

No. 1,379.—“The Applications of Asphalt.” By ERNEST CHABRIER, Civil Engineer, Paris. (Translated by W. H. DELANO, Assoc. Inst. C.E.)

EARLY STUDIES.

THE nature of asphalt was first seriously discussed in a report by M. Leon Malo, C.E., published in the *Annales des Ponts et Chaussées* in 1861.¹ This report, written after the author had resided for several years at the mines of Seyssel, in the capacity of manager and superintendent, passed through several editions, and latterly formed the basis of a volume, published in Paris, in 1866, which is the only complete work on the subject.

Following the precedent of M. Malo, the word “asphalt” will be used to designate bituminous limestone, although scientific men regard asphalt as being synonymous with the matter impregnating the limestone, viz., bitumen.

Asphalt is pure carbonate of lime naturally impregnated with bitumen in very variable proportions; but which for road-making should be limited to between 7 and 12 per cent. It is found in beds, frequently of great extent, for the most part of a lenticular shape, from 23 to 26 feet in thickness, and sometimes separated by other beds of entirely white limestone, the nature of which seems to be the same as that of the limestone impregnated with bitumen. It takes an irregular fracture, without definite cleavage. The texture and grain vary with the layers. The grain should be regular and homogeneous, not too close. Exposed to the atmosphere, asphalt gradually assumes a grey, almost a white tint, caused by the bitumen evaporating from the surface and leaving a film of limestone.

HISTORY.

In a pamphlet published in 1721, a Greek professor, Eirini d'Eyrinys, mentions the discovery he had made, ten years before, in the Val de Travers, canton Neufchatel, of a mine of asphalt similar to the beds of that substance existing in the valley of

¹ *Vide* 4^e Série, 1^{er} semestre, tome 1, p. 69.

Siddim, near Babylon.¹ He enumerates at length the advantages of this substance; regarding it as a panacea for human ills, and at the same time as a substitute for mortar in buildings. He states that its employment as cement is antediluvian, and in support of his assertion cites the Book of Genesis, ch. vi., v. 14, where in relation to Noah's Ark it is stated, "and shalt pitch (asphalt) it, within and without with pitch (asphalt);" and, again, ch. xi., v. 3, "and slime (asphalt) had they for mortar." He does not hesitate to attribute the historical resistance of the Babylonian buildings to the employment, as mortar, of asphalt from the valley of Siddim; and asserts that the walls of the famous hanging gardens of Babylon were coated with asphaltic mastic, and that the Tower of Babel itself would not have held together without this substance.

The use of asphaltic mastic tends to justify these somewhat enthusiastic hypotheses, and it is difficult to explain why no trace of its employment should be found amongst the western nations. The details given by D'Eyrins on the curative properties of "asphaltic balm," both for men and for animals, are very curious, but less interesting than the advantages claimed for the use, in buildings, of asphaltic mastic, which he calls natural cement. He cites, with a thorough conviction of its success, instances of works carried out with it, as cisterns, jointing of paving stones and flags, coating of terraces, &c. It would, however, appear that his successors in the working of the Val de Travers mine contented themselves with extracting asphalt for medicinal purposes, disregarding its merits as a material for paving, though this was afterwards destined to be its principal application.

Until the end of the century only the extraction of bitumen was thought of, as is proved by the concession made by the French Directory in the year V. of the Republic (1797), to a man named Secretan, of all the country situated between Seyssel and Bellegarde, a tract of about 14 miles in length by $1\frac{1}{2}$ mile in width on both banks of the Rhone. Secretan had certainly no other object than to extract the bitumen from the bituminous earth and sandstone, from which it is more easily separated than from the limestone, as is proved by the state of the works at that time; consequently when, later, the employment of asphaltic mastic and the quarrying of the bituminous limestone began to increase, many disputes arose as to the terms of the concession. It was claimed that no right to quarry the limestone existed; the word "mine"

¹ "Dissertation sur l'Asphalte, ou Ciment Naturel." 8vo. Paris.

was even disputed, only open workings were allowed. A lawsuit was the result, and it was not until 1845 that the question was resolved by a decision of the Council of State, which maintained to the concessionary the title of mine, and the right to extract limestone and bitumen, notwithstanding the contrary opinion of the minister. In 1834 M. de Puvis, in the "*Annales des Mines*,"¹ furnished particulars of what was being done at Pymont for the manufacture of asphaltic mastic. Without entering into a subject so new, and without inviting his colleagues in other parts of France to the discovery of similar seams, the author simply gave expression to his doubts, and noticed the heavy expenses of starting works. He recorded, however, the confidence which was already felt in the results of the asphaltic mastic footpaths of the Morand Bridge at Lyons, though the price of bitumen was at that time 800 francs (£31 15s.) per ton, whereas the price is now 300 francs (£11 18s.) per ton, and the mastic which was then sold at 140 francs (£5 11s.) per ton is now sold at 70 francs (£2 15s. 6d.) per ton. However slowly the natural cement of Eirini d'Eyrins came into general use, the results were such that engineers did not fail to notice them, and to aid in the development of such remarkable qualities; but speculators intervened, and led the public into acts of folly. As soon as the first footpaths were made, it was maintained that all towns would be paved with this new material.

