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The Location, Construction, and Ma

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THE LOCATION, CONSTRUCTION, AND MAINTENANCE

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A careful study of the topographical features will determine the best route consistent with easy grades, and will enable the Engineer to reduce the number of bridges and ravine crossings to a minimum.

Low and marshy ground, swamps, etc., can be avoided, and the ease and cost of drainage can be looked out for in making such a survey.

A careful observation of the geological features will determine location, as regards difficulty and expense of excavation.

The determination of the nature of the soil and its adaptedness

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# T H E S I S

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## The Location, Construction, and Maintenance of

### Public Highways.

I Location - The location of a Public road is very similar to that of a Railroad, and consists in determining and marking out on the ground, those points through which the road should pass in order to satisfy, as nearly as possible, the requirements of what a road ought to be. These requirements are as follows: 1 The road should be as straight as possible, but straightness should be considered subordinate to easiness of grade. 2 The road should be as level as possible. In hilly country, grades of 1 <sup>in</sup> 3 are occasionally found. In comparatively flat country, grades of 1 <sup>in</sup> 8, are not infrequent. 3 The cost of the road should be the least possible that will make the road what it ought to be.

In order to comply with the above requirements, a careful reconnaissance of the country through which the road is to be run should be made, and the topographical and geological features of the same should be carefully studied.

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to road building and the quantity and kind of gravel and rock that a certain route will furnish, will be determined by a careful observance of the above features.

The Preliminary Survey follows the reconnaissance, and can be made by Stadia and Lock Level, or Transit, Level, Lock Level, and chain. The chief advantage of the Stadia Survey is the little cost attached in comparison with the Transit Survey, because of less time and fewer men being required; but the inaccuracy arising from the measurement of distances by visual angles and of elevations by small vertical angles, where a small error in the vertical angles multiplies the error as the distance increases, more than offsets the advantages attached to this Survey. The Stadia Survey is dependent upon the accuracy and complete adjustment of one instrument which is very undesirable. A good profile giving the correct elevations at regular intervals not greater than 100'; should be obtained before construction begins, and this can not be obtained by the Stadia Survey.

In consideration of the above, and other advantages, the Transit Survey is the one generally resorted to, and the individuals compassing same should be divided into three parties; namely, Transit, Level, and Topography party.

The Transit party takes the bearings and lengths of courses run. The chief of this party should ascertain, or estimate, the value of land passed over, the owners' names, and boundary lines crossed by the line of survey. He examines all streams and estimates the sizes and character of the culverts and bridges

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which they will require; selects suitable sites for bridges, examines the character of the foundations, inspects the various soils, rocks, &c.

The leveler takes charge of the Level party, and keeps the notes of the work done by this party. He should read the rod on all stations to tenths, and direct good bench marks to be made at least every half mile along the line. A careful note *of the elevations* of all streams and high water marks should be made, so as to insure the road to be built out of all danger of being flooded.

The Topography party in conjunction with the Level party should take cross sections of the line at regular intervals near enough together to make calculations of the amount of cuts and fills reasonably accurate to suffice for a good estimate.

After deciding upon the general route to be taken; it may be found that a change in certain parts of the line would be advisable on account of decreasing the length of line, or gaining a more desirable location. These secondary lines, or cut offs, should be run with the Stadia, since they can be checked by the notes taken of the main line.

Before the final location and grade lines are decided upon; all notes should be carefully mapped and an accurate profile made of the line run.

The map of the lines give the lengths, directions, and heights of the different portions of the line, and is essential in determining the most practical route as regards easy grades, lengths of lines, and right of way.



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An accurate profile must be made before the grades can be established, and much pains and precautions should be taken in fixing upon the most economical position of the same. Other things being equal, that position which makes the amount of cuts and fills equal is the one adopted; but this principle fails when an excavation has to be made in rock and such material that is difficult to excavate. From the profile the cuts and fills are determined, and where the latter are excessive, the line is most generally changed. One heavy grade may so affect a line of road as to render an increase from 5% to 10% in the length of line justifiable, since all loading must be governed by the maximum grade to be hauled over.

The percent of the grade, or inclination, can be determined by Baker's formula

$$g = \frac{Wt - T}{W}$$

Where,  $g$  = per cent of grade, or inclination.

