small at the upper end, and of medium size, or about 2½ to 2¾ inches square in the middle and lower portion. The dust and small particles pass through the meshes in the upper end, while the large fragments which issue out of the lower end of the cylinder, are returned to the machine to be broken again. The rest is suitable for road-covering without any further preparation. The proper speed of these machines is about 200 revolutions of the crank per minute. They are made of several sizes, requiring engines of 4 to 12 horse power, and their working capacity varies correspondingly from 3 to 7 cubic yards of broken stone per hour. The best size for breaking road material is one having a capacity to receive stones 8 to 9 inches thick and 14 to 15 inches wide.

Thickness of the Road-covering.

The thickness of the covering need not exceed 10 or 11 inches of well consolidated materials on a good road bed, for roads in cold climates subjected to the heaviest traffic. The French road engineers consider ten inches sufficient in France, upon the most important roads, and 6, 7, and 8 inches where the traffic is comparatively light. Macadam considered 10 inches of well compacted materials enough for very heavy traffic, and generally advocates less thickness than most English constructors. Six inches for the minimum and ten for the maximum thickness appear to have been his limits. In one instance he speaks of a road which "having been allowed to wear down to only three inches, this was found sufficient to prevent the water from penetrating, and thus to escape any injury from frost," and in another, states that "some new roads of six inches in depth were not at all affected by a very severe winter."

Applying the Road-covering.

The drainage of the road bed having been provided for by side-ditches, and if necessary by suitable cross-drains, an excavation is then made to the sub-grade for the reception of the road materials, sloping from the middle toward the sides the same as the finished road surface, the depth of the excavation being regulated by the thickness adopted for the covering. It would be well, especially in made ground to consolidate the bed by rollers, or by ramming.

A layer of broken stone three inches in thickness is then applied, care being taken, if dumped from carts or barrows, to spread it evenly with a rake. The road is then opened to travel in order that it may be compacted before the addition of more stone. This operation may be greatly hastened by rolling, beginning with the light and ending with the heavy roller. If the road bed be soft and yielding, whether naturally so at all times, or exceptionally so from recent rains, it may be necessary to omit using the heavy roller, for fear of forcing the bottom stone down into the soil.

Ruts must be carefully raked in as fast as they are formed. Experience has demonstrated that 3, or at most 4 inches of broken stone, is the greatest thickness that can be well compacted at one time.

The "Wings" of Country Roads.

As it will seldom be necessary, except near large towns and cities, to apply the broken stone over a greater width than 16 feet, pit gravel, or sandy or gravelly earth may be used for extending the layer over the "wings." This should be laid on and consolidated at the same time with the broken stone. When the lower layer shall have attained an even and tolerably well compacted surface, a second layer of stone not exceeding 3 inches in thickness, with gravel or earth on the wings, is then applied, and compacted by traffic and by rolling as before. The top layer is spread and consolidated in the same manner, but here the process of rolling should be prolonged, and an ample force of men should be kept constantly employed in filling in the ruts, and in removing lumps and elevations, so that the finished surface shall not only be hard and smooth, but accurately adjusted to the required gradients and transverse form. The roller should pass over every portion of the road surface from 40 to 60, or if necessary, even 100 times, and if the weather be dry the materials should be kept damp by sprinkling carts. A binding layer about 1 inch in thickness of gravel, or gravelly earth or hard pan, may be spread upon the top layer after it has become nearly consolidated, unless the character of the broken stone is such as to render this precaution unnecessary. When thoroughly consolidated, the finished road surface will not show any tendency to rise up and form a ridge in front of a 9 ton or 10 ton roller.

Telford Roads.

These roads—named after Thomas Telford, by whom they were first constructed in Great Britain—are made with layers of broken stone resting upon a sub-pavement of stone blocks. Fig. 33 shows a transverse half-section of a road 30 feet wide, with a Telford covering 16 feet wide along the middle, and gravel wings.

Telford's specifications for a roadway 30 feet wide were as follows: "Upon a level bed prepared for the road materials a *bottom course or layer of stones* is to be set by hand in the form of a close, firm pavement. The stones set in the middle of the road are to be seven inches in depth; at nine feet from the centre, five inches; at twelve from the centre, four inches; and at fifteen feet, three inches. They are to be set on their *broadest edges and lengthwise across the road,* and the breadth of the upper edge is not to exceed four inches in any case. All the irregularities of the upper part of the said pavement are to be broken off by the hammer, and all the interstices are to be filled with stone chips, firmly wedged or packed by hand with a light hammer, so that when the whole pavement is finished, there shall be a convexity of four inches in the breadth of fifteen feet from the centre.