The first, and perhaps the only inquiry by an engineer at that time into the subject of asphalt then appeared, but it referred to mastic instead of bituminous limestone. Analysis proved the composition to be limestone and bitumen, and this enabled an imitation to be produced. A panic then ensued, which led to the breaking up of the asphalt companies. The remnants of these various undertakings did not agree to amalgamate their interests until the formation, in 1855, of the General Asphalt Company, the management of which being confided to a civil engineer, led to the engagement of another civil engineer, M. Malo, as manager of the mines at Pymont. By prudence, in spite of low prices, which the successive opening of railways alone made bearable, operations were begun, and from that moment must be dated the regular development of the asphalt industry.

Mechanical apparatus superseded manual labour; the rock was quarried according to the most approved rules of mining, instead of being simply dug where it cropped up. The primitive method

¹ *Vide 3^e Série*, tome 6, p. 179.

of mixing the mastic in small open cauldrons, and thus subjecting for weeks the inhabitants and the luxurious portions of the city to its noisome fumes, was abandoned, and means were found of transporting the mastic hot and ready mixed to the work, so that it could be applied at once. Besides these modifications, particular attention was paid to the process, then quite new, of applying compressed asphalt, which allowed of the employment of the bituminous limestone in its natural state without admixture.

A trial on a small scale had been made in Paris in 1854, under M. Vaudry, then roadway engineer; and another on a more important scale was made at the expense of the Company in the square in front of the Palais Royal in 1858. At this time the Rue St. Honoré had a traffic of thirteen thousand one-horse vehicles daily, upon a width of roadway of 8 mètres (26 feet). The result was satisfactory, and the municipality decided to reserve, for this mode of paving, the streets comprised between the Madeleine and the Halles Centrales along the Rue de Rivoli. Machinery was prepared in proportion to the needs of the experiment, but the scheme was nearly jeopardised by the necessity of completing all the subterranean works of drainage, &c., before the asphalt was laid down. Thus the asphalt was applied upon soil recently disturbed to the depth of 10 feet to 12 feet. This induced instability of the subsoil, involving the breaking up of the layer of asphalt, 2 inches thick, which could not resist the subsidence of the foundation. Profiting by the experience thus gained, engineers in London insisted upon a thick layer of concrete for a foundation, which served to consolidate the soil.

GEOLOGICAL HISTORY OF ASPHALT.

The geological phenomena which produced asphalt have been little studied by men of science. The first theory is that bituminous vapours, meeting seams of limestone under favourable conditions of pressure and temperature, have penetrated the stone and become condensed therein. The examination of the beds would seem to negative this theory. Seams of limestone separate seams of asphalt, which limestone, though of the same nature as that containing the asphalt, is unimpregnated with bitumen. The contact of the two seams is clearly defined, and there is no exudation. Besides, the seams are never more impregnated in the middle than on the outside; rather the contrary.

Another hypothesis is based upon the often-demonstrated existence of bituminous springs under lakes. It has been supposed

that periods of deposition may have occurred under such conditions, that the molecules of limestone in suspension in the water have become mixed with the elements of bitumen; and that fortuitous circumstances caused the bitumen to fail. There would then be precipitated a white sediment, which would become impregnated on the return of the bituminous emanations: but when the repulsion which bitumen bears to damp substances is considered (simply wetting the fingers permits of its being touched without its adhering to them), there is little ground for belief in the existence of sufficient affinity between bitumen and limestone to support this theory.

Lastly, a Swiss geologist attributes the formation of asphalt to the presence of banks of the oyster called "*Caprotine*," capable of existing in deep seas. These animals, crushed by some convulsion of nature, afforded the bitumen said to be produced by all animal matter under certain conditions, as well as, in their shells, the limestone by which it was absorbed.

EXTRACTION.

Bitumen is widely distributed in nature, but bituminous limestone is rare; indeed it has not been much sought after. The seams best known, which up to the present have supplied the demand for asphalt, are those of Seyssel and Val de Travers, both worked in the same manner on the surface, or in galleries, according to the position of the seams compared with the surface soil. Asphalt is quarried like limestone, with the advantage that the mine-holes can be made with an awl, and the stuff itself used for tamping.

PULVERISATION.

Asphalt blocks must be pulverised before being used, and for this operation several processes have been tried.

1. Decrepitation, or breaking-up, takes advantage of the peculiar quality asphalt possesses of fusing, by the softening of the bitumen which holds together the limestone molecules. In the early stages of this process the asphalt was placed on heated iron plates called 'decrepitators'; but the stuff was spoiled by overheating, and by the bitumen being evaporated, so that the plan was abandoned.

2. At Seyssel, where the rock is harder, the decrepitators were replaced by crushing mills, which at an ordinary temperature produced a powder sifting well, but at a high temperature caused the rock to become sticky, and the mill to clog.

