cover the pile, taken from either side, leaves two good sized ditches, and the timber though not split, is easily charred; and when charred, the earth is removed to the side of the ditches, the coal raked down to a width of fifteen feet, leaving it two feet thick at the centre and one at the sides, and the road is completed." The material was found to pack well, not form into ruts, nor get soft and spongy in wet weather, although the water was not drained from the ditches. Its cost was $660 per mile, and contracts for two such roads were given out in Wisconsin at $499 and $520 per mile, respectively. (See Gillespie on Roads and Railroads.)

CHAPTER IV.

MAINTENANCE AND REPAIRS OF ROADS.

It is not considered to be fairly within the scope of this work, to enter upon a discussion of the methods by which the funds necessary for the proper maintenance of a public highway shall be raised and applied.

The turnpike system, however, under which those who make the longest trips are required to pay tolls for keeping up the road, is not believed to be equitable in all respects, nor the most advantageous to the community living on or adjacent to the line.

Many unthinking persons would be deterred from locating upon a turnpike, on account of the tolls to which they would be thereby subjected, regardless or ignorant of the fact that their haulage and other road expenses are likely to be greatly augmented by their unwise selection.

A judicious policy of road administration will attract population to the best roads, and therefore increase the amount of traffic to be accommodated, and correspondingly lessen the expense per capita for road maintenance. Any system which does not secure these substantial results, if not complicated by controlling circumstances of an adverse nature, must be either inherently bad, or inefficiently administered.

The advantage of maintaining a public highway in excellent condition, from motives of *economy* alone, is a question

which rarely receives that careful attention from those having the matter in charge, to which its importance justly entitles it.

The average endurance or *life* of draught animals and of vehicles, are functions—calculable within reasonable limits—which enter directly into and should in a great measure control all considerations of policy on this subject, since they are not only not in conflict, but strictly coincident with the most advanced humanitarian views having a bearing on the question.

The traffic upon any given highway requires for its service a certain number of animals and vehicles, their number depending in great measure on the condition in which the road is maintained; and observation has shown that the amount of improvement in the surface of a metaled or other road, as ordinarily maintained throughout the United States that would enable eight horses, for example, to do the work of ten without extra fatigue, is greatly below the estimate usually placed upon it by non-professional persons.

If, for instance, we take the case of a well-made broken stone road, clean and dry, and compare it with the same well-made road in a wet and muddy condition, we find that by Macneill's formula, page 29, a stage wagon weighing 1500 pounds, in order to carry a load of 1500 pounds at the rate of 5 feet per second (about $3\frac{4}{10}$ miles per hour), will require the constant exertion of a force of only $94\frac{3}{4}$ pounds upon the dry and clean road, while a force of $119\frac{3}{4}$ pounds will be required to move it at the same rate over the same road in a wet and muddy state. This increase of nearly 28 per cent in the force expended is due entirely to the fact that the road surface was not kept clean by sweeping off and removing the dust.

Hence if the amount of traffic on a given length of the clean and dry road required the daily service of 54 draught animals, their number would have to be increased to 69, to perform the same amount of service on the wet and muddy road. If the animals are driven singly there would be an addition of 15 drivers, and if in pairs one half that number. It would perhaps be fair to assume 5 pairs and 5 single horses, thus requiring 10 additional drivers on the inferior road. A yearly allowance of $225 for the purchase, feeding and care of each animal, and the purchase and keeping up of harness and vehicle, would probably be below the actual cost in those portions of the country provided, or which should be provided with metaled roads, amounting to $3,375 per year for the 15 extra horses and the equipments.

The hire and support of each driver may be set down at not less than $35 per month, or $4,200 per year for 10 drivers.

The aggregate amounts to the sum of $7,575 per year for extra cost of service upon a wet and muddy road, for the traffic of which 54 horses would suffice if the road were kept clean of dust, and consequently clear of mud.

During those seasons of the year when the inferior road is covered with dust only, but not with mud, Macneill's formula shows a difference of not quite 16 per cent in the force required to conduct the service, against the dusty as compared with the clean and dry road, equivalent, on the same basis of calculation used above, to an extra cost of about $4,300 per year for the service of animals, vehicles and men.

A draught animal, properly taxed, can accomplish upon a fair road 20 miles per day. from day to day, without unusual

or excessive fatigue. If the road under discussion connects two towns 10 miles apart, one trip and return, carrying a load both ways, would be a day's task, the total amount of freight conveyed daily being the same whether the road be in good condition or otherwise.

It would be carried by 54 round trips daily on the dry and clean road, less than 63 round trips on the dusty road, and 69 trips during the seasons when the dust is converted into mud.

