

THE  
INSTITUTION  
OF  
CIVIL ENGINEERS.

---

SESSION 1878-79.—PART IV.

---

SECT. I.—MINUTES OF PROCEEDINGS.

---

April 29, 1879.

JOHN FREDERIC BATEMAN, F.R.S.S.L.&E., President,  
in the Chair.

No. 1634.—“Street Carriageway Pavements.”—By GEORGE  
FREDERICK DEACON,<sup>1</sup> M. Inst. C.E.

As a branch of Civil Engineering street paving has never occupied a very high place. It is true that, when once the conditions of its maximum economy and efficiency are ascertained, exceptional skill is not required to put them into practice; but those conditions have rarely received at the hands of engineers the consideration in detail which they demand; and when the very high degree is duly appreciated, in which the welfare of the community is influenced by the method of paving adopted, it must be conceded that the divergent opinions and practice at present extant should at once be formulated and fairly compared. The Proceedings of the Institution have contained no discussion on the subject for many years. The Author therefore proposes to state his practice, and to tabulate its results in a manner which, if generally adopted, will remove much of the present difficulty of making accurate comparisons between the various classes of pavements and the different modes of constructing them.

The present Paper will be confined to Street Carriageways, and will exclude the consideration of such roads as form lines of communication between centres of population, or between

---

<sup>1</sup> The discussion upon this Paper was taken together with that upon the one following.

scattered rural dwellings and market towns, railway termini, or harbours. The former division of the subject of road making offers abundant matter for consideration in a single Paper, and the latter division has been ably dealt with by Mr. W. H. Wheeler,<sup>2</sup> M. Inst. C.E. Up to page 20 of this Paper the details and cost of construction of certain pavements will be given, and their relative advantages will then be generally considered.

### I.—CONSTRUCTION.

#### CARRIAGEWAYS OF HAMMER-DRESSED STONE, OR SET PAVEMENTS.

*Figure of Sets.*—Sets when properly secured in position and formed of the hardest stones are so durable, even under the heaviest traffic, that it is not worth while to make them more than from 6 to 7½ inches deep. Two depths are employed in Liverpool: the first for moderate traffic, averaging 6¼ inches; and the second for the heaviest traffic, averaging 7¼ inches. In relation to its other dimensions, a set should be of such depth that when the wheel of a heavy cart passes over one edge of its upper surface it should not tend to tip. The resultant direction of pressure of the load and adjoining sets should, in short, always tend to depress the whole set vertically. Where, as frequently happens, this precaution is neglected, the maintenance of a uniform surface is impossible. This consideration would lead *per se*, for sets of the above-mentioned depth, to a surface of 4 or 5 inches square. Sets of this figure remain comparatively stable, even on bad foundations and with defective joints. There are other influences, however, which lead to a modification of this form. It is desirable that the width of each set measured along the street should be small. If it is large, a horse drawing a heavy load attempting to find a joint slips back, and requires an exceptionally wide joint to pull him up. The wide joint induces increased wear of the upper corners of the sets, and increased noise.

In practice, the Author has found that, for all but the softer stones, upon which, even if there were no joints, horses could travel with facility, it is desirable that the widths of the sets should be such that four taken at random, and placed side by side, will not measure more than 14 inches across. As in this measurement the irregular projections of the sets are taken into account, the average

---

<sup>2</sup> "Roads and Highways; their history, construction, cost, repair, and management." By W. H. Wheeler, M. Inst. C.E. Journal of the Royal Agricultural Society of England, vol. xii., part 2, page 382. London, 1876.

surface width is less than 3 inches; and if with this width the surfaces are square, the number of longitudinal joints is so great that it is impossible for the paviors to break joint properly, and at the same time to keep the joints close, without much loss of time in selecting each set as it is placed. Two or more longitudinal joints in nearly the same line, or a single rather wide longitudinal joint, almost invariably initiates a groove.

The square form which, for stability, would otherwise have been the best, has therefore been altered in the Author's practice to an oblong of the width above stated, and of a length varying from 5 to 7 inches, which, when the set is fixed in position in the manner about to be described, is not found to be too great in relation to the depth to secure stability.

These conclusions may be summarised as follows:

*Hard stone, in which joints are necessary for foothold.*

	Depth.		Width.		Length.	
	Inches.	Inches.	Sets.	Inches.	Inches.	Inches.
Sets for moderate traffic .	6	to 6½	4	to 14	5	to 7
Sets for heaviest traffic .	7	„ 7½	4	„ 14	5	„ 7

*Softer stones, in which joints are unnecessary for foothold.*

	Depth.		Width.		Length.	
	Inches.	Inches.	Sets.	Inches.	Inches.	Inches.
Sets for light traffic or inclines	6	to 6½	3	to 14	5	to 7

*Materials of Sets.*—Among the igneous, plutonic, and metamorphic rocks are to be found a great variety of stones suitable for paving, of all degrees of hardness, brittleness, and toughness; but the durability under traffic, the tendency to wear round rather than flat and to become slippery, are dependent upon no conditions which can readily be foreseen. The size and distribution of the crystals, the nature and hardness of the constituent minerals, operate in such a manner that two opposite combinations often produce nearly the same result; while rocks of nearly equal hardness frequently behave very differently under traffic. The specific gravity, moreover, appears to afford no assistance in the determination.

The only sedimentary rocks which it is desirable to use for street pavements are some portions of the millstone grits and other more laminated grits of the coal measures, and the use of these should be confined to steep gradients and to streets of little traffic. Specimens of rocks used in Liverpool for paving are exhibited, and in the following table (page 4) are stated the localities from which

Locality from which Sets are obtained.	Description of Stone. <sup>1</sup>	Specific Gravity.	Behaviour under Traffic.
A. Penmaenmawr, Carnarvonshire (old quarry): sets from this quarry have not been laid in Liverpool since 1871 . . . . .	Very close-grained. { { { Quartz, felspar, hornblende } } }	2.75	{ More durable than any rock known to the Author, but becomes very slippery under traffic. Corners apt to wear round by chipping off.
B. Penmaenmawr, sets now used . . . . .	Close-grained. { { { Quartz, felspar, hornblende } } }	2.82	{ Very durable; suitable for the heaviest traffic in streets of moderate gradients. Corners apt to wear round by chipping off.
C. Port Nant, Carnarvonshire	Close-grained. { { { Quartz, felspar, hornblende } } }	2.70	{ Very durable; nearly as hard, and not so slippery, as B.
D. Yr Eifl, Llanelliarn, Carnarvonshire . . . . .	Close-grained. { { { Quartz, felspar, hornblende } } }	2.63	{ A very tough rock, nearly as hard, and not so slippery, as B. Corners not so apt to wear round. Suitable for the heaviest traffic in streets of moderate gradient.
E. Pistyll, Carnarvonshire	Close-grained. { { { Quartz, felspar, hornblende } } }	2.60	{ Wears similarly to C.
F. Llanbedrog, Carnarvonshire	Coarse-grained. { { { Felspar, quartz, hornblende } } }	2.53	{ Has not been long used in Liverpool. It is not slippery, and is moderately durable.
G. Festiniog, Carnarvonshire	Rather coarse-grained. { { { Felspar, quartz, hornblende } } }	2.59	{ Has not been long used in Liverpool. It is not slippery, and appears to be as nearly as durable as F.
H. Minford, Portmadoc, Carnarvonshire . . . . .	Close-grained. { { { Quartz, felspar, hornblende } } }	2.9	{ Free from slipperiness: harder than J, but in other respects similar.
J. Gimblet, Pwllheli, Carnarvonshire . . . . .	Rather coarse-grained. { { { Hornblende, felspar, quartz } } }	2.9	{ Not so hard as H; free from slipperiness, and wears to a very flat surface.
K. Newry, Ireland . . . . .	Coarse-grained. { { { Felspar, quartz, hornblende } } }	2.7	{ These are softer rocks than any of the foregoing; but where the cost is small, they are satisfactory for inclines, or streets of light traffic. They are not slippery.
L. Bessbrook, Ireland . . . . .	Coarse-grained. { { { Felspar, quartz, hornblende } } }	2.65	
M. Dalbeattie, Scotland . . . . .	Very coarse-grained. { { { Quartz, felspar, hornblende } } }	2.7	{ Softer than K and L; not slippery.
N. Ragbie, Creetown, Scotland	Coarse-grained. { { { Quartz, felspar, hornblende } } }	2.62	
O. Lancashire . . . . .	Millstone grit . . . . .	2.44	{ Only suitable for the lightest traffic. May be employed with advantage in streets of very steep gradient.

