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United States Department of Agriculture,

OFFICE OF ROAD INQUIRY.

METHODS OF CONSTRUCTING MACADAMIZED ROADS.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF ROAD INQUIRY,
Washington, D. C., June 6, 1896.

SIR: The Bureau of Highways of the State of California having requested Her Majesty's Office of Works to "acquaint them with the methods employed in England in the matter of highway improvement," the Marquis of Salisbury transmitted the following report prepared by the chief engineering inspector of the local government board to the ambassador of the United States, who forwarded it to the Secretary of State with the observation that, "in view of the general interest felt in this subject, I venture to suggest that it would appear very expedient if the report now transmitted could be printed for public information."

The Office of Road Inquiry has obtained permission of the California Bureau of Highways to make any desired use of this report, and, in view of the many valuable suggestions contained therein, I would recommend its publication as Circular No. 21 of this office.

Very respectfully,

ROY STONE,
Special Agent and Engineer.

HON. J. STERLING MORTON,
Secretary of Agriculture.

Extract from a Report Prepared by the Chief Engineering Inspector of the Local Government Board.

INTRODUCTION.

Our country roads have not been made with any particular kind of material, or in any particular way, but have grown up just as the exigencies of trade or traffic demanded and according to no set rules or principles. They consequently present the greatest differences. While some are as wide as the widest streets in towns, others are mere lanes where two carriages meeting can not pass each other.

In England it can hardly be considered that there was any art or science in roadmaking until the early part of the present century, and it is almost impossible to enter into any discussion of the technical points in connection with the formation and maintenance of roads without referring to the maxims and practice of the great pioneer in this branch of civil engineering whose genius is not only universally acknowledged, but has even stamped itself on the European languages.

After a considerable experience of roadmaking in Scotland and elsewhere, John Loudon Macadam appears to have settled some time before 1820 at Bristol, where he was made a magistrate of the county and appointed general surveyor of the roads in the district. When he took charge of these roads it is admitted that they were more or less in a deplorable condition, but in a very short time after they passed under his charge they were transformed as if by the wand of the magician into such an efficient state that all classes bore the amplest testimony to his success, especially that class who had the best opportunities of judging and whose

interests were pecuniarily affected by the state of the roads—the great coach proprietors before railways were introduced into the country. His experience, moreover, was not confined to any single county, but he was consulted by authorities in all parts of England, so that his knowledge of the subject, both in respect of its technical details and its actual practice, was such as no one else possessed.

His experience, too, was of that highest kind which is derived from the actual carrying out of works over a wide field of action. He constructed roads on plains and over hills, on hard grounds and on soft, over rocks and across swamps, with granite, with whinstone, with flints, with limestone, with gravel, and with every kind of available materials, and he appears to have carefully observed the results of his labors in each instance. These results were obtained, moreover, not with an increased expenditure, but with an actual saving. His roads cost less both to form and to maintain.

Just as no work on roads is ever written without an explanation of Macadam's principles, so it is equally necessary in this paper to refer from time to time to those principles, and to discuss them in connection with the more extended knowledge and better appliances of the present day.

WIDTH OF ROADS.

There is nothing like uniformity in the width of the county roads in the Kingdom, some of which are as wide as 80 feet, while others are only one-tenth of that width, i. e., so narrow that even two carts can not pass each other on them. The average width, however, may approximately be taken at from 15 to 30 feet for the metaled portions. There is also no uniformity as to the footways. On some roads there are no footpaths on the sides at all; on others there is a footway on one side only; and on others, on both sides. Moreover, these paths, which are usually of gravel and raised from 6 to 12 inches, but in some places much more, above the metaled portions of the road, and which generally slope toward the carriage ways, differ much in width.

In some places also there is a strip of greensward on the side of the carriageway which is used by equestrians, sheep, and cattle.

These same observations apply also to all other roads in the country. There is no more uniformity to be found in them than in the county roads. They vary in width exceedingly, being in some places as wide as first-class county roads, and in others dwindling down to exceedingly narrow lanes. These roads too have in some places footpaths, and in others none.

With regard to the proper width that should be given to roads, it is manifest that this should depend on the object to be served by the particular road. Main roads, which are the principal means of communication between large centers of population, must not only be wider than mere country roads, which run from village to village, or are only required for the purposes of farmers, but must be wider near towns than at a distance from them.

Macadam thought that "roads near great towns ought not to be less than 30 or 40 feet wide, but at a distance from great towns it would be a waste of land to make them so wide."

No hard and fast rule can be made unless it is that every road which is intended for carriage traffic should be sufficiently wide to admit of two carriages passing each other easily, otherwise the greatest inconvenience must be caused. The surveyor in designing new roads must be guided by his knowledge of the traffic of the district and must regulate their widths accordingly. For country roads the widths should be somewhat more than twice the width of the vehicles and carts used in the particular country or locality, so as to allow the wheels to pass each other easily, and for ordinary main roads twice this width would answer every reasonable purpose. If a road is made less than the width of two carts, it should widen out for a short length, at regular distances apart, to a little more than the width of two carts, so as to admit of carts passing each other at these refuges; but this is at best an imperfect arrangement, as the drivers do not see each other till they suddenly meet, when one must go back to the nearest refuge to let the other pass.