A fair average during the year, of the extra cost of service on the inferior road (amounting to the rate of $4,300 per year while the road is dusty, and to $7,575 per year when it is wet and muddy) will, of course, vary within certain limits, with the varying character of the seasons—with the wind, rain, sun, and temperature — but may, it is believed, be moderately set down at $5,000. The traction upon a well-constructed and well-kept metaled road, does not vary materially with varying moisture upon its surface.

We may therefore state the result of the foregoing discussion as follows: If the traffic between two towns connected by a well-maintained metaled road 10 miles long requires the constant service of 54 draught animals, the extra cost of conducting the same traffic will amount to at least $5,000 per year if the road be allowed to become covered and to remain covered with dust. This greatly understates the inevitable results of neglect, inasmuch as it assumes that the inferior road differs from the other only in the accumulation of dust upon its surface, while in point of fact it will soon wear into ruts and gutters which will convey the surface water into the road material, hastening the wear upon the surface, and greatly increasing the expense of haulage and the destruction of animals and vehicles.

The foregoing comparison has not been made between one road in a superior condition, having a hard and smooth surface, and another in a state so bad that it might be characterized as heavy, soft and rough; but the same well-conditioned road-covering has been under consideration; in one case kept clean, and in the other covered with dust or mud. A road of which the metal is in good condition generally, although covered with dust, is quite different from a rough, soft and heavy road, terms which imply that ruts, gullies, and inequalities of various kinds, all of which greatly increase the traction and the wear and tear upon animals and vehicles, have been allowed to form, and the dust and mud to accumulate upon the surface, a condition into which any good Macadamized road will degenerate in a very few years if neglected. If a road in this state be compared with one having a dry, hard and smooth surface, such as a well-maintained metaled road should possess, it will be found, whether the calculations are based upon the investigations of Sir John Macneill, or upon those of M. Morin, that an animal can draw about four times as much weight, vehicle included, over the good road, as he can over the bad one.

If, therefore, a suitable load for 2 horses over the good road be 4,000 pounds carried on a vehicle weighing 2,000 pounds,—total 6,000 pounds—only 1,500 pounds could be drawn by 2 horses over the bad road, rendering it necessary to add a third horse to draw the vehicle alone. These results are obtained in about the same ratio at all rates of speed not faster than an ordinary trot, and with all kinds of vehicles—carts, trucks, stage-coaches, and carriages for light driving.

If the traffic upon 10 miles of good road requires the

constant employment of 50 horses and 25 drivers, at an aggregate annual cost of $21,750, (putting the cost and support of men and animals the same as before,) it would cost $87,000 per annum, to conduct the same amount of traffic upon the same length of road covered with deep ruts and thick mud, and it would, beyond question, be a wise policy to expend the whole excess of $55,250, chargeable to the bad road, in improving and maintaining this road in a superior condition of smoothness and hardness, were such a large expenditure necessary to secure that result; for there would be saved thereby, not only this large amount, chargeable directly to extra men, animals, vehicles, etc., but money expenditures on other accounts not easy to estimate, together with the sacrifice or injury of local interests upon which it is difficult to put a money value; such as economy of time due to greater speed, a longer endurance for animals and vehicles; the advantage of lighter and cheaper vehicles; freedom from excessive dust and mud; and the increase of population, and therefore of traffic, attracted by better facilities for business intercourse.

Relation of Animal Force to Traffic on Different Roads.

The cost of maintaining a road in good condition, under a given traffic, falls greatly below the extra cost of conducting the same traffic upon a bad road; the ratio between the two depending on local prices of labor and material, the quality of the road materials at command, and other circumstances not easily covered by a general rule.

If we assume that the amount of traffic between the two towns already referred to, requires the constant service of 50

horses with trucks weighing 2½ tons inclusive of load, upon a very dry and smooth broken stone road, then the additional horses required upon other kinds and conditions of roads, will be as shown in the following table, calculated from the results of M. Morin's experiments. The influence upon the force of draught exercised by the character of the vehicle, is omitted, as unnecessary in this discussion.

Kind and Condition of Road.	Relative number of horses required to conduct a given traffic.
Broken stone road, very dry and smooth.....	50 horses.
Oaken platform, or plank road in good condition..	59 "
Broken stone road, moist and dusty.....	71 "
Causeway of earth, or dirt road in good condition..	93 "
Broken stone road, with ruts and mud.....	112 "
Broken stone road, with deep ruts and thick mud.	192 "
Solid causeway of earth, covered with gravel 1½ inches thick.....	245 "

It may therefore be adopted as a well established principle, that in all communities where the amount of traffic is sufficient to justify the construction of a good road of any description, or any road that is good of its kind, it should be maintained in a high degree of excellence, as a simple measure of economy.