<sup>1</sup> The Author is indebted to Mr. Isaac Roberts, F.G.S., for the determination of the order of the relative volumes of the constituent minerals, in which order they are placed in the second column of the table.

they are obtained, their lithological characters, and their behaviour under traffic, so far as is known to the Author, when paved as described in this Paper.

*Mode of Jointing.*—Until 1871 the joints of Liverpool set pavements were simply filled with gravel, well worked down with a tool called a cramming iron. In many towns a grouting of hydraulic lime and gravel is brushed into the joints. The first method answers moderately well for streets of light traffic; the second binds the gravel to some extent, but in very few cases do the sets fail to work loose, and the grouting to become disintegrated, even if the vibration of the traffic, which is generally too soon turned upon the pavement, has ever allowed it to set firmly. Joints made according to the first method are always very pervious to water; those made by the second method are less so: but, owing to the fact that the grouting is almost always disintegrated, they are far from impervious.

In pavements of which the foundations are not of concrete, imperviousness is of the utmost importance; for where water can percolate to the substratum, that substratum is softened, and under continuous traffic portions of it work up through the joints, or press the sets upwards in places where the traffic is lighter. In either case hollows are formed. Unless a strong concrete foundation is employed, it is useless to attempt to make the joints impervious with a brittle material such as cement or lime; and so far as the Author is aware, the only thoroughly impervious joints under such circumstances have been formed with various asphaltic compositions. For more than thirty years the authorities of many towns in Lancashire and Yorkshire have made the joints of their pavements by first filling them with clean gravel, and then pouring in a boiling asphalt of pitch and creosote oil.

A crucial examination of many classes of pavements satisfied the Author, in 1871, that those jointed with asphalt retained their figures better, and wore out less rapidly, than any others. This method of jointing is often very indifferently performed; and, as it is scarcely known in the south of England, it may be useful to describe in detail the mode which experience has shown to be the best. The sets, which should be dry, are paved as closely as possible, having regard to the maintenance of each course in a straight line, upon whatever foundation may have been prepared for them. If upon a concrete foundation, about  $\frac{3}{4}$  inch of sharp sand is allowed to intervene between the pavement and the foundation.

When a considerable area is ready, it is covered with clean, dry,

and hard gravel, which has been passed through a  $\frac{3}{4}$ -inch riddle and rejected by a  $\frac{1}{4}$ -inch riddle. When this gravel has been well brushed into the joints, the sets are thoroughly rammed with the old-fashioned two-handled vertical rammer, which the rammer-man swings between his legs. The effect of this is to shake the gravel down, and cause it in most places to disappear; more gravel is then added, and the ramming repeated. After a third, if not after the second, gravelling and ramming, each set should be perfectly firm. The vibration of the ramming shakes the pebbles even into the narrowest spaces, where they act as most efficient wedges. The firmness of the pavement even at this stage is generally surprising to those who see it for the first time.

The asphalt is prepared in boilers on wheels. The large-sized boilers for making carriageways contain about 25 cwt. of asphalt, while the small sizes used for repairs contain from 5 to 10 cwt. The coal-tar pitch employed costs in Liverpool about 1s. 6d. per cwt. Care must be taken that it is not too brittle; foremen accustomed to the work can judge of this quality by biting it. Pitch, from which so much of the essential oil has been expelled as to make it brittle, and to raise its melting point too high, will never assume that permanently plastic condition, when boiled with oil, which is necessary to prevent subsequent cracking. The oil employed for softening the pitch is the impure carbolic acid or dead oil from the distillation of coal tar. It is known in the trade as creosote, or creosote oil, but is quite distinct from true creosote. It costs about 2½d. per gallon. About fifty gallons of creosote oil are required for every ton of pitch, but the exact quantity depends chiefly upon the quality of the pitch. During the process of boiling, the consistency of the asphalt is determined from time to time by cooling small portions in water and kneading it in the fingers.

The hot asphalt is drawn off into iron buckets, each containing rather less than 1 cwt. Each bucket is carried to the prepared pavement on a carrying bar between two men, and the contents ladled out. No attempt is made to run it into the joints without covering the whole surface. The asphalt penetrates the smallest interstices, and for many hours after the joints are apparently full it continues to sink until only a thin coating is left on the surface, with here and there a hole, which is filled from a small ladle. Lastly, the pavement is finished by covering it with small sharp gravel, which, with much of the remaining pitch, is subsequently squeezed into the joints by the traffic.

The cost per square yard in Liverpool of pavements laid as

above described, exclusive of the foundation and of excavation, is as follows:

*Impervious pavement with asphalt joints, as now laid in Liverpool.*

		s.	d.
0·31 ton	Stone sets, 7½ inches deep, including cartage, at 28s.	8	8
0·064 "	Gravel for bedding, ¾ inch thick . . . . .	6s. 6d.	0 5
0·015 "	Pitch . . . . .	30s.	0 5·25
0·6 gallon	Oil. . . . .	2½d.	0 1·5
0·002 ton	Coke . . . . .	12s.	0 0·25
0·018 "	Shingle, dried and riddled . . . . .	7s.	0 1·5
	Labour. . . . .		0 8·5
		10	6
	Add establishment expenses, 8 per cent. . . . .	0	10
	Total per square yard . . . . .	11	4

	s.	d.
Similar pavement with sets 6½ inches deep per square yard . . . . .	10	4

Pervious pavements with ordinary gravel joints as formerly laid in Liverpool (present prices per square yard):

	s.	d.
0·31 ton	Stone sets, 7½-inches deep, including cartage, at 28s.	8 8
0·096 "	Gravel for bedding, 1 inch thick . . . . .	6s. 6d. 0 7·5
0·02 "	" " joints . . . . .	6s. 0 1·5
	Labour . . . . .	0 5
		9 10
	Add establishment expenses, 8 per cent. . . . .	0 9
	Total per square yard . . . . .	10 7

	s.	d.
Similar pavement with sets 6½ inches deep per square yard . . . . .	9	6

# FOUNDATION.

It has already been stated that in 1871 the Author gave the preference to asphalt-jointed pavements. Prior to that time they had never been employed in Liverpool; and as the Liverpool traffic was probably heavier than that of any other town, it became necessary to consider whether, in addition to the change in the method of jointing, any alteration should be made in the foundations of the carriageways.

In the oldest Liverpool streets the sets had simply been paved upon an old macadamised surface, but in those more recently constructed, it had been usual to form foundations after the manner

adopted by Telford for highways, of which the wearing material was broken stone. Those foundations consisted of rough stones 10 or 12 inches long, set on end by hand to the proper curvature of the road. The tops of any projecting stones were broken off, and the hollows filled in with smaller stones and rolled. The traffic was then allowed to pass for several weeks before the pavement was laid.

	s.	d.
Present cost per yard of hand-pitched foundation, as	1	5
formerly adopted in Liverpool. . . . . }		
Add for establishment expenses, 8 per cent. . . . .	0	1.36
Total per square yard . . . . .	1	6.36

Apart from all other considerations, this method of forming the foundation was obviously undesirable, where it was necessary to reconstruct the pavements of existing streets, on account of the long time occupied in consolidation.