$W$  = weight of the horse.

$t$  = tractive power in percent of the weight of the horse.

$T$  = tractive power on a level.

The determination of the angle of ruling gradient as given by Rankine is as follows.

Let  $W$  equal greatest load to be pulled up decent.

"  $F$  equal proportion of the resistance to the load on a level.

"  $i$  equal Siné of the angle of inclination.

"  $P$  equal tractive force available.

Then  $(F+i)W$  equals the resistance which should not exceed  $P$ .

$$i \text{ should not exceed } \frac{P}{W} - F$$

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F - for macadamized roads =  $\frac{1}{40}$  and for gravel roads =  $\frac{1}{15}$

After the grade line has been laid down on the profile, the calculations of excavation and embankment are made by the aid of the level and cross section notes, and volumes computed by the prismatical formula:

$$\frac{1}{6} (A + 4 A' + A'')$$

A and A'' in this formula are the end areas, and A' the area of the middle section. The latter is never the mean ~~of~~ the two end areas ~~if~~ the prismoid contain any pyramids, or cones among the elementary forms.

After a careful determination of the volume of material to be handled has been made, the cost of the road can be closely approximated by a careful consideration of the following. First, the cost of right of way as determined by length and environments of the line. Second, the cost of bridges, culverts, drains, &c, as estimated by the notes taken by the Engineer in charge. Thirdly, the cost of preparing the road which can be closely approximated by a careful consideration of the usual price allowed contractors for doing such work, distance of hauling, accessibility of work, &c. Fourthly, the cost of covering, as determined by accessibility as noted in geological features.

Before the work of construction begins, any changes thought to be advantageous should be carefully considered to avoid the useless expense incurred by making changes after construction begins. The route being definitely decided upon; all notes should be carefully checked, and errors eliminated before further expense is added.



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Theoretically the shortest radius of curvature allowable on roads depends upon the width of the road, and upon the maximum length of teams frequenting the road, rather than the speed of the shorter teams; as their speed can be lessened. Since the length of a four horse team and vehicle is about 50', to permit such a team to keep upon a 12-foot road way would require a radius of the inside curve of about 100'; on a 16 foot roadway a radius of about 75' would be required; and on an 18-foot roadway a radius of about 66 feet.

The foregoing matters having been settled, the center line consisting of a series of tangents and different kinds of curves is established. The legal width of right of way varies greatly in different states. In most of the states of the Mississippi Valley, particularly those in which land was divided according to the System of U. S. public land surveys; the legal width of right of way is usually 66 ft. In the Eastern and New England States, however, where land is more valuable, a less width is adopted, and usually varies from 40 to 66 ft, and it is customary to preserve about 6 feet outside the ditch on each side for a foot-way, leaving a width from 28 to 54 feet. The matter of width being settled, the slope stakes are set and the work of grading can begin.

## II. CONSTRUCTION - EARTH ROADS.

The first and most important matter to be considered in the proper construction of a road is the subject of drainage, as any neglect in providing for the drainage will change a good road

into a bad one in a very short time. A road properly drained should have three systems of drainage, each of which must receive special attention, if the best results are to be obtained.

These three Systems are as follows.

(1) Underdrainage.

(2) Side Ditches.

(3) Surface Drainage.

Underdrainage - The three principal objects of underdrainage are as follows. Firstly, to lower the water level in the soil. Secondly, to dry the ground quickly after a freeze. Thirdly, to remove the underflow which is due to the fact that water rises slowly in the soil by the hydrostatic pressure of the water in higher places.

Underdrainage not only removes the water, but prevents, or greatly reduces the destructive effect of frost which is due entirely to the presence of water in the earth.