Macadam Roads seldom well kept up.

It is rare indeed, that a Macadamized or a gravel road is kept up in the thorough manner above indicated. In the

great majority of cases the mud and dust are allowed to remain upon the road for long periods, and are seldom entirely removed; wheel ruts are allowed to form and enlarge, by reason of which not only is the resistance to draught, and the wear and tear of vehicles, greatly increased, but the surface drainage is destroyed to such extent that a large portion of the rain-fall collects in the depressions and finally percolates into the road covering; the side ditches become so obstructed that, in wet weather, water stands in them in places to the depth of a foot or a foot and a half, and upwards. The result is that during the wet season the road covering being at its foundation only a few inches, if at all, above the level of the water in the side ditches, and receiving by percolation from above a larger portion of the rain-fall, remains thoroughly soaked with water, which causes it to be soft and heavy. In this condition it yields readily to the wearing effects of traffic, loses its form on the surface, and soon becomes badly cut up with deep ruts and gullies.

The work of repairing a road in the condition above described, will be substantially the same, whether due to defective construction, subsequent neglect, or to both these causes combined; except where there was a failure to establish the necessary sub-drainage at the outset, in localities requiring it, in which case the repairs may practically amount to a re-construction of the road, or nearly so.

Assuming, therefore, that the road bed does not require to be disturbed, or, in other words, that it was suitably provided with cross-drains when constructed, or else from the character of the soil did not require them, the repairs should be conducted in the manner described in the pages which follow.

The Maintenance of Broken Stone (Macadam) Roads.

The proper maintenance of a broken stone road consists in preserving the smoothness, hardness, and form of its surface, and thickness of covering, by a systematic restoration of the materials that are worn away by the traffic, and removed in the form of dust or mud.

The wear of materials is not in direct proportion to the average daily tonnage conveyed over the road, but increases much more rapidly than the tonnage, other conditions being the same

Two Methods of Maintenance.

Upon the roads in France, which have been the subject of prolonged and careful observation by the officers of the Corps des Ponts et Chaussées, two methods of maintenance are practiced, viz:

First. The method of minute daily repairs by which the road covering is preserved at a constant thickness; applicable to roads of *moderate traffic* upon which the average daily tonnage does not exceed about 600 tons, upon a road covering 18 to 20 feet wide.

Second. The method of partial repairs, accompanied by periodical additions of material, by which the diminished thickness of road covering is restored at stated periods: adapted to roads of *great traffic* upon which the daily tonnage exceeds 600 tons upon a road of the same width.

These two systems will be described separately.

Maintenance of Broken Stone Roads of Moderate Traffic.

The thorough maintenance of a stone road of this class,

to such degree that extensive periodical repairs will not become necessary requires:

1. That it should be kept clear of dust and therefore clear of mud.

2. That thorough drainage should be maintained.

3. That minute repairs to the surface should be made systematically in small patches, as often as, and as soon as ruts or depressions begin to show themselves.

Under this method, properly followed, the thickness of the road covering will be maintained without diminution for an indefinite time.

The mud and dust, or dirt, should be cleaned from the surface and deposited beyond the side ditches, so as to expose the road metal slightly to view, without laying it bare, or removing the binding material from around the stones at the surface. This may be done by men suitably provided with hoes, stiff brooms set at right angles to the handles, shovels and wheelbarrows.

The hoes should have blades of hard wood, as those of iron or steel, unless used with the greatest care, might loosen up some portions of the stone, and needlessly and injuriously roughen up the surface. The brooms may be of birch, willow or other suitable wood.

The sweeping should not be so thorough as to remove the detritus, or binding material from around the stone slightly projecting above the general surface, so as to loosen them in their position, and endanger their being crushed separately piece by piece.

Draught animals instinctively follow in the track of preceding vehicles, the result being relatively excessive wear, and a tendency to form ruts along that track. Upon a road kept

under watchful care this may easily be prevented in sweeping, by constantly effacing the wheel marks.

Machine-scrapers and brooms of various kinds, drawn by horses, have been used for cleaning the road surface, with considerable saving in both time and expense. It is necessary to use them with great care, in order to avoid loosening the stones at the surface.

Mr. Whitworth, of Manchester, invented a machine broom for sweeping up the mud and conveying it away. "It consists of a species of endless broom, passing around rollers attached to a mud cart, and so connected by cog wheels with the wheels of the cart that, when the latter is drawn forward, the broom is caused to revolve, and sweeps the mud from the surface of the road up an inclined plane into the cart." It is drawn by one horse and is said to clean the surface better, cheaper and more quickly, and with less injury to the road and less annoyance to passengers, than it can be done by machine-scrapers, or by hand labor.

