cents per cubic yard. In some places rotary screens are used in connection with elevators and storage bins similar to those above described. In these plants water is frequently used for washing gravels containing clay and loam. Washed gravels are seldom desired for road building.

Applying the Gravel.

Before the gravel is put on the road bed is graded so as to conform to profile and cross-section. Shoulders of common earth or other suitable material are formed on each side of the gravel bed for the purpose of retaining the gravel in position. For single track roads it is important that the contour of the gravel bed shall be parallel to the finished surface, as a uniform depth of gravel is required. See cross-section for Michigan, Plate 1.

On double track roads the edges of the metal are often made thinner than the center, when the sub-grade should be formed accordingly. See sections for Massachusetts, Maine and Vermont, Plate 1.

On soft mealy sand, if the travel is very heavy and a single track road is to be built, it is best to build the shoulders of some better class of earth. Often strippings from the gravel pit can be used at small cost. The writer frequently forms shoulders by putting a row of sods along each margin of the gravel bed, placing them two sods deep and bottom side up. The sand is then scraped up to the sods and substantial and quite satisfactory shoulders formed.

Where the sand bed is so mealy that it inclines to mix with the first layer of gravel, especially if the gravel is clean or of a sandy nature, some binding material must be spread over the sub-grade before the gravel is applied. frequently a layer of clay is placed under the gravel, but this usually works up through the gravel in time and makes a muddy road in wet seasons. Other materials are better. The author has successfully used thin layers of marsh hay, rotten straw and coarse horse manure. Pliable woody fibers, such as cedar bark and tan bark, would doubtless serve the same purpose.

In Michigan the state reward road law requires that enough gravel be put on in two layers to make eight inches of compacted gravel. Experience proves that the packing is about twenty per cent, ten inches of loose gravel being required to form an eight inch road.

It is best to use six inches of loose gravel for the first layer. This gives depth enough so that it is not readily cut through, and is more economical, in that somewhat larger pebbles may be used in the bottom layer.

The writer prefers to gage the depth of gravel, the loads all being the same size by calculating the distance that one, two or three loads of gravel, when dumped side by side, will cover and make the required thickness. Thus, on a nine foot gravel bed two loads of one yard each will cover twelve feet six inches thick, for the first layer and eighteen feet four inches thick for the second layer. A few pegs are set in the shoulders along the margin of the gravel bed the required distances apart and shifted ahead as the work progresses. Then all the foreman has to do is to see that the required number of loads of gravel are evenly spread so as to cover the distance between the stakes.

Compacting the Gravel.

Immediately heavy rolling will not do much to consolidate a gravel road, and dry rolling is a nuisance rather than a benefit, except to dicover soft spots in the subgrade, which usually have to be corrected by adding mofe gravel, unless the gravel contains so much material of a clayey nature that it is sure to make a muddy road in wet weather, Experience with gravel roads soon teaches us that gravel will not "come down" under the roller like macadam, but on the contrary requires some traffic to properly harden it.

In the early stages no compacting tool is so efficient as a spike toothed land harrow, especiaaly one that permit of tilting the teeth backwafds. This harrowing should begin with the first layer, as soon as three of four hundred feet of the road has been covered, and kept up every day thereafter during the construction unless the road becomes so firm that the harrow teeth make little impression. One or two rounds at a time are sufficient, preferably at noon and night, so as to keep the wheel tracks continually filled.

After the first rain that thoroughly saturates the road, or if no rain comes it will be necessary to sprinkle, begin to roll, and also to work the harrow all the time the rolling is in progress. At first it is well to use a land roller, weighted to about two tons, but as the road becomes firmer a heavier roller hastens the packing, and wherever possible a much heavier horse roller or steam roller, weighing not over ten tons,should be used. This treatment applies to each of the courses, and it is impossible to build a first class gravel road without applying the gravel in at least two sepa-

rately. layers.

Even with the treatment above outlined no gravel road becomes perfect until it has been traveled for some time, usually not until the second season after it is built. During all of this formative period it must be carefully looked after and kept free from wheel tracks and hollows. It can usually be kept smooth by means of plank float, the timber or angle iron drag, or sometimes by the skillful use of the road grader. The last named tool, however, often does much damage, by digging up hard places, while the former tools simply shove the loose gravel forward, gradually pushing enough of it towards the cneter of the road to preserve the crown, but always depositing it where there is the least depression. Whenever there is an extra deep wheel track, or evidence of rutting a little new gravel of the best quality should be put on before the floating is done.

Repairs.

The completed gravel road can be kept in good repair by placing a little good gravel in the hollows immediately after rains, when standing water will point out the least depression. At such times the surface is softer and the new gravel will unite quickly with the old bed. Once or twice a year, spring and fall are the best times, the scraping grader or some other smoothing tool must be used to preserve the crown and fill the central path, which is commonly formed by single horses. Care must be taken so that no earth is scraped onto the gravel. Such treatment will keep a gravel road in good condition until it wears so thin that resurfacing it required.