3. At the Val de Travers mines it was not possible to use crushing mills, or edge-runners revolving in a circular trough, on account of the nature of the rock; for they soon became covered with a layer of compressed asphalt, which had to be removed with a hammer and chisel.

4. With the extended use of asphalt all existing means for supplying the necessary quantity proved insufficient. Recourse was then had to plain rollers, which laminated the asphalt in thin sheets. The application of a little heat caused these sheets to fall to powder.

5. But the greatest improvement was the employment of Carr's disintegrator, first used by the Compagnie Générale des Asphaltes about 1867.

Asphalt reduced to powder admits of two distinct modes of application, viz., as compressed asphalt, which is obtained by heating the powder up to from 212° to 250° Fahrenheit, and causing the molecules to cohere under strong pressure; and as liquid asphalt, or asphaltic mastic, for which a manufacturing process is necessary. Then by heating the powder with an addition of from 5 to 8 per cent. of free bitumen, the latter causes the asphalt to melt, and gives a peculiar mastic which must be remelted before being employed. Although the introduction of compressed asphalt is of later date than asphaltic mastic, it will be described first, because the process is simpler, and is effected without the admixture of other matters.

II.—COMPRESSED ASPHALT.

The application of rock-asphalt to the construction of roads resulted from observing a fact of daily occurrence in asphalt mines. The detritus detached from the lumps of asphaltic rock, when crushed by the wheels of the carts employed on the works, forms on frequented roads a crust of superposed layers of compressed asphalt; but this effect is long in production, and only takes place in summer. In order to investigate this property of asphalt of reintegrating itself into blocks by compression, a series of experiments was undertaken, which proved that a certain degree of heat was required to render agglomeration easy. To effect this the apparatus for reducing the rock to powder was first employed, viz., the decrepitor, of boiler-plate slightly bowed out, placed above a fire-grate. The powder was spread over the plate, and frequently stirred. By this plan a careless workman might easily spoil a large portion of the material by overheating. Besides, the

powder when shovelled out lost heat rapidly. To mitigate these evils an apparatus analogous to a coffee-roaster was designed, viz., a closed cylinder slowly turning over a fire. The grate was movable, so that it might be replaced by a cart when the heating was complete. This apparatus, worked by suitable gearing, was fed at the axis end, and discharged the material by a trap in the circumference. Among the various attempts at preparing the powder, one was made of using steam. Blocks of asphalt inclosed in a cylinder were brought to the desired degree of heat by being subjected to a jet of steam from a portable engine. As soon as condensation ceased, the jet was turned off, the cylinder was emptied, and the blocks broken up. The powder thus produced was however spread with difficulty and irregularly; the rammers at times encountered parts thoroughly pulverised, at others refractory lumps requiring a much greater effort to make them into a level surface. Hence resulted inequality in the work; moreover, it was feared that the rock being impregnated by watery vapour might prevent the cohesion of the molecules.

The manner of spreading the powder over the soil previous to compression has varied considerably since works in asphalt became of importance. At first, when the rock was brought on to the ground like macadam, and decrepitated or comminuted on the spot, the small quantities of heated powder thus obtained necessitated the employment of rulers, which were placed across the street about 3 feet 3 inches to 5 feet apart, and limited the spreading or laying out of each batch. The powder within these boundaries was dressed down by hand with a wooden gauge. When, latterly, the heated powder was deposited from closed boxes with double sides, the guides were placed longitudinally in the street, so that it could be brought close to the work and used at once. These sections, spaced longitudinally at distances of 3 feet apart, required corresponding joints, which, although constituting a crucial test of the work, always stood well. At length it was found that asphalt cooled very slowly, and could be therefore allowed to remain for a considerable time in an open cart without inconvenience, and hence the use of gauges was abandoned; the workmen got into the habit of spreading the stuff with a rake to the required thickness completely across the street, and only made a joint where the work ceased for the day. To insure an equal thickness and regularity of the material, workmen skilled in the use of the rake were required. A mechanical rake, or spreader, which, whilst laying out the powder, would leave it at the proper thickness, is still a desideratum.

COMPRESSION BY THE RAMMER.

Compression is effected either by rammers or by a roller. The employment of rammers had been impeded in the first instance by a tendency of the powder to adhere to the metal of which they were constructed and to agglomerate on it; their surfaces were planed without success; at last the difficulty was obviated by heating the rammers, when adherence ceased.

STEAM RAMMER.

The difficulty of relying upon even ramming, on account of the variation in the muscular efforts of the workmen, induced a persistent research for compression by mechanical means. Tolerable results were obtained as long as the work was done in narrow transverse strips, the compression being effected by a steam hammer moving on rails; but this ingenious system could not be applied to large works unless rails or rulers were laid beforehand.