In Manchester, where the pavements were, on the whole, the most perfect the Author had seen in any of the towns examined, the sets were simply laid upon a well consolidated bed covered with cinders, and the impervious joints were trusted to prevent the unequal sinking so generally caused by water soaking into the foundations; but where heavy traffic constantly passed over the same lines, the sets did undoubtedly sink beneath those lines. The Author decided, therefore, that, for the heavier traffic at least, it was desirable to employ concrete foundations. Subsequently, asphalt-jointed pavements were tried, both with and without concrete foundations, with so marked an advantage in favour of the concrete that it has since been used in all except the quietest streets, and within the last six years about 200,000 superficial yards have been laid. The methods adopted have varied slightly from time to time, but experience has led for some years past to the following practice: The concrete employed is either Portland cement or bituminous concrete. Before reconstructing a carriageway for heavy traffic, parts of the existing foundation are exposed in many different places. If, as often happens, no part of this foundation is worth retaining, the ground is excavated to the proper depth for Portland cement concrete. If, as sometimes happens, either an old macadamised road, or an old hand-pitched foundation, is met with at a sufficient depth below the base of the proposed pavement, Portland cement concrete is still employed. If, on the other hand, the macadamised surface or the hand-pitching reaches in places close up to the pavement,



so that only a very thin stratum of concrete can be used without removing it, bituminous concrete, incapable of cracking, is used in preference to the comparatively brittle Portland cement concrete.

*Portland Cement Concrete Foundations.*—Where, as in the case of a carriageway foundation, a comparatively thin stratum of concrete is required, it is especially necessary that that stratum should be uniform in strength, or homogeneous, if the term can be properly applied to such a mixture. The most perfect concrete which the Author has produced is made as follows:

The ground on which the foundation is to be laid is first well watered; upon it is then scattered a layer of wet broken stone like coarse macadam; upon this layer is spread with the spade a thin stratum of cement mortar, and upon the mortar a further layer of wet broken stones. The upper layer of broken stones is then beaten into the lower layer with beaters like large spades, with straight handles 4 feet  $4\frac{1}{2}$  inches long and flat beaters of sheet iron about 12 inches square and  $\frac{1}{4}$  inch thick. Another stratum of mortar, followed by a third of stone, is then laid, and the beating process continued; and so on, until the required thickness is attained, when the surface is first beaten and then finished by rubbing with the beaters to the proper curvature of the carriageway. The surface is thus made as smooth and uniform as a plastered wall. By this method a complete but thin coating of mortar is left round every stone, and a maximum of strength is attained with a minimum of cement. When cut through, no sign of lamination is found. The mortar is composed of six parts by measure of gravel and one of Portland cement. The broken stones, measured separately, represent about eight parts, but when the whole is mixed and beaten together, the proportion of stones and gravel to set cement is as 11 to 1. This, however, includes the upper layer, in which there is more than the average proportion of mortar.

No cement is allowed to be used the tensile strength of which is less than 800 lbs. on a section of  $2\frac{1}{4}$  square inches, or which sets in less than three hours so firmly as to take no impression from a Vicat's needle, having an area of  $\frac{1}{100}$ th part of a square inch and a weight of  $2\frac{1}{2}$  lbs., or of which more than 10 per cent. is rejected by a 50-gauge sieve. Though seldom laid more than 6 inches in thickness, this concrete is so strong that when, for the purpose of laying new service pipes, or of reaching old ones, it has to be removed, it is simply cut out with a saw-pick, just as slabs of stone are quarried, in pieces about 3 feet square. When the excavation has been refilled and rammed, these blocks are relaid, cemented to the

old concrete, and paved upon at once. On the following day the traffic is allowed to pass over them, and no subsequent sinking has ever been known to take place—a striking contrast to the old system, in which the paving over trenches in streets of considerable traffic was generally relaid three times, and sometimes oftener.

The Author desires to lay great stress upon the homogeneity and strength of the concrete, which renders it possible to saw it out, and upon the smoothness and exact form of the surface, which not only insures uniformity of the subsequent paving, but guides the workmen in replacing cut out blocks.

Experience has shown that concrete, made in the manner described, should not be paved upon for at least eight days after being placed *in situ*. Eight days is a serious addition to the time during which part of a street must be closed for pavement, but in order to obtain the best result the inconvenience must be endured; moreover no real advantage is gained by paving one half at a time, and leaving less than one half open to traffic. It is impossible under such circumstances to do the work so well; it is impossible to do it so quickly; and the blocks which take place in the traffic create, in the Author's opinion, more inconvenience on the whole than if all the traffic sought from the first a different route. The most important thoroughfares in the greatest forwarding town in the world have been repaved with Portland cement concrete foundations within the last six years. The idea of closing them entirely was at first not contemplated, and when it was adopted many complaints were naturally made. Those who know the central 3 miles of Liverpool dock streets can well understand this; but it will be shown later on that the loss was rapidly recouped; and since the first few thousand yards of the new pavements were opened, warehouse owners and carriers have alike submitted, without complaint, to the temporary loss, for which they obtain so great a return.

Owing to the mode in which the broken stone is added, the quantity of concrete to be mixed on the boards is less by about 50 per cent. than under the ordinary system. Hitherto the work has been performed by hand, as follows: Each man stands before a board 4 feet square with three sides 8 inches high. The boards are placed in the segment of a circle, touching, or nearly touching, each other, with their open edges towards the centre. Behind and between every pair of boards is a frame of galvanised iron, supporting a galvanised iron cistern of about 3 cubic feet capacity. From each cistern project two

pipes, fitted with roses and taps, one over each board. Hinged to the back of each board is a box, having a capacity of  $1\frac{1}{2}$  cubic feet. This box has a strong handle, by which its contents may be readily tipped on to the board. Behind the boards are tipped the gravel and the cement. Suppose the boards to be lettered from A to G. Box A is filled from behind by the gravel man, then B, then C, and so on to G. Mixer A pulls over box A with his spade, and spreads out the gravel, over which the cement boy, who follows the gravel man from A to G, scatters the cement from a hemispherical vessel, containing  $\frac{1}{2}$  cubic foot. Mixer A then turns over his gravel and cement, until thoroughly incorporated. He next turns the tap on to a bare part of the board, and shovels over the mixture, scattering it among the spray. An experienced man will scatter the mixture at such a rate that when all turned over it will have exactly the required dampness. The tap is then turned off, and very little more labour is necessary to make the mixture perfectly uniform. By this time a cart or a barrow has arrived from board G. Having discharged the contents of his board, mixer A finds that the gravel man from G has already filled his box, which he pulls over as before, and the whole cycle of operations is repeated. It is obvious that close supervision of such a system is very easy.

One of the most important results effected by the process is perfect mixing with very little water. The concrete is only so far wetted that when squeezed forcibly in the hands a slight dampness appears on the surface. So small is the quantity of water used, that many persons accustomed to concrete mixing have remarked that the mortar will not set properly without more water. Concrete formed with mortar of this consistency can be beaten into a much more compact mass than when a larger proportion of water is used; it is much stronger, and can be formed to a more accurate figure at the surface.

In the earlier trials of this work in Liverpool, the concrete mixing was performed in the street. A carriageway, running for example north and south, having been closed, the excavation, commenced at the north end was proceeded with, at first by carting both northwards and southwards. When a sufficient opening was made the concreting was commenced at the northern end, the mixers being placed south of the concrete, and the materials for concrete south of the mixers. As the concreting progressed, the mixers were moved southwards. It was found to be impossible to mix so much concrete within the limits of the carriageway as could be laid *in*

*situ* in the same time, and the work was much impeded by the limited space.

In order to ascertain whether any mode of mixing at a short distance from the site could be devised which would not diminish the strength of the concrete owing to subsequent disturbance in laying, the Author tested carefully prepared samples of concrete, some moulded immediately after mixing, and others moulded, and thus disturbed, at different periods after mixing. In a modified degree the results had been anticipated; but the incorrectness of the prevalent opinion as to the effect of remixing was shown to be much greater than was expected, so far at least as concrete made with good slow-setting Portland cement was concerned.