It should be borne in mind that the cost of maintaining a well-formed road is not in proportion to its width, but more in proportion to the traffic passing over it, so that in laying down a new road it is better to make it too wide than too narrow. Greater width affords greater convenience to traffic, and the road is not so often under repair. A narrower road, for the same amount of traffic, is oftener under repair and wears out both horses and carts much sooner. This is particularly the case where the road is formed with inferior material.

GRADIENTS.

Inasmuch as the roads everywhere have been constructed as they have been required in times past, and without the technical knowledge of the present day, the gradients usually were made to conform in great part to the character of the country over which they passed, and where obstacles such as hills were met with, the roads were generally carried over them without any ruling gradient having been adopted. Some of the old roads with very steep gradients have been, or are being, gradually altered from time to time, but it would be very desirable to improve many others in the same way. Sir John Macneil advocated a ruling gradient of not less than 1 in 40; Professor Mahan, 1 in 33; and Telford, about 1 in 30. If a ruling gradient not steeper than 1 in 30 could be generally adopted throughout the country, except for very short distances, in cases where the cost would be out of all proportion to the advantage gained, an immense benefit would be derived by the public.

The limit of the longitudinal gradient for macadamized roads as to steepness should not exceed about 1 in 20, and as to flatness, about 1 in 100. A perfectly flat road is generally objectionable, in consequence of the difficulty of draining it properly, but the objection does not hold good if the road is raised above the surface of the country, and its drainage can be effected properly.

Although the first cost of a road with a good gradient may be greater than that with a steeper one, the subsequent charge of maintenance is in favor of the former, as flat roads with the same amount of traffic do not cost nearly so much as steep ones.

CROSS SECTION.

The gradient from the middle of the road to the side is a technical point of the first importance, and, as usual, it was Macadam who really reasoned out the principle which should guide the surveyor. He said:

"A road should be as flat as possible with regard to allowing the water to run off at all, because a carriage ought to stand upright in traveling as much as possible. I have generally made roads 3 inches higher in the center than I have at the sides when they are 18 feet wide. If the road be well made the water will run off very easily in such a slope.

"When a road is made flat, people will not follow the middle of it as they do when it is made extremely convex. Travelers generally follow the track in the middle, which is the only place where the carriage can run upright, by which means three furrows are made by the horses and the wheels, and the water continually stands there; and I think more water actually stands upon a very convex road than on one which is reasonably flat."

The cross slope, therefore, recommended by Macadam, viz: 3 inches in a road 18 feet wide, would be 1 in 36. For a road 30 feet wide Macadam also recommended a fall of only 3 inches from the center to the sides. This would be a gradient of only 1 in 60. There is no explanation of this apparent discrepancy in his practice, but he may have considered that a wider road might have a flatter cross section because it has generally a smoother surface. Another engineer, John Walker, who lived in Macadam's time, advocated that the surface of the road "should be made with a very gentle curve in its cross section, just sufficient to permit the water to pass from the center toward the sides. The declivity may increase toward the sides, and the general section form a very flat ellipsis, so that the side should (upon a road of about 30 feet in width) be 9 inches below the surface in the middle." Such a slope would practically be equivalent to 1 in 20, and would be much steeper than the best authorities in the present day recommend.

The slopes actually given to the roads in the country follow no rule. Some of the roads are almost flat, while others are very convex.

There is one serious disadvantage in giving the surface of the road an elliptical form, which is that the center portion has one slope while the sides have another. This is most inconvenient to traffic and actually dangerous to carriages moving at a great pace. The sudden change from one slope to another is very apt to overturn the vehicle, particularly if there should happen to be any loose stones lying on the surface. It is somewhat illogical, moreover, to advocate such a form for a road, as, if the flatter portion of the surface has a sufficient slope, the remaining portion must have too steep a one; or, again, if the sides have a proper slope, the middle of the road must be too flat. Extreme steepness at the sides practically narrows a road for use, and also tends to the more rapid destruction of these portions of the highway.

The slope should be regulated with the following objects in view:

The rain falling should be able to escape readily to the sides, but not with such a velocity as to create ruts on the surface.

The road should be as flat as possible consistent with the first principle, so as to offer no inducement to vehicles to keep to any particular part of it, and thus to wear that part out.

FOUNDATION.

Macadam thought a foundation of large stones or other suitable material for the metaling to rest on was not only unnecessary, but that it was positively injurious.

A thickness of 10 inches of metaling well consolidated in layers of about 3 inches or so, and placed on a dry subsoil (a *sine qua non* with him), was in his opinion sufficient to carry the heaviest traffic even over soft ground. He never used large stones for a foundation in his practice of roadmaking. He said:

"The roads can never be rendered perfectly secure until the following principles be fully understood, admitted, and acted upon, viz: that it is the native soil which really supports the weight of traffic; that while it is preserved in a dry state it will carry any weight without sinking, and that it does in fact carry the road and the carriages also; that this native soil must be previously made quite dry, and a covering impenetrable to rain must then be placed over it in that dry state; that the thickness of a road should only be regulated by the quantity of material necessary to form such impervious covering, and never by any reference to its own power of carrying weight.