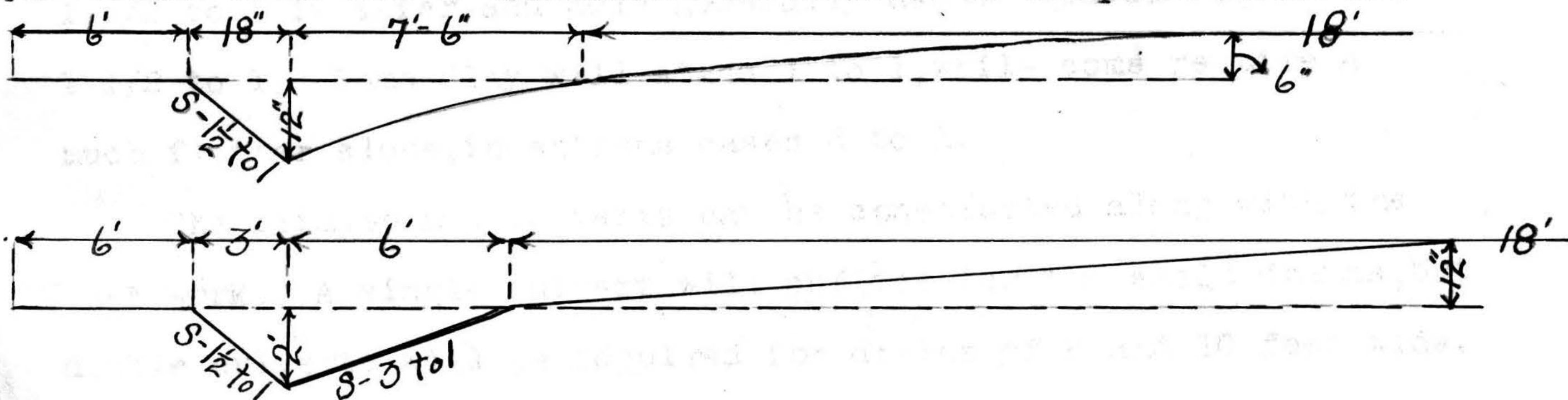
The best and cheapest method of securing underdrainage is to lay a line of porous, or farm tile 3 to 4 feet deep on one, or both sides of the roadway. If only one line is laid, it should be on the high side of the road in order to intercept the ground water flowing down the slope under the surface. The tile should vary from 3 to 30 inches depending upon the amount of drainage, and are usually located 2 1/2 to 3 feet deep under the ditch at the higher side of the road.

Side Ditches - The side ditches are to receive the water from the surface of the traveled way and hillsides on either side the road, and carry it rapidly and entirely from the road side.



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They need not be very deep, especially when the road is properly tilled, but should have a broad flaring side towards the traveled way to prevent accident, if a vehicle should be crowded to the extreme side of the roadway, and the outside bank should be flat enough to prevent caving. Side ditches are especially necessary when the road is in excavation to prevent the water running down the middle. There is considerable difference of opinion as to the exact form to be given to the surface of a roadway. Some claim that it should be an arc of a circle, while others contend that it should consist of two planes meeting at the center, and having their junction rounded off with a short curve. Great refinement in this matter is neither possible nor important, as no particular form can be maintained on account of frequent rains &c.



The above is a sketch of two forms which have been largely adopted in this country. Their use is partly due to the fact that they can be maintained by a road machine and the drag and scoop scrapers. If the slope is too great it will cause the traffic to keep continually in the middle, and wear the road hollow, and vehicles will find it difficult to turn out and pass each other. The flow of water into the ditches will be so great as

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to wash the slopes into the ditches.

It is found by experience that slopes varying from 1 in 24 to 1 in 12 can be safely adopted, but in no case should the latter slope be exceeded.

It is important to note that the crown should be greater on steep grades than on the more level portions, since on the grade, the line of steepest descent is not perpendicular to the length of the road, and consequently the water in getting from the center of the road to the side ditches travels obliquely down the road.

In making the excavation and embankment the following slopes are found by experience to be about right. Solid rock may be cut with a slope of  $1/4$  to 1. Common earth will stand 1 to 1, but  $1\ 1/2$  to 1 is safer and more generally used. Gravel requires  $1\ 1/2$  to 1. Some clay will stand 1 to 1, while some require a much flatter slope, in extreme cases 6 to 1.

The bridges and culverts can be constructed along with the other work. A single culvert will suffice for the small drains, but double culverts will be required for drains of 8 and 10 feet wide. These usually consist of stone abutments which are generally laid in mortar, though sometimes dry, and across from one abutment to another are laid large flat stones. The covering of earth is then put on making the culvert invisible from above, excepting the up and down stream wings to the abutment; the former are to prevent dirt from falling around the ends and to keep water from tending to cut around the abutments; the latter for the first mentioned reason alone. Most generally the bottom of the culvert



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is laid with rough stone, concave downward, to prevent the water from cutting under the abutments, and to confine the flow in the middle of the channel.