In the city of New York, and other eastern cities, street sweepers of various devices have been employed, with greater or less saving of manual labor and expense. The one that has given the best satisfaction consists of a cylindrical brush or broom about 16 inches in diameter and 7 feet long, attached beneath the axle and connected by suitable gearing with the wheels of a two-wheeled vehicle drawn by one horse. The axis of the broom is set horizontally at an angle of about 40 degrees with the axle of the vehicle. The rear end of the broom is therefore about 4½ feet further from the horse than the front end. When working, the broom rests firmly on the surface of the pavement or road-covering and revolves in a direction opposite to that of the wheels, sweeping the dust

and mud sidewise and leaving it in a ridge behind the rear end of the broom, thus sweeping a strip about 5½ feet wide. A second sweeper, or a second trip of the same sweeper if only one is used, moves the ridge of dirt 5½ feet further toward the side of the street and widens the part swept to about 11 feet. In this manner the dirt is finally delivered in the side gutters, where it is heaped up by hand with hoes,

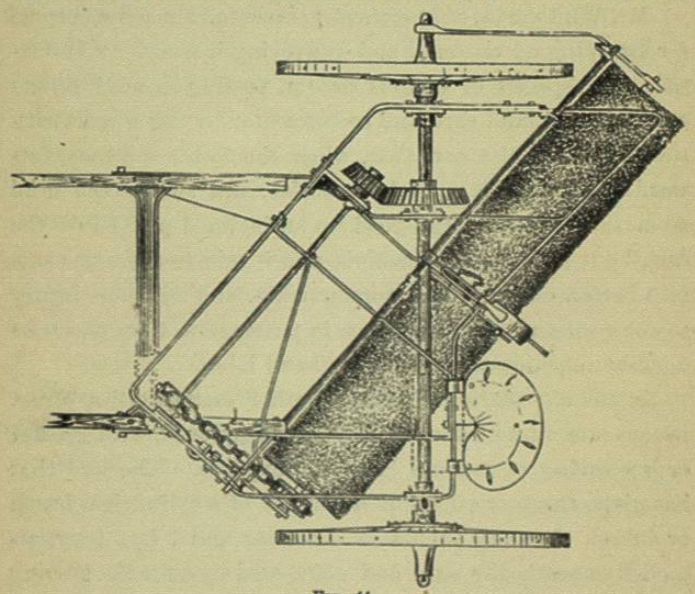

FIG. 44.

shoveled into carts and carried away. When at work the wheels and axle are rigidly connected, and revolve together. When not sweeping the broom is raised up a few inches from the ground and the axle is disengaged from the wheels, when both broom and axle cease to revolve.

This machine with 1 horse, 1 driver, and 10 men with

hoes, will do the work of 30 men with brooms and hoes, the shoveling into carts and carting away being of course the same in both cases. These data were obtained from an inspector of police engaged in the street-cleaning department in the city of New York, and are the results of prolonged and careful observation. A drawing of this sweeper is shown. Fig. 44.

In using this machine upon a road, the precaution should be taken to see that the brush is not too stiff. What would be entirely suitable, and in all respects well adapted for sweeping street pavements of stone blocks, wood, or asphalt, might injure the surface of an ordinary broken stone or gravel road, by penetrating too deeply, thereby loosening the stones at the surface and destroying the bond. It is important that the unity of surface should not be disturbed.

Applying the New Materials.

The application of new materials to the road must be made not only with system and regularity, but under suitable precautions and restrictions, in order to combine efficiency and economy. Indeed the road should be always undergoing repair, in order that no necessity for making extensive repairs can occur.

"Every road should be divided into lengths, on each of which an intelligent laborer, who thoroughly understands his business, should be placed, to attend constantly and at all times to the proper state of the road, and for which he should be responsible. His office would consist in keeping the road always scraped clean and free from mud, in filling in any ruts or hollows the moment they appeared, with broken stone, which should be kept in depôts or recesses

formed on the sides of the road, and one of which should be provided in each quarter of a mile. Those depôts should be capable of containing about 30 cubic yards of materials, and are best when the sides are formed with walls, so that the quantity of materials in them can be easily ascertained" (H. Law, C. E.).

Each of these men should be provided with a wheel-barrow, a shovel, a pickaxe, a scraper, a stiff broom and a rammer.

Upon roads that have lost their proper transverse form, a level of a length adapted to the width of the roadway, should also be provided.

During the autumn and spring, when the surface is soft and more work is necessary, additional men should be placed under the orders of the permanent laborers, but not in such manner as to divide the responsibility of the latter for the good condition of the road at all times.