"The middle eighteen feet of pavement is to be coated with hard stones to the depth of six inches. Four of these six inches are to be first put on and worked in by carriages and horses, care being taken to rake in the ruts until the surface becomes firm and consolidated, after which the remaining two inches are to be put on. The whole of this stone is to be broken into pieces as nearly cubical as possible, so that the largest piece, in its longest dimensions, may pass through a ring of two inches and a half inside diameter.

"The paved spaces on each side of the eighteen middle feet, are to be coated with broken stones, or well cleansed strong gravel, up to the footpath or other boundary of the road, so as to make the whole convexity of the road six inches from the centre to the sides of it. The whole of the materials are to be covered with a binding of an inch and a half in depth of good gravel, free from clay or earth."

The Telford Sub-pavement.

For the sub-pavement the stone may be of inferior quality, as it is not subjected to severe wear and tear; but the toughest and hardest materials should be used for the top layer of broken stone.

The only advantage gained by setting the sub-pavement on a level bed, and gaining the required convexity of cross section by placing the deeper stones in the middle of the roadway, is a saving of expense in allowing the use of small stones at the sides. A better drainage of the road bed would doubtless be secured by making it parallel to the finished road surface, as was done with the Telford roads constructed in the New York Central Park.

The advantages and disadvantages of the sub-pavement or "bottoming," which forms the characteristic difference between the Telford and the Macadam roads, have been the subject of lengthy discussion between the advocates of these two methods of road construction.

It is alleged against the Macadam roads, that in compressible soils like clay, the weight of loaded wagons forces the stones into the earth; that in wet weather the clay rises up into the voids between the stone fragments, and prevents a thorough consolidation of the road covering; that in high latitudes the extreme cold of winter breaks up the road; that after a thaw the surface is liable to be cut up into deep furrows by the wheels; that during a drought the ordinary traffic upon the road causes a constant movement and consequently excessive wear among the broken stones; that there will also be considerable movement and therefore wear and tear due to the elasticity of the road bed, which cannot

be entirely prevented by any ordinary thickness of broken stone alone; and finally that the Telford bottoming constitutes a thorough underdrain, and besides being a remedy for all these imputed defects, is less costly than its equivalent of broken stone, as substituted by Macadam.

On the other hand, it is claimed by the partisans of the Macadam system, that the evils complained of do not exist to the extent alleged; that suitable drainage will prevent them entirely; that between the loaded vehicles above and the stone pavement below, the broken stone wears away much more rapidly than if laid directly on the earth; and that generally a soft and elastic bottom is superior to a hard and unyielding one.

In constructing a road—whether a Telford or a Macadam—upon newly embanked earth, or any light soil that has not become thoroughly compacted, it is well to put the bottoming, or the lower course of broken stone, upon a layer of brushwood or fascines, in order that the settlement may be equalized as far as possible, and the formation of deep ruts prevented.

Rollers for compacting the road bed, before the bottoming is put down, and for consolidating the layers of broken stone, may of course be used in the same manner and with equal advantages upon Telford roads, or upon those where the covering is broken stone only, or gravel only.

Telford Sub-pavement, with Gravel and broken Stone on top.

In some localities there may be an abundance of stone, such as sandstone and the softer varieties of limestone and gneiss, which is entirely suitable for the Telford bottoming but does not possess the requisite hardness and toughness for the top layer of broken stone. In such cases after the bottoming is set, the road may be finished with three to four inches of good gravel surmounted by a top or surface layer of good broken stone; or, the broken stone if too costly, may be omitted altogether, and the surface finished with a second layer of good gravel, in the manner described for gravel roads.

Whenever it is necessary to use an inferior quality of stone for the sub-pavement, the method of gaining the requisite transverse convexity by setting the smaller stones on the wings should not be followed, lest the road covering should fail there before it becomes seriously impaired in the middle. This precaution is specially applicable in cases where the amount of traffic is so great that the entire width of the road is used more or less constantly.

Rubble-Stone Sub-foundation and Telford Pavement.

In soft ground it is very desirable that the foundation should possess sufficient firmness and unity of mass, to be able to resist any tendency to motion among the stones composing it, caused by the weight of passing vehicles, and the working up of the underlying soil into the interstices of the road covering. In order to secure this condition, a layer composed of rubble stones, varying in thickness from 3 to 5 inches, and in width and length from 8 to 18 inches, is sometimes placed upon the road bed as a foundation for the Telford sub-pavement. The stones are placed close together side by side flatwise, and rammed to their places, the interstices being afterwards filled in and leveled up with chips

and spalls. A thin layer of sand or gravel is then spread over the surface, and compacted by ramming or rolling. Upon the foundation thus prepared, the Telford pavement is set, and the road is then finished with broken stone or gravel in layers, after the manner already described.