The use of a roller was suggested by its constant employment in the construction of asphalt roads; but, besides the difficulty of draught, the powder was driven before it. Adhesion was prevented by covering the powder with a cloth, over which the roller was worked. As this system was not available for large surfaces, it was necessary to reduce considerably the weight of the roller, also to suspend to the axles a basket of live coal to prevent adherence and the displacement of the powder. The principal advantage of this plan was the regular compression obtainable without the employment of skilled labour. It would be well to complete the compression by means of a steam roller; the plan is simple, and will be necessitated by the extension of this kind of work. After ramming, and previous to the cooling down of the material, compression was generally equalised by a heavy roller. This operation was easy when rails were employed, as then the roller could not penetrate beyond a certain depth, but it became less so when the spreading of the material was continuous. Going too early on the still hot surface of the compressed powder with the heavy roller causes it to fly and tears it. Latterly, a roller composed of several sections placed on the same axle has been tried with success. When the surface containing an excess of heat mounts the narrow spaces between the different sections of the roller, just as it is displaced by the passage of a carriage, the surface is crossed and recrossed by the roller.

Compressed asphalt is the best roadway for bridges, on account

of its lightness, only a thickness of a few inches being required. With asphalt for a roadway there is no noise, no jarring of carriages, no street mud, and consequently no dust. Being impermeable, it does not absorb organic matters, the decomposition of which is so noxious to the public health of large towns; and in this respect it is better suited for narrow and damp streets than for wide thoroughfares, to which it has hitherto been specially devoted.

EARLY APPLICATIONS OF COMPRESSED ASPHALT.

In 1858, three sides of the Palais Royal, Paris, comprising an area of 3,000 square mètres (3,588 square yards), were laid with compressed asphalt. The material was brought to the site in the state of rock crushed into small pieces, and was heated and powdered by decrepitators; the concrete was 5·9 inches thick, the asphalt was 2·4 inches thick in the Rue St. Honoré and the Rue de Richelieu, and 2 inches in the Rue de Valois.

In order to overcome the hesitation of the city engineers, the company was obliged to propose a combination of payments by annuities, which were to include maintenance. The entire expense to the town of Paris was fixed at 20 francs per square mètre (say 13s. 3d. per square yard), payable by annuities of 4 francs during five years.

Success was complete in spite of an unpropitious season; and in the following year the engineers proposed that the Rue des Petits Champs should be paved in the same manner. This street had to be repaved for its entire length of more than 1,000 yards, on account of the construction of a large drain; but the circumstance was unfortunate. The street had been occupied by drainage works in the fine weather; and it was not until the month of October that the roadway could be begun, and then on a soil newly filled in to a depth of 10 to 13 feet. A bed of concrete only 4 inches thick was laid down, on which was superposed a layer of 2 inches of asphalt. The work was carried on during the months of November and December in rain and snow; and the street was opened for traffic on the 1st of January. Cracks immediately appeared, which completely checked the further extension of asphalt roadways. However, the experiment in the Palais Royal continued to give the best results; and as the same materials had been used, it became evident that the true causes of failure were the settling of the soil and the constant wet during the process of laying. Repairs were undertaken of each damaged

part in succession, and at the return of the fine weather all the evil had been remedied. The chief engineer in charge of the roadways declared this trial more satisfactory than the previous one, inasmuch as it proved that the material could be repaired extensively without stopping the traffic of the street. This work, which was carried out without any special conditions, was paid for at the rate of 15 francs the square mètre (say 10s. per square yard), including the concrete, estimated at 2 francs (1s. 7d.). This price was to serve as a basis for future proposals for repairing streets; and the examination of the plans by the engineers of the town of Paris was required by the Prefect. Despite the fact of the first experiment having been made on a loose subsoil, the company shortly afterwards received orders to repave on the same system the Rues Richer and Petites Ecuries, in which the construction of sewers had necessitated such deep cuttings that several foundations had settled, and the houses had to be rebuilt. Unusual precautions were taken to consolidate the soil. The disintegration of the asphalt had thus been much less than in the case of the Rue des Petits Champs; but repairs were more frequent than in other places where the foundation was solid.

Compressed asphalt, amongst other asphalts, was likewise laid down in the Rue Buffon, near the Museum of Natural History. In this case the asphalt rock was comminuted by means of steam.

About the year 1865, the engineers proposed to substitute compressed asphalt for granite sets to the extent of 100,000 square mètres (24·7 acres), to be executed in three years and paid for in five years. This work was begun in 1867, and was arrested in course of execution by the war of 1870. Here trials were first made with other rock than the Val de Travers, which had hitherto been exclusively used for compressed work. Seyssel rock was laid down on that part of the Rue de Richelieu comprised between the Boulevard and the Bourse, one of the busiest streets in Paris, and has answered perfectly. As in other roadways, the concrete was 4 inches thick and the asphalt 2 inches thick. The use of pure Seyssel rock was continued at the Place Louvois and the streets adjacent, with the same success.

Besides replacing granite sets, asphalt has been used to form crossings for foot passengers, in bands from 10 to 15 feet wide. Sometimes the asphalt is applied directly upon the hard macadam, sometimes upon prepared concrete. The crossings are paid for at the same rate as the larger surfaces, only an extra sum is allowed for repairs at the points of contact with the flints, where the wear and tear is much greater than that of ordinary asphalted roads.