The length of road to be given in charge of one man depends on circumstances varying greatly with the width of roadway, the character of the soil, quality of material used in repairs, etc. Three miles a man would not be too great a length upon some narrow country roads, one mile would be a full allowance upon others, while upon the great thoroughfares near large towns, a small fraction of a mile would be ample.

In France it has been found that one man can sweep in dry weather from 260 to 270 lineal yards of road, 5 to 6 yards wide, daily, if in a middling state, and twice that area if in an excellent state. If he had one and a half miles of road in charge, it could be swept from one to two times per month, according to its condition, which would be quite sufficient in

most cases, thus leaving from 20 to 25 days in each month for other work, such as collecting and breaking stone, conveying it in wheel-barrows, to the road, spreading and compacting it, and keeping the gutters and side ditches free.

A machine-sweeper, if employed, could be used in common upon several of the sub-divisions of the road. As it would not thoroughly clean out the ruts and depressions, especially if these be of considerable depth, its work would, to some extent, have to be supplemented by hand sweeping.

The wear upon the surface of a well built road is slow, and so long as the vehicles can be prevented from following in each other's tracks, very even, a condition of things which can only be maintained by careful watching. A slight and apparently unimportant depression, if neglected, soon becomes a rut, in which the wear goes on with an increasing rapidity due to the increasing force of the blows imparted to it as it becomes deeper and deeper.

The new material should be added little by little, from time to time in the depressions and deficient places, and it should be broken fine, in comparison with that used in the original construction, containing all sizes and shapes upon to the largest, which ought not to exceed one inch and a half in longest diameter.

This method is strictly one of patching, and it should be done so constantly, that the small patches of broken stone will never exceed one to two inches in thickness, preferably not more than the thickness of one stone. If done when the road is firm and dry, the surface of the depressions to be filled should be loosened slightly with a light pick, to the depth of half an inch, so that the layer of new material may promptly become united with the old road, and some of the

fine loose material can, with advantage, be taken out and spread over the broken stone as a binding. The loosening may be dispensed with in most cases, when the mending takes place soon after a rain, or after sprinkling, or when the road is in a soft condition.

Frequently the tendency to form a rut may be effectually arrested by sweeping into it the loose detritus from the adjacent parts of the road, and the free and expert use of the rake and broom will be found of great advantage at all stages of the work.

Penfold says that the ruts formed by wheels ought not to be filled up with loose broken stone, thus forming a ridge of materials possessing greater hardness than the parts immediately adjacent thereto, but that the rake should be worked back and forth across the rut and on either side of it, the object being to unite the old loose material with the new, in some degree at least, so that the patch will be as little unlike the unrepaired portions as possible. By this method of mending, a cubic yard of stone will usually suffice for a superficial rod of depressions and incipient ruts. The covering of large areas, exceeding eight to ten square yards, should not be undertaken at one time, and where there are several depressions in close proximity to each other, the worst should be patched first, and allowed to get even and solid, before the others are taken in hand.

"It is one of the greatest mistakes in road making that can be committed, to lay on thick coats of materials, and when understood, will no longer be resorted to. If there be substance enough already in the road, and which indeed should always be carefully kept up, it will never be right to put on more than a stone's thickness at a time. A cubic yard,

nicely prepared and broken, as before described, to a rod superficial, will be quite enough for a coat, and, if accurately noticed, will be found to last as long as double the quantity put on unprepared and in thick layers. There is no grinding to pieces when so applied; the angles are preserved, and the material is out of sight and incorporated in a very little time. Each stone becomes fixed directly, and keeps its place; thereby escaping the wear and fretting which occur in the other case." (Penfold.)

Even in this patching process, rollers are sometimes employed for consolidating the stone, but by the judicious use of rammers weighing from 12 to 20 pounds, in conjunction with rakes and brooms, with which the wheel tracks are promptly effaced, and filled in, and the new stone slightly covered with detritus to bind it together, rollers may be dispensed with.

The deeper the depressions and ruts to be filled, the larger the fragments of stone used for repairs may be, up to the standard adopted for new roads. In a long continued season of drought, the road becomes baked and the metal begins to loosen after a while and consequently wears away with increased rapidity. In such cases great injury would ensue unless precautions are taken to fix the loose stone and restore firmness and stability to the surface layer. This can be done effectually by moderate sprinkling and light ramming or rolling, care being taken to so regulate the supply of water that it shall resemble a gentle shower of rain in its effect upon the surface, but not render the draught heavy. Too much water, by softening the binding layer on top, allows the stones to work upon each with increased grinding power.