A summary of the results of four hundred and eighteen experiments, both in compression and tension, which determine this question, are given in the following table (page 13).

Since the time when the first set of these experiments was made, concrete mixing in the street for which the concrete is destined has been abandoned, and any convenient yard or other place has been used, from which the concrete may be deposited within a moderate time after mixing. In the Author's opinion, the change has not diminished the strength of the concrete.

It is well known that fresh Portland cement is unfit for use, on account of the large quantity of uncombined lime it contains. If moulded in this condition the lime slakes while the cement is setting, and often breaks it up completely. To avoid this the cement must be thoroughly purged, that is, exposed to the atmosphere for a considerable time. By this means the lime is slaked to a sufficient extent to prevent any failure of the work from subsequent slaking. This action diminishes as the purging becomes more complete; but even in the best Portland cement after exposure to the air for an indefinite time there is rarely a diminution, though there is sometimes an increase of strength if allowed to stand fifteen or twenty minutes between the process of mixing and placing *in situ*. It is difficult to ascribe any cause for this, except on the hypothesis that even in the best purged cement there remain minute points of compression, scattered throughout the mass, and produced by minute particles of lime, which are slaked on the application of water. Whether or not this be the true explanation, the facts are indisputable, and have an important bearing upon many works in concrete.

The cost per superficial yard of Portland cement concrete

AVERAGES OF 418 TESTS OF PORTLAND CEMENT AND PORTLAND CEMENT CONCRETE, PLACED IN SITU AT VARIOUS INTERVALS OF TIME AFTER MIXING.

Number of Minutes between Mixing and Moulding . . .	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
Means of crushing strengths of 24 blocks, 5 parts river gravel, 1 part ce- ment; 1 cube foot each; tested 26 and 28 days after moulding. Tons per square foot . . . .	43.55	..	..	49.00	>50.00 <sup>1</sup>	..	48.58	..	47.07	..	45.15	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Ditto, ditto; 24 and 28 days after moulding. Tons per square foot . . . .	49.57	..	..	..	..	>50.00 <sup>1</sup>	..	..	>50.00 <sup>1</sup>	..	..	47.56	..	46.55	..	..	43.55	..	..	..	..	..	..	..	..
Means of tensile strengths of 240 2½-square-inch sections of pure cement, and Oporto gravel and cement varying from 1 to 1 to 4 to 1; pure ce- ment tested 7 days, con- crete 14 days, after moulding. Lbs. per 2½- square-inches . . . .	..	602	579	571	604	598	599	594	609	523	498	567	507	..	..	..	..	..	..	..	..	..	..	..	..
Means of tensile strengths of 144 2½-square-inch sections of pure cement, and Oporto gravel and cement varying from 1 to 1 to 5 to 1; pure ce- ment tested 7 days, con- crete 14 days, after moulding. Lbs. per 2½- square-inches . . . .	..	..	593	..	590	..	581	..	578	..	580	..	588	..	581	..	562	..	544	..	566	..	560	..	524

<sup>1</sup> 50 tons was the greatest compression capable of being applied by the machine employed.

foundations in Liverpool, 6 inches deep, constructed in the manner above described, is as follows :

		s.	d.
0·132 ton	Broken stones, including cartage, at 6s.	0	9·5
0·174 „	River Dee gravel „ „ „ 5s. 6d.	0	11·5
0·024 „	Portland cement „ „ „ 52s.	1	3
	Labour, mixing concrete . . . . .	0	3·25
	„ laying <i>in situ</i> , beating, and shaping . . . . .	0	2·75
		3	6
	Add for establishment expenses, 8 per cent. . . . .	0	3
	Total per square yard . . . . .	3	9

*Bituminous Concrete Foundations.*—The positions in which bituminous is preferred to cement concrete, have already been described. It is constructed in Liverpool as follows: On the hard but often irregular bed of the old foundation, previously well brushed, is thrown the required thickness of broken stone of the size of rough macadam. This is well levelled and rolled to the proper form, and over it is poured precisely the same asphaltic composition as that above described for making the joints of sets. The asphalt sinks to the bottom, and fills the smallest crevices between the stones. On the surface, while the asphalt is still warm, is laid a thin stratum of small broken stone, which is thoroughly rolled into the asphalt, and fills up the upper spaces between the larger stones. As in the process of rolling the soft asphalt rises between the smaller stones, still smaller riddlings are scattered over it, until a perfectly true and uniform surface is obtained. In a few hours this surface will bear any amount of ramming without distortion.

The cost per square yard of bituminous concrete foundations in Liverpool, 6 inches deep, is as follows :

		s.	d.
0·153 ton	Broken stones, including cartage, at 6s.	0	11
0·041 „	Pitch „ „ „ 30s.	1	3
1·2 gallon	Oil „ „ „ 2½d.	0	3
0·007 ton	Coke „ „ „ 12s.	0	1
	Labour . . . . .	0	9
		3	3
	Add for establishment expenses, 8 per cent. . . . .	0	3
	Total per square yard . . . . .	3	6

## CARRIAGEWAYS OF BITUMINOUS CONCRETE, OR ASPHALT MACADAM.

A pavement may be constructed precisely in the same manner as the bituminous concrete foundations above described. It is absolutely impervious to moisture, and in first cost less expensive, though by no means so durable as a stone pavement, or as a rock-asphalt pavement; but, nevertheless, it is sufficiently durable for the numerous back streets of a great town, in which facility of cleansing is of primary importance.

In constructing such pavements it is desirable that the upper layer of large stones should be of smaller size than is necessary for concrete, and that they should not be harder than limestone. The still smaller stones and riddlings should be similarly limited in hardness. The object of this proviso is that the asphalt between the stones may not wear down much more rapidly than the stones, and thus leave in time an uneven surface. The proper consistency of the asphalt is of even more importance than when it is simply used for joints. About 23,000 square yards have been laid in Liverpool, and on sanitary grounds the system will probably be extended annually over large numbers of back streets.

The cost per superficial yard of bituminous concrete pavements 6 inches deep, as constructed in Liverpool, is as follows :

	s.	d.
0·144 ton Broken stone and limestone chippings, including cartage, at 7s. 6d. . . . .	1	1
0·041 ton Pitch, including cartage, at 30s. . . . .	1	3
1·2 gallon Oil           "           "           " 2½d. . . . .	0	3
0·007 ton Coke           "           "           " 12s. . . . .	0	1
Labour . . . . .	0	10
	3	6
Add for establishment expenses, 8 per cent. . . . .	0	3
Total per square yard . . . . .	3	9

Bituminous concrete is usually prepared in other places by pouring coal tar over broken stones of the size of macadam and previously heated. The stones are then laid, and thoroughly rolled to the contour of the finished surface; after which about an inch of similarly prepared chippings, by preference limestone, is spread upon them and thoroughly rolled.

The Author tried this method in Liverpool, but subsequently obtained greater success by the first method described. In some Lancashire towns where the second method is employed, the surfaces appear generally to become disintegrated more

readily than those in Liverpool. Recently, however, he has examined some street carriageways laid in Derby by Mr. Clement Dunscombe, according to the second method, and they are among the best artificial asphalt pavements he has seen. As creosote oil cannot readily be obtained in all towns, and as tar can be obtained wherever gasworks exist, a knowledge of the details of Mr. Dunscombe's practice and experience would be of great service to the surveyors of provincial towns, even if it does not supersede the first method where creosote oil is cheap.