"The erroneous opinion so long acted upon and so tenaciously adhered to, that by placing a large quantity of stone under the roads a remedy will be found for the sinking into wet clay or other soft soil, or, in other words, that a road may be made sufficiently strong artificially to carry heavy carriages though the subsoil be in a wet state, and by such means to avert the inconvenience of the natural soil receiving water from rain or other causes, has produced most of the defects of the roads of Great Britain.

"At one time I had formed the opinion that this practice was only a useless expense, but experience has convinced me that it is likewise positively injurious."

The following evidence given by him before a Parliamentary committee shows still more clearly what views he held on the subject:

"I should think that 10 inches of well-consolidated material is equal to carry anything."

Query: "That is, provided the substratum is sound?"

Answer: "No, I should not care whether the substratum was soft or hard; I should rather prefer a soft one to a hard one."

Query: "You don't mean you would prefer a bog?"

Answer: "If it was not such a bog as would not allow a man to walk over I should prefer it." * * * "I think when a road is placed on a hard substratum, such as rock, the road wears much sooner than when placed on a soft substratum."

Query: "But must not the draught of a carriage be much greater on a road which has a very soft foundation than over one which is of a rocky foundation?"

Answer: "I think the difference would be very little indeed, because the yield of a good road on a soft foundation is not perceptible."

Macadam thought that a road lasted much longer over a soft than over a hard substratum, and independent evidence was given before Parliament to prove this in respect of a road between Bristol and Bridgewater, part of which ran over a morass, and part over a rocky foundation. It was contended by Macadam that the unyielding rock caused the road to wear away much faster. This seems, however, to be directly opposed to the experience of most engineers whose practice it usually is to secure as hard and unyielding a foundation as possible.

Macadam's great objection to laying down a bottom of large stones was that such a foundation acts "as a sieve which lets the water in which penetrates the whole mass, when the road is liable to give way in all changes of weather." Frosts and thaws were in his opinion the great evils to be guarded against, and no made foundation was equal to the natural soil in a dry state.

There is no doubt that little uniformity prevails in the country. It may safely be said that most of the old roads, if dug up, would be found to have little or no foundation, but many of those formed within, say, the last twenty or thirty years would be found to rest on foundations of stones, or ballast, or some suitable material of the kind.

When a foundation is used, a thickness of from 6 to 12 inches is recommended and over this from 4 to 6 inches of metal. But here, again, no hard and fast

rule can be laid down. The surveyor must be guided by circumstances—by the nature of the ground, the kind of material at his disposal, the traffic, etc.

It is manifest that a greater thickness of foundation should be given to a road where the ground is soft and the traffic is of a heavier nature than where the ground is hard and the traffic light. A less thickness of good tough metaling will suffice, than of softer material, which is liable to break under pressure.

Where roads are made without foundation, Macadam's rule will probably be found as correct as any. He considered 10 inches of metaling sufficient for any road, but, in carrying this out in practice, it must never be forgotten that Macadam insisted on the soil underneath being perfectly dry, and the metaling, after being properly prepared being thoroughly consolidated; so consolidated, in fact, as to prevent any water passing through it. It is this water getting under the surface and alternately freezing and thawing which destroys a road quicker than anything else.

DRAINAGE.

The drainage of the ground over which the road is to run is manifestly of the very first importance, because, unless every precaution is taken to insure that the soil on which the road rests is kept dry under all conditions of weather, as insisted upon by Macadam, the road is certain sooner or later to be destroyed.

In setting out the lines for a road the engineer should ascertain very carefully how the ground over which the road is to pass drains, so that he may be able to make the best use of the natural outfalls of the country, and thus get rid of the water from his road drains in the readiest way possible.

Walker particularly recommended that the side drains should be "on the field side of the fence with apertures in the fence for the water to pass from the sides of the road into them," but this is by no means a rule that has been generally adopted, nor is it always possible. The objection to it is the difficulty of getting at the drains at every point to keep them clear, nor can the men in charge of the roads so readily observe if a stoppage takes place and requires to be removed.

The drains are in some places within the fences and in others beyond; but wherever the drain may be placed, its width and depth must evidently be regulated according to local circumstances. In places where the drain after running short distances can relieve itself by discharging the water into some natural ditch or stream, its dimensions may be small, but where there is no natural outlet for a long distance the quantity of water which it will have to remove will be far greater and its dimensions will consequently require to be adjusted to these circumstances. It is therefore clear that in some places a drain 18 inches square, or even smaller, would more than suffice for its object, while in others a drain 3 feet square, or larger, would fail to carry away the water flowing into it.

In some situations, moreover, the road might intercept the surface drainage of the country, and provision would have to be made for the water which would naturally flow into the drain from the adjacent lands in addition to that from the road.