In some places mixed roadways, composed of macadam in the middle and asphalt at each side, have been introduced. The point of contact with the rough stones is found to be perfectly supported by the asphalt edge, and the wheel traffic has no deleterious effect. This has been carried out in the Rue Royale, Boulevard de Sebastopol, Cours de Vincennes, and the Avenue de la Grande Armée, in Paris; and at Brussels the same system has been employed in the new boulevard of La Senne, only in the latter place granite pitching replaces macadam.

Compressed asphalt, moreover, has been successfully applied for courtyards and the interior of houses, where the thickness need not exceed $1\frac{1}{2}$ inch, as the duration appears to be unlimited. In Paris, the courtyards of the Grand Hôtel, the Hôtel de Louvre, the new Opera House, and of a large number of private establishments, amongst others, the Jockey Club and the Rue Scribe, are thus treated; and horses never stumble in such instances, for the asphalt is always kept clean.

The only objection that has ever been made against asphalt roads is that horses slip, and this reproach is only relative. In point of fact, asphalt is much less slippery than stone or granite, but its surface, being without joints, offers no resistance when a horse stumbles. How little slippery asphalt really is may be noticed after the washing effected by heavy rain. The fine dust deposited from the atmosphere, mixed with the staling of horses, gets spread over the surface by the street sweepers. It adheres closely to the asphalt as long as dry weather lasts, and cannot be removed by brooms. Essentially hygrometrical, it will absorb as much as ten times its volume of water. Therefore under the influence of the slightest humidity it begins to swell, and the thin pellicle is solved into a layer of greasy mud, which interposed between the horses' shoes and the asphalt, causes slipping. A simple precautionary measure is all that is needed, viz., to wash the asphalted surfaces every morning during wet or damp weather. The principal cause of slipping would thus disappear, and with it a good deal of prejudice against asphalt.

WEAR AND TEAR.

The effect produced by wear and tear on asphalt is so trivial, that asphalt might almost be said to be imperishable, so long as no other cause than the friction of wheels occurs to alter its working conditions. On asphalted crossings in macadamised roads the wear and tear is rapid. In a few years the original thickness

of $2\frac{1}{2}$ inches is reduced to $1\frac{1}{2}$ inch, and finally to $\frac{1}{2}$ inch; but in streets of ordinary circulation the annual wear and tear is inappreciable. This is evidently owing to the malleability of this body, which yields under a heavy load without being crushed.

Disintegration results most frequently from a singular phenomenon. After the asphalt has been laid and subjected to traffic for a short time, fissures appear on the surface, in places forming an endless network. Eventually the horses' hoofs remove small pieces, leaving holes. The reason of this is that parts perfectly good on the surface are fissured underneath, and that the fissures form nodules. No satisfactory explanation of this fact has been given. Greenish tints, found in fissures over earth blackened by gaseous emanations, have induced the belief that escaping coal gas was the cause; but chemical action would tend to pulverisation and not to nodulation; moreover, the effect is produced on parts free from such escapes of gas. This appearance is mostly noticed in work carried out during wet weather. When powder heated to 260° to 300° Fahr. is spread on a damp surface, steam is generated, which would permeate the whole if compression did not cause cohesion of the molecules on the surface, and force the watery vapour to localise itself, dividing the asphalt only to a height proportionate to the amount of humidity in the soil and the rapidity of the compression. The surface is always well compressed; and where the upper layer joins the nodulated part it is distended by the steam. This is the only cause of disintegration which can escape the eye of the engineer, and it can be avoided by care in laying.

The other causes which may be traced to deficient aggregation of the molecules are discovered either during the work or by the first vehicle which crosses the road. Deficient aggregation may arise from two circumstances; either the powder is too cold when employed, or it has been overheated. Overheating asphalt renders it as inert as sand. Another cause of deterioration, though rare, is the use of asphaltic rock too rich in bitumen. When this is the case, the compressed asphalt forms waves underneath the wheels of vehicles, sometimes longitudinal with the footways, at other times transversely thereto.

MAINTENANCE.

The maintenance of asphalted roadways has engrossed the attention of engineers since asphalt has been substituted for granite. The advantages of asphalt as regards simplicity of application, cleanliness and facility of cleansing, pleasing ap-

pearance, and in many cases prime cost, are patent. Time and extended use alone can show whether this kind of road will last longer and be less costly than granite.

In Paris compressed asphalt had to compare with macadam and other systems of paving in stone, porphyry, granite, red sandstone, flags, cubes, &c. The advantage of less cost for repairs over macadam was incontestable. As regards paving stones, the difference was much less marked. A single estimate would scarcely suffice; but, the authorities of Paris alone possessing the data for making the calculation of the cost of maintenance of paving stones, it was necessary to proceed by induction. About twenty years ago the average maintenance of granite causeways was about 50 centimes the square mètre (4*d.* per square yard). The traffic having trebled, the needs of the public having increased, and the materials employed costing more, it was thought reasonable to ask double this price for a system offering so many advantages over paving stones; thus the Compagnie Général des Asphaltes contracted, in 1868, to keep roads in repair at the rate of 1 franc the mètre per annum (8*d.* per square yard), which price included an obligation to renew every year one-tenth¹ of the surface over five years old. This price was not arrived at by calculation alone; it was not possible that it should be, as the works already executed included the cost of experiments imperative with new works. Moreover, the large proportion of asphalted roadways being in streets where the traffic was heavy, did not admit of making a reliable comparison with the average cost of repairs of the roadways in the rest of the city, which included many streets with little traffic.