The bridges for highways are usually contracted for with bridge companies; the data given being volume of flow, width of channel, and load to be carried.

### GRAVEL ROADS.

A gravel surface is most suitable for country highways not having exceedingly heavy traffic, for frequented streets in villages and small cities, and for park roads.

To be suitable for road building purposes, the gravel should fulfill the following conditions.

1. The fragments should be so hard and tough as not easily to be ground into a dust by the impact of wheels and hoofs.
2. The pebbles should be of different sizes, each in the proper proportion.
3. There should be intermixed with the coarser particles some material which will cement and build the whole into a solid mass.

An important requisite for good road building gravel is that it shall bind, or pack well. If not well packed the wheels will sink into the gravel and increase traction, and the rain water will penetrate the road bed and soften it. It is very necessary to use some binding material such as clay, loam, silica, stone dust, iron oxide, or some ingredient which will crush under traffic and furnish a fine dust. Clay is largely used for the purpose of a binder, and is very satisfactory, because of it being easily



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reduced to an impalpable powder by the action of wheels, or by water. It is often found already mixed with the gravel, and is plentiful and cheap.

The gravel for covering, and clay for a binder having been supplied, the subgrade should be prepared in substantially the same manner as an earth road.

There are many forms of construction, but what is known as the Trench construction will only be discussed here. In this form of construction; a trench is excavated 10 to 12 inches deep, and of the required width for the reception of the gravel. The bottom of the trench is usually made parallel to the finished road surface by sloping it from the center towards the sides. The crown is  $3/4$  inch per ft. of distance from side to center, or 6 inches for a 16 foot roadway. The gravel is put on in layers of 3 or 4 inches, and consolidated by either throwing the road open to traffic, or by rolling. The latter is preferable, since teams in passing each other are liable to break down the edges of the trench and mix the earth with the gravel, and since the wheels are liable to break through the thin layer of gravel.

The large pebbles should be used in the lower layer, in which case the layer can not be compacted either by the wheels, or by rolling. If the gravel is slightly deficient in binding material it will be impossible to use a heavy roller, since the gravel will push along in front of it. This is one way the amount of binding material may be gaged. Additional layers are added as rapidly as the preceding one is compacted, until the desired depth is reached. Before rolling the last layer, the



earth at the sides of the trench, commonly called "shoulders" or "wings", should be thoroughly rolled, and then the rolling of the gravel should proceed from the sides towards the center to prevent the gravel from slipping outward. The gravel will compact much better when damp, but if it is sprinkled, care should be taken that the gravel is not made so wet that the earthy binding material becomes semi-fluid, and collects on the surface and that the subgrade is not unduly softened.

#### BROKEN STONE ROADS.

A broken stone road is one built by placing small fragments of stone on the ground, and compacting them into a solid mass. John Loudon MacAdam, a famous English builder of roads, was the first to build such a road, hence this road has always been called a macadam road. The broken stone is often called macadam, and the work of construction macadamizing. The principal requisites of a material for a broken stone road are hardness, toughness, cementing or binding power, and resistance to the weather. Usually any stone that is hard and tough will resist the weather reasonably well, but such stone as shales and slates, though hard and tough when first quarried, soon disintegrate when exposed to the weather, and should never be used as covering for a road. The material used should be uniform in quality, or the surface will wear unevenly, and the depressions which occur where the material is comparatively soft will hold water, thus softening the road-bed and occasioning damage difficult to repair. The stone to be used should be put through several tests in order to determine their



usefulness in road building, which are known by the following names:

1. Abrasion test which determines the toughness of a stone.
  2. Impact test which determines the ability of the stone to resist impact.
  3. Cementing test.
  4. Crushing test which determines the hardness of the stone, but is seldom used, since the hardness is more easily determined by the impact and abrasion test.
  5. Absorption<sup>P</sup> test which determines the probable effect of frost upon the material.
- The different methods of making these tests will not be discussed here, but can be found in a good treatise on roads. Stone crushed from Trap, Granite, Limestone, Quartz &c, has been found to withstand the foregoing tests satisfactorily enough to meet with the requirements and be used in road building.