This system of maintenance for roads of moderate traffic seems open to the objection of being unnecessarily expensive, but observation and experience have fully demonstrated that such is not the case, and that the "stitch in time" policy applies here with peculiar and significant force. It is not only vastly cheaper to maintain such a highway in good condition, for a given traffic adapted to it, than to pay the extra expense of conducting the same traffic on a bad road, but it is also vastly cheaper to keep the road in excellent order than it is to restore it to that state after a period of injurious neglect, during which it has become filled with deep ruts, and thickly covered with dust and mud.

A capital distinction must be made between the method here inculcated, which involves a constant and unceasing daily and hourly care of a road, in order to arrest every incipient tendency to deterioration upon its surface, and any and every other method whatever, whether by frequent repairs; or only occasional repairs; or by repairs at long intervals. The first only embraces the true principle, that of prevention. All the others are cures.

The French engineers of the Corps des Ponts et Chaussées were the first to give anything approaching to an exhaustive practical study to this question. It was found that in proportion as the intervals between the periods of repairs were shortened upon roads of small traffic, two important and valuable results invariably followed, viz., that the annual expense was lessened; and that the roads were always in better condition; and finally that the roads were never so good, nor the expense of maintenance so small, as when the system of unremitting and minute attention was in full operation.

Among the statistics bearing upon and elucidating this branch of the subject, room is here made for the following extract:

"The following took place with respect to the high roads of the Department de la Sarthe, somewhat less than 250 miles in extent.

		Per mile.
In 1793 a demand was made to put them in complete order for	£15,280, or	£60
In 1824 the demand was above	9,000, or	36
In 1836 the demand was above	7,760, or	31
In 1839 the demand was above	6,640, or	26

And the roads have become better concurrently with the reduction in cost of maintenance, from being in 1793 in deep ruts, to 1839, when they were in very good order.

Part of the great road between Lyons and Toulouse, till 1833, was in a dreadful state, and yet it had cost habitually about £110 per annum per English mile for maintenance, when Mr. Berthault Ducreux introduced a system of patching instead of general repairs, since when, the road was gradually improved, till it was in a very good state, and the annual expense reduced, by £13 or £14 per mile" (Gen. Sir John F. Burgoyne, Bart.). During the period from 1833 to 1845 the traffic on this road never reached an average daily tonnage of 600 tons. From 1845 to 1852 it increased to over 900 tons; in 1856 it had reached 2500 tons with a steady increase still going on until it touched 2800 tons, when, upon the opening of a parallel railroad from Saint Etienne to Firminy, it fell off to about 2000 tons, which i maintained up to the last published reports in 1865. It was not therefore until 1845 and subsequent thereto, that the amount of traffic on this road was sufficiently great to render

a change in the method of maintenance either necessary or expedient. This road will be further discussed when treating on the method of maintenance by periodical reconstruction with intermediate repairs.

In another case, that of the road from Tours to Caen it was reported in May 1836 to be in such bad condition as to require the expenditure of £2,000 on the entire line, to prevent the danger of its becoming impassable. It had been the subject of *occasional* repairs from 1832 to 1836, both included, at an annual cost of £978 for material and labor.

In January, 1837, M. L. Dumas of the Corps des Ponts et Chaussées was placed in charge of it, when in its worst condition. It was afterwards kept up by the method of constant and minute repairs. In August, 1838, it was reported, upon inspection, to be in a very good state, and it subsequently became better from year to year, at an average annual cost, from 1837 to 1841, a period of five years, of £820 for labor and material.

In 1834 the mail coach required five horses to draw it, and the service was so severe upon them that eleven died from over-work during that year. After 1838 only two horses were necessary to draw the coach, which they did without loss of animals or over-fatigue. Omitting all consideration of the cruel destruction of animal life inflicted by the bad road, there was in this case a saving, under the new and proper system of maintenance, of about 12 per cent per annum in the expense of labor and material put upon the road, and 250 per cent per annum in the amount of annual power required, for a specified item of traffic.

Maintenance of Broken Stone Roads of large Traffic.

Experience upon the French roads seems to indicate that when the amount of traffic exceeds 600 tons per day over a road of 16 to 18 feet width of metal, the method of maintenance above described, by minute daily repairs, is not the most economical.

The wear of material is not in direct ratio to the tonnage passing over it. Other conditions remaining the same, it augments much more rapidly than the tonnage.

It is believed that for roads of great traffic the method of maintenance by periodical reconstruction, accompanied by partial repairs or patching during the intervals, offers superior advantages in respect to cost of labor and interference with traffic, to the method by minute and constant repairs.