Macadam.

It has been said that, "The discovery by Macadam that angular fragments of hard rock, sufficiently reduced in size, will coalesce or bind together into a compacted mass of stone under the pressure of wheels, thus forming a sort of natural mosaic impervious to water; and the system of road making based upon it have been of greater service and benefit to mankind than any other contribution to the science of locomotion, except the invention of the steam engine."

In the language of Macadam, a well built road is "an artificial floor forming a strong, smooth, soiled surface, capable of carrying great weight, and over which carriages may pass without impediment."

It is true that Tresaguet had used broken stone on his roads, but never with out a floor or foundation, and it was left for Macadam to discover that this floor was not necessary He argued that the native soil must bear the weight, no matter what kind of surface was put on it, and that any well drained earth was easily capable of carrying the weight of the paving and the carriages that pass over it.

The Massachusetts Highway Commission has estimated that non-porous soils, drained of ground water, at their worst, will support a load of about 4 pounds per square inch; and havin mind these figures have adjusted the thickness of their macadam roads to suit the traffic, assuming that on a road built of fragments of broken stone the downward pressure takes an angle of 45 degrees from the horizontal, and is distributed over an area equal to the square of twice the depth of the broken stone. Thus if a division of the load in pounds at any point, by the square of twice the depth of the stone gives a quotient of 4 or less, then will the road foundation be safe at all seasons of the year. On sand or gravel the pressure may be safely taken at 20 pounds per square inch.

Quality of Stone.

A good stone for road building must be hard and tough and the dust, resulting from crushing and the wear of traffic, should have reasonably good cementing qualities. Having the above in mind six of the most common road building rocks may be arranged in the order of their economic value as follows: (1) trap, (2) syenite, (3) granite, (4) schist, (5) gneiss, (6) limestone.

Michigan Rocks.

In Michigan the most used road stones in order of their value are: trap, cobble-stones, or field bowlders and limestone. The former is found in the Upper Peninsula only, and thus far has been little used except in the vicinities of Marquette and Calumet. A little, however, has been shipped to Detroit for park roads. There is no doubt that trap rock from Upper Michigan would be used extensively in the southern portion for the surface layer of macadam roads were it commercially available on a large scale at reasonable cost. It could as well be transported to the Lower Peninsula as is limestone from Illinois and Wisconsin, which states now supply nearly all the macadam used on the west side of Michigan. It would easily be worth twice as much as the limestone we are now using and the supply in the Upper Peninsula is inex-

haustable.

Cobble-stones consist of a variety of rocks ranging from the hardest traps, to the various grades of granite, quartzite and some limestone, to an occasional worthless sand rock. They are not uniformly distributed, some sections having an abundance, while in other sections they are entirely wanting. Crushed cobble-stones are not available on a commercial scale, and are usually crushed with portable machines in places where they are used. In a few instances, as in Wayne County at the present time, they are shipped by rail to the large crushing plants in the limestone quarries and there crushed and re-shipped to the places where used.

There is no difficulty in crushing them with portable crushers, where the best types of crusher are employed. Cast iron crushers and ordinary cast iron die plates are of little service for this work. Cast steel frames and manganese steel dies seem to be required to resist the stresses and excessive wear.

The most satisfactory way to purchase cobble-stone is by weight. From 13,500 pounds to 14,000 pounds is usually required for a cord, the weight being stipulated by the purchaser when the order is placed. Contractors figure that a cord of cobble-stones will make 5 cubic yards of crushed rock measured in the different grades.

In crushing a pile of 94 cords purchased and delivered by rail, the writer found an average of 5.7 cubic yards of crushed rock to the cord of cobbles, measured in wagons as drawn from the crusher. (Details of this work may be found in the Michigan Engineer of 1903.)

The labor cost of crushing, including fuel and oil, can usually be kept down to 25¢ per cubic yard under good managment. If one figures repairs and depreciation, interest on the investment, etc. it would add approximately another 15¢ per cubic yard to the cost of crushing.

To prepare suitable sizes of road metal it is necessary that the crusher be equipped with a rotary screen, the drum of which should be not less than 9 feet long, and 30 inches in diameter, consisting of three sections perforated to give the required sizes of metal. Usually the writer prefers to have these sections perforated into ¾ inch, 2 inch and 3 inch holes. Pieces of rock that are too large to pass through the 3 inch section should be returned to the crusher and re-crushed. Frequently a belt conveyor is provided to do this work automatically. If the stone is softer than the average, the ¾ inch perforations may supply too great a percentage of screenings, in which case a ½ inch mesh wire screen can be placed around the plate screen and bolted to it to as to form a jacket. The wire screen should be placed on blocks so as to leave an annular space of 3 inches between the two screens, and so adjusted that the material passing over it will be discharged into the second pocket of the storage bin with the 2 inch stone. Thus three grades of stone are provided which are discharged into separate pockets of the storage bins from which they are drawn by gravity directly into the wagons in the order they are to be placed on the road. The fine stone is called "screenings" or "binder", but for convenience the different grades are usually designated by the numbers, 1, 2, and 3, number 3 being the largest size.