#### WOOD PAVEMENTS.

In Great Howard Street, Liverpool, where the traffic exceeds 3,300,000 tons annually, or 216,000 tons per yard width of carriageway, one of the most important hospitals in Liverpool is situated. Near all hospitals it is of course desirable to reduce the noise to a minimum. At first this was done by the use of macadam in the middle half of the carriageway; but the difficulty of maintaining it became so great, that in 1871 a set pavement was laid. In 1872 the Author recommended the substitution of timber. The northern half of the work, about 700 square yards, was accordingly paved in 1873 by the Improved Wood Pavement Company. The site having been excavated and levelled, boards of Baltic pine,  $1\frac{1}{4}$  inch thick, were laid diagonally upon 3 inches of sand, and upon these a second layer of similar boards was spiked. The blocks of wood were of Baltic pine, 6 inches deep, 7 inches and 8 inches long, and 3 inches wide. The ends were placed in contact, and a space of  $\frac{3}{4}$  inch was maintained between each row by a narrow strip of wood nailed to the planking. This space was subsequently caulked with gravel and a bituminous composition. The whole surface was finished with a coating of asphalt and gravel. This work was subject to very frequent repair, and was entirely relaid after four years' use. The defects were due chiefly to the absence of a proper foundation, for though the blocks had worn down from 2 to  $2\frac{1}{2}$  inches during the four years, they would, if properly held in position, have lasted some time longer. The Author declined to recommend the further trial of wood in this place unless laid upon a good bed of concrete. Accordingly, in 1877, a pavement, the surface of which was similar to that employed in the first instance, was laid upon a bed of bituminous concrete, constructed as already described, and underlying the plank foundation.

The southern half of the work, about 700 square yards, was also laid in 1873, by different contractors, on a material which was dignified with the name of concrete. The blocks were of Baltic pine,



grouted with Portland cement mortar, a material quite unsuited for use in combination with wood. Notwithstanding the consolidating action to which for years the ground had been subjected, the lines of heaviest traffic soon showed signs of sinking, while the adjoining blocks were pressed upwards; and after ten months' use the pavement became dangerous, and was entirely relaid on the same system, at the contractors' risk. This pavement had to be removed in twelve months, when a wood pavement similar to that originally laid on the northern half was substituted. The pavement shows very plainly the want of a concrete foundation.

In 1874 the pavement of Bold Street, 4,250 superficial yards, was laid by the Improved Wood Pavement Company, in a manner precisely similar to the northern half of the Great Howard Street work. It is a shop street, with a traffic consisting chiefly of carriages, amounting to about 94,000 tons per annum per yard in width; but even here the want of a concrete foundation soon became manifest, though on the whole the pavement has worn, with moderate uniformity, to the extent of about  $\frac{3}{8}$  of an inch in four years.

When it became desirable to continue wood pavement along the upper part of Church Street, the Author accordingly recommended a bituminous concrete foundation,  $3\frac{1}{2}$  inches thick, which was laid under his direction in 1878. Upon this the Henson Street Paving Company laid their pavement, which consisted simply of pine blocks from Soroka, 3 inches by 6 inches by 9 inches long, separated only by a single thickness of tarred felt, a layer of which was also placed between the foundation and the blocks. A transverse V groove, 1 inch wide, was cut by the contractors in a row of blocks at every 12 inches, ostensibly with the object of preventing horses from slipping. Owing no doubt to the nature of the foundation, this pavement has retained its original form better than any wood pavement the Author has seen.

The Author has not hitherto required the surface blocks of wood pavement to be creosoted, but they have always been selected with the greatest care. The foundation boards when used have been creosoted with not less than 10 lbs. per cubic foot.

In order to maintain a wood pavement in good condition it is necessary to scatter fine sharp siliceous gravel over it from time to time. This operation adds considerably to the cost of maintenance, but, if properly done, it prevents slipperiness; and if not overdone, the little angular pieces become so firmly embedded in the fibres of the wood that they are prevented from rolling, and are gradually worn away on one side only.

[1878-79. N.S.]

C

The first costs of the wood pavements most recently laid in Liverpool have been as follows :

*Cost of Wood Pavements per superficial yard.*

	s.	d.
Improved wood pavement, as laid in Great Howard Street, in 1877, including double plank foundation . . . . .	16	0
Improved wood pavement, as laid in Bold Street, including double plank foundation . . . . .	15	3
Henson's wood pavement, as laid in Church Street, including bituminous concrete foundation 3½ inches deep . . . . .	15	10

It is scarcely just to wood pavement, however, to compare these figures with those previously given for other classes of pavement. In the case of the wood pavements, the work was executed by London companies ; in the case of the other pavements, by the workmen of the Corporation ; and the 8 per cent. allowed in the latter case for establishment expenses, would inadequately represent the additional cost necessarily involved in the contract work.

With Liverpool prices at the present time, the actual cost per square yard of wood pavement, with blocks 6 inches deep and bituminous concrete foundation, would be as follows :

	s.	d.
Bituminous concrete . . . . .	2	0
Creosoted Baltic pine blocks, pitch grouting, and gravel, including labour . . . . .	12	0
	14	0
Add for establishment expenses, 8 per cent. . . . .	1	1½
Total . . . . .	15	1½

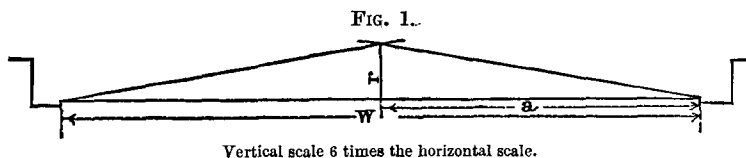
**MACADAMISED CARRIAGEWAYS.**

There are no thoroughfares near the centre of Liverpool, and but few in the outskirts, which are still paved with macadam. The cost of maintaining macadamised carriageways where the traffic is great is so much in excess of the cost of maintaining set pavements ; the dirt in wet weather, and the dust in dry weather, are so objectionable ; and the quantity of detritus washed from them into the sewers is so large, that for many years they have been abandoned except for a few leading carriage thoroughfares to the outskirts. The proper construction of the substratum of macadamised roads is well known, but not always followed. Much difference of opinion exists, however, as to the best mode of finishing or blinding the surface. The Author has tried many methods. Under a 15-ton steam roller, preceded by a watering cart, 1,200 yards of trap-rock macadam, without blinding, can only be moderately consolidated by twenty-seven hours' continuous rolling.

If blinded with hard rock chippings from a stone breaker the same area may be moderately consolidated by the same roller in eighteen hours. If blinded with siliceous gravel from  $\frac{3}{4}$  inch to the size of a pin's head, mixed with about one-fourth part of macadam sweepings obtained in wet weather, the area may be thoroughly consolidated in nine hours. Macadam laid according to the last method wears better than that laid by the second, and that laid by the second much better than that laid by the first.

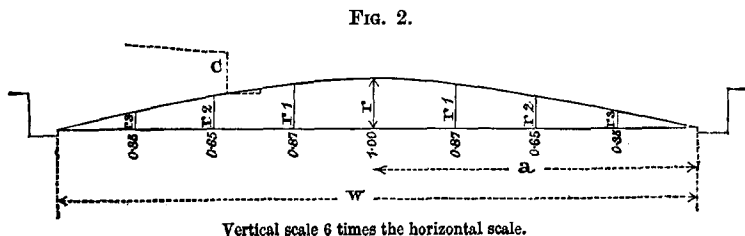
#### CONTOUR OF CROSS-SECTION.

For the purposes of traffic, and traffic alone, the best form of cross-section for a carriageway would be a level line, as any cross-fall produces friction, additional traction, and wear and tear of horse and vehicle. But for the rapid discharge of rainfall a cross-fall is necessary. The problem is therefore to design the section in such a manner that the water shall be properly discharged with the least possible maximum fall. Suppose the least desirable inclination to be known, if this were adopted as the maximum inclination also, the profile shown with an exaggerated vertical scale in Fig. 1 would be obtained. This profile would be



objectionable on the ground of appearance, and because the breasting would tend to wear hollow.