The Author is therefore of opinion that where the work can be carried out under favourable conditions, and where the majority of the streets are paved with this material, town councils need not pay 1 franc per mètre (8*d.* per square yard) for the maintenance and renewal of the roads. It is probable that for a large surface the average would be inconsiderable, and thus allow towns of secondary importance to procure for their inhabitants the advantages of roads paved with compressed asphalt.

COST PRICE.

The value of the raw material is too great, and the cost of transport is too important, to enable a price to be quoted without specifying the locality where the material is to be employed; but

¹ Now one-fifteenth part.—NOTE OF TRANSLATOR.

the quantity of raw material necessary for covering a given surface can be given, and thus every engineer can ascertain the price by adding the cost of transport to that of purchase.

The specific weight of asphalt being 2·2 to 2·3, the theoretical weight of 1 cubic mètre will be 2,300 kilogrammes (3,874 lbs. av. per cubic yard), and that of 1 square mètre, 1 centimètre thick (0·394 inch), 23 kilogrammes (50·7 av. lbs.), which in practice may be considered 25 kilogrammes (55·1 lbs. av.). Works employing say ten men, most of them labourers, a 25 to 30-HP. engine, and fitted with the necessary apparatus to avoid useless labour, can receive, crush, pulverise, and heat, in a day of ten hours, 30 to 40 tons of asphalt. The coal required for heating may be about 2 tons. The carts should take one horse-load, so that not too much material may arrive at the work at one time. The time of transit may last an hour without inconvenience.

For laying down, supposing the concrete ready and the workmen only occupied with the asphalt, the work in full swing, the job extensive and regularly supplied with hot powder, the labour costs little; a gang of ten to twelve men can complete 50 square mètres (538 square feet) in an hour. But for small undertakings the price of labour rapidly increases in proportion, being largely absorbed, for instance, in the cost of making cuttings for gas and water works, and in filling up depressions of the soil.

As regards the relative value of the only two asphaltic rocks used at present in laying compressed asphalt roadways, the Val de Travers limestone has not so close a grain, is softer, and is more regularly impregnated with bitumen than the Seyssel rock; but no engineer could conscientiously say that the Val de Travers is better than the Seyssel asphalt. The former may be safer in the execution of a work not subjected to supervision; the latter offers greater guarantees of good execution, because more care is required in the work.

III.—ASPHALT MASTIC.

It was under the form of mastic, designated by D'Eyrinys as "natural cement," that asphalt was first employed in public works in modern times. The slowness with which this material has made its way in the construction of houses can only be attributed to the mode of its employment necessitating heavy plant, and skilled workmen, who require a long apprenticeship.

Mastic asphalt has all the qualities of cement for uniting building materials, but the Author confines his attention to its application in making footpaths.

[1875-76. N.S.]

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It has been already stated that bituminous limestone heated to between 212° and 300° Fahr. loses its consistency and is reduced to powder. If the heating be increased the powder does not melt, but the bitumen is evaporated, leaving the limestone, when at red heat, perfectly pure. If, however, on attaining a temperature of between 390° and 480° , a small portion of free bitumen be added the asphalt melts. This property leads to a complete transformation of the bituminous limestone; after melting it is no longer possible to reconstitute the asphalt and bitumen. Analysis gives bitumen and white limestone, but not bituminous limestone or asphalt. Moreover, of two pieces of asphalt rock, one containing 5 to 6 per cent. of bitumen, the other 15 per cent. of bitumen, the latter will not melt alone, whereas it will suffice to add from 7 to 8 per cent. of pure bitumen to the former to induce fusion and make a mastic, though less rich in bitumen than the first; but it will not remelt without a fresh addition of bitumen. It would thus appear that pure bitumen acts as a flux.

BITUMEN.

Bitumen is widely disseminated, occurring in the products of decomposition of all organisms. That first employed for pharmaceutical purposes was evidently extracted from the asphalt itself. There existed an affinity between the two elements of fusion, and the mastic obtained would be of superior quality, but the process must have been very costly, on account of its necessitating distillation and of its wasting a large quantity of bituminous limestone. At Seyssel, for a long period bitumen was employed, produced from the bituminous sand of the soft greenstone which crops up frequently on the banks of the Rhone. Later a very rich seam of this stone was discovered at Bastennes in France.