Limestone is nearly always bought from the large crushing plants, broken to such sizes as the work requires, and delivered by boat or rail at points within teaming distance of the road.

Applying the Stone.

All that has, heretofore, been said about preparing the grade, forming the road bed and shoulders for gravel, applies equally well to macadam. The same may be said of drainage and the binder that is sometimes required on a sandy bed to prevent the sand from working up into the broken stone.

In Michigan the state reward road law requires a six inch crust of macadam after it is thoroughly compacted, which must be formed in two layers. This will require approximately 8 inches of the larger stones, loose measure, and about 2 inches of screenings - 10 inches of material in all.

For the first layer the writer prefers to put on 5 inches of the No. 3 stone and after this has been rolled a few times over, cover with $\frac{3}{4}$ of an inch of screenings. If the subgrade is not clay, or other earth that easily becomes muddy, water is added quite freely as the rolling progresses. In any event mud should not be worked up into the bottom layer of stone. Rolling should be continued until the stones are not easily displaced by the wheels of a loaded wagon. It is not the intention to apply screenings enough to entirely cover the larger stones, but rather to fill the voids in the coarse stone to such an extent as to prevent the working up of earth from the sub-grade as much as possible, and insure the complete filling of them when the next layer of screenings is added.

The writer is aware that some engineers use no screenings on the bottom layer, but thinks that his experience warrants their use.

When the first layer has been completed as above specified, No. 2 stone will be spread on the road to the depth of 3 inches, loose measure, rolled enough to smooth the surface then covered with an inch of screenings. Watering and rolling must now begin in earnest. As the work progresses the screenings will disappear in patches and more screenings must be added and the watering and rolling continued until a wave of water moves before the roller and the road becomes so hard that fragments of rock will crush under the roller before penetrating the surface. The road must be completely covered with screenings, but an excess is damaging.

The common faults in macadam road building are : too little water, too little rolling and an excess of screenings. When the latter is used to excess a good looking road surface is made quickly with comparatively little rolling, but it soon ruts and begins to go to pieces under travel after it dries out.

Under normal conditions one steam roller can compact from 50 to 75 cubic yards of stone daily, or about the out put of a medium sized portable crusher. Limestone compacts more readily than cobbles or trap rock. Much dry rolling is detrimental as it soon rounds off the angular edges and

corners of the broken stone and leaves them like pebbles, after which consolidation is more difficult. It is estimated that 4 cubic feet of water is required for each cubic yard of macadam.

A properly porportioned and consolidated macadam surface, is literally a stone road. Nothing should enter it from start to finish but stone, ranging in size from stone dust to the No. 3 stone. In this condition it approximates but does not attain the condition of solid rock. Generally speaking the nearer it approaches to a solid the better will be the road.

Such a road is bound together in a two fold manner. (1) by the locking together of the angular pieces of rock which are forced into the smallest possible space by heavy rolling. and (2) by the cementing action of the fine particles of stone dust, which varies greatly with the kinds of rock. The mixing of limestone dust with that of granite or trap rock increases this cementing quality very much, even making a stronger cementing material than either of the two before mixing.

Bituminous Binders.

The advent of the aubomobile has introduced a new and very destructive agent to macadam road surfaces, and one that is still quite perplexing to engineers. Where the travel is principally with teams, the horses' feet with iron shoes and the iron tires of wagons constantly grind off enough dust from the macadam to replace the binder that is blown and washed away.

But as soon as automobile travel becomes a considerable part of the whole, conditions are changed. The rapidly revolving rubber tires produce a suction that picks up all the fine particles of the binder and hurls them into the air only to be blown away from the road.

Oils and chemicals have been tried, nearly always with some degree of success, but the lasting qualities have not been such as to warrant the expense of their general use. At present the coal tar treatment looks the most promising. The macadam roads built in Wayne County this year will all be dressed with coal tar.

The main requirements seem to be that, the tar shall be free from water and applied hot to dry and thoroughly cleaned road surfaces then immediately covered with a layer of stone screenings and rolled. Better results will be produced with chips from hard stone from which the dust has been removed.

Authorities.

In the preparation of this Thesis I am indebted to the works of Gilmore, Byrne, Baker, Gillete, The Good Roads Magazine and various state reports.

Frank Foster Rogers