Having due regard, however, to these considerations, the figure should approximate as nearly as possible to two straight lines, meeting at the vertex of the carriageway. If the vertex is slightly rounded, and the breasting still more slightly rounded, a profile is obtained approximating to a hyperbola, as in Fig. 2,



and differing widely from the segment of a circle too often adopted, in which the crown is very level and the breasting unnecessarily inclined.

Let  $a$  = the horizontal distance from the vertex to the lowest channel in feet.

Let  $r$  = the rise of the vertex above the lowest channel in feet.

„  $d$  = the difference of the levels of the two channels in feet.

„  $w$  = the width between the channels in feet.

For well made impervious pavements

$$r = \frac{a}{36}$$

When there is a cross-fall from channel to channel, the crown or vertex of the pavement is generally placed too near the centre, and an unnecessary fall on the lower side is involved. In order that the inclination of the pavement on the two sides of the vertex may be the same, it is necessary to include only that portion of the curve in Fig. 2 which lies between the two channels, when the upper channel is placed in such a position  $c$  that the known ratio  $\frac{w}{d}$  is maintained. If  $\frac{w}{d} = 36$ , the figure of the carriageway is half the above figure. If  $\frac{w}{d}$  is greater than 36, the figure of the carriageway is greater than one-half of the above figure, and the fall is towards both channels. If  $\frac{w}{d}$  is less than 36, the figure is less than half the above figure, and the fall is wholly towards the lower channel.

The height  $r_1$  above the chord line, of a point at the distance  $\frac{a}{4}$  from the vertex, should be  $0.87 r$ .

The height  $r_2$  above the chord line, of a point at the distance  $\frac{a}{2}$  from the vertex, should be  $0.65 r$ .

The height  $r_3$  above the chord line, of a point at the distance  $\frac{3a}{4}$  from the vertex, should be  $0.35 r$ .

In order to apply these deductions to practice the curve in Fig. 2 should be drawn to a large scale for reference. For pavements without cross-fall the full curve is to be included. For pavements with cross-fall the upper channel  $c$  is to be so placed on the curve that  $\frac{w}{d}$  in the street is equal to  $\frac{w}{d}$  in the figure, and only

the portion of the curve between *c* and the lower channel is to be taken.

It is thus a very simple matter to set out the cross-section of any pavement to the proper curve, when the width between the channels and the difference of their levels are known; and if, in fixing the heights, foremen were always instructed to follow such simple rules, the minimum friction arising from lateral pressure in vehicles, consistent with proper water-discharging power of the pavement, would be attained. The fact that these objects are not always sought must be the Author's excuse for bringing such simple matters before the Institution.

Having so designed the cross-section of a carriageway, that without unduly increasing the traction, and wear and tear of vehicles owing to lateral pressure, water runs from it to the channels with maximum efficiency, it is important to consider the best mode of conveying that water to the sewer gullies. The best channels are heavy blocks of hard rock 12 to 18 inches wide, with at least one natural and perfectly smooth face. The slabs should be set upon concrete, with close dressed joints filled with asphalt, and with a fall of  $\frac{1}{4}$  inch per foot towards the curb, and not, as is sometimes done, with the same, comparatively great fall, as the breasting of the pavement, which tends to throw the wheels of vehicles against the curb. The lower edge of the pavement should be about  $\frac{3}{8}$  inch higher than the upper edge of the channel. If constructed in this manner a longitudinal fall of 1 in 200 is sufficient to discharge the water rapidly.

## II. COMPARATIVE ADVANTAGES OF VARIOUS CLASSES OF PAVEMENTS.

Much has from time to time been written on the relative advantages of various classes of pavements; but the elements necessary to make the statements comparable have always, so far as the Author is aware, been absent. Light traffic, and much oftener heavy traffic, is spoken of; but the heavy traffic is often so called because a few times in the year a heavy boiler or piece of machinery is drawn over it; and, in another case, because the carriageway is crowded with Hansom cabs and other light vehicles. The Author has endeavoured to formulate the question in such a manner that the results may be generally applied.

With reference to the traffic, the knowledge of three easily ascertained facts is necessary:

- (a) The tonnage passing over the carriageway in twelve months.
- (b) The width of the carriageway.

(c) The number of wheels on which the twelve months' traffic is borne.

Then  $\frac{a}{b}$  = the weight of traffic per yard of width, and  $\frac{a}{c}$  = the number of tons per wheel, giving a fair relative knowledge of the average kind of traffic in various streets.

With respect to the wear of a pavement, the following course should be adopted. If stone sets are in question, one or two rows of sets, the full width of the carriageway, should be taken up and weighed. They should then be carefully replaced, so as to be perfectly flush with the surrounding pavement, and at the end of twelve months again weighed. If the material is wood the exact measurement of a number of sets is sufficient. In addition to the information thus obtained, a street ledger should be kept, giving at a glance the cost per square yard of maintaining every pavement for each year. If, in writing of the relative durability of various pavements, this information were given, an immense amount of experience might be rendered generally available. Without some such information, any statements made can be little more than the opinion of individuals based upon impressions with respect to the traffic, which are by no means always correct.

About 300,000 square yards of stone pavement, constructed as described at pages 2 to 9, have been laid within the last six years, in streets of varying traffic in Liverpool, up to 360,000 tons per yard width per annum, and an average of 0·923 of a ton per wheel including empties—two figures which, taken together, are probably not surpassed, if indeed they are equalled, by any other traffic in the world.<sup>1</sup>

The old pavements in streets of such traffic were generally of the hardest and most durable stone (A and B in the Table page 4), and the foundations, as already stated, of hand pitching; nevertheless, the pavements cost about 3d. per square yard per annum to maintain, and they were never in good condition. The hard stone sets B and C, paved on concrete, and with impervious joints, remain in excellent condition. The oldest of these pavements, constructed in 1872, though subjected to a traffic of 218,000 tons per annum per yard of width, and a mean load of 0·679 ton per wheel including empties, have hitherto cost nothing to maintain beyond the occasional filling up of joints with asphalt, and the restoring

---

<sup>1</sup> The traffic given is that in the dock line of streets. In the average load of 0·923 ton per wheel, empties and light traffic are included.

of a few sets, not worn, but split and crushed by loads of 60 tons on four wheels.

The rate of wear under the greatest traffic has not exceeded 0·02 of an inch of solid stone per annum, except at junctions of streets and some other places, where very hard stones were avoided in order to prevent slipperiness.

Under a smaller traffic the macadam opposite the hospital in Great Howard Street cost 3s. 6d. per yard per annum to maintain, and would now cost 4s. 8d.; and in the same place wood costs the Corporation, including gravelling, 1s. 11d. per annum to maintain. The greater part of this is, however, paid to the Company for maintenance, and really therefore includes a sinking fund.

These figures serve to show generally the great divergence in the cost of maintenance; but they do not include cleansing, the figures relating to which are still more favourable to the asphalt-jointed pavements. But a much more correct idea of the total difference of cost may be gathered from the following table (see page 24), in which first cost, renewal, and maintenance are all duly considered.

If the standard of traffic be taken at 40,000 instead of 100,000 tons per annum for every yard in width of carriageway, the figures for the last three pavements are as follows:

Description of Pavement.	Original Cost per Square Yard at present Prices.	Deductions from First Cost to determine Cost of Renewal.		Interest on Original Cost at 4 per Cent. per Square Yard per Annum.	Sinking Fund Invested at 3 per Cent. Compound Interest.	Maintenance per Square Yard per Annum.	Scavenging <sup>1</sup> per Square Yard per Annum.	Gravelling per Square Yard per Annum.	Total Annual Cost per Square Yard.
		Cost of Foundation requiring Renewal.	Allowance for old Materials at Date of Renewal.						
No. 6. Bituminous concrete pavement . . .	s. d. 3 9	s. d. Nil	s. d. Nil	d. 2·0	d. Nil	s. d. 0 9	d. 2·4	d. ..	s. d. 1 1·4
No. 7. Wood pavement . . .	15 1·5	2 0	Nil	7·5	4·3	0 1·0	2·7	5·0	1 8·5
No. 8. Macadam pavement . . .	6 9	Nil	Nil	3·4	Nil	1 0	8·0	Nil	1 11·4

<sup>1</sup> For the figures relating to the cost of scavenging, the Author is indebted to Mr. R. S. Reynolds, M.R.C.V.S., who, as chief of the scavenging department in Liverpool, has given great attention to the subject.