The process employed for separating the bitumen from the sand is still the same as that described a century ago by D'Alembert in his Encyclopedia. The bituminous sand is poured into a boiler containing boiling water; at this temperature the bitumen becomes liquid and separates from the sand; being lighter than water, it rises to the surface, whereas the sand sinks to the bottom. This primitive mode answers perfectly so long as the rich sand is found at the surface and near roadways, but it becomes too expensive if the sand has to be carted to a distance.

Repeated attempts have been made to utilise the quality possessed by sulphuret of carbon of dissolving bitumen. An establishment was erected in Auvergne, where a great deal of sand rich

in bitumen was found. At Naples more extensive experiments were made with an apparatus which treated at the same time sulphur ore; but the results, though interesting, were too expensive to admit of the establishment of works. They showed, however, the expediency of continuing trials in this direction. The great drawback is the high price of sulphuret of carbon, combined with its great volatility, which causes loss from leakage.

For a long time Seyssel mastic was made with pure bitumen extracted from the soft stone, and for remelting the mastic when laying the footpaths Bastennes bitumen was obtained by the washing process as long as the seam lasted.

The chief quality required for bitumen used for footpaths is the retention of the pasty appearance under the influence of great variation of temperatures.

INDIGENOUS BITUMENS.

At first indigenous bitumens were tried, but the supply from Judæa was limited, and the price too high. Here it may be said that gas-tar is decidedly the worst form of bitumen for paving purposes, as it passes from the dry to the liquid state, and *vice versa*, according to the season, and is very brittle.

TRINIDAD BITUMEN.

Indigenous bitumens being found also in the state of dry pitch mixed with earth and water, efforts have been made to utilise those found on Lake Brea in the Island of Trinidad.

The spring of indigenous bitumen must have been considerable, for the water has almost disappeared from the lake, the bitumen forming a mass traversed only by a few narrow channels. The bitumen constantly springing up has overflowed the banks, and, following the fall of the earth, has spread out seaward, forming a regular jetty, protecting vessels during their lading. Under the ardent sun of these latitudes the viscid matter partially evaporated, partially mixed with dust, has become solid on the surface, and forms the raw dry pitch exported to Europe. The process of removing 25 per cent. of foreign matter is effected by pouring into open boilers, which should not be exposed to naked flame, a given quantity of shale oil; as the oil gets heated, raw bitumen to about double the weight of the shale oil is added. The cooking with a steady fire lasts about eighteen to twenty hours. After sundry strainings and decantings, the purified bitumen is cooled and put into casks. This bitumen serves to replace that extracted

from the soft stone and sand when the operation is properly conducted, and the pitch is of good quality, but it also costs much less. The process of preparation is a delicate one, and the despatch in casks allows of fraud.

MANUFACTURE OF MASTIC.

M. Malo, in his treatise, gives full explanations concerning the manufacture of mastic, which will not be further referred to. The material is sent to the places of consumption in blocks or cheeses 1 foot in diameter and about 4 inches thick. Like rock asphalt, heated alone, mastic does not melt, but only becomes soft; if the heating is continued it loses its bitumen and leaves a coal-like residuum. To endure remelting a fresh quantity of pure bitumen must be added.

Although it is only intended to refer to asphalt mastic in its relation to footpaths, it may be permitted to mention its application, under similar conditions, as a covering for vaults, its elasticity and malleability guaranteeing it against the cracks and fissures so often complained of in cement and mortar coverings.

The employment of asphalt mastic for footpaths is considerable. It is probable that, by illicitly using it as mortar, the idea arose of mixing sand with it. The result has proved excellent. No chemical union takes place between the mastic and the sand, but the cohesion is so complete that the fracture of sanded mastic will show the simultaneous fracture of the grit. Moreover, the non-susceptibility of sand to the heat of the sun compensates for the susceptibility of the mastic; and, as the quantity of grit or sand may reach 60 per cent., the price of the work can be proportionately reduced. The conditions necessary for the laying of mastic are to prepare it with the least possible quantity of bitumen, and to lay it as hot as practicable.

LAYING DOWN.

For many years the apparatus for remelting the mastic consisted of boilers of a primitive construction of wrought iron, fitted with stove chimneys: but the use of these boilers in the streets was too inconvenient in such important works as those of the city of Paris. It became therefore necessary to contrive other means, and in 1858 the mastic was prepared in large stationary boilers in dépôts, and delivered hot to the works in portable boilers, which could be heated and stirred during transport. The fixed boilers for preparing the sanded mastic are similar to those used for ordinary mastic, except that they are provided with a bell-shaped

mouthpiece to allow of the hot material being poured into the portable furnaces. The layer of mastic possessing no resistance in itself, and being simply a carpet, necessitates the consolidation of the soil, which is ordinarily done by concrete, the surface of which is floated with mortar.

PRICE OF WORK.

As with compressed asphalt, it is difficult to fix a price without knowing the locality of the work to be executed, on account of the cost of transport. The cost can, however, be readily arrived at as follows:—The preparation of 1 ton of sanded mastic requires 13 cwt. of pure block mastic, 2 qrs. 12 lbs. of bitumen, 7 cwt. of grit or sand washed and dried, and 2 cwt. of coal. A workman can easily prepare 3 tons of material in a day of twelve hours.