Rubble-Stone Foundation without the Telford Pavement.

When the foundation is of rubble stones only, Fig. 38, it should, if the material is not too costly, have a depth of not less than one-half nor more than two-thirds of the entire

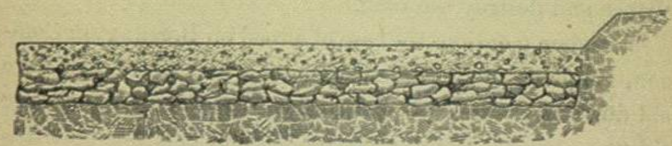

FIG. 38.

thickness of the road covering, whether the superstructure be of broken stone or gravel. For a total thickness of 10 inches of road covering, the rubble foundation may be from 6 to 7 inches thick, while 7 to 8 inches of rubble will not be too much for a road 12 inches thick.

The foundation should be constructed with great care, the larger stones being laid down first, side by side, flatwise upon the road bed, and firmly set to their places with rammers. The interstices are then filled in and leveled up with smaller stones, care being taken by selecting the pieces, to get them to fit as closely together as possible, and thereby to mutually sustain each other in place. The object is to use as much material as possible in a given thickness, so as to reduce the volume of voids to a minimum.

In placing the superstructure the first layer, whether it be broken stone or gravel, should not exceed 2 inches in thickness, and it should be thoroughly compacted by rollers and by traffic before another is applied, in order that it may penetrate and unite with the foundation, and become indeed a part of it, during the process of construction. Otherwise there will be a subsequent tendency to work down into the rubble work unequally, causing ruts and depressions in the road surface. Moreover, it is of great importance that the foundation itself should remain firm and intact, and that the least motion among its elementary parts should be avoided, lest the stones should, in process of time, work up to the surface and destroy the road.

Macadam mentions the case of a road on Breslington Common, England, in the construction of which flag stones were laid down over the entire road-bed, and the road covering laid upon them. Their constant motion, or the slight tilting up of one end whenever a heavily loaded vehicle passed over the other end, kept the surface in a loose and unsettled state. Eventually they were found canted up and standing on their edges, and it was necessary to reconstruct the road.

Any possible motion in the foundation should be scrupulously guarded against, as likely to prove fatal to the stability and durability of the road. Where there is any reason to apprehend trouble from this cause, and indeed when the closest supervision cannot be had over the work, it will be safer to set the stones on their edge as nearly as possible after Telford's method, even should they be greatly dissimilar in size and shape, for an opportunity is then afforded to wedge in between them with chips and spalls, so as to guard quite effectually against their subsequent displacement from the effects of moving loads. The stones may vary in thickness from

3 to 6 inches, in width or depth from 6 to 9 inches along the middle of the road, and in length from 8 to 18 inches, without rendering it difficult to form them systematically into a subpavement, greatly superior in firmness and stability to any mere rubble-work foundation. Even flat cobble stones can be used, mixed in with the irregular fragments. The plan of such a foundation is shown in Fig. 40, and a vertical section transversely to the line of the road in Fig. 39.

Fig. 39.

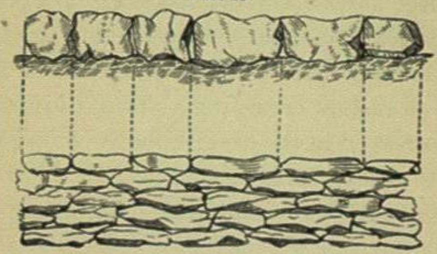

Fig. 40.

Concrete Foundation surmounted with Gravel or broken Stone.