While discussing the other comparative advantages of various classes of pavements, the total annual cost as shown by the foregoing Table should be borne in mind.

TABLE SHOWING THE TOTAL COSTS OF VARIOUS PAVEMENTS.

In this Table the cost of Maintenance and Scavenging are reduced to a standard traffic of 100,000 tons per annum for every yard in width of the carriageway. It is assumed that the work is done by the Corporation, and 8 per cent. of the cost of both labour and materials is included for establishment expenses.

Description of Pavement.	Original Cost per Square Yard at present Prices.		Deductions from First Cost to determine Cost of Renewal.				Interest on Original per Square Yard per Annum.		Sinking Fund Invested at 3 per Cent. Compound Interest.		Maintenance per Square Yard per Annum.		Scavenging per Square Yard per Annum.		Gravelling per Square Yard per Annum.		Total Annual Cost per Square Yard.		Remarks.	
	s.	d.	Cost of foundation not requiring renewal.	s.	d.	Allowance for old materials at Date of Renewal.	s.	d.	d.	d.	s.	d.	d.	d.	s.	d.				
No. 1. Sets 7½ inches deep. Class of stone A, B. Gravel joints. Hand-pitched foundation.	12	1	1	6	3	0	6	5	1	8	0	1	0	4	2	Nil	1	1	5	Old Liverpool pavements.
No. 2. Sets 7½ inches deep. Class of stone B, C, D, E, F. Asphalt joints. Portland cement concrete foundation.	15	1	3	9	3	0	8	2	0	6	0	0	25	2	4	Nil	0	11	45	Pavement now constructed in Liverpool for heavy traffic.
No. 3. Sets 7½ inches deep. Class of stone B, C, D, E, F. Asphalt joints. Bituminous concrete foundation.	14	10	3	6	3	0	8	0	0	6	0	0	25	2	4	Nil	0	11	25	Ditto ditto.
No. 4. Sets 7½ inches deep. Class of stone G, H, J, K, L, M, N. Asphalt joints. Portland cement concrete foundation.	15	1	3	9	3	0	8	2	3	7	0	0	5	2	4	Nil	1	2	8	Pavement now constructed in Liverpool for light traffic, or steep gradients, and junctions of streets.
No. 5. Sets 7½ inches deep. Class of stone G, H, J, K, L, M, N. Asphalt joints. Bituminous concrete foundation.	14	10	3	6	3	0	8	0	3	7	0	0	5	2	4	Nil	1	2	6	Ditto ditto.
No. 6. Bituminous concrete pavement . . . . .	3	9	Nil	Nil	Nil	Nil	2	0	Nil	1	6	0	0	2	4	Nil	1	10	4	Pavement recently employed in Liverpool for back streets, and for street carriageways of very light traffic.
No. 7. Wood pavement, blocks 6 inches deep. Bituminous concrete foundation.	15	1	2	0	Nil	Nil	7	5	10	1	0	1	0	2	7	5	2	2	3	Creosoted wood pavement, if constructed by Corporation.
No. 8. Macadam pavement, hand-pitched foundation . . . . .	6	9	Nil	Nil	Nil	Nil	3	4	Nil	2	0	0	0	8	0	Nil	2	11	4	Now only employed in Liverpool for suburban roads.



*Pavement No. 1.*—In this old form of Liverpool pavement the hard sets of the class A and B, when subjected to slow and heavy traffic, were invariably after a few years pushed from the vertical line, by the backward pressure of the horses' feet, through a considerable angle often as large as  $25^{\circ}$ . As the sets on the two sides of the street were pressed in opposite directions, a wave-line was assumed by each course. Instead of the whole upper surface of each set being duly presented to the wheels, each surface was therefore inclined, and the wear was confined chiefly to the upper edges. The effect of this in the production of noise may be readily conceived; but as such pavements, though cheaper in first cost, are shown by the foregoing table to be more expensive than the best class of hard stone pavements, Nos. 2 and 3, it is unnecessary to refer to them further.

*Pavements Nos. 2 and 3.*—These pavements are now exclusively employed for the straight lines of heavy traffic in Liverpool, where the gradients are moderate, and the sets maintain the positions in which they are originally placed. For some time after the asphalt has worn off the surface, the noise caused by traffic is considerable, and horses appear much more liable to slip than at subsequent periods. The noise is due to the irregularities of the surface; and the slipping, though on first thoughts it may appear anomalous, is due to the same cause.

*Cæteris paribus*, a horse is less liable to slip upon a level unpolished surface with narrow joints, 3 inches apart, than upon the irregular surface of new hard stone sets. This may be partly due to the greater traction and partly to the uncertainty with which the horse feels the ground. In the North John Street pavement, the first of the class in question laid in Liverpool, this fact has been very obvious. For the first year of its life the pavement was strongly objected to by the carters on account of the slipperiness; but in this, as in all other cases, the complaints ceased when the larger projections had worn off. Owing, however, to the original existence of those projections, and owing also to the fact that many arrises are unduly broken off, the sets do not wear to so uniform a level as they undoubtedly would if the upper surfaces were better formed in the first instance. With the harder trap rocks and syenites the Author believes that a more perfect pavement for heavy traffic than has yet been produced could be formed, if the upper surface of each set were roughly but uniformly dressed. The present method of wearing down the projections by the rolling contact of wheels in street traffic is certainly not an economical method; and if the smoothing were done at the quarries the objections which obtain to

the use of such sets in many places, owing to the noise, and liability to slipping which they at first cause, would be in a great measure removed. The time required to wear down such projections, when the sets are properly held in position, may be judged from the fact that in North John Street almost every other set still shows hollows which originally existed in the surface, and which the wear of a total traffic in six-and-half years of about 1,417,000 tons for every yard in width has not yet reached. The difficulty of sufficiently dressing one surface of such sets by hand is no doubt very great; but the design of a machine for the purpose is well worthy of attention. The problem must not be confounded with that involved in the dressing of any ordinary rock, even the hardest used in building, or even with that of dressing granite for paving purposes.

*Pavements Nos. 4 and 5* have been employed in Liverpool for light quick traffic, or where the gradient is too great for pavements Nos. 2 and 3, and at the junctions of streets where, in turning corners, horses are more liable to slip. Each stone classed under this and the last head has its own peculiarities, which are explained, so far as possible, in the table at page 4. They all wear much more rapidly than those of the last class, but some of them, while absolutely free from slipperiness, wear flat, and retain their arrises. On this account they are remarkably suitable for quick traffic, and produce but little noise. The stones in this class wear so readily to a uniform surface, that it would not be worth while to dress their surfaces as is suggested in the last case.

*Pavements Nos. 2 to 5 inclusive* may be classed together with regard to cleanliness and traction. They are easily cleansed, and the result of a single sweeping is most satisfactory. They are remarkably free from dust in dry weather, and from mud in wet weather.

Some years ago, the Author considered the desirability of testing the traction on various pavements by a dynamometer; but subsequent observation convinced him that such a course would only give misleading results. The work capable of being performed by a horse in drawing a load is dependent, not only upon the absolute power required to move the load at a certain speed, but also, and in a high degree, upon the uniformity of the resistance, and upon the ease with which the horse travels—depending again upon the uniform roughness, if the term may be applied, without such irregularities as cause uncertainty in feeling the ground.