This method consists in allowing the broken stone covering to wear down gradually and—so far as its wear can be controlled—evenly, limiting the work upon it to the preservation of its unity of surface, by filling in holes, depressions, and incipient ruts, with small quantities of stone, not rising above the general surface, and therefore not intended to restore that surface to its original height. The surface of the road is therefore constantly kept in good condition, and its resistance to draught at a minimum.

When the road covering, however, has been worn down to a thickness of 4 or 5 inches, a thorough repair to the extent of a restoration of the original thickness is made.

Experience has shown that the period of this general repair should not be deferred beyond a certain point, and

that re-fillings of 3 to 4 inches in thickness are preferable to heavier ones.

The new layer, after being carefully spread to the required thickness, should be compacted with heavy rollers.

The season of least traffic is selected for this work, and, in order to lessen the interference with travel, the road-way may be covered and rolled upon only one-half its width at a time, and the rolling may be done at night.

This method has the advantage of providing a road surface which remains in a compact and regular shape for a long time after each periodical rolling is completed, during which only occasional and insignificant repairs are needed.

Some practical precautions, however, should be observed, viz. :

1. The re-laying and rolling should, if possible, be done in wet weather. If dry weather cannot be avoided, the road should be sprinkled rather copiously, so that the new material will unite readily with the old. A light picking up of the old crust will help materially to effect this union.

2. The new material after being carefully spread, should be repeatedly sprinkled and rolled until the stones are well pressed together into a compact layer, with an even and smooth surface. Then a layer of sand, or stone dust, or detritus, not exceeding half an inch in thickness, is spread over the top, lightly sprinkled with water and again rolled, in order to force it well into the voids of the new material. It is important not to put too much sand on at once. A repetition of thin layers is better than an excess in the first instance.

3. The wear of a road is represented by the decrease in the thickness of the stone crust, and the only reliable means

of finding this out correctly is to take occasional soundings to ascertain not only the thickness, but the composition of the road covering, with respect to solid material and detritus.

It has become customary to express the wear of a road in functions of its tonnage rather than of the number of collars, for the evident reason that a collar may represent only half a ton upon some roads and more than a ton upon others. But even the tonnage is not entirely reliable as a basis of comparison, and much depends on the kind of material used for the road covering.

The following table gives some of the results obtained on the roads in the Department of the Loire, France, from 1857 to 1860, as reported in 1865, by M. Graeff, engineer-in-chief des Ponts et Chaussées. The road covering was schist, and about 21 feet in width.

Length of road.	Mode of Maintenance.	Daily Tonnage.	Annual wear in cubic yards.
1 mile.	Periodical reconstruction.....	1400	579
1 "	Minute and constant repairs....	1400	727
1 "	Periodical reconstruction.....	1800	1866
1 "	Minute and constant repairs....	1800	2104
1 "	Periodical reconstruction.....	2300	2794
1 "	Minute and constant repairs....	3200	4635
1 "	" " "	5400	9934

Some of the roads in the arrondissement of St. Etienne, built with basalts, furnished the following data :

Length of road.	Mode of Maintenance	Daily Tonnage.	Annual wear in cubic yards.
1 mile.	Periodical reconstruction.....	1200	175
1 "	" "	2000	372
1 "	Minute and constant repairs....	2000	480

The foregoing tables show (1) that the destruction of road material increases much more rapidly than the tonnage; (2) that the tough basalts are much more valuable for road coverings than soft schist; and (3) that for roads of large traffic the system of maintenance by periodical reconstruction, accompanied by such intermediate repairs, more or less constantly, as will secure hardness and smoothness of surface, and uniformly diminishing thickness, is superior to the one of minute and constant repairs exclusively. Indeed, it is now generally admitted in France, that this last named system is not advantageously applicable to roads upon which the daily tonnage exceeds 600 tons.

Curves of Tonnage and Wear.

The French engineers are very careful and methodical in collecting data, and arranging them in convenient form for practical use. Having ascertained by careful and systematic observation, the average daily tonnage, and the annual wear of materials upon different portions of a road of given width, or upon different roads, curves may be constructed with the average daily tonnage abscisses, and the quantity of material worn out annually upon any unit of length—say 1 mile—as ordinates. A separate curve for each kind of road material