There are two methods of preparing the subgrade to receive the stone which are known as Surface, and Trench construction.

The Surface construction consists simply in placing a layer of broken stone upon the former earth road and leaving it to be compacted by traffic. Such roads are not first class, but give good returns on their cost. On account of the simplicity of construction, this form of road will not be considered further.

The Trench construction consists in excavating a trench of the required width and depth, and depositing broken stone in it.

There are two methods of procedure regarding the lower course of stone, which are known as the Telford and Macadam construction.

The Macadam road construction consists of two, or more layers of crushed stone; its distinguishing characteristic being that the lower course of crushed stone is placed directly upon the earth road-bed.



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The Telford road consists of a pavement of stone blocks set upon the road-bed and covered with one or more layers of crushed stone; its distinguishing features being the paved foundation.

Each of these systems has its earnest advocates who contend for its exclusive use. The most important claims of the advocates of the Telford construction are: (1) that the open foundation is necessary for drainage: (2) that the sub-pavement is necessary on soft, poorly drained soil in order to prevent the small fragments of broken stone from working down into the soil, and the soil from working up into the stone: (3) that the Telford is cheaper, since the expense of crushing is saved.

The advocates of the Macadam system claim: (1) that the drainage afforded by the Telford construction is no better than that with the Macadam: (2) that on any well drained soil there is no tendency of the stone to work down, or the soil to work up: (3) that tile drainage and Macadam construction are cheaper than the Telford system: (4) that since the introduction of the machine rock-breaker, it is cheaper to crush the stone and lay the Macadam foundation than to place the Telford.

Both of the above methods have met with such universal favor that the nature and condition of the soil should be a deciding factor, as to which system should be used. If the road-bed is thoroughly drained and is composed of material which will not readily soften, there will be no need of a Telford foundation. If, however, the soil is retentive of moisture and can not be thoroughly drained; it may be necessary to provide a foundation which will prevent the soil from working up into the stone, and the road provided.



covering from working into the soil; in which case the Telford system is a very good one to adopt.

The finished surface of the road should have about the same crown as that prescribed for earth roads, in order that the water may flow off rapidly into the side ditches. There are two methods of securing this crown for broken stone roads. In one, the earthen surface is made level, and the slope is given by a greater thickness of metaling at the center than at the sides; in the other the slope is given to the earth bed, and the metal has a uniform thickness.

The advocates of the first system claim that this additional thickness at the center is necessary because there is more wear there. Those who advocate the uniform thickness claim that it is necessary in order to distribute the concentrated pressure of the wheel over a greater surface of the earth bed.

Both forms are in common use, although the preference seems to be slightly in favor of making the subgrade parallel to the finished road surface, and the stone of uniform thickness.

A width of 16 feet for road-way is sufficient, as two wagons having a width of wheel base of 5 feet, and a width of load of 9 feet, can pass on a 16-foot roadway and leave 6 inches between the outer wheel and the edge of the paved way, and a clearance of 1 foot between the inner edges of the loads. The above width only refers to the paved portion, but an additional width is necessary to keep the broken stone in place, particularly while being rolled. This strip of earth usually called a shoulder, should have a width depending upon the soil, climate and amount of rolling. Usually 2 or 3 feet is sufficient, although 5 to 7 feet is frequently provided.



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The object of placing a layer of broken stone upon the trackway, is to secure a smooth hard surface; a water-tight roof, and a more or less rigid stratum which will distribute the concentrated pressure of the wheel over an area of the subgrade so great that the soil can support the load without indentation. There are a number of formula given for calculating a proper thickness of stone to meet the foregoing objects, but they can not be relied upon on account of different kinds of soil and material used. Early in the century a depth of 18 to 24 inches was frequently considered necessary for heavy traffic, but later it was reduced to 12 and 15 inches, while experience has proven that 6 inches is often sufficient.

The size of the stone to be used depends upon their quality of hardness and toughness, and upon the weight of the traffic. One of MacAdam's rules was to exclude any fragment weighing more than 6 ounces. Telford's limit was 8 ounces.