The Author decided, therefore, to draw his conclusions from a broader basis; and, fortunately, the actual increase of work performed on the new pavements is so great, that there is no difficulty

in doing this. It appears that in those lines of traffic in which pavements Nos. 2 to 5 inclusive have been substituted for pavement No. 1, the ordinary load of two horses has been increased by about 1 ton, and of one horse by about  $\frac{1}{2}$  ton. There is a general impression also that the speed even of the heavy cartage has been increased; if from no other cause, this is probably owing to the comparative absence of blocks in the traffic, for the speed of the quicker traffic is undoubtedly increased, and for a given traffic any given area of pavement is less crowded than before. The cost of maintaining vehicles is also stated to have been much reduced. It is difficult, however, to arrive at any absolute figures for the saving in wear and tear of horses and carts; but from the above data, taking the actual cartage rate of 1s. 6d. per ton, there is a saving in cost of cartage alone exceeding £10,000 a year for every mile of such a pavement as is now laid in the dock line of streets in Liverpool. This estimate can only be approximate; but the Author is satisfied that if the wear and tear of horses and carts could be included, the £10,000 per mile would be found to be considerably less than the actual measure of the benefit, apart from cleanliness and reduction of noise and cost of maintenance, which the public derive from comparatively perfect pavements. In the streets of quick traffic the actual loads conveyed may not be greater, but there is certainly a reduction in the wear and tear of horses and vehicles, and an increase of speed.

The Author has in this Paper devoted much attention to the consideration of pavements for streets of heavy traffic, as he is satisfied that in most of the great forwarding towns such pavements have received too little attention. It is no uncommon thing to find in the heart of the heaviest traffic of large towns, both in this country and abroad, pavements constructed of boulders, or of sets so indifferently laid as to move under every passing wheel. The older pavements of Liverpool were indeed excellent as compared with many elsewhere. If the authorities of such towns took a broad view of the subject, they would at once see the great loss to the trade of the country in general, and of their own towns in particular, which the continuance of such pavements causes.

In connection with pavements for heavy traffic, the use of stone tramways,<sup>1</sup> such as those employed on London Bridge, has often been advocated. With the pavement No. 1, as formerly constructed in Liverpool, tramways of perfectly smooth Penmaenmawr rock have

---

<sup>1</sup> Called in some towns "wheelers," with as much reason as stones to be broken for macadam are called "breakers."

been largely used. The stones were 12 to 18 inches wide, and were appreciated by the carters; though, owing to the limited width of the carriageways, the number of standing carts, and the varying rates of the vehicles, constant diversions from the line took place. This inconvenience is not, of course, felt to the same extent on a bridge.

When the impervious asphalt-jointed pavements were introduced, stone tramways were in some cases again employed; but it soon became obvious that they were no longer appreciated; and it was by no means uncommon to see the horse walking on the tramway stones drawing a load with wheels on the sets. The difference in traction was, in short, no longer perceptible. Replies to inquiries made of the Liverpool Cartowners' Association, and other large carriers, have supported this view, and tramways have been discontinued in all ordinary cases. Stone tramways are the outcome of defective pavements. Under heavy traffic they are exceedingly difficult to maintain in a stable position. They induce exceptional traffic on the sets adjoining them, and therefore cause grooves to be formed. In crowded streets, even on bad pavements, their utility is but slight; while on good pavements they are worse than useless.

*Pavement No. 6*, of bituminous concrete, is shown by the table to cost ultimately 1s. 10·4d. per yard for a traffic of 100,000 tons per yard of width. This is considerably more than stone set pavements, when laid in the best manner. It is not, however, suitable for streets of greater traffic than about 40,000 tons per yard of width per annum; and in such a street the annual cost of maintenance of bituminous concrete is so much more reduced than that of the stone pavements, that the prices become about equal, as is shown by the second table (see page 23), where the standard traffic is taken at 40,000 tons per yard of width per annum. In every town, whether great or small, there are many streets of dwelling-houses through which only the local traffic passes, and for such cases this pavement is admirably adapted. Wheels make as little noise upon it as upon rock asphalt, and horses' shoes make less; while it is moderately easy to cleanse.

*Rock Asphalt Pavements.*—In 1871 the Author investigated the subject of the Val de Travers and other rock asphalts. If it had been possible to adopt asphalt pavements for any considerable section of the Liverpool streets, there can be little doubt that the system would have been commenced. Moderately level streets exist in Liverpool running north and south, but nearly all those running east and west have inclinations, upon which such pave-

ments would be undesirable. Rock asphalt pavements have therefore not even been tried in Liverpool. It is to be hoped, however, that the experience of metropolitan engineers will enable a comparison between rock asphalt and other pavements to be made in the course of the discussion on this Paper, on the principle adopted in the Tables on pages 23 and 24.

No. 7, *Wood Pavement*.—To a number of energetic companies the successful introduction of wood pavement into this country is due. The stimulus given by the existence, or, in some cases, the fancied existence of several patents has initiated a work which, under other circumstances, would probably have been long delayed. Beyond a keen and useful competition, however, the patented inventions have not, as a rule, produced any special advantages, and the best forms of wood pavement are now probably open to any one to construct. This being the case, the Author has at pages 23 and 24 taken the cost of wood pavements, if constructed like the stone pavements of Liverpool by the Corporation. Even under these conditions it is clear that wood pavements must be regarded as luxuries when compared with the best stone pavements, though for traffics approaching or exceeding 40,000 tons per yard of width per annum they are less costly than macadam. Wood pavement, however, has not, in the Author's opinion, been yet constructed in the best manner. When first introduced into this country, it was thought necessary to provide foot-hold for horses by keeping the blocks from  $\frac{1}{2}$  an inch to 1 inch apart. The consequence was, that the fibres being spread by the traffic, absorbed impurities and wore away unduly. Experience has shown, however, that a close-jointed wood pavement, properly gravelled, is not more slippery than a wide-jointed wood pavement also properly gravelled. In the former the fibres cannot spread, and the little grains of quartz are much more firmly held in position than in the latter. Nor does it appear that creosoting makes the blocks when properly gravelled more slippery.

Wood pavements having wide joints, or imperfectly laid upon yielding foundations, have properly been objected to on sanitary grounds; but between these and close-jointed pavements upon concrete foundations there is a wide distinction; and although creosote is of little use where the fibres are liable to spread, it would greatly diminish absorption if applied to the extent of 12 to 14 lbs. per cubic foot, where the joints are close and where the fibres cannot spread. Under the most favourable conditions, however, wood pavement cannot be so efficiently washed, or otherwise cleansed, as asphalt-jointed sets, or rock asphalt, though

in this as in all other respects it is to be preferred to ordinary gravel-jointed stone-set pavements or macadam.

No. 8, *Macadamised Carriageways*.—Of all pavements macadam appears to the Author the least satisfactory for street carriageways in which the traffic exceeds about 30,000 tons per yard of width per annum. It is the most costly, the dirtiest, and, on the average of all kinds of weather and all conditions of repair, probably involves a greater traction for a given load than any of the other systems when thoroughly well laid. Its dirtiness consists, not only in the excessive mud of wet weather, and the excessive and impure dust of dry weather, but also in the facility with which organic impurities are absorbed by it, decomposed within it, and exhaled to the atmosphere. In country, and in some suburban roads the extent of this objection is insignificant, and no other pavement is better than well maintained macadam; but in some of the carriageways of the west end of London one would regard it as intolerable, had it not been tolerated so long. To the unsophisticated provincial the manner in which, on a hot July day, fashionable London rolls over her tainted macadam pavements, apparently without even smelling them, is a mystery almost as great as surrounds the fact that the metropolis, alone among the great centres of civilisation in this country if not in the world, still submits with apparent satisfaction to an intermittent water supply, impure at times in almost every household, however pure the source of that supply may be, when with absolute pecuniary benefit a constant supply might be obtained.

---