In adjusting the sizes of drains to roads one important consideration should always be borne in mind, and that is that the velocity of the water should not be so great as to wear away the sides and bottom of the drain. Sewers are made as small as possible to secure the greatest velocity and scouring power with a given quantity of water. The opposite principle must be borne in mind in designing drains for roads. The drain should rather be made too large than too small, and too wide and shallow than too narrow and deep, in order to reduce the velocity of the stream, so that it shall not destroy the drain. Deep drains by the side of the road are very dangerous.

The level of the water in the drains should be kept well below the material forming the road. Macadam considered 3 or 4 inches sufficient, but others recommend as much as a foot at least, and more even, if it can be easily obtained.

Where the road has a comparatively steep longitudinal gradient, and the water must flow with considerable force, it may be necessary to go to the expense even of a covered drain constructed with slabs of stone or stoneware pipes or masonry.

It is manifest that in some places drains would not be required on both sides of the road. One may suffice, but in these cases the water falling on one-half of the road would require to be conveyed to the ditch on the other side by drains laid under the roadway.

Some surveyors recommend that cross drains should never run at right angles to the line of the road, but in a slanting direction. One advantage of this is that a better gradient can be secured for the drain.

The surveyor should take great care that the line chosen for the road does not run over any natural springs rising to the surface. Such springs should be avoided if possible; but in cases where this is not practicable, special means must be adopted to lead off the water by drains laid under the road.

When there is a footpath by the side of the road, the water falling on that half of the road is conveyed to the ditch at regular distances apart by covered drains laid at a proper inclination under the path, and where the longitudinal gradient of the road is so steep that the water flowing alongside of the footpath is liable to cut up the surface, a proper paved or other suitable channel to resist the action of the water should be laid down.

Nothing so much conduces to the preservation of roads as good curbs and proper side channels for the removal of rain, but, unfortunately, curbs are seldom laid except in towns, and not near sufficient attention is paid to the construction of side channels, which are soon worn into ruts by the rain.

HEDGES AND FENCES.

Air and sunshine are as necessary for the preservation of roads in good order as for the vigorous health of plants and animals. Water and want of light are among the most destructive agents in nature, and no road can be kept in order which is always in a damp state and on which the sun never shines. Everything, therefore, that prevents a perfect perflation of the air and obstructs the revivifying effects of sunshine is to be avoided.

Considered, then, from a purely engineering point of view, there is no doubt that a road would be all the better without hedges and fences of any kind, but inasmuch as a barrier of some kind or other between roads and the adjoining fields is absolutely necessary on other grounds, e. g., to keep cattle from straying from one to the other, to mark the limits of property, etc., a hedge may be considered a necessary evil, and the point, therefore, for the consideration of the engineer is how to minimize the evil.

Obviously, the higher and thicker the hedge the more obstruction must it offer to the sun and wind. The object to be borne in mind should be to erect such a barrier as first, shall allow the greatest amount of light and air to pass through it, and secondly, shall best answer the nonengineering purposes for which it is required.

According to these principles, the best barrier would be one of iron, or of iron and wood combined, provided that it was sufficiently strong to resist being broken down by cattle, horses, etc. Iron wire should not be used, as it is easily bent out of shape, and cattle and horses are very apt to injure themselves in attempting to jump over the fence or to force themselves through it. Barbed wire is still more objectionable, and its use, which is cruelty to animals, should be strictly forbidden.

A strong iron fence forms, perhaps, the best barrier, but it is costly, and few authorities would be prepared to go to the expense of putting it up, especially as it deteriorates with time and entails a constant charge for maintenance in consequence of the corrosion of the iron and the necessity for periodically painting it.

Wood is not a suitable material for a fence, as it is easily destroyed by willful persons and rots under the effects of the atmosphere; but, if used, it should be oak or some other kind which resists rot as long as possible. Most kinds of wood are perfectly useless for the purpose.

The commonest fence in England is the quickset hedge, and its almost universal use is perhaps due to the fact that it is cheap and requires no skilled labor to maintain, but it is a mistake to suppose that a good quickset hedge can be established without care in planting and constant subsequent watchfulness.

One of the first engineers who drew attention to the importance of the subject of hedges in connection with roads was John Walker, who in his evidence before Parliament said:

"The fences on each side form a very material and important subject with regard to the perfection of roads; they should in no instance be more than 5 feet in height above the center of the road, and all trees which stand within 20 yards of it ought to be removed. I am sure that 20 per cent of the expense of improving and repairing roads is incurred by the improper state of the fences and trees along the side of it, on the sunny side more particularly. This must be evident to any person who will notice the state of a road which is much shaded by high fences and trees, compared to the other parts of the road which are exposed to the sun and air. My observations with regard to fences and trees apply when the road is on the same level as the adjacent field; but in many cases on the most frequented roads in England more stuff has been removed from time

to time than was put on; the surface of the road is consequently sunk into a trough or channel from 3 to 6 feet below the surface of the fields on each side. Here all attempts at drainage or even common repairs seem to be quite out of the question; and by much the most judicious and economical mode will be to remove the whole road into the field which is on the sunny side of it."