The bottom course of a macadam road built of soft stones is often composed of fragments 3 to 4 inches in greatest dimension, but if it is built of hard, tough stone, the sizes are 2 to 2 1/2 inches. The sizes for the lower courses are not so important, however, as those for the surface course. The top course of hard stones are usually 1 to 2 inches for heavy traffic, and 1/2 to 1 inch for light traffic. The custom is to lay the stone in courses of substantially one size, although some road builders prefer to leave the sizes mixed when thrown into the road, because of the fact that less rolling is required.

The amount of rolling required varies with the weight of the roller, the hardness and size of the stone, and the amount of binder

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and water used. Trap rock being very hard requires two to three times as much rolling as most other stone. An excess of binding material and of water gives a compact surface with comparatively little rolling, but the road is not as durable as though it had been more thoroughly rolled.

Clay and loam are frequently used for binding in construction of this road, and there is much difference of opinion among competent engineers, as to the best method of applying the binding material. Some apply it on the top of each course and some on top of only the last course. In the first case, all the voids from the bottom to the top of the road are filled with fine material; in the second case the binder usually fills the voids of the top course only. Those who advocate the first method claim that the whole mass should be filled to prevent the stones from moving under the traffic, and also to prevent the soil from working below; while the advocates of the second method claim: (1) that filling the top layer is sufficient to hold the stone in place near the surface: (2) that the stones of the lower courses have no tendency to move: (3) that the unfilled voids of the lower course promote drainage: (4) that as the upper layer wears away, the dust will wash down into the lower open spaces in such a manner as always to keep the 3 or 4 inches just below the surface properly bound. The amount of binding required is 25 to 35 per cent of the thickness filled.

#### M A I N T E N A N C E

The proper maintenance of a road is as important as good construction, and a distinction should be made between maintenance



and repairing. The former keeps the road in good condition, while the latter makes it so only occasionally.

The chief objects of maintenance should be to keep the surface smooth and properly crowned so that rain will shed into the side ditches. An exceedingly important matter to be considered in obtaining this, is the matter of width of tire used on the vehicles. The laws of some countries require 1 inch of tire for each 500 lbs. of load, and that the lengths of the two axles should be unequal to prevent the hind wheel following in the track of the fore wheel.

All ruts, depressions and mud holes, should be filled as soon as they appear. There are several machines, or devices, which are very effective in filling ruts and depressions, and in keeping the surface smooth. A harrow drag<sup>ged</sup> over the road at certain times of the year will cause the surface to become smooth. A Railroad rail will effect the same purpose.

The side ditches should be examined constantly to see that they are not clogged with corn stalks, brush, &c. In localities subject to heavy falls of snow, it is an important matter to keep the roads from becoming obstructed by it during the winter. This can be done by driving horses, or cattle, back and forth along the road, or by rolling the road with a heavy farm roller.

The destructive agents are the same for gravel, as for earth roads, except that for gravel roads a gradient is an element of destruction whose importance varies with steepness.

When a gravel road is first thrown open to traffic, it should be carefully watched and all incipient ruts and depressions should



be filled as soon as formed, either by raking in gravel from the side of the depression, or by adding fresh gravel. If fresh gravel is used, it should be finer and contain more building material than that employed in the original construction of the road. After the gravel becomes thoroughly consolidated so that the wheels no longer make, even, shallow ruts, the only care the road is likely to need for several years is to keep the side ditches and culverts free from weeds and floating trash, and to attend to the drainage of the surface when the snow is melting.

The maintenance of a broken stone road is in many respects the same as the earth and gravel roads. There are two general methods called: (1) continuous maintenance and, (2) periodic repairs. By the first system the waste on account of traffic is supplied gradually as it is worn off, by adding a patch here and there, and in this way the full thickness of the road is constantly maintained; while by the second system the road is permitted to wear thin, and an entirely new surface is added.

Those favoring continuous maintenance claim: (1) that it is the only system that gives a constantly good road, since with periodic repairs the road is seldom good, being bad just after repairs, becoming passable after a time, and then deteriorating until repaired again: (2) that continuous maintenance is the cheapest in the long run. Those favoring the periodic system of repairs claim: (1) that a well built road will wear uniformly until so thin as to need re-surfacing: (2) that the system of continuous maintenance does not give as good a surface as the other method, since the new



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material is constantly being added at every point to supply the loss of wear, and this material must be consolidated by the traffic, and (3) the system of maintenance by patching is excessively expensive, requiring a needless amount of material and labor.