employed should be made, as shown in the diagram Fig. 45, which exhibits the results obtained on certain routes in the Department of the Loire, France, already referred to. The wear of four different kinds of stone was observed, viz., Schist, Quartz, Granite and Basalt. The width of the road covering was 21 feet. The lower horizontal line gives the average daily tonnage for different years, or upon different portions of the road for the same year, all measured from the zero point on the left. The left hand vertical line shows the yearly wear of road material in cubic yards per mile of road. The curve for schist was obtained by M. Graeff, who states that the deviation of the points D and E from the general curve may be ascribed to the mass of detritus brought upon the road by the exceptional traffic caused by the caving in of a neighboring tunnel on the St. Etienne and Lyons railroad. If the wear upon the road was proportional to the amount of traffic, the law would be expressed by straight lines instead of curves. The line for schist would pass through the points O and A, intersecting the ordinate corresponding to a daily tonnage of 5400 tons, at the point M, indicating an annual wear of only 2097 cubic yards, whereas the actual observed wear for that amount of tonnage was 9934 cubic yards. The observations on the wear of Quartz, Granite and Basalt were made by M. Montgolfier, and although not so numerous as might be desired, being limited to a daily traffic of 1800 tons for granite and quartz and 2000 tons for basalt, they still give an idea of the relative value of these materials for road covering. The ordinates of these three curves corresponding to the abscissa of 5400 tons daily traffic, were obtained by calculation, on the assumption that the ordinates of the several curves for any one abscissa bear the same rela-

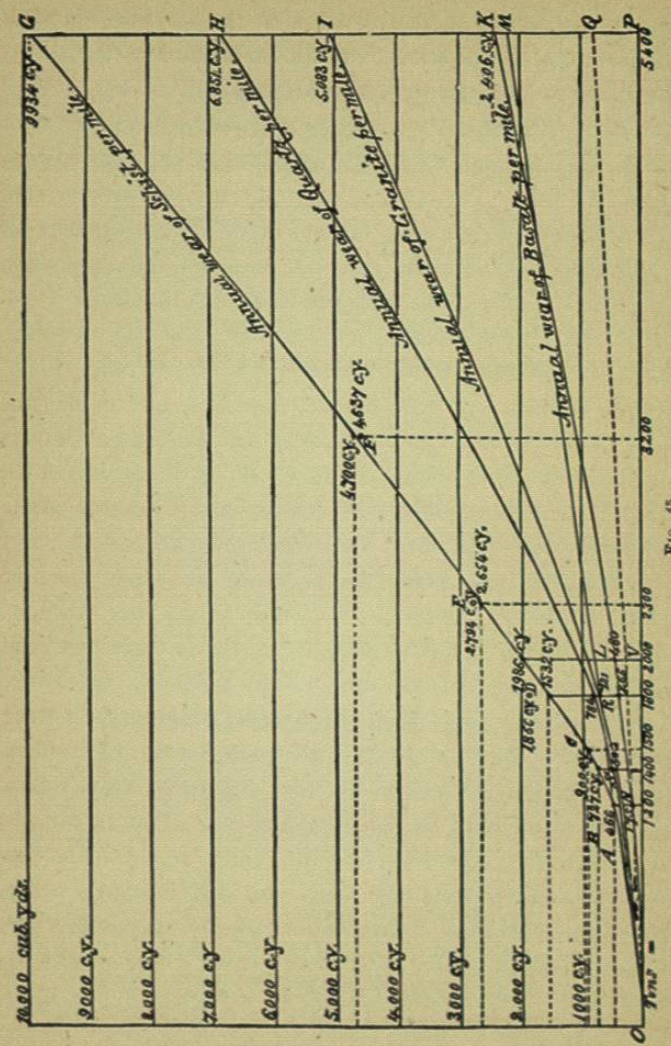

FIG. 45.

tion to each other as for any other abscissa. The following proportion gives the point K on the basalt curve.

$$480 : 1986 :: PK : 9934$$

$$PK = 2405 \text{ cubic yards.}$$

Besides the important deduction that no road can be maintained on the hypothesis that the wear is proportional to the tonnage passing over it, the diagram also shows that the necessity for employing only the best material, even when quite expensive, increases rapidly with the tonnage.

Apportionment of Materials.

The apportionment of repairing materials, under the method of maintenance by periodical reconstruction, may be expressed by the formula $\mathbf{n} \times C = A + \mathbf{n} \times E$, in which $\mathbf{n}$=the number of years intervening between the periods of reconstruction or rolling.

C=the number of cubic yards of wear per year, per mile.

E=the mean number of cubic yards per year, per mile, for small repairs.

A= the mean number of cubic yards required for rolling. C and A become known for each road by careful observation for a sufficient length of time. E varies from year to year during a period of $\mathbf{n}$ years, being smallest in the year immediately succeeding a re-rolling, and largest in the year preceding the next rolling. In practice E will never exceed $\frac{1}{2}$ C, but will increase from zero to $\frac{1}{2}$ C in $\mathbf{n}$ years, with a mean average value of $\frac{1}{4}$ C, from which there results the practical rule of $\mathbf{n} = \frac{4}{3}\frac{A}{C}$.

It may be assumed that of the whole quantity of material