In soft, wet and elastic soils, liable to more or less constant saturation with water, and especially in cuttings through clay banks, and in other localities where the side slopes are badly infested with springs, the difficulty in the way of securing firmness and stability in the road foundation is frequently of very serious character, in consequence of imperfect sub-drainage. Parnell instances the case of the Highgate-Archway Road, near London, located between banks of clay where the soil was surcharged with water. Many fruitless attempts to drain the road bed had been made, a large quantity of broken stone had been used in the first instance, and subsequently taken up and relaid on gorse, brush and pieces of refuse tin. It was found impossible to consolidate the broken stone. It mixed up with the clay, and rapidly wore round and smooth, and the road finally became nearly impassable. It was rebuilt under the direction of Sir John MacNeill in the following manner: A thorough system of sub-drainage was applied by making four longitudinal drains throughout the entire length of the road, with cross drains at intervals of 90 feet. Smaller drains were placed 30 feet apart. On the road bed thus prepared to a width of 18 feet, a foundation of concrete 6 inches thick was laid. The surface of the concrete was indented transversely by a series of shallow triangular grooves, formed by embedding strips of wood in the concrete before it had set. These grooves were about 4 inches apart, and had a fall of 3 inches from the centre of the road to the sides, in order that any water which might percolate through the broken stone covering, would be promptly carried off. After the concrete had set, the superstructure consisting of six inches of broken stone was laid upon it, the wings or sides being carried out to the side gutters with flint gravel. By this means a dry and firm foundation was secured for the broken stone, and all possibility of any displacement of the latter by mixing in with the clay subsoil, or by the action of frost, prevented. The result, as might have been expected, was a first rate road. The concrete used for the foundation was composed of 1 part of Roman cement, and 1 part of sand mixed together dry. Eight parts of broken stone was then incorporated, using as little water as possible. From these proportions it is evident that there was not enough mortar in the concrete to fill the voids in the broken stone, while there doubtless was sufficient to bind the ballast together firmly,

and resist the tendency to break up under the weight of loaded vehicles.

Concrete foundations, even if laid upon a level bed, should be finished on top with a slope from the centre to the sides, about the same as that given to the road surface, to facilitate the drainage of the top covering.

Foundation of Rubble-stone and Concrete.

Reference has been made to the difficulty experienced in wet and elastic sub-soils in keeping a foundation of rubble stones firm and intact, and in preventing the stones working up and finally destroying the road surface. A remedy for this evil is found in the judicious use of hydraulic concrete between the stones, as shown in Fig. 41. In founding by

FIG. 41.

this method, the largest stones and those most nearly approaching the form of cubical and rectangular blocks, should be laid down first, side by side, but not in close contact, each stone being firmly set to its place by ramming. Concrete, in which the ballast should be composed of stone fragments not exceeding ¾ inch in longest dimension, or of a mixture of such fragments and pebbles of all sizes up to ¾ inch diameter, is well tamped in between and around the stones and carried up to the general line of their top surfaces. If a thickness of 6 to 8 inches is secured in this manner by one course of stones, this will suffice, and the road may be finished in the usual manner with layers of broken stone or gravel.

A foundation of this kind is believed to be as firm and durable as one of the same thickness composed entirely of concrete, while it costs considerably less. Its top surface should slope from the centre to the sides, in order to carry off all the water which percolates through the top layer of stone or gravel, a condition which can be secured either by sloping the road bed, or by selecting the larger or deeper stones for the middle and gradually decreasing their depth toward the sides, thus giving a greater thickness of foundation in the centre than at the sides.

It is of capital importance, in a foundation of this description, that the stones should be of such shapes that when set in place their side surfaces will be nearly vertical, or rather will be as nearly perpendicular to the road surface as possible, so that the concrete, after setting, will hold them firmly together, and effectually prevent any upward or downward movement, especially the latter, which might take place if the stones are of unsuitable shape or improperly set, as shown in Fig. 42.

FIG. 42.

If the stones very generally, or a great portion of them, are thin and slab-like in form, they should be set with their two largest and opposite surfaces cross-wise of the road and perpendicular to the road-surface, showing in vertical

FIG. 43.

longitudinal section as in Fig. 43. The concrete will then

hold them firmly in place, even upon a wet and spongy road bed.

Shell Roads.

Upon the South Atlantic and the Gulf coasts of the United States, stone suitable for road coverings does not exist, and in most localities good coarse gravel or pebbles cannot be procured except at such an outlay for transportation as to practically exclude their employment for road construction. Oyster shells, however, can generally be had at from 4 to 5 cents per bushel, exclusive of land haulage, and when applied directly upon sandy soil, as a covering, 8 to 10 inches in thickness, they form an excellent road for pleasure driving or light traffic. They wear much more rapidly, of course, than broken stone or gravel of good quality, and require more constant supervision to keep them in good order. When properly maintained they possess most of the essential requisites of a good road.

Charcoal Roads.

The novel expedient of using charcoal for road coverings is not likely to be resorted to except in newly settled, heavily wooded districts, where the standing timber has no market value, and must be gotten rid of before the land can be devoted to agricultural pursuits. A case is mentioned in Michigan where a good road was made through a swampy forest in the following manner:

"Timber from six to eighteen inches through is cut twenty-four feet long, and piled up lengthwise in the centre of the road, about five feet high, being nine feet wide at the bottom and two at top, and then covered with straw and earth in the manner of coal pits. The earth required to 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