Mr. Law in his work on "Roads" makes some very useful observations:

"Few persons are aware of the extent to which a road may be injured by high hedges or lines of trees. Trees are worse than hedges, because they not only deprive the road of the action of the air and sun, but they further injure it by the dripping of rain from their leaves, as a consequence of which the road is kept in a wet state long after it would otherwise have become dry.

"When fences are indispensable they should be placed as far as may be from the sides of the road, and should be kept as low as possible. When there is a deep ditch on either side of the road it becomes necessary, to prevent accident, that the fence should be placed between the road and the ditch, but in other situations the fence should be placed on the field side of the ditch. In so doing the surface draining of the road into the side ditches is less interferred with and the action of air and sunshine is less obstructed by the fence.

"The different descriptions of fence which may be employed are various. In districts where stone is plentiful, and especially in the immediate neighborhood of quarries, where stone rubble can be obtained at a trifling cost, dry rubble walls, without any mortar, are very good and cheap and require little or no repair.

"For the road itself, an open post-and-rail fence is the best which can be employed, because it scarcely impedes the action of the wind and the sun upon the surface of the road, but the great practical objection to timber fences is their liability to decay, which occasions freqent and constant expense for renewal.

"The most common, and, all things considered, the most useful fence is the quickset hedge. If properly planted and carefully attended to for the first few years, a natural fence may be obtained sufficiently strong to resist the efforts of cattle to break through, and very economical in cost for maintenance. A bank or mound of earth at least 2 feet in depth should be prepared for the reception of the quicks, which should be three years' plants which have been transplanted two years. The best kind of soil is one of a light sandy nature, admitting sufficient moisture to nourish the plants and retaining moisture in dry seasons. Heavy clay soils are not sufficiently pervious to water, and plants placed in such soils are never found to thrive. A mixture of peat or of rotten leaves is of great use and causes the plants to grow with much vigor. The quicks are most commonly planted in a single row, at distances of about 4 inches apart. But a much better hedge is formed by planting them 6 inches apart in a double row, as shown below, with a space 6 inches between the rows,

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and so arranged that the plants in one row are opposite the spaces in the other. By this arrangement, although the plants are really not so crowded, and have more space around their roots from which to derive nourishment than in a single row, they form a thicker hedge. The proper time for planting quicks is during the autumn or the spring, and, in fine seasons, the operation may be continued during the whole winter. A temporary fence should be put up to protect the young plants from injury, and the fence should be retained until the hedge has attained sufficient strength to require its protection no longer—a period, under favorable circumstances, of three or four years after the quicks are planted. That the plants may thrive they must be carefully attended to at first, and it is essential that they should be properly cleaned and weeded at least twice every year. Once every year, toward the end of the summer, the hedge should be judiciously trimmed, not to such an extent as to produce stunted plants, but by merely cutting off the upper and more straggling shoots, so as to bring it to a level and even surface. By proceeding in this manner, a neat, strong, and compact hedge of healthy plants will be obtained in about three years after planting."

Trees, however much they may add to the picturesqueness of a road, add still more to the difficulty of keeping it in repair; and thick avenues, i. e., trees planted close to each other on both sides of a road, are quite incompatible with the due preservation of the surface. The evil is worse the narrower the road is, for then very little sunshine can get to the road at all, so that the macadam is constantly damp and wears away much more rapidly under traffic.

What are understood as boulevards are not so objectionable, because the roads are usually very wide and the trees are not planted so close as in an avenue, but from an engineering point of view, everything that interferes with the sun and prevents the circulation of air is objectionable.

MACADAM.

It is to the use of broken stone for the formation of roads to which, more than anything else, we owe the great improvement in the roadways of this country. It is not quite clear who really discovered the virtues of hard stones broken into small, angular pieces, but John Loudon Macadam has probably a better claim to the title of discoverer than anyone else. He it was, at all events, who explained the principles of the use of macadam, the size to which stone should be broken, the manner in which it should be laid, and so forth; and thus it is that the kind of road he introduced has ever since borne his name, not only in England but in many foreign countries.

Macadam attached the greatest importance to the size to which stone should be broken. He said:

"The size of stone used on a road must be in due proportion to the space occupied by a wheel of ordinary dimensions on a smooth, level surface. This point of contact will be found to be, longitudinally, about an inch, and every piece of stone put into a road which exceeds an inch in any of its dimensions is mischievous."

But he thought it a better plan to specify the size, not by its dimensions, but by its weight, and he fixed 6 ounces as the proper maximum weight of each piece. His reasoning was that by experiment he had found very little difference in the sizes of different kinds of stone broken to this weight, however much the stone might vary in specific gravity.

He said: "I hold six ounces to be the maximum size. If you made the road of all six-ounce stones it would be a rough road; but it is impossible but that the greater part of the stones must be under that size."

Whether Macadam was right or wrong, the principle he laid down has not been adopted in this country. Nowhere is the size of macadam regulated by weight, but invariably by dimensions. It is propable that the inconvenience of having to weigh stones in a balance to be carried about by the surveyor compared with the rapidity with which they can be measured by means of a gauge, has caused the former practice to be abandoned. Broken stone to be used for a road is now generally specified to be of a size so that it shall just pass in any direction through a gauge of certain dimensions.

Considerable importance is attached to the manner in which macadam is prepared for use. Machine-broken stone is not considered of the same value as that broken by hand. The stones are not of so regular a size and shape, and there is a greater proportion of inferior stuff. A mechanical crusher is apt to stun the material and does not leave the edges so sharp for binding as they are when the stone is broken with a small hammer.

It is probable that the crusher by its severe blows affects the interior constitution of the stone and renders the fragments more liable to split under the roller.

Macadam, who never thought anything regarding road-making beneath his notice, laid it down that stone should only be broken by people sitting on their haunches and striking it with a small hammer. This serves just to break the stone and no more. The edges are sharp and the fragments, not having received too great a blow to affect the internal structure of the stone, remain thoroughly sound and are tough enough to resist the crushing power of the roller. It should be borne in mind, however, that in Macadam's time mechanical stone-crushers were not in existence, nor even were road rollers in regular use, although they had been invented.

Taking all these points into consideration, it is probable that the best size for macadam for hard and tough stones, such as basalt, close-grained granite, syenite, gneiss, and the hardest of the primary crystallized rocks, is from $1\frac{1}{4}$ to $1\frac{3}{4}$ inches cube, according to their respective toughness and hardness, while stone of medium quality ought to be broken to gauge of from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches, and the softer kinds of stone might vary between the limits of 2 and $2\frac{1}{4}$ or $2\frac{3}{4}$ inches, but the latter is a size which should seldom be specified.

As in everything else in connection with roads, no hard and fast line can be drawn, but the surveyor must prescribe the size to which macadam should be broken according to his knowledge of the properties of the stone he proposes to use. Stones which bear even the same name are often as different in their properties as possible.

The present writer is opposed to the use of large macadam. Where the surveyor has only a comparatively soft stone to form his roads with, the better plan in his opinion is to break the stone to 2 or 2½ inches gauge, but in putting it down in any quantity to roll it at first with a light roller till the stones are fitted into their places and have become well consolidated. The passage of a heavy roller afterwards will not then be so apt to crush the material. Unfortunately most surveyors are so enamored of heavy rollers that very few are aware of the advantages to be derived from the judicious use of light ones, which are seldom to be found in the country.

ROLLERS AND ROLLING

The proper method of rolling macadam and the best weight for rollers are very important questions in the formation and repair of roads. It does not at all follow that the best weight for a roller for one county or country is the best for all. In a district where the only materials to be had are more or less of a soft nature a much lighter roller is necessary than in one where the toughest basalts, granites, etc., are used. Heavy rollers would crush the soft materials to powder and so destroy them for all practical purposes. Such rollers, moreover, are quite unsuitable for roads under which there are water and gas pipes laid at a sufficient depth beneath the surface to resist the crushing power of a heavy load. The penalty to be paid for destroying a water or gas pipe is too serious to be lightly incurred, and before deciding on the weight for his roller, the surveyor should be careful to ascertain the positions and sizes of all the pipes under the roads in his district, together with the depths below the surfaces at which the pipes have been laid, or he may do much mischief before he becomes aware of it.

The present writer is of opinion that the use of heavy rollers, which has been growing of late, is a mistake, and is only to be justified in towns where it is desirable to finish roads as soon as possible, so that there shall be the minimum of interruption to traffic. The heavier the roller, the more liable is the material to be crushed under the load, so that, unless the very best material is used, a 15-ton roller is much too heavy for the object in view—most certainly for the general purposes of the surveyor in a county district.

When the materials used in a district are of different kinds, i. e., when granites, syenites, basalts, etc., are used for the best roads, and inferior stone for the minor ones, it is essential that there should be two rollers—one of a heavier, and the other of a lighter kind, each to be used on the materials suited to it.

The present writer is of opinion that a road formed with a light roller, although it can not be made to consolidate so soon, lasts longer than one formed with a heavier roller. The consolidation in the latter case is effected more rapidly, but at the sacrifice of much of the stone being broken or crushed into position. The lighter roller effects a truer binding of the macadam without breaking the stones into smaller fragments.

Even when the best and toughest materials are used, it will be found advantageous to begin the rolling with a light roller, and only finish with a heavier one.

In rolling fresh material the use of the light roller should be continued until it is observed that none of the stones advance from their positions, when the heavier roller should be brought onto the work, and its use continued until again it is found that no shifting of the macadam takes place.

MAKING A ROAD.

After the land over which the road is run has been properly drained and fenced in, the surface of the ground should be leveled, or, rather, brought to the form of the curve of the road, and all soft and boggy soil rectified, either by its removal and replacement with sound, hard material, or in some other way. Some surveyors recommend the use of faggots and brushwood, which, if used, should be laid down in fascines or bundles, one layer over the other and crosswise; but others consider the use of such material for raising a road very objectionable, unless the brushwood is always in water. If it is alternately wet and dry, it rots, and its destruction soon follows, causing the road to sink.

The present writer is altogether opposed to the use of brushwood except across a morass, where it may be considered to serve the same object as that of pontoons across a river—i. e., to support the road and prevent its sinking through the bog.

Some surveyors recommend that the surface soil should be removed, while others prefer not to disturb it. Here, again, common sense must dictate the proper course to be pursued. If the surface soil is suitable for a foundation and superior to that on which it rests, it should be retained; but if otherwise, it should be removed, so as to give the road the best foundation possible—i. e., the driest and firmest.

When all the soft and defective places have been excavated and refilled with good material, and the entire surface has been brought to the proper curve, the road should be well rolled with a light roller, and materials should be added in the soft places as these sink from time to time. The rolling should be continued until no more sinking takes place in any part of the road, when the light roller should be taken off and a heavy one substituted in its place, the soft places again being made good with good material as they sink. When all sinking has ceased the surface soil may be considered fit to receive the foundation.

Where the soil is very soft, it will often be found impossible to use a roller at all, in which case the foundation must be put down before the rolling begins.

This foundation is formed in various ways, and, of course, with such materials as can be obtained in the district. When stones of a rather large size are used, they should be, as recommended by Telford and so many of the surveyors, hand-pitched with their broadest side downward, so as to insure them bedding properly, and the interstices should be filled with smaller stones. Then a layer of 2 or 3 inches of macadam should be put down and a thin sprinkling of some binding material should be thrown over the macadam. The road should then be well watered and rolled. When this has been thoroughly well consolidated the second layer of macadam, about 3 inches thick, with some binding material, if the stone is too clean, should be put down; when this has been well rolled and has become consolidated, carriages may be allowed to pass over the road.

The materials used for foundations are of very different kinds, many being quite unsuited for the purpose; large stones of almost any sort, furnace slag and clinkers, ballast, flints, chalk, broken pottery, tin cans—any material indeed that can be found ready to hand.

The use of soft material in a foundation should be avoided if possible, as the effect of rolling the road will be to crush the material to powder, and this is the state to which such foundation must inevitably be reduced by the traffic in the course of time.

It is almost the universal practice now to sprinkle some binding material over the macadam before rolling it. This is usually gravel or sand or chalk or clippings from quarries. It is a practice, however, which Macadam condemned with all the force of his character. His opinion was that any material like sand, or fine gravel or chalk, allowed rain to pass through to the bottom, whereas, by rolling the macadam without the use of any binding material, the mass became so consolidated as to offer an impenetrable barrier to the passage of the water.

The views expressed by Mr. Law, C. E., in his "The Art of Constructing Common Roads," on this subject, are worthy of much consideration. He says:

"If the materials of which the covering is to be formed are in angular masses no binding of any description is requisite, as they quickly become united by dovetailing, as it were, amongst each other much more firmly than they would by the use of any kind of artificial cement.

"When the stones instead of being angular are round and pebly, like gravel stones, it is necessary to mix them with just sufficient foreign matter of binding nature as will serve to fill up the interstices between the stones, for otherwise these would roll about and prevent the road from becoming solid.

"There are then two methods of cementing or solidifying the surface of a road—one by the mechanical form of the materials themselves, forming a species of bond; the other, by the use of some cementing or binding matter. And in comparing the relative merits of the two, the preference must certainly be given to the former—that in which the stones are united by virtue of their angular form without the use of any cementing material. The principal reason for this preference is that roads formed with stones so united are not materially affected by wet or frosty weather, whereas roads whose surfaces are composed of pebbly stones united by cementing material become loose and rotten under such circumstances, the cementing material becoming softened by the wet and reduced to a loose, pulverulent condition by subsequent frost."

Mr. Law reasons on the subject exactly as Macadam did, whose views the present writer indorses.

Some surveyors are of opinion that, in laying down macadam, it should be sorted into two or three different kinds, with a view to the larger-sized material being placed at the bottom and the smaller at the top. This is not recommended by the present writer.

When the surveyors have expressed any opinion on the subject they seem to be nearly all agreed that the bottom of the road should not be leveled, but formed to the curve of the surface of the road, as it is to be when completed. When the natural ground on which the road rests is clay, or other impervious

soil, it is clear that to make the bottom of the road flat, is to induce the water percolating through the macadam and foundation to rest in hollows below, whereas, if the bottom is curved, the water is more likely to flow off to the sides, and thus to leave the foundation and macadam dry. Moreover, as the wear of the road should be the same in all parts, the thickness of the material should likewise be the same everywhere.

REPAIR OF ROADS.

As in the making and maintenance of roads, it is essential that there should be abundance of water, without the use of which the surface can not be easily broken up, nor the macadam be got to consolidate properly, the best season for doing work of this nature is that part of the year when water is plentiful and can be easily got, and when the roads are softened with rain or moisture, i. e., the late months of autumn and early winter.

It is not considered a good plan to coat a long length of road with material at once, because, if this is done, vehicles avoid going over the macadam, and thus prevent it from consolidating quickly. If short lengths only of the road are put under repair, the drivers find it more troublesome to be constantly avoiding them than to keep straight on their course, and thus the material is got to bind much sooner.

After April and in summer, or the dry months of the year, all loose stones should be removed from the road, for, if allowed to remain, wheels passing over them loosen the material on which those stones rest, and thus cause much damage to the surface of the road.

The proper maintenance of a road consists in keeping the surface always smooth for traffic and in taking care that the thickness of the macadam is not unduly diminished by wear. A road may be smooth on the surface, but, if the material is nearly worn away, it can not be considered to have been properly maintained. To keep a road in an efficient manner unceasing vigilance is required. Ruts and hollows should be at once filled in with macadam, and all weak places as soon as observed treated similarly.

A common fault is to put too great a thickness of stone down at once. Penfold says:

"It is one of the greatest mistakes in roadmaking that can be committed to lay on thick coats of materials, and when understood it will no longer be resorted to. If there be substance enough already in the road, 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 to a rod superficial will be quite enough for a coat, and 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."

For repairs of this nature, where, in fact, the mere surface of the road only is sought to be put in order, no binding material is used or necessary. The wheels of the carriages gradually push the stones into their places, and make them bind with the old material on the road. Some engineers are of opinion that no macadam should be laid down, however thin the coating may be, without the surface of the road being roughened with a pick. There is no doubt that this tends to make the new material bind with the old much sooner, but, on the other hand, it tends to disturb and to weaken the crust if it should be very thin.

For more extensive repairs, i. e., when a road has been allowed to become very thin, and it is necessary that a considerable thickness of material should be laid on, the road must be what Macadam termed "lifted," or broken with a pick to the depth of 2 or 3 inches, and all large stones must be thrown aside to be broken to the required dimension. A thin layer of new macadam must now be added and the road rolled. It will usually be found that no binding material will be necessary. When this layer has become consolidated, another, 2 or 3 inches thick, should be laid down and again rolled, and so on until the desired thickness of material for the road has been obtained.

Macadam objected to the use of any binding material, such as gravel, sand, chalk, etc., being used with the view to help the macadam to bind, but the almost universal practice now is to sprinkle some such material over the macadam before rolling it.

The present writer's views accord with those of Macadam. In his opinion the bad state of many of the roads in the country and the constant repairs required to them, are in great part the result of the use of binding materials, which being invariably of a pervious nature, afford the rain innumerable passages through the macadam to the foundation underneath. Thus, not only is there water below the road, but the macadam and foundation are so thoroughly saturated with wet that no power on earth can possibly resist the loosening, disintegrating and destroying effect of a few alternations of frosts and thaws.

No road should be lifted unless it has been softened with rain, and there is plenty of water to finish the work of reformation. To lift and remake a road in dry summer weather should not be attempted. The work should be deferred to the later months of the year, but not too late, lest frosts should set in. Some engineers consider October the best month in the year for lifting a road, so that the material may be sifted and sorted when dry, and be consolidated in November and December.

It is, indeed, of great importance to avoid all extensive work on a road if there is any likelihood of frost, for the effect of a frost and then a subsequent thaw on macadam recently laid after it has been well watered and has just become consolidated, but is still saturated with rain, is not only to loosen it, but also to disintegrate the material.

Macadam thought that a road which had a sufficient thickness of stone but was out of order should not be repaired with new material, but by picking up the old stone and reforming the road with it.

He said:

"No addition of materials is to be brought upon a road unless, in any part of it, it be found that there is not a quantity of clean stone equal to 10 inches in thickness.

"The stone already in the road is to be loosened and broken up, so that no piece shall exceed 6 ounces in weight.

"The road is then to be laid as flat as possible. A rise of 3 inches from the center to the side is sufficient for a road 30 feet wide.

"The stones when loosened in the road are to be gathered off by means of a strong, heavy rake, with teeth $2\frac{1}{2}$ inches in length, to the side of the road and there broken, and on no account are stones to be broken on the road.

"When the great stones have been removed and none left in the road exceeding 6 ounces, the road is to be put in shape and a rake employed to smooth the surface, which will at the same time bring to the surface the remaining stone and will allow the dirt to go down.

"When the road is so prepared, the stone that has been broken by the side of the road is then to be carefully spread over on it. This is rather a nice operation and the future quality of the road will greatly depend on the manner in which it is performed. The stone must not be laid on in shovelfuls, but scattered over the surface, one shovel following another and spreading over a considerable space."

A little new macadam, however, mixed with the old, will considerably improve the surface of the road. The old material lifted with a pick, even if broken afresh, never has the sharp edges of new macadam, and much of it is too rounded to bind in the same effective manner as freshly-broken stone. Moreover, a great portion of the old macadam when lifted will be found to consist of material which has been reduced either to dust or to too small a size to be fit for subsequent use. This material ought to be rejected, or, if used, it should only be employed for binding purposes.

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