The specific weight of mastic being about the same as that of asphalt and sand, the weight of 1 cubic metre of sanded mastic will be, say, 2 tons 6 cwt. (1 ton 15 cwt. per cubic yard), and consequently a layer 1 centimètre (0·39 inch) in thickness will give, theoretically, about 50 lbs. weight per square metre, or, practically, 56 lbs. per square metre (46 lbs per square yard).

It requires a long apprenticeship before the workman can obtain a layer of uniform thickness. A skilled workman can, when the surface is well prepared, and the hot mastic supplied continuously and well poured by his assistants, lay from 120 to 150 square mètres (140 to 180 square yards) in a day, 15 millimètres (0·6 inch) thick. As an average, 120 square mètres can be obtained by a gang of three men, *i.e.*, one spreader, and two bringers. When, on the other hand, the workman is obliged to prepare the mastic in the old pot boilers himself, he requires an assistant for each boiler, and the preparation takes four to five hours, without counting the laying and pouring. Under such conditions, a gang of three men will only lay 55 square mètres (66 square yards) a day.

The thickness generally used for footpaths and public buildings is 15 millimètres, equal to 35 to 38 kilogrammes of sanded mastic per square metre (64 lbs. to 71 lbs. per square yard). For railway stations, where there is goods traffic, 2-centimètres thickness of mastic, or 45 kilogrammes per mètre (83 lbs. per square yard), is generally adopted; and for passages and entrances subject to heavy carriage traffic about 4 to 5 centimètres (1·6 inch to 2 inches) thickness is used.

ROADWAYS OR CAUSEWAYS.

In Lyons mastic has been applied to several roadways, chiefly in the small, narrow, damp streets and alleys, for sanitary reasons;

and as the traffic is trifling, the repairs have been few. Some of these roadways are twenty years old.

The trials in Paris have given much less satisfactory results. The failure may perhaps be attributed to the mixture of two bodies—asphalt and grit, the resisting powers of which are essentially different. When, owing to the wear of the mastic, the grit appears on the surface of the roadway, it is soon displaced, leaving the socket exposed. This is a cause of disintegration, which, often repeated, soon leads to the breaking up of the roadway, and the drier the mastic, the quicker the destructive action. For roadways mastic asphalt has been generally abandoned in favour of compressed asphalt rock, which is homogeneous in texture.

DURATION.

The duration of asphalt beds has, unfortunately, never been stated with sufficient accuracy, taking into account the modifications caused in laying gas and water pipes; but it is certain that asphalt mastic on footpaths will bear for a long time a considerable traffic of passengers.

In Paris, under the arcades of the Rue de Rivoli, of a mastic sidewalk laid in 1845, and which was not relaid until 1868, there remained a thickness of 3 to 4 millimètres (0·12 inch to 0·16 inch), which was removed in large sheets. Again, in the Place des Célestins, at Lyons, asphalt mastic laid in 1840 still exists in spite of heavy traffic.

In ordinary conditions, a duration of fifteen years may be reckoned upon. This basis has been adopted for a system of maintenance for more than twenty years in Paris for the footpaths. Against an annual payment of a fixed sum per mètre, the contractor undertakes the repair of the paths, and renews every year one-fifteenth part of the existing surface. Thus the normal thickness of the layers of mastic is always maintained.

IMITATION ASPHALT.

By analysis asphalt mastic gives limestone and bitumen. By mixing heated limestones and gas-tar, a material having some of the properties of asphalt mastic has been obtained, just as stucco has some of the properties of marble.

The first trustworthy trials gave a bad result, and the employment of imitation asphalt was proscribed in all specifications of public works: but as detection is difficult, frauds soon took place on a large scale. As the great economy in imitation asphalt is in the

saving of carriage, the proof of transport from the mines will prevent this in many cases. Imitation asphalt is applicable in certain rare cases, great care being taken in its preparation; but it should never be used for footpaths or in places exposed to great variations of temperature. Bitumen, artificially combined with limestone, is unable to resist the tendency to disintegration inherent in those bodies, the components of which have been subjected to unknown conditions of temperature and pressure.

At present the formation of roads and footways is the principal application of asphalt. When engineers know the material and can rely upon its special qualities, the field of its employment will be considerably extended. Thus, in the construction of buildings exposed to floods, a layer of asphalt mastic under the foundations, and a narrow wall of bituminous concrete all round up to the extreme water-level, will protect the building from damp.

A bed of rubble smeared well with mastic at the point where the masonry rises from the surface of the ground will prevent the rise of damp by capillary attraction.

Blocks of concrete for the construction of marine jetties and piers, furnished with an exterior layer of bituminous concrete 4 to 5 inches in thickness, may be made of ordinary materials. The asphalt mastic opposes its elasticity to the percussive action of the shingle, and its bitumen to the decomposing action of marine salts upon limestones and cements. Several such blocks, of 13 cubic yards, have existed for more than ten years at the Pont de Graves, near Bordeaux, and justify the Author